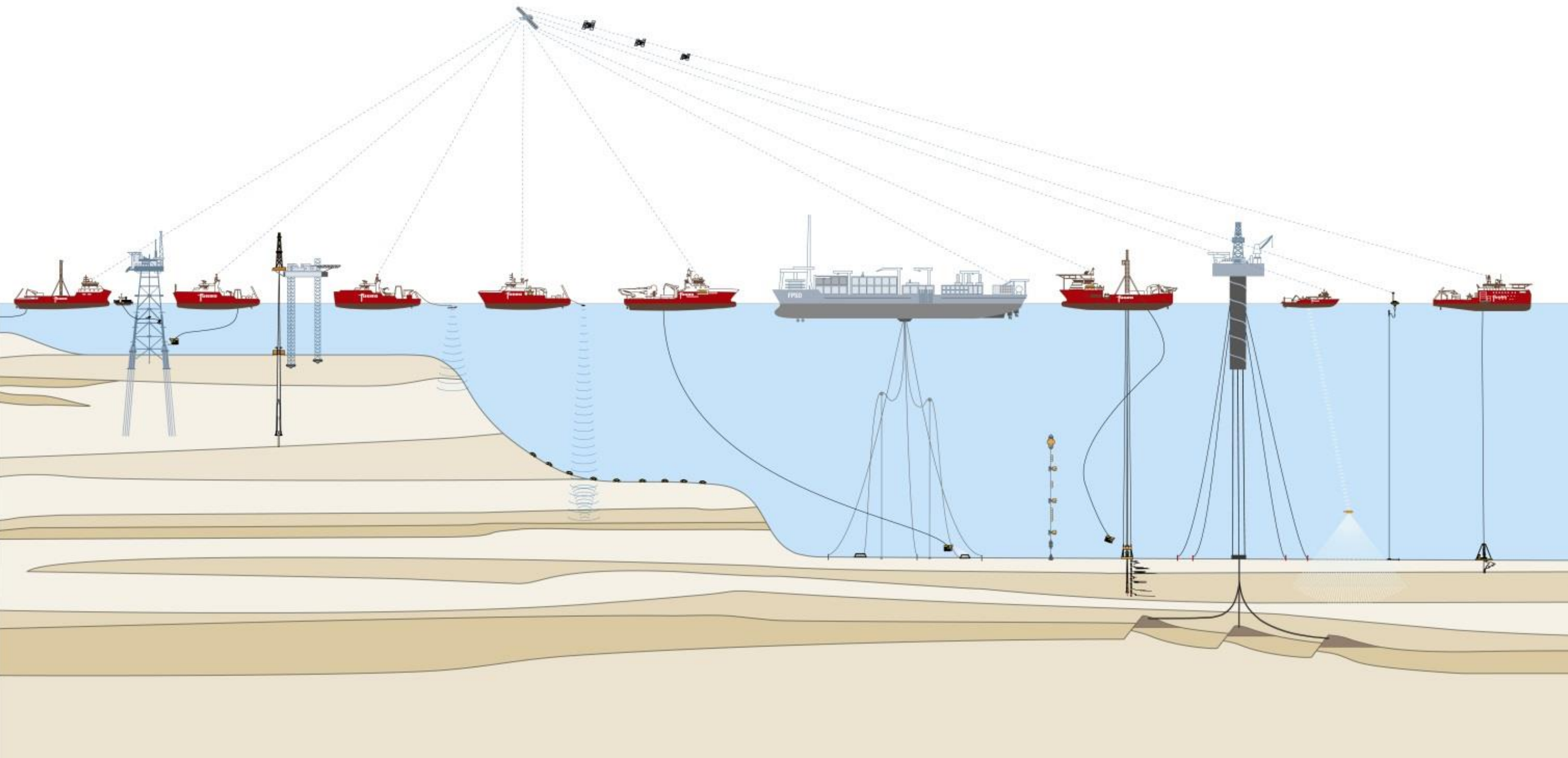
Environmental Impact Assessment Report
Aberdeen Harbour Expansion Project: Revised Blasting Methodology
Nigg Bay, Aberdeen

Fugro Document No.: 181469-R007(01)
Issue Date: 28 October 2019

Aberdeen Harbour Board

Dragados UK

Final Report



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REPORT ISSUE LOG

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03	Complete	First issue to client.		13 February 2019
04	Complete	Report update to include results of iPCoD modelling.		10 May 2019
05	Complete	Final report issued to client.		22 May 2019
06	Complete	Updates to include statutory comments		06 September 2019
07	Complete	Updated to include revised blasting methodology		28 October 2019

NON-TECHNICAL SUMMARY

Introduction

The Aberdeen Harbour Expansion Project (AHEP) provides opportunity for expanding current port operations at Aberdeen Harbour, securing new business streams for the area and further facilitating the offshore oil and gas industry. It contributes to delivering the Scottish Government's National Planning Framework (NPF3) for future development in Scotland.

Nigg Bay, located just to the south of the existing harbour at Aberdeen, was selected for the AHEP following a detailed feasibility study. Applications for Marine Licences for the construction of the scheme were submitted in 2015, together with an accompanying Environmental Statement (ES). Consent for the scheme was granted and Marine Licences, a Harbour Revision Order and Planning Permission in Principle allowing construction and dredging were awarded in 2016. Construction commenced in 2017.

The three primary consents lay out a series of conditions for the implementation of measures which mitigate for the predicted environmental effects of construction activities, including rock blasting and dredging activities, and which describe requirements for the implementation of post-consent environmental monitoring. Mitigation measures and requirements have since been incorporated within AHEP construction methodologies and form part of the Construction Environmental Management Document (CEMD) prepared in agreement with the regulators. Construction and post-consent monitoring is ongoing.

In 2018, delays to the blasting programme necessitated changes to the blasting methodology to be proposed. These changes included an extension to the period during which blasting is permitted to be undertaken, the use of larger weight explosive charges (> 20 kg) and an extension to the period of construction and permitted dredging and sea disposal.

On the most recent advice of Marine Scotland Licensing Operations Team (MS-LOT), the proposed changes could be determined material changes and as such require applications for new Marine Licences. These applications need to be accompanied by an Environmental Impact Assessment Report (EIAR), which considers the potential environmental consequences of the changes, and which proposes additional mitigation and environmental monitoring if necessary. On agreement with regulators, any new measures and monitoring will be incorporated within a revised CEMD.

This document represents the EIAR, including its non-technical summary, and accompanies the application for new licences. It has been prepared by Fugro in reference to the Marine Works (Environmental Impact Assessment) (Scotland) Regulations 2017, and provides:

- Updates to existing baselines described in the 2015 ES;
- A description of the proposed changes to the blasting methodology;
- An assessment of the likely significant environmental impacts of the proposed changes;
- Additional monitoring and mitigation measures to avoid or minimise unacceptable environmental impacts.

The scope of this EIAR includes an assessment of the likely significant effects of the proposed changes on fish and shellfish ecology, marine mammals, marine birds and the Nigg Bay Site of Special Scientific Interest (SSSI), both alone and cumulatively with other plans and projects, and was determined following issue of a scoping report (Fugro, 2018) to the following organisations:

- Marine Scotland (Science and Licensing Operations Team);
- Aberdeen City Council;
- Transport Scotland;

- Scottish Natural Heritage (SNH);
- Dee District Salmon Fishery Board (DDSFB);
- Whale and Dolphin Conservation (WDC);
- Scottish Environment Protection Agency (SEPA);
- Royal Society for the Protection of Birds (RSPB) Scotland;
- Northern Lighthouse Board (NLB).

Since the scoping advice was issued, the proposed scope of the changes requested has evolved, as consulted upon during subsequent regulator progress meetings. This EIAR presents the current scope of the proposals.

The EIAR is supported by new underwater noise modelling using a modified version of the original Confined Blast Model used during the 2015 ES. In addition, new numerical predictions of longer-term effects on marine mammal populations using the interim population consequences of disturbance (iPCoD) model have been prepared to underpin assessment conclusions presented here.

Environmental Controls

AHEP construction activities have already received consent and are presently ongoing, with the exception of blasting which was only permitted for a period of 7 months and which ended in March 2019. Consented activities incorporate considerable environmental monitoring and the implementation of mitigating measures which remove or minimise previously identified unacceptable environmental impacts. Such measures include the use of marine mammal observers (MMO) and passive acoustic monitoring (PAM) to ensure that marine mammals are absent from a 1 km mitigation zone around blast areas prior to blasting, the use of a double bubble curtain to prevent unacceptable levels of noise from propagating to open water areas, monitoring of noise and vibration against agreed environmental thresholds and controls on vessel movements to minimise risks to marine mammals and birds on the water. Fish scarers are used to startle fish away from blast areas prior to each blast.

Environmental monitoring is linked to adaptive management and intervention, including pausing work if environmental thresholds are breached and is described in the agreed project Construction Environmental Management Document (CEMD). The possible use of acoustic deterrent devices and seal removal is currently being discussed with regulators but is not considered further in this assessment as they do not affect the conclusions of this EIAR.

Baseline Conditions, Impacts and Effects

Fish and Shellfish Ecology

The River Dee Special Area of Conservation (SAC) is located approximately 0.8 km to the north and outside of the AHEP. It supports Atlantic salmon (*Salmo salar*) and freshwater pearl mussel (*Magaritifera margaritifera*) which are qualifying features of the SAC designation and thus of high nature conservation importance. Salmon and sea trout, together with other species, migrate to and from the River Dee during their life cycles. As hosts for larval stages of freshwater pearl mussel, effects to salmon and sea trout populations could indirectly effect mussel populations.

Intensive sampling in Nigg Bay in August and September 2017 only returned five salmon and two sea trout suitable for tagging suggesting low use of the site during these particular months but historic commercial catch data (1986 to 1999) suggested a greater use of local coastal waters by salmonids with peak abundance occurring in July. Tagged salmon and sea trout were shown to generally move quickly out of the Nigg Bay.

With respect to other species, Nigg Bay still seems to continue to function as part of the wider, regional inshore nursey habitat despite ongoing construction activities at the AHEP as evidenced by the presence of juvenile herring and whiting in post-blasting fish kill surveys.

Underwater noise modelling undertaken as part of this EIAR has shown that in the absence of the AHEP double bubble curtain, significant adverse impacts are predicted to extend over tens of metres or hundreds of metres depending on the weight of charge used causing mortality and potential mortal injury to fishes over these distance ranges. However, with the double bubble curtain in place, the model showed that sufficient noise energy is forecast to be removed that these impacts are not met anywhere beyond the double bubble curtain for charge weights of up to 100 kg, even considering the worst-case noise attenuation and configuration of the double bubble curtain. Fishes outside of the double bubble curtain are therefore at no greater risk than they are currently due to the proposed changes to the blasting methodology. Fishes inside the double bubble curtain, within Nigg Bay, however, may be at increased risk, due to the larger impacts associated with the use of larger charge weights although the current use of fish scarers will minimise this. Fish mortality and potential mortal injury are forecast to occur over tens to hundreds of metres within the bay (within the double bubble curtain) depending on the charge weight used. Reverberation of noise around the bay may exacerbate effects but effects will remain within the double bubble curtain.

New studies since the issue of the original ES (AHB, 2015) have characterised salmon smolt dispersal from the River Dee. Salmon smolt dispersing from the River Dee towards the offshore licence dredged material disposal site will not be significantly affected by disposal activities due to the limited noise and sediment impacts associated with this activity and the ability of salmon to avoid localised, temporary adverse areas. There will be no increases to the amount of dredging or disposal activities due to the proposals and so fishes are at no greater risk from associated impacts than previously assessed.

Sand eels (Ammodytidae) outside of the AHEP are not forecast to be affected by the proposed changes to the blasting methodology and so prey availability for marine mammals and marine birds across the wider area will not change significantly.

Additional mitigation in respect of fish and shellfish populations over and above that already provided, is not considered necessary or practicable and is not proposed. A strict protocol for reporting any kills of diadromous species will be provided within the revised CEMD.

Marine Mammals

Marine mammals in UK waters are protected at international level (Annex IV and II of the EC Habitats Directive) as implemented though the Habitats Regulations 1994 (as amended in Scotland). All cetaceans are European Protected Species (EPS) and are of high conservation importance.

The region supports a number of marine mammal species including bottlenose dolphin (*Tursiops truncatus*), harbour porpoise (*Phocoena phocoena*), Risso's dolphin (*Grampus griseus*) and white-beaked dolphin (*Lagenorhynchus albirostris*). Grey seal (*Halichoerus grypus*) is the most commonly occurring species of seal in the waters off Aberdeenshire waters. Harbour seal (*Phoca vitulina*) is occasionally recorded.

The current monitoring of marine mammals shows that harbour porpoise, grey seals and bottlenose dolphin frequently and consistently use the area around the AHEP despite ongoing construction disturbances. Grey seals and harbour porpoise have been observed to return to the AHEP quickly (within hours) following blasting events.

Underwater noise impact modelling showed that without the AHEP double bubble curtain in place, the proposed changes to the blasting methodology could cause injury (both permanent and temporary) to some marine mammals over hundreds or thousands of metres depending on the weight of explosive charge used. However, with the double bubble curtain and mitigation zone in place, bottlenose dolphin, grey seal and minke whale will not be at any risk of experiencing adverse underwater noise effects regardless of charge weight used up to 100 kg even considering the worst-case noise attenuation and configuration of the double bubble curtain.

For harbour porpoise, noise levels indicative of causing permanent injury to individuals were not predicted beyond the mitigation zone for charge weights up to 80 kg while the noise threshold for temporary injury to individuals was reached beyond the mitigation zone for charge weights of 40 kg or more, if the minimum noise attenuation of the double bubble curtain was assumed. If the average double bubble curtain attenuation is considered, then adverse noise effects on harbour porpoise are not predicted to be experienced beyond the mitigation zone. Population viability analysis predicted that the AHEP proposals alone would not significantly affect the long-term population size of any marine mammal species investigated and that the AHEP would not contribute significantly to cumulative effects with other projects so long as the double bubble curtain is in place.

Overall, impacts on marine mammals were predicted to be within those assessed within the existing ES. Harbour porpoise may experience PTS and TTS depending in the charge weight used but only if the lowest double bubble curtain attenuation is considered. If the average double bubble curtain attenuation performance is considered, as measured during on site measurements, then harbour porpoise will not be affected as per the predictions of the existing ES.

Marine Birds

The wider area supports a range of seabirds including pelagic species that mostly use the waters offshore of the AHEP where there is suitable prey (sand eel) habitat, including common guillemot (*Uria aalge*), razorbill (*Alca torda*) northern fulmar (*Fulmarus glacialis*) and kittiwake (*Rissa tridactyla*) and coastal birds, including terns and eider duck and passage or migrant waders such as dunlin (*Calidris alpina*), common sandpiper (*Actitus hypoleucos*), curlew (*Numenius arquata*) and Sanderling (*Calidris alba*) as well as a range of wintering wildfowl which use local areas in low numbers.

Terns, wintering wildfowl and waders and non-breeding eider are qualifying features of several European marine sites (EMS) within the wider area.

Sandwich tern (*Thalasseus sandvicensis*) and common tern (*Sterna hirundo*) are locally common using the rocky shore at Greyhope Bay for roosting and the outer areas of Nigg Bay for feeding where there is sand eel habitat. Little tern (*Sternula albifrons*) is present during breeding periods within the Ythan Estuary, Sands of Forvie and Meikle Loch Special Protection Area (SPA) proposed marine extension but appears to make little or no use of the local area based on modelled foraging ranges.

Although previously common in Nigg Bay, eider duck have been largely displaced from the AHEP by the onset of the overall construction activities, as previously predicted, although summer moulting habitat nearby at Greyhope Bay and Girdle Ness is still used. The proposed increased to the current blasting period will increase the overall licenced construction period and so is likely to extend temporal displacement effects over and above those previously assessed. Displaced birds are expected to be able to continue to use alternative habitat in Aberdeen Bay and elsewhere, as currently.

Effects of the proposed changes to the blasting methodology are expected to remain highly localised within the AHEP and are intermittent and temporary. Distances over which injury to birds may be expected due to the use of larger charge weights were estimated to be only a few tens of metres. Consequently, no significant adverse effects to marine birds due to the proposed changes to the blasting methodology were forecast.

No additional mitigation or monitoring is considered necessary within respect to marine birds. However, in recognition that submerged/diving birds may be more vulnerable to explosions than those on the surface, it was recommended that the pre-blast checks for rafting birds also include a check that there are no birds actively diving in blast zones prior to each blast.

Nigg Bay Site of Special Scientific Interest (SSSI)

The Nigg Bay SSSI is located along the southern shore of Nigg Bay. It was notified in 1984 for its geological importance as a reference site for interpreting the glacial history and ice movement patterns in north-east Scotland.

It is considered that the slope face is undergoing a progressive failure as a result of natural weathering processes and will continue to do so until it achieves a natural angle of stability.

In light of potential increased vibrations due to the proposed changes to the blasting methodology and associated increase in risk of cliff face slippage, the SSSI is presently being monitored through regular photographic surveys and use of vibration monitoring equipment against established tolerance thresholds. Blasting will be suspended in the event that these thresholds are breached. Monitoring records to date show that blasting has not caused thresholds to be exceeded and that vibration levels remain well within management limits. Monitoring methods and reporting protocols which also consider the construction of a temporary haul road have been approved and are incorporated within the revised CEMD.

With monitoring in place, it is considered that there will be sufficient early warning of a potential for a slippage to occur and for construction works to be paused and the appropriate authorities notified. Consequently, significant adverse effects to the SSSI are not expected and no additional mitigation or monitoring is deemed necessary.

Habitats Regulations Appraisal (HRA)

An appraisal of the likely significant effects (LSE) of the proposed changes to the blasting methodology on designated sites, both alone and in combination with other plans or projects, has been undertaken and updates the Habitats Regulations Appraisal (HRA) completed in support of the initial AHEP applications in 2015.

Effects of the current proposals considered in the updated HRA included increased mortality, injury and avoidance for the following interest features and designated sites:

- Bottlenose dolphin – Moray Firth SAC;
- Grey seal – Isle of May SAC;
- Atlantic salmon and freshwater pearl mussel – River Dee SAC;
- Non-breeding eider duck, Sandwich tern and Common tern - Ythan Estuary, Sands of Forvie and Meikle Loch SPA;
- Sandwich tern and Little tern and Ythan Estuary, Sands of Forvie and Meikle Loch SPA proposed marine extension.

Due to the mitigation in place, qualifying features are at no greater risk of significant impact due to the proposed changes to the blasting methodology either alone or in-combination with other plans or projects than initially assessed.

With respect to bottlenose dolphin, the iPCoD model outputs showed that the AHEP is unlikely to significantly contribute to cumulative population effects and thus will not affect the Moray Firth SAC interests in-combination with other plans and projects. Elsewhere, other projects potentially giving rise to concurrent impacts are remote to the AHEP and are also mitigated for the protection of marine mammals. Based on this, it was considered that there will be no likely significant effects on the integrity of the Moray Firth SAC either alone or in combination with other plans or projects.

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TABLES IN THE MAIN TEXT

FIGURES IN THE MAIN TEXT

ABBREVIATIONS

AA	Appropriate assessment
ACC	Aberdeen City Council
ADD	Acoustic deterrent device
AHB	Aberdeen Harbour Board
AHEP	Aberdeen Harbour Expansion Project
CD	Chart datum
CEMD	Construction Environmental Management Document
CIEEM	Chartered Institute of Ecology and Environmental Management
CMS	Construction Method Statement
DDSFB	Dee District Salmon Fishery Board
dSAC	Draft Special Area of Conservation
DUK	Dragados UK
ECoW	Ecological Clerk of Works
EcEIA	Ecological Environmental Impact Assessment
EIA	Environmental Impact Assessment
EIAR	Environmental Impact Assessment Report
EMS	European Marine Sites
EPS	European Protected Species
ES	Environmental Statement
HGV	Heavy goods vehicles
HRA	Habitats Regulations Appraisal
HRO	Harbour Revision Order
iPCoD	Interim Population Consequences of Disturbance
JNCC	Joint Nature Conservation Committee
LDP	Local Development Plan
LOT	Licensing Operations Team
LSE	Likely significant effects
MMMP	Marine Mammal Mitigation Plan
MMO	Marine mammal observer
MS-LOT	Marine Scotland – Licensing Operations Team
MSS	Marine Scotland Science
NLB	Northern Lighthouse Board
NMFS	National Marine Fisheries Service
NPF3	National Planning Framework 3
N-RIP	National Renewables Infrastructure Plan
PCL	Precautionary Control Limit
PAM	Passive acoustic monitoring
PMF	Priority Marine Features
PPV	Peak particle velocity
PTS	Permanent threshold shift
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SDP	Strategic development plan
SEPA	Scottish Environment Protection Agency
SNH	Scottish Natural Heritage
SPA	Special Protection Area
SPL	Sound pressure level

SPP	Scottish planning policy
SSSI	Site of Special Scientific Interest
TTS	Temporary threshold shift
WDC	Whale and Dolphin Conservation

1. INTRODUCTION

The Aberdeen Harbour Expansion Project (AHEP) (Figure 1-1) is being developed by Aberdeen Harbour Board (AHB). The primary contractor for the port construction is Dragados UK (DUK).

The AHEP will provide additional capacity and opportunity for growth of current port operations at Aberdeen Harbour, secure new business streams and further facilitate the oil and gas sector in Scotland. It is recognised by the Scottish Government as an infrastructure project of national significance in helping achieve development ambitions for Scotland and forms an important part of the Scottish Government's National Planning Framework (NPF3).

Figure 1-1: Imposed aerial view of the AHEP after construction

Nigg Bay, located just to the south of the existing port at Aberdeen, was selected for the AHEP following detailed feasibility study and assessment of alternatives. Work to assess and mitigate the likely environmental consequences of constructing and operating a new port at this location was completed and reported in 2015 (see Environmental Statement (ES), 2015). Consent for the AHEP was granted and Marine Licences, a Harbour Revision Order and Planning Permission in Principle allowing construction and dredging were awarded in 2016. Construction commenced in 2017.

The three primary consents lay out a series of conditions for the implementation of measures which mitigate for the predicted environmental effects of construction activities, including rock blasting and dredging activities, and which describe requirements for the implementation of post-consent environmental monitoring. Mitigation measures and requirements have since been incorporated within AHEP construction methodologies and form part of the Construction Environmental Management Document (CEMD) prepared in agreement with the regulators. Construction and post-consent monitoring is ongoing.

In 2018, delays to the construction blasting operation were incurred. Delays were due to adverse weather, winter storm damage to the double bubble curtain used to mitigate underwater noise levels and the frequent presence of seals within the mitigation zone. The last day of blasting was in November 2018 before the programme was suspended. The consequence of the delays is that the required blasting programme now cannot be achieved within the timeframe conditioned within the Marine Licence (7 months). Changes to some aspects of the blasting methodology are also required to complete the construction. Statutory requests to vary existing licences will be required before such changes can be implemented.

While initially advising that the required changes were non-material, as reported within the scoping report, Marine Scotland–Licensing Operations Team (MS-LOT) has since confirmed during subsequent activity update meetings with regulators that the required changes to the blasting methodology could constitute a material change under section 30(7) of the Marine (Scotland) Act 2010. The change in statutory advice reflects development of the scope of blasting requirements and extension to dredging since the issue of the scoping report and as discussed during subsequent regulator meetings.

In this case the required changes would need statutory determination via application for a new marine licence, to supersede the existing licence, and would need to be supported by an Environmental Impact Assessment Report (EIAR). This document represents the EIAR and supports the applications for new marine licences to supersede the existing licences and is presented with reference to the Marine Works (Environmental Impacts Assessment) (Scotland) Regulations 2017.

This Environmental Impact Assessment Report (EIAR) accompanies the requests for new marine licence applications. It has been prepared by Fugro under commission from Dragados UK (DUK) (primary contractor) and on behalf of AHB (scheme proponent and Marine Licence holder). It has the following aims:

- To describe the proposed changes to the blasting methodology;
- To update environmental baselines using the available post-consent environmental monitoring data;
- To identify and assess the likely significant environmental effects of the proposed changes which are over and above the effects already assessed for the existing AHEP;
- To identify mitigation measures.

It is prepared with reference to the Marine Works (Environmental Impact Assessment (Scotland) Regulations 2017. Its technical and geographical scope have been informed through consultation with statutory and non-statutory consultees as described in Chapter 4 (Methodologies) and in the subsequent Technical Chapters (Chapters 5 to 8). Further assessment compliant with the requirements of the Habitats Regulations (Habitats Regulations Appraisal) (HRA) has also been prepared (Chapter 10) and is intended to inform and facilitate the Competent Authority's Appropriate Assessment (AA).

2. THE PROJECT

2.1 Project Background

The AHEP was awarded consent under the Harbours Act 1964, Town and Country Planning (Scotland) Act 1997 (as amended) and Marine (Scotland) Act 2010. A Construction Marine Licence (05965/16/0), Dredging Marine Licence (05964/16/0) (and Dredging Marine Licence Variation 05964/19/0) have been awarded to AHB and a European Protected Species (EPS) Licence (MS EPS 06/2018/1) has been awarded to DUK to allow for construction activities, including drilling and blasting of the bedrock, to take place within the marine environment subject to conditions. Construction has been ongoing since 2017 in accordance with these licences and as documented within the approved Construction Environmental Management Document (CEMD).

2.2 Previous Impacts Assessments

Applications for the existing licences were supported by an ES, prepared and submitted in 2015 under the Marine Works (Environmental Impact Assessment) Regulations 2007 (as amended), and were subject to a Habitats Regulations Appraisal (HRA) and Appropriate Assessment (AA) conducted under Regulation 48 of the Conservation (Natural Habitats, &c.) Regulations 1994 ("the Regulations"), in accordance with Council Directive 92/43/EEC on the conservation of natural habitats under wild fauna and flora ("the Habitats Directive").

Following submission of these documents, an 'Additional Environmental Information Report' was provided in April 2016 and included *inter alia* further information on the following aspects:

- Blasting methodology and mitigation;
- Clarification of effects on eider;
- Clarification on effects on terns.

Construction and Dredging Marine Licences were duly issued in November 2016 and construction of the AHEP commenced in the summer 2017. The current EPS licence was issued in April 2018.

2.3 Location

The consented project (the AHEP) is located in Nigg Bay approximately 0.8 km south of the existing harbour within Aberdeen city centre (Figure 2-1). It lies within a natural bay which looks out into the North Sea and covers an area of approximately 0.87 km^2. The bay is surrounded by rocky cliffs and headlands to the north (Girdle Ness) and south (Greg Ness) which slope down to a cobble beach to the west, and the North Sea to the east. The main consented activities and work packages for the construction of the AHEP include:

- Dredging the existing bay to design depths varying from -9 to -10.5 m chart datum (CD), with some areas of localised deeper dredge pockets to facilitate construction. The dredged material is expected to comprise of sand/alluvium, glacial till and rock materials;
- Profiling the existing southern slopes of the bay. This is intended to reduce wave reflection within the central berthing and approach channel areas of the development by absorbing incoming waves;

- Construction of two rubble mound breakwaters 634 m (North Breakwater) and 640 m (south breakwater). The purpose of these structures is to protect the new facilities from North Sea metocean conditions;
- Construction of approximately 886 m of closed and 538 m of open quays to provide a combined total of over 1400 m of quayside capable of berthing vessels;
- Land reclamation activities to provide a paved area immediately to the rear of the quayside installations. This will use materials recovered from dredging operations supplemented by imported materials;
- Provision of ancillary welfare accommodation, quayside furniture and water tank installations for the facility's operational stages;
- Numerous stages of off-site highway work to allow free flowing traffic around the new facilities during construction and operation. This will include improved access for heavy goods vehicles (HGVs).

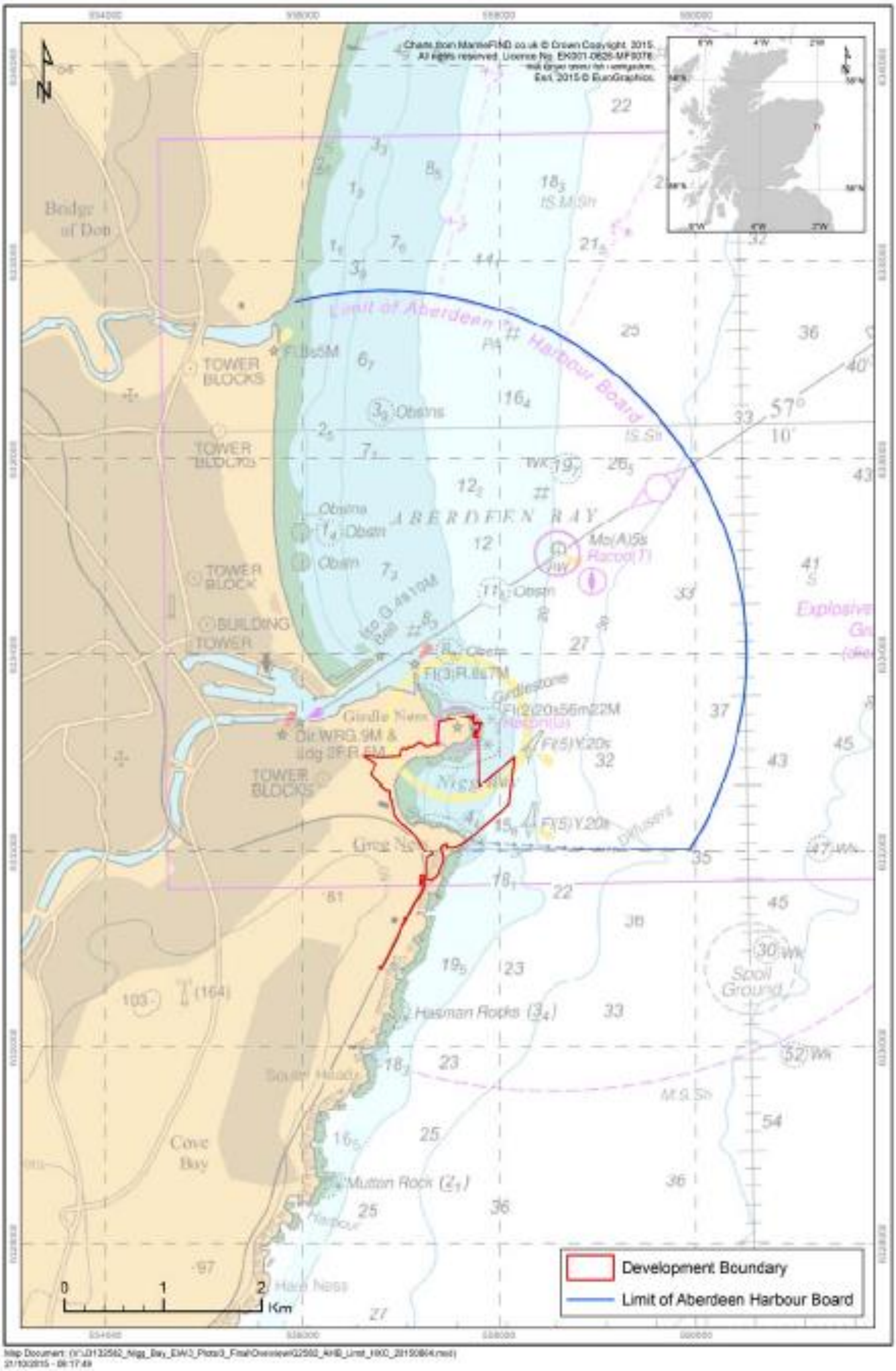

Figure 2-1: Location of the AHEP

2.4 Drilling and Confined Blasting

2.4.1 Description of the Procedure

Drilling and confined blasting is a consented activity that is required to remove rock and allow the target dredged depth to be attained. Confined blasting includes the placing and detonation of explosive charges in shot-holes that have been pre-drilled into the seabed. In this way, the majority of the blast energy is directed into the surrounding substrata for the purposes of fracturing the surrounding substratum prior to removal by dredging. The shot-holes that are required for the blasting operations are drilled from a platform constructed on land, or from a jack-up platform with a drill tower using the following procedure:

- Before drilling starts, the outer guidance tube is lowered on the seabed and pushed into the overlaying layer, down to the rock level, by means of air wash;
- The vertical position of the outer guidance tube is used for recording the top of rock level. This level is logged in the blasting plan chart, and is later used to calculate the amount of explosive;
- When the drilling of a hole is finished, the drill rod is removed, and the hole is ready for charging;
- An igniter/starter is placed in the bottom of the hole and the hole is charged by pumping the explosive;
- The drill rig is moved to the next hole position in the row and the drilling and charging operation is repeated;
- Upon completion of the row, the second row is drilled and charged, after that the pontoon is moved to its next spud position, by means of stepping round one lowered spud at a time.

The number of shot holes drilled and the quantities of explosives packed into them vary depending on the desired outcome of each blast. Not all of the shot holes are filled with charges of the same weight and during typical operations, lesser amounts of explosives than the maximum permitted may be used depending on the specific aims of each blast.

The existing Construction Marine Licence currently limits the schedule of the blasting works to a maximum of seven consecutive months (which expired at the end of March 2019), two blasts a day and obligates contractors to *inter alia* take measures to ensure the smallest practicable size charges are used (Condition 3.2.5(g & h)). The licence also limits the total amount of explosive that can be used to 675 tonnes (Condition 2.4) and allows drilling and dredging works to be carried out 24 hours per day, 7 days per week except for blasting which is limited to. daylight hours unless during exceptional circumstances (Condition 3.2.5(a)) Any instances where blasting has occurred outwith daylight hours due to exceptional circumstances are to be recorded and reported to the licensing authority (Condition 3.2.5(b)). The schedule of mitigation measures within the Aberdeen Harbour Revision Order (HRO) 2016 (2016 No.414) requires that blasting is limited to the periods between 7 am to 7 pm Monday to Friday and 9 am to 4 pm on Saturdays and that blasting does not take place on Sundays (4-(1)). Blasting should also be undertaken on the landward side of a partially or wholly constructed breakwater.

In line with Condition 3.2.4 of the existing Construction Marine Licence and Dredging Marine Licence and Schedule 2 of the Harbour Revision Order, a Construction Method Statement (CMS) was prepared to inform stakeholders of the methods and programme for the construction of the AHEP which was subsequently promulgated within an approved Construction Environmental Management Document (CEMD). The CEMD draws upon the measures described in the ES and the Additional Environmental

Information Report. It is the key management tool for the implementation of the mitigation identified in the 2015 ES and for the minimisation of environmental effects arising from the AHEP.

The CEMD encompasses a range of topic specific management plans which set out environmental management measures including those relating to blasting. The blasting methodology and associated environmental controls are set out within the Marine Mammal Mitigation Plan (MMMP) which comprises Chapter 11 of the CEMD. Although not a condition of the Licence, the current approved CEMD states that 20 kg charges will be used unless agreed by Marine Scotland - Licensing Operations Team (MS-LOT), and the Additional Environmental Information Report states that the number of charges per blast will be between 25-100.

In May 2017, the CEMD was approved by Marine Scotland as required by Conditions 3.2.4 and 3.2.5 of the Construction Marine Licence, Transport Scotland under the Harbour Revision Order (HRO), and Aberdeen City Council (ACC) under the Planning Permission in Principle. It stated that the minimum practicable size charge will be used, and that Marine Scotland should be contacted in the event that underwater noise levels exceed a benchmark of 170 dB re 1 µPa rms (equivalent to 183 dB re 1µPa peak) at 400 m from the blast location or outside the double bubble curtain, whichever is the greater distance. A double bubble curtain should also be deployed prior to blasting. Changes to the CEMD must be agreed with MS-LOT prior to being implemented.

The approved CEMD has been updated to account for the changes detailed within this EIAR. The revised CEMD describes the updated blasting procedure for which the licences are being applied for and the commitments that DUK will adopt for the protection of the marine environment. Section 2.6 below describes the updated blasting procedure presented within the revised CEMD which includes a programme of incremental increases in the charge weight and monitoring up to a maximum of 80 kg and which commits DUK to ensuring that marine mammals are not exposed to previously agreed noise levels above 183 dB re 1 µ Pa (peak) equivalent to 170 re 1 µ Pa (rms). Section 2.5 explains the need for the method change.

2.5 Need for the Changes to the Blasting Methodology

In 2018, factors including the delay of the start to the blasting programme to August, the presence of seals in the mitigation zone and adverse weather conditions have limited the amount of rock removed by blasting to date. This has caused significant delays to the overall AHEP construction programme. The last day of blasting was in November 2018, when damage occurred to the double bubble curtain, before the programme was suspended. No blasting has been undertaken since.

As of October 2019, 114,553 $m^3$of rock remain to be removed by blasting from the AHEP. Appendix A presents a map of the total of rock already removed and the remaining rock yet to be removed.

Blasting, including larger charge weights than used previously on the project, remains an important option to achieve this removal particularly in areas where large quantities of rock are present and where mechanical tools are considered inefficient. The following describes the proposed changes relating to the licence application.

2.6 Description of the Proposed Changes to the Blasting Methodology

The required changes to the blasting methodology that are needed to construct the AHEP and the associated licence application sought are explained below. Note that if blasting is permitted to resume with the proposed changes, it will be used in conjunction with other rock removal methods. Consequently, not all of the remaining rock will necessarily be removed by blasting although for the purposes of the current assessment, a worst case scenario of blasting of all remaining rock is assumed.

2.6.1 Increase in the Duration of the Period of Blasting

Condition 3.2.5 (h) of the existing Construction Marine Licence specifies that the Marine Mammal Mitigation Plan (MMPP) must set out measures to prevent injury and disturbance to marine mammals and must include, but shall not be limited to, measures to ensure blasting works are undertaken for a maximum period of 7 consecutive months, with no more than 2 blasts per day.

Given that blasting commenced in August 2018, then the permitted blasting period (7 months) ended in March 2019. Due to the delays described in Section 2.5, the number of blasting days was very limited within this 7-month period (12 days in total), whereas the 2015 ES assumed that blasting would take place up to 6 days per week throughout the 7-month period.

Since March 2019, some rock removal has been achieved using mechanical means, but for some areas of the AHEP where larger quantities or more resistant rock remains, blasting is required. It is therefore necessary to now extend the period within which blasting is permitted to take place to complete the existing construction programme.

Table 2.1 has been prepared to compare timelines for DUK’s planned programme for the remaining blasting works for each weight of explosive charge and assuming a resumption of blasting on 15 March 2020, and also assuming that all the remaining rock will need to be blasted rather than removed by other means. Two scenarios have been drafted, the first one is the ideal scenario, in which no delays to the programme are considered. The second one is the realistic scenario, in which delays (caused by i.e. weather or other sources) are taken into account.

Table 2.1. Anticipated programme of remaining blasting

Charge weight	Planned Start Date	Days for blasting (Mon to Sat)	Planned End date	Days for blasting accounting for weather (64.18%)	Total days needed to complete blasting (Mon-Sun)	End date after delays (approx.)
		Ideal scenario (no delays)		Realistic scenario (with delays)		
20kg	15/03/2020	216	22/11/2020	337	393	**12/04/2021**
40kg	15/03/2020	183	14/10/2020	285	333	**11/02/2021**
50kg	15/03/2020	167	25/09/2020	260	303	**12/01/2021**
60kg	15/03/2020	151	07/09/2020	235	274	**14/12/2020**
70kg	15/03/2020	138	23/08/2020	215	251	**21/11/2020**
75kg	15/03/2020	131	14/08/2020	204	238	**08/11/2020**
80kg	15/03/2020	124	06/08/2020	193	225	**26/10/2020**

In order to calculate the ideal scenario for each charge weight (in terms of the remaining blasting programme timeline), DUK has considered the likely number of days needed to complete the removal of a specific amount of rock from Monday to Saturday, based on 2 blasts per day, using just the blasting methodology and assuming no delays. Thus, under these premises, it is estimated that a total of 216 days (excluding Sundays) will be required to remove the residual rock from the AHEP using blasting with a 20 kg charge. It will only take 124 days (excluding Sundays) to remove the residual rock when using charge weights of 80kg. The number of days of remaining blasting is estimated on the basis that 114,553 m^3 rock remains to be removed. Based on experience from 2018 blasting campaign, these scenarios are unlikely to be achieved but are provided for comparison purposes.

The realistic scenario takes into account DUK's 2018 experience and assumes there will be delays, caused by adverse weather and other technical reasons. The consequences of adverse weather to 2018 blasting campaign resulted in that only 64.18% of the days were workable. Thus, the realistic scenario shows that 193 days of blasting (Mon-Sat) will be required to complete the blasting programme with 80kg charge weights but it might take as long as 337 days (Mon-Sat) to complete if 20 kg charges are used. Accounting for Sundays (when no blasting is permitted), then the realistic timeline to complete the remaining blasting programme will be between 393 days using 20 kg charges and 225 days using 80 kg charges.

Assuming a start date of 15th March 2020, then the completion date will be 12th April 2021 if 20 kg charges are used. For assessment purposes therefore, the maximum duration of the remaining blasting programme is assumed to be 393 days and will be completed on 12th April 2021

Note that the realistic scenario does not take into account delays caused by other sources, i.e. the presence of seals inside the mitigation zone, since these delays are now considered to be avoidable due to the combination of mitigation measures in place and under consideration when blasting is due to begin (i.e. seals relocation licence).

It is acknowledged that the proposals will increase the time over which construction impacts occur compared to the original proposals (AHB, 2015) but this will not result in any significant increases in effects over those already assessed. This is because the locations and quantities of seabed material to be dredged and disposed remain as originally planned and so no additional impact is anticipated in this regard. Furthermore, the frequency at which these activities will take place will be less than that originally assessed (AHB, 2015) as the same amount of dredging and disposal will take place but over a longer period of time. Fish and marine mammal populations in open water areas continue to be protected by ongoing mitigation measures while any individuals of species that are currently displaced from Nigg Bay will continue to be displaced, or partially displaced, during the operational phase as described and accepted in the 2015 ES (AHB, 2015). Also, the data from fish kill surveys shows that Nigg Bay continues to be used as part of the wider coastal nursery habitat for herring and whiting despite ongoing construction (see Chapter 5: Fish and Shellfish Ecology). Delays in the return of eider duck to the bay are considered insignificant given the wider availability of suitable habitat in adjacent areas.

2.6.2 Increase in Charge Weight

Condition 3.2.5 (g) of the existing Construction Marine Licence specifies that the MMMP must set out measures to prevent injury and disturbance to marine mammals and must include, but shall not be limited to, measures to ensure that the minimum amount of blasting is undertaken using the smallest practicable charges. As discussed above, the current approved CEMD states that 20 kg charges will be used unless agreed by MS-LOT.

The maximum charge weight to be used during the remaining blasting programme is limited by DUK's obligation to achieve the currently agreed threshold of 170 dB re 1 µPa rms (equivalent to 183 dB re 1µPa peak) at 400 m from the blast location or outside the double bubble curtain, whichever is the greater distance, or some revised threshold in light of new guidance (i.e. NMFS, 2018, Southall et al, 2019) but for current assessment purposes is intended to be 80 kg maximum.

To determine the maximum acceptable charge weight which will generate underwater noise within this threshold, it is now proposed to undertake a programme of incremental charge weight increases coupled with monitoring of the resultant noise against the agreed threshold limit. This current proposed programme differs from the incremental increases originally communicated to stakeholders in December 2018 during the scoping stage (Fugro, 2018). At that time, stakeholders were advised that the charge will initially be increased to 30 kg and that between 4 and 6 blasts at this charge weight will be monitored in accordance with the existing agreed monitoring procedures. Simultaneous monitoring by hydrophones were to provide an initial 'indication' of the maximum noise level and MS-LOT and SNH were to be notified of the results on the same day as the blast. If noise levels exceed the agreed threshold then the charge weight would have reverted to 20 kg. The initial 'indication' data would have been processed by an appointed acoustician to calculate the calibrated noise level and reported to MS-LOT within 72 hours. The reports were to provide both the raw 'indication' data and the processed calibrated data and the differences assessed. If the calibrated noise levels for the 4 to 6 blasts were below the benchmark then the process would have been repeated, increasing in increments of 10 kg. The increment would have been reduced if the calibrated noise level suggested that a 10 kg increase would result in noise levels exceeding the agreed threshold. If any of the initial 'indicators' or calibrated results exceed the threshold, then DUK would revert back to the previously accepted charge weight pending further discussion with MS-LOT.

A proposal for incremental increases in charge weights was provided to MS-LOT via email on 21 January 2019 but has undergone minor modification since this time as presented in the updated CEMD (Chapter 11: MMMP). The current proposal represents a highly precautionary approach, in terms of marine environmental protections and compliance with the existing agreed underwater noise threshold, and will deliver project completion within a reasonable and practicable timeframe. It draws upon the knowledge and experience gained over the previous 2018 blasting campaign and associated underwater noise recording and numerical model calibration. It recognises and respects the agreed threshold for underwater noise and proposes use of a new lower level to initiate action if approached. The following describes the current proposal for incrementally increasing the blast weight.

The proposal for incrementally increasing blast weights is divided in two phases;

Phase 1 starts with a charge weight of 20 kg, and then the charge weight is increased to 40 kg in 10 kg increments. During phase 1, six blasts will be undertaken for each charge weight before increasing to the next.

Phase 2 then starts and the charge weight increments are reduced to 5 kg. The number of repetitions with each charge weight remains six before increasing to the next charge weight. The maximum charge weight is 80kg.

The increments are summarized below:

- Phase 1 blasting regime: 20, 30,and 40
- Phase 2 blasting regime: 45, 50, 55, 60, 65, 70, 75 and 80 kg.

After each detonation, if the peak level measured is below the noise threshold (183 dB Peak/170 dB RMS), then the charge weight will be increased to the next increment. All noise measurements will be reported on the same day of the blasting to MS-LOT.

Additional considerations:

A Precautionary Control Limit (PCL) has been defined by AHEP to minimise the chances of reaching the noise threshold. PCL is set as 178 dB Peak/167dB RMS (5dB below peak level threshold (183dB)) and 3dB below RMS threshold (170dB) respectively). The following actions will take place in respect of the PCL.

1 If any noise measurement reaches the PCL (but remains below the noise threshold), all remaining planned blasts for that charge weight will be undertaken. Two scenarios are then contemplated:

   1.1 If the noise measured for the remaining blasts with that same charge size are all below the PCL, the charge size will continue to be gradually incremented but reducing the size of the planned increments by half .i.e. 5 kg instead of 10 kg and so on).

   1.2 If the noise level measured for any of the remaining blasts for that same charge size is again over the PCL, the charge size will not be incremented further.

2 If any noise measurement reaches or exceeds the noise threshold (183 dB Peak/170 dB RMS), the charge size will be reduced by 5 kg. and the blasting plan will continue but all planned increments will be reduced by half (i.e. 2.5 kg instead of 5 kg). The following scenarios are then considered:

   2.1 If all following blasts are below the PCL, the charge weight will continue to be gradually incremented with reduced increments as described above.

   2.2 If any of the following blasts reaches the PCL, the charge weight will not be incremented further.

   2.3 If any of the following blasts reaches the threshold, the charge weight will be further reduced by 5 kg and will remain fixed for all remaining blasts.

	Noise level measured below PCL
	Noise level measured over PCL but below RMS/Peak threshold
	Noise level measured equal or higher than RMS/Peak threshold

Scenario 1 - No exceedances

Charge size (Kgs.)	20.0	30.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0
Blast number	1	7	13	19	25	31	37	43	49	55	61
	2	8	14	20	26	32	38	44	50	56	62
	3	9	15	21	27	33	39	45	51	57	63
	4	10	16	22	28	34	40	46	52	58	64
	5	11	17	23	29	35	41	47	53	59	65
	6	12	18	24	30	36	42	48	54	60	66

Scenario 1.1 - One measurement over PCL

Charge size (Kgs.)	20.0	30.0	40.0	45.0	50.0	52.5	55.0	57.5	60.0	62.5	65.0	67.5	70.0	72.5	75.0	77.5	80.0
Blast number	1	7	13	19	25	31	37	43	49	55	61	67	73	79	85	91	97
	2	8	14	20	26	32	38	44	50	56	62	68	74	80	86	92	98
	3	9	15	21	27	33	39	45	51	57	63	69	75	81	87	93	99
	4	10	16	22	28	34	40	46	52	58	64	70	76	82	88	94	100
	5	11	17	23	29	35	41	47	53	59	65	71	77	83	89	95	101
	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102

Scenario 1.2. - Two measurements over PCL

Charge size (Kgs.)	20.0	30.0	40.0	45.0	50.0	55.0	55.0	55.0	55.0	55.0	55.0
Blast number	1	7	13	19	25	31	37	43	49	55	61
	2	8	14	20	26	32	38	44	50	56	62
	3	9	15	21	27	33	39	45	51	57	63
	4	10	16	22	28	34	40	46	52	58	64

Scenario 2.1 - One exceedance, then always below PCL

Charge size (Kgs.)	20.0	30.0	40.0	45.0	50.0	55	60.0	55	57.5	60.0	62.5	65	67.5	70.0	72.6	75.0	77.5	80.0
Blast number	1	7	13	19	25	31	37	43	49	55	61	67	73	79	85	91	97	103
	2	8	14	20	26	32	38	44	50	56	62	68	74	80	86	92	98	104
	3	9	15	21	27	33	39	45	51	57	63	69	75	81	87	93	99	105
	4	10	16	22	28	34	40	46	52	58	64	70	76	82	88	94	100	106
	5	11	17	23	29	35	41	47	53	59	65	71	77	83	89	95	101	107
	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108

Scenario 2.2 - One exceedance, one subsequent measurement over PCL

Charge size (Kgs.)	20.0	30.0	40.0	45.0	50.0	55	60.0	55	55	55	55
Blast number	1	7	13	19	25	31	37	43	49	55	61
	2	8	14	20	26	32	38	44	50	56	62
	3	9	15	21	27	33	39	45	51	57	63
	4	10	16	22	28	34	40	46	52	58	64
	5	11	17	23	29	35	41	47	53	59	65
	6	12	18	24	30	36	42	48	54	60	66

Scenario 2.3 - One threshold exceedance, one subsequent measurement over threshold

Charge size (Kgs.)	20.0	30.0	40.0	45.0	50.0	55	60.0	55	50	50	50
	1	7	13	19	25	31	37	43	49	55	61

Blast number											
	2	8	14	20	26	32	38	44	50	56	62
	3	9	15	21	27	33	39	45	51	57	63
	4	10	16	22	28	34	40	46	52	58	64
	5	11	17	23	29	35	41	47	53	59	65
	6	12	18	24	30	36	42	48	54	60	66

The blasting will likely resume in the south of Nigg Bay where blasting has so far not been conducted, other than small trial blasts using 3 kg charge weights. For assessment purposes, it has been assumed that the southern breakwater will not be in place and that any shielding from blasting noise that might otherwise have been provided for marine receptors in open sea areas beyond the harbour will not be present. However, it is the case that a small section of the southern breakwater is already in place albeit only a few tens of metres in extent. Seabed rock derived from the resumption of blasting is required to be beneficially used in the construction of this developing breakwater so that further shielding of open sea areas can be provided as the blasting programme progresses.

To date up to 217 charges have been detonated in a single field although the typical number has varied between 40 and 60 per blasting event. There have been no exceedances of the agreed underwater noise threshold reported regardless of the numbers of charges used. As discussed in Section 2.4.1, variable numbers of charges and charge weight combinations are used to achieve specific outcomes. This means that the numbers of charges detonated alone does not necessarily relate to the overall blast noise level (section 4.3.2 describes the relationship between numbers of detonations and noise levels recorded to date). Because of this, this EIAR does not assume a maximum number of charges per blast as this could conceivably be any number, and in any configuration, that is required to achieve the desired outcome of each blast.

It is also worth noting that the noise (peak sound pressure) of each blast will only be as high as that of the largest (loudest) detonation in each blast sequence. Subsequent detonations in the sequence which are of equal or lesser noise level will not add to the overall noise of the blast, although the time component of the blast event will increase. Other factors, such as local geological conditions, shot hole drill depth, shot hole geometry, water depth and water stratification can also influence noise levels propagating from each blast. Such variables further limit the consideration of the effect of charge numbers on blast noise levels alone.

2.6.3 Number of blasts per day

During scoping, it was stated that DUK intend to increase the number of permitted blasts from two to three per day. However, this is no longer proposed, as discussed with stakeholders at a meeting on 16 January 2019. The current proposal therefore does not include any increase in the number of blasts per day and the maximum number of blasting events that will take place each day will remain at two.

2.6.4 Construction Application

The intention to apply for a new Licence differs from the advice provided to stakeholders during scoping (Fugro 2018) which stated the intention to apply for a Licence variation. At that time, the proposed changes were not considered to constitute a material change under section 30(7) of the Marine (Scotland) Act 2010 and therefore would need a marine licence variation application, supported by an Environmental Impact Assessment Report (EIAR). However, in light of the gradual increase in the scope of the changes requested since initial scoping, the proposals could now potentially be considered material changes which would require a new Licence, as advised by MS-LOT during the scheduled progress update meeting on 13 March 2019.

Based on the information provided in section 2.6.1 and 2.6.2 above, we intend to apply for a new Construction Marine Licence to permit blasting to up to 31 December 2021 and for use of a maximum permissible charge weight of 80 kg. This represents a change to the proposals described at scoping (Fugro 2018) which indicated that an extension to the blasting schedule to 5 February 2020 would be required. The increase in timeframe reflects the latest available information on the likely programme.

The maximum charge weight being sought is 80 kg.

2.6.5 Dredging Licence Application

DUK were granted a licence variation permitting dredging and disposal of dredged material up to 27 February 2020. It is intended that a new application will be requested to permit dredging and disposal to operations till 31st December 2021. This represents a change from the advice provided at scoping which stated that an extension would be sought to February 2020 via a licence variation application. The new application is required to allow the dredging of rock that will be removed under the proposed Construction Licence application. Rock removed from the seabed will be beneficially used on site in the construction of the southern breakwater.

2.7 What's Staying the Same?

The location, spatial extent, overall construction methods, boundaries and design of the AHEP will not change due to the proposed changes to the blasting methodology. The total (indicative) amount of explosives to be used is stated in section 2.4 of the Construction Marine Licence as 675 tonnes and will also not change. Also, the total number of blasting events required to remove the remaining rock has not increased and if authorised, the use of larger charge weights is expected to reduce the number of blasting events required and shorten the duration of the period of blasting (see Table 2.1). Furthermore, the total quantity of rock to be removed by blasting has not increased and the zones in which rock is to be blasted remain the same. The dredging and disposal efforts will also remain as planned. There will be no increase in the amounts of unconsolidated seabed sediment to be removed from the AHEP and disposed at the licensed offshore disposal site. All rock removed from the seabed will be used beneficially on site.

2.8 Alternatives to the Proposed Changes to the Blasting Methodology

During periods when blasting is not permitted, and in areas where the quantities of rock are small and blasting may not be warranted, it is possible to loosen rock prior to dredging by mechanical tools. These tools include gravity fall tools, hydraulic rock breakers, drum cutters and rock rippers. DUK have committed to undertake underwater noise measurements on first use of each item of equipment, the results of which will be submitted to MS-LOT. It is therefore likely that not all the rock remaining will be removed by blasting techniques but that less 'noisy' mechanical methods will be employed where such tools can be practically deployed (see CEMD, Chapter 11). The amount of blasting actually completed during the remaining AHEP construction programme could therefore be less than described in this EIAR.

3. LEGISLATIVE CONTEXT

This chapter describes the policies and legislation that regulate the consenting, construction, operation and maintenance of the AHEP. It describes the international regulations which influence and drive the national legislation and leads on to discuss the regulatory framework and consenting regime for both the onshore and offshore elements of this project. The requirement to undertake an Environmental Impact Assessment (EIA) and HRA are also discussed.

The AHEP has previously obtained licences under the Harbours Act, Town and Country Planning (Scotland) Act, Marine (Scotland) Act and a European Protected Species Licence under the Habitat Regulations.

3.1 Marine (Scotland) Act 2010

The Marine (Scotland) Act 2010 defines the Scottish Marine Area, set outs general duties of the Scottish Ministers as well as prescribing regimes for planning, licensing, conservation, enforcement, sea fisheries and other further provisions. Section 4 of the Marine Act concerns licensing for which the AHEP is consented.

The AHEP project previously applied for and has been consented with two Marine Licences under section 4 of the Act. The first Marine Licence is for construction (05965/16/0), under 21(1) 5 and the second for dredging (05964/19/0) under 21(1) 7. The licences issued by Marine Scotland (on behalf of the Scottish Ministers) were conditional licences as described in section 29(1)(b).

This EIAR supports a request for new Marine Licence application under the Marine Act and reflects the current proposed scope of the changes to the blasting methodology.

3.2 EIA Directive

European Council Directive 2014/92/EU on the assessment of the impacts of certain public and private projects on the environment (the EIA Directive) (codification) (as amended by Directive 2014/52/EU), provides that European Union authorities giving consent for specific projects must take into consideration any significant environmental or socio-economic effects the proposed project may cause.

The associated transposing regulations for the EIA Directive that are relevant to the AHEP are:

- The Town and Country Planning (Environmental Impact Assessment) (Scotland) Regulations 2017;
- The Marine Works (Environmental Impact Assessment) (Scotland) Regulations 2017);
- Schedule 3 of the Harbours Act 1964.

The AHEP has been identified as a “trading port for loading and unloading connected to land and outside ports (excluding ferry piers) which can take vessels of over 1350 tonnes” as listed in paragraph 8 of Annex I of the EIA Directive. The EIA Directive requires a full EIA be undertaken in respect of development listed in Annex I. The competent authority Transport Scotland advised in its Scoping Opinion (ES Appendix 1-D: Scoping Opinion 2014) that a full EIA and associated ES are required through production of a Scoping Opinion. The project subsequently carried out and EIA, produced an ES and Additional Information which was submitted alongside the application in November 2015 then April 2016.

AHEP has been advised by MS-LOT that the changes to blast may require a variation to the Marine Licences and that the request should be accompanied by an EIA Report.

3.3 Marine Works (Environmental Impact Assessment) (Scotland) Regulations 2017

The Marine Works (EIA) (Scotland) Regulations 2017 provide the legal process for how Scottish marine projects should comply with the EIA Directive. The regulations cover the determination of whether an EIA is required, procedures for applications, preparation of EIA Reports, additional information, decisions and multi-stage approvals.

The AHEP project has an existing consent under the Marine (Scotland) Act which was supported by an ES and Additional Information submitted under the previous Marine Works (EIA) Regulations 2007 (as amended). After consultation with MS-LOT it was advised that the proposed changes should be supported by an EIA Report (EIAR) covering just the impacts foreseen as relating to the changes.

A formal request for a scoping opinion was not made and instead AHB/DUK have completed an EIAR based on consultation advice sought through an informal scoping process held during January 2019 with key stakeholders and through subsequent meetings.

Schedule 1 of the Marine Works (EIA) (Scotland) Regulations 2017 describes the projects and their applicable thresholds for the purposes of ‘Schedule 1 Works’ and therefore qualify as a ‘EIA Project’ under these regulations. The AHEP classifies under 8(2) as a trading port for loading and unloading connected to land which can take vessels of over 1350 tonnes.

Schedule 4 of the Marine Works (EIA) (Scotland) Regulations 2017 sets out the information required for inclusion in EIA Reports:

- A description of the work;
- A description of the alternatives;
- A description of the current environment (baseline scenario);
- Factors specified affected by the works;
- Description of likely significant effects;
- A description of methods or evidence used to forecast or identify effects including difficulties encountered and uncertainties involved;
- A description of mitigation measures envisaged to avoid, prevent, reduce or offset and identified adverse effects. This should also include monitoring, where appropriate;
- The risk to the environment born out of the work vulnerability to major accidents and or disasters where relevant to the project concerned;
- A non-technical summary;
- References.

3.4 EC Habitats Directive

In addition to the requirement to undertake an EIA, European Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (the Habitats Directive) and the transposing Habitats Regulations require development projects to consider the effects of potential developments on sites and species of international nature conservation importance. Where any plan or project is likely to significantly affect features of a nature conservation site which has been designated under the Habitats Regulations, an HRA is required.

Due to the proximity of the development area to sites and species of international nature conservation importance, an HRA under the Conservation of Habitats and Species Regulations 1994 will be undertaken by the Competent Authority. In this case, the Competent Authorities are Transport Scotland, Marine Scotland and ACC. Should the HRA identify the potential for likely significant effects (LSE) on the Special Area of Conservation (SAC), then the Competent Authority will be required to undertake an AA.

3.5 The Conservation (Natural Habitats, &c.) Regulations 1994 (as amended)

When consenting projects under the Marine (Scotland) Act 2010, the competent authorities (in this case Transport Scotland or Marine Scotland) must consider potential impacts on European designated sites and species of nature conservation importance.

A European Protected Species (EPS) Licence revision will be required (from Scottish Natural Heritage (SNH)) or MS-LOT for proposed activities that could impact protected species as listed in the Habitats Regulations to cover the altered methodologies described in this EIAR.

In addition to the requirement to undertake an EIA, European Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (the Habitats Directive) and the transposing Habitats Regulations require development projects to consider the impacts of potential developments on sites and species of international nature conservation importance. Where any plan or project is likely to significantly affect features of a nature conservation site which has been designated under the Habitats Regulations, a Habitats Regulations Appraisal (HRA) is required.

Due to the proximity of the development area to sites and species of international nature conservation importance, a Habitat Regulations Appraisal (HRA) under the Conservation of Habitats and Species Regulations 1994 has been undertaken by the Competent Authority. In this case, the Competent Authorities are Transport Scotland or Marine Scotland. The Appropriate Assessment concluded that proposal would not adversely affect the integrity of the SACs, SPAs or pSPAs provided it was undertaken in strict accordance with the conditions set out in in the assessment. To provide confidence that this conclusion is still correct updated information to support the appropriate assessment is presented in Chapter 10.

3.6 Applicable Policy

The determination of the consents and licences applicable to this project involve a wide range of considerations, including relevant national, regional and local government policies. This section describes the overarching policies that have been taken into account in the preparation of the EIAR.

3.6.1 National Policy

3.6.1.1 <u>UK Marine Policy Statement 2011</u>

The UK Marine Policy Statement of March 2011 sets out the framework for preparing Marine Plans and taking decisions that affect the marine environment. The Marine Policy Statement identifies potential impacts on the marine environment resulting from coastal and marine development projects including port developments and marine dredging and disposal, both of which are relevant to this project.

3.6.1.2 National Marine Plan (Scotland)

The National Marine Plan (The Scottish Government, 2015) adopted in March 2015 is guided by the UK Marine Policy Statement (described in section 3.6.1.1). Like the Marine Policy Statement, the National Marine Plan is relevant to this project as it will sit alongside and interact with existing planning regimes and will be consistent with the strategic priorities set out in National Planning Framework 3. The National Marine Plan states that, as most uses of, and development in, the marine environment also have an onshore component, the alignment between terrestrial and marine planning is important and that it "should be achieved through consistency of policy guidance, plans and decisions" (The Scottish Government, 2015). The National Marine Plan goes on to further state that "marine and terrestrial planning authorities should consult one another formally during plan preparation but also collaborate closely throughout the planning process to ensure consistency in their respective plans" (The Scottish Government, 2015).

The National Marine Plan contains objectives that are directly relevant to the proposed development, with Chapter 13: Shipping, Ports, Harbours and Ferries, being the most relevant and identifying the key impacts associated with such activities. The objectives set out in the plan for this sector are summarised here:

- Safeguarded access to ports and harbours and navigational safety;
- Sustainable growth and development of ports and harbours as a competitive sector;
- Safeguarded essential maritime transport links to island and remote mainland communities;
- Linking of ferry services with public transport routes to help encourage sustainable travel;
- Best available technology to mitigate and adapt to climate change, where possible (The Scottish Government, 2015).

It is recognised in the plan that trade is essential to Scotland's economic prosperity, and that shipping is an important element of this trade. The plan emphasises the need to encourage development of Scottish ports and harbours and that this is essential for the continuation and growth of economic prosperity. It is important that marine planning ensures shipping access and navigational safety to the 11 major commercial ports, which includes Aberdeen (The Scottish Government, 2015).

These ports also provide support to other sectors, including oil and gas where the location of Scottish ports in relation to oil and gas reserves in the North Sea means they have strategic importance, with Aberdeen Harbour being one of the ports of particular importance. Ports and harbours are important for supporting other sectors such as renewable energy. The National Renewables Infrastructure Plan (N-RIP) has identified a spatial framework of port and harbour sites, based on best fit locations against offshore renewable industry needs, i.e. construction/installation, manufacturing and inspection, repair and maintenance. Aberdeen Harbour has been identified as an N-RIP site (see section 3.6.1.5 for further information on the N-RIP). The National Marine Plan also sets out the potential interactions with other users of the marine environment and these include other ports and harbours, and shipping and ferries. The Marine Plan also discusses the future of the sector where a trend for larger ships and larger ports is expected (The Scottish Government, 2015).

This is strengthened by the marine planning policies identified within Transport 2 which states that "Marine development and use should not be permitted where it will restrict access to or future expansion of major commercial port or, existing or proposed ports identified as National Developments in the current NPF or as priorities in the N-RIP", of which Aberdeen is classed as both.

In addition to the specific policies on transport, the plan also includes relevant objectives encompassing tourism, recreation and landscape which are captured within the Recreation and Tourism Objectives 2 and 5:

Recreation and Tourism Objective 2:

- "The extent to which the proposal is likely to adversely affect the qualities important to recreational users, including the extent to which proposals may interfere with the physical infrastructure that underpins a recreational activity;
- The extent to which any proposal interferes with access to and along the shore, to the water, use of the resource for recreation or tourism purposes and existing navigational routes or navigational safety;
- Where significant impacts are likely, whether reasonable alternatives can be identified for the proposed activity or development;
- Where significant impacts are likely and there are no reasonable alternatives, whether mitigation, through recognised and effective measures, can be achieved at no significant cost to the marine recreation or tourism sector interests".

Recreation and Tourism Objective 5:

- "Marine planners and decision makers should support enhancement to the aesthetic qualities, coastal character and wildlife experience of Scotland's marine and coastal areas, to the mutual benefit of the natural environment, human quality of life and the recreation and tourism sectors".

3.6.1.3 National Planning Framework

The National Planning Framework is a strategy for the long-term development of Scotland's towns, cities and countryside over the next 20 years. The National Planning Framework identifies key strategic infrastructure needs to ensure that each part of the country can develop to its full potential.

NPF3 (The Scottish Government, 2014), was laid to the Scottish Parliament on 23 June 2014 and sets out the spatial strategy for Scotland's development over the next 20 years to 30 years. It delivers a framework for the spatial development of Scotland as a whole, as well as identifying 14 national developments, to deliver the strategy. NPF3 is accompanied by a strategic environmental assessment, which assesses the impact of the Framework on Scotland's environment, ensuring that issues of environmental sustainability are explicitly addressed throughout. Whilst national development status establishes the need for a project, it does not grant development consent. Planning permission and any other necessary assessments and consents will still be required at the consenting stage.

NPF3 recognises the significance of the harbour expansion project, stating that "Aberdeen Harbour is a nationally important facility which supports the oil and gas sector, provides international and lifeline connections and makes significant contribution to the wider economy of the north-east. Expansion of the harbour is required to address current capacity constraints and to consolidate and expand its role" (The Scottish Government, 2014).

The expansion of Aberdeen Harbour is subsequently identified as a 'National Development', as defined by the Town and Country Planning (Hierarchy of Developments) (Scotland) Regulations 2009 (The Scottish Government, 2009). The site is identified as Nigg Bay, with an accompanying location plan identifying the site boundary in line with that included in Chapter 1: Introduction to the Proposed Development, Figure 1.2.

NPF3 states "Aberdeen is the energy capital of Europe. The north-east of Scotland has above average incomes, low unemployment and a high quality of life. The area's exceptional economic performance provides a real opportunity to build on its success and benefit Scotland as a whole. The City Investment Plan sets out an ambition "to maintain Aberdeen's position as one of the world's key energy capitals and to maximize its growth potential and diversification into other sectors." Infrastructure provision is a key part of this agenda for growth and investment (The Scottish Government, 2014)".

NPF3, page 18 states: "Aberdeen and its wider city region is well-placed to take advantage of continued exploitation of North Sea oil and gas reserves and to develop its expertise in serving this sector, and the growing renewable energy sector around the world'. The expansion of Aberdeen Harbour will strengthen its key role in supporting the economy of the north east, as too will continued improvements to infrastructure including the Aberdeen Western Peripheral Route and Aberdeen Airport. The economic significance of the region is recognised through the need for infrastructure capacity enhancement, both within the city region and in terms of wider links." (The Scottish Government, 2014).

NPF3 includes a section on the Aberdeen city region outlining the successes and opportunities for further growth in the area.

Key actions highlighted to deliver the aims of the spatial strategy in NPF3 of particular relevance to this EIA are:

- "We will continue to take action to help generate the equivalent of 100 % of Scotland's gross annual electricity consumption from renewable sources by 2020, with an interim target of 50 % by 2015.";
- "Working with Scottish Enterprise and Highlands and Islands Enterprise, we will implement the National Renewables Infrastructure Plan with planning enabling development across the locations it identifies.";
- "We will implement the Scottish Biodiversity Strategy, including completing the suite of protected places and improving their connectivity through a national ecological network centred on these sites.";
- "We will deliver the strategic transport projects in the Infrastructure Investment Plan and work with the freight sector to identify priority developments for inclusion in NPF4." (The Scottish Government, 2014).

Planning authorities are required under the Planning etc. (Scotland) Act 2006 to take NPF3 in to account in development plans and development management decisions. The planning legislation also requires

Scottish Ministers to revise the National Planning Framework within 5 years or provide an explanation of why they have decided not to revise it (The Scottish Government, 2014a).

ES Appendix 4-A: Planning and Legislation Supporting Information, outlines the policy statement relevant to the Aberdeen Harbour development.

3.6.1.4 Scottish Planning Policy

Scottish Planning Policy (SPP) (The Scottish Government, 2014b) is a statement of Scottish Government policy on how nationally important land use planning matters should be addressed across the country. The Policy is designed to promote consistency in the application of policy across Scotland whilst allowing sufficient flexibility to reflect local circumstances. It also sets out the policy that will help deliver the objectives of the NPF3. It was approved by Scottish Ministers in June 2014, concurrently with NPF3. This superseded SPP 2010 which informed the preparation of much of the other current planning policy which is of relevance to the Harbour expansion.

SPP outlines a number of statements that support the development. The SPP requires planning authorities across the marine and terrestrial boundaries to work together and introduces a presumption in favour of development that contributes to sustainable development (SPP, page 9, paragraph 27).

ES Appendix 4-A: Planning and Legislation Supporting Information, outlines the relevant subjects and supporting planning guidance documents that require to be considered.

3.6.1.5 National Renewables Infrastructure Plan

The National Renewables Infrastructure Plan (N-RIP) is designed to support the development of a globally competitive offshore renewables industry based in Scotland. The Scottish Government's Renewable Action Plan was published in June 2009 and instigated the development of an investment plan to support appropriate infrastructure for the emerging offshore wind, wave and tidal energy industries. The aim of N-RIP is to establish how port owners can provide sites for offshore renewables use in locations that the industry favours and in a way that fits with the principles of sustainable development and the timescales for use that the industry requires. Aberdeen Harbour has been identified, amongst others, as a Scottish location to support the renewables industry (N-RIP stage 2, page 33 to page 34) (Scottish Enterprise and Highlands and Islands Enterprise, 2010).

3.6.1.6 Scottish Offshore Development Sites – Aberdeen City and Shire Cluster

Aberdeen City and Shire is seen as critical to support the delivery of the offshore renewables industry goals in Scotland having built up an experienced and vast supply chain and labour force from oil and gas, particularly in areas of installation, operation and maintenance of subsea infrastructure. The report by Scottish Enterprise on Aberdeen City and Shire Cluster (Scottish Enterprise and Scottish Development International, 2011) covers two priority sites within the wider renewable strategy: Aberdeen Harbour and Peterhead Port.

The Aberdeen City and Shire Cluster is located for accessing many opportunities on the east coast of the UK and beyond, principally:

- Crown Estate Round 3 Sites; Firth of Forth and Moray Firth;

- Scottish Territorial Waters Offshore Wind Farms: Beatrice, Inch Cape and Neart na Gaoithe;
- The European Offshore Wind Deployment Centre;
- Kincardine Offshore Wind Farm;
- Crown Estate tidal and wave energy leases in the Pentland Firth and Orkney Waters.

A scoping report carried out by Fisher Associates (as discussed within the Directions for Growth report commissioned by AHB (2012) to respond to the recognised need for the expansion of the Aberdeen Harbour facilities) identified significant opportunities for growth in new and existing markets which could be targeted through the expansion of Aberdeen Harbour.

These markets include rising oil production in West Africa, oil and gas decommissioning activities which are expected to increase over the next decade, other oil and gas related shipping growth, offshore wind farm support, marine energy support services, growth in the passenger and car markets and the potential to accommodate larger vessels.

3.6.1.7 Scotland's Oil and Gas Strategy 2012 to 2020

Scotland's Oil and Gas Strategy 2012 to 2020 (Scottish Enterprise, 2012) describes the priority actions and vision for the sector in Scotland. The vision for the industry in Scotland is for one that is increasingly integral to the Scottish economy but outward looking, with Scottish expertise and products in high demand in the global export market.

One of the key issues highlighted in the strategy is the presence of adequate and effective infrastructure. It is seen as a priority to invest in improvements in Aberdeen City and Shire to ensure that Scotland remains competitive. It is only through investments in infrastructure that Scotland will continue to be an attractive long term investment location. The development of transport infrastructure in the north-east of Scotland is seen as vital to ensure connectivity between the sector in Scotland and markets in Europe and further afield.

3.6.2 Regional and Local Policy

3.6.2.1 Current Development Plan

The purpose of the development plan is to set the framework for new developments. In addition, planning applications are assessed against the provisions (land allocations and policies) of the development plan.

The current development plan for the ACC area comprises:

- The Aberdeen City and Shire Strategic Development Plan (2014) (Aberdeen City and Shire Strategic Development Planning Authority, 2014);
- The Aberdeen Local Development Plan (2012) (Aberdeen City Council, 2012), which will be replaced by the new Aberdeen Local Development Plan (2016) (Aberdeen City Council, 2015).

The Aberdeen City and Shire Strategic Development Plan (SDP) was approved by Scottish Ministers on 28 March 2014. The plan covers the whole of Aberdeen city and Aberdeenshire, except the part within the Cairngorms National Park and represents a shared vision for the future of the area to 2035. The main aims of the Aberdeen City and Shire SDP are to:

- "Provide a strong framework for investment decisions which help to grow and diversify the regional economy, supported by promoting the need to use resources more efficiently and effectively;
- Take on the urgent challenges of sustainable development and climate change".

The SDP identifies four strategic growth areas which will be the main focus of development in the area up to 2035 these include Aberdeen city, Aberdeen to Peterhead, Aberdeen to Huntly and Aberdeen to Laurencekirk. Aberdeen Harbour is noted in the plan as "a vital gateway for the regional economy and provides important passenger and freight links to the Northern Isles. The harbour has been identified as a key port in the National Renewables Infrastructure Plan. Work will be needed to set out in more detail the likely implications of this … and how the growth of the harbour can be accommodated to inform the next local development plan" (SDP, page 14, paragraph 3.20). The SDP also notes that improvements to the port facilities at Aberdeen will make the most of their opportunities and potential, particularly to support the energy (including offshore wind) and fishing sectors.

The LDP recognises the importance of Aberdeen Harbour and the importance of safeguarding land in "strategic locations", including beside the Harbour – including land suitable for harbour related uses. The Harbour is described as a "vital hub… (providing)… a service for the region as a whole".

Policy B14 states "within the operational land applying to Aberdeen Airport and Aberdeen Harbour there will be a presumption in favour of uses associated with the airport and harbour respectively. Due regard will be paid for the safety, amenity impacts on and efficiency of uses in the vicinity of the airport and harbour".

The LDP notes that the Harbour Board Operational Area will be subject to a Masterplan which will provide detailed guidance in respect of land uses, policies, proposals, access and connectivity within it and the adjoining areas. The provision of such guidance was undertaken as part of the Draft Nigg Bay Development Framework (2015) which is currently being consulted upon and if approved will provide supplementary guidance for this area.

The Development Framework outlines the connections between the Harbour and the city and considers how these connections can be improved so that the Harbour can continue to complement and support Aberdeen's economic and cultural growth. It also provides guidance to ensure that the objective for a greater mix of uses at the Harbour can be delivered without impacting on the operations of the Harbour. It includes guidance on how to avoid adverse effects upon the qualifying features of the River Dee SAC, which runs throughout the Harbour and also upon bottlenose dolphins, which frequent the outer Harbour and mouth and are qualifying features of the Moray Firth SAC and are an EPS.

4. METHODOLOGIES

4.1 Assessment Scope

An informal scoping request and supporting scoping report (Fugro 2018) was issued to consultees in December 2018 to determine the geographic and technical scope of this EIAR. A narrow range of issues was subsequently identified for consideration relating to the following topics:

- Salmon and sea trout populations;
- Marine mammal populations (grey seal, bottlenose dolphin, harbour porpoise and minke whale);
- Marine birds (terns and eider duck);
- Nigg Bay SSSI.

Stakeholders and regulators consulted during the scoping included the following:

- Marine Scotland (Science and Licensing Operations Team);
- Aberdeen City Council (ACC);
- Transport Scotland;
- Scottish Natural Heritage (SNH);
- Dee District Salmon Fishery Board (DDSFB);
- Whale and Dolphin Conservation (WDC);
- Scottish Environment Protection Agency (SEPA);
- Royal Society for the Protection of Birds (RSPB) Scotland;
- Northern Lighthouse Board (NLB)

As discussed in Section 2.6.1, the scoping document included a proposal to incrementally increase the charge weight up to a maximum weight which yields an underwater noise level which does not exceed the agreed threshold level of 170 dB re 1 µPa rms (equivalent to 183 dB re 1µPa peak) at 400 m from the blast location or outside the double bubble curtain, whichever is the greater distance. As advised at scoping, the initial charge weight would have been 30 kg and would have increased in 10 kg increments, or reverted back to the previously agreed charge weight depending on the outcomes of the simultaneous noise monitoring.

The proposed scope of issues raised at scoping and considered in this EIAR were discussed with consultees at the Environmental Advisory Group (EAG) meeting on 16 January 2019. Consultee responses are presented within the proceeding technical chapters (chapters 5 to 8) where they relate to a specific receptor topic issue. General consultee comments, that do not relate specifically to a receptor topic, are presented in Table 4.1.

Table 4.1: General Consultee Comments

Consultee	Scoping Response	Where Addressed in this EIAR
Northern Lighthouse Board	Confirmation that NLB has no objections to the proposals.	Acknowledged.
RSPB Scotland	Confirmation that RSPB Scotland do not have significant concerns on the proposed scope [of the EIAR] and have no further comments.	Acknowledged.

Consultee	Scoping Response	Where Addressed in this EIAR
SEPA	Confirmation that the proposals are not likely to have any additional significant adverse effect on matters within SEPA's authority and that SEPA do not require any additional matters to be addressed in the scope of the EIA Report.	Acknowledged.
	Acknowledging that other matters, such as the potential for impact on migrating salmonids, should be assessed by MS-LOT as part of the Habitats Regulations Assessment/Appropriate Assessment.	Chapter 10 presents a Habitats Regulations Assessment including consideration of the Atlantic salmon interest of the River Dee SAC.
Transport Scotland	Confirming involvement will be limited to approving any revised CEMD.	Acknowledged.
Scottish Natural Heritage	Request for clarification on the numbers of charges to be used and likely impact of increased underwater noise.	Section 4.3.2 presents current observations on numbers of charges and noise levels.
	Highlights that there is currently insufficient evidence to support the [current] approach and advises that there should be no increase in charge weight in the south of the bay until there is sufficient evidence of underwater noise and effectiveness of the double bubble curtain in this area. Advocates that a 20kg charge should remain the starting point for blasting in the southern part of Nigg Bay	
Marine Scotland Science	In principle, MMS welcome fewer blasts at larger charge weights noting previous concerns regarding: ■ Number of observations; ■ Consideration of the numbers of charges used; ■ Uncertainties with the on-site noise measurements.	
	Charge sizes should be increased in increments of 5 kg.	Acknowledged.
Aberdeen City Council	Marine activities are out with the Town & Country Planning EIA Regulations and therefore ACC is not the licensing authority.	Acknowledged.
	Agree in principle to the proposed changes to the duration of blasting as there won't be any significant environmental impact	Acknowledged
	Request for confirmation of any changes to the methodologies relating to the land reclamation activities to the rear of the quayside installations.	DUK confirm that there are no changes to the methodology.
	Agreement with the matters to be scoped in and out	Acknowledged
	Justification is required for scoping out changes in water quality and bioavailability of sediment contaminants considering the Water Framework Directive and the Scotland River Basin Management Plan objectives.	The quantities, nature, methods and locations of seabed dredging and disposed will not change and so any associated water quality impacts and increased bioavailability of sediment contaminants

Consultee	Scoping Response	Where Addressed in this EIAR
	Justification is required for scoping out interactions of pollutants with marine mammals due to accidental spills or release of sediments.	remains as assessed previously in the 2015 ES. There will be the same amount of vessel movements as previously planned and overall construction methods have not changed and so there is no increased risk in accidental spills or sediment releases occurring. The proposals do not involve a significant change in waste management plans. A revised CEMD will be provided for statutory agreement.
	Overall, the scoping proposals for the EIAR are accepted, subject to the comments above.	Acknowledged.

As described in Section 2.6, the programme of blasting has changed since the scoping advice was issued and discussed at the regulator meeting on 16 January 2019. The current proposals are for a programme of incremental increases in charge weights which will include a resumption of blasting using a charge weight of 20 kg and an increase in charge weights through 30, 40, 45, 50, 55, 60, 65, 70, 75 and 80 kg. An extension to the blasting and dredging programme is also sought. Further details of the current proposals are provided in Section 2.6.

4.2 Study Area

The study area for this EIAR includes the AHEP and the local sea area around Aberdeen but also encompasses the wider region of the Aberdeenshire coast which is available for use by local marine birds, marine mammals, fish and shellfish. In addition, information on other projects and activities between the Firth and Forth to the south and the Moray Firth to the north, and which may be within the range movement of mobile receptors such as bottlenose dolphins and Atlantic salmon, have been obtained.

4.3 Data Sources Used

Environmental conditions and spatial and temporal distributions of selected receptors have already been comprehensively studied in the 2015 ES (AHB, 2015). These are reviewed again here in Chapters 5 to 8 to define the current baseline conditions in this EIAR. Data are supplemented with results from ongoing post consent compliance monitoring studies including:

- Fish kill monitoring following blasting;
- Salmon and sea trout electronic tagging;
- Marine mammal observation and hydrophone (C-POD) recordings;
- Eider duck monitoring;
- Underwater noise and vibration monitoring.

4.3.1 Underwater Noise Technical Study

A specific underwater noise impact study has been undertaken to inform this EIAR and is presented in Appendix B. It uses a modified version of the Confined Blast Model that was initially used to predict impacts ranges from underwater noise from blasting in the 2015 ES (Technical Report 13-B) but which has since been validated to correlate better with empirical observations from the current noise monitoring efforts at the AHEP. Such monitoring efforts have been ongoing throughout the construction of the AHEP in 2018 primarily to demonstrate compliance with existing licence conditions, but also to estimate the actual noise attenuation capabilities of the double bubble curtain and to validate predictions of the Confined blast model used in the 2015 ES (AHB, 2015). The following describes the underwater noise monitoring and model validation conducted to date,

4.3.1.1 Underwater noise monitoring 2018

Only 12 days of blasting have so far been completed. Nevertheless, 33 recordings of noise levels have been collected from within the double bubble curtain and 21 recordings outside of the double bubble as summarised in Table 4.2.

On some blasting days, not all of the charges laid were detonated in the initial blast and so it was necessary to perform a repeat blast, a few seconds later, to ensure that all remaining charges had been detonated for safety purposes. This second 'safety' blast provided opportunity to collect additional underwater noise measurements from blasting and accounts for the apparent occurrence of more than two blasts on some days.

All monitoring data have been collected from blasts using 20 kg charges or less from the north of Nigg Bay with the exception of a small number of detonations (3 no.) using smaller (<20 kg) charge weights undertaken to the south of the bay in November 2018. All noise levels recorded from outside of the double bubble curtain have been well below the agreed noise threshold of 170 dB re 1 µPa rms (equivalent to 183 dB re 1µPa peak) at 400 m from the blast location or outside the double bubble curtain, whichever is the greater distance.

Table 4.2. Results of the underwater noise monitoring from blasting

Blast Date	No. holes drilled	Charges detonated/ primed	Inside double bubble curtain			Outside double bubble curtain		
			Dist. from blast site [m]	Blast level [dB re 1 µPa]		Dist. from blast site [m]	Blast level [dB re 1 µPa]	
				Peak	rms		Peak	rms
20-Aug-18	45	42/45†	437	183.6	168	~	~	~
20-Aug-18	90	90/90	442	192	169.5	~	~	~
24-Aug-18	3	3/3†	457	160	135.8	806	‡	138.9‡
24-Aug-18	63	63/63	424	188.8	168.5	769	168.5	153.7
06-Sep-18	65	65/65	285	207.4	188.1	~	~	~
06-Sep-18	86	86/86	262	209.5	185.8	~	~	~
12-Sep-18	132	92/132	232	209.2	184	~	~	~
12-Sep-18		40/132	252	189.1	161.2	~	~	~
12-Sep-18	77	30/77	270	212	189	~	~	~
12-Sep-18		47/77	293	205.1	184.6	~	~	~
14-Sep-18	99	59/99	326	212	190	893	142.6	131.8
14-Sep-18		40/99	336	181.1	151.6	869	141.3	128.8
14-Sep-18		40/99*	336	202.6	183.3	899	126	115.3
14-Sep-18	53	53/53	358	213.9	189	922	138	121.6
14-Sep-18		53/53*	358	196.2	176.7	~	~	~
17-Sep-18	134	134/134	565	204.7	177.4	964	154	143.2
17-Sep-18	47	47/47	589	206.4	174.8	990	147.2	135.9
08-Oct-18	100	100/100	306	210.6	196.8	644	162.1	149.8

<table>
<tr><th rowspan="3">Blast Date</th><th rowspan="3">No. holes drilled</th><th rowspan="3">Charges detonated/ primed</th><th colspan="3">Inside double bubble curtain</th><th colspan="3">Outside double bubble curtain</th></tr>
<tr><th rowspan="2">Dist. from blast site [m]</th><th colspan="2">Blast level [dB re 1 µPa]</th><th rowspan="2">Dist. from blast site [m]</th><th colspan="2">Blast level [dB re 1 µPa]</th></tr>
<tr><th>Peak</th><th>rms</th><th>Peak</th><th>rms</th></tr>
<tr><td>08-Oct-18</td><td>48</td><td>48/48</td><td>463</td><td>213.8</td><td>198.9</td><td>846</td><td>162.1</td><td>152.3</td></tr>
<tr><td>08-Oct-18</td><td rowspan="2">149</td><td>119/149</td><td>393</td><td>210.3</td><td>188.5</td><td>746</td><td>162.1</td><td>152.3</td></tr>
<tr><td>08-Oct-18</td><td>30/149</td><td>393</td><td>205.2</td><td>180.1</td><td>746</td><td>161.8</td><td>146.1</td></tr>
<tr><td>13-Oct-18</td><td>84</td><td>84/84</td><td>446</td><td>209.3</td><td>180.3</td><td>696</td><td>166.3</td><td>151.2</td></tr>
<tr><td>17-Oct-18</td><td>38</td><td>38/38</td><td>354</td><td>198.3</td><td>168.5</td><td>919</td><td>163</td><td>151.6</td></tr>
<tr><td>17-Oct-18</td><td>49</td><td>49/49</td><td>371</td><td>226.5</td><td>197.9</td><td>953</td><td>163</td><td>151.6</td></tr>
<tr><td>25-Oct-18</td><td>51</td><td>51/51</td><td>575</td><td>211.2</td><td>185.9</td><td>1163</td><td>158.1</td><td>146.2</td></tr>
<tr><td>25-Oct-18</td><td rowspan="2">69</td><td>12/69</td><td>613</td><td>204.7</td><td>181.7</td><td>1224</td><td>156.3</td><td>144.5</td></tr>
<tr><td>25-Oct-18</td><td>57/69</td><td>528</td><td>220.9</td><td>180</td><td>1194</td><td>157.4</td><td>143.2</td></tr>
<tr><td>25-Oct-18</td><td rowspan="2">71</td><td>36/72</td><td>537</td><td>204.7</td><td>183.8</td><td>1075</td><td>156.3</td><td>140.9</td></tr>
<tr><td>25-Oct-18</td><td>36/72</td><td>486</td><td>205.1</td><td>190.5</td><td>1075</td><td>158.5</td><td>142.7</td></tr>
<tr><td>17-Nov-18</td><td>121</td><td>121/121</td><td>257</td><td>206.4</td><td>208.3</td><td>707</td><td>~</td><td>~</td></tr>
<tr><td>17-Nov-18</td><td>55</td><td>55/55</td><td>262</td><td>231.3</td><td>211.9</td><td>771</td><td>~</td><td>~</td></tr>
<tr><td>17-Nov-18</td><td>77</td><td>70/77</td><td>245</td><td>237.6</td><td>208.8</td><td>740</td><td>~</td><td>~</td></tr>
<tr><td>17-Nov-18</td><td>3</td><td>3/3††</td><td>255</td><td>234.8</td><td>196.4</td><td>302</td><td>~</td><td>~</td></tr>
<tr><td>24-Nov-18</td><td rowspan="2">217</td><td>217/217</td><td>~</td><td>~</td><td>~</td><td>860</td><td>166</td><td>151.9</td></tr>
<tr><td>24-Nov-18</td><td>198/198</td><td>~</td><td>~</td><td>~</td><td>831</td><td>165.9</td><td>150.8</td></tr>
<tr><td colspan="9">Key
‡ not evident in acoustic record: estimated rms level only
† 10 kg charge
†† blasting undertaken to the south of Nigg Bay
~ no recording, equipment failure
*repeat measurement</td></tr>
</table>

4.3.1.2 Model validation report

At the time of the ES (AHB, 2015), the blast noise propagation modelling (Confirmed Blast Model) (Technical Appendix 13-B) was calibrated using available data from the literature; however, the report prepared at that time acknowledged that very little published data on underwater noise levels from confined explosions exists. Since then, monitoring data have been collected from the 2018 blasting programme (see Table 4.2) and used to validate and improve the accuracy of the same model used in the original ES, and which has been subsequently re-run for larger charge weights to inform this EIAR (AECL, 2019) (see Appendix B). Information on the validation and improvement of the model is provided in the model calibration report (Award Environmental Consultants Ltd (AECL), 2018a), which was included in the EIA Scoping Report (December 2018) (Fugro, 2018) and is provided again in Appendix C of this EIAR. The calibration report provided at scoping explained the iterative process of data collection and model structure refinement. At the time of issue, the calibration report considered all of the monitoring data that had been collected between August and October 2018. On the basis of these data, the calibration report provided improved estimates of double bubble curtain attenuation and an enhanced correlation between predicted and observed blast levels compared to previous analyses in the 2015 ES. The estimate of double bubble curtain attenuation at the time of the issue of the calibration report was 45 dB ±10dB. In addition, it was predicted with a high degree of certainty (97.7%) that the maximum permitted explosive charge weight could be increased to over 100 kg, without exceeding agreed thresholds regardless of double bubble curtain location assuming an attenuation performance of 45 dB ±10dB. However, the agreed threshold would be exceeded at a distance of up to 360 m beyond the double bubble curtain for a charge weight of 70 kg (the largest weight considered during this model scenario) if the lower range attenuation (35 dB) is assumed and the double bubble curtain is approximately 100 m from the blast site.

4.3.1.3 Further model calibration and additional monitoring

Since the issue of the calibration report, additional noise monitoring data from November 2018 have become available (AECL, 2018b) (Appendix D). This provided additional opportunity to refine the same Confined Blast Model still further(Appendix B). Thus, it is now possible to provide estimates of double bubble curtain performance and predictions of noise levels from blasting in terms of impact ranges on fish and marine mammal receptors with higher accuracy as it uses all of the empirical observations now available from the monitoring to modify the same model. The following explains the current model and underlying data used in the technical noise report in support of this EIAR (Appendix B).

4.3.1.4 The underwater noise model

The model used to support this EIAR (Appendix B) is a modified version of the original model which was accepted in the ES which itself drew upon a pre-existing semi-empirical technique (Wright and Hopky, 1998). This technique was used to model the transmission of sound from an explosion in a borehole and hence determine the distance over which sound levels attenuate to certain levels and was used here as the basis of a model describing the propagation of a blast wave in water.

The propagation of acoustic energy in water can be generally modelled using the term N Log10[R] where N is the propagation constant and R is the distance in metres between the blast site and the measurement station. Drawing upon the underwater noise measurement data collected at Nigg Bay to date, a constant of N = 13 best matches the observations collected between August and November 2018. However, it should be noted that these observations were only collected over a short distance (up to approximately 1 km from Nigg Bay) so that propagation characteristics of underwater noise from confined blasts at Nigg Bay over greater distances have not been measured. To account for the natural increased attenuation over longer distances, a further adjustment has been applied based on the propagation of broadband signals in shallow waters, based on a model developed by Marsh and Schulkin (1962) (see Appendix B).

From the current underwater noise measurements for charge weights of 20 kg, estimates of source levels for a series of charge weights up to 100 kg were calculated as shown in Table 4.3. The results indicate that increasing the charge weight from 20 kg to 100 kg results in a predicted increase in peak blast levels of approximately 11 dB.

Table 4.3: Estimated Source Levels for a Range of Explosive Charge Weights

Charge Weight	**20 kg**	**30 kg**	**40 kg**	**50 kg**	**60 kg**
SL dB re 1 uPa at 1 m	244.2	247.0	249.0	250.6	251.8
Charge Weight	**70 kg**	**80 kg**	**90 kg**	**100 kg**	
SL dB re 1 uPa at 1 m	252.9	253.8	254.7	255.4	

Applying the noise source estimates to the propagation characteristics then allowed for the peak blast levels to be established as a function of distance as indicated in Figure 4-1.

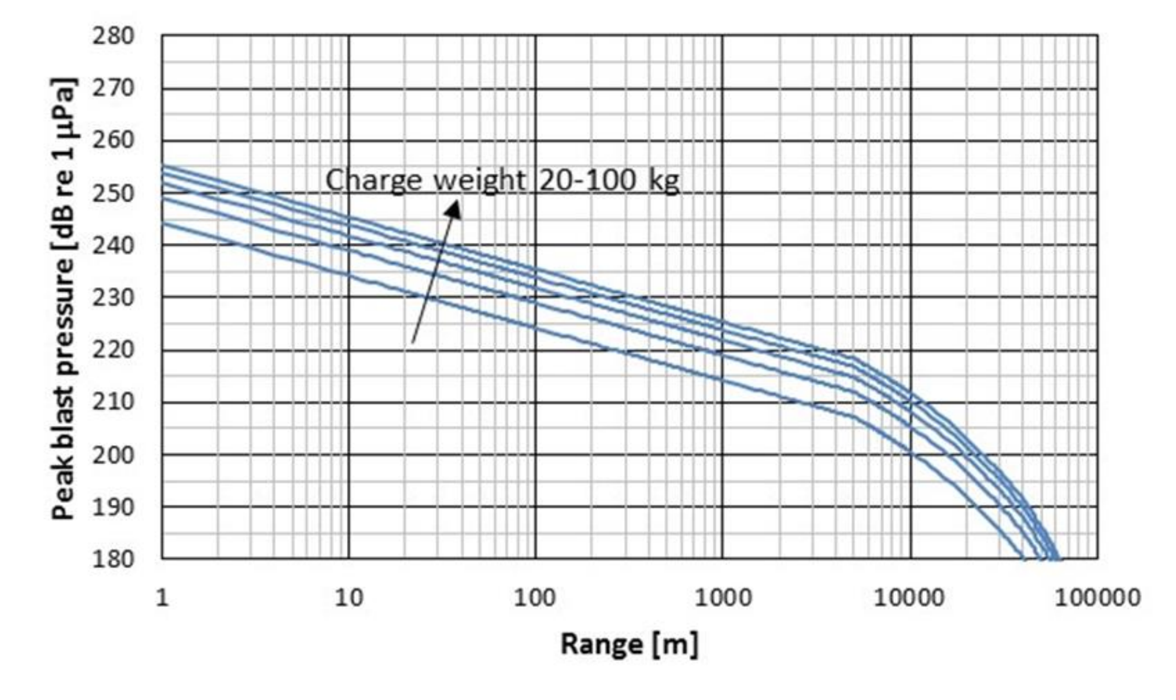

Figure 4-1: Predicted peak blast levels using the modified confined-blast model

In practice, the conditions indicated in Figure 4-1 are not met as a double bubble curtain is deployed at the mouth of the Nigg Bay which has the effect of absorbing a significant level of noise. Furthermore, the long-range propagation modelling undertaken using the Marsh-Schulkin model assumed that sea surface losses were minimal. In the event that the sea surface was perturbed, i.e. due to wind or wave action, then the resulting propagation pressure levels would be somewhat lower than indicated in Figure 4-1. Consequently, the peak pressure levels shown may be regarded as precautionary.

From on-site measurements of all noise collected from either side of the double bubble curtain, which itself was located between 650 m and 700 m from blast source noise at the AHEP (Figure 4-2), it can be seen that the double bubble curtain has a mean attenuation of 38 ± 16 dB (AECL., 2018b) (Appendix D). The potential minimum attenuation is thus 22 dB although attenuation could be as high as 54 dB. This estimate of double bubble curtain attenuation differs from that reported in the calibration report (Appendix C) and as advised at scoping and is considered here as an improved estimate based on all currently available monitoring information collected between August and November 2018.

A certain amount of uncertainty is apparent in the dataset due to the relatively large scatter of data points. Variability may be accounted for by charge weight distribution for each blast and local variations in the underlying geology, water depth and structure of the overlying water column and which could influence how well the acoustic energy is firstly, coupled into the seabed and secondly, propagated to any distance (AECL, 2018b). The recorded blast noise may also be dependent on the position of the hydrophone within the water column as well as any movement of the hydrophone caused by surface disturbances due to wind and waves or the presence of any sea swell (AECL, 2018b).

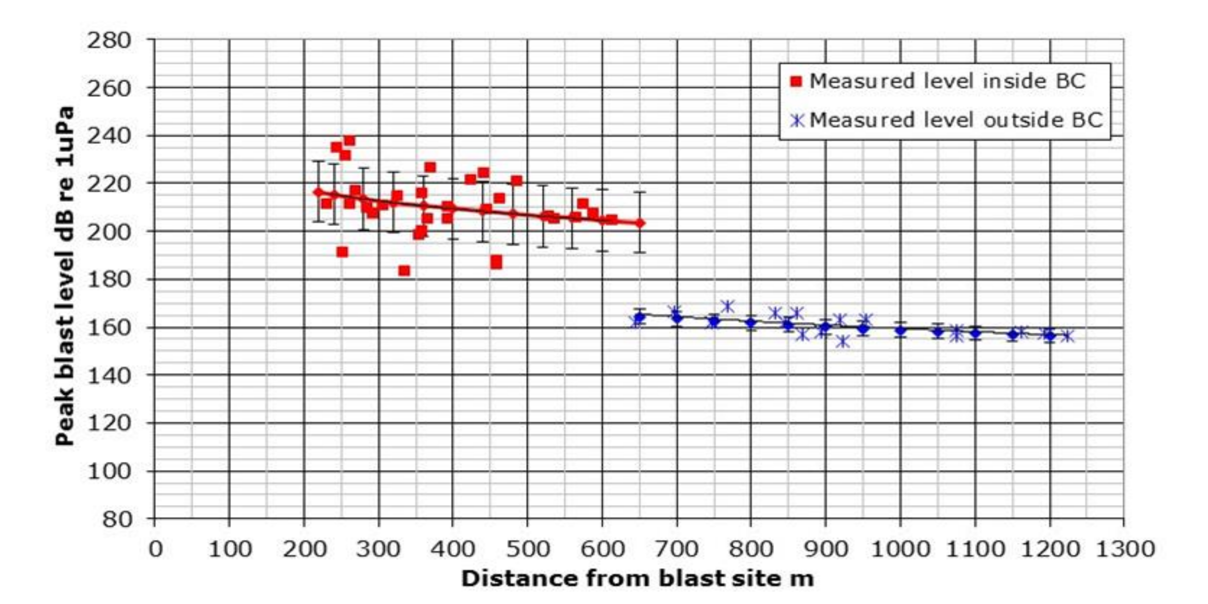

Figure 4-2. Peak blast levels recorded before and after the double bubble curtain at Nigg Bay (**Source:** AECL, 2018b).

Having established the double bubble curtain attenuation performance, the levels of underwater noise created by the detonation of charge weights ranging between 20 kg and 100 kg in weight were then used to estimate impact ranges for the different functional hearing groups for fish and marine mammals (grey seal, harbour porpoise, bottlenose dolphin and minke whale) using the impact thresholds derived from the most recent guidelines including the National Marine Fisheries Service (NMFS) guidelines for marine mammals (NMFS, 2016; 2018[1]) and ANSI Accredited Standards Committee guidelines for fishes (Popper et al., 2014) and based on the following two scenarios:

i. The absence of the double bubble curtain;
ii. The presence of the double bubble curtain with an attenuation of 22 dB and positioned 100 m from the blast site. This scenario replicates a possible worse-case configuration of the double bubble curtain during blasting in the south of Nigg Bay and the minimum attenuation performance of the double bubble curtain based on current measurement data.

Both scenarios above assume that the southern breakwater would not be present at the time that blasting resumes so that open water areas would not be afforded any potential protection from construction noise by its physical presence. Rock removed from the seabed by blasting will be beneficially used in the breakwater construction so that such protection would be provided as blasting progresses.

Peak sound pressure levels (dB re 1 µPa $_{peak}$) have been used to determine permanent threshold shift (PTS) and temporary threshold shift (TTS) in marine mammals and for mortality and potential mortal injury in fish. Noise levels indicative of behavioural responses in marine mammals are expressed as

[1] Updated guidelines for marine mammals (Southall et al., 2019) have since been published but provide similar threshold levels as NMFS, so it is considered that conclusions will not change.

root mean square (rms) sound pressure levels (dB re 1 µPa rms) and are derived at by applying a precautionary conversion factor to the acquired peak sound pressure levels of 11 dB.

In addition to the peak and rms metrics, the sound exposure level (SEL) has also been computed for PTS and TTS for marine mammals which assumed that exposure to blast noise lasted 2.2 seconds, this being the mean duration of the outgoing pulse as determined by on site monitoring at the AHEP.

Results of the analyses are presented in Chapter 5 (Fish and Shellfish Ecology) and Chapter 6 (Marine Mammals).

4.3.2 Number of Charges Used in the Blasting Procedure

The original ES (AHB, 2015) did not consider the influence of the number of charges used per blasting event on noise levels. However, potential relationships can be explored using the noise monitoring data as discussed below.

To date, the numbers of charges detonated per blasting event has generally varied between 30 and 217 with most blasting events involving between 40 and 60 charges. The charges are detonated separately but are only separated by milliseconds in time but altogether result in a mean duration of 2.2 seconds.

To date, noise levels have been measured at different distances from the blast source and have involved different numbers of detonations (Table 4.2) as well as different distributions and charge weight combinations thus confounding direct comparison between blasting events. Nonetheless, some attempt at a comparison of noise levels between different blasting events has been made here to assess the effect of different charge numbers. Figure 4-3 and Figure 4-4 show recorded noise (rms noise) levels propagated to 400 m distance from the blast site. This procedure attempts to cancel out any variance in noise levels due to the different distances from the blast source over which noise was recorded but doesn’t account for any differences in the distributions of change weights across the different fields.

Inside the double bubble curtain (Figure 4-3), there is a very high degree of scatter of noise levels with little apparent relationship with the number of detonations per blasting event. While an overall trend of increasing noise levels with increasing numbers of detonations can be interpreted from the results, the majority of data points are located far from the trend line suggesting a weak or no relationship in this regard. This likely reflects the variable deployments of charge weights across the different blast fields although other confounding factors may also be involved.

Outside the double bubble curtain (Figure 4-4), the data supports a relatively more convincing relationship between noise levels and numbers of detonations, with data points clustering more closely to the trend of increasing rms levels with increasing numbers of charges. Although a very slight overall increase in noise levels with increasing numbers of detonations is apparent the data shows that on some occasions lower numbers of detonations result in higher noise levels compared to large number of detonation outside the double bubble curtain so that the relationship remains uncertain.

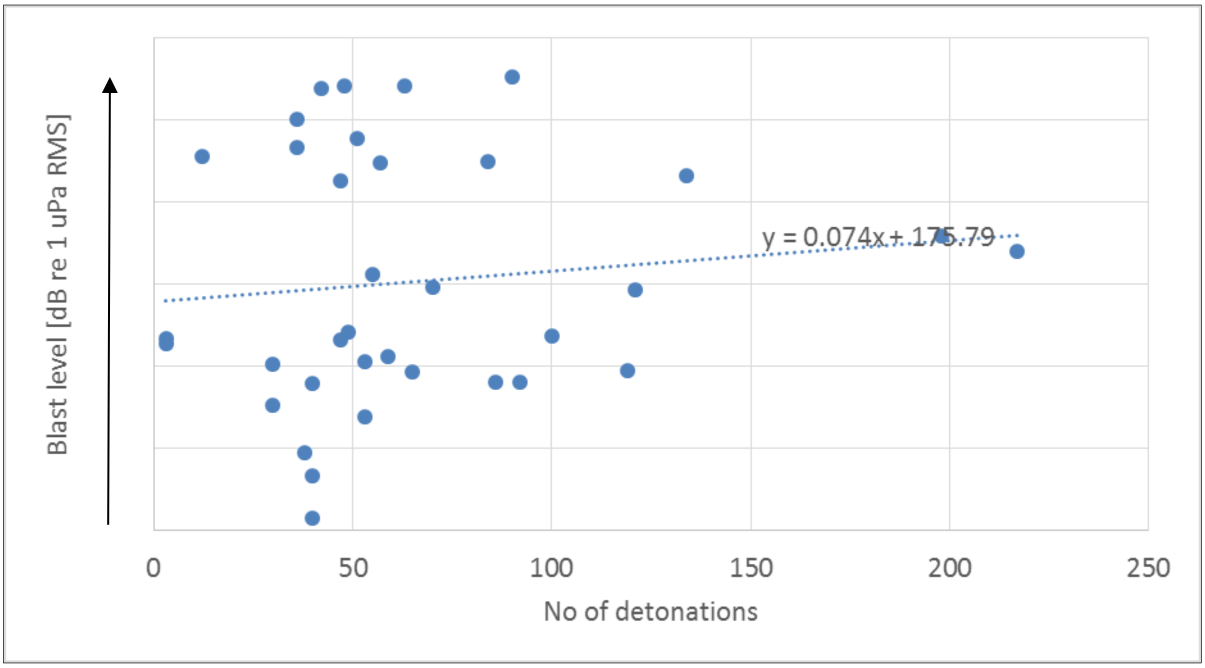

Figure 4-3: Blast level propagated to 400 m as a function of number of charges detonated inside the double bubble curtain.

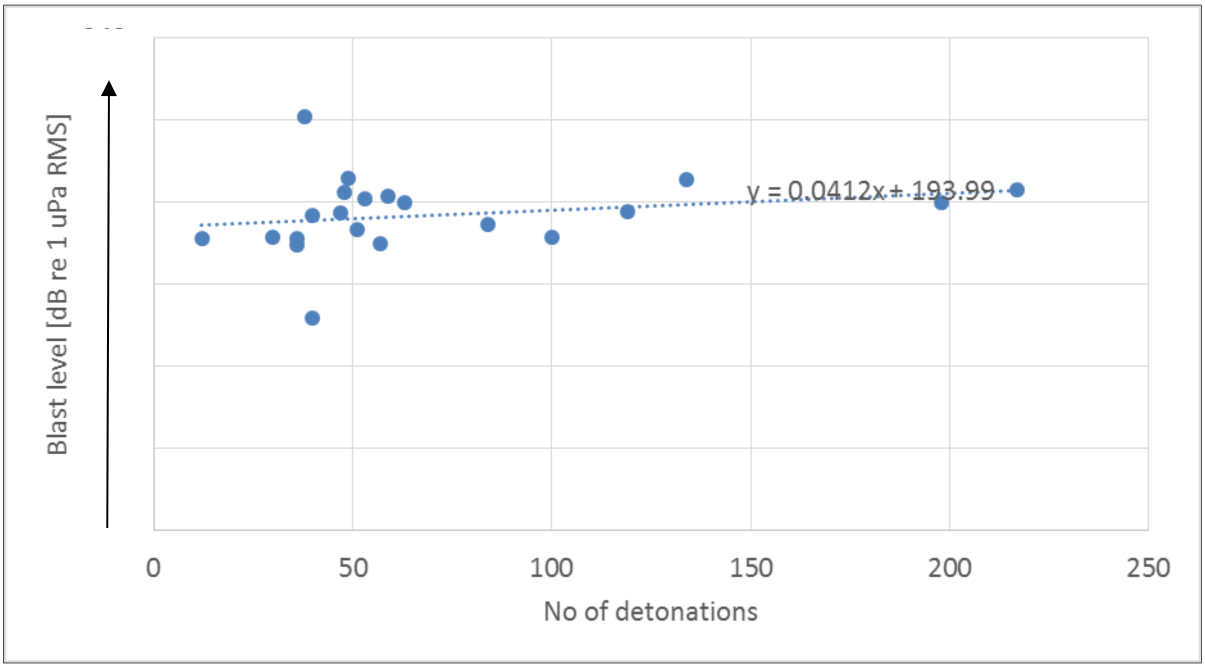

Figure 4-4. Blast level propagated to 400 m as a function of number of charges detonated outside the double bubble curtain. .

4.4 Data Uncertainties

4.4.1 Field Data Quality

Ideally, the data presented in Figure 4-2 should be limited to those that are "environmentally paired" to minimise potential differences in environmental noise, such as wind and waves between recording occasions. This may allow for a fairer comparison of noise levels either side of the double bubble curtain at the AHEP for assessment of the double bubble curtain attenuation. However, with only few data points collected to date, limiting the information in this way will further reduce an already limited data set, reducing statistical power while data for key locations, such as close to the double bubble curtain, may be lost.

4.4.2 Peak Particle Velocity

As well as sound pressure, fish can also detect, and be sensitive to, the particle motion component of the sound field (Popper and Hawkins, 2018; 2019; Hawkins and Popper, 2016; Nedelec et al., 2016). Andersson et al. (2017) explain that all fish can detect particle motion with their inner ears and a lateral line organ and even invertebrates like squid can detect particle motion. It is considered that all fishes are primarily detectors of particle motion with relatively few species using sound pressure (Popper & Hawkins, 2019) Atlantic salmon (*Salmo salar*) are considered to be particularly sensitive to particle motion (Hawkins and Johnstone, 1978; Popper & Hawkins, 2019) .

Particle motion describes the oscillatory (back and forwards) movement of particles in a medium which are set in motion by the introduction of a vibrating source. The oscillating particles move the particles that are next to them which then move the particles next to them and so on so that the vibrating energy propagates outwards from the source of vibration. The particles do not move through the medium with the propagating sound source but move back and forth at the same location transmitting this movement to neighbouring particles.

Responses of fishes to increased particle motion are poorly understood (Popper & Hawkins, 2019) and there are no regulatory standards or guidelines relating to particle motion for assessment purposes (Andersson et al., 2017) which instead focus on sound pressure levels. Indeed, Popper & Hawkins (2019) call for amended guidelines which consider particle motion as currently, only sound pressure is accounted for. The authors further highlight that there is a growing awareness that fishes possess particle motion receptors and that this must be taken into account when setting future criteria. Consequently, the effects of increased particle motion to fishes are acknowledged as a source of uncertainty in this EIAR. The exception to this is the mortality threshold of 13 mm/s peak particle velocity (PPV) for fish eggs and larvae (Popper et al., 2014).

There is also no information on the attenuation properties of the double bubble curtain in use at the AHEP with respect to particle motion although previous work (Macgillivray and Racca, 2006) has shown that a double bubble curtain was effective at reducing the peak particle velocity from hammering a single pile at 10 m by over 11 dB.

Substrate-borne vibrations caused by confined blasts may travel beneath the double bubble curtain and out into the wider area beyond the AHEP boundaries. Using the PPVs data generated from the confined blast model (Appendix B) (Figure 4-5) it can be shown that increased vibrations in the seabed sediments are predicted to diminish rapidly with increasing distance from the blast site and that beyond 10 m levels fall logarithmically. PPVs reduce to 0 after approximately 300 m for a 20 kg weight explosive charge and after approximately 750 m for a charge weight of 100 kg. The mortality threshold of 13 mm/s peak velocity for fish eggs and larvae is not met beyond 200 m even for the largest charge weight considered (100 kg) (Appendix B).

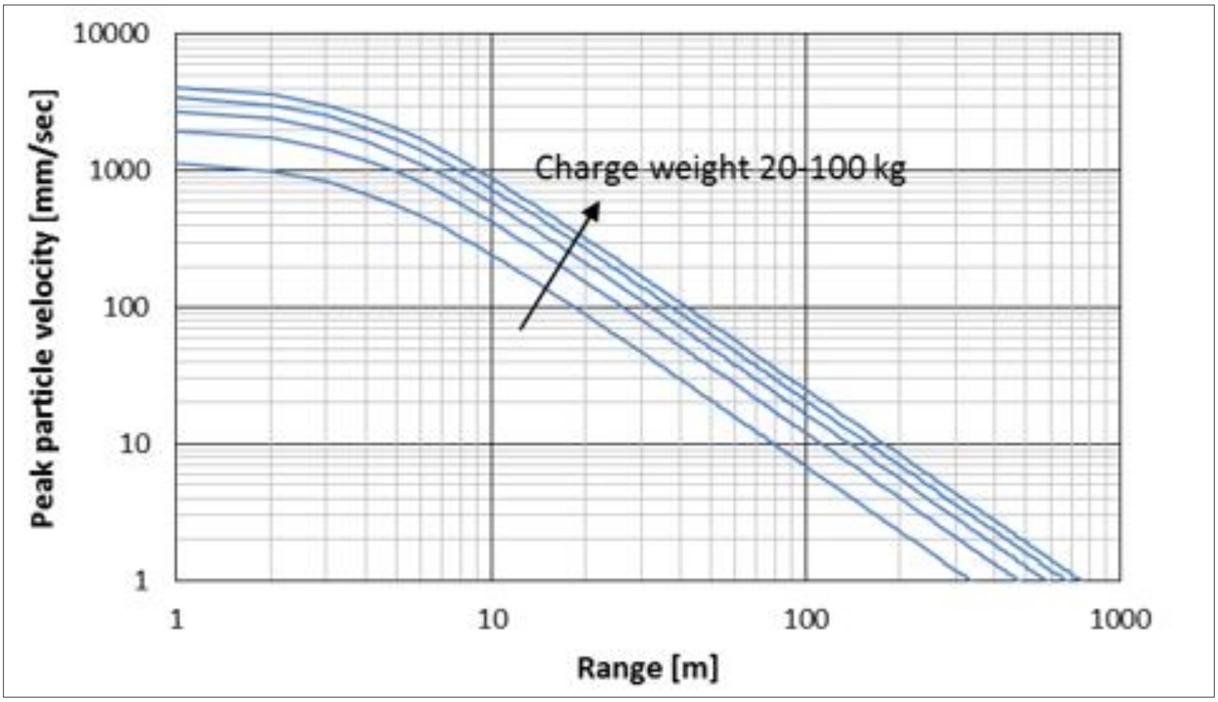

Figure 4-5: Modelled PPV from a blast site for variously weights of charges (20, 40, 60, 80 and 100 kg)

(**Source:** AECL, 2019; Appendix B).

4.4.3 Increase in Airborne Noise

The potential for airborne noise levels to increase due to the proposed changes to the blasting methodology is not known but for the purposes of this assessment is considered to be small given the limited transmittance of noise through the sea – air interface.

The air-sea interface creates a substantial sound barrier (Hildebrand, 2004) and only an exceedingly small fraction of acoustic energy, or a few hundredths of a percent, is transmitted through the interface (Godin, 2008). Acoustic impedance may be reduced when the sea surface is at all rough and energy for low frequencies may be radiated to the atmosphere when the source is near the interface within a fraction of the acoustic wavelength (Godin, 2008; Bolghazi, 2017) however, overall the transmission of noise from seabed to the open air is considered marginal.

Therefore, while it is possible that confined seabed blasts at the AHEP are audible in the air, any increase in airborne noise due to the use of larger explosive charges (> 20 kg), and the associated effects on in-air receptors, such as local residents or marine birds, would seem to be negligible.

Measurements of in-air noise collected near to the lighthouse at Girdle Ness, and other locations around Nigg Bay as part of routine monitoring, show no significant peaks in noise levels at the times of detonations. This may be demonstrated in Figure 4-6 which shows example airborne noise levels (expressed as maximum levels (LAFmax dB) over successive 5-minute periods) either side of a blasting event that occurred at 09:50 on 24 November 2018. These data suggest that peak noise levels at around the time of the blasting event were no louder at the lighthouse monitoring station than at some other times when no blasting was taking place.

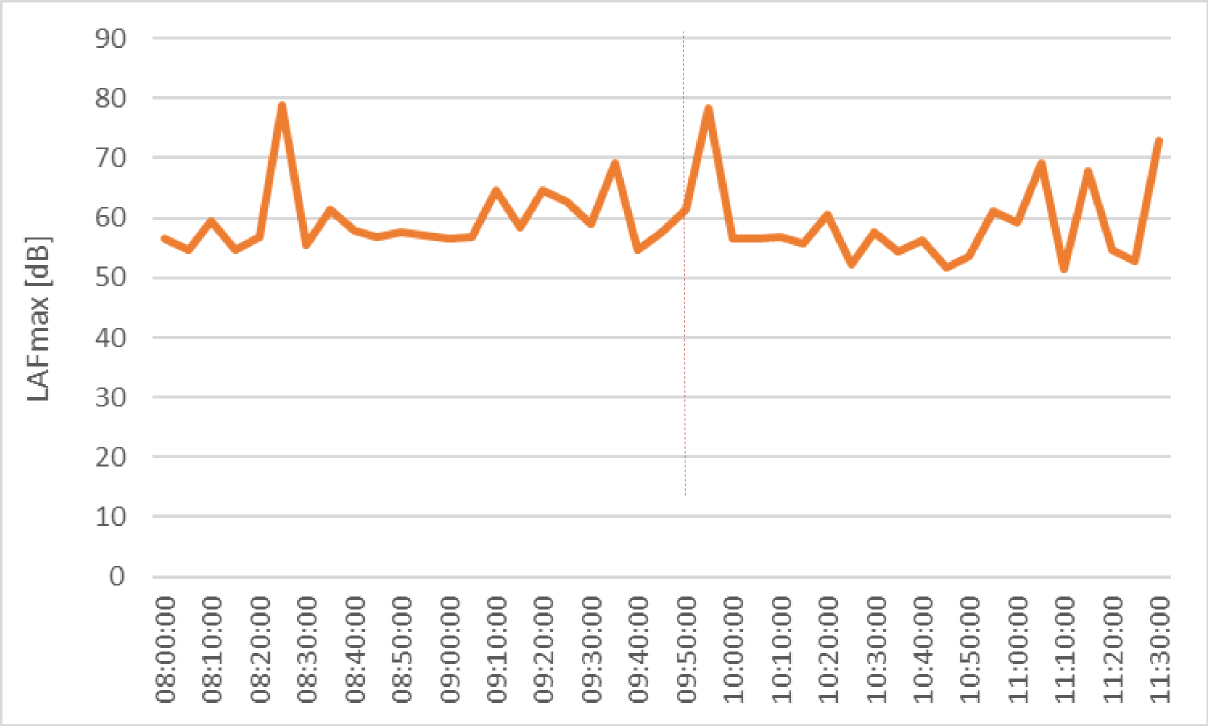

Figure 4-6: Example airborne noise levels recorded at the lighthouse at Girdle Ness either side of a blasting event at 09:50 on 24 November 2018

4.4.4 Increase in Sea Surface Disturbances

At the AHEP, domes of seawater and sea surface disturbances are created directly above the site of confined blast using a 20 kg charges. Current observations suggest that typical diameters of domes may be up to some tens of metres across (see for example Figure 4-7) although accurate measurements have not been undertaken.

The extent and characteristics of sea surface disturbances directly above an underwater explosion vary depending on several factors including charge weight, depth of charge detonation and proximity of reflecting boundaries such as the ocean bottom (Costanzo, 2011).

Figure 4-7: Typical sea surface disturbance (dome) following detonation of 20 kg charge at the AHEP

Kolksy et al (1949) showed that heights and diameters of domes of water generated at the water surface directly above underwater explosions correlate with the depth and weight of charge used. Larger charges detonated at greater depths create greater domes on the water and have larger diameters than those created by smaller and more shallow explosions. The diameters of surface domes however only increase with depth up to a critical depth (i.e. 8.5 m for a 4.5 kg weight charge) after which the diameters become smaller.

In calm water it was found that the diameters of the domes were considerably smaller than when the water was at all rough (Kolksy et al., 1949). Diameters of domes in calm water following detonation of a 10 lb (4.5 kg) charge at 3 m for instance reached 16 m but reached nearly 22 m when detonated in rough water. For the same weight of charge detonated at 10 m in rough water, the diameter of the dome was 29 m.

Quantifying any additional sea surface disturbances due to the proposed changes in blasting methodology at the AHEP is difficult at this time and is likely to relate to the depth and weight of the explosive charge used, the geometry of the seabed holes into which the charges are placed and the sea conditions at the time of detonation amongst other possible factors. Seabirds are expected to be temporarily displaced from the immediate vicinity of blast sites due to associated vessel movements and charge laying activities and so are unlikely to be caught in blasts or within domes of disturbed water.

4.5 Assessing Effect Significance

Impact assessment methods refer to those used in the 2015 ES for EIA (ABH, 2015) as well as those described in Chartered Institute of Ecology and Environmental Management (CIEEM) guidelines (CIEEM, 2018) for the conduct of Ecological Environmental Impact Assessment (EcEIA).

The key aim of this EIAR is to identify additional likely significant effects, which may occur over and above those already identified for the existing AHEP, so that they can be mitigated accordingly.

To establish how the significance of an effect is established, guidelines typically refer to a combination of the '*magnitude*' of the associated impact, within some geographical frame of reference, and the '*value*' of the receptor. The following describes the classification of the different aspects of effect significance used in this EIAR to assist repeatability across different receptor topics and transparency and to meet the EIA aims. Thus, in this EIAR, impact magnitude is taken to comprise the following elements and categories:

- **Spatial extent:** the area over which the impact occurs as defined as:
  - Local (within the AHEP);
  - Regional (beyond the AHEP to east coast of Scotland);
  - National (Scotland);
- **Recoverability:** the potential of a receptor to recover from an impact, either naturally or through mitigation intervention, and as defined as:
  - Full recovery (the receptor is forecast to fully recover accounting for the impacts of the operational AHEP);
  - Partial recovery (full recovery is no longer possible but the receptor will partially recover accounting for the impacts of the operational AHEP);
  - No recovery (the receptor can no longer fully or partially recover);
- **Duration:** the length of time receptors are exposed to the impact and defined as:
  - Short term (the impact stops within the remaining construction programme);
  - Long term (the impact persists beyond the remaining construction programme);
  - Permanent (the impact persists beyond the operation of the AHEP).

The measure of the magnitude of impact relates to the expected response of the receptor in question and has been defined by combining each category as follows:

- **Negligible** impact magnitude: the impact is predicted to cause no detectable change (effect) over and above the natural variation;
- **Minor** impact magnitude: the impact is likely to cause a change (effect) which is confined to the boundary of the AHEP, will stop on completion of the construction phase and from which the receptor is expected to recover;
- **Moderate** impact magnitude: the impact is forecast to cause a change (effect) beyond the AHEP, will persist beyond the duration of the construction phase and from which the receptor may not fully recover;
- **Major** impact magnitude: the impact is predicted to cause a change (effect) at a regional or national scale, will persist beyond the construction and/or operation of AHEP and from which the receptor is not expected to be able to fully or partially recover.

Typically, receptor value takes account of the nature conservation status of the receptor in question for instance, whether a species is a qualifying or cited feature of, and connected to, a nature conservation site but also whether it is rare or scarce at a particular geographic scale or is a keystone species. Habitat value considers whether the habitat is part of a designated site or is critical to a species.

In this EIAR, the receptors that have been scoped in for assessment relate to qualifying species of European Marine Sites (EMS), amongst other designations, as well as the Nigg Bay SSSI (see Chapters 5 to 8). These features are of national and international importance and are protected and are thus all considered **high value** receptors. Considering this, receptor '*value*' does not then contribute to the differentiation of significance criteria and effect significance becomes a function of impact magnitude and is evaluated as follows:

- **Negligible:** the impact is predicted to cause an effect that is unmeasurable above the background variation;
- **Minor significance:** the impact is predicted to cause a short-term change (effect) to the receptor feature or to one or a few individuals of the receptor population at the local level and will recover either naturally or following intervention;
- **Moderate significance:** the impact is predicted to cause a short to long-term change (effect) to a receptor or to an important assemblage of a receptor population at the local to regional level, resulting in possible population level consequences, and will require mitigation;
- **Major significance:** the impact is predicted to cause a long-term or permanent change (effect) to the receptor or receptor population at local, regional or national scale and will require mitigation.

4.6 Assessing Likelihood and Certainty

Statements on effect significance are further qualified using a measure of likelihood and certainty.

Likelihood reflects the chance of the effect actually happening and is based largely on the mitigating measures already in place. In this EIAR, it is considered that due to the existence of monitoring and mitigating measures, and particularly with regard to high value receptors, significant adverse effects arising from the impacts of the proposed changes to the blasting methodology are **unlikely** to occur. Effects that are **likely** to occur include those which have already been observed or are unmitigated at present.

Certainty expresses the degree of doubt concerning statements on effect significance and likelihood and largely reflects the availability and quality of the data used in reaching conclusions. Here, certainty is categorised as high, medium and low based on the following criteria;

- **High certainty:** temporal and spatial distributions of the receptor are quantified through site specific investigation. Impact magnitude has been modelled and is subject to monitoring against agreed thresholds and management intervention if breached. Existing mitigation measures have already been shown to be effective;
- **Medium certainty:** temporal and spatial distributions of the receptor are well or broadly understood from literature review. Impact magnitude has been modelled or is understood from observation elsewhere. Agreed mitigation and monitoring measures are already in place or are proposed to be enhanced in a revised CEMD. Existing mitigation measures seem to be effective;
- **Low certainty:** temporal and spatial distributions of the receptor are not well known. Impact magnitude is moderately or poorly understood. Mitigation and monitoring measures are proposed. There is little or no evidence as to the effectiveness of the existing mitigation measures.

4.7 Mitigation

The level of effect significance is used to determine the use and level of mitigation measures. Where potential effect is assessed as 'moderate' or 'major', this is considered 'significant' in EIA terms and requires mitigation (where possible) to reduce the effect to an acceptable level.

As highlighted above, comprehensive mitigation measures are already embedded and enacted at the AHEP to avoid or minimise previously identified significant negative effects. Additional mitigation is therefore not generally warranted for the majority of impacts/receptors. However, for some specific impact/receptor interactions, recommendations have been made to enhance the existing monitoring and mitigating measures and are described in the following technical chapters.

4.8 Residual Effects

Residual effects are those that remain following the application of mitigating measures and are expressed in terms of their significance and the likelihood of happening as described above.

4.9 Cumulative Impacts

Other past, present and foreseeable future schemes, activities and plans that may give rise to impacts that may act cumulatively with those arising from the proposed changes in blasting methodology have been identified through scoping and from review of the 2015 ES. Table 4.4 and Figure 4-8 present the schemes, activities and plans considered in the cumulative assessment and which have also been taken forward for consideration of in-combination effects on interest features of local Natura 2000 sites (see Chapter 10: Habitats Regulations Assessment). Although broad-scale lease areas for future offshore wind have recently been identified for Scotland, the locations, types (i.e. floating or grounded) and timescales of individual facilities is unknown and so remain unforeseeable and are not considered in this EIAR or HRA.

Table 4.4: Schemes, Activities and Plans Considered in Cumulative Assessment

Project/Proposed Development	Description	Location	Approx. Distance to Project (By Sea) [km]	Status	Rationale
Aberdeen maintenance dredging	Harbour maintenance dredging	Aberdeen	1	Consented, ongoing	Potential for cumulative sediment effects of disposal of dredged material on migrating salmon smolt
Seagreen Alpha and Bravo offshore wind farm	Round 3 offshore wind farm	Outer Firth of Forth	64	Consent approved	Development must commence by October 2022
Inch Cape Round 3 wind farm	Scottish Territorial Waters offshore wind farm	Outer Firth of Forth	65	Consent approved	Marine construction due to commence in 2022
Neart na Gaoithe Round 3 wind farm	Scottish Territorial Waters offshore wind farm	Outer Firth of Forth	95	Consent approved	Marine construction due to commence in 2020
Moray East offshore wind farm	Round 3 offshore wind farm	Outer Moray Firth	130	Consent approved	Overall offshore construction: May 2019 to

Project/Proposed Development	Description	Location	Approx. Distance to Project (By Sea) [km]	Status	Rationale
					October 2021 (approximately) Piling: May 2019 to April 2020
Beatrice Round 3 offshore wind farm (BOWL)	Scottish territorial waters offshore wind farm	Outer Moray Firth	135	Operational	Piling complete. Installation of the turbine towers and nacelles is now complete.
Ardersier Port	Port construction and dredging application renewal	Inner Moray Firth	190	Application (planning in principle)	Proposed start date for piling at the quay wall is April 2019
North Connect Cable	Norway - UK interconnector	Peterhead (UK landfall)	45	Consent approved	Cable laying including seabed trenching and rock placement to commence in 2020 and 2021
Port of Cromarty Phase 4	New berthing space and reclamation	Inner Moray Firth	190		Works including quay wall piling and anchor piling planned for 2019.
Montrose Port Quay Wall	Construction of new quay wall	Montrose	55	Consented, ongoing	Works including vibro and impact piling are scheduled for Sept 2018 to June 2019
Peterhead Port Authority Harbour Masterplan	Harbour deepening	Peterhead	45	Consented	Drilling and possible piling in inner harbour (Piling may be substituted for drilling. Noise may be largely confined to the inner harbour area)
Kincardine offshore wind farm	Floating offshore wind farm	South-east Aberdeen	12	Consented (new design under application)	In construction.
Moray West	Round 3 offshore wind farm	Outer Moray Firth	130	Application	Offshore construction planned to commence in Q1 2022 (subject to CfD) and to be complete in 2024.

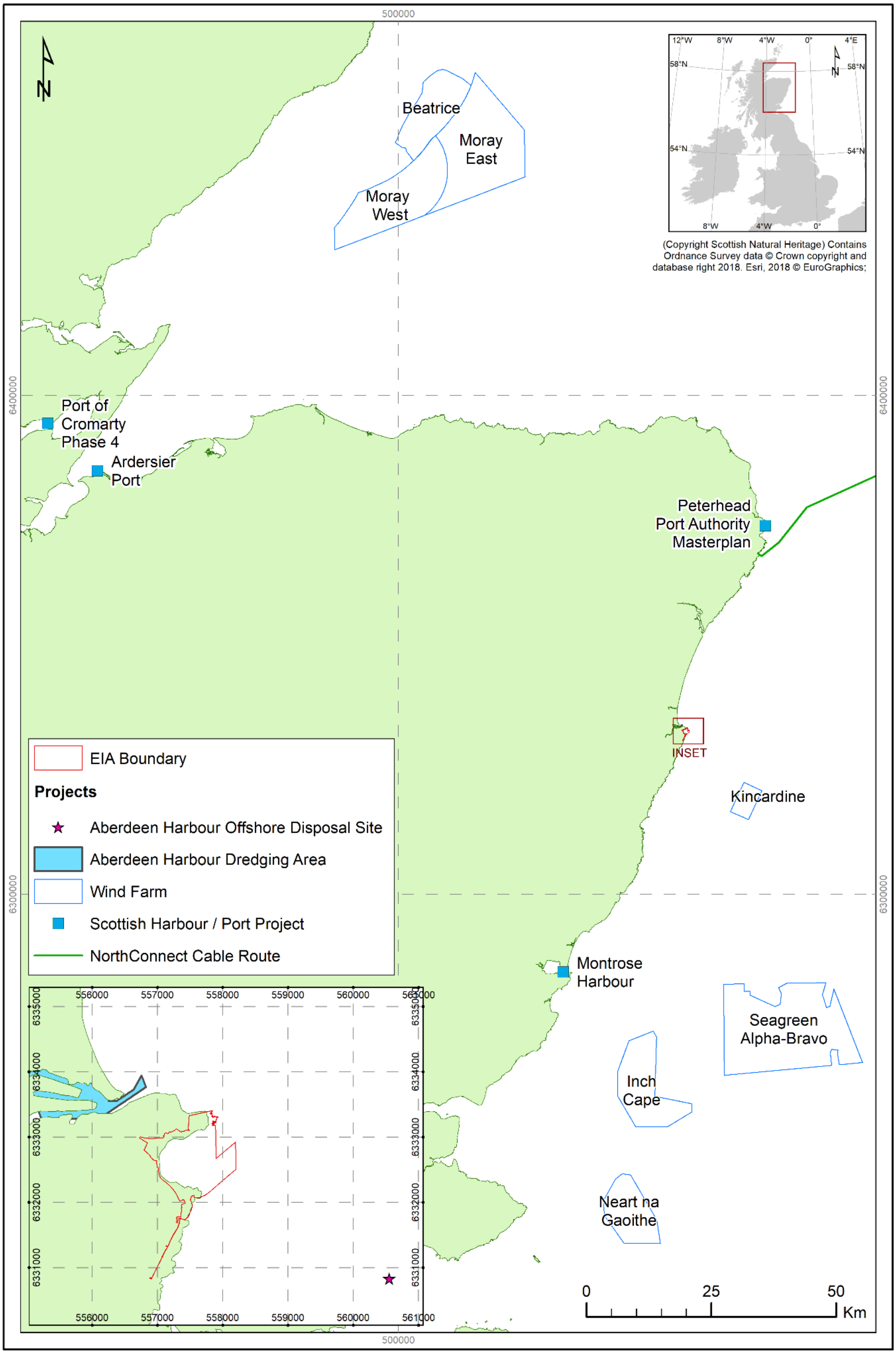

Figure 4-8: Location of other projects considered for cumulative assessment

Kincardine floating offshore wind farm is a floating facility located 12 km from the AHEP. While construction of the wind farm could coincide with the extended period of blasting at the AHEP, no grounded foundations are expected to be installed at Kincardine so no adverse noise effects associated with piling will occur. According to the Kincardine ES (Atkins Ltd., 2015) the loudest underwater noises arising from the Kincardine construction relate to trenching and rock placement but these are only forecast to affect (displace) the most sensitive species, including bottlenose dolphin, up to 140 m. Salmon are only predicted to be displaced over a range of < 1 m. On this basis, the Kincardine offshore wind farm is not included in the cumulative impact assessment for marine mammals and fish, although it is included in the assessment for birds.

The Moray West offshore wind farm is under application and is not due to commence construction, including piling, until 2022 and 1 years after the completion of the AHEP, so it is not included in the cumulative impact assessment.

Construction for the European Offshore Wind Deployment Centre (Aberdeen) offshore wind farm and the Hywind Scotland Pilot Park offshore wind farm, located 10 km and 51 km from the AHEP respectively, have been completed and these schemes are now operational. Operational noise from these facilities is not forecast to have significant adverse effects on the selected interest features, so they are not included in the cumulative impact assessment.

Piling and turbine installation for the Beatrice offshore wind farm, located 135 km from the AHEP, has been completed. Consequently, no significantly ‘noisy’ underwater activities are expected from this project and adverse effects of noise on the marine features considered in this EIAR are not anticipated, so it is not included in the cumulative impact assessment.

5. FISH AND SHELLFISH ECOLOGY

5.1 Introduction

This Chapter assesses the likely impacts of the proposed changes to the blasting methodology on fish and shellfish ecology with a focus on the species identified from scoping (see Table 5.1) and compares assessment findings with those made in the 2015 ES (AHB, 2015) and upon which the AHEP is consented. It draws upon the information previously provided in Chapter 13 of the 2015 ES (AHB, 2015), its supporting technical appendix (Technical Appendix 13-A), and the site-specific benthic ecology beam trawl survey (Technical Appendix 12-A). More recently, studies of fish kills following blasting events in Nigg Bay have been conducted, the results of which are summarised here as an update to the previous baseline.

Table 5.1: Scoping Responses Concerning Fish and Shellfish Ecology

Consultee	Summary Scoping Response	Where Addressed in this EIAR
SEPA	Potential for impact on migrating salmonids, should be assessed by MS-LOT as part of the Habitats Regulations Assessment/Appropriate Assessment.	Chapter 10 presents Habitats Regulation Assessment in support of the AA.
Dee District Salmon Fishery Board	Further information on mitigating measures and impact assessment is required considering the likelihood that salmonids may be present within Nigg bay during the Spring/Summer and Autumn.	Table 5.2 **Table** 5.2 presents information on the numbers of fish killed before and after improvements to the deployment of the fish scarer. Section 5.2 presents the impact assessment on fish.
	We would also like to be kept informed of any fish kills post blasting, numbers, species etc.	Acknowledged.
	Request for a protocol or action plan relating to any salmonids killed/injured as a result of blasting.	This will be provided in the revised CEMD (see section 5.6).
	Sound pressure measurements are not appropriate for assessing impacts on salmonids which are primarily responsive to particle motion.	This is noted as a data uncertainty in section 0 and acknowledged as part of impact conclusions (section 5.6.1).
	We would like to know if there is any data that evaluates the effectiveness of the bubble curtain for mitigating particle motion.	No data are available as acknowledged within section 4.4.2 and impact assessment conclusions (section 5.6.1).
	The findings of recent smolt tracking work should be considered in an assessment of any likely impacts of noise and disturbance from the waste disposal site for fine dredged material may have on the smolt migration.	The available smolt tracking work is reviewed in section 5.3. An assessment of noise impacts arising from the disposal site is provided in sections 5.6.2 and 5.6.3.
	Request that cumulative impacts with AHB annual dredging programme be undertaken in light of the findings of the recent smolt tracking studies.	Addressed in section 5.7.1.
Scottish Natural Heritage	Request for clarification of the effectiveness of the fish scarer mitigation measure.	Addressed in section 5.2 and Table 5.2.
	Request that mortality, injury and startle be scoped in.	Addressed in section 5.6 and Appendix B.
	A clear rationale should be provided to support the decision to scope out turbidity plumes.	Increases in the levels of fine suspended sediments due to the changes in blasting methodology

Consultee	Summary Scoping Response	Where Addressed in this EIAR
		will be minimal or negligible against the background levels of turbidity created by the ongoing capital dredging and disposal operations at the AHEP and which have already been permitted. The changes to the proposed blasting methodology do not involve any increase in the numbers of blasts, or the amount of dredging or disposal required so no significant increase in sediment plumes are anticipated (section 5.6).
Marine Scotland Science	It is appropriate that diadromous fish are scoped in. Topics to be addressed in the EIAR are appropriate. The intention to improve the modelling, using latest guidance and inclusion of Dee DSFB is good.	Acknowledged.
	Full details of the fish kill surveys, methods for collecting, retaining, examining and ensuring the correct identification of dead fish and documenting this will need to be presented within the EIAR.	Section 5.2 and Table 5.2 present results of the fish kill surveys to date. Section 5.5 describes the approved protocol for recording and documenting salmonid kills and the triggers for notifying the appropriate authorities. Attempts to recover and record dead or injured fish that may or may not be present on the seafloor after a blast by divers and/or by netting is not realistic and may also have safety implications for other marine activities at AHEP. Netting and divers are not proposed to be used for fish kill monitoring.
	The EIAR should examine what opportunities there may be for further useful monitoring on the effects of blasting on fish including diadromous fish and the effectiveness of the bubble curtain including the double bubble curtain.	Monitoring efforts to date have included electronic tagging of adult salmonids, and the collection and identification of fish killed after each blasting event as described in section 5.3. The effectiveness of the double bubble curtain is outlined in section 4.3.1 and is detailed in Appendix B. The effectiveness of the fish scarer is summarised in section 5.2.
	Prior to assessing the impact of the proposed increases in charge size and frequency of blasts it would be useful for the developer to review the extent to which the 2015 conclusions proved valid in the light of the observations on mortalities and any observations on distressed or injured fish, and the effectiveness of the mitigation methods which were in place.	The presence of juvenile fishes (herring and whiting) in fish kill surveys suggests that Nigg Bay continues to support juvenile fish despite ongoing construction. No diadromous species have been recorded as killed. Impact conclusions of **minor** significance made in the 2015 ES thus seem warranted. Improvements to the fish scarer technique appear to be beneficial in terms of reducing fish kill (Table 5.2). Noise levels in open water areas beyond the AHEP remain far below current guidelines

Consultee	Summary Scoping Response	Where Addressed in this EIAR
		(Popper et al, 2014) for mortality and potential mortal injury (sections 4.3.1, 5.2, 5.3 and 5.6).
	It would be useful if the EIAR considered the extent to which the construction work to date may have reduced what use is made of Nigg Bay by diadromous fish.	Section 5.3.1 discusses the potential current use of Nigg Bay by salmonids. In the absence of pre-construction data, a temporal comparison would be difficult.

5.2 Summary Characterisation

Fish and shellfish assemblages within coastal waters across the wider area comprise a mix of temporary visitors, migrants and permanent residents. Overall species composition in Nigg Bay and local coastal waters is likely to fluctuate seasonally especially in relation to natural seasonal spawning behaviours.

Temporary species include juvenile cod (*Gadus morhua)*, haddock (*Melanogrammus aeglefinus*)*,* whiting (*Merlangius merlangus*)*,* plaice (*Pleuronectes platessa*) and dab (*Limanda limanda*) which use the local inshore waters as nursery habitat before moving off to offshore deeper water as they mature. Observations of juvenile whiting and herring during post-consent monitoring surveys suggests that Nigg Bay continues to support juvenile fish despite ongoing AHEP construction.

Permanent residents within local waters include gobies, (Gobbiidae), blennies (Blenniidae) and dragonets (Callionymidae) as well as shellfish species such as the common whelk (*Buccinum undatum*), king scallop (*Pecten maximus)* and various crab species and provide an important food source for larger commercial species such as cod, saithe (*Pollachius virens*) and thornback ray (*Raja clavata*). These species tend feed on the seabed surface and use burrows and holes in the sediment for refuge. The current use of Nigg Bay by these types of species during construction is unclear but due to current level of dredging of the seabed within the AHEP, these species are expected to have been reduced or displaced as predicted in the 2015 ES (AHB, 2015).

Migrant species within the wider region include Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*), European eel (*Anguilla anguilla*) and sea lamprey (*Petromyzon marinus*). These species are likely to pass through, or close to, the AHEP on their entry to, or emergence from, the River Dee, or other freshwater environments. Salmon and sea trout are hosts to the freshwater pearl mussel, (*Margaritifera margaritifera*) and its distribution is therefore reliant on these fish species. As highlighted in the 2015 ES (AHB, 2015), the current use of the bay by salmonids is unclear (see section 5.3).

Sand eels are keystone species as prey for marine mammals, birds and other fish, such as salmon. Although some individuals of sand eels have previously been found in Nigg Bay (AHB, 2015), the main sand eel habitat of clean medium and coarse sand, is found outside of Nigg Bay and beyond the area of AHEP construction.

Observations of dead fish within Nigg Bay by the dedicated Ecological Clerk of Works (ECoW) following blasting events are indicative of shock trauma within the immediate vicinity (a few tens of metres) of the blast sites. The dead fish observed have so far been limited to juvenile herring and whiting with one individual of juvenile cod. The results of these surveys have been highly variable with up to 100 fish being recorded after one blast while no fish have been recorded at other times. No salmon or sea trout have been observed during post-blasting fish surveys. Table 5.2 summarises observations of fish kills following blasting at the AHEP to date.

Table 5.2: Results of Fish Kill Surveys after Blasting at the AHEP

Date	No. Dead/ Injured Fish	Comment
Fish Scarer Detonates 5 Minutes Prior to Main Detonation		
20/08/2018	< 10	Minimal amount of small fish. No large fish only sile – small herring and whiting ~ 10 cm.
24/08/2018	< 10	Minimal amount of small fish. No large fish only sile – small herring and whiting ~ 10 cm.
06/09/2018	Approx. 100	Large bird frenzy shortly after. No large fish only sile – small herring and whiting ~ 10 cm.
12/09/2018	< 10	Minimal amount of small fish. No large fish only sile – small herring and whiting ~ 10 cm.
14/09/2018	0	Visual inspection in boat found no evidence of dead fish.
17/09/2018	< 10	Minimal amount of small fish. No large fish only sile – small herring and whiting ~ 10 cm.
08/10/2018	0	Visual inspection in boat found no evidence of dead fish.
13/10/2018	No data	
Fish Scarer Detonates 1 Minute Prior to Main Detonation		
17/10/2018	Approx. 50	Aquatic specialist confirmed silver species herring, larger species are whiting and one young cod was identified.
25/10/2018	0	Visual inspection in boat found no evidence of dead fish.
17/11/2018	0	Visual inspection in boat found no evidence of dead fish.
24/11/2018	3	Aquatic specialist confirmed species as herring.

A fish scarer is used prior to each blast to drive fish out of the blast site. Initially the fish scarer was used 5 minutes before each blast. However, since 17 October 2018, the fish scarer has been used one minute prior and, with reference to Table 5.2, seems to have had some benefit in reducing fish kills although further observations are required to confirm the effectiveness of this measure.

5.3 Salmon and Sea Trout Review

Salmon and sea trout are among a number of migratory fish species which potentially use local waters for the purposes of passing from or to the River Dee, as well as other freshwater locations.

Salmon smolts, generally migrate downstream between April and June (Hendry and Cragg-Hine, 2003) although there is unlikely to be any significant emigration after May. Malcolm et al. (2010) further refines the smolt migration window as occurring between day 103 and 145 (where 1st January is day 1). Trout smolts generally migrate downstream in June and July. Recent salmon smolt tracking studies have shown that smolts migrate through the existing Aberdeen Harbour between mid-April and the end of

May and that migration behaviour relates to river discharge rates and is predominately nocturnal (Dee District Salmon Fishery Board, 2019).

The migration behaviour of salmonid smolts from east coast Scottish rivers, including the River Dee is currently being investigated using electronically tagged smolts by the Dee River Trust and Marine Scotland Science as part of Vattenfall (European Offshore Wind Deployment Centre) funded research efforts. The research is ongoing but preliminary findings suggest that the average direction of travel of the smolts during the first 4 km after leaving the river mouth is easterly (see Figure 5-1) subject to tidal conditions on emergence from the River Dee, and towards the general direction of the licenced offshore disposal site (Figure 4-8) used as part of the AHEP construction and by Aberdeen Harbour for disposal of maintenance dredged material (Vattenfall, 2018).

Figure 5-1: Interim results of the River Dee smolt tracing study showing mean direction of travel (red lines)

(**Source:** Vattenfall, 2018).

Smolts emerging from the River Dee are initially separated from the AHEP by the rocky promontory at Girdle Ness and are thus likely to be shielded from any significant adverse noise arising from the blasting. In addition to the natural rock promontory, the presence of the newly constructed North Breakwater and the double bubble curtain provide additional shielding to fish within the open water beyond the AHEP.

Furthermore, smolt migration from the River Dee predominately occurs during the hours of darkness when blasting does not take place (Dee District Salmon Fishery Board, 2019).

Licence compliance monitoring of noise shows that noise levels remain far below current guidelines (Popper et al., 2014) indicative of mortality and potential mortal injury. Once in the local marine environment it is thought that salmon smolts disperse rapidly offshore. Sea trout smolts, on the other hand, are thought to disperse more slowly feeding within coastal waters and estuaries.

Adult salmon are thought to return to the River Dee through the coastal waters from the south. Consequently, they may traverse the AHEP from south to north prior to entry to the river mouth. Salmon may return at any time during the year so that there is no defined period of entry into the River Dee. Sea trout generally return to natal rivers between February and October.

Marine Scotland catch statistics (rod and line release) for the River Dee (Table 5.3) suggest that most wild salmon are taken from the river during May and September while sea trout are most frequently caught during June indicating peak returns to the River Dee during these months. Note however, that these data are not corrected for catch effort so conclusions in this regard should be treated with caution.

Table 5.3: Number of Salmonids Caught and Released by Rod and Line by Month for the River Dee (1994 to 2018)

Month	No. Wild Salmon	No. Wild Grilse	No. Sea Trout	No. Finnock
February	3449	0	110	21
March	7803	3	964	229
April	9944	37	1423	369
May	13058	756	4008	288
June	9140	3154	11480	84
July	5590	5540	4819	181
August	7879	7092	3395	619
September	16038	7150	3337	999
October	4791	1632	697	147

5.3.1 Use of Nigg Bay by Salmonids

To understand the regional and local scale temporal and spatial distributions of salmonids in the local sea are, historic salmon coastal net fishery data have been reviewed for 13 coastal netting stations located between the south of Aberdeen beach (District Boundary) to Crawton Bay (Figure 5-2).

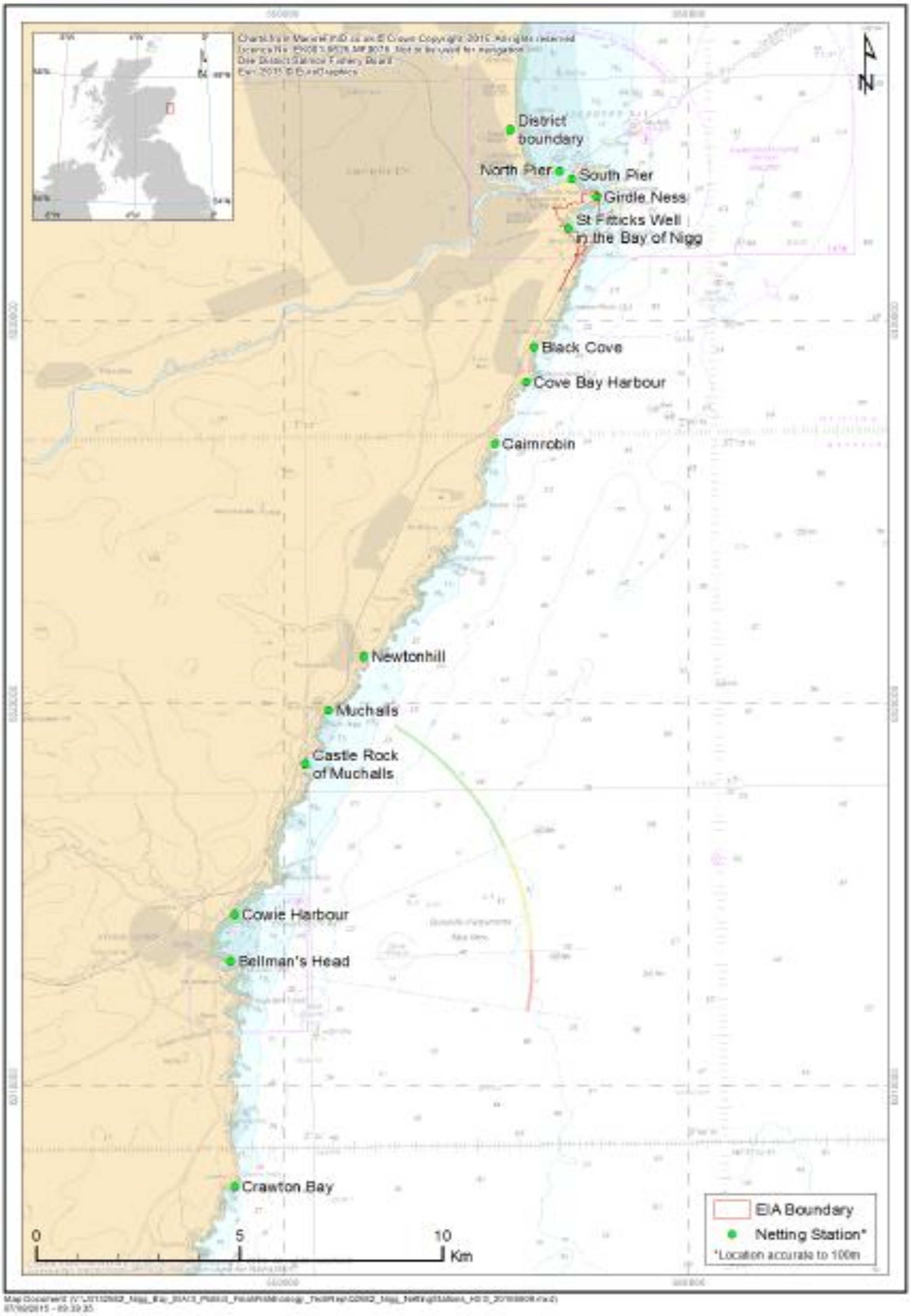

Figure 5-2: Location of coastal salmon netting stations for which catch data have been provided (**Source:** Crown copyright Marine Scotland Science, courtesy of The River Dee Trust).

At the local scale, catch statistics were only available as aggregate data for 1986 for stations at Aberdeen Beach (District Boundary), North Pier, South Pier and Girdle Ness (see Table 5.4). Records for the coastal net station at St Fitticks Well (Figure 5-2) were not available post 1986 as the station was purchased and fishing stopped at this location at this time.

Table 5.4: Summary Coastal Net Catches of Salmonids Between the South of Aberdeen Beach (District Boundary) and Girdle Ness for 1986

Month	No. MSW Salmon	No. Grilse	No. Sea Trout	Effort			
				Minimum Traps	Maximum Traps	Minimum Persons	Maximum Persons
February	4	0	0	6	6	3	3
March	59	0	0	6	9	3	3
April	30	0	17	6	10	3	3
May	19	3	80	10	11	3	3
June	130	448	193	11	17	4	4
July	305	1531	149	17	19	4	4
August	347	816	21	4	19	5	5

The data available shows that locally between Aberdeen Beach and Girdle Ness, peak salmonid numbers (mostly grilse[2]) occurred in July with moderate numbers occurring in June and August. No grilse was recorded in local coastal waters during the months of February, March, April and May. Salmon, on the other hand, were recorded in all months suggesting that they may use local coastal waters for the majority of the year. Data on salmon abundance for September to January are not available.

Sea trout abundance between Aberdeen Beach and Girdle Ness was highest in June and July with moderate numbers in May. Numbers quickly decline in August. Sea trout are absent from catch records in February and March are were only present in comparatively low abundance in April.

At the regional scale, salmon and sea trout catch data are available for coastal netting stations between Crawton Bay in the south and Aberdeen Beach/Dee District boundary in the north (Figure 5-2). While some stations only have sparse records, such as those between Aberdeen Beach and Girdle Ness presented above, other stations to the south of Nigg Bay have more extensive records covering the years between 1986 to 1999. Figure 5-3 presents a summary of the coastal netting salmon and sea trout catch data for the region for the years 1986 to 1999, corrected for fishing effort.

These data indicate that while there is variability between years, peak salmon numbers (mostly grilse) consistently occurred in local coastal fisheries in July while peak sea trout numbers occurred in June. Grilse appeared to be only present in coastal waters from May onwards, initially in low numbers, but rapidly increasing in abundance in July before declining again in August. In contrast, salmon and sea trout were present within coastal waters from February, albeit in low numbers, with peak numbers occurring in June and July.

[2] Salmon that mature after one year (winter) at sea.

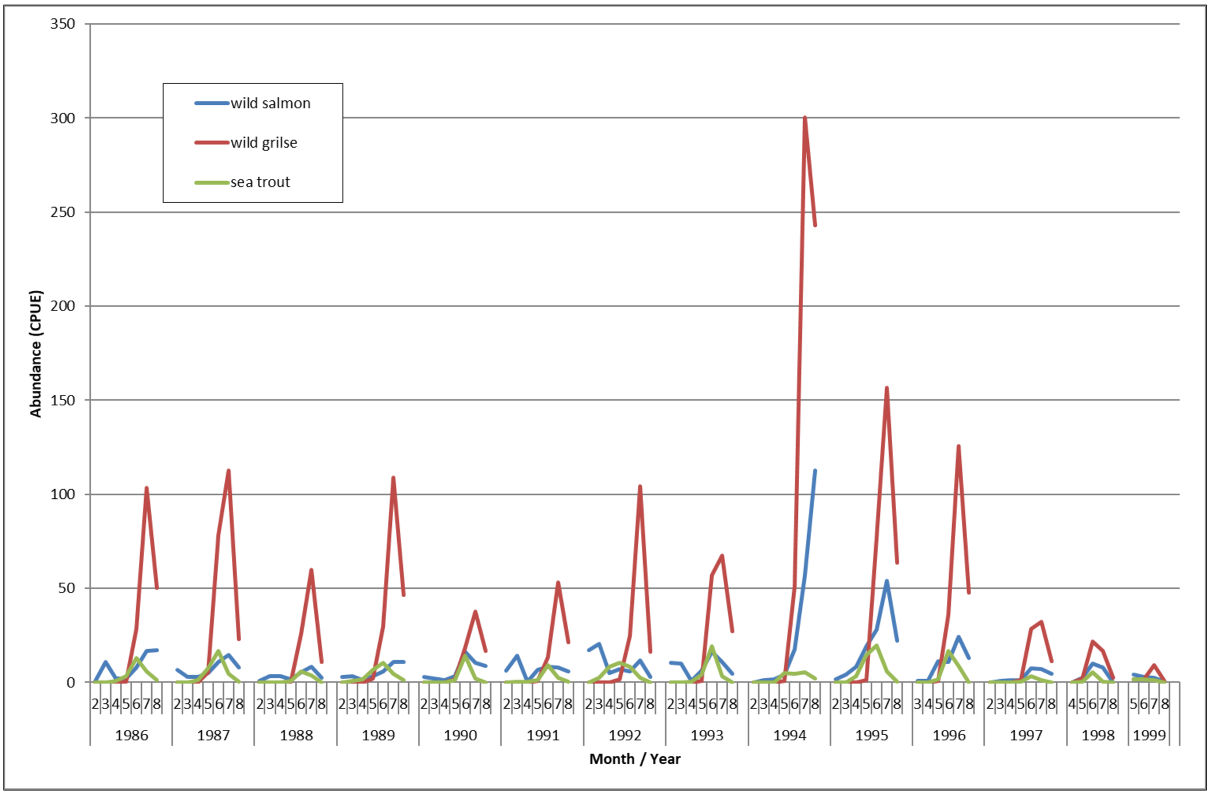

Figure 5-3: Abundance of salmonids caught per month (February to August) in local coastal net fisheries between 1986 and 1999. Data are aggregated over 13 local netting stations (see Figure 5-2) and corrected for fishing effort

(**source:** Crown copyright Marine Scotland Science, courtesy of The River Dee) Trust.

Use of coastal waters by salmonids between September and January is not known as the commercial netting fishing data were not collected during this period. There is currently no commercial coastal net fishing within the wider Aberdeenshire area and records are only available up to 1999.

To update the knowledge on local salmonid distributions, an electronic tagging study was conducted in Nigg Bay in 2017 (Newton et al, 2018). Salmonids were captured using a bag net installed in Nigg Bay. However, despite '*very intensive and continuous fish collection activity from 5 August 2017 until 21 September 2017*, *only seven salmonids suitable for tagging with acoustic tags were sampled'*. The total catch included five Atlantic salmon (*Salmo salar*) caught between 7 August 2017 and 6 September 2017 and two sea trout (*Salmo trutta*) caught on 10 August 2017 and 18 August 2018 respectively. The low number of captures suggests very low use of the bay by salmonids during August and September during the 2017 sampling. No sampling was undertaken in July during the apparent period of peak abundance of salmonid in adjacent coastal waters.

Salmon and sea trout captured, tagged and released in Nigg Bay were found to utilise the wider open sea area and did not appear to spend any extended period within, or return to, Nigg Bay although the low numbers of fish tagged and monitored in the study (n = 7) would caveat conclusions in this regard.

5.4 Conservation Importance

Salmon is listed on Appendix III of the Bern Convention and Annex II and V of the EC Habitats and Species Directive. The Rivers Dee, Spey, South Esk, Tay and Tweed all cite Atlantic salmon as a primary species for SAC selection. Salmon are listed on the National Biodiversity Framework and OSPAR list. In addition, the marine part of their life cycle is included on the Scottish list of Priority Marine Features (PMFs).

Sea trout is included in the National Biodiversity Framework list and the marine part of the species life-cycle is included on the Scottish list of PMFs.

Salmonids host the freshwater pearl mussel which is a qualifying feature of the River Dee SAC.

5.5 Existing AHEP Management Measures

Management measures to avoid or minimise potential impacts on fish and shellfish ecology are described within a dedicated Fish Species Protection Plan which is part of the approved CEMD prepared in compliance with condition 3.2.4 of the Construction Marine Licence (see chapter 8 of the approved CEMD). The key measure described comprises a double bubble curtain which is used to shield blasting noise from open water areas.

In addition to the measures provided for within the approved CEMD, an addendum document '*Environmental Mitigation – South Breakwater and Shore Blasting*' (AHEP-DRA-EP-0003) was approved by MS-LOT in April 2019, and has been incorporated into the revised CEMD Chapter 11. This details the construction and mitigation methodologies for rock drilling, blasting and rock dredging for the southern trenches and South Breakwater methodology and for the southern shore works. It commits the blasting contractor to using a small detonator, such as a 'Shockstar MS', containing 720 mg of explosives one minute before each start-up of the double bubble to scare away fish. As described in section 5.2, up to 13th October 2018, the fish scarer was detonated 5 minutes prior to the main blast. However, after this date the fish scarer was detonated one minute prior with apparently improved results from the 25th October although further observations would be required to confirm this.

Fish kill surveys are conducted after each blasting event to check for the presence of any dead or injured fish. Dead or injured salmonids will be reported as agreed with MS-LOT.

In addition, there is a requirement that noise levels should not exceed the current noise benchmark condition of 170 dB re 1 µPa rms (equivalent to 183 dB re 1µPa peak) at 400 m from the blast location or outside the double bubble curtain, whichever is the greater distance. Recent monitoring and model verification studies suggests that the double bubble curtain is effective at providing noise attenuation of 38 ± 16 dB (Award Environmental, 2018). For the purpose of impact assessment, a worst-case double bubble curtain noise attenuation of 22 dB has been considered and which represents the lower limit of the measured attenuation achieved to date at the AHEP.

5.6 Assessment of Effects

With reference to Table 5.1 the impacts and effects assessed in this section include:

- Impacts on migrating salmonids;

- Noise impacts of offshore disposal on smolts;
- Impacts of sediment disposal at the offshore disposal site on smolts;
- Cumulative impact of dredged material disposal at the licence disposal site on migrating smolts.

5.6.1 Impacts on Migrating Salmonids

Fish and shellfish are killed and/or injured by underwater explosions if sufficiently close. Shrimps and bivalves (oysters) seem to be relatively resilient to even quite large underwater explosions of many 10s of kgs compared to fish (Keevin and Hempen, 1997) and invertebrates are usually unharmed unless in very close proximity to explosions (Traxler et al., 1993). Surface explosions generally kill more fish than charges buried in the substrate (Traxler et al., 1993).

Freshwater pearl mussel are dependent on salmonids during larval stages of their life cycle so any impacts on local salmonids could indirectly impact on mussel populations in the River Dee.

Fish kills and injury relate to exposure to very high amplitude sounds and rapid pressure changes and associated damage to internal organs (barotrauma). Species that are most susceptible to these impacts include those with gas-filled swim bladders which can be damaged by sudden changes in pressure and hearing specialists, such as herring, which have intricate connections between its swim bladder and inner ear resulting in improved hearing sensitivity. Sea trout and salmon are considered to be moderately sensitive to underwater noise as they have a gas-filled swim bladder but they lack the intricate connection between the swim bladder and the internal ear present in herring specialists.

Studies on the effects of pile driving noise on fishes (Popper & Hawkins, 2019) have shown that Chinook salmon (*Oncorhynchus tshawytscha*) suffered no tissue damage following exposure to cumulative sound below SEL_{cum} 210 dB re 1 µPa^2 s^{-1} but that injuries started to appear at levels of around 219 dB re 1 µPa^2 s^{-1}. Studies on other species of fish showed that ion general the onset of physiological effects was always >203 dB re 1 µPa^2 s^{-1}. Chinook salmon, together with some other fishes studies, were found to have recovered from all apparent physical effects within 10 days of exposure, but this was noted to be in a laboratory and animals in the wild with lower fitness may be at increased predation or disease risk. Traxler et al. (1993) found no apparent trauma or injuries to caged fish exposed to sub-sediment detonations of 4.5 and 9.1 kg charges within shot holes drilled at 27.4 m and 33.5 m depths.

Published guidelines (Popper et al., 2014) for a single explosion of a small charge of the type used for the dismantling of in-water structures suggest that noise levels of 229 to 234 dB re 1µPa can cause mortality and potential mortal injury in fishes. Those with swim bladders are at high risk of impairment (i.e. recoverable injury, temporary threshold shift (TTS[3]) and behavioural change) if present at near and intermediate distances. Note that the terms ‘near’ and ‘intermediate’ refer to distances of tens of metres and hundreds of metres respectively (Popper et al., 2014).

Table 5.5 summarises the different hearing groups for fishes and respective acoustic impact thresholds presented within these guideline (Popper et al, 2014). For fish eggs and larvae, the guidelines (Popper

[3] Temporary threshold shift (TTS) refers to a temporary reduction in hearing sensitivity due to exposure to a sound source. Once the sound producing factor ceases, hearing sensitivity returns. Fishes experiencing TTS may lose fitness, and be unable to communicate, detect predators or properly assess their surroundings.

et al., 2014) suggest a peak particle velocity (PPV) threshold of 13 mm/s for causing mortality and potential mortal injury.

Table 5.5: Acoustic Impact Thresholds for Fish

Functional Hearing Group	Notes	Mortality and Potential Injury	Recoverable Injury	TTS
Hearing generalist ("low sensitivity") fish	Species with no swim bladder or other gas-filled chamber that are less susceptible to barotraumas and only detect particle, not sound pressure. However, some barotraumas could result from exposure to sound pressure.	229-234 dB re 1 µPa Peak	High risk at near distance Low risk at all other distances	High risk at near distance Moderate risk at intermediate distance Low risk at far distance
Hearing generalist ("medium sensitivity") fish	Species with swim bladders in which hearing is separate from the swim bladder or any other gas-filled chamber. While hearing only involves particle motion not sound pressure these species are susceptible to barotrauma.	229-234 dB re 1 µPa Peak	High risk at near and intermediate distances Low risk at far distance	High risk at near distance Moderate risk at intermediate distance Low risk at far distance
Hearing specialist fish	Species in which hearing involves a swim bladder or other gas-filled chamber, these species are susceptible to barotrauma as well as particle motion.	229-234 dB re 1 µPa Peak	High risk at near and intermediate distances Low risk at far distance	High risk at near and intermediate distances Low risk at far distance
Fish eggs and larvae	-	>13 mm s^{-1}peak velocity	High risk at near distance Low risk at all other distances	High risk at near distance Low risk at all other distances

Notes:
TTS = Temporary threshold shift
(**Source:** Popper et al, 2014)

Based on observations to date, it appears that only juvenile herring and whiting are susceptible to blasting in the AHEP and are the species found during post-blast dead fish surveys (one individual of cod was also found dead) (section 5.2). The numbers of whiting and herring killed by blasting in Nigg Bay have been highly variable (between 0 and 100) and presumably relate to the chance presence of fish aggregations in affected zones at the moment of detonation and their relative sensitivity to underwater noise, although other factors may be involved. Reducing the period between the detonation of the fish scarer and the main explosive charge to 1 minute after 13th October 2018 appears to have limited the numbers of reported fish killed (see Table 5.2) although further observations are recommended to confirm this.

Salmonids, and other diadromous fish, have to date, not been observed as being killed by blasting. This may relate to their comparative insensitivity to underwater noise, their apparent low use of the bay during the periods within which blasting has so far occurred (August to November) and/or that the mitigation (fish scarer) is efficient at protecting these species.

The 2015 ES (AHB, 2015) predicted that underwater noise from a detonation of a 20 kg charge would significantly affect fishes over a very small area only and suggested that fishes needed to be very close to the detonation site (i.e. within 24 m for a fish of 0.2 kg in size) for any mortality or potential mortal injury to occur. For a fish of body weight of 5kg, the 50 % mortality criterion was forecast to lie at a range of 4 m while the no-injury effect range was predicted to be just 12 m. Overall, the results indicated that fishes may suffer injury and lethality over a distance of a few tens of metes due to the detonation of a 20 kg charge weight.

Results of the new underwater noise modelling undertaken for this EIAR (Appendix B and Table 5.6) and drawing upon the guidelines provided in Popper et al (2014), largely agree with previous predictions that fishes need to be very close to the detonation site of a 20 kg charge (within 34 m) to suffer mortality or potential mortal injury even. For a charge weight of 100 kg, and in the absence of a double bubble curtain and assuming the minimum adverse noise threshold for fish, it is predicted that fishes need to be within 440 m to suffer mortality or potential mortal injury. If a double bubble curtain is used at 100 m then sufficient noise is removed that the mortality and potential mortal injury criteria are not reached at all outside of the double bubble curtain. Within the double bubble curtain, noise impacts would remain as calculated in Table 5.6. Any fishes, including migratory species, inside the double bubble curtain and present at the distances indicated in Table 5.6 at the point of detonation would be at risk of mortal and potential mortal injury. The use of larger weight explosives (>20 kg) would affect fish over a larger distance range within the double bubble curtain than that predicted in the original ES, which only considered charge weights of 20 kg. However, the use of larger weights of explosives would mean that fewer blasts would be required and so the temporal scale of the effects would be less. Noise from blasting may reverberate within the bay which may exacerbate effects although effects would remain within the bay (within the double bubble curtain).

Table 5.6: Summary Effect Ranges for Fishes in the AHEP Area When Exposed to Blast Noise Using SPL Peak Metrics

Criteria	Threshold (Sound Pressure Level) (SPL_{peak})	Weight of Charge [kg]								
		20	30	40	50	60	70	80	90	100
Double bubble curtain Absent										
Mortality and potential mortal injury	234 dB re 1 µPa peak	11 m	21 m	32 m	46 m	61 m	78 m	97 m	120 m	140 m
	229 dB re 1 µPa peak	34 m	64 m	110 m	150 m	200 m	250 m	310 m	370 m	440 m
Recoverable injury		High risk at near distance. Low risk at all other distances.								
TTS		High risk at near distance. Moderate risk at intermediate distance.								

Criteria	Threshold (Sound Pressure Level) (SPL_{peak})	Weight of Charge [kg]								
		20	30	40	50	60	70	80	90	100
		Low risk at far distance.								
Double bubble curtain Present (at 100 m)										
Mortality and potential mortal injury	234 dB re 1 µPa peak	11 m	21 m	32 m	46 m	61 m	78 m	97 m	100 m	100 m
	229 dB re 1 µPa peak	34 m	64 m	100 m	100 m	100 m	100 m	100 m	100 m	100 m
Recoverable injury		High risk at near distance. Low risk at all other distances								
TTS		High risk at near distance. Moderate risk at intermediate distance. Low risk at far distance.								
Notes: TTS = Temporary threshold shift										

Impacts on fish eggs and larvae have been estimated in terms of PPV (Table 5.7). Model predictions suggest that mortality and potential mortal injury impact criterion for fish larvae and eggs increases from a distance of 68 m for a 20 kg charge weight up to a distance of 160 m for a charge weight of 100 kg.

Table 5.7: Summary of Impact Ranges for Fish Eggs and Larvae When Exposed to Blast Noise Using PPV Metrics

Impact	Threshold	Weight of Charge [kg]						
		20 kg	30 kg	40 kg	50 kg	60 kg	80 kg	100 kg
Mortality and potential mortal injury	13 mm/sec	68 m	83 m	96 m	110 m	120 m	140	160

With mitigation in place, there will be no impacts on fishes, including migrating salmonids beyond the double bubble curtain due to the proposed changes the blasting methodology (with respect to mortality and potential mortal injury) regardless of the weight of charge used (up to 100 kg) even considering the worst-case double bubble curtain attenuation. Impacts will remain local to the AHEP (within the double bubble curtain) and will be highly intermittent (up to 2 times a day, 6 days a week) on individuals of fish including salmonids (high value receptors) if present inside the double bubble curtain at the point of detonation and will cease on completion of the blasting programme resulting in an overall effect of **minor** significance. The use of larger weight explosives (>20 kg) would affect fish and shellfish over a larger within the double bubble curtain distance range than considered in the original ES (AHB, 2015) but would result in fewer blasting events being required. Noise from blasting may reverberate around the bay and refract from the water surface which may exacerbate effects but these will remain local to within the double bubble curtain.

With respect to salmon and sea trout (and indirectly to freshwater pearl mussel) effects are, in general, **unlikely** to occur given their absence in recent fish kill data, their apparent low use of the area and the use of fish scarers prior to each blast. However, the lack of site-specific data concerning salmonid use of the bay (section 5.3.1) and the potential effects of increased particle motion (see section 4.4.2) at close range suggest **low certainty** in this regard. Risk to salmonids inside the double bubble curtain (inside Nigg Bay), will increase in July when abundance of these fish increases in local coastal waters. In comparison with the 2015 situation (AHB, 2015), fish, including salmon, present within the double curtain at the point of detonation are likely to be at greater risk of mortality or potential mortal injury due to the greater impact radii associated with the use of larger charge weights.

For herring and whiting, minor effects are **likely** to occur within the double bubble curtain only as these species have been observed during previous post-blast fish kill surveys. However, there is **medium to low uncertainty** in this regard as recent modifications to the use of the fish scarer seem to prevent or reduce fish kills. Fish kill surveys will continue to further evaluate the effectiveness of the fish scarer. Herring and whiting located outside of the double bubble curtain are not expected to be significantly affected by the use of larger explosive charges due to the attenuation properties of the double bubble curtain even considering the worst-case scenario.

For remaining fish species, including key prey species such as sand eels, effects are **unlikely** to occur as they have not been recorded as killed during fish kill surveys. Individuals within the double bubble curtain at the time of detonation will be at increased risk than previously assessed in the 2015 ES (AHB, 2015) due to the larger charge weights used although fish beyond the AHEP double bubble curtain remain beyond mortality and potential mortal injury effect ranges and will generally be at no greater risk due to the proposed changes to the blasting methodology than previously assessed. Sand eel habitat occurs beyond the boundary of the AHEP and is similarly outside of predicted impact ranges. Also, at these distant locations, sand eels will encounter little or no increased substrate vibration even for the largest explosive charge weights proposed (see section 4.4.2). Significant effects to the feeding of predator species in the locale due to the proposed changes to the blasting methodology are therefore not expected.

5.6.2 Noise Impacts of Offshore Disposal on Smolts

Since the issue of the original ES (AHB, 2015) recent work on smolt tracking (Section 5.3) has provided new insights into the potential for interaction between smolts emerging from the River Dee and AHEP disposal activities at the offshore disposal site. The following provides an assessment of impacts of noise generated by offshore disposal on salmon smolt.

Levels of underwater noise associated with dredged material disposal at the offshore disposal site were studied during in the 2015 ES (Technical Appendix 13-B) (AHB, 2015) and were found to be so low that they generally fell within background noise levels at relatively short distances (tens of metres at most). At that time, it was predicted that if background noise was approximately 130 dB re 1µPa, then it is likely that material disposal would be inaudible even at close range. If the background noise level is taken to be 120 dB re 1µPa, then noise from disposal may be heard to a few metres.

Recent field monitoring of underwater sound during AHEP construction (Newton et al., 2018) (Table 5.8) supported these earlier findings and showed that noise generated from the disposal of material at the offshore disposal site is generally within the range of ambient noise, although the mean noise value for disposal is slightly (3 dB) higher.

Table 5.8: Ambient Noise Levels and Noise from Material Disposal

Activity	Time	Mean dB RMS (±s.d.*)	Min. dB RMS	Max dB. RMS
Ambient	Day	130.436 (±5.610)	124.5	139.7

Activity	Time	Mean dB RMS (±s.d.*)	Min. dB RMS	Max dB. RMS
	Night	129.436 (±5.058)	125.1	139.7
Disposal	Day	133.384 (±2.419)	129.6	139.8
	Night	132.12 (±1.468)	130.3	134.9

Notes:
s.d. = Standard deviation
Source: Newton et al, 2018

In conclusion, only low levels of noise arise from offshore disposal so underwater noise impacts are expected to be highly localised, affecting a small radius around the offshore disposal site. Any adverse noise events will be intermittent, limited to the frequency of dredging occasions, while the small area of effect will be expected to be avoided by highly mobile and wide ranging species, such as salmonids. Impact significance is thus considered to be **minor**. Given the location of the disposal site and the principal direction of smolt dispersion, as indicated by recent tracking studies, smolts could encounter the disposal ground at the time of a disposal operation suggesting effects are **likely** to occur. Noise levels arising from disposal at the disposal site have been measured and dispersion patterns of local smolts are being studied so this conclusion is associated with **high certainty**.

5.6.3 Impacts of Sediment Disposal at the Offshore Disposal Site on Smolts

As discussed above, recent smolt tracking studies since the issue of the original ES has provided new information on the potential for interaction with AHEP offshore disposal activities. The following provides an assessment of the potential impact of sediment disposal at the offshore disposal site on smolt.

There is presently around 535,000 m^3 of soft sediment remaining to be dredged from the AHEP of which approximately 262,000 m^3 will be beneficially used on-site, i.e. as in-fill for the caissons. This means that there is around 273,000 m^3 of soft sediment material remaining to be disposed at the licenced offshore disposal site. In addition, there is 114,553 m^3 of rock remaining to be blasted and removed. All of the rock from blasting will be used on-site, for example for the construction of the southern breakwater, and none will be disposed of offshore.

Dredging at the AHEP is undertaken using a combination of Trailer Suction Hopper Dredging (TSHD) for unconsolidated material and backhoe dredging for consolidated sediment. The unconsolidated sediments comprise mainly gravel and sand while the consolidated sediments comprise mainly silt.

Release of unconsolidated material at the offshore disposal site creates a limited turbidity plume orientated along a north-east/south-west direction, following the direction of the principal tidal currents for a distance of approximately 1.5 km, before being diluted to background levels. From the sediment modelling prepared for the 2015 ES (AHB, 2015), disposal of dredge material at the offshore disposal site will create peak suspended sediment concentrations (SSCs) that are forecast to reach 10,192 mg/l but which are very short lived. Average SSCs at the disposal site, are predicted to reach 300 mg/l (see Chapter 7 of the 2015 ES) (AHB, 2015). Within 0.5 km from the disposal site average SSC falls to between 7 mg/l and 8 mg/l on each TSHD release.

Release of consolidated (silt) material creates a more extensive sediment plume extending some 11 km along the principal tidal axes. Initial peak SSCs at the disposal site are forecast to be comparatively lower (4 719 mg/l) but on average are comparable to those following release of the consolidated material (309 mg/l). Within 0.5 km from the disposal site average SSC falls to between 13 mg/l and 14 mg/l on each backhoe release.

To put these values into context, the peak baseline SSCs at the disposal site reaches 19,524 mg/l during annual maintenance dredging at Aberdeen Harbour (Chapter 7 of the 2015 ES) (AHB, 2015). Therefore, the disposal of AHEP dredged material at the disposal site is much less than the baseline licensed maintenance dredging (section 5.7.1 presents an assessment of the potential cumulative impacts of disposal).

The proposed changes to the blasting methodology do not involve any increase in dredging or dredged material disposal and the areas to be dredged and the nature of the material to be removed remains as planned and assessed in the 2015 ES.

Responses of smolts, and other fishes, to elevated SSCs in open seas is unclear. In general, estuarine and demersal fish are more tolerant to increased SSCs than pelagic species given their natural association with seabed habitats and estuarine environmental conditions.

Juvenile and adult fish can generally tolerate high concentrations of suspended sediment with direct mortality only occurring when concentrations are extremely high (i.e. in the 10 000 mg/l to 100 000 mg/l range) (Robertson et al., 2006; Engell-Sørensen and Skyt, 2001). Such levels are no predicted to occur as a result of AHEP disposal operations

Salmonids tend to avoid excessively turbid water (Bash et al., 2001). For instance, a mean avoidance of 25 % was discovered for juvenile coho salmon (*Oncorhynchus kisutch*) exposed to 7 000 mg/l suspended sediment (Bash et al., 2001).

In terms of salmonid feeding, increased SSCs may have two competing effects: a reduction in foraging rate, due to reduced visibility of prey, on the one hand; but an increase in foraging rate due reduced predation risk, on the other, such that some salmon species may actually prefer slightly moderately turbid conditions for foraging. Greatest foraging rates in juvenile chinook salmon were found to occur at SSCs of 50 mg/l to 200 mg/l and were lowest when SSCs were 0 mg/l and 800 mg/l (Robertson et al., 2006). Subsequent research (Robertson et al, 2007) found that short term increases in sediment levels of 20 mg/l significantly influenced the behaviour of juvenile Atlantic salmon by increasing foraging activity, which then declined at concentrations of > 180 mg/l. Seasonal differences in avoidance behaviour of juvenile Atlantic salmon were also noted and suggested tolerance to SSCs is greater in winter than in autumn.

As a migratory species, smolts at the AHEP offshore disposal site would be expected to be able to avoid temporary adverse sediment conditions due to their mobility and large range movement and will be tolerant to raised SSCs to a certain degree due to their presence in turbid estuarine environments through which they pass on their migration. Exposure to elevated SSCs at the disposal site, if encountered, would be very short as smolts will be dispersing to distant feeding grounds. Peak SSCs are not predicted to be at levels indicative of causing mortality and will diminish rapidly with distance along dispersion pathways. The proposed changes to the AHEP blasting methodology do not increase the amounts of material that are required to be disposed at the offshore disposal site. Impacts on emigrating smolts will thus be no greater than those previously assessed and will remain localised to the disposal site, of short duration and intermittent and, suggesting that effects will be of **minor** significance and will be well within the longer-term impacts associated with ongoing disposal of the maintenance dredge spoil from Aberdeen Harbour. Effects are **likely** to occur given the location of the disposal site and the dominant dispersion pathways of smolts emerging from the River Dee as detected during recent tracking studies. This impact conclusion is associated with **high certainty** as SSCs at the disposal site have been modelled and dispersion behaviours of smolts have been, and continue to be, studied.

5.7 Cumulative Impacts

Table 4.4 presents the projects considered for cumulative impacts assessment. All projects presented in the Table are considered as they may fall within the range movement of salmon and other migratory species present within the vicinity of the AHEP.

Diadromous species, such as salmon, are highly mobile and wide ranging and may therefore encounter impacts arising from two or more separate construction projects. A cumulative effect may occur if the effect of a repeat encounter adds to the effect of the previous one, for instance if a fish repeatedly fails to feed due to repeated startle and avoidance reactions to successive adverse noise or turbidity plume impacts.

With reference to Table 4.4 and Figure 4-8 there are no projects close to the current AHEP that are likely to simultaneously or consecutively displace fishes as a result of adverse noise or turbidity plumes. The nearest projects with potential concurrent noisy or sediment disturbance activities are those at Montrose Harbour located 55 km to the south and the Moray East offshore wind farm located 130 km the north. The North Connect cable construction at the landfall site near Peterhead and the Peterhead Port Masterplan project may also contribute short-term and localised noise, noting that the latter project may involve blasting the effects of which may be constrained to inner harbour areas as there is limited or no direct line of sight to open water locations.

While these projects, together with those at Ardersier and Cromarty Port in the Inner Moray Firth, are within the possible range movements of migratory salmonids using the area around the AHEP, the large distance separation between these projects, and the likely presence of suitable habitat within the intervening distance for feeding and refuge, suggests that significant cumulative effects to migratory salmonids, and other diadromous fishes, are unlikely. Beyond the double bubble curtain, levels of underwater noise are reduced to those that are not forecast to significantly affect salmonids while any localised adverse areas at the offshore disposal, due to dredged material disposal, site are likely to be avoided.

5.7.1 Cumulative Impact of Dredged Spoil Disposal at the Licence Disposal Site on Migrating Smolts

The offshore disposal site currently receives dredge spoil from the AHEP and the Aberdeen Harbour maintenance dredging operation. Sediment plume modelling of a simultaneous release of TSHD spoil and spoil from the Aberdeen Harbour maintenance dredge at the offshore disposal site predicted a peak cumulative SSC of 29 169 mg/l, falling more than an order of magnitude to 2 774 mg/l at 708 m to the north, and to 2 363 mg/l at 886 m to the south (see Chapter 7 of the 2015 ES) (AHB, 2015). Average cumulative SSCs were more than 35 times lower at the disposal site, at 813 mg/l and fall to 101 mg/l at 463 m to the north and to 106 mg/l at 463 m to the south. Average cumulative levels were found to be within natural background variability less than 0.5 km from the disposal site. However, these predictions reflect an unrealistic (worse-case) situation as it would be highly unlikely that dredgers from both schemes would be discharging dredged material at exactly the same location at exactly the same time, although dredgers from the AHEP and Aberdeen harbour could be operating on the same day on some occasions.

As highlighted in section 5.6.3 above, migratory species, such as salmonids, would be expected to be able to tolerate elevated SSCs for a short time at least, and will be able to avoid localised adverse areas. Therefore, no significant cumulative effects of raised sediment plumes due to simultaneous AHEP and Aberdeen Harbour dredged material disposal on migrating smolts are forecast.

5.8 Recommended Mitigation and Residual Impacts

No additional mitigation over and above that already provided is deemed unnecessary as only minor effects are predicted.

A fish scarer is used to startle fish away from blast zones prior to detonation. Further monitoring will allow the effectiveness of this measure to be determined. Where it is practicable to do so, it is recommended to also record any stunned or distressed fish, fish kills outside the double bubble curtain as part of the ongoing fish kill surveys.

A protocol for recording and reporting salmon carcasses, if found, to the statutory authorities will be agreed and provided in a revised CEMD.

6. MARINE MAMMALS

6.1 Introduction

An assessment of the proposed changes to the blasting methodology on marine mammals, including grey seal, harbour porpoise, minke whale and bottlenose dolphin is provided in this section. Comparison with assessment findings from the original ES (AHB, 2015), and upon which the current AHEP is consented is given. Information is taken from chapter 15 of the 2015 ES and its supporting Technical Appendices (Appendix 15-A and 15-B). Information is also drawn from the Supplementary Information for the application for an EPS licence (2 October 2018) and the AA undertaken by MS-LOT (October 2016). Results from mitigation monitoring, including marine mammal observers (MMO), passive acoustic monitoring (PAM) studies and C-POD deployments are also presented and update the previous baseline and assessment (OSC, 2019a, b, c, d, f, g & h). In addition, new numerical modelling using the interim Population Consequences of Disturbance (iPCoD) model v5.0 has been performed (OSC, 2019e) (see Appendix E). This new work updates previous predictions provided in MS-LOT's AA concerning the long-term effects of the AHEP proposals alone and in-combination with other plans and projects on bottlenose dolphin, grey seal, minke whale and harbour porpoise populations.

Marine mammal issues identified during the EIAR scoping and which are important to the consideration of the potential impacts of the proposed changes to the blasting methodology are presented in Table 6.1.

Table 6.1: Scoping Responses Concerning Marine Mammals

Consultee	Summary Scoping Response	Where Addressed in this EIAR
Whale and Dolphin Conservation	Conducting an iPCoD analysis based on the longer timescales of works would be helpful to inform level of impacts.	iPCoD modelling has been performed for harbour porpoise, bottlenose dolphin, minke whale and grey seal (see Section 6.4 and Appendix D).
	Confirmation that analyses consider injury and grey seals.	Appendix B (underwater noise impact modelling) estimates injury ranges (TTS and PTS) for marine mammals including seals. Section 6.4 provides an assessment of effects, including injury effects, and grey seals.
	Confirmation of the proposed changes to the project to be assessed.	The proposals (changes) assessed in this EIAR are presented in Section 2.6.
	Request for Kincardine Offshore wind farm to be scoped in to cumulative assessment.	Section 4.9 rules out the Kincardine wind farm for marine mammals.
	Request that monitoring and reporting requirements be considered.	Section 6.7 considers the mitigation and monitoring requirements.
Scottish Natural Heritage	Impact assessment should use the NOAA/NMFS thresholds to PTS and TTS and that mortal/physical injury ranges should also be presented.	Section 6.4 and Appendices A and B use NMFS (2018) guidance to assess PTS and TTS and Southall et al (2007) guidance in respect of behavioural responses. It is acknowledged that since the current underwater noise and iPCoD modelling have been completed, guidance on marine

Consultee	Summary Scoping Response	Where Addressed in this EIAR
		mammal noise exposure criteria has been updated (Southall et al., 2019). The updated criteria are comparable to those used in NMFS (2018) and have the same TTS and PTS limits and so would result in similar outcomes and assessment conclusions as presented here.
	Recommend that estimated source levels that relate to each charge weight are presented and that an assessment of how the number of charges used affects source levels.	Section 4.3.1 assesses source levels for a range of blast weights and presents current data correlating source levels with numbers of charges.
	Peak sound pressure and sound exposure levels to be used. At a minimum, disturbance should be assessed using the TTS metric. Numbers of individuals of each species predicted to suffer PTS and TTS is to be estimated for both mitigated an unmitigated scenarios.	Impacts are based on both peak pressure and sound exposure levels. The requested species parameters and metrics are used in this EIAR (see section 6.4 and Appendix B).
	A population viability analysis (PVA) is recommended. Bottlenose dolphin, harbour porpoise, grey seal and minke whale should be considered in the PVA.	iPCoD modelling has been performed to assess the long-term viability of populations of harbour porpoise, bottlenose dolphin, minke whale and grey seal (see Section 6.4 and Appendix D).
	Our preference is to use the lower estimate of attenuation. Maps with impact radii should be presented.	Impacts ranges used in this EIAR are based on the latest blasting underwater noise measurement data which indicates a lower limit of attenuation for the double bubble curtain of 22 dB (section 6.4). Maps showing impact radii are not given however Appendix B provides comprehensive results showing PTS, TTS and behavioural response impact ranges for charge weights between 20 kg and 100 kg
Marine Scotland Science	Recommends that significant developments within the home range of the SAC population are considered within the CIA process.	Significant projects considered in CIA are listed in Table 6.12.
	The C-POD information should be more explicit.	Section 6.2.5 discusses the construction monitoring C-POD information that has been collected for porpoise and dolphin.
	Additional information concerning the vantage point surveys would be helpful for the interpretation of the data.	Section 6.2.5 summarises the findings of the vantage point surveys with additional detail provided in Technical Appendix 15-A of the 2015 ES.
	Greater clarity is required when referring to PTS and TTS. The peak and not the RMS is the primary concern with respect to marine mammals and the potential for PTS and TTS.	Appendix B and section 6.4 provide PTS and TTS estimates based on peak levels.

6.2 Summary Characterisation

Marine mammals in UK waters are protected at international level (Annex IV and II of the EC Habitats Directive) as implemented nationally though the Conservation (Natural Habitats &c.) Regulations 1994 (as amended in Scotland). All cetaceans are European Protected Species (EPS). Deliberate disturbance or injury to cetaceans would constitute an offence (JNCC, 2010a) under the Regulations. Relevant AHEP activities are currently controlled by an existing EPS licence, granted under the Habitats Regulations 1994, which will require to be amended.

The region supports a number of cetacean and pinniped species including bottlenose dolphin (*Tursiops truncatus*), harbour porpoise (*Phocoena phocoena*), Risso's dolphin (*Grampus griseus*) and white-beaked dolphin (*Lagenorhynchus albirostris*) and Minke whale (*Balaenoptera acutorostrata*). Grey seal (*Halichoerus grypus*) is the most commonly occurring pinniped in the waters off Aberdeenshire waters. Harbour seals (*Phoca vitulina*) are occasionally recorded. Grey seal and bottlenose dolphin are qualifying features of the Isle of May Special Area of Conservation (SAC), 108 km to the south and Moray SAC, at approximately 150 km north-west, respectively. Four species of marine mammals including grey seal, harbour porpoise, bottlenose dolphin and minke whale are considered in this assessment following scoping, brief accounts of which are provided below.

6.2.1 Grey Seals

Grey seals are generalist feeders feeding on a variety of fish according to seasonal availability and regional distribution (SCOS, 2017). They are known to feed primarily on sand eels, gadoid fish species, and on salmon and marine fish in the Don and Dee estuaries (2015 ES, Technical Appendix 15-A) (AHB, 2015). Grey seals will spend more time in coastal waters and ashore in local haul-out sites during their annual moults (February and April), and during the pupping season (October to November). The closest haul-out sites are located at the mouths of the river Don (5 km to the north) and Ythan (20 km to the north), at Catterline (28 km to the south), in Cruden Bay (31 km to the north), in Boddam (41 km to the north) and in Peterhead harbour (45 km to the north)

Seal tagging studies (2015 ES, Technical Appendix 15-B) (AHB, 2015) showed that grey seal range widely throughout the region. Some individuals that use local waters also use the Isle of May SAC. Tagged adult and pup grey seals were observed to cross Nigg Bay although many adult grey seals appeared to transit along the coast, passing just offshore while grey seal pups tended to spend most of their time off Newburgh to the north of the development at the top of the Nigg Bay or just south of Stonehaven. Most tagged grey seals (77 %) recorded less than 5 % of their locations in the Nigg Bay area, with 40 % only recording up to 0.5 % of their locations in the area.

6.2.2 Bottlenose Dolphin

Bottlenose dolphin are frequently encountered along the east coast of Scotland between Montrose and Aberdeen in waters less than 20 m depth and within 2 km of the coastline. They appear to remain a common feature of Aberdeen Harbour according to observational records made by the National Whale and Dolphin Watch data despite ongoing construction in Nigg Bay.

There is significant movement of highly mobile individuals along the east coast of Scotland with the same identified individuals seen in the Moray Firth as well as off the Grampian/Fife coast (Cheney et al., 2013). It is thought that nearly 200 dolphins make up the east coast population management unit (MU) with known differences in site fidelity and ranging behaviour within this population (Thompson et al. 2011; Cheney et al. 2012; Quick et al. 2014). Around 25 % of the total east coast MU regularly uses the coastal stretch between Aberdeen and Stonehaven further south, and some 60 % of the total Scottish population is using the coastal seas between Aberdeen and the Firth of Forth (Quick, et al. 2014). The bottlenose dolphin found off Aberdeen are thought to be part of the Moray Firth Special Area of Conservation (SAC) resident population that range as far south as the Firth of Forth. During the spring and early summer months calves are known to be present in Aberdeen's coastal waters (Genesis 2012, Quick, et al. 2014).

6.2.3 Harbour Porpoise

Harbour porpoise are the most common species of cetacean living in the North Sea and are found in both coastal and offshore areas. In Scottish waters the principal prey species for harbour porpoise are sand eels, but they are also known to feed on a wide range of marine fish. Harbour porpoise is regularly observed throughout the year in the inshore waters off Aberdeen, with peak activity in August and September. This has been attributed to the inshore movements of lactating females with their calves and associated movements by males (2015 ES, Technical Appendix 15-A) (AHB, 2015). Peak calving occurs in May to July in Scottish seas, with calves often observed off the Aberdeenshire coast between May and September. (Genesis, 2012; Robinson, et al. 2008).

6.2.4 Minke Whale

Minke whale is widely distributed along the east coast of Scotland and occur close to the coast, especially between Aberdeen and Stonehaven during spring and summer months. Minke whales move into the North Sea waters at the beginning of May, with sightings most likely to occur in July to August, and are present until October. They occur in shallow waters depths between 20 m and 50 m, with 70% of sightings occurring in such waters during a study of the species' habitat preferences. Minke whale prey upon a variety of invertebrates and fish species, in particular sand eels. They are generally seen singly or in pairs but can form aggregations of up to fifteen individuals when feeding.

In the autumn, a general offshore movement of the species has been reported and has been linked to breeding which is known to occur during periods between autumn and spring.

Although not recorded during site specific surveys, two minke whales have recently been observed off Aberdeen on 15 September 2018 (one day after a blasting event at the AHEP) (http://www.seawatchfoundation.org.uk/5-south-grampian/) (Minke whale (x 2) off Aberdeen, Aberdeenshire at 10:30 on 15 September 2018 by Oliver Pettifer).

6.2.5 Site Specific Data

There has been, and continues to be, considerable effort in the recording of the spatial and temporal distributions of marine mammals in relation to the AHEP as reviewed below.

Two C-PODs were deployed just outside of Nigg Bay in 2014 as part of initial EIA investigations (AHB, 2015). The C-PODs were designed to detect and continuously monitor the 20 kHz to 160 kHz frequency range of odontocete (toothed whales) echolocation clicks having an effective range of 150 m for porpoise and 700 m for dolphin. Porpoises were recorded on 97 % of all days, 53.4 % of all hours and 9.5 % of all minutes throughout the EIA investigation period and generally showed increased activity during daylight hours and much reduced activity at night. Dolphin activity was less than porpoise activity and was detected on 56.5 % of all days, 5.15 % of all hours and 0.4 % of all minutes. Comparison of these detection rates with those found at other locations along the coast of Scotland suggested that the local area is regionally important for bottlenose dolphin and locally important for harbour porpoise.

Vantage point surveys, comprising observations and recordings of marine mammals from the rocky headlands to the north and south of Nigg Bay between June 2014 and May 2015 further characterised local spatial and temporal distributions of marine mammals around Nigg Bay (AHB, 2015). Figure 6-1 summarises the numbers of bottlenose dolphins, grey seals and harbour porpoises recorded throughout the year.

Bottlenose dolphin were observed from January to June and in September, October and December at distances ranging between 100 m and 1 km from the shore. Sightings took place at various times of the day and covered all tidal states. No sightings of bottlenose dolphin were recorded in July, August or November.

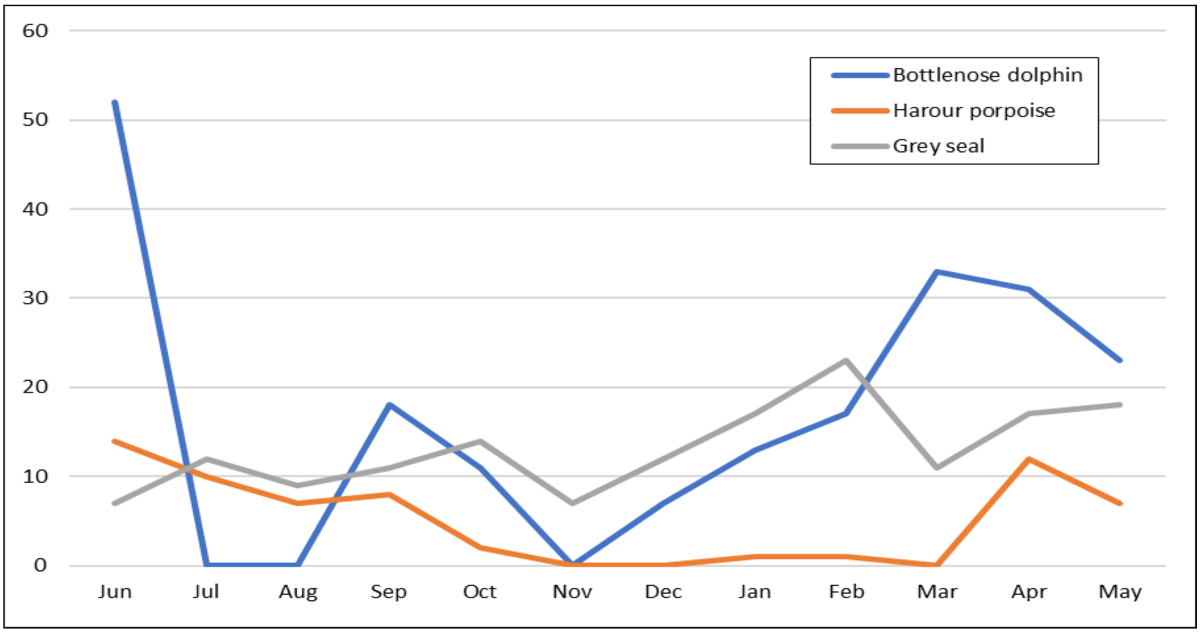

Figure 6-1: Mean numbers of individuals of bottlenose dolphin, harbour porpoise and grey seal per month recorded from vantage point surveys at Nigg Bay (June 2014 to May 2015)

Harbour porpoise were recorded at distances ranging between 500 m and 2 km from the shore. There were only single sightings during the months of January and February with no sightings in March. The numbers of sightings increased in April and May with continued sightings to October. There were no sightings in November or December. Sightings took place at various times of the day and covered all tidal states.

Grey seals were recorded in all months, with the distance from shore ranging from less than 100 m to up to 1 km. Sightings took place at various times of the day and covered all tidal states but were most common between mid and high tides, with few sightings at low tide.

Three white-beaked dolphins were also recorded in July. Minke whale were not recorded during the vantage point survey.

Currently there are two C-PODs deployed in Nigg Bay (one to the north and one to the south) to continuously record cetacean presence around the AHEP during construction. Data (click trains) are periodically downloaded from the C-PODs and reported as detection positive hours (DPH) for dolphin and porpoise. Currently, nine C-COD data downloads and reports on dolphin and porpoise presence at Nigg Bay between April 2018 and August 2019 have been provided as summarised in Table 6.2.

Table 6.2: Summary of C-POD Deployments and Data Collected at the AHEP

Deployment Period	No. Hours Deployed	Concurrent Blasting Activity	Median and Inter-Quartile Range Porpoise DPH	Median and Inter-Quartile Range Dolphin DPH	Reference
27/04/18 - 06/05/18	216	No blasting undertaken during deployment	3 (2-4) (north) 5 (3.25-6) (south)	3.5 (3-5) (north) 4.0 (3-4) (south)	OSC (2019a)
03/08/18 – 06/09/18	810	20/08/18 (1951 BST) 24/08/18 (1303 BST) 06/09/18 (1901 BST)	10 (7-15 (north) 10 (7-14.5) (south)	1 (0-2.5 (north) 2 (0-3) (south)	OSC (2019b)
06/09/18 - 27/10/18 06/09/18 – 12/10/18*	1222	12/09/18 (1030 BST) 14/09/18 (1305 BST) 17/09/18 (1642 BST) 08/10/18 (1701 UTC) 13/10/10 (0942 UTC) 17/10/18 (1149 UTC) 25/10/18 (0813 UTC)	10 (7-14 (north) 5 (3-7) (south)	0 (0-1) (north) 0 (0-2) (south)	OSC (2019c)
08/12/18 – 10/01/19⁺	790	17/11/18 (1356 UTC) 24/11/18 (0950 UTC)	12 (9-15.75) (south)	1 (0-3) south)	OSC (2019d)
10/01/19 - 31/01/19	499	None	18.5 (16-21.75) (south)	2 (1-3) (south)	OSC (2019f)
31/91/19 - 25/03/19	1271	None	16 (12.25-19) (south)	2 (1-3) (south)	OSC (2019g)
25/03/19 – 07/05/19	1028	None	5.5 (2-16) (south)	2.6 (1-7) (south)	OSC (2019h)
19/06/19 – 21/07/19	767	None	3 (1-5) (north) 2 (1-4) (south)	2 (1-4) (north) 3 (1-5) (south)	OSC (2019i)
21/07/19 – 13/08/10	551	None	4.5 (2-8.25 (south)	4.5 (2-5.25) (south)	OSC (2019j)

Notes:
* = The south mooring broke free on 12/10/18, and the north mooring broke free on the 27/10/18
⁺ = The north mooring broke free on 10/12/18.

The C-POD data have been valuable in characterising porpoise and dolphin use of the local area during the construction of the AHEP including before and during blasting events as well as throughout the current period during which blasting has been suspended. It shows that dolphins and porpoise have been detected throughout pre- and during-construction stages including during periods when blasting has taken place. Closer inspection of the data as part of population consequences modelling (discussed later in this Chapter) (see Appendix E) (OSC, 2019e) shows that porpoise return quickly to the area around the AHEP following a blasting event and typically within a few hours.

Figure 6-2 and Figure 6-3 show the number of detection positive hours each day for harbour porpoise and dolphin respectively during the first deployment of the C-PODS (April – May 2018) in the north and south of Nigg Bay and prior to the commencement of blasting. They highlight a generally low level of activity for harbour porpoise between 27 April 2018 and 6 May 2018 with the exception of a peak in activity on the 27 April and 3 May 2018. Detections of dolphins were broadly consistent throughout the deployment period.

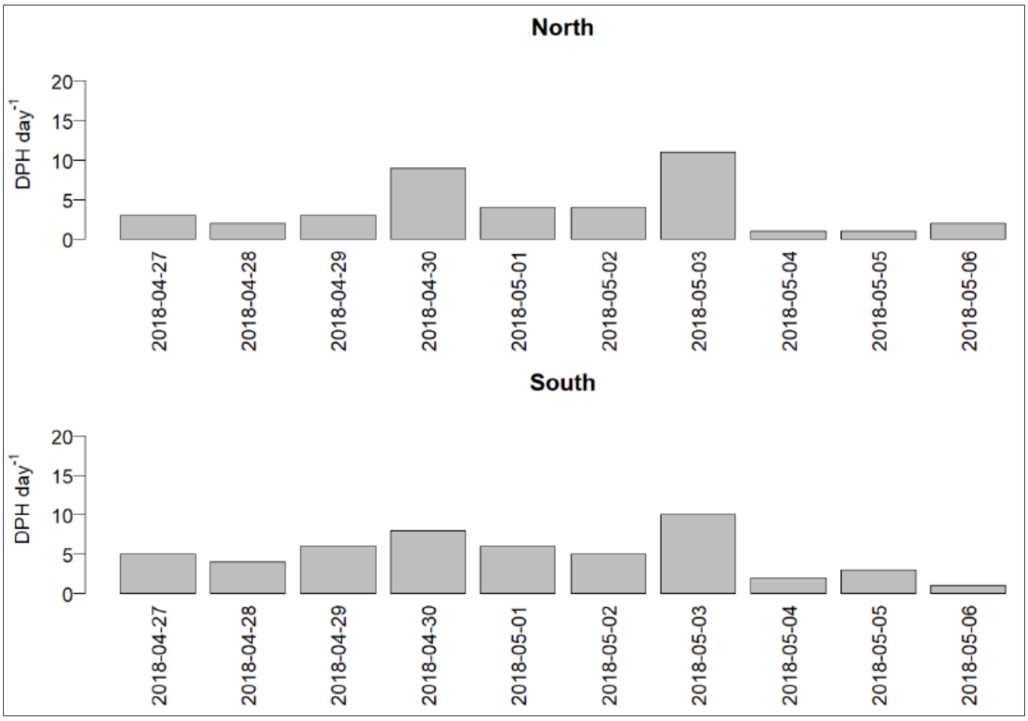

Figure 6-2: Detection positive hours per day for porpoise during deployment 1
(**Source:** OCS, 2019a).

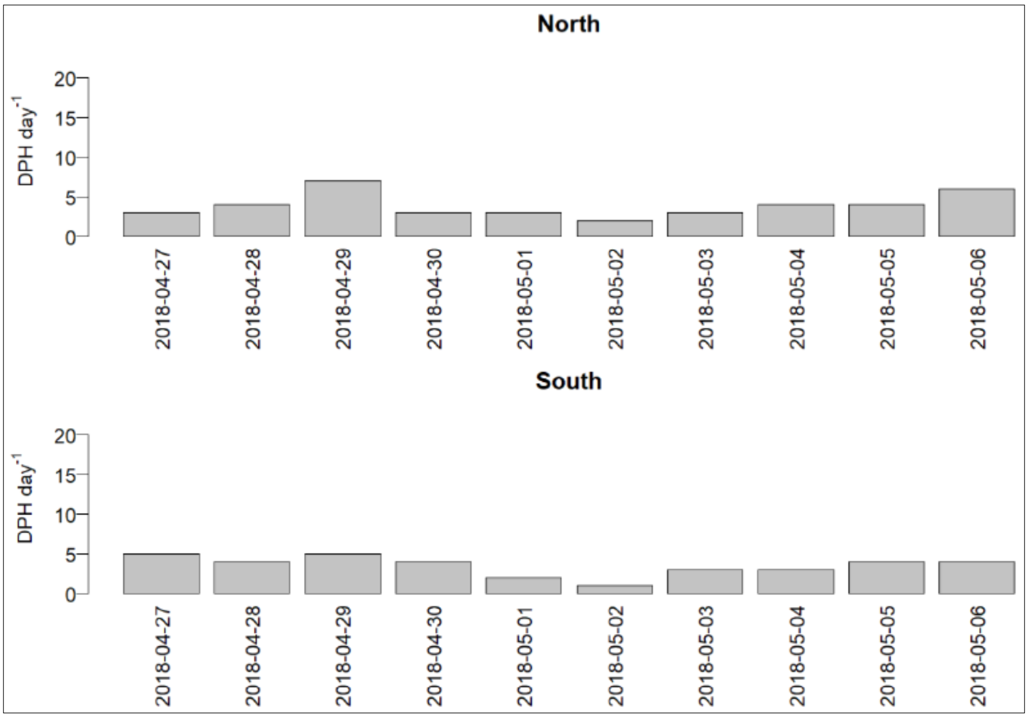

Figure 6-3: Detection positive hours per day for dolphin during deployment 1

(**Source:** OCS, 2019a).

Figure 6-4 and Figure 6-5 show the numbers of detection positive hours for porpoise and dolphin respectively during the second deployment (August and September 2018) during which three blasting events occurred. During this second deployment a higher level of harbour porpoise activity was recorded compared with April and May. The data suggest that on occasion, detection positive minutes for porpoise reduced after a blasting event but returned quickly to previous levels although definitive cause-effect relationships are not confirmed. Detections did not diminish completely following blasts suggesting the porpoise remained in the area. Subsequent detailed analysis by OSC (OSC, 2019e) (Appendix E) shows that harbour porpoise were detected 2 to 3 hours following blasting events on 20 and 24 August respectively (see Figure 6-4).

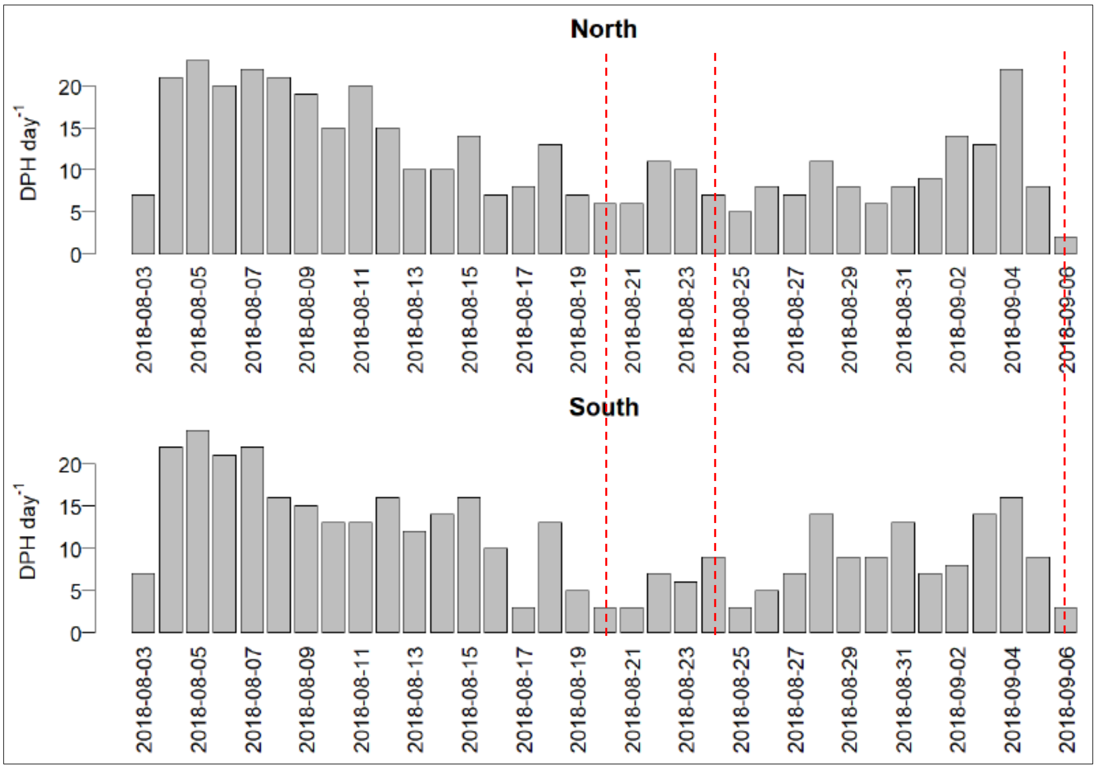

Figure 6-4: Detection positive hours per day for porpoise during deployment 2

Notes:

Red dotted lines indicate blasting days

(**Source:** OCS, 2019b).

Dolphin detections were lower during the second deployment (August and early September) compared to the April-May period reflecting the pre-construction vantage point survey situation (Figure 6-1). No clear relationship between temporal distribution for dolphins and blasting events are apparent.

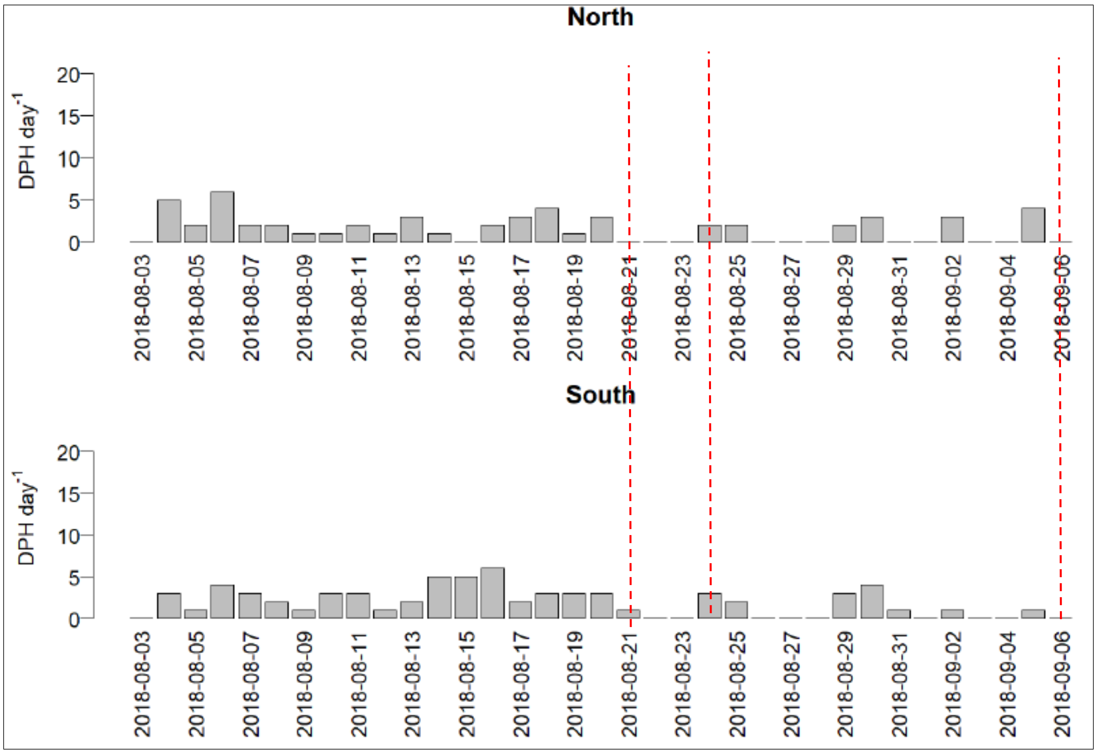

Figure 6-5: Detection positive hours per day for dolphin during deployment 2

Notes:
Red dotted lines indicate blasting day
(**Source:** OCS, 2019b).

Figure 6-6 and Figure 6-7 show the number of porpoise and dolphin detection positive hours during deployment 3 (September – October 2018) respectively and during which eight blasting events took place. Data were only retrieved for the north C-POD up to 26 October and up to 12 October for the south C-POD meaning that the last two blasting events in November were not covered. Within the data that were recovered, porpoise detections were variable throughout the deployment period. Subsequent analysis (OCS, 2019e) (Appendix E) revealed that porpoise were detected between 0 and 6 hours following each blast during this period.

Numbers of dolphin detections were low or absent suggesting only partial use of the locale during this period. However, detections increased between 4 and 11 October and despite a blasting event on 8 October, dolphins remained within the area and were detected on the southern C-POD over the following 3 days.

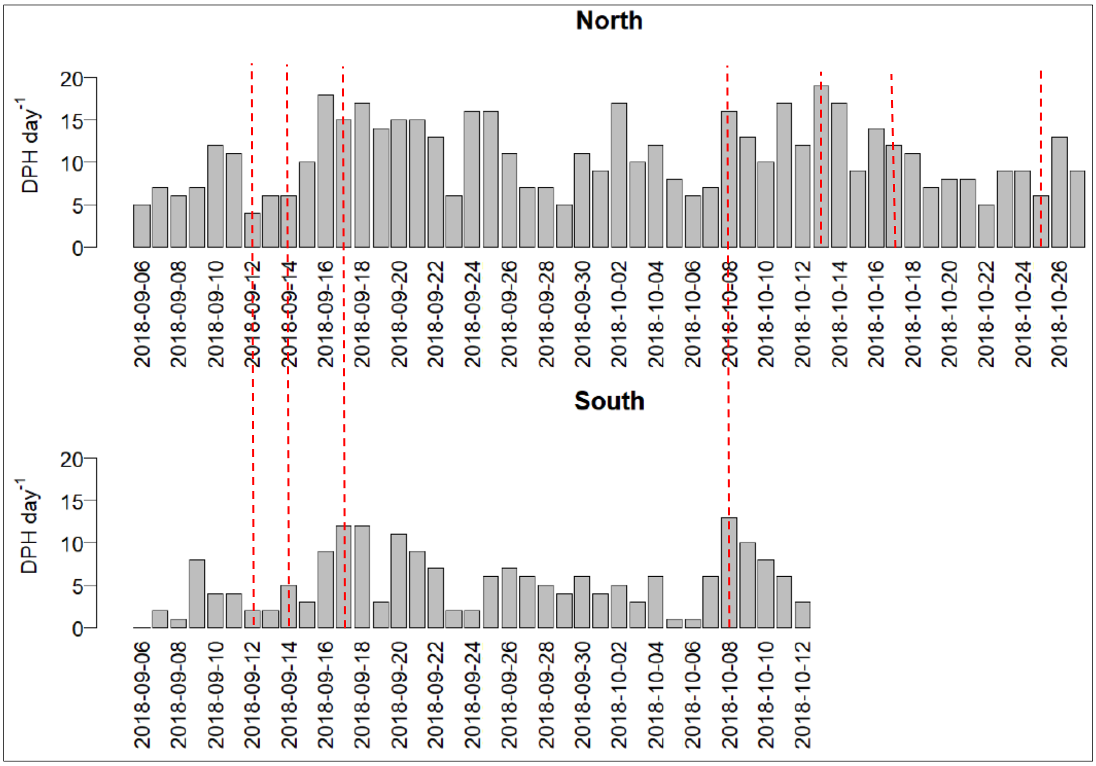

Figure 6-6: Detection positive hours per day for porpoise during deployment 3

Notes:

Red dotted lines indicate blasting days

(**Source:** OCS, 2019c).

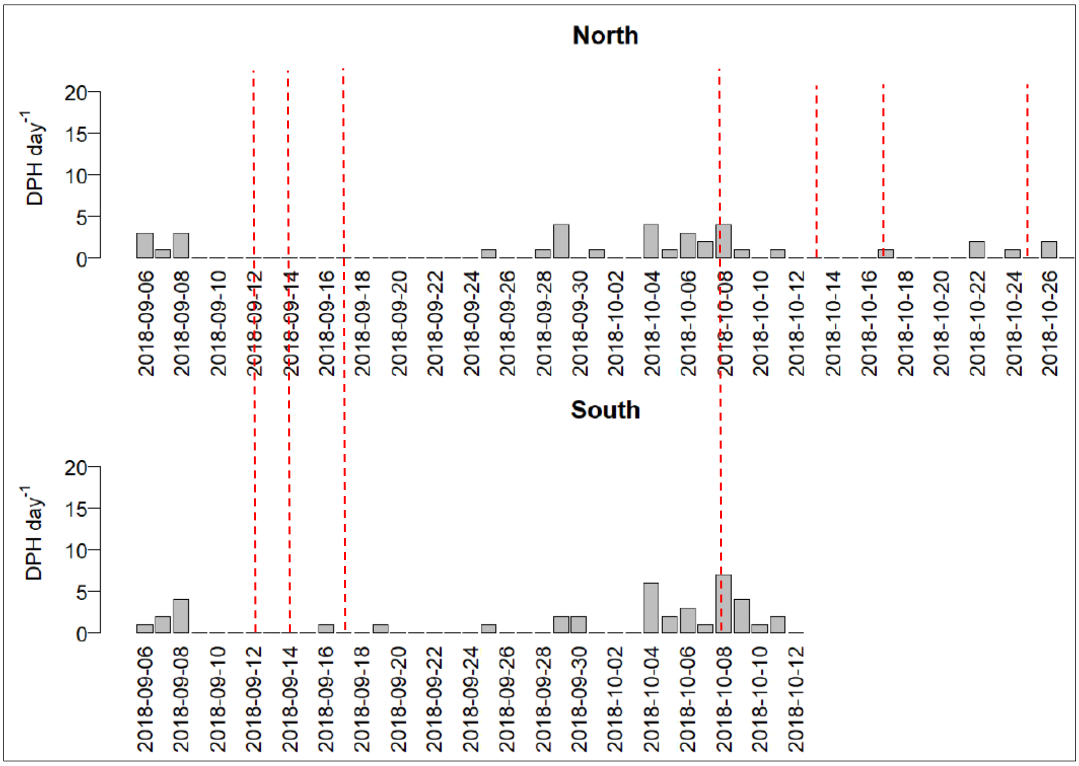

Figure 6-7: Detection positive hours per day for dolphin during deployment 3

Notes:

Red dotted lines indicate blasting days

(**Source:** OCS, 2019c).

Figure 6-8 and Figure 6-9 present the numbers of detection positive hours per day for porpoise and dolphin at the southern C-POD for the fourth deployment period (December 2018 – January 2019) respectively during which no blasting events occurred. Data for the north C-POD were not retrieved during this deployment period.

The numbers of detections for porpoise were variable throughout the period. Low numbers of porpoise on 15, 16, and 18 December correlated with periods of high noise indicating storm conditions (OSC, 2019d).

Dolphin detections remained low but increased through late December and January broadly matching pre-construction vantage point observations (Figure 6-1).

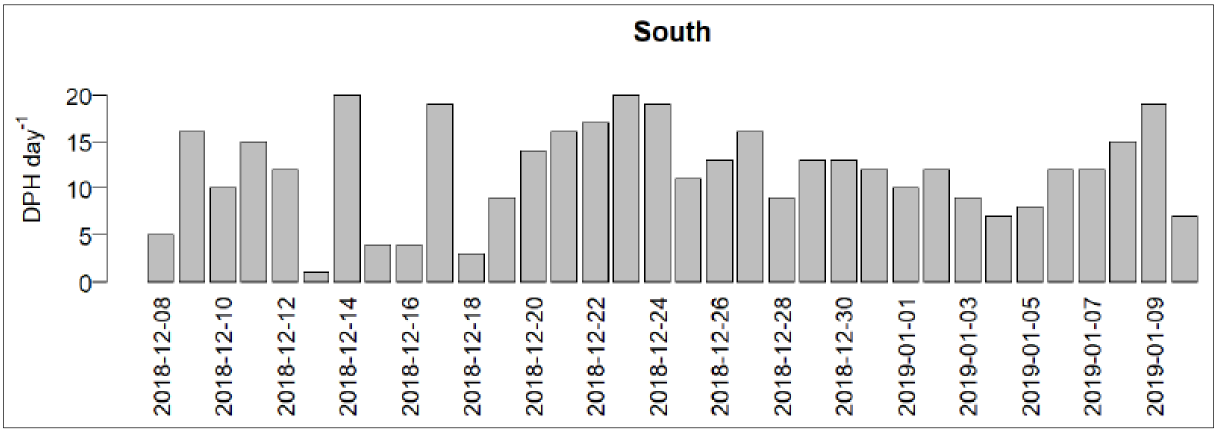

Figure 6-8: Detection positive hours per day for porpoise during deployment 4

Notes:

Red dotted lines indicate blasting day

(**Source:** OCS, 2019d).

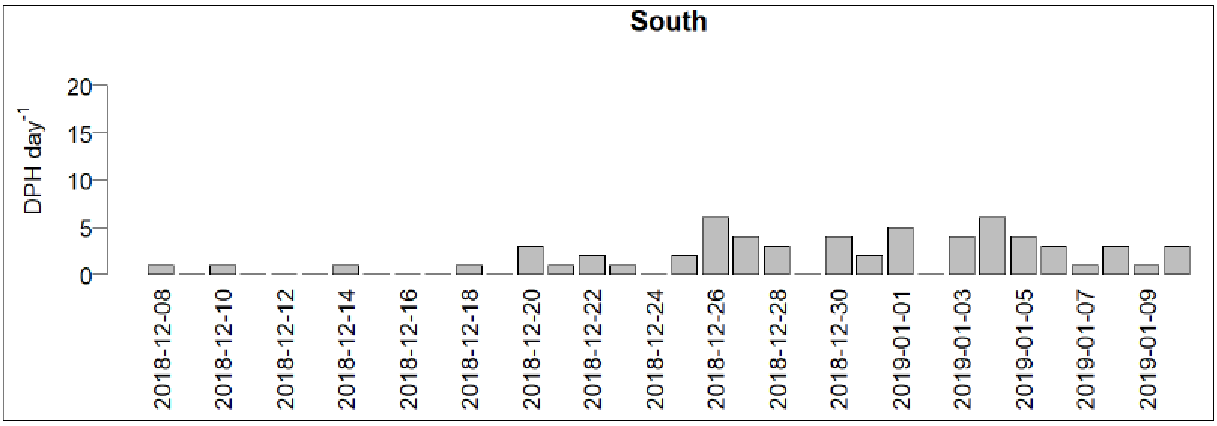

Figure 6-9: Detection positive hours per day for dolphin during deployment 4

(**Source:** OCS, 2019d).

Since the beginning of January 2019, the southern C-POD has been deployed on a further five occasions while the northern C-POD has been deployed once (see Table 6.2 above) with the most recent data collected on 13 August 2019. No blasting has been undertaken during these most recent deployment occasions. The median rates of porpoise and dolphin detected (Table 6.2) appear broadly comparable or slightly higher than those for periods within which blasting occurred although further analysis and consideration of local seasonal trends would be required to confirm any relationship.

In addition to the C-POD deployments, marine mammal observations (MMO) and passive acoustic monitoring (PAM) are undertaken as part of the ongoing licence condition monitoring and mitigation during construction blasting activities at the AHEP. These monitoring activities provide further evidence of the presence of marine mammals within and around the AHEP pre- and during construction. MMO and PAM weekly observations collected during the ongoing works are summarised in Table 6.3 and show that both grey seals and bottlenose dolphin have been consistently observed within the vicinity of the AHEP throughout the construction observation period. Using the MMO data, OSC (2019e) (Appendix E) estimate that grey seals are detected within the AHEP site on average 12 hours following a blasting event and that this is likely to be an over-estimate.

Table 6.3: Summary of weekly observations (counts) and PAM detections of marine mammals during AHEP construction (August to October 2018)

Week Commencing	Activity	No. Observations Per Week		
		Grey Seal	Bottlenose Dolphin	Porpoise
14/08/2018	Drill/Blast	49	30	1
20/08/2018	Blasting	12	10	Faint clicks
27/08/2018	-	60	5	-
03/09/2018	Blasting	39	10	Clicks
10/09/2018	Blasting	35	7	-
17/09/2018	Blasting	16	-	-
24/092018	Blasting	-	-	-
26/09/2018	Drill/Blasting	33	17	-
05/10/2018	Drill/Blasting	21		1
15/10/2018	Drill/Blasting	10	7	-

6.2.6 Compilation of construction monitoring data

Table 6.4 consolidates all of the on-site marine mammals observations (counts), the PAM detection data and the C-POD monitoring data collected prior, during and after the 2018 blasting campaign and up to January 2019. This shows that porpoise have been detected within the C-POD data on each day throughout this period despite on-going construction as well as blasting using 20 kg explosive charges. Given that the C-POD effective range for detecting porpoise is only 150 m then these animals appear to remain in very close proximity to the AHEP even when blasting, and other construction activities, have taken place. Similarly, dolphin are also frequently recorded in close proximity to the AHEP (within 700 m of the C-PODs) and are apparent within the locale even around the time of blasting. Grey seals are also frequently observed by the on-site marine mammals observers within and around Nigg Bay despite on-going construction disturbance including blasting. As mentioned above, grey seal and harbour porpoise appear to return to the site very quickly (within 12 hours) following a blasting event (OSC, 2019e) (Appendix E).

Table 6.4. Compilation of current marine mammal observations, PAM data and C-POD data

Date		Site observations (counts)			PAM detections	C-POD data	
	Activity	Grey seal	Bottlenose dolphin	Harbour porpoise		Porpoise	Dolphin
27/04/2018						Present	Present
28/04/2018						Present	Present
29/04/2018						Present	Present
30/04/2018						Present	Present
01/05/2018						Present	Present
02/05/2018						Present	Present
03/05/2018						Present	Present
04/05/2018						Present	Present
05/05/2018						Present	Present
No observations between 6 May 2018 and 2 August 2018							
03/08/2018						Present	
04/08/2018						Present	Present
05/08/2018						Present	Present
06/08/2018						Present	Present
07/08/2018						Present	Present
08/08/2018						Present	Present
09/08/2018						Present	Present
10/08/2018						Present	Present
11/08/2018						Present	Present
12/08/2018						Present	Present
13/08/2018						Present	Present
14/08/2018		1				Present	Present
15/08/2018		8				Present	Present
16/08/2018		23				Present	Present
17/08/2018		20	8		HP	Present	Present
18/08/2018		26	4	1	BD	Present	Present
19/08/2018						Present	Present
20/08/2018	Blasting	11				Present	Present
21/08/2018		8				Present	Present
22/08/2018		7				Present	Present
23/08/2018		6			HP	Present	
24/08/2018	Blasting	1	7			Present	Present
25/08/2018		6				Present	Present
26/08/2018						Present	
27/08/2018		13				Present	
28/08/2018		10				Present	
29/08/2018		11				Present	Present
30/08/2018		10	5			Present	Present
31/08/2018		7	Present			Present	Present
01/09/2018		11				Present	
02/09/2018						Present	Present

Date		Site observations (counts)			PAM detections	C-POD data	
	Activity	Grey seal	Bottlenose dolphin	Harbour porpoise		Porpoise	Dolphin
03/09/2018		3				Present	
04/09/2018		5			HB	Present	
05/09/2018		6	5		BD	Present	Present
06/09/2018	Blasting	7	1			Present	Present
07/09/2018		4				Present	Present
08/09/2018		3				Present	Present
09/09/2018		11				Present	
10/09/2018		6				Present	
11/09/2018		5				Present	
12/09/2018	Blasting	3	6			Present	
13/09/2018		5	1			Present	
14/09/2018	Blasting	3				Present	
15/09/2018		13				Present	
16/09/2018						Present	Present
17/09/2018	Blasting	2				Present	
18/09/2018		5				Present	
19/09/2018						Present	Present
20/09/2018						Present	
21/09/2018		5				Present	
22/09/2018		2				Present	
23/09/2018		3				Present	
24/09/2018		4		1 (3?)		Present	
25/09/2018		10				Present	Present
26/09/2018		4	3			Present	
27/09/2018		2				Present	
28/09/2018		2	3			Present	Present
29/09/2018		2				Present	Present
30/09/2018		2				Present	Present
01/10/2018		6	6			Present	Present
02/10/2018		3				Present	
03/10/2018		2				Present	
04/10/2018		5	5			Present	Present
05/10/2018		1				Present	Present
06/10/2018		3				Present	Present
07/10/2018		4				Present	Present
08/10/2018	Blasting	2				Present	Present
09/10/2018		2		1		Present	Present
10/10/2018		5				Present	Present
11/10/2018		2				Present	Present
12/10/2018		1				Present	
13/10/2018	Blasting	1				Present	
14/10/2018						Present	
15/10/2018		1	7			Present	

Date		Site observations (counts)			PAM detections	C-POD data	
	Activity	Grey seal	Bottlenose dolphin	Harbour porpoise		Porpoise	Dolphin
16/10/2018						Present	
17/10/2018	Blasting	2				Present	Present
18/10/2018						Present	
19/10/2018						Present	
20/10/2018		4				Present	
21/10/2018		3				Present	
22/10/2018						Present	Present
23/10/2018						Present	
24/10/2018						Present	Present
25/10/2018	Blasting					Present	
26/10/2018						Present	Present
No observations between 27 October 2018 and 7 December 2018							
08/12/2018						Present	Present
09/12/2018						Present	
10/12/2018						Present	Present
11/12/2018						Present	
12/12/2018						Present	
13/12/2018						Present	
14/12/2018						Present	Present
15/12/2018						Present	
16/12/2018						Present	
17/12/2018						Present	
18/12/2018						Present	Present
19/12/2018						Present	
20/12/2018						Present	Present
21/12/2018						Present	Present
22/12/2018						Present	Present
23/12/2018						Present	Present
24/12/2018						Present	
25/12/2018						Present	Present
26/12/2018						Present	Present
27/12/2018						Present	Present
28/12/2018						Present	Present
29/12/2018						Present	
30/12/2018						Present	Present
31/12/2018						Present	Present
01/01/2019						Present	Present
02/01/2019						Present	
03/01/2019						Present	Present
04/01/2019						Present	Present
05/01/2019						Present	Present
06/01/2019						Present	Present
07/01/2019						Present	Present

Date		Site observations (counts)			PAM detections	C-POD data	
	Activity	Grey seal	Bottlenose dolphin	Harbour porpoise		Porpoise	Dolphin
08/01/2019						Present	Present
09/01/2019						Present	Present

6.3 Existing AHEP Management Measures

A specific Marine Mammal Mitigation Plan (MMMP) is already in place as part of the CEMD (Chapter 11) to protect marine mammal populations during the construction phase. This includes time restrictions on noisy underwater activities, adherence to JNCC guidelines (JNCC, 2010b) relating to the use of MMOs and PAM, and the use of a double bubble curtain prior to each blast. Such measures are secured within the Marine Licences, CEMD and its subsidiary Method Statements as well as the current EPS licence. In addition, the MMMP provides several cross-references to other plans within the CEMD which impart direct or indirect protection to marine mammal populations. These include a Vessel Management Plan (CEMD Chapter 17), incorporating the Aberdeen Harbour Dolphin Code, the Dredging and Dredge Spoil Disposal Monitoring Plan (CEMD Chapter 7) and the Piling Management Plan (CEMD Chapter 14) which provide controls on potentially harmful activities to marine mammals. Furthermore, a Fish Species Protection Plan (CEMD Chapter 8) is also in place to protect salmon and sea trout stocks in response to their nature conservation and economic importance, but which may also act to provide an indirect benefit to local bottlenose dolphins in that adverse impacts on potential fish prey items are limited.

As a further protective measure, it was agreed with regulators that blasting would cease should recorded underwater noise levels exceed an agreed threshold of 170 dB re 1 µPa rms (equivalent to 183 dB re 1µPa peak) at 400 m from the blast location or outside the bubble curtain, whichever is the greater distance. Further to this the applicants propose to use a Precautionary Control Limit (PCL) equal to 5 dB below this threshold which, if exceeded, will limit any further incremental increases in charge weight as an extra level of precaution as explained in section 2.6.2.

It is expected that a range of other marine mammal species will also be present within the general area around the AHEP albeit less frequently and that the environmental controls already in place for the protection of characteristic species, including the double bubble curtain, MMO and PAM monitoring, underwater noise modelling and use of an agreed noise threshold and PCL, are equally relevant for the protection of those species that appear in the area less frequently.

6.4 Assessment of Effects

With reference to Table 6.1, the impacts and effects assessed in this section include:

- Increased injury and mortality due to increased levels of noise;
- Increased avoidance due to increased levels of noise.

For the purposes of this EIAR, these impacts and effects are addressed together.

6.4.1 Increased Mortality, Injury and Avoidance Due to Increased Levels of Noise

Marine mammals use sound in various important contexts, such as in social interactions, foraging, and response to predators (Southall et al., 2007). Hearing is the primary sensory system for marine mammals, which is clearly shown by their level of ear and neural auditory centre development (Ketten, 2004). As the sea has never been a silent place, the ears of marine mammals, and those of whales and dolphins in particular, have evolved to function well within this context of ambient noise. However, little information exists to describe how marine mammals respond physically and behaviourally to intense sounds and to long-term increases in ambient noise levels (NRC, 2003).

Marine mammals vary in regard to their hearing sensitivities and in order to assess the impacts of sound on them, NMFS (2018) classes marine mammals into functional hearing groups[4]. The classification into functional hearing groups takes into account that not all marine mammal species have identical hearing or susceptibility to noise-induced hearing loss. Table 6.5 applies this classification to the key species scoped in to this EIAR. Outside the generalised hearing range, the risk of auditory impacts from sounds is considered highly unlikely.

Table 6.5: Functional Marine Hearing Groups for Marine Mammals (based on NMFS, 2018)

Functional Hearing Group	Estimated Auditory Band Width	Species Scoped in to Assessment
Low frequency cetaceans	7 Hz to 35 kHz	Minke whale
Mid frequency cetaceans	150 Hz to 160 kHz	Bottlenose dolphin
High frequency cetaceans	275 Hz to 160 kHz	Harbour porpoise
Phocid Pinnipeds in water	50 Hz to 86 kHz	Grey seal

According to this classification, harbour porpoises are regarded as high-frequency cetaceans with an estimated auditory bandwidth between 275 Hz to 160 kHz. All other toothed whales (odontocetes) present in the North Sea are classified as mid-frequency cetaceans, with an estimated auditory bandwidth between 150 Hz to 160 kHz. This classification is based on the fact that odontocetes have highly advanced echolocation systems that use intermediate to very high frequencies. They also produce social sounds in a lower-frequency band, including generally low to intermediate frequencies (1 kHz to tens of kHz). Consequently, their functional hearing is expected to cover this whole range; however, their hearing sensitivity typically peaks at or near the frequency where echolocation signals are strongest.

The large baleen whales (mysticetes) are all categorised as low-frequency cetaceans. No direct measurements of hearing exist for these animals and theories regarding their sensory capabilities are consequently speculative. In these species, hearing sensitivity has been estimated from behavioural responses (or lack thereof) to sounds at various frequencies, most common vocalisation frequencies, body size, ambient noise levels at the frequencies they use most, and cochlear morphology. At present, the lower and upper frequencies for functional hearing in mysticetes, collectively, are estimated to be 7 Hz and 35 kHz (NMFS, 2018 and 2016).

Research indicates that marine mammals can react differently to the introduction of additional noise into the marine environment. Reactions may vary depending on sound source level, propagation conditions

[4] Southall et al., (2019) propose updated hearing groups but which do not alter the conclusions here.

and ambient noise, in addition to species, age, sex, habitat, individual variation, and previous habituation to noise (Richardson et al., 1995).

6.4.2 Potential for Mortal Injuries on Cetaceans and Pinnipeds

Pressure pulses from explosions can have higher peak levels than those from any other man-made source, and very rapid rise times. At close distances, explosives also produce shock waves. Underwater explosions have the potential to cause injury or even death of cetaceans (JNCC 2010b). However, very limited scientific information is available on severe injury or death on cetaceans and/or pinnipeds caused by underwater explosions or blasting. There are a few studies on the effects of explosions on submerged land mammals and human divers, but these generally refer to explosions in the open water, which behave different from embedded charges under the seabed, such as those used at the AHEP. Parvin et al (2007) provides a detailed review of all available data on this subject and quote a study by Nedwell (1989) which describes that the peak pressure for explosives buried in a rock seabed (i.e. an embedded charge) is reduced substantially, to approximately 5 %, and the impulse to approximately 30 % of that for the equivalent unconfined charge. However, the duration of the blast wave is increased tenfold over that for an equivalent freely-suspended charge, typically to 1 ms to 2 ms. The rise time of the wave is also greatly extended to the order of a millisecond. The resulting blast wave is therefore likely to contain a high proportion of low frequency energy components. There is, however, no bubble pulse.

Parvin et al (2007) summarises the reviewed data on the impact of underwater transient pressure waves as follows:

- At incident peak underwater sound levels of ≥10 MPa (≥260 dB re 1µPa), or at 700 Pa·s and above – always lethal;
- At incident peak underwater sound levels of 1 MPa (≥240 dB re 1µPa) – increasing likelihood of death or severe injury leading to death in a short time;
- At incident peak underwater sound levels of ≥0.1 MPa (≥220 dB re 1µPa) – Direct physical injury to gas-containing structures and auditory organs may occur, particularly from repeat exposures.

For a small marine mammal of mass 80 kg:

- Incident impulse 812 Pa – 50 % mortality;
- Incident impulse = 516 Pa – 1 % mortality.

And for levels unlikely to cause injury:

- Peak pressure below 220 dB re 1µPa and impulse below 100 Pa – unlikely to cause injury.

6.4.3 Injury Thresholds for Cetaceans and Pinnipeds

The blasting operations produce intermittent sound pulses, which are considerably more intense than the continuous noise emitted by most industrial noises in the ocean, such as shipping engine noise, for example. There are few direct data regarding the effects of intense sound on cetaceans, making it difficult to predict accurate safe exposure levels for these mammals (Finneran et al., 2000). Nonetheless attempts have been made to create a set of injury criteria for individual marine mammals exposed to discrete noise events, such as airgun pulses by Southall et al., (2007), and more recently by the U.S.

National Marine Fisheries Service (NMFS) which introduced a new set of injury criteria in 2016 (NMFS, 2016), which have been revised since in 2018 (NMFS, 2018)[5]. These guidelines aim to set acoustic thresholds, at which individual marine mammals are predicted to experience changes in their hearing sensitivity (either temporary or permanent) for acute, incidental exposure to underwater anthropogenic sound sources.

The first metric used by NMFS (2018) to assess PTS and TTS onset, is the unweighted, or 'flat', threshold value for impulsive sounds (Table 6.6).

Table 6.6: Peak SPL Thresholds for TTS/PTS Onset for Impulsive Sounds

Cetacean Group	TTS Threshold (dB re 1 µPa (0 to peak))	PTS Threshold (dB re 1 µPa (0 to peak))
Low frequency cetaceans	213	219
Mid frequency cetaceans	224	230
High frequency cetaceans	196	202
Phocid Pinnipeds (underwater)	212	218

The second metric used in the NMFS (2018) guidelines is a set of weighted auditory thresholds for the cumulative exposure (SEL_{cum}) of marine mammals to impulsive sounds (Table 6.7).

Table 6.7: Peak SEL_{CUM} Thresholds for TTS/PTS Onset for Impulsive Sounds

Cetacean Group	TTS Threshold (dB re 1 $\mu Pa^2 s$)	PTS Threshold (dB re 1 $\mu Pa^2 s$)
Low frequency cetaceans	168	183
Mid frequency cetaceans	170	185
High frequency cetaceans	140	155
Phocid Pinnipeds (underwater):	170	185

The weighted SEL_{cum} metric takes into account both received level and duration of exposure, both factors that contribute to noise-induced hearing loss. Often this metric is normalised to a single sound exposure of one second. The NMFS (2018) guidelines intend for the weighted SEL_{cum} metric to account for the accumulated exposure (i.e. weighted SEL_{cum} cumulative exposure over the duration of an individual activity within a 24-h period).

It should be noted that for individual impulsive sounds, like the proposed blasting operations, the first metric (i.e. Peak SPL) is the most useful to assess the potential impacts.

6.4.4 Avoidance and Behavioural Reponses

With appropriate mitigation measures in place it is unlikely that the proposed blasting operations will cause any permanent injuries to marine mammals, however, they are likely to evoke a certain level of behavioural responses from cetaceans and pinnipeds in the vicinity of the blasting operations. Research indicates that marine mammals can react differently to the introduction of additional noise into the marine environment. Reactions may vary depending on sound source level, propagation conditions and

[5] The updated Southall et al. (2019) guidance proposes the same TTS and PTS onset thresholds for impulsive noise exposure as those used in NMFS (2018).

ambient noise, in addition to species, age, sex, habitat, individual variation, and previous habituation to noise (Richardson et al., 1995).

There are no known studies on the direct effects of blasting operations but as evidenced above, porpoise and grey seal appear not to be significantly affected by current blasting operations and are detected within the vicinity of the AHEP within a few hours following a blasting event.

Several studies on the behaviour of (small) odontocetes to seismic survey and piling sound, which being impulsive sound sources of similar sound levels may be regarded as a proxy to describe the anticipated behavioural effects from the proposed blasting operations, generally show that they exhibit some form of avoidance during these operations. Goold (1996) for example, reported general avoidance behaviour of common dolphins to airgun sound at a distance of up to 1 km during a 2D seismic survey off the coast of Pembrokeshire in the Irish Sea. Another study, looking at the effects of seismic surveys around the UK, showed that small cetaceans remained significantly further from the seismic vessel during periods of shooting (Stone and Tasker, 2006). Comparable behaviour was observed for Atlantic spotted dolphins by Weir (2008) during seismic exploration offshore Angola. All three authors suggest that the avoidance behaviour appeared to be limited to within a few kilometres from the seismic airgun array. A similar effect was reported by Parente and de Araújo (2005) who reported a reduction in cetacean diversity, mainly among members of the family Delphinidae, during seismic surveying offshore Brazil. Thompson *et al*. (2013) found behavioural responses to 2D seismic survey noise in the Moray Firth in harbour porpoises within 5 km to 10 km; although animals were typically detected again at affected sites within a few hours. Contrary to this, in their review of the effects of seismic surveys on marine mammals, Gordon et al. (2004), quote a study which showed no change in the rate of detection of harbour porpoises during two seismic surveys, using an automated click detector.

Most studies on low-frequency cetaceans report behavioural responses at received sound levels around 140 dB re 1 µPa to 160 dB re 1 µPa, and sometimes even higher (e.g. Southall et al., 2007; Richardson et al., 1995). These responses typically consist of subtle effects on surfacing and respiration patterns. Sound levels of 150 dB to 180 dB will generally evoke behavioural avoidance reactions (Richardson et al., 1995). The SPL will drop below 150 dB at a distance of approximately 1.2 km.

Pinnipeds (seals, sea lions, and walruses) also produce a diversity of sounds, although generally over a lower and more restricted bandwidth (generally from 100 Hz to several tens of kHz). Their sounds are used primarily in critical social and reproductive interactions (Southall et al., 2007). Most pinniped species have peak sensitivities between 1 kHz and 20 kHz (NRC, 2003). Common seals are most sensitive to sounds between 6 kHz to 12 kHz (Wolski et al., 2003), although their threshold for hearing and responding to sound lies at frequencies much lower than that. Kastak and Shusterman (1998) measured the underwater sound detection threshold of a common seal, which ranged between 101.9 dB and 62.8 dB for frequencies between 75 Hz and 6400 Hz respectively. The audiograms of common and grey seals are very similar (Thompson, 1998), and their reaction to anthropogenic underwater sound is therefore expected to be similar as well. Sound levels of between 90 dB re 1µPa and 140 dB re 1µPa @ 1 m do not appear to induce strong behavioural responses in pinnipeds (Southall et al., 2007).

The thresholds used to indicate behavioural responses in marine mammals in this EIAR are those derived by Southall et al. (2007) and represent the levels at which extensive or prolonged changes in behaviour, including brief or minor separations of female from dependant offspring may occur. Table 6.8 presents the impact thresholds for behavioural responses.

Table 6.8: Summary of Acoustic Impact Threshold Criteria for Behavioural Effects for Each Functional Hearing Group When Exposed to Explosive Noise

Functional Hearing Group	Strong Responses dB re 1 μPa rms	No Responses dB re 1 μPa rms
Cetaceans LF	170 – 180	120 - 130
Cetaceans HF	170 – 180	130 - 140
Cetaceans VHF	140 – 150	90 - 100
Phocids MPCW	190 – 200	170 - 180

It is acknowledged that since the current underwater noise and iPCoD modelling have been completed, guidance on marine mammal noise exposure criteria has been updated (Southall et al., 2019). The updated criteria are comparable to those used in NMFS (2018) and have the same TTS and PTS limits and so would result in similar outcomes and assessment conclusions as presented here.

6.4.5 Results of the Underwater Noise Modelling

The results of the confined blast underwater noise modelling showing the impact ranges for PTS, TTS and behavioural responses for each of the different marine mammals hearing groups for an indicative range of explosive charge weight of between 20 kg and 100 kg, and based on both peak levels and sound exposure levels, are presented in Appendix B. Impact ranges for PTS, TTS and behavioural responses based on peak levels for an are summarised in Figure 6-10, Figure 6-11and Figure 6-12 respectively. These figures compare impact ranges in the presence and absence of the AHEP double bubble curtain assuming a worse-case double bubble curtain attenuation of 22 dB positioned 100 m from the blast source. This level of attenuation is considered to be very precautionary and is derived from the lower limit of mean noise measurements collected at the AHEP during blasting events between August and November 2018 (Award Environmental Ltd, 2018). However, the mean noise attenuation achieved by the AHEP double bubble curtain was measured to be 38 dB (with a higher limit of 54 dB). If this average level of attenuation is considered, then the ranges over which underwater noise impacts occur will be considerably less.

The results also do not consider that the southern breakwater is currently under construction and so will be in place, or will be partially in place once blasting resumes. The presence of this breakwater will provide further shielding of adverse noise levels propagating into open water areas and may result in impacts that are less than those indicated here.

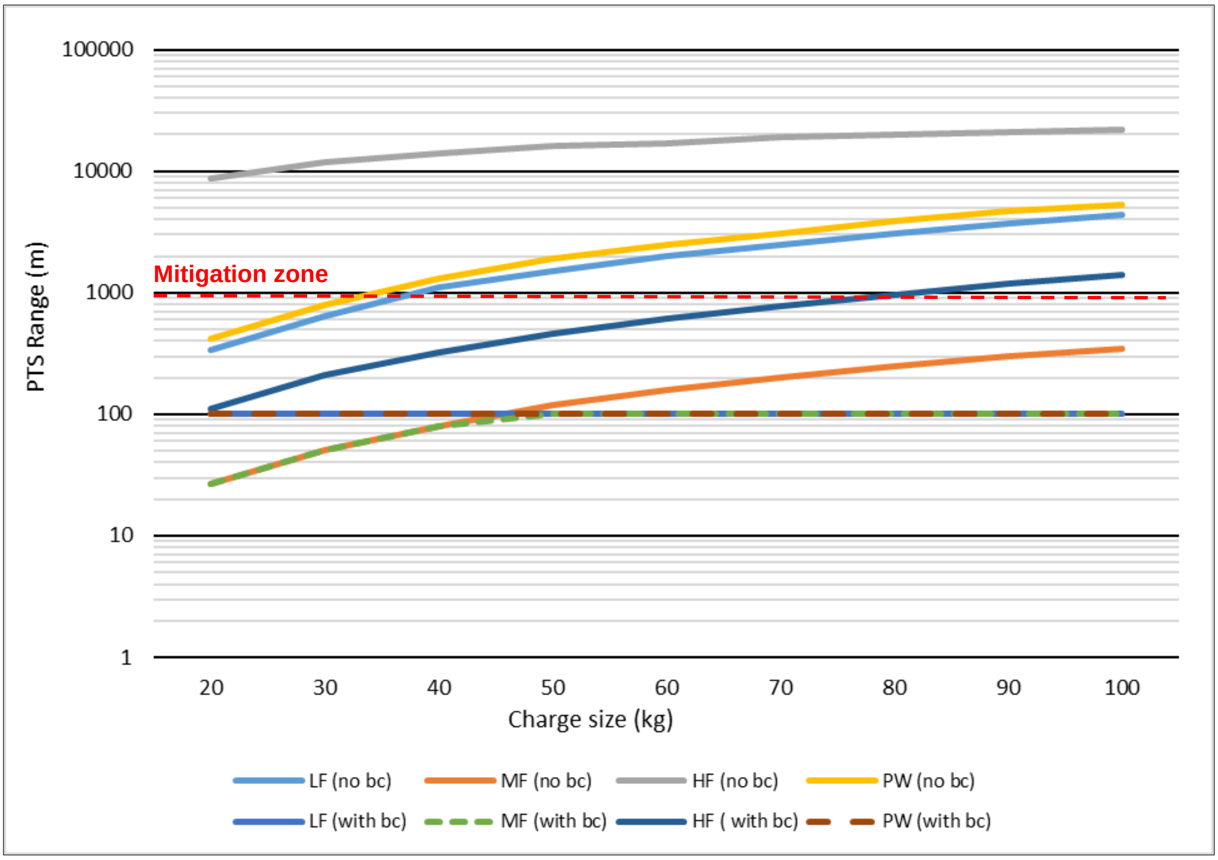

Figure 6-10: Predicted ranges for the onset of PTS for functional hearing group

Notes:

LF = low frequency cetaceans

MF = medium frequency cetaceans

HF = high frequency cetaceans

PW = pinnipeds in water

bc = double bubble curtain

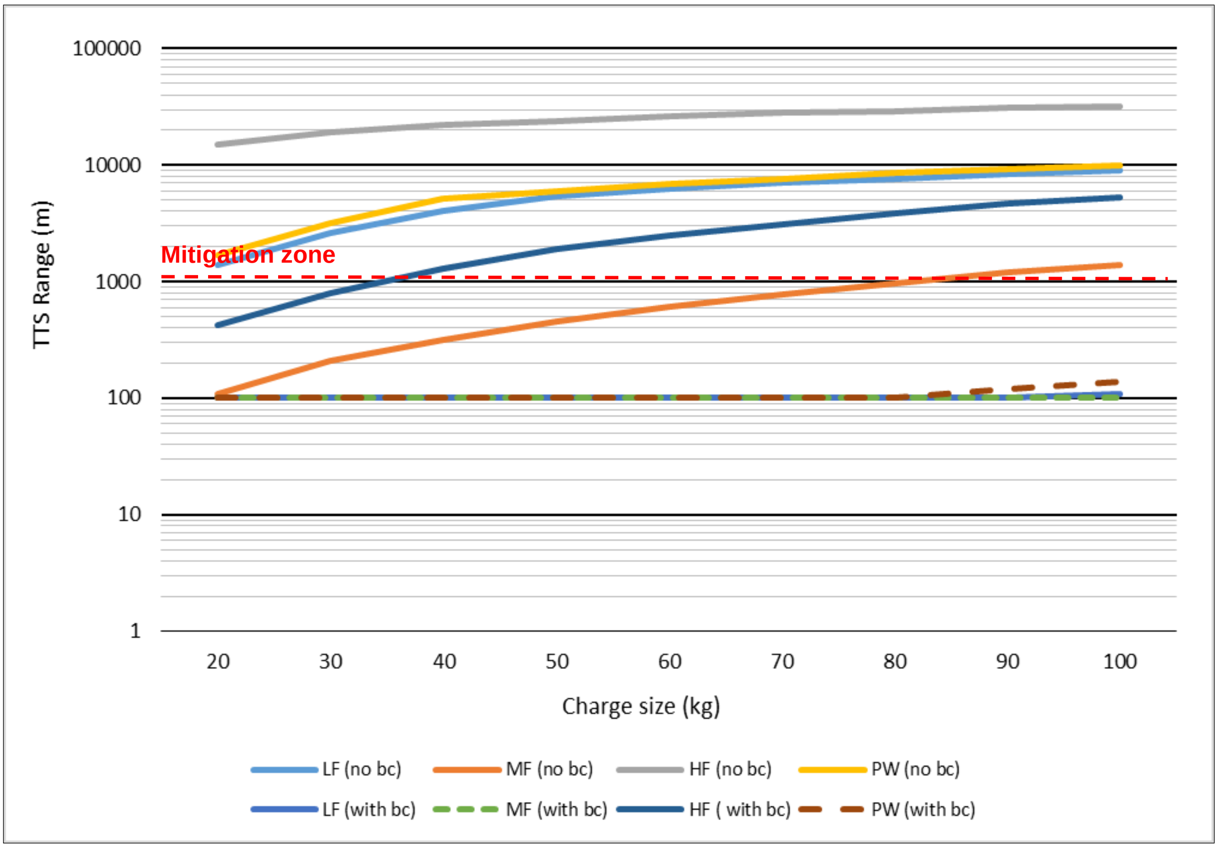

Figure 6-11: Predicted ranges for the onset of TTS for functional hearing group

Notes:

LF = low frequency cetaceans

MF = medium frequency cetaceans

HF = high frequency cetaceans

PW = pinnipeds in water

bc = double bubble curtain

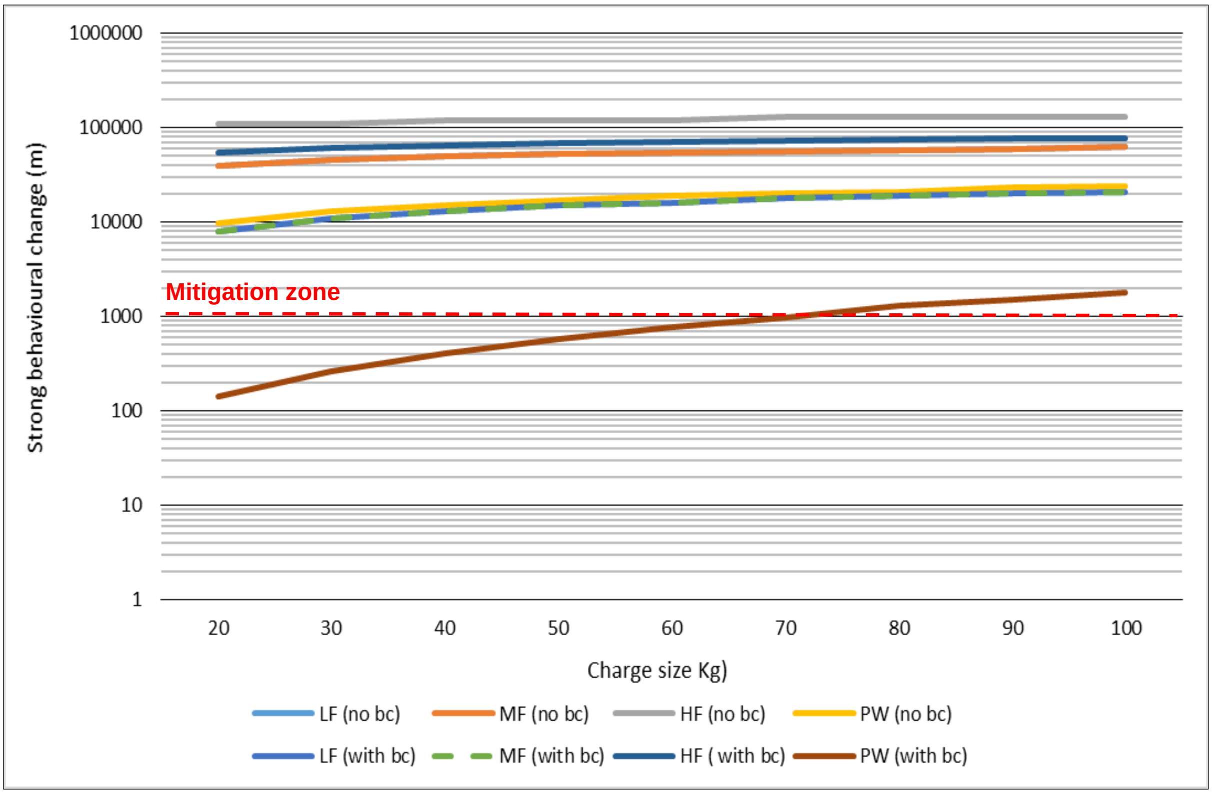

Figure 6-12: Predicted distance ranges for the onset of behavioural responses for functional hearing group

Notes:
LF = low frequency cetaceans
MF = medium frequency cetaceans
HF = high frequency cetaceans
PW = pinnipeds in water
bc = double bubble curtain

Table 6.9 and Table 6.10 present estimates of the numbers of individuals of minke whale, bottlenose dolphin, harbour porpoise and grey seal predicted to be at risk of PTS and TTS respectively due to detonations of indicative explosive charge weights of 20 kg, 50 kg and 100 kg with the double bubble curtain in place at a distance of 100 m and without the double bubble curtain.

The estimates of the numbers of animals potentially exposed to sound levels exceeding the PTS and TTS thresholds were calculated by multiplying the area in which these thresholds were breached by the relevant SCANS III density data of marine mammal distributions (Hammond et al, 2016). The affected areas were calculated as the area of sea within a circle centred on Aberdeen Harbour with radius equal to the predicted distance over which PTS and TTS will occur for each species and as predicted by the underwater noise impact modelling presented in Appendix B. The numbers of animals within each 'circle' or 'semi-circle' in each case were taken to represent the numbers of individuals potentially affected by each charge weight and is regarded as a very conservative estimate, as no account of the potential noise attenuation from the rocky headlands and the northern and southern breakwaters was made. If the headlands and the southern and northern breakwaters are considered, then the estimated underwater noise impact ranges, and numbers of individuals of marine mammals affected, may be even less than indicated in Table 6.9and Table 6.10.

As indicated in Table 6.9 and Table 6.10 (see also Appendix B), sufficient noise energy is predicted to be removed by the double bubble curtain positioned at 100 m that minke whale, bottlenose dolphin and grey seal are not forecast to experience PTS or TTS beyond (or much beyond) 100 m even if the largest charge weight (100 kg) is considered. Instead, noise levels indicative of causing PTS and TTS for these species is only anticipated to largely occur within and up to the position of the double bubble curtain for all charge weights considered, up to 100 kg. Without the double bubble curtain in place, marine mammals are expected to experience PTS and TTS over much greater distances.

Table 6.9: Estimated Numbers of Minke Whale, Bottlenose Dolphin, Harbour Porpoise and Grey Seal Within Predicted PTS Impact Zones

Species	Charge Weight [kg]	PTS Range [m]	Area [km^2]	Number of Individuals Present	% of Population
Minke whale (no bc)	20	340	0.363	0.0142	0.00010
Minke whale (no bc)	50	1500	3.900	0.1521	0.00103
Minke whale (no bc)	100	4400	37.130	1.4481	0.00981
Minke whale (with bc)	20	100	0.031	0.0012	0.00001
Minke whale (with bc)	50	100	0.031	0.0012	0.00001
Minke whale (with bc)	100	100	0.031	0.0012	0.00001
Bottlenose dolphin (no bc)	20	27	0.002	0.0001	0.00003
Bottlenose dolphin (no bc)	50	120	0.045	0.0014	0.00068
Bottlenose dolphin (no bc)	100	350	0.385	0.0115	0.00577
Bottlenose dolphin (with bc)	20	27	0.002	0.0001	0.00003
Bottlenose dolphin (with bc)	50	100	0.031	0.0009	0.00047
Bottlenose dolphin (with bc)	100	100	0.031	0.0009	0.00047
Harbour porpoise (no bc)	20	8800	147.970	88.6340	0.02566
Harbour porpoise (no bc)	50	16000	453.730	271.7843	0.07869
Harbour porpoise (no bc)	100	22000	838.490	502.2555	0.14542
Harbour porpoise (with bc)	20	110	0.038	0.0228	0.00001
Harbour porpoise (with bc)	50	460	0.490	0.2935	0.00008
Harbour porpoise (with bc)	100	1400	3.300	1.9767	0.00057
Grey seal (no bc)	20	420	0.460	0.9200	0.00066
Grey seal (no bc)	50	1900	6.690	13.3800	0.00957
Grey seal (no bc)	100	5300	53.520	107.0400	0.07657
Grey seal (with bc)	20	100	0.031	0.0628	0.00004
Grey seal (with bc)	50	100	0.031	0.0628	0.00004
Grey seal (with bc)	100	100	0.031	0.0628	0.00004

Notes:
Population estimates: Hammond et al, 2017; Quick et al, 2014; SMRU, 2016
Species abundance data: Hammond et al, 2017; Scottish Government, 2019
n/d = no data

Table 6.10: Estimated Numbers of Minke Whale, Bottlenose Dolphin, Harbour Porpoise and Grey Seal Within Predicted TTS Impact Zones

Species	Charge Weight [kg]	TTS Range [m]	Area [km^2]	Number of Individuals Present	% of Population
Minke whale (no bc)	20	1400	3.26	0.1271	0.00086
Minke whale (no bc)	50	5400	55.86	2.1785	0.01476

Species	Charge Weight [kg]	TTS Range [m]	Area [km^2]	Number of Individuals Present	% of Population
Minke whale (no bc)	100	9000	148.75	5.8013	0.03931
Minke whale (with bc)	20	100	0.03	0.0012	0.00001
Minke whale (with bc)	50	100	0.03	0.0012	0.00001
Minke whale (with bc)	100	110	0.04	0.0015	0.00001
Bottlenose dolphin (no bc)	20	110	0.04	0.0011	0.00057
Bottlenose dolphin (no bc)	50	460	0.49	0.0147	0.00735
Bottlenose dolphin (no bc)	100	1400	3.30	0.0990	0.04950
Bottlenose dolphin (with bc)	20	100	0.03	0.0009	0.00047
Bottlenose dolphin (with bc)	50	100	0.03	0.0009	0.00047
Bottlenose dolphin (with bc)	100	100	0.03	0.0009	0.00047
Harbour porpoise (no bc)	20	15000	399.61	239.3664	0.06931
Harbour porpoise (no bc)	50	24000	989.73	592.8483	0.17165
Harbour porpoise (no bc)	100	32000	1692.60	1013.8674	0.29356
Harbour porpoise (with bc)	20	420	0.46	0.2755	0.00008
Harbour porpoise (with bc)	50	1900	6.69	4.0073	0.00116
Harbour porpoise (with bc)	100	5300	53.50	32.0465	0.00928
Grey seal (no bc)	20	1700	5.24	10.4800	0.00750
Grey seal (no bc)	50	6000	68.31	136.6200	0.09773
Grey seal (no bc)	100	9900	179.50	359.0000	0.25680
Grey seal (with bc)	20	100	0.03	0.0628	0.00004
Grey seal (with bc)	50	100	0.03	0.0628	0.00004
Grey seal (with bc)	100	140	0.06	0.1232	0.00009

Notes:
Population estimates: Hammond et al, 2017; Quick et al, 2014; SMRU, 2016
Species abundance data: Hammond et al, 2017; Scottish Government, 2019
n/d = no data

In the absence of the double bubble curtain, the PTS and TTS threshold distances for bottlenose dolphins extend to 250 m and 970 m for an 80 kg charge (Figure 6-10 and Figure 6-11, Appendix B, which are within the 1 km mitigation zone (see section 6.3 for existing environmental controls at the AHEP). For minke whale and pinnipeds, the expected PTS threshold distance are predicted to extend beyond the current mitigation zone for charge weights of 40 kg or higher, whereas the TTS threshold distances will be experienced over considerable distances (kilometres) beyond this, even for the smallest charges considered here (20 kg), based on peak sound levels. The PTS zone for harbour porpoise would also extend well beyond the 1 km mitigation zone to a distance of 8.8 km from the AHEP for a 20 kg charge and up to 22 km for a 100 kg charge. The extent of the TTS zones for these charge weights for harbour porpoise would be more than 15 and 32 km respectively (Appendix B). Behavioural responses are forecast to occur over considerable distances (between many tens of kilometres and up to 150 km or 250 km) depending on the charge weight used. These scenarios are provided for comparison purposes only, since no blasting will take place without the double bubble curtain in place (without the agreement of MS-LOT).

With the AHEP double bubble curtain in place, and placed at 100 m from the blast source, Appendix B predicts that sufficient noise energy is removed from the blast that the PTS and TTS impact criteria for grey seals, bottlenose dolphins and minke whales will not be reached beyond the 1 km mitigation zone for all charge weights up to 100 kg. Therefore, with the double bubble curtain and 1 km mitigation zone in place, these marine mammal species are not at risk of experiencing TTS or PTS due to the proposed changes in the blasting methodology and are at no greater risk than originally assessed in the 2015 ES (AHB, 2015). For harbour porpoise, on the other hand, TTS threshold distances are predicted to extend beyond the 1 km mitigation zone for charge weights of 40 kg and above and PTS could be experienced beyond the 1 km mitigation zone due to the use of charge weights of 90 kg or more (Appendix B). Based on indicative 50 to 100 kg charge weights, this equates to between 4 and 32 individuals or 0.00116 to 0.00928% of the population of harbour porpoise that might experience TTS (Table 6.10) and between 0.49 and 3.3 individuals (or 0.00008 to 0.00057% of the population) that might experience PTS (Table 6.9). Note that these predictions are based on the assumption that the double bubble curtain only achieves the minimum noise attenuation (22dB) and that the southern breakwater is not in place. If the actual mean double bubble curtain noise attenuation (38 dB) is considered, then the predicted effect zones are considerably smaller and will remain well within the mitigation zone as shown in Table 6.11.

Table 6.11. Range over which PTS and TTS is predicted to be met for harbour porpoise when the double bubble curtain has an attenuation of 38 dB and is 100 m from the blast source based on the refined Confined Blast Model (Appendix B).

	Charge weight [kg]				
	20	40	60	80	100
Harbour porpoise PTS	100	100	100	100	120
Harbour porpoise TTS	100	100	210	340	480

Further to this, if it is considered that the southern breakwater will be in place, or will be partially in place, at the time of the resumption of blasting, then open water areas will be further shielded from adverse noise and impact ranges may be considerably less than those predicted here.

Beyond the distances where PTS and TTS effects may occur, the proposed blasting operations can be expected to evoke a certain level of behavioural responses from cetaceans and pinnipeds. Behavioural changes may occur over large distances (kilometres) from blast sources even with the double bubble curtain in place (Appendix B), the short-term significance of which will be context dependent (Southall et al., 2007). Modelling of the consequences of long-term disturbances to marine mammals at their population scale has been undertaken using the iPCoD modelling framework (OSC, 2019e) the results (and model assumptions) of which are presented in Appendix E. The iPCoD outputs indicate that there will be no significant long-term (25 years) effects on any of the marine mammal populations investigated here regardless of charge weight used up to 100 kg, so long as the double bubble curtain is in place. Thus, despite predictions of some individuals of harbour porpoise suffering TTS and PTS for some of the larger charge weights, the numbers involved are insignificant in terms of the long-term population level effects. Even in the absence of the double bubble curtain, significant long term effects on the sizes of populations of harbour porpoise, bottlenose dolphin and grey seal are not forecast by the iPCoD model despite the charge weight used up to 100 kg although effects on the minke whale population sizes become insignificant at charge weights of 50 kg and less.

It is worth noting again at this point that as a further level of protection for marine mammals (and other marine life), contractors at the AHEP are committed to ensuring that levels of noise beyond the AHEP will not exceed the current agreed threshold of 170 dB re1 µPa rms (equivalent to 183 dB re 1µPa peak) beyond 400 m from the blast location or outside the double bubble curtain, whichever is the greater distance and that a PCL will be used to limit charge weight increases. Incrementally increasing the charge weight supported by monitoring and use of the PCL is being applied for and is described in Section 2.6.2 and CEMD Chapter 11 and will ensure protection for marine mammals whilst optimising the explosive charge weight used.

There will be no increase in dredging effort due to the current blasting proposals. Locations and quantities of seabed substrate to be removed remain as previously assessed in the initial 2015 ES. Consequently, impacts associated with dredger operations and the quantities of dredged material disposed at the offshore disposal site will be the same as planned and as already assessed (AHB, 2015).

6.5 Impact Conclusion (the scheme alone)

Blasting at the AHEP is an intermittent, infrequent and near-instantaneous impact often punctuated by large time gaps (days) while dredging, subsequent laying of charges and other construction activities take place. With mitigation in place, impacts (PTS and TTS) will also be highly localised in respect of pinnipeds and mid and low frequency cetaceans even when large charge weights are used (up to 100 kg). Mitigation measures are already in place to ensure that marine mammals are not within TTS and PTS impact ranges up to a distance of 1,000 m so no individuals of these types of species are predicted to be affected suggesting an effect that will be of **negligible significance** for minke whale, grey seal and bottlenose dolphin.

Individuals of harbour porpoise, on the other hand, are forecast to be at risk of TTS due to the use of charge weights of 40 kg or above and at risk of PTS due to the use of charges of 90 kg but only if a minimum double bubble curtain attenuation of 22 dB is assumed. In this scenario, this would constitute an effect which could be of up to **major significance** due to the conservation importance of this species although there would be no significant long-term population level consequences as indicated by the iPCoD modelling (Appendix E). If, however, the average attenuation of the double bubble curtain (38 dB) is considered, then PTS and TTS impacts on harbour porpoise would not occur in the presence of mitigation for any charge weight assessed here up to 100 kg. The assessment also assumes that the southern breakwater is not in place. However, this structure is already under construction so will be in place, or partially in place once blasting resumes. This may further shield open water areas from the effects of blasting to some degree providing yet further protection for harbour porpoise, and other marine species. Threshold limits for underwater noise are already in place for marine species protection and use of the PCL adds further precaution when increasing the charge weight.

Impact ranges and long-term population consequences for bottlenose dolphin, minke whale and grey seal have been modelled based on data derived from the modified Confined Blast Model and using a worst-case double bubble curtain attenuation. As such it is with **high certainty** that impacts of negligible significance, where identified, are **likely** to occur**.** Harbour porpoise are forecast to experience TTS and PTS beyond the mitigation zone but only if the double bubble curtain is assumed to achieve the minimum attenuation. However, even assuming this worse-case scenario, no significant long-term population level consequences are forecast (Appendix E). If the average performance of the double bubble curtain is considered, then TTS and PTS effects on harbour porpoise are **unlikely**. The southern breakwater will provide additional shielding from adverse blasting noise. Current C-POD data suggests harbour porpoise remain in close proximity to the AHEP despite on-going construction disturbances, including blasting suggesting rapid recovery. It is therefore with only **low** to **medium certainty** that impacts on harbour porpoise will be of major significance.

6.6 Impact Conclusion (cumulative impacts)

There are no projects close to the current AHEP that are likely to exacerbate the effects of underwater noise from blasting although several significant construction schemes are located at distance from Nigg Bay, to the north and south, and which may be within the range movements of marine mammals using the area around the AHEP (see Table 4.4 and Figure 4-8). Individuals may experience cumulative impacts if, during their range movement, they were to encounter a significantly adverse noise source from one of these other schemes whilst recovering from an earlier impact from the AHEP. This however is considered highly unlikely, as the AHEP alone will not result in any significant adverse effects on bottlenose dolphin, minke whale or grey seal, as established above. Consequently, significant cumulative effects cannot occur with respect to these species so long as the mitigation is in place.

Some individuals of harbour porpoise are predicted to be exposed to TTS and/or PTS effects for charge weights of 40 kg and 90 kg and above respectively although the numbers involved have been found to be insignificant over the longer term and at the population level as shown in the iPCoD modelling (Appendix E). With reference to Table 4.4, construction for the Neart na Gaoithe wind farm and Moray East wind farm could coincide with the AHEP construction programme (Table 2.1). However, cumulative PTS and TTS effects on harbour porpoise from these projects is considered **highly unlikely** due to the distance separations involved, the likely recovery time of harbour porpoise from TTS effects (minutes to hours) (Kastelein et al., 2017; 2015; 2012) and the implementation of specific marine mammal mitigation measures at both wind farm sites as described in their respective environmental reports.

To investigate the potential for long-term cumulative impacts to occur on the sizes of marine mammals population, the iPCoD study (OSC, 2019e) (Appendix E) was extended to consider the collective effects of several significant recent and foreseeable marine developments in the region with those arising from the worst-case AHEP scenario. Table 6.12 presents the numbers of individuals of species estimated to be exposed to PTS, TTS and behavioural disturbances due to these other developments as derived from respective environmental reports (OSC, 2019e) (Appendix E).

Table 6.12: Construction schedules of selected projects within the region of the AHEP and estimated numbers of animals expected to be exposed to permanent threshold shift (PTS), temporary threshold shift (TTS) and behavioural disturbance (BD) as a result of construction impacts for each project (taken from OSC, 2019e).

Project/Proposed Development	Species	Impact Criteria	Approximate Construction Year						
			2017	2018	2019	2020	2021	2022	2023
AHEP (100 kg charge weight and double bubble curtain present)	Harbour porpoise	PTS BD/TTS				2 32			
	Bottlenose dolphin	PTS BD/TTS				<0.1 <0.1			
	Minke whale	PTS BD/TTS				<0.1 <0.1			
	Grey seal	PTS BD/TTS				<0.1 0.1			

Project/Proposed Development	Species	Impact Criteria	Approximate Construction Year						
			2017	2018	2019	2020	2021	2022	2023
Seagreen Alpha and Bravo offshore wind farm (concurrent)	Harbour porpoise	PTS BD/TTS						0 1,177	
	Bottlenose dolphin	PTS BD/TTS						0 4	
	Minke whale	PTS BD/TTS						0 76	
	Grey seal	PTS BD/TTS						0 24	
Beatrice Offshore Wind	Harbour porpoise	PTS BD/TTS	9 3,191						
	Bottlenose dolphin	PTS BD/TTS	0 19						
	Minke whale	PTS BD/TTS	36 177						
	Grey seal	PTS BD/TTS	78 347.5						
Inch Cape Round 3 wind farm	Harbour porpoise	PTS BD/TTS					0 302		
	Bottlenose dolphin	PTS BD/TTS					0 8		
	Minke whale	PTS BD/TTS					7 158		
	Grey seal	PTS BD/TTS					0 1,236		
Neart na Gaoithe Round 3 wind farm	Harbour porpoise	PTS BD/TTS				77 1,177			
	Bottlenose dolphin	PTS BD/TTS				0 2			
	Minke whale	PTS BD/TTS				14 77			
	Grey seal	PTS BD/TTS				1 821			
Moray East offshore wind farm	Harbour porpoise	PTS BD/TTS				0 3,442			
	Bottlenose dolphin	PTS BD/TTS				0 19			
	Minke whale	PTS BD/TTS				0 185			
	Grey seal	PTS BD/TTS				0 1,184			
Port of Cromarty Phase 4	Harbour porpoise	PTS BD/TTS			0.9 14.2				
	Bottlenose dolphin	PTS BD/TTS			0 0				
	Minke whale	PTS BD/TTS			0.066				
	Grey seal	PTS BD/TTS			0.05 3.02				
Moray West offshore wind farm	Harbour porpoise	PTS BD/TTS						0 1,609	

Project/Proposed Development	Species	Impact Criteria	Approximate Construction Year						
			2017	2018	2019	2020	2021	2022	2023
	Bottlenose dolphin	PTS BD/TTS						0 15	
	Minke whale	PTS BD/TTS						0 30	
	Grey seal	PTS BD/TTS						0 207	

Notes
Shading denotes approximate construction period
PTS = permanent threshold shift
TTS – temporary threshold shift
BD = behavioural disturbance

With the AHEP excluded, the cumulative iPCoD model forecasted that there would be strongly significant decreases ($p<0.0001$) in the sizes of populations of bottlenose dolphin and minke whale and significant decreases ($p<0.05$) in the grey seal population over 25 years in the event that all other schemes proceed. The harbour porpoise population was also predicted to decline over this period but not significantly ($p>0.05$).

With the effect of the AHEP included in the analysis, similar declining trends in population sizes were predicted but these were found not to be significantly different to those computed for the cumulative models where the AHEP was excluded for any species. This suggests that the AHEP does not significantly contribute to cumulative effects on bottlenose dolphin, minke whale, harbour porpoise or grey seal and will not significant affect the long-term population size of any of these species.

With the double bubble curtain in place, the long-term population sizes for any species are not significantly affected even using a charge weight of 100 kg. Furthermore, the AHEP does not contribute significantly to cumulative effects with other developments. Consequently, the cumulative impacts of the AHEP are considered to be no worse than the AHEP project in isolation.

Cumulative effects have been quantified using the iPCoD model framework and the attenuation properties of the double bubble curtain have already been measured (section 4.3.1). It is thus with **high certainty** that significant cumulative impacts are **unlikely** to occur.

6.7 Recommended Mitigation and Residual Effects

Other than the use of a PCL, no additional mitigation measures, over and above those already provided, are proposed in respect of marine mammals. Depending on the charge weight used, harbour porpoise have the potential to experience TTS and PTS beyond the mitigation zone if large charge weights are used and only if the double bubble curtain is only achieving minimum attenuation performance, otherwise sufficient noise is removed by an average performing double bubble curtain such that TTS and PTS will not occur outside the mitigation zone.

7. MARINE BIRDS

7.1 Introduction

This section reviews the marine birds found within and around the AHEP with a focus on the species and marine bird issues identified from scoping (see Table 7.1) and which are important to the consideration of the potential additional impacts and effects of the proposed changes to the blasting methodology. It draws upon and updates the information previously provided in chapter 14 of the 2015 AHEP ES and its supporting technical appendices (Technical Appendix 14-A and 14-B). Recent results of the ongoing post-consent monitoring of local eider duck (*Somateria mollissima*) are summarised.

Table 7.1: Summary of Scoping Responses Concerning Marine Birds

Consultee	Scoping Response	Where Addressed in this EIAR
Scottish Natural Heritage	Kincardine offshore windfarm should be considered for in-combination impacts for birds	Chapter 10: Habitats Regulation Appraisal considers the Kincardine project in relation to in-combination impacts.
	Increases in airborne noise should be assessed in respect of displacement effects	Section 4.4.3 addresses uncertainties concerning the effects associated with increases in airborne noise. Section 7.5.2 provides an assessment of potential impacts.
	Increased turbidity or sediment plumes should be assessed for changes to bird prey availability	Addressed in section 7.5.3.
	A review of current eider monitoring is required to inform the EIAR.	Section 7.2.1 presents a review of the eider monitoring to date.
	Cumulative assessment should focus on eiders and Sandwich terns.	Addressed in section 7.6.
	An assessment of impacts of sea water disturbances (breaks) due to increasing explosive charge sizes on birds is required (from meeting minutes 17/12/18).	Addressed in section 7.5.4.
Marine Scotland Science	The EIAR scope appears appropriate.	Acknowledged.

7.2 Summary Characterisation

Previous site specific surveys (Technical Appendix 14-A and 14-B) identified 35 species of pelagic and coastal birds using the site and wider area.

Pelagic species comprise those that mostly use the waters offshore of the AHEP although some, such as common guillemot (*Uria aalge*), razorbill (*Alca torda*) northern fulmar (*Fulmarus glacialis*) and kittiwake (*Rissa tridactyla*), are known to use local cliffs to the south of the site for breeding and to occasionally feed in the outer waters of Nigg Bay where there is suitable prey (sand eel) habitat.

Coastal birds include passage or migrant species such as dunlin (*Calidris alpina*), common sandpiper (*Actitus hypoleucos*), curlew (*Numenius arquata*) and sanderling (*Calidris alba*). These species were infrequent or temporary users of the site during the site surveys and were generally present in low numbers. Red-throated divers (*Gravia stellata*) were observed all year round prior to construction of the AHEP but only in small numbers passing the headlands. In spring small groups use the bay for roosting and foraging by diving in pursuit of small fish within and close to the bay.

Eider duck (*Somateria mollissima***)** were recorded using the bay in large numbers for shelter within the lee of the rocky headlands and to congregate at nearby locations at Greyhope Bay and Girdle Ness during their summer moult. Eider also use adjacent areas in Aberdeen Bay. At the moment, and while AHEP construction activities are on-going, eider are largely absent from Nigg Bay, as predicted in the initial ES (AHB, 2015), but remain in large numbers at nearby locations at Greyhope Bay and Girdle Ness.

Sandwich tern (*Thalasseus sandvicensis*) and common tern (*Sterna hirundo*) use the rocky shore at Greyhope Bay for roosting and the outer areas of Nigg Bay for feeding where there is sand eel habitat. Little tern (*Sternula albifrons*) breed at the nearby Ythan Estuary, Sands of Forvie and Meikle Loch proposed Special Protection Area (SPA) extension but have not been recorded within or around the AHEP during site surveys. All three species of terns are likely to use offshore area of Nigg Bay for foraging. Breeding season foraging distances for these species of terns and for eider are presented in Table 7.2 below.

Table 7.2: Breeding Season Foraging Ranges

Species	Average Foraging Range [km]	Maximum Foraging Range [km]
Common tern	4.5	30
Little tern	2.1	11
Sandwich tern	11.5	564
Eider duck	2.4	80
Notes: Source: Thaxter et al., 2012		

Modelled foraging ranges for Sandwich tern and Little tern colonies of the Ythan Estuary, Sands of Forvie and Loch Meikle SPA proposed extension (SNH, 2016) suggest that the Sandwich terns from this colony make only moderate or low use of the AHEP while Little Tern do not use the local area at all.

Other coastal birds recorded within Nigg Bay and local areas include a range wildfowl and waders which are seasonal (winter) visitors, making temporary or limited use of the bay, and gulls, some species of which can form large roosts locally.

Limited information is available regarding current bird use of the AHEP during construction. The exception to this is eider duck which is monitored as part of the programme of agreed post-consent monitoring discussed in section 7.2.1.

7.2.1 Eider Duck Monitoring

As described in the 2015 ES (AHB, 2015), flocks of eider regularly occurred in nearshore waters within and around Nigg Bay, and other areas coastal waters towards the Ythan Estuary where they undergo a seasonal moult in summer after breeding. Up to 903 eider were recorded in pre-construction surveys. Once the moult cycle is complete many eider move further south to winter in the Tay Estuary.

Eider duck abundance within and around Nigg Bay has been monitored since commencement of the AHEP construction (Dragados, 2019). This has included vantage point surveys, walk-over surveys and ad-hoc walk-overs commencing in June 2017 and on-going. Appendix F presents the full eider monitoring data set available for this monitoring period (June 2017 – April 2019) including counts of eider within the Bay and at nearby seasonal moulting habitat at Greyhope Bay and Girdle Ness. Figure 7-1 summarises the ad-hoc counts of eider duck recorded over this monitoring period and highlights the moment of first blasting on 20 August 2018.

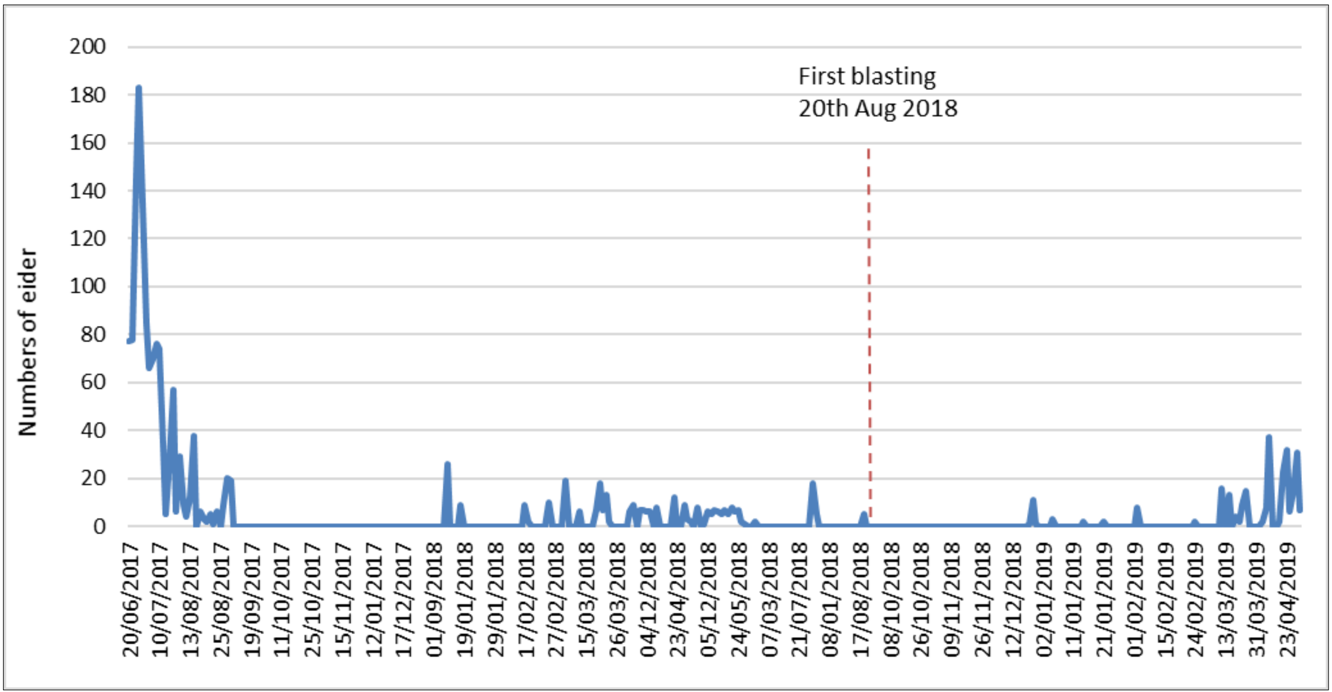

Figure 7-1: Numbers of eider in Nigg Bay during AHEP construction (June 2017 to April 2019)

Boats were introduced into the bay to create a level of disturbance for birds prior the onset of blasting which was originally expected in late summer 2017. This activity may account for the low numbers of eider from this time. Eider appear to have remained absent or present in low numbers in the bay since this initial disturbance and throughout the construction period with small rises in numbers over late winter and early spring periods in 2018 and 2019.

Despite their apparent displacement from within the AHEP boundaries, the post-consent monitoring data shows that eider duck remain local to key sites in Greyhope Bay and Girdle Ness, for feeding, roosting and moulting in summer. To demonstrate this point, Figure 7-2 summarises the numbers of eider recorded during peak periods of eider duck abundance during moulting in June, July and August in Nigg Bay (AHEP) and at Greyhope Bay and Girdle Ness in 2017 and 2018.

Additional monthly monitoring in October, November and December 2018 (Dragados 2018b, c and d) show that eider continue to use the area at Girdle Ness albeit in generally lower numbers as many eider naturally disperse further south to overwinter in the Tay Estuary following moulting. Eiders however remain largely absent from the AHEP boundaries with only a low number of birds recorded using the southern area of Nigg Bay in December 2018.

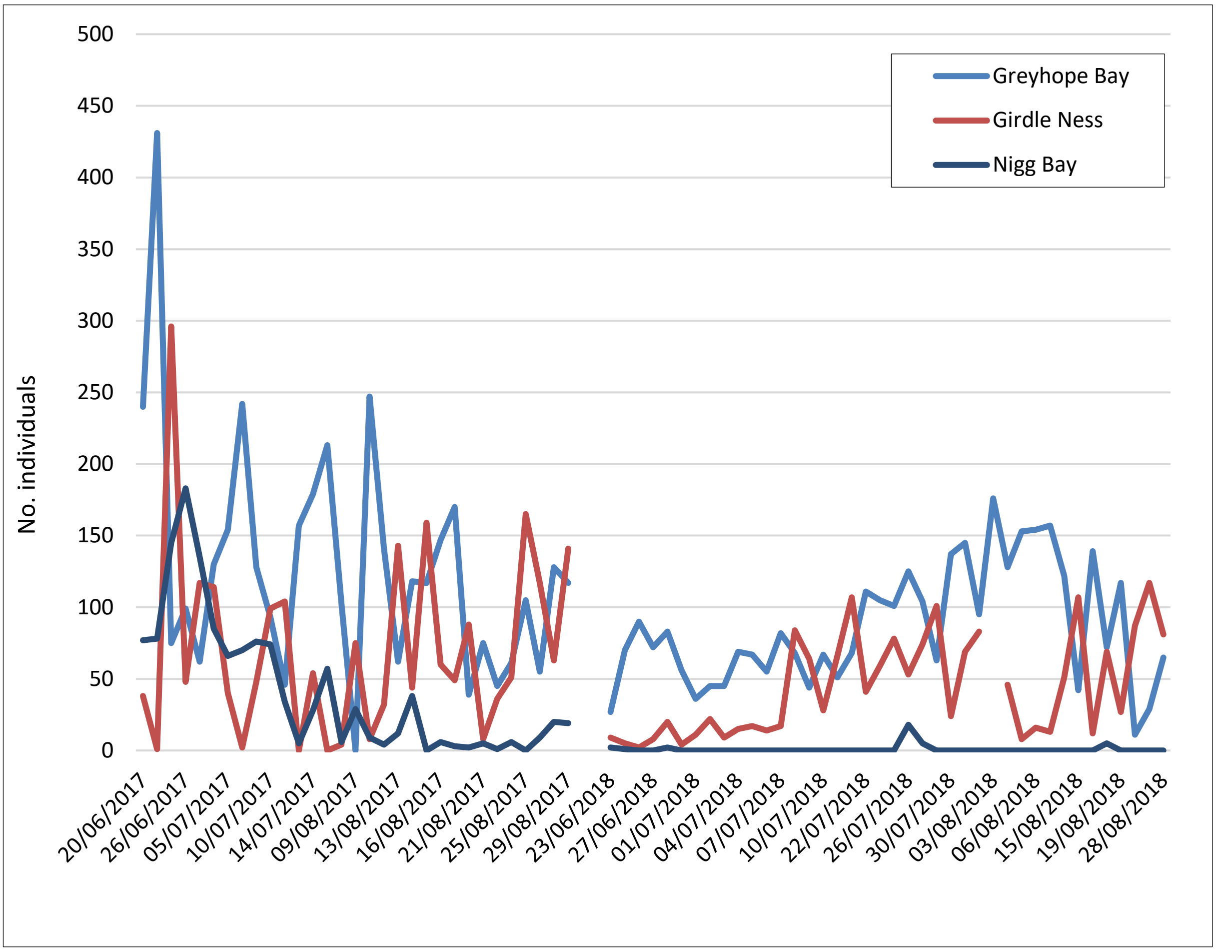

Figure 7-2: Summary of the abundance of eider duck at Greyhope Bay, Girdle Ness and Nigg Bay in June, July and August 2017 and 2018

Notes:

Data for Nigg Bay is the sum of all four Nigg Bay count units

7.3 Conservation Importance

Non-breeding eider and Common, Sandwich and Little terns, amongst other species, are qualifying features of, and connected to, several Special Protection Areas (SPAs) in the region and are thus considered high value receptors. Chapter 10 presents a Habitats Regulations Assessment and considers the likely impacts of the proposed changes to the blasting methodology in respect of eider duck and terns and the likely significant effects to the integrity of local SPAs for which they are a qualifying feature.

7.4 Existing AHEP Management Measures

Eider duck are subject to mitigation and monitoring during construction in compliance with condition 3.2.4 of the Construction Marine Licence and HRO and implemented through the agreed project CEMD as follows:

- Construction vessel exclusion zones have been established around Greyhope Bay in the interests of eider conservation;
- Monitoring of the use of the new harbour and surroundings by eider during construction and once it is operational;

- Temporal restrictions on the commencement of construction of the breakwaters;
- Avoidance of rafting birds by construction vessels.

Further to the agreed CEMD, an addendum document '*Environmental Mitigation – South Breakwater and Shore Blasting*' (AHEP-DRA-EMP-0003) was approved by MS-LOT (and has subsequently been incorporated into the revised CEMD), which commits the contractors to conduct pre-blast surveys of the proposed blast site to check that the area is clear of rafting birds. To date, no dead or injured birds have been reported during post-blast observations.

A double bubble curtain is used to prevent adverse levels of underwater noise propagating beyond the AHEP and into adjacent sea areas. There is also a requirement that RMS blast levels should not exceed the noise benchmark condition of 170 dB re 1 µPa rms (equivalent to 183 dB re 1µPa peak) at 400 m from the blast location or outside the double bubble curtain, whichever is the greater distance, which will minimise effects on submerged diving birds.

7.5 Assessment of Effects

With reference to Table 7.1, the impacts and effects assessed in this section include:

- Increased injury and mortality;
- Increased displacement of birds due to increases in airborne noise;
- Changes in prey availability;
- Increased area of sea surface disturbance and plumes above detonation sites and effects on marine birds.

7.5.1 Increased Injury and Mortality

Studies on the effects of underwater explosions on marine birds are limited in comparison to those concerning fishes and marine mammals; however, it is understood that ranges from explosions considered safe, injurious or lethal to both diving birds and birds on the water surface are a function of distance and charge weight (Yelverton and Richmond, 1981).

Underwater explosions can cause injury and death in sea birds, including pulmonary haemorrhage, ruptured livers, air sacs, ear drums and kidneys and coronary air embolism, if present at close range (i.e. a few tens of metres) (Yelverton et al., 1973).

Submerged birds are more susceptible to harm from explosions than birds on the water surface. Ducks placed at 2 m depths, to simulate diving birds, were injured within 25 m from an in-water detonation of a 0.46 kg charge. However, ducks on the surface were comparatively less affected, even after exposure to blasts of 3.6 kg of explosives. It was postulated that this was because critical organs, such as lungs, remain above, or partially above, the water line (Yelverton et al., 1973) and are thus less vulnerable to damage from water-borne impulses from the blasts.

Impulse criteria of underwater blasts indicating safe levels for submerged/diving birds have been determined by Yelverton et al. (1973) and Richmond and Jones (1974) and as reported in the literature review conducted by Lewis (1996). Using the modified underwater noise model (Appendix B) and with reference to the criteria indicating safe levels described above, safe ranges for submerged/diving birds for various explosive charge weights can be estimated as shown in Table 7.3.

Table 7.3: Estimated Impact Ranges for Submerged/Diving Seabirds When Exposed to blast Noise Using Impulse Metrics

Impact	Threshold	Charge Weight [kg]								
		20	30	40	50	60	70	80	90	100
50 % mortality	896 Pa.s	3 m	5 m	6 m	7 m	8 m	8 m	9 m	10 m	11 m
Mortality threshold	690 Pa.s	4 m	6 m	7 m	8 m	9 m	10 m	11 m	12 m	13 m
Slight blast injuries	276 Pa.s	7 m	10 m	12 m	14 m	16 m	18 m	19 m	20 m	22 m
Safe level	207 Pa.s	9 m	12 m	15 m	17 m	19 m	22 m	22 m	24 m	25 m

The underwater noise modelling shows that impacts on diving/submerged birds are likely to occur over relatively short distances from the blast site for explosive charges up to 100 kg. The 50 % mortality impact is met within maximum distances of 3 m to 9 m from the blast site over the range of charge weights modelled. By contrast, the safe level of impact extends to a maximum distance of 25 m for the largest charge weight investigated (100 kg). Note that beyond this distance the seabirds are predicted to be unharmed but may nevertheless be startled at the moment of detonation, if not already disturbed away from the immediate area of a blast site by pre-lay vessel activities and ongoing construction. Given the limited noise energy transmitted through the air - sea interface (section 4.4.3) then the range over which birds may be startled may be limited (see section 7.5.2).

In conclusion, the impacts of the proposed changes to the blasting methodology are expected to remain highly localised to the AHEP, intermittent and temporary and, given that eider are already largely displaced from Nigg Bay, are not expected to affect aggregations or populations of birds over and above the current effects of the AHEP. Birds will need to be extremely close to a blast (within 25 m) to be at risk of injury and mortality from up to an 100 kg weight explosive charge, although submerged diving birds may be more susceptible to effects than those on the surface. Pelagic species, such as guillemot, razorbill and terns, forage offshore and within areas of sand eel habitat beyond the AHEP boundaries. Pelagic birds are therefore not expected to occur within the immediate vicinity of blast sites and will remain well beyond predicted mortality and injury zones for the charge weights considered. With mitigation in place, including checks for rafting birds prior to detonations, the overall significance of the impact is judged to be **minor**.

Impacts have been modelled and so it is with **high certainty** that increased mortality and injury due to the proposed changes to the blasting methodology are **unlikely** to occur due to the (i) very small area of effect, (ii) the spatial and temporal separation between blasting events and marine bird distributions during construction and (iii) the mitigation measures already in place.

7.5.2 Increase in Displacement of Birds Due to Increases in Airborne Noise

Only very small amounts of acoustic energy are typically transmitted across the air-sea interface (around 0.01%) (see section 4.4.3) so any increases in air-borne noise due to the use of larger charges is expected to be imperceptible and associated effects on local birds is likely to be insignificant. With regards to eiders, local populations have already been displaced a full year before blasting commenced due to the agreed use of vessels to create an initial level of disturbance (see section 7.2.1). Seasonal moulting aggregations nearby are shielded from noise increases at the AHEP by the rocky promontory at Girdle Ness and remain in use by eider during construction. The majority of the remaining blasting is scheduled for southern areas of Nigg Bay and so will be further away from summer moulting habitats in Greyhope Bay and Girdle Ness. Increases in noise levels (if any) will therefore be offset by the greater distance separation. Significant increases in spatial displacement of birds due to increase in air-borne noise are therefore not expected as a result of the current proposals.

In conclusion, increases in air-borne noise due to the use of larger charge weights is expected to be imperceptible given the very limited transmission of noise energy from the seabed to the air and the increased spatial distance between blasting in the south of the bay and moulting habitat around Girdle Ness. Birds are already displaced from the AHEP, as originally assessed, and the significance of any increased spatial displacement is thus considered to be **negligible**. No blasting will take place during winter 2019 (see Table 2.1) so any individuals of eider duck using the bay at this time will not be disturbed by this activity.

7.5.3 Changes in Prey Availability

Sand eel habitat, and other prey resources in the outer Nigg Bay and beyond the AHEP are shielded from adverse noise impacts from blasting by the North Breakwater and the deployment of the double bubble curtain. Increases in sediment vibration which may pass under the double bubble curtain diminish quickly with distance from a blast site (section 4.4.2) and are not forecast to significantly affect the wider sand eel habitat. There are no increases in dredging activity or changes to the areas to be dredged and so sediment plumes arising from the capital dredge and offshore disposal, and associated impacts, remain as predicted in the 2015 ES (AHB, 2015). Significant adverse effects on sand eels, and other bird prey species, are thus not expected and so bird prey availability will not change. It is thus with **high certainty** that effects will be of **negligible significance** and **unlikely** to occur.

7.5.4 Increased Area of Sea Surface Disturbance

Section 4.4.4 explained that any additional sea surface disturbance due to the proposed changes in blasting methodology at the AHEP is difficult to quantify but is likely to relate to the depth and weight of the explosive charge used, the geometry of the seabed holes into which the charges are placed and the sea conditions at the time of detonation amongst other possible factors. Current experience at the AHEP using 20 kg weight charges suggests that the diameters of disturbed domes of water measure in the order of tens of metres.

Seabirds are expected to be temporarily displaced from the immediate vicinity of blast sites due to associated vessel movements and charge laying activities and so are unlikely to be caught in blasts or within domes of disturbed water. Checks for rafting birds are made prior to each blast reducing this risk still further.

The proposals do not involve any increase in the number of blasts over the construction period and the frequency of blasting remains as planned. Considering the above, the effect range is expected to be local (limited to a few tens of metres) (section 4.4.4), intermittent (up to two blasts per day) and temporary to individuals of wider populations suggesting an effect of **minor** significance and which is **unlikely** to occur. This conclusion has **low** to **medium certainty** as the effect ranges of sea surface disturbance due to the use of larger explosives (>20 kg) are not known but are expected to be limited to a few tens of metres.

7.6 Cumulative Impacts

There are no projects close to the current AHEP that will give rise to significant adverse noise effects or which may overlap with noise from the proposed blasting. The nearest projects with potential concurrent 'noisy' activities are those at Montrose Harbour located 55 km to the south and Moray East offshore wind farm located 130 km the north respectively. The Peterhead Harbour Masterplan and North Connect inter-connector cable may contribute localised and short-term noise.

With limited average foraging ranges, it is unlikely that Common tern, Sandwich tern and Little tern will have simultaneous encounters with these distant projects. Also, during their summer moult, eider duck are flightless and have limited mobility and so are similarly, not expected to have simultaneous encounters with these schemes. Seabird species with a wide foraging range like gannet and fulmar might be at greater risk of encountering concurrent 'noisy' projects but as they are foraging over such wide areas, the potential loss of feeding represented by this will be negligible.

Although located within potential foraging ranges, eider duck, Common tern and Sandwich tern were not recorded during site specific surveys at Kincardine offshore wind farm and, together with Little tern, were not considered in the cumulative assessment of effects of this development (Atkins, 2016). This suggests that these species do not occur at the Kincardine site or only make very low use of the area. Significant cumulative effects with the Kincardine offshore wind farm are thus not expected with respect to these species of terns and eider duck.

7.7 Recommended Mitigation and Residual Effects

No additional mitigation or monitoring is considered necessary as there are already comprehensive monitoring and mitigation measures in place to protect marine birds and to monitor protected eider duck to inform management decisions if necessary.

Submerged birds may be more vulnerable to explosions than those on the surface. Pre-blast checks for rafting birds could be extended to check that any diving birds have re-surfaced prior to blasting.

8. NIGG BAY SITE OF SPECIAL SCIENTIFIC INTEREST (SSSI)

8.1 Introduction

This chapter presents a description of the Nigg Bay Site of Special Scientific Interest (SSSI) and assesses the potential impacts of the proposed changes to the blasting methodology. Issues relating to the assessment of effects on the SSSI identified from the scoping study are presented in Table 8.1.

Table 8.1: Scoping Responses Concerning the Nigg Bay SSSI

Consultee	Scoping Response	Where Addressed in this EIAR
Scottish Natural Heritage	Vibration from blasting could destabilise the unconsolidated sediments of the cliff.	Section 8.3 summarises the existing vibration monitoring and section 8.4 provides an assessment of potential risks.

8.2 Summary Characterisation

The Nigg Bay SSSI (Figure 8-1) is a section of cliff exposure notified in 1984 for its geological importance. It is considered to be a classic locality for Quaternary stratigraphy in north-east Scotland where several characteristic glacial deposits of the area can be seen. Covering 4.72 ha, it is recognised as a key reference site for interpreting the glacial history and ice movement patterns in north-east Scotland and demonstrates the complexity of deposits which may be produced during a single glacial episode. The site is subject to the following management objectives:

- Maintain the visibility of the exposures;
- Maintain access to the exposures.

It is considered that the slope face is undergoing a progressive failure as a result of natural weathering processes and will continue to do so until it achieves a natural angle of stability.

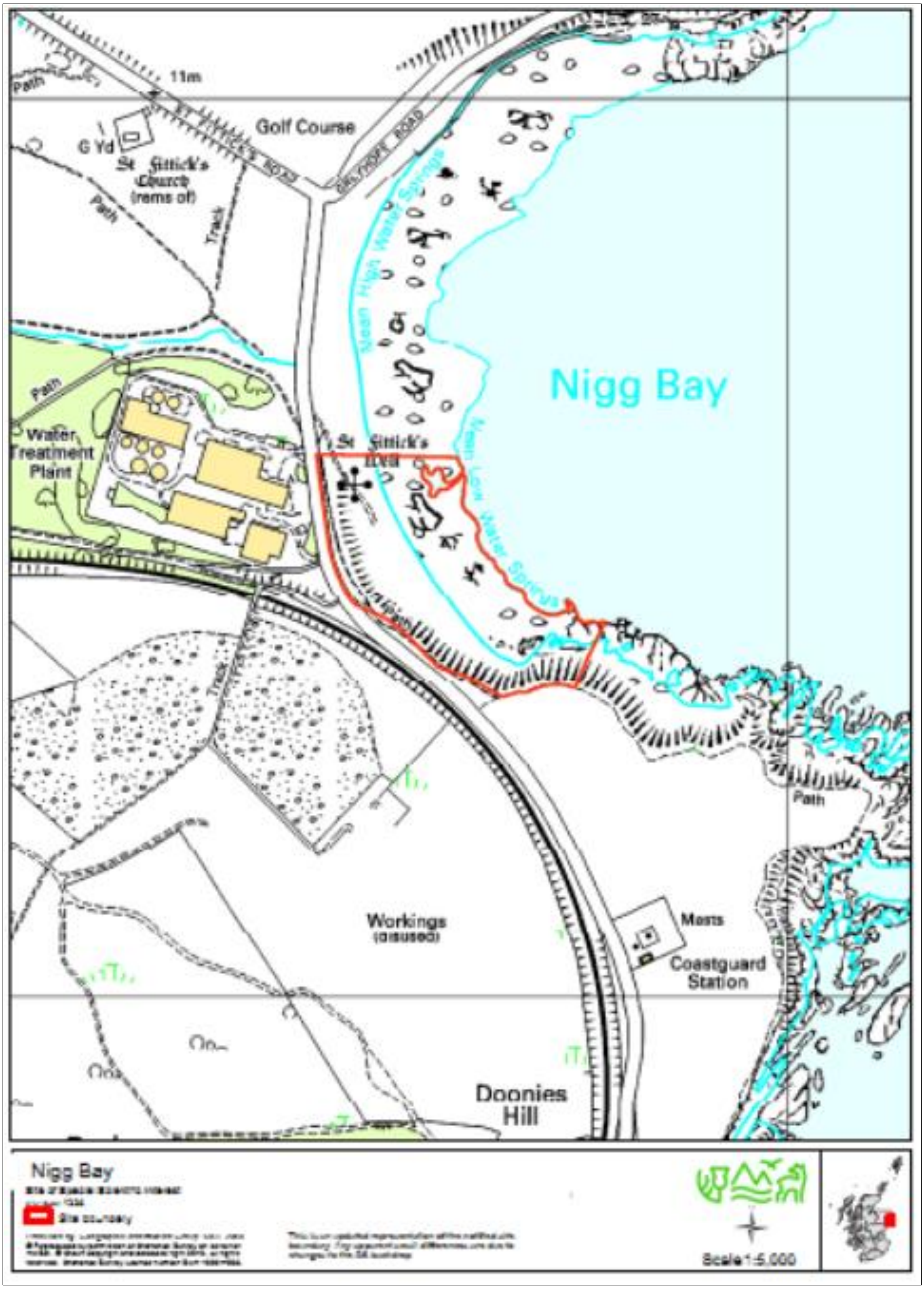

Figure 8-1: Location of Nigg Bay SSSI

Source: https://sitelink.nature.scot/site/1224.

8.3 Existing AHEP Management Measures

The Nigg Bay SSSI lies within the boundary of the AHEP and is thus subject to a comprehensive management plan to manage potential risks to this feature due to the construction of the AHEP (see chapter 16 of the existing CEMD). In addition to the CEMD, two addendum documents have been approved by SNH and MS-LOT to describe proposed construction methodologies and associated monitoring and mitigation for working on the southern shore of Nigg Bay as follows:

- '*Environmental Mitigation – South Breakwater and Shore Blasting Methodology*' (AHEP-DRA-EP-0003) describing the construction and mitigation methodologies for rock drilling, blasting and rock dredging for the southern trenches and South Breakwater methodology and for the southern shore work (this method statement has been incorporated into the revised CEMD Chapter 11);
- '*AHEP Southern Shore Works*' (AHEP-DRA-COS-004) describing construction of a temporary access haul road and sea protection platforms and blasting along the south shore and associated environmental controls.

Collectively, these documents provide comprehensive monitoring and mitigation measures associated with proposed construction works on the south shore in Nigg Bay particularly with respect to the potential for increased vibration at the SSSI to result in slippage of the slope face.

To minimise the likelihood of a slippage occurring due to construction works, weekly observations and vantage point photographs of cliff features have been taken since September 2017 for monitoring of any change in slope conditions during construction. Distinct features within exposed cliff faces and distinctive earth edges have been carefully selected for monitoring of any movement which might be indicative of potential slope face slippage. In addition, four cliff top points in the SSSI are monitored involving weekly measurements of lateral displacement and level to within 1 cm and warnings set at ± 5 cm (that have not yet been triggered). DUK will continue to monitor all of these features and will pause construction works and notify SNH if movement indicative of increased slope slippage is detected.

Further to this, DUK has established remote vibration monitoring equipment adjacent to the cliff slope within the SSSI and are currently undertaking recordings of vibrations (peak particle velocity (PPV)). The vibration meter is set with a low-level early warning trigger at 8 mm/s and is taken to be the level of vibration indicative of possible slope instability.

Table 8.2 shows vibration data recorded at the SSSI during blasting in the AHEP to date. While most blasts have been undertaken at the opposite (north) end of the bay and away from the SSSI, the vibration data does include one record of an onshore test blast in the south (albeit quite small).

Table 8.2: Sample of Vibration Monitoring Data Recorded at the Nigg Bay SSSI During Blasting

	Date	Time	Fields	PW Appx	Blast Size		UWN		SSSI Vibration		
					Charge [kg]	No of Holes	Initial Indication	Max. Outside Curtain [rms]	Trans	Vert	Long
North (Marine)											
1	20/08/18	1951 BST	2	A	10/20	90		Equipment Failure	0.54	0.89	0.46
2	24/08/18	1303 NST	2	B	10/20	66		153.7	1.08	1.72	1.58
3	06/09/18	1901 BST	2	C	20	151		Equipment Failure	0.89	0.82	0.84
4	12/09/18	1030 BST	2	D	20	122		Equipment Failure	Equipment Failure	Equipment Failure	Equipment Failure
5	14/09/18	1305 BST	2	E	20	152		131.8	0.80	0.39	0.54
6	17/09/18	1642 BST	2	F	20	181		143.2	0.65	0.41	0.46
7	08/10/18	1701 UC	3	G	20	`100		152.3	0.68	0.71	0.63
8	13/10/18	0942 UTC	1	H	20	84		151.2	1.11	0.60	0.61
9	17/10/18	1149 UTC	2	I	20	87		151.6	0.81	0.54	0.53
10	25/10/18	0813UTC	2	J	20	63		146.1	0.79	0.35	0.51
11	17/11/18	1356 UTC	3	K	20	246	Equipment Failure	Equipment Failure	1.25	0.46	0.77
12	24/11/18	0950 UTC	2	L	20	415	152.3	151.9	1.85	0.38	0.91
South (Land)											
1	17/11/18	1540 UTC	1	K	3/6	3	Equipment Failure	Equipment Failure	0.39	0.37	0.31

In all cases, levels of vibration have remained very low and have only reached 1.85 mm/s and 0.91 mm/s in the horizontal axes and 0.38 mm/s in the vertical axis during the largest detonation (24 November 2018). Current vibration levels from blasting are thus well within the 8 mm/s limits adopted for the Nigg Bay SSSI monitoring campaign. Continued monitoring will be undertaken to record vibration levels as further blasts are undertaken in the south part of the bay.

8.4 Assessment of Effects

With reference to Table 8.1, the impacts and effects assessed in this section include:

- Slippage of the cliff slope of the SSSI.

8.4.1 Slippage of the Exposed Cliff Slope Of the SSSI

Caltrans (2013) explains that any blast energy not used in the breaking up of rock will be dissipated in the form of seismic waves. These waves excite the particles of rock and soil as they travel outwards from the blast site causing them to oscillate. The measurement of this oscillating particle motion is recorded as vibration.

The use of larger charge weights (> 20 kg) is likely to result in the dissipation of increased seismic waves from each blast site causing higher particle velocities and higher intensity vibration at the SSSI than currently. Higher intensity vibrations at the SSSI could increase the potential for a slope failure and slippage of the cliff slope of the SSSI to occur if current threshold limits (8 mm/s) are exceeded. Any slope slippage could then impinge on the site management objectives. The impact of this would likely be long term or permanent and depending on the spatial scale of the failure, relative to the size of the SSSI, may be extensive on a high a high value receptor constituting an effect of up to **major** significance should it occur.

The actual increase in vibration that will occur at the SSSI due to the use of larger charge weight > 20 kg will depend on the final charge weight used, the configuration of the shot holes, the distance from each blast event and the nature of the substrate through which the seismic waves are dissipated. However, given the very low levels of vibration recorded at the SSSI to date, blasting is not expected to cause significant effects to the slope. Continued monitoring using the vibration monitoring equipment will further ensure that vibration does not exceed agreed limits.

The stability of the cliff face (and the potential for a slippage to occur) will depend on the degree of water ingress and saturation of the cliff slope sediments and fine-scale variations in rock parameters amongst other possible factors. There is a comprehensive programme of monitoring already in place, to provide early warning of potential slope slippage, as described in section 8.3, and to allow construction works to be paused and the appropriate authorities to be notified where monitoring limits are exceeded.

8.5 Impact Conclusion

The use of larger explosive charges could increase the levels of vibration at the SSSI raising the risk of a slope failure and slippage within the Nigg Bay SSSI resulting in an effect of up to **major** significance should this occur. However, a slippage due to blasting is considered **unlikely** to happen given the comprehensive monitoring already in place and the low levels of vibration from blasting recorded to date. This assessment is associated with **high certainty** as risks can be mitigated and effective monitoring and management is already in place.

8.6 Cumulative impacts

There are no other projects close to the current AHEP that will give rise to any significant cumulative vibration impacts. Construction of a temporary haul road at the base of the cliff is subject to revised methodologies which have been approved.

8.7 Recommended Mitigation and Residual Effects

No additional mitigation or monitoring is deemed necessary as current monitoring efforts are considered to be sufficient to provide early indications of potential cliff slippage and to allow blasting to be paused, and authorities notified, should any significant slope movement or vibration outside of established limits be detected.

An incremental increase in charge weight would allow vibrations to be monitored up to maximum acceptable limits.

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9. CONCLUSIONS AND RECOMMENDATIONS

A programme of incremental increases of blast charge weight is proposed that will provide ongoing protection of marine receptors and allow the continued development of the consented AHEP within a reasonable and practicable timeframe. This document provides an assessment of the potential effects of implementing the programme in line with EIA Regulations and assesses these against the outcomes of the existing ES upon which the initial consent decision was based. Table 9.1 summarises the findings of the current assessment of the environmental effects of the proposed changes to the blasting methodology and shows the significance of identified likely effects, the likelihood of it occurring, any additional mitigation proposed over and above that which already exists and the residual significance/likelihood of effects for each receptor topic considered. A comparison with the findings of the 2015 ES (AHB, 2015) in terms of effect significance, and upon which AHEP consent is granted, is also provided.

Table 9.1 :Table of Impact Conclusions

Impact	Effect Significance	Likelihood (of Impacts Occurring)	Certainty	Mitigation Proposed	Residual Significance/ Likelihood	Effect Significance in existing ES (AHB, 2015)	Change from existing ES (AHB, 2015)
Fish and Shellfish Ecology							
Impacts on migrating salmonids.	Minor	Unlikely (higher likelihood in July)	Low	Revised CEMD (recording and reporting salmon carcasses)	Minor/Unlikely	Negligible	No change in effect significance outside of the bubble curtain but higher risk inside the bubble curtain due to the use of larger charge weights (>20 kg).
Noise impacts of offshore disposal on smolts.	Minor	Likely	High	None	Minor/Likely	Not assessed.	-
Sediment impacts of offshore disposal on smolts.	Minor	Likely	High	None	Minor//Likely	Minor	No change in effect significance
Marine Mammals							
Increased injury and avoidance.	Negligible (for pinnipeds and medium and low frequency cetaceans)	Likely	High	None	Negligible/ Unlikely	Minor (with mitigation)	No change in effect significance
	Up to major (for high frequency cetaceans)	Likely to unlikely depending on assumed double bubble curtain performance and shielding from the southern breakwater.	Medium	None	Up to major Likely to unlikely		Increase in effect significance for charge weights of 40 kg and above in respect of harbour porpoise only and only if the minimum bubble curtain performance is considered. Otherwise no increase in effect significance.
Cumulative effects	Negligible (long term population level consequences)	Unlikely	High	As above.	Negligible/ Unlikely	Unlikely	No change in likelihood of experience cumulative effects.
Marine Birds							
Increased injury and mortality.	Minor	Unlikely	High	Pre-blast checks to also consider birds that may be diving.	Minor/ Unlikely	Up to Minor (originally assessed as disturbance and displacement due to both marine and	No change in effect significance
Increased displacement of birds	Minor	Likely	Low	None	Negligible		No change in effect significance

Impact	Effect Significance	Likelihood (of Impacts Occurring)	Certainty	Mitigation Proposed	Residual Significance/ Likelihood	Effect Significance in existing ES (AHB, 2015)	Change from existing ES (AHB, 2015)
due to increases in airborne noise.						terrestrial construction activities).	
Changes in prey availability.	Negligible	Unlikely	High	None	Negligible/ Unlikely	Up to Minor	No increase in effect significance
Increased area of sea surface disturbance.	Minor	Unlikely	Low / medium	None	Minor/Unlikely	Not assessed in the existing ES	-
Nigg Bay SSSI							
Slippage of the cliff slope of the SSSI.	Up to major	Unlikely	High	None	Up to major/ unlikely	Negligible	Increase in effect significance but highly unlikely with current mitigation in place.

10. HABITATS REGULATION APPRAISAL

10.1 Introduction

This chapter updates the Habitats Regulation Appraisal (HRA) which accompanied the initial AHEP application (2015 ES, Volume 4: Habitats Regulation Appraisal) and informs the Competent Authority's forthcoming Appropriate Assessment (AA) for the determination of the current application for a Marine Licence. It has been completed by Fugro in accordance with the requirements of Regulation 48 of the Conservation (Natural Habitats, &c.) Regulations 1994 and Council Directive 92/43/EEC on the conservation of natural habitats, wild fauna and flora (Habitats Directive) and in accordance with advice received from SNH.

HRAs are required for projects which are likely to have an adverse effect on a site which forms part of Europe's Natura 2000 network of protected sites (Natura sites) developed under the European Commission's Habitats Directive (Directive 92/43/EEC) and Birds Directive (79/409/EEC). Natura sites include Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) as well as sites designated under the Ramsar Convention (Ramsar sites). A number of Natura sites are present within the area and which have connectivity with the AHEP, through the natural range movement of qualifying species and which thus require consideration of potential effects to their integrity in respect of their conservation objectives.

Information used in this HRA has been drawn from the current EIAR, the existing ES (AHB, 2015) and also from the initial Appropriate Assessment conducted by Marine Scotland Licensing Operations Team (MS-LOT).

10.2 Background

The previous HRA submitted to accompany the ES in 2015 represented an extensive screening exercise to identify and assess potential interactions between the proposed AHEP activities and the interest features of Natura sites including Special Protection Areas (SPA), Special Areas of Conservation (SAC) and proposed SPAs that were within predicted zones of influence of the proposals and/or were within the range movement of relevant qualifying species. Among the activities assessed were construction noise including blasting. The HRA screening conducted at the time concluded that there would be no likely significant effects (LSE) of proposed AHEP activities on the integrity of the designated sites as they would not undermine the conservation objectives of the sites investigated.

On completion and submission of the HRA screening, MS-LOT, as the Competent Authority in this matter, undertook an AA to determine the LSE of the AHEP proposals. The AA included population viability analysis (PVA) modelling in respect of the long-term consequences to the east coast Scotland bottlenose dolphin population. On completion of their AA, MS-LOT concluded that the AHEP proposals would not adversely affect the integrity of SACs, SPAs or proposed SPAs (pSPA).

10.3 Aim of the Current HRA

As a result of the proposed changes to the blasting methodology, it is necessary to review and present updated information on their potential impacts on Natura 2000 sites in light of their respective conservation objectives. The updated information will help determine whether the new proposals will have any LSE either alone or in-combination with any other plans or projects on interest features of the

Natura sites and will inform a further AA. The further AA, if required, will be undertaken by the Competent Authority which in this instance is expected to be MS-LOT.

10.4 The Proposals

As explained in Chapter 2 of the EIAR, changes to the blasting methodology are required to ensure that AHEP construction objectives can be achieved following delays in 2018 due to adverse weather, the presence of seals in the mitigation zone and winter storm damage to the double bubble curtain. The changes needed include:

- An increase in the duration of the period within which blasting is permitted (the current permitted blasting period ended on 24 March 2019. The extension required is to 12 April 2021;
- An increase in the weight of charge that can be used (> 20 kg);
- An increase in the duration of permitted dredging and disposal. DUK have been granted a licence variation (05964/19/0) to permit dredging and disposal of dredged material to continue up to 27 February 2020. A new application is requested to 12 April 2021.

The upper weight of the explosive charge being sought is 100 kg but will be limited by the requirement to meet the agreed underwater noise threshold of 170 dB re 1 µPa rms (equivalent to 183 dB re 1µPa peak) at 400 m from the blast location or outside the double bubble curtain, whichever is the greater distance. A PCL is proposed as additional precaution against exceeding the agreed threshold (see section 2.6.2).

10.5 Designated Sites Considered in this HRA

Table 10.1 lists the designated sites and respective qualifying features that are considered in this HRA as identified through scoping and statutory consultation.

Table 10.1: Designated Sites and Qualifying Features Considered in the HRA

Site	Conservation Objectives and Qualifying Features
Moray Firth SAC (approx. 160 km from AHEP)	To avoid deterioration of the habitats of the qualifying species or significant disturbance to the qualifying species, thus ensuring that the integrity of the site is maintained, and the site makes an appropriate contribution to achieving favourable conservation status for each of the qualifying features and to ensure for the qualifying species that the following are established then maintained in the long term: ■ Population of the species as a viable component of the site; ■ Distribution of the species within site; ■ Distribution and extent of habitats supporting the species; ■ Structure, function and supporting processes of habitats supporting the species; ■ No significant disturbance of the species. ***Qualifying Species*** ■ Bottlenose dolphin (*Tursiops truncatus*).
River Dee SAC (approx. 1.0 km from AHEP)	To avoid deterioration of the habitats of the qualifying species or significant disturbance to the qualifying species, thus ensuring that the integrity of the site is maintained and the site makes an appropriate contribution to achieving favourable conservation status for each of the qualifying features and to ensure for the qualifying species that the following are maintained in the long term: ■ Population of the species, including range of genetic types for salmon, as a viable component of the site; ■ Distribution of the species within site; ■ Distribution and extent of habitats supporting the species; ■ Distribution and viability of freshwater pearl mussel host species;

Site	Conservation Objectives and Qualifying Features
	■ Structure, function and supporting processes of habitats supporting the species; ■ Structure, function and supporting processes of habitats supporting freshwater pearl mussel host species; ■ No significant disturbance of the species. ***Qualifying species:*** Atlantic salmon (*Salmo salar*); ■ Fresh water pearl mussel (*Margaritifera margaritifera*).
Isle of May SAC (approx. 110 km from AHEP)	To avoid deterioration of the habitats of the qualifying species (listed below) or significant disturbance to the qualifying species, thus ensuring that the integrity of the site is maintained and the site makes an appropriate contribution to achieving favourable conservation status for each of the qualifying features and to ensure for the qualifying species that the following are maintained in the long term: ■ Population of the species as a viable component of the site; ■ Distribution of the species within site; ■ Distribution and extent of habitats supporting the species; ■ Structure, function and supporting processes of habitats supporting the species; ■ No significant disturbance of the species. ***Qualifying species*** Grey seal (*Halichoerus grypus*)
Ythan Estuary, Sands of Forvie and Meikle Loch SPA (approx. 20 km from AHEP).	To avoid deterioration of the habitats of the qualifying species (listed below) or significant disturbance to the qualifying species, thus ensuring that the integrity of the site is maintained; and to ensure for the qualifying species that the following are maintained in the long term: ■ Population of the species as a viable component of the site; ■ Distribution of the species within site; ■ Distribution and extent of habitats supporting the species; ■ Structure, function and supporting processes of habitats supporting the species; ■ No significant disturbance of the species. ***Qualifying species*** Common tern (*Sterna hirundo*) Eider (*Somateria mollissima*) Little tern (*Sterna albifrons*) Sandwich tern (*Sterna sandvicensis*)
Ythan Estuary, Sands of Forvie and Meikle Loch SPA proposed marine extension (approx. 2.5 km from AHEP)	General – to enable the application of special conservation measures concerning the marine habitat of Annex 1 birds and regularly occurring migratory birds, to ensure their survival and reproduction in their area of distribution. Specific - To protect foraging habitat used by Sandwich tern and little tern breeding at the Ythan Estuary, Sands of Forvie and Meikle Loch SPA. The conservation objectives for the Ythan Estuary, Sands of Forvie and Meikle Loch SPA proposed marine extension are: to avoid deterioration of the habitats of the qualifying species or significant disturbance to the qualifying species, subject to natural change, thus ensuring that the integrity of the site is maintained in the long-term and it continues to make an appropriate contribution to achieving the aims of the Birds Directive for each of the qualifying species.

10.6 Potential Impacts and Effects

Impacts associated with the proposed changes to the blasting methodology include:

- increased underwater noise and vibration as a result of the use of larger weight charges;
- increased duration of impacts due to the extended blasting period.

The spatial extents of the impacts are already constrained by the deployment of a double bubble curtain and underwater noise monitoring against an agreed tolerance threshold. In addition, the impacts remain highly intermittent (up to 2 blasts per day), limited to daylight hours (Monday to Saturday) and there will be periodic breaks to allow for the setting of charges, and likely delays due to adverse weather and presence of seals and other marine mammals. With reference to the blasting achieved in 2018, then the actual rate of blasting that can be expected is between 2 to 3 blasts per week.

Likely effects on interest features include:

- increased avoidance of preferred habitat or migration routes for fish and marine mammals due to blasting over an extended period,
- physical injury and mortality for fish and marine birds within the AHEP boundaries;
- changes to prey availability for marine mammals, fish and marine birds.

Effects on individual receptor groups are addressed in the EIAR in Chapter 5 (Fish and Shellfish Ecology), Chapter 6 (Marine Mammals) and Chapter 7 (Marine Birds). This HRA should be read in conjunction with these chapters.

10.7 Pathways for Likely Significant Effects (LSE)

The AHEP boundaries do not overlap with any designated sites and so direct effects on interest features and Natura sites will not occur.

The proposed changes to the blasting methodology do not change the quantities of material to be dredged from the seabed (or disposed) or the areas to be dredged. The numbers of dredger vessel movements remain as planned. All material arising from the blasting will be used beneficially within the scheme (for example within the southern breakwater construction) and will not be disposed offshore. Indirect impacts of the movement of sediment plumes and sediment deposition, over and above those already assessed and accepted will not occur. MS-LOT’s previous AA has already concluded that effects arising from the existing AHEP activities are of sufficiently limited magnitude or can be constrained by the recommended mitigating measures so as not to give rise to any LSE on designated sites.

With the mitigation recommended by MS-LOT in their previous AA now in place, residual pathways for LSE arising from the current proposals for the changes in the blasting methodology relate to the predicted increases in trauma (mortality and injury) zones within the project site and increases in the duration over which adverse underwater noise from blasting occurs. Impact - receptor pathways resulting in LSEs on selected interest features are illustrated in Table 10.2.

Table 10.2. Impact - Receptor Pathways for LSEs

Impact	Features Affected	Risks
Increase in the spatial extent and duration of impacts of underwater noise.	■ Atlantic salmon, ■ Freshwater pearl mussel; ■ Eider duck; ■ Sandwich tern; ■ Little tern.	■ Increased mortality, injury and avoidance/displacement; ■ Changes to prey availability.
	■ Bottlenose dolphin; ■ Grey seal.	■ Increased displacement; ■ Changes to prey availability.

10.8 In-combination Effects

In addition to impacts of the scheme alone, the Habitats Regulations require that the activities of other plans or projects that may give rise to similar impacts be considered in respect of potential in-combination effects. These include effects that may or may not interact with each other, but which could affect the same receptor or interest feature (i.e. a habitat or species for which a site is designated). There are a number of projects, programmes, plans or activities that, in combination with the noise effects arising from the proposed changes to the blasting methodology, could have an effect on a site's qualifying features) and which have been identified through scoping. Table 4.4 and section 4.9 of the EIAR (Chapter 4: Methodologies) lists the other projects considered in this HRA and provides rationale for those that have been excluded.

10.9 Assessment of LSE

This section assesses the potential impacts on interest features of the designated sites identified in Table 10.1 due to the proposed changes to the blasting methodology in respect of the sites' respective conservation objectives.

10.9.1 Moray Firth SAC – Bottlenose Dolphin

10.9.1.1 <u>Impacts of AHEP Blasting Proposals Alone</u>

Bottlenose dolphins were frequently recorded within the vicinity of the AHEP during pre-construction vantage point survey as reported in Chapter 15 of the 2015 ES (AHB, 2015) and continue to use the local area during and after current blasting as evidenced by current MMO sightings, PAM and C-POD data (see section 6.2.5).

The local bottlenose dolphin population makes long range movements up and down the east coast of Scotland (Quick et al, 2014; Cheney et al, 2013; Thompson et al; 2011) and photo identification has confirmed that at least some individuals of the population using local waters are from the Moray Firth SAC. While they likely use the local area, and particularly the mouth of the River Dee for feeding, they are also able to forage more widely along the east coast of Scotland.

The 2015 ES (AHB, 2015) estimated that there are nearly 200 dolphins that make up the east coast group. In 2012 to 2013, 60 % of the total Scottish east coast bottlenose dolphin population was using the area between Aberdeen and the Firth of Forth (Quick et al., 2014).

Chapter 6 of the current EIAR explains that because of the existing mitigation already in place at the AHEP, bottlenose dolphin will not be present within 1 km of the AHEP during blasting. Furthermore, the double bubble curtain currently in place at the AHEP is predicted to protect bottlenose dolphin from injury (both permanent and temporary) regardless of charge weight used up to 100 kg (see impact modelling technical report in Appendix B and section 6.4 of the EIAR). Because of these measures, bottlenose dolphins linked to the Moray Firth SAC are not expected to be exposed to noise levels indicative of injury (permanent or temporary) and effects arising from the proposed changes to the blasting methodology are anticipated to be of negligible significance. Numerical modelling using the interim population consequences of disturbance (iPCoD) framework (OSC, 2019e) predicted that the AHEP would not have any significant adverse effects on the population size of bottlenose dolphin (see Appendix E of the EIAR) due to the use of any weight of explosive charge up to, and including, 100 kg.

Furthermore, the current agreed noise threshold within open water areas beyond the AHEP is 170 dB re 1 µPa rms (equivalent to 183 dB re 1µPa peak) at 400 m from the blast location or outside the double bubble curtain, whichever is the greater distance and is considerably lower than the currently accepted NMFS (2018) noise levels that are indicative of injury to bottlenose dolphin.

Chapter 5 of the EIAR assesses the potential impacts of the changes of the blasting methodology on fish and indicates that significant effects to potential fish prey items (including salmon and sand eels) in the wider area beyond the double bubble curtain are not expected. Significant adverse effects on prey availability for bottlenose dolphin are thus not predicted as a result of the proposed changes to the blasting methodology.

The quantities, locations and types of seabed material to be dredged and disposed remain the same as planned and so impacts associated with this activity will not change from those initially assessed in the 21015 ES (AHB, 2015).

Given that only negligible effects are predicted to occur due to the proposed changes to the blasting methodology, then it is considered that the bottlenose dolphin interest of the Moray Firth SAC is not at any greater risk than originally assessed in the 2015 ES and HRA.

10.9.1.2 Impacts of the AHEP Blasting Proposals In-combination With Other Plans and Projects

Previous PVA undertaken as part of MS-LOT's AA, found that there would be no long-term effects on the population of bottlenose dolphins as a result of them avoiding the area during one year (one breeding cycle) of blasting at the AHEP. The analysis went on to conclude that the effects of the AHEP alone are small and do not contribute significantly to in-combination effects with other developments and that they would not have an adverse effect on the integrity of the bottlenose dolphin feature of the Moray Firth SAC.

A repeat of the analysis using the iPCoD framework (see section 6.6 and Appendix E of the EIAR) supported the earlier PVA conclusions and similarly found that the current AHEP proposals do not contribute significantly to in-combination effects with other developments.

10.9.1.3 Conclusion

Bottlenose dolphins continue to use local waters despite ongoing construction activities. Open water areas used by bottlenose dolphins are shielded from adverse noise from blasting by a double bubble curtain. Underwater noise modelling suggests that noise effects will be of negligible significance regardless of the charge weight used up to 100 kg. The bottlenose dolphin population of the Moray Firth SAC is therefore not at any greater risk than previously assessed, so long as the existing mitigation is in place. No likely significant effects on this feature of the Moray Firth SAC either alone or in-combination with other local plans and projects are therefore expected due to the proposed changes to the blasting methodology.

10.9.2 River Dee SAC – Atlantic Salmon and Freshwater Pearl Mussel

10.9.2.1 Impacts of the AHEP Blasting Proposals Alone

Freshwater pearl mussel rely on salmonids as hosts during larval stages of their life cycle so that any effects on salmonid populations could also affect freshwater pearl mussels. Impacts on freshwater pearl mussel are therefore assessed in terms of effects on Atlantic salmon.

Salmon smolt emerge from the River Dee in spring (peak emergence is April to June although emigration is significantly completed by end May) (section 5.3 of the EIAR). On emergence they are separated from any adverse construction noise from the AHEP by the rock promontory at Girdle Ness and by the new breakwaters and double bubble curtain across Nigg Bay. Underwater noise modelling (Appendix B and section 5.6 of the EIAR) shows that with the double bubble curtain in place, noise levels indicative of mortality or injury to fish will not occur anywhere beyond the AHEP (beyond the double bubble curtain). Adults returning to the Dee are similarly protected from adverse noise that might arise from the AHEP. Compliance monitoring against an agreed threshold (170 dB re 1 µPa rms (equivalent to 183 dB re 1µPa peak) at 400 m from the blast location or outside the double bubble curtain, whichever is the greater distance) ensures that underwater noise from the AHEP remains well below levels indicative of mortality or potential mortal injury to fish beyond the construction site boundaries.

Noise levels at the offshore disposal site during disposal of material are broadly within the range of ambient conditions although mean levels are marginally (3 dB) higher (Newton et al, 2018). Any salmon smolts dispersing beyond Girdle Ness and towards the offshore disposal site, as indicated in recent research (Vattenfall, 2018), are expected to be generally tolerant of this temporary noise effect and to be capable of avoiding local adverse areas if encountered.

Noise levels from blasting within the double bubble curtain, however, are predicted to result in mortality or potential mortal injury of fishes if they are sufficiently close to a blast source at the point of detonation as indicated in Table 5.6 (see Chapter 5: Fish and Shellfish Ecology). Any salmon entering the AHEP will therefore be at risk if a detonation occurs while they are inside the double bubble curtain and sufficiently close to the blast as indicated in Table 5.6 (see section 5.6 of the EIAR). In comparison with the situation assessed in the 2015 ES (AHB, 2015) individuals of salmon, and indirectly freshwater pearl mussel, inside the bay (inside the double bubble curtain) are likely to be a greater risk of mortality or potential mortal injury due to the greater impact ranges associated with larger charge weights. Any reverberation of blasting noise around the bay may exacerbate effects although effects will remain within the double bubble curtain. Presently, it is not clear how salmon are using Nigg Bay or what proportion of the River Dee population may be present in this area although historic commercial catch data suggest peak use of local coastal waters by salmon in July. Netting surveys in August and September 2017 recorded only a low number of salmon (total of 5 individuals) and sea trout (total of 2 individuals) in Nigg Bay suggesting low use at this time (Chapter 5: Fish and Shellfish Ecology). Fish scarers are currently used to drive fish away from blast zones immediately prior to a blast, to reduce risk, and as yet, no salmonids have been reported as killed following blasting. A detailed protocol for reporting dead salmon identified during blasting will be provided in a revised CEMD.

The consequences of reduced prey items in Nigg Bay on salmon and other freshwater pearl mussel host species will be negligible as it is considered that individuals returning to the River Dee for spawning do not tend to feed and would preferentially take pelagic food items in any case. Sand eel prey populations outside the proposed harbour are predicted to remain unaffected due to the proposed changes to the blasting methodology and are largely beyond modelled distance ranges of elevated substrate peak particle velocities (see EIAR Chapter 5: Fish and Shellfish Ecology).

Dredging and offshore disposal activities at the AHEP will not change due to the proposed changes to the blasting methodology so increased dredging disturbance and turbidity plume impacts over and above those already assessed will not occur.

10.9.2.2 Impacts of the AHEP Blasting Proposals In-combination With Other Plans and Projects

Quantities of material dredged from the AHEP and from the Aberdeen Harbour maintenance dredge operation for disposal at the licenced offshore disposal site remain the same as planned and as previously assessed in the existing ES (AHB, 2015) and will not change due to the proposed changes to the blasting methodology (section 5.7.1 of the EIAR). Seabed substrate material arising from proposed blasting will not be disposed offshore. Potential cumulative impacts of offshore disposal, including raised suspended sediment concentrations (SSCs) and sediment deposition therefore remain the same as assessed in the ES (AHB, 2015).

Sediment plume modelling to forecast the effects of simultaneous dredge disposal (AHB, 2015) predicted peak cumulative SSCs at the disposal site of 29 169 mg/l, falling more than an order of magnitude to 2774 mg/l at 708 m to the north, and to 2363 mg/l at 886 m to the south. Average SSC was more than 35 times lower at the disposal site, at 813 mg/l. Average SSC falls to 101 mg/l at 463 m to the north and to 106 mg/l at 463 m to the south. These cumulative average levels were found to be within natural background variability less than 0.5 km from the disposal site. While dredgers from both schemes could be operating on the same day on some occasions, it is highly unlikely that they will dispose dredged material at exactly the same time at exactly the same location. Consequently, cumulative effects are not predicted.

Section 5.7.1 of the EIAR explains that migratory species, such as salmonids, would be expected to be able to avoid adverse turbidity conditions due to their mobility and large range movement, and will be tolerant to raised SSCs to a certain degree due to their presence in turbid estuarine environments through which they pass on their migration. Therefore, considering the low average levels of SSCs predicted and the general avoidance and tolerance capability of salmonids, no significant effects of raised sediment plumes of AHEP disposal in-combination with Aberdeen Harbour maintenance dredge material disposal on migrating smolts are forecast.

Individuals of salmon may encounter other projects with ‘noisy’ activities as identified in Table 4.4 of the EIAR during their migration. However, it is considered that these projects are sufficiently distant from the AHEP, and/or their construction timescales do not overlap (see section 5.7 of the EIAR), that significant in-combination effects would be highly unlikely.

10.9.2.3 Conclusion

With mitigation in place, the salmon (and indirectly the freshwater pearl mussel) interests of the River Dee SAC outside of the AHEP double bubble curtain are not at any increased risk due to the proposed changes to the blasting methodology than previously assessed in 2015 (AHB, 2015). Individual salmonids, and indirectly freshwater pearl mussel, entering the AHEP double bubble curtain however are likely to be at greater risk of being killed or mortally injured compared to the 2015 situation due to the greater predicted impact radii associated with the larger charge weights proposed here. Fish scarers are used to drive fish away from blast sites, and so far, appear to be successful in terms of salmonids (see section 5.2 of the EIAR). Recent comprehensive fish surveys support only limited use of the bay by salmonids.

10.9.3 Isle of May SAC – Grey Seal

10.9.3.1 Impacts of the AHEP Blasting Proposals Alone

Grey seals forage widely throughout the east coast of Scotland and are occasionally seen foraging and resting in the area of the AHEP despite ongoing construction. Individuals have been observed using the area shortly after blasting events (within an hour or two).

Seal tracking studies (Technical Appendix 15-B of the 2015 ES) (AHB, 2015) showed that the Isle of May SAC grey seals likely travel through or close to the AHEP and use local waters. While grey seals from other SAC populations could also visit the AHEP, MS-LOT, in their previous AA, suggested that the degree of connectivity is only of sufficient level to warrant further assessment in connection with the Isle of May SAC population. The seal tracking study also showed that grey seals tagged at the Isle of May SAC and which entered the Nigg Bay study area, did not enter the Moray Firth so would be unlikely to have any significant interaction with the Moray Firth offshore wind farms (see Figure 10-1).

Increases in underwater noise due to the proposed changes in blasting methodology will not kill or injure grey seals as they are already mitigated out of predicted PTS and TTS impacts areas for explosive charge weights of up to 100 kg (section 6.4 of the EIAR). The long-term viability of the populations is not forecast to be significantly affected as shown by the iPCoD modelling (Appendix E). Construction activity at present does not appear to have significantly displaced grey seal from the local area as evidenced by current MMO sightings (section 6.2.5 of the EIAR).

As indicated in MS-LOT's previous AA, only a small proportion of the Isle of May population is thought to use Nigg Bay and there should not be an adverse effect on the integrity of the population.

10.9.3.2 Impacts of the AHEP Blasting Proposals In-combination with Other Projects

Other projects comprising 'noisy' activities are remote to the AHEP (at least 130 km to the north and 55 km to the south) (see Table 4.4 and Table 6.12 of the EIAR) and also include measures to mitigate against injury and mortality of marine mammals. Projects at Peterhead may contribute some localised and short term noise and impacts of proposed blasting at Peterhead Port is only likely to affect areas within 150 m as most areas beyond this distance are not in any direct line of sight.

In-combination displacement effects during periods of simultaneous construction noise are unlikely to occur given the distance separations between projects, the small impact ranges predicted and the availability of habitat in the intervening distances between projects. Based on tracking data (Figure 10-1) the Isle of May SAC grey seals using the local waters around the AHEP do not appear to enter the Moray Firth suggesting that there will be little, if any, potential for in-combination impacts to occur with Moray Firth projects. As highlighted in the 2015 ES (AHB, 2015) grey seal pass through the area with little or no apparent reliance on local resources or habitats although they do feed and rest locally as observed during mitigation monitoring. Any displacement from the AHEP due to blasting will be highly localised and intermittent and short-term and will therefore have negligible adverse consequences for the Isle of May SAC population.

Modelling of the grey seal population within the iPCoD framework (see section 6.6 and Appendix E) indicated that with the double bubble curtain in place, blasting at the AHEP with any weight of explosive charge, up to 100 kg, is not forecast to significantly affect the grey seal population either singly or in-combination with other developments.

10.9.3.3 Conclusion

The area of Nigg Bay is very small in the context of the potential range movement of the SAC grey seal population. In the presence of existing mitigation, an increase in noise due to the proposed changes to the blasting methodology will not result in any injury or mortality and grey seals are not considered to be at any greater risk than previously assessed even considering the worst-case scenario. In-combination impacts are not anticipated based on the findings of quantitative cumulative (iPCoD) assessment (Appendix E). Consequently, no likely significant adverse effects on the grey seal interest of the Isle of May SAC either alone or in-combination with other local plans and projects is predicted.

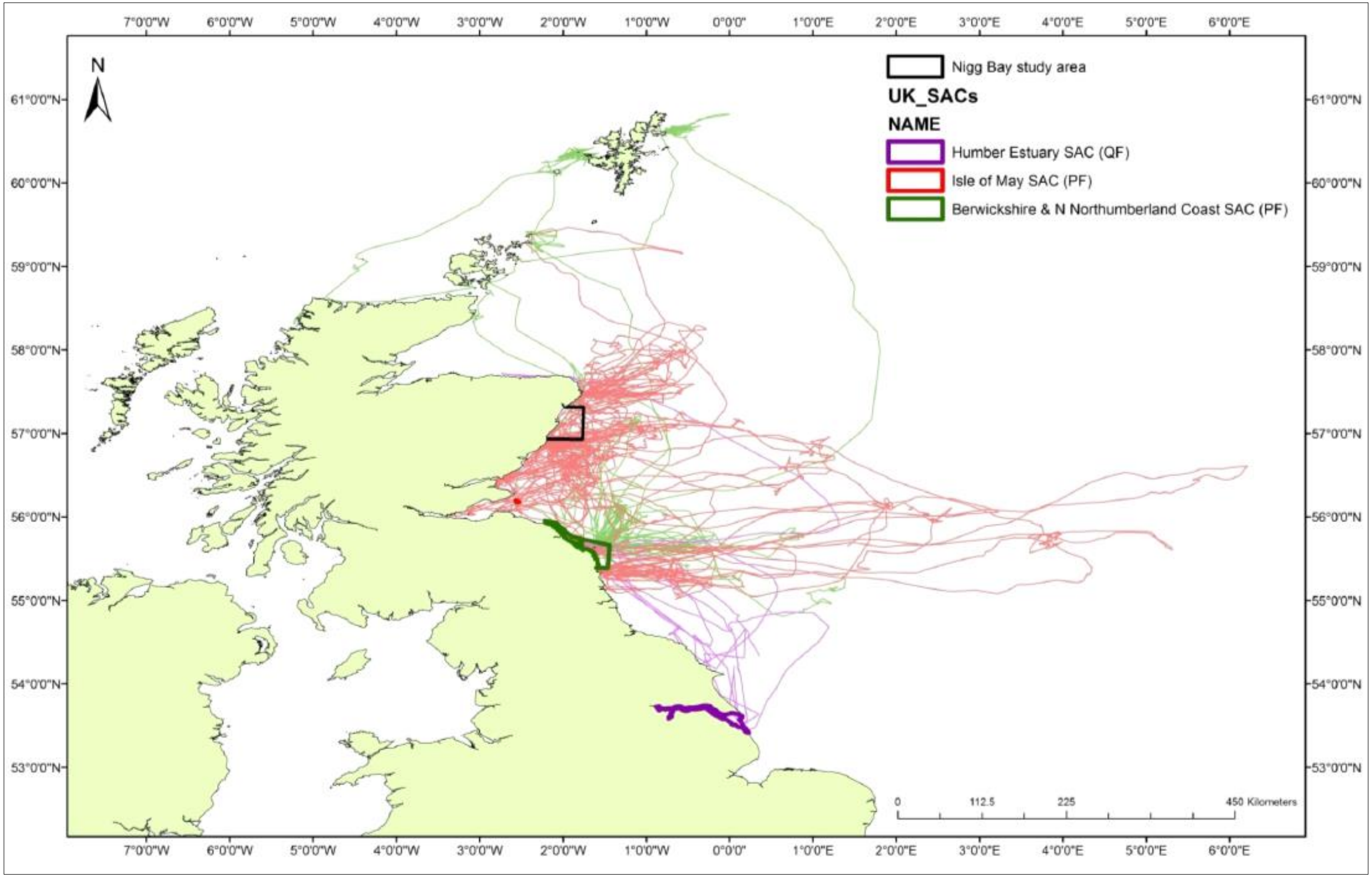

Figure 10-1: Tracks of grey seal tagged at grey seal SACs and that entered the Nigg Bay study area

(**Source:** Technical Appendix 15-B of the 2015 ES).

10.9.4 Ythan Estuary, Sands of Forvie and Meikle Loch SPA and Ythan Estuary, Sands of Forvie and Meikle Loch SPA Proposed Marine Extension – Non-breeding Eider Duck, Little Tern, Sandwich Tern and Common Tern

10.9.4.1 <u>Impacts of the AHEP Blasting Proposals Alone</u>

Terns are summer migrants to the wider Aberdeenshire coast. They feed on small fish and crustaceans by plunge diving from a few metres.

The AHEP lies outside of the mean breeding season foraging ranges for Sandwich tern (11.5 km) and Common tern (4.5 km) (Thaxter et al, 2012) using the Ythan Estuary, Sands of Forvie and Meikle Loch SPA but is within maximum ranges for these species. Modelled foraging distributions indicate that the Sandwich tern colony of this proposed SPA extension only makes low use of local area around Nigg Bay while the Little tern colony does not use the site or local environs at all (SNH, 2016). Pre-construction site specific surveys recorded terns using offshore areas in the outer Nigg Bay where there is sand eel habitat for foraging and also using the rocky shores in Greyhope Bay for roosting and as crèches for their young in summer (ES Chapter 14 and Technical Appendix 14-A) (AHB, 2015).

Eider duck are already currently displaced from Nigg Bay, as predicted in the previous ES, although individuals may occasionally be present within the AHEP boundaries. Eider are able to use other areas within the region and large numbers are known to occur at Blackdog Bridge of Don (Chapter 7 of this EIAR). Local moulting habitats at Girdle Ness and Greyhope Bay remain well utilised despite on-going AHEP construction (see section 7.2.1 of the EIAR).

Increases in the levels of airborne noise due to the proposed changes to the blasting methodology are likely to be imperceptible given that transmission of noise from water to air is very limited (see section 4.4.3 of the EIAR) so that any significant additional displacement of marine birds due to increased levels of noise is not expected. The majority of the remaining blasting will be undertaken to the south of the bay and thus will be further away from summer moulting aggregations of eider and roosting terns at Girdle Ness and Greyhope Bay.

The underwater noise impact modelling (Appendix B and section 7.5 of the EIAR)) showed that the radii of effect ranges of blasts for birds are very small (i.e. 25 m for a 100 kg weight charge) and so will be confined to within the AHEP boundaries and therefore will not affect eider duck or terns using adjacent areas. Increased sediment vibration due to the use of larger explosives is forecast to remain localised and not to affect the wider sand eel habitat offshore of the AHEP (see section 5.6 of the EIAR) so feeding of terns is not expected to be significantly affected.

A watch for rafting birds is already undertaken prior to each blast. Extending the time over which this watch is conducted would ensure that any submerged birds have re-surfaced prior to blasting (section 7.6 of this EIAR).

10.9.4.2 <u>Impacts of the AHEP Blasting Proposals In-combination with Other Projects</u>

Sandwich tern, Common tern and Little tern are highly unlikely to encounter or be displaced from other ‘noisy’ projects identified in Table 4.4 in-combination with the AHEP due to their comparatively limited foraging ranges and the distance separations between other projects with ‘noisy’ construction activities. In-combination effects are thus not expected with respect to terns.

Eider duck are flightless during their summer moult and have limited mobility and so are unlikely to be able transit between different projects and encounter multiple ‘noisy’ activities elsewhere in-combination with the AHEP blasting during this period. Monitoring of eider in Nigg Bay show that they generally avoid the AHEP construction site as previously predicted but still use adjacent areas.

From site specific survey it appears that eider duck, Common tern and Sandwich tern make little or no use of the waters within and around the Kincardine offshore wind farm (Atkins, 2016) so significant in-combination effects with this project are not expected.

10.9.4.3 Conclusion

Due to their limited use of the AHEP, it is considered that the tern and eider duck interests of the Ythan Estuary, Sands of Forvie and Meikle Loch SPA and Ythan Estuary, Sands of Forvie and Meikle Loch SPA proposed marine extension are not at any greater risk due to the proposed changes in blasting methodology than previously assessed. No LSE on the integrity of these sites is therefore forecast due to the proposed changes in blasting methodology either alone or in-combination with other plans or projects.

10.10 HRA Conclusion

It is considered that with the existing mitigation measures in place and the distance separations between the AHEP and other coastal and marine developments within the region, none of the wildlife populations for which local Natura sites are designated are likely to be significantly affected by the proposals either alone or in combination with any other plans and projects. This HRA is underpinned by specific underwater noise modelling and long-term population consequences modelling to qualify conclusions.

Individuals of the River Dee SAC Atlantic salmon, and indirectly the freshwater pearl mussel, populations inside the bubble curtain are likely to be at increased risk of mortality or potential mortal injury compared to the 2015 situation (AHB, 2015) due to the greater predicted impact ranges associated with the larger charge weights proposed here. Otherwise, salmonids and freshwater pearl mussel are at no greater risk than originally assessed outside of the bubble curtain. Fish scarers are used to minimise effects and strict reporting is undertaken of any salmonid killed. No salmonids have been reported as killed during any previous blasting.

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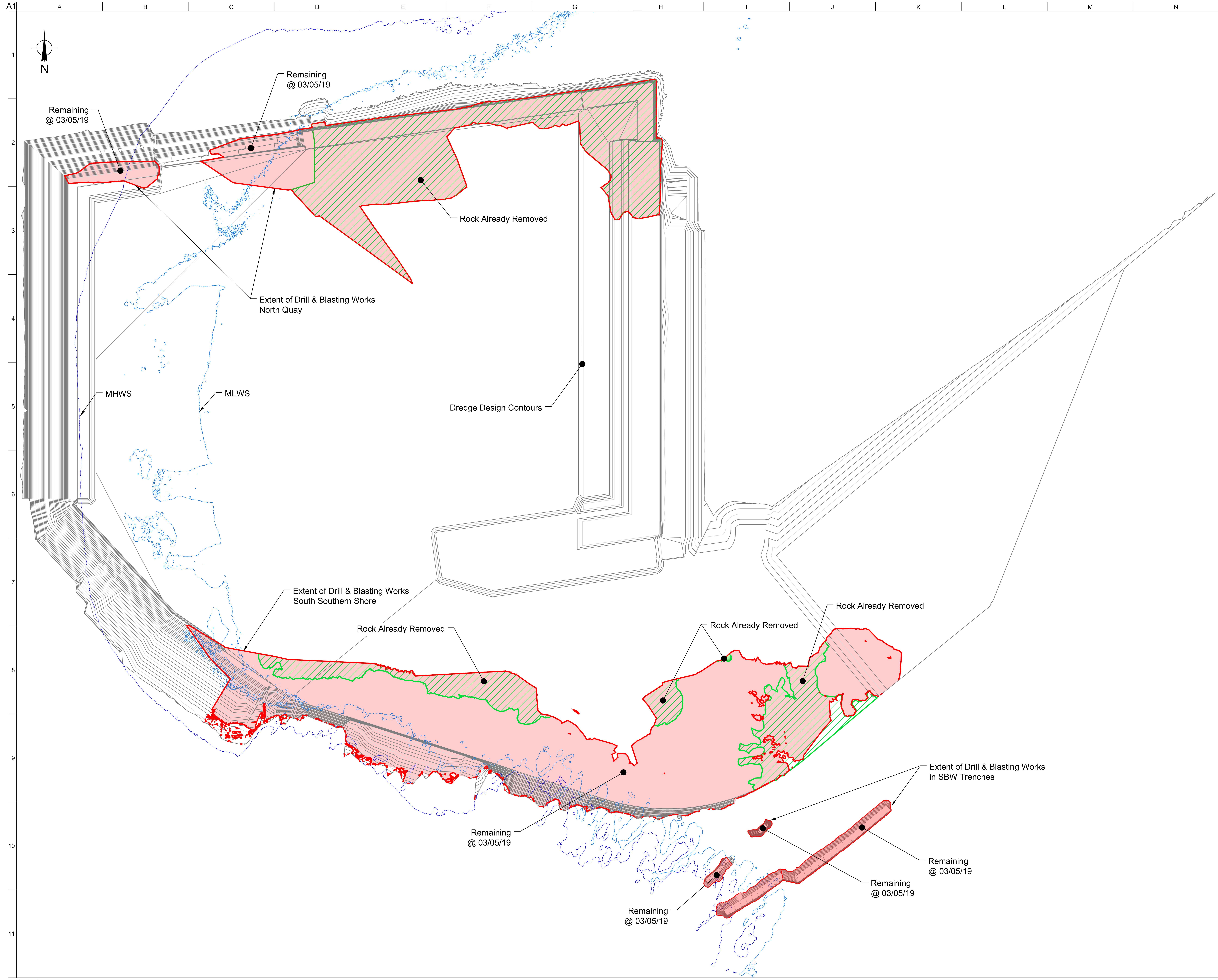
APPENDICES

A. MAP OF NIGG BAY CONSTRUCTION AREA



Notes:

1. All dimensions are in metres unless stated otherwise.
2. All levels are in metres to chart datum.

Key:

MHWS

MLWS

Drill and Blast Extents

Rock Already Removed

Drawing Status:

FOR INFORMATION ONLY
NOT VALID FOR CONSTRUCTION

Issue	Date	By	Chkd	Appd
0	03/05/19	CW	MM	MM
	Issued For Information			

DRAGADOS

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Client

Aberdeen Harbour

Job Title

Aberdeen Harbour
Expansion Project

Drill and Blasting
Work Areas

Scale at A1: Not To Scale

Discipline: Civil Engineering

Drawing Status: **Issued For Information**

Drawing No: **AHEP-DRA-SKE-0343-001**

Issue: **0**

Do not scale

B. UNDERWATER NOISE IMPACT MODELLING TECHNICAL REPORT

Aberdeen Harbour Expansion Project: Underwater acoustic impact study for increased blast charge weights

P D Ward
Award Environmental Consultants Ltd

Rep: 201807-002-V1.1

05 February 2019

Administration Page

Customer Information	
Customer reference number	
Project title	Aberdeen Harbour Expansion Project: Underwater acoustic impact study for increased blast charge weights
Customer Organisation	FUGRO GB Marine Ltd
Customer contact	Paul English
Contract number	AECL/201807-002-V1.1
Date due	05 February 2019

Principal authors	
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Record of changes		
Issue	**Date**	**Detail of Changes**
1	30 January 2019	First draft
1.1	05 February 2019	Impact distances revision

Contents

EXECUTIVE SUMMARY

This document has been prepared by Peter Ward of Award Environmental Consultants Ltd for FUGRO GB Marine Ltd. The key objective is to carry out underwater blast propagation modelling using a range of charge weights of explosive. From the ensuing results, it is required to establish distances at which underwater noise levels associated with blasting meet internationally agreed threshold levels relating to various acoustic impacts. The impact criteria, relating to mortality and potential injury; recoverable injury, permanent and temporary deafness; and behavioural responses, are given in terms of sound pressure level using both peak and root-mean-square metrics; sound exposure level and peak particle velocity.

The study concluded the following:

- when cetaceans exposed to blast noise are assessed using peak level and rms metrics, in the absence of a bubble curtain, for high-frequency cetaceans (being the most sensitive of all cetacean groupings considered when assessed using SPL metrics) the PTS impact criterion is met at a maximum distance of 17 km following the detonation of a 60 kg charge weight. The TTS impact is met at a distance of 26 km while that for Strong Behavioural Responses extends to a distance of 120 km. When a bubble curtain is located at a distance of 650 m from the blast site, the maximum distances over which the PTS and TTS impact criteria are met falls to 660 m and 2.5 km respectively. The Strong Behavioural Response criterion extends to a maximum distance of 16 km for both low- and medium frequency cetaceans while for the high-frequency cetaceans, the criterion is met at a maximum distance of 71 km. When the bubble curtain is installed at 100 m from the blast site the PTS and TTS impact criteria extend no further than 100 m for the low- and medium-frequency cetaceans. For high-frequency cetaceans the PTS and TTS impact criteria extend to 610 m and 2.5 km respectively;

- when the same functional hearing groups are assessed using sound exposure levels (SEL), in the absence of a bubble curtain, the PTS impact criterion is met at distances between 14 km and 24 km when considering all functional hearing groups. Similarly, the TTS impact criterion extends to a maximum distance of 51 km. When the bubble curtain is present at 650 m from the blast site, the PTS impact criterion extends to a maximum distance of 660 m while the TTS impact criterion is met at a maximum distance of 2.5 km. When the bubble curtain is located 100 m from the blast site, for the low- and medium-frequency cetaceans both PTS and TTS impact criteria are met at a distance of 100 m while that those for the high-frequency cetaceans are met at 610 m and 2.5 km;

- for phocid pinnipeds assessed using peak level and rms metrics, in the absence of a bubble curtain, the PTS and TTS impact criteria are met at maximum distances of 2.5 km and 6.9 km respectively following exposure to the 60 kg charge weight. The Strong Behavioural Response criterion is met over a maximum distance of 19 km. With a bubble curtain in place at 650 m both the PTS and TTS impact criteria are met at a maximum distance of 660 m, while the distance over which the Strong Behavioural Response impact extends is reduced to 770 m. For a bubble curtain located at 100 m,

both the PTS and TTS impact criteria are met at a maximum distance of 100 m while the Strong Behavioural Response impact remains at 770 m;

- when phocid pinnipeds are assessed using SEL metrics, with no bubble curtain installed the PTS and TTS impact criteria cover distances of 2.8 km and 17 km respectively. With a bubble curtain at 650 m, both criteria are met at 660 m. With a a bubble curtain located at 100 m the PTS impact criterion is met at 100 m while that for TTS extends to 560 m;

- for fish of all hearing abilities when assessed using peak level metrics, the distances over which the Mortality and Potential Mortal Injury criterion are met for all charge weights are so short that they fall at distances inside the bubble curtain when it is located at 650 m. Hence the Mortality and Potential Mortal Injury impact criterion is met at no more than 200 m from the blast site for the largest charge weight considered. When the bubble curtain is installed at 100 m from the blast site, this becomes the limit over which the impact extends for the largest charge weight considered. There is the possibility of a high risk that both the Recoverable Injury and the TTS impact criteria will be met at near distances to the blast site;

- for fish eggs and larvae the Mortality and Potential Mortal Injury is defined in terms of the Peak Particle Velocity. This impact is met at a maximum distance of 120 m from the blast site for the greatest charge weight considered. The distance over which this impact extends is unaffected by the presence of the bubble curtain;

- for seabirds impacts are assessed in terms of impulse. The Safe Level impact at which the birds are unharmed but may nevertheless be startled extends to a maximum distance of 19 m from the blast site. The distance over which this impact extends is unaffected by the presence of the bubble curtain.

1 INTRODUCTION

Construction work on the Aberdeen Harbour Expansion Project (AHEP) commenced in August 2018 with works whose objective was to increase the water depth at locations around Nigg Bay so that appropriate deep-water berths would be provided. This work, which is ongoing, is achieved by the detonation of explosive charges located in boreholes drilled into the seabed. The fractured rock is then removed with the aid of a dredging vessel.

The permit to proceed with the works followed the submission and approval of an environmental statement (ES) produced by FUGRO GB Marine Ltd in 2015. One key part of the ES documentation was an underwater noise study[1] which comprised an assessment of the impact of man-made noise, including explosive blast, on marine life. The study involved modelling the acoustic blast levels likely to arise following the detonation of an explosive charge having a maximum weight of 20 kg.

There is now a project requirement to increase the maximum permissible explosive charge weights to above 20 kg. As a result, the regulatory authorities require the production of a revised underwater noise impact study that reflects the proposed changes to the charge weights.

This report has been prepared by Peter Ward of Award Environmental Consultants Ltd on behalf of FUGRO GB Marine Ltd, to establish distances at which underwater blast noise levels meet relevant sound exposure criteria for marine mammals and fish (including eggs and larvae). This study comprises the following:

- Discussion of the source parameters relating to underwater explosive blast;
- Summary of relevant acoustic impact thresholds based on international published literature on studies of animal audiology, injury and behaviour, taking into account marine fauna known, or likely, to be present within the AHEP area;
- Description of the noise propagation modelling undertaken;
- Application of the acoustic impact models to determine the maximum distances over which each threshold is met; and
- Discussion of the results obtained.

[1] Aberdeen Harbour Expansion Project, Volume 3: Technical Appendices - Appendix 13-B Underwater Noise Impact Study, November 2015 - "Underwater noise impact study for Aberdeen Harbour Expansion Project: Impact of construction noise", Kongsberg Report 35283-0004-V5.

2 DESCRIPTION OF UNDERWATER NOISE AND ASSESSMENT UNITS

2.1 Introduction

Studies by Thomsen *et al.*[2] and Southall *et al.*[3] amongst others, provide detailed reviews of the metrics used to measure and assess the impact of underwater noise in the marine environment. A detailed discussion has not therefore been provided here, although a brief overview is provided to assist the reader. It is noted that a number of these definitions and parameters draw on the advice given in American National Standards Institute (ANSI) S12.7-1986[4].

Sound may be defined as the periodic disturbance in pressure from some equilibrium value. The unit of pressure is given in Pascals (Pa) or Newton per square metre (N/m^2). The measurements however cover a very wide range of pressure values, typically from 1×10^{-3} Pa for the hearing threshold value of a human diver at 1 kHz to 1×10^{7} Pa for the sound of a lightning strike on the sea surface. For convenience therefore, sound levels are expressed in decibels (dB) relative to a fixed reference pressure commonly 1 μPa for measurements made underwater.

2.2 Peak Sound Level

For transient pressure pulses such as an explosion or a single strike of an impact hammer, the peak sound level is the maximum absolute value of the instantaneous sound pressure recorded over a given time interval. Hence:

Peak Level (zero-to-peak) = $20 \times \log_{10} (P_{peak} / P_{ref})$ eqn. 2.1

When the pulse has approximately equal positive and negative parts to the waveform, the peak-to-peak level is often quoted and this is equal to twice the peak level or 6 dB higher.

2.3 RMS Sound Pressure Level

The Root-Mean-Square (RMS or rms) Sound Pressure Level (SPL) is used to quantify noise of a continuous nature. Underwater sound sources of this type include shipping, sonar transmissions, drilling or cutting operations, or background sea noise. The RMS SPL is the mean square pressure level measured over a given time interval (t), and hence represents a measure of the average sound pressure level over that time. It is expressed as:

RMS Sound Pressure Level = $20 \times \log_{10} (P_{RMS}/P_{ref})$ eqn. 2.2

When RMS SPLs are used to quantify the noise from transients arising from *e.g.* impact piling, the time period over which the measurements are averaged must be quoted as the RMS value will vary with the averaging time period: generally the longer the

[2] Thomsen F., Luedemann K., Kafemann R. and Piper W., (2006). "Effects of wind farm noise on marine mammals and fish". Biola, Hamburg, Germany on behalf of COWRIE Ltd. (Coll. Offshore Wind Res. Environ.) Ltd.

[3] Southall B.L., Bowles A.E., Ellison W.T., Finneran J.J., Gentry R.L., Greene Jr. C.R., Kastak D., Ketten D.R., Miller J.H., Nachtigall P.E., Richardson W.J., Thomas J.A., Tyack P.L., (2007), "Marine mammal noise exposure criteria: initial scientific recommendations". Aquatic Mammals 33, 411–521.

[4] ANSI S12.7-1986, "Methods for measurement of impulse noise", Issued by the American National Standards Institute, 20 February 1986.

averaging period, the greater the RMS SPL. When the noise is continuous, as in the examples given above, the time period over which measurements are taken is not relevant as the measurement will give the same result regardless of the period over which the measurements are averaged.

Peak SPLs may be converted to equivalent RMS SPL following consideration of the nature of the signal. For a sinusoidal signal, the relationship between peak level signal and the RMS equivalent is given by peak level – 3dB. Piling noise signals are not sinusoidal in shape so this conversion is not valid. Furthermore, during propagation the outgoing source signal stretches out in time (see *e.g*. Urick[5]) and this is attributed to the sound travelling along multiple paths and each arriving at a given location at a slightly different time. As a result, the difference between peak level and RMS varies with distance. Various studies[6,7,8] suggest a range of values between 2 dB and 20 dB. The lower the conversion factor, the greater the overestimation of RMS SPL for any given non-sinusoidal signal. For the purpose of the analysis undertaken in the earlier ES[1], and based on the assertion that the shape of the outgoing signal was unknown, it was recommended that a range-invariant 13 dB be used to convert all RMS metrics to peak level metrics. From the analysis that followed the acquisition of underwater noise data during the 2018 blasting programme[9], it was found that the conversion factors fell in the range 11-32 dB. Accordingly, a precautionary conversion factor of 11 dB is chosen for the subsequent analysis described herein.

2.4 Sound Exposure Level

The problems associated with the time period over which the Sound Pressure Levels are averaged, as highlighted above, can be overcome by describing a transient pressure wave in terms of its Sound Exposure Level (SEL). The SEL is the time integral of the square pressure over a time window long enough to include the entire pressure-time history. The SEL is therefore the sum of the acoustic energy over a measurement period, and effectively takes account of both the level of the sound, and the duration over which the sound is present in the acoustic environment. Sound Exposure (SE) is defined by the equation:

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

eqn. 2.3

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

5 Urick, Robert J. (1983), Principles of Underwater Sound, 3rd Edition. New York. McGraw-Hill.

6 Madsen P.T., (2005), "Marine mammals and noise: Problems with root mean square sound pressure levels for transients", J. Acoust. Soc. Am. 117(6), 3952.

7 Greene Jnr C.R.,"Physical acoustics measurements". In: W.J. Richardson (ed.) Northstar Marine Mammal Monitoring Program 1996: Marine Mammal and Acoustical Monitoring of a Seismic Program in the Alaskan Beaufort Sea. LGL Rep 2121-2, LGL Ltd, Canada and Greeneridge Sciences Inc. USA for BP (Alaska) Inc. and Nat. Mar. Fish Serv. Alaska. 245 pp.

8 McCauley, R.D., Fewtrell, J., Duncan, A.J., Jenner, C., Jenner, M.N., Penrose, J.D., Prince, R.I.T., Adhitya, A., Murdoch, J. and McCabe, K. (2000). Marine seismic surveys – a study of environmental implications. APPEA Journal 2000:692-708.

9 Ward P. D., "Aberdeen Harbour Expansion Project: Results of underwater noise monitoring during test blasting 2018, Award Env. Con Ltd Tech Report 201804-005-V0, December 2018.

To express the Sound Exposure as a logarithmic decibel, it is compared with a reference acoustic energy level of 1 μPa^2.s. The SEL is then defined by:

$$\mathrm{SEL} = 10\log_{10}\int_0^T \frac{p^2(t)dt}{\mathrm{P_{ref}}^2} \qquad \text{eqn. 2.4}$$

When the time period is less than 1 second, the RMS SPL is greater than the SEL. For signals of more than 1 second duration, the SEL will be greater than the RMS SPL where:

$\mathrm{SEL} = \mathrm{SPL} + 10 \times \log_{10}(T)$ eqn. 2.5

2.5 Cumulative Sound Exposure Level

Where multiple noise events occur, the total or cumulative SEL can be calculated by summing the SEL from the individual events. The events themselves may be separated in time or space or both. For instance, the events could be consecutive from impact piling at a given site or concurrent from two piling operations taking place in close proximity at the same time.

2.6 Source Level

The source level (SL) is the apparent strength of a noise source at a reference distance, usually 1 m, from the source. For example, a source may be quoted as having a source SPL of 180 dB re.1μPa at 1 m. In practise the parameters of the source are rarely measured at such a close range and the source level is inferred by back-propagating the noise from a number of far field measurements.

2.7 Transmission Loss

The transmission loss (TL) represents the loss in intensity or pressure of the acoustic field strength as the noise propagates from source to a receptor. In general, terms the transmission loss is given by:

$\mathrm{TL} = N \log(r) + \alpha r$ eqn. 2.6

where r is the range from the source, N is a factor for attenuation due to geometric spreading, and α (in dB.km-1) is a factor for the absorption of sound in water. Rarely is transmission loss as simply described as this; the subject is discussed further in Section 5.

It is noted that the terms transmission loss and propagation loss (PL) are synonymous.

2.8 Received Level

The Received level (RL) is the strength of the acoustic field at a given depth and range relative to the source. At a range r from a source, this is given by:

$\mathrm{RL} = \mathrm{SL} - \mathrm{TL}$ eqn. 2.7

From eqn 2.6, this can be written in the form:

$$RL = SL - N \log(r) - \alpha r \qquad \text{eqn. 2.8}$$

As the sound level varies with range, it is important to state the range at which the measurement has been taken or the estimate has been made.

3 SOUND SOURCE CHARACTERISTICS

3.1 Blasting scenario

The objective of rock blasting in Nigg Bay is to fracture and remove the bedrock in order to increase water depth at key locations.

In preparation, a given blast site has a number of holes, varying from 10-20 to as many as 140-150, drilled 0.125 m diameter down to a depth of 2.5 m below dredge level. In practice this means that up to 12 m of bedrock is to be removed. Currently each drill hole is loaded with up to 20 kg of high explosive – the precise amount depends on how much bedrock is to be fractured. The explosives are wired together with time delays between each hole in order to effect a staged sequence of blasts. Two time delays are available; 25 ms and 40 ms. The boreholes are then packed with a stemming plug. This is an inert material such as crushed stone the purpose of which is to prevent the combustion gases and the shock wave from being transmitted directly into the water. Pentolite-based detonators initiate the explosions and the fractured rock is then removed using the backhoe dredger. At the moment of detonation underwater noise is generated and this has the potential to impact on marine life.

3.2 Blast noise

A review of the published literature revealed that there was very little information on which it is possible to determine underwater blast levels following the detonation of an explosive charge. For explosions in open water (as opposed to the confined blasting undertaken in Nigg Bay), the initial outgoing shock wave eventually collapses in on itself before oscillating a number of times[5]. The peak value, which occurs around a microsecond after detonation is given by the empirical expression[10]

$$P_{peak} = 5.24 \text{ x } 10^{13} \left[\frac{W^{1/3}}{R}\right]^{1.13} \ \mu\text{Pa} \qquad \text{eqn 3.1}$$

where W is the charge weight in kg; and R is the distance from the blast site. For a 20 kg charge, the peak pressure in open water at a distance of 12 m from the blast site is 259 dB re 1 μPa. When the explosive is contained in a borehole and the shock wave propagates through bed rock, it is likely that the peak pressure will be reduced[11]. The above equation is therefore no longer adequate and hence needs to be modified somewhat.

[10] Cole, R. H. (1948). Underwater Explosions. Princeton University Press, Princeton, New Jersey. 437 pp.

[11] Baker K., (2008), "Assessment and Mitigation of Marine Explosives: Guidance for Protected Species in the Southeast U.S". National Marine Fisheries Service draft report.

A study by Nedwell and Thandavamoorthy[12] involved measurements in water from detonations in bore holes. These indicated that the peak pressure could be as low as 6% of that generated in equivalent, open water conditions. During the Miami harbour deepening project, Hempen *et al*.[13] showed levels of blast pressure in water following borehole detonations, falling to 19% to 41% of that recorded in open water. Wright and Hopky[14] proposed a semi-empirical technique to determine the distance between a blast site and a fish habitat such that limiting thresholds for peak particle velocity and peak pressure would not be exceeded. The peak pressure is seen to be weakly dependent on the charge weight (similar to that given in eqn 3.1 above) and the technique also incorporates pressure coefficients[5] that permit the transmission of sound across the bedrock-water interface. The underpinning data was derived from measurements of underwater blast recorded at the nearest location in the water to the blast site. Given the physical similarity of this arrangement to that of the Nigg Bay blasting scenario it is deemed appropriate to develop further the Wright and Hopky[14] technique so that peak pressure levels in the water may be modelled. This is described in detail in Section 5 below.

[12] Nedwell, J. R., Thandavamoorthy, T. S., 1992. The Water Borne Pressure Wave from Buried Explosive Charges, An Experimental Investigation, Applied Acoustics, 37, 1-14.
[13] Hempen, G.L., T.M. Keevin, and T.L. Jordan. (2007). Underwater Blast Pressures from a Confined Rock Removal During the Miami Harbor Deepening Project. International Society of Explosives Engineers, 2007 G Volume 1, 12 pp.
[14] Wright D.G., Hopky G.E., (1998), "Guidelines for the Use of Explosives In or Near Canadian Fisheries Waters", Canadian Technical Report of Fisheries and Aquatic Sciences 2107, Department of Fisheries and Oceans, Canada.

4 CRITERIA FOR ASSESSING IMPACTS UPON MARINE FAUNA

4.1 Introduction

This section commences with an overview of the animal species found in and around the AHEP area. It is followed by a discussion of the assessment criteria against which the impact of underwater blast on marine species is quantified. These criteria are used to estimate impact zones about the sound sources using the results from underwater sound propagation modelling.

Since the ES[1] was issued in 2015, it is understood that no additional marine species have been found in the area. However, the science underpinning the establishment of acoustic impact criteria and their corresponding thresholds for both marine mammals and fish species has been updated significantly. Accordingly, the changes are reflected in this section.

4.2 Species of interest to the AHEP Area

4.2.1 Introduction

Studies previously commissioned by the client have identified a number of species of fish, invertebrates and marine mammals as being present in and around the Aberdeen Harbour Expansion Project area. This section provides an overview of the susceptibility of the species to underwater sound as far as is known and also notes their conservation status according to the Red List of the International Union for Conservation of Nature (IUCN)[15] and the presence of any other legislation covering their environmental sensitivity or denoting a relevant management plan.

4.2.2 Mammals

A number of species of mammal are regularly found in and around the AHEP area. Table 4.1 notes the species especially of concern to this study along with their conservation status.

Cetaceans make extensive use of underwater sound and have hearing that is highly tuned for the undersea environment[15]. Their susceptibility to impacts arising through the introduction of man-made noise into the marine environment is subsequently well documented. The cetacean species of concern to the development are bottlenose dolphin and harbour porpoise. Bottlenose dolphin are a feature of the Moray Firth Special Area of Conservation (SAC)[16] and may be found around the mouth of Aberdeen harbour throughout the year. White beaked dolphin, Risso's dolphin and minke whale are also seen from time to time in and around Aberdeen Bay.

The pinniped species present in the development area are harbour seals and grey seals. Although seals are classed as marine mammals they spend considerable periods of time on land. As a consequence, seals are known to hear very well in-air as well as underwater. When diving or swimming, they may be susceptible to impacts arising

15 The IUCN Red List of Threatened Species. Version 2018-2, http://www.iucnredlist.org. Accessed January 2019. (CR – Critically Endangered, EN – Endangered, VU – Vulnerable, NT - Near Threatened, LC - Least Concern, DD - Data Deficient, NE - Not Evaluated).

16 Joint Nature Conservation Committee (JNCC) website accessed at http://jncc.defra.gov.uk

from high levels of underwater sound. Equally, when on land, they may be liable to impacts arising through the emission of sound in-air such as construction noise.

The only other species of concern to the development is the otter. The European otter (*Lutra lutra*) is a terrestrial mammal that also spends time in coastal seas. It is not to be confused with the sea otter (*Enhydra lutris*) which is classified as a marine mammal and is found around the coasts of the north and eastern Pacific Ocean. There is no hearing data on the European otter however audiograms have been obtained for the sea otter[17]. These indicate that the otter's peak underwater hearing sensitivity lies in the range 7 kHz to 16 kHz while overall sensitivity levels are somewhat reduced compared with pinniped species.

Mammals	Legal / Conservation Status
Cetacea	
Harbour porpoise (*Phocoena phocoena)*	IUCN Least Concern, Annex II, IV of Habitats Directive, EPS
Common bottlenose dolphin *(Tursiops truncatus)*	IUCN Least Concern, Annex II, IV of Habitats Directive, EPS
White beaked dolphin (*Lagenorhynchus albirostris*)	IUCN Least Concern, Annex IV of Habitats Directive, EPS
Risso's dolphin (*Grampus griseus*)	IUCN Least Concern, Annex IV of Habitats Directive, EPS
Minke whale (*Balaenoptera acutorostrata*)	IUCN Least Concern, Annex IV of Habitats Directive, EPS
Pinnipedia	
Common or Harbour seal (*Phoca vitulina*)	IUCN Least Concern, Annex II, IV of Habitats Directive, EPS
Grey seal (*Halichoerus grypus*)	IUCN Least Concern, Annex II, IV of Habitats Directive, EPS
Other species	
European otter (Lutra lutra)	IUCN Near Threatened, EPS

Table 4.1: Marine mammal species found in the Aberdeen Harbour Expansion Project area

4.2.3 Fish

Table 4.2 lists the species of fish of conservation concern found in and around the Aberdeen Harbour Expansion Project area. Also noted is the sensitivity of the fish to sound where this draws on discussions by Fay and Popper[18] and Popper and Fay[19]. It was observed that the relative sensitivity of fish to underwater sound is dependent on their internal physiology. Some fish species lack a swim bladder (*e.g*. dab, plaice) and as a consequence they have poor sensitivity to sound and thus relatively poor hearing. By contrast, a number of fish species do possess a swim bladder. This gas-filled sac performs several different functions such as acting as a float which gives the fish buoyancy; as a lung; and as a sound-producing organ. In addition, the swim bladder can enhance the hearing capability of the fish species through the amplification of underwater sound although this alone, would not necessarily make such a fish highly sensitive to sound. These fish would be deemed to have a moderate level of auditory

[17] Ghoul A., Reichmuth C., (2014), "Hearing in the sea otter (Enhydra lutris): auditory profiles for an amphibious marine carnivore", Journal of Comparative Physiology A; 200(11):967-81. Sage Journals OnlineFirst.
[18] Fay R.R. & Popper A.N. (eds) (1999) Comparative Hearing: Fish and Amphibians. New York: Springer-Verlag.
[19] Popper A. N. & R. R. Fay (2009). "Rethinking sound detection by fishes". Hearing Research.

sensitivity. For some species (*e.g*. members of the herring family) there is a connection between the inner ear and the swim bladder and it is this feature which results in them being the most sensitive to underwater noise. Subsequently, there is the potential for such species to be more susceptible to acoustic impacts than fish with low or medium hearing sensitivity.

Of all the fish species of interest to AHEP only herring and cod may be classed as having high auditory sensitivity and this is borne out by audiogram data[20]. Eel, sea trout and salmon all have a gas-filled swim bladder but nevertheless lack the connection between the swim bladder and the internal ear. These species are all moderately sensitive to underwater noise[21]. By contrast, there is a general lack of information on hearing in lamprey and no audiograms have been reported. They lack any specialist hearing structures hence they are considered to have low sensitivity to underwater sound[22].

Fish	Legal / Conservation status[23]	Hearing sensitivity
Sea lamprey (Petromyzon marinus)	IUCN Least Concern	Low
River lamprey (Lampetra fluviatilis)	IUCN Least Concern	Low
Eel (Anguilla anguilla)	IUCN Critically Endangered, CITES App II	Medium
Sea trout (Salmo trutta trutta)	IUCN Least Concern BAP, PMF,	Medium
Cod (Gadus morhua)	IUCN Vulnerable	High
Herring (Clupea harengus)	IUCN Least Concern, BAP, NERC PI, EU MP	High
Atlantic salmon (*Salmo salar*)	IUCN Least Concern, Ann II, V Hab Dir, BAP, PMF, OSPAR, NERC PI	Low

Table 4.2: Fish species found in and around the Aberdeen Harbour Expansion Project area

4.2.4 Seabirds

Various species of seabirds may be seen at the coast and these can spend short periods of time diving for food underwater. Key species that may be seen in and around the AHEP area are listed in Table 4.3 below along with their IUCN conservation status.

Puffins will dive to the seabed in the search for sandeels, often returning to the sea surface with several in their bill; the guillemot dives down to a depth of 60 m for food, mostly fish; while the gannet dives for fish under water from a height of 20 m or more, entering the water at speeds over 90 km/hr.

The avian ear provides a means of both hearing and balance and is found to be somewhat similar in structure to the mammalian ear in that it comprises three parts:

[20] Enger, P.S., (1967), "Hearing in herring". Comp. Biochem. Physiol. 22:527-538.

[21] Popper, A. N., Fay, R. R., Platt, C. & Sand, O. (2003). "Sound detection mechanisms and capabilities of teleost fishes". In Sensory Processing in Aquatic Environments (Ed Collin, S. P. & Marshall, N. J.), pp. 3–38. New York, NY: Springer-Verlag.

[22] Popper A. N., (2005), "A Review of Hearing by Sturgeon and Lamprey", Report submitted to the US Army Corps of Engineers, Portland District.

[23] Ann II, IV Hab Dir – Annex II, IV Habitats Directive (1992); BAP – UK Biodiversity Action Plan (1994); PMF –Priority Marine Feature in Scottish waters; OSPAR – OSPAR Convention (1992); BC App II, III – Bern Convention Appendix II, Appendix III; CITES App II (1963), EU MP – European Union Management Plan, NERC PI –Principle Importance under Section 41 of NERC Act 2006

an external ear; a middle ear and an inner ear. A number of species have been tested audiologically in air and are known to be sensitive around the frequency range 250 Hz to 8 kHz. Until recently, the functionality of the avian ear underwater was based on comparisons with the human ear in air and in water[24] where it was found that the range of key sensitivity was shifted down to below 2-4 kHz and that trapped air may allow the middle ear to function as a swim bladder in fish. Electrophysiological methods have been deployed to measure the in-air hearing of ten species of seabirds but as yet there are no data on the underwater hearing abilities of diving birds[25].

Seabirds	Legal / Conservation Status
Guillemot (*Uria aalge*)	IUCN Least Concern
Black guillemot (*Cepphus grylie*)	IUCN Least Concern
Gannet (Morus bassanus)	IUCN Least Concern
Puffin (Fratercula arctica)	IUCN Vulnerable
Arctic tern (Sterna paradisaea)	IUCN Least Concern
Great skua (Catharacta skua)	IUCN Least Concern
Manx shearwater (*Puffinus puffinus*)	IUCN Least Concern
Razorbill (*Alca torda*)	IUCN Near Threatened

Table 4.3: Seabird species found in and around the Aberdeen Harbour Expansion Project area

4.3 Acoustic impact thresholds

Following the methodology presented by Southall *et al*.[3] subsequently updated by NMFS[26] for marine mammals; and Popper *et al*.[27] for fish, the marine species found in and around the AHEP area have been divided into a total of 8 functional hearing groups and these are listed in Table 4.4 below. There are no data on underwater hearing of seabirds so they fall outside this paradigm.

Noting hearing damage can arise through exposure to a single loud noise or else to a lower level over a longer period of time, Southall *et al*.[3], NMFS[26] and Popper *et al*.[27] provide threshold levels using both SPL and SEL metrics for, where appropriate, percussive type noises such as that produced by explosive blast and continuous noises such as that produced by vessels.

[24] Dooling R. J., Therrien S. C., "Hearing in birds: what changes from air to water", Advances in Experimental Medicine and Biology. 730:77-82, 2012.

[25] Crowell S. C., "Measuring In-Air and Underwater Hearing in Seabirds", Advances in Experimental Medicine and Biology. 875:1155-60, 2016.

[26] 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. NOAA Technical Memorandum NMFS-OPR-55, 178 p.

[27] 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., Løkkeborg, 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.

Functional hearing group	Note
Low-frequency cetaceans (Mlf)	Minke
Medium-frequency cetaceans (Mmf)	Common bottlenose dolphin, White beaked dolphin, Risso's dolphin
High-frequency cetaceans (Mhf)	Harbour porpoise
Phocid pinnipeds (Mpw)	True seals – Harbour seal, Grey seal
Hearing generalist ("low sensitivity") fish[28]	Species with no swim bladder or other gas-filled chamber that are less susceptible to barotraumas and only detect particle, not sound pressure. However some barotraumas could result from exposure to sound pressure.
Hearing generalist ("medium sensitivity") fish	Species with swim bladders in which hearing is separate from the swim bladder or any other gas-filled chamber. While hearing only involves particle motion not sound pressure these species are susceptible to barotrauma.
Hearing specialist fish	Species in which hearing involves a swim bladder or other gas-filled chamber, these species are susceptible to barotrauma as well as particle motion.
Fish eggs and larvae	-

Table 4.4: Functional hearing groups for species known or likely to be present within the vicinity of the project area

4.3.1 Marine mammals

For marine mammals, threshold levels for permanent hearing damage (indicated by Permanent Threshold Shift (PTS)) and temporary hearing damage (indicated by Temporary Threshold Shift (TTS)) in SPL(peak) and SEL metrics following exposure to impulsive noise and continuous noise are given in Table 4.5. Southall *et al.*[3] note that when dual metric criteria are available then the most precautionary is the preferred option.

Southall *et al*.[3] point out that the SEL-based thresholds for marine mammals are related to the animal's audiological sensitivity. As with humans, marine mammals do not hear equally well across all frequencies. In order to account for this, the researchers proposed a series of frequency-dependent weightings that were applied to the hearing sensitivity curves for each functional hearing group. These have the effect of emphasising the frequencies over which the animals are most sensitive and de-emphasising the remaining frequencies. Collectively these are known as M-weightings (see Figure 4.1), sets of which are applied to the hearing sensitivity curves for each of the marine mammal functional hearing groups listed in Table 4.4.

Threshold levels for various behavioural effects were derived by Southall *et al*.[3] having reviewed a considerable body of research involving the behaviour of animals when exposed to man-made underwater sound of varying sound level, frequency and duration. Observations of the resulting behavioural response were standardised by being quantified on a Behavioural Response Severity Scale (BRSS) ranging from 0 (No observable response) through to 9 (Outright panic, flight, stampede, stranding).

[28] Strictly, fish are classed as being hearing-specialist or hearing-generalist. In the latter case, physiological differences account for the fact that some species of hearing-generalist fish are more audiologically sensitive than other species. In order to differentiate between these two groups, the terms "low sensitivity" and "medium sensitivity" are used. It is acknowledged that this terminology is not used widely outside this note, it is nevertheless considered helpful to use these terms from an environmental impact assessment perspective as a range of fish species are present in the project area.

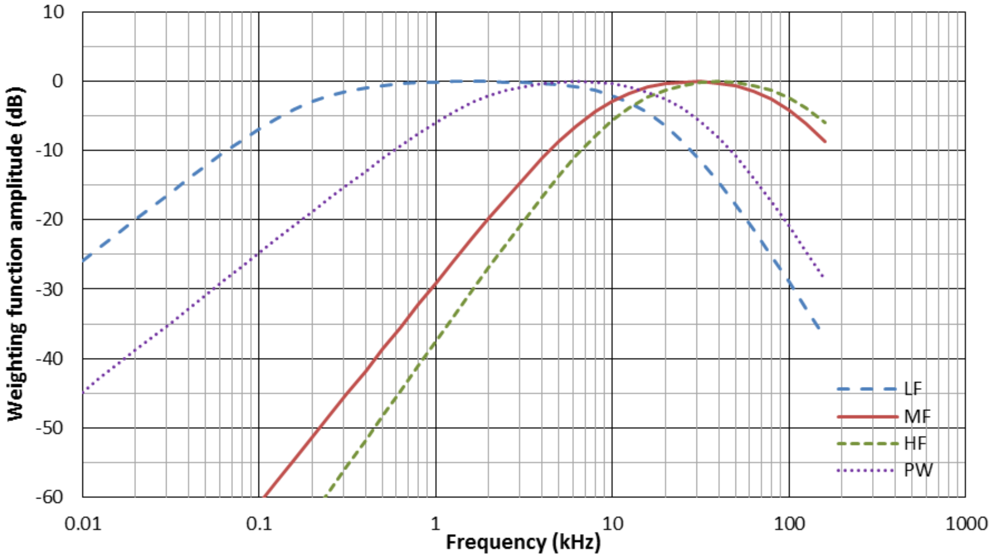

Figure 4.1: Underwater auditory weighting functions for marine mammal functional hearing groups

Having defined a BRSS, Southall *et al.*[3] provided a range of sound pressure levels on the animal over which each behavioural response had been observed. The ensuing data were categorized into 10-dB SPL bins and then ranked by the severity of the behavioural response observed over that SPL range. This tended to show that the higher the SPL on the animal the greater the BRSS score and the more severe the behavioural response.

It is noted that frequently, the data on which the BRSS is based is somewhat sparse, consisting as it does of relatively few observations of animal behaviour; behavioural responses being variable, context-dependent (*i.e.* costs or benefits of fight-or-flight) and less predictable than physical/physiological effects; and there being a considerable overlap in the range of sound pressure levels over which a given mode of behaviour might be prevalent. Some degree of interpretation and extrapolation is thus required when applying the data in the manner required in the current study. For instance, Southall *et al.*[3] show that for a given severity response score the BRSS may indicate that more animals were observed giving a strong response to noises having low SPLs than at higher SPLs. This challenges the idea behind the continuum represented by the BRSS that low SPLs produce weak responses and high SPLs lead to stronger responses. Digging deeper into the data reveals that some of the observations may relate to species of marine mammal not found in the project area hence these data can reasonably be overlooked.

It is understood that Southall has refined and updated the noise exposure criteria presented in the NMFS update report[26,29] and also substantially revised the behavioural response severity scale (in press). Where appropriate, such changes will be reflected in subsequent acoustic impact modelling. In the absence of a metric to assess and quantify adverse behavioural effects of noise exposure, and pending the publication of

[29] Southall B., (2018), "Biological importance of sound to marine mammals", Workshop on the NOAA Guidance on Underwater Acoustic Exposure for Marine Mammals, London, UK.

the aforementioned updated guidance, the best available information has been applied at time of writing.

For the behavioural responses given in Table 4.6: "Strong Responses" have a BRSS rating of 6 and are represented by extensive and/or prolonged changes in the behavioural traits mentioned above as well as aggressive behaviour amongst individuals and brief or minor separations of females and dependent offspring. By contrast, "No response" has a BRSS of 0 where no change in behavioural response was observed.

Functional hearing group	Unweighted peak thresholds dB re 1 μPa Peak		M-weighted SEL thresholds dB re 1 μPa^2 s	
	PTS	TTS	PTS	TTS
Cetaceans LF	219	213	183	168
Cetaceans HF	230	224	185	170
Cetaceans VHF	202	196	155	140
Phocids MPCW	218	212	185	170

Table 4.5: Summary of acoustic impact threshold criteria for PTS and TTS for each functional hearing group when exposed to explosive noise

Functional hearing group	Strong responses dB re 1 μPa rms	No responses dB re 1 μPa rms
Cetaceans LF	170 - 180	120 - 130
Cetaceans HF	170 - 180	130 - 140
Cetaceans VHF	140 - 150	90 - 100
Phocids MPCW	190 - 200	170 - 180

Table 4.6: Summary of acoustic impact threshold criteria for behavioural effects for each functional hearing group when exposed to explosive noise

4.3.2 Fish

Popper *et al*.[27] conducted a similar process for fish as Southall *et al*.[3] had completed for marine mammals where they reviewed a number of studies and subsequently suggested various noise thresholds related to potential impacts that were a function of the hearing sensitivity of fish species. The hearing function groupings, labelled as "High sensitivity"; "Medium sensitivity"; and "Low sensitivity"; refer back to studies either of the internal physiology of the fish or else to their auditory sensitivity (see Section 4.2 above).

Popper *et al*.[27] state that when taking into account the different species tested; the different types of explosive considered; and the differing charge weights, ultimately there are little or no consensus data on exposure or received levels that enable guideline threshold levels to be set for each functional hearing group.

For fish, Table 4.7 shows threshold levels for mortality and potential mortal injury are given in SPL metrics while those for recoverable injury (denoted by hair cell damage, minor internal or external hematoma (pooling of blood outside the blood vessels), etc. where none of the injuries are likely to result in mortality) and hearing impairment (TTS) are given in terms of relative risk and the distances are expressed qualitatively rather than quantitatively.

Functional hearing group	Mortality and potential injury	Recoverable injury	TTS
Hearing generalist fish ("Low-sensitivity")	229-234 dB re 1 µPa Peak	High risk at near distance Low risk at all other distances	High risk at near distance Moderate risk at intermediate distance Low risk at far distance
Hearing generalist fish ("Medium-sensitivity")	229-234 dB re 1 µPa Peak	High risk at near and intermediate distances Low risk at far distance	High risk at near distance Moderate risk at intermediate distance Low risk at far distance
Hearing specialist fish	229-234 dB re 1 µPa Peak	High risk at near and intermediate distances Low risk at far distance	High risk at near and intermediate distances Low risk at far distance
Fish eggs and larvae	>13 mm s^{-1}peak velocity	High risk at near distance Low risk at all other distances	High risk at near distance Low risk at all other distances

Table 4.7: Summary of acoustic impact threshold criteria for fish

4.3.3 Seabirds

Lewis[30] reviewed a number of studies that discussed the effects of explosive blast on seabirds. The underpinning data was based on ducks held underwater and exposed to an in-water explosive blast. The impact on the birds was found to vary with size of explosive charge and distance to the blast. On post-mortem the ducks nearest to the blast were found to have extensive pulmonary haemorrhage, ruptured livers and kidneys, ruptured air sacs and coronary air embolism. Further out, the damage was limited to lung haemorrhage and liver and kidney damage. From such studies, underwater blast impact criteria were established[31,32] and these are summarised in Table 4.8 below.

For seabirds, the impulse (as opposed to peak or rms pressure) is the metric against which impacts are quantified. This is a measure of the maximum pressure over a period of time and is thus most suitable for impulse-type noise.

Impulse (Pascal.seconds)	Criteria
896-1030	50% mortality. Survivors seriously injured and might not survive on their own.
690-827	Mortality threshold. Most survive; moderate blast injuries and should survive on their own.
276-413	Slight blast injuries.
207	Safe level.

Table 4.8: Summary of acoustic impact threshold criteria for seabirds

[30] Lewis J., (1996), "Effects of underwater explosions on life in the sea". Published by DSTO Aeronautical and Maritime Research Laboratory, Melbourne, Australia. DSTO-GD-0080.

[31] Yelverton J. T., Richmond D. R., Fletcher E. R., Jones R. K., "Safe distances from underwater explosions for mammals and birds", Report DNA 3114T, Washington DC. Defense Nuclear Agency.

[32] Richmond D. R., Jones R. K., "Safe distances from underwater explosions for mammals and birds", In G. A. Young (Ed.) Proceedings of the 1st conference on the environmental effects of explosives and explosions (May 30-31, 1973), Tech. Rep. 73-223, pp. 113-118, White Oak, MD: Naval Ordnance Lab.

5 UNDERWATER ACOUSTIC PROPAGATION MODELLING

5.1 Introduction

The confined-blast modelling described in the earlier ES[1] drew on a semi-empirical technique developed by Wright and Hopky[14]. Predictions of expected peak blast level were made and this was followed by a requirement to verify the predictions where possible using measurements of underwater noise acquired during the ensuing blasting programme.

When the initial blasting programme in Nigg Bay commenced, measurements of underwater blast noise were routinely recorded over the period August to October 2018 (i) in order to verify the model output; and (ii) to monitor noise levels for the purpose of maintaining environmental compliance. During the following data analysis it was found that the confined-blast model consistently underestimated peak blast levels by up to 32 dB. This prompted a revision of the confined-blast model which henceforth gave a much improved fit using additional data subsequently acquired during the blasting program that took place in November 2018[9].

The following sections describe the modified confined-blast model along with the input data parameters required to populate the model.

5.2 Rockborne wave

When an explosive charge confined in a bore hole detonates, a shock wave consisting of a near-instantaneous region of high pressure is created. The outgoing wavefront is of such intensity that it overcomes the cohesive strength of the surrounding rock thus causing it to shatter.

Wright and Hopky[14] present a semi-empirical technique that models the transmission of sound from an explosion in a borehole and hence determines the distance at which sound levels have fallen to given levels. As a result, it is possible to generate a very simple model of the environment in which the waterborne blast wave decays and this is used as a starting point to model the propagation of a blast wave in the water.

A detonation takes place at location *o* as indicated in Figure 5.1. The initial source level in the rock is given by SL dB re 1 μPa at 1 m. The blast wave propagates through the surrounding bedrock and it undergoes a degree of attenuation which is proportional to the path length over which it has travelled.

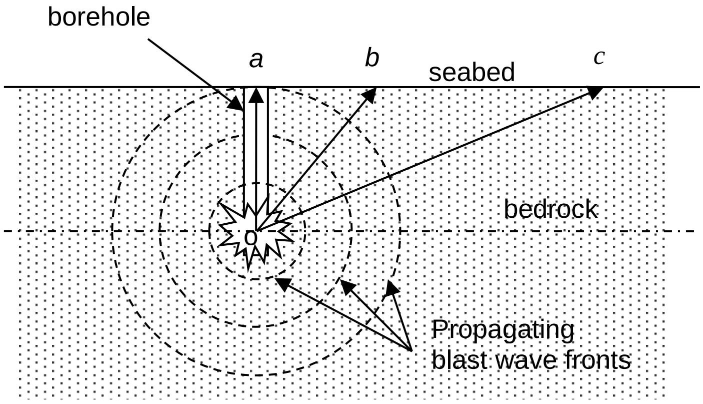

Figure 5.1: Schematic of confined blasting scenario

At location *a* on the seabed immediately above the detonation site, the blast wave has travelled through the distance *oa*. The attenuating nature of the bedrock ensures that acoustic energy is absorbed and dissipated into the rock thereby reducing the blast wave pressure level by an amount equal to $\alpha(oa)$ dB. The blast wave pressure level (BPL) at location *a* is thus given by:

$$BPL_{oa} = SL - \alpha(oa) \qquad \text{(i)}$$

At some lateral distance *b* from the detonation site, the blast wave has travelled over a longer path given by *ob*. Hence the attenuation in the bedrock is given by $\alpha(xb)$ dB and the blast wave pressure level at location *b* is given by

$$BPL_{ob} = SL - \alpha(ob) \qquad \text{(ii)}$$

Similarly, the blast wave pressure level at location *c* is given by

$$BPL_{oc} = SL - \alpha(oc) \qquad \text{(iii)}$$

It is noted that the further the wavefront propagates through the rock the smaller the BPL at the seabed hence $BPL_{oc} < BPL_{ob} < BPL_{oa}$.

Using the equations developed by Wright and Hopky[14], the explosive blast peak pressure level as a function of distance from the detonation site may be calculated and the results for a 20 kg charge weight are shown in Figure 5.2. This shows that the instantaneous peak level at a distance of 1 m from the detonation site is 244 dB re 1 μPa falling to approximately 200 dB re 1 μPa at a distance of 100 m and 167 dB re 1 μPa at a distance of 1000 m.

It is important to caveat these results: the blast propagation model assumes a very simple representation of the environment whereby the bedrock is single-layered and homogenous in nature. In practice, it is known that the seabed sediments at Nigg Bay consists of sandstone of varying thickness and which overlays a metamorphic bedrock. The effect of such layering on the propagation of the blast wave is not known but is thought likely that the amplitude of the peak blast level will be reduced through the introduction of further acoustic losses as the wave front propagates over the interface between the two layers.

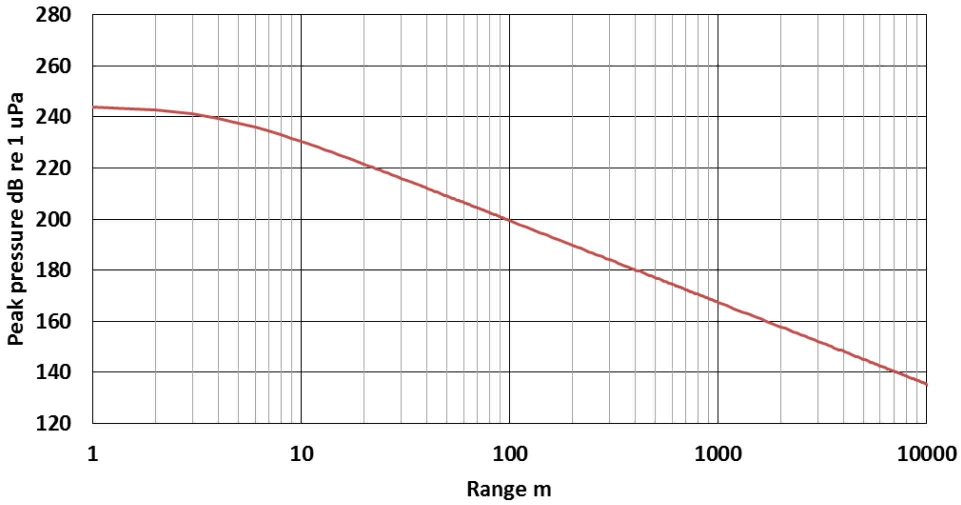

Figure 5.2: Rockborne blast levels for a 20 kg charge weight in a borehole 2.5 m deep, as a function of distance from the detonation site

5.3 Waterborne wave

Now consider the schematic diagram shown in Figure 5.3 where, it is assumed, each location on the seabed *oa, ob, oc etc*. acts as a point source radiating sound into the water. In effect, the blast pressure level in the bedrock at *oa* represents the source level of the waterborne blast wave. Subsequently, instead of propagating at the speed of sound in the bedrock, the wave front now propagates at the speed of sound in the water. The waterborne wave is attenuated in the water at some given constant rate - excluding any effect from, say, a bubble curtain. An example given in Figure 5.4 shows the rockborne wave and also the waterborne wave both as a function of distance from the point of detonation. It is emphasised that the waterborne wave is the component that is actually measured in the water. The rockborne component merely provides the source level term from which the waterborne component subsequently attenuates during propagation. The question now arises as to what degree of attenuation due to propagation is appropriate.

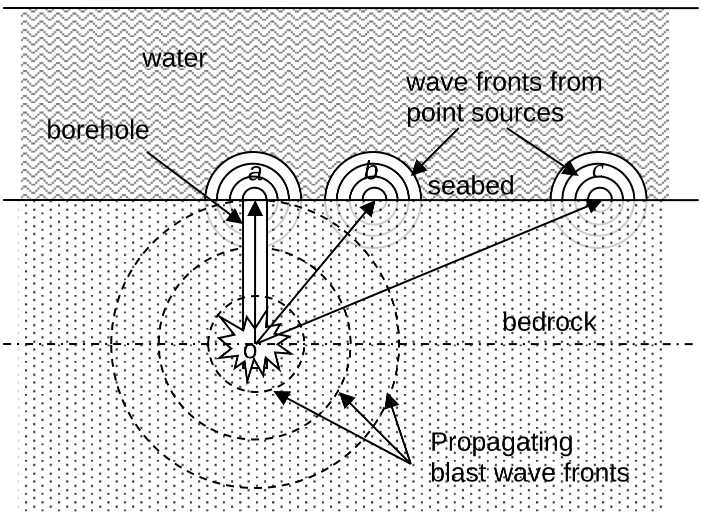

Figure 5.3: Schematic of confined blasting scenario

In general terms, underwater acoustic propagation may be modelled as N Log10[R] where N is the propagation constant and R is the distance in metres between the blast site and the noise recording location. Urick[5] shows that in a shallow water channel where acoustic propagation is best described using cylindrical spreading, an appropriate value is given by N=10. Analysis of the acoustic data acquired during the blasting programme that took place in Nigg Bay over the period August to October 2018[9] shows that this may be refined: accordingly a value of N=13 is used for the subsequent analysis.

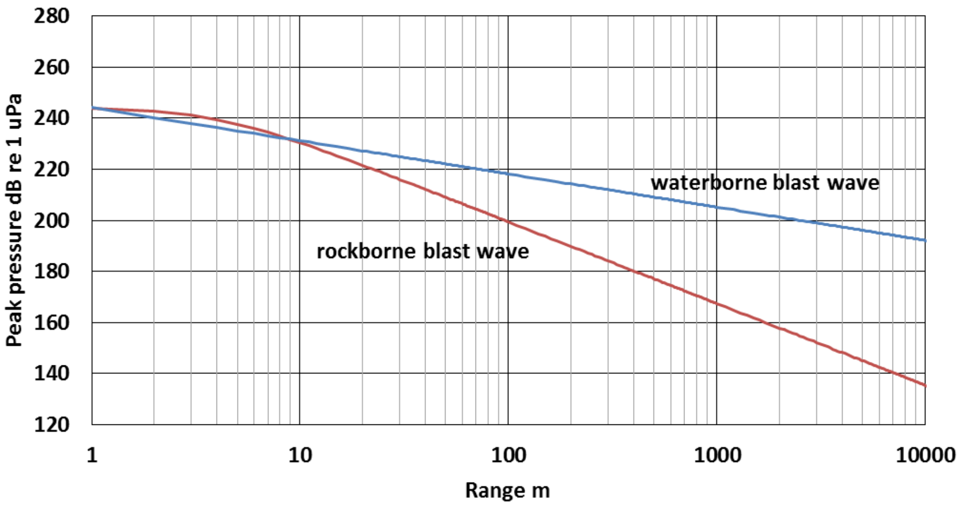

Figure 5.4: Rockborne and waterborne blast wave levels as a function of distance from the detonation site.

5.4 Long distance acoustic propagation

The modified confined-blast model may be used to predict peak blast levels in the water for the distances over which it has been verified using field data measurements. It is therefore valid up to a maximum distance of 1.2 km[9]. However, it is to be expected that the blast noise propagates over considerably further distances. It is necessary therefore to draw on a technique that models the propagation of broadband noise in a shallow water environment.

Marsh and Schulkin[33] provide a means by which propagation loss in a shallow water channel may be estimated. This is achieved by considering the distances at which acoustic propagation transitions from being predominantly spherical to being predominantly cylindrical[5]. The transition distances are given in terms of water depth which is assumed to be range-independent. The resulting semi-empirical propagation equations (which themselves are derived from acoustic measurements made in shallow waters over many years) include terms that quantify the additional acoustic losses that arise through boundary interaction with both the seabed and sea surface.

The Marsh-Schulkin model[33] commences with the assumption that propagation is modelled initially as being spherically-spreading where N=20 (see Section 5.3 above). At some further distance, cylindrical-spreading given by N=10 becomes applicable. At

[33] Marsh H. W. and Schulkin M., (1962), "Shallow-Water Transmission", Journal of the Acoustical Society of America 34, 863.

intermediate distances the propagation loss transitions smoothly from being spherical through to being cylindrical. Given that N=13 provides a good fit to the acoustic data acquired during the 2018 blasting program in Nigg Bay[34], it is assumed that at the distances from the blast site at which the acoustic measurements were made (over the range 400 m to 1200 m) the propagating wave front was already in the transition zone.

Strictly, the Marsh-Schulkin shallow water model[33] requires frequency as an input parameter. This is used to calculate the absorption coefficient in sea water and the boundary attenuations. The first of these only become significant at high frequencies ($\gtrapprox$ 10 kHz) and hence may be ignored for blast noise where the outgoing signal is assumed predominantly low frequency in content. To address the second requirement it is assumed that the bulk of the acoustic energy is transmitted at a single low frequency. For the purpose of the propagation calculations undertaken and described herein, the frequency is taken to be 100 Hz. For the purpose of the modelling discussed in the current report, it is assumed that the sea surface is plane and smooth, that is to say, the sea surface is not perturbed through the action of wind and wave. For such a surface, the boundary losses are minimal.

The following section consists of a discussion on a number of results generated by using the modified confined-blast model together with, where appropriate, the Marsh-Schulkin shallow water propagation model.

[34] Ward P. D., (2018),"Calibration of the Confined-Blast model in connection with the blasting program in Nigg Bay for Aberdeen Harbour Expansion Project", Award Env. Con Ltd Tech Report 201804-007-V3, November 2018.

6 ACOUSTIC PROPAGATION MODELLING RESULTS

6.1 Peak blast levels

The modified Confined-Blast model together with the Marsh-Schulkin shallow water model[33], as discussed in Section 5, is used to determine suitable peak blast levels for a variety of charge weights.

Figure 6.1 shows peak blast levels as a function of distance from the point of entry in the water calculated for charge weights increasing from 20 kg to 100 kg. The figure shows that in increasing the charge weight from 20 kg to 100 kg, there is a predicted increase in peak blast levels of approximately 11 dB.

The model indicates that, given a maximum charge weight of 100 kg, peak blast levels are in excess of 190 dB re 1 μPa at distances in excess of 40 km. In practice this condition is not met as a bubble curtain arrangement is constructed in the water column a short distance (~100 m to 700 m) downstream of the point of entry. This has the effect of absorbing a significant level of energy: the bubble curtain constructed during the August-November 2018 blasting program provided an attenuation of 38±16 dB[9].

The longer-range propagation modelling undertaken using the Marsh-Schulkin model drew on the assumption that sea surface losses were minimal. In the event that a perturbed surface (indicative of wind or wave action) was included in the model the resulting propagated pressure levels would be somewhat lower than indicated in Figure 6.1. For this reason, the peak pressure levels shown below may be deemed precautionary.

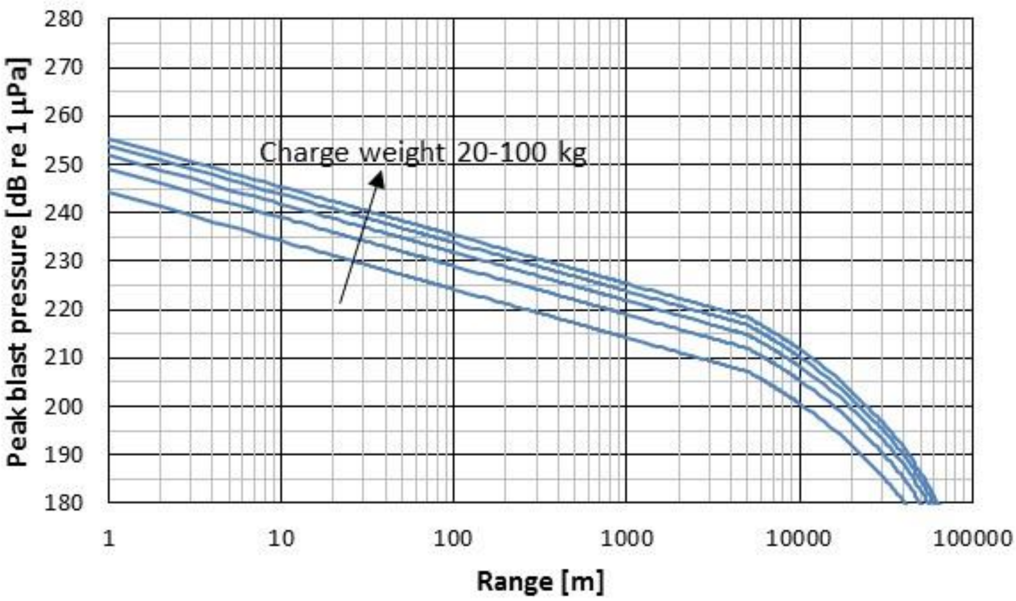

Figure 6.1: Predicted peak blast levels using the modified Confined-Blast model

6.2 Impulse

The modified Confined-Blast model does not calculate impulse as a metric therefore it is necessary to resort to the use of the in-water blast model as described by Gaspin[35]. Impulse requires time as a key parameter: Gaspin[35] provides a time-delay function which quantifies the time difference between the direct arrival of a wavefront propagating between source and receiver and the surface reflected arrival. The impulse is subsequently given by the product of the time-delay and the peak blast pressure in the water.

Figure 4.2 shows that there is a five-fold increase in peak impulse as charge weight is increased from 20 kg to 100 kg. Impulse is seen to fall rapidly with increasing distance: over a distance of 10 m the peak impulse has fallen to less than a tenth of its peak value oat 1 m from the source

It is assumed that the peak blast level and therefore corresponding impulse for a waterborne detonation is higher than the peak blast impulse following a confined detonation. Peak impulse levels in Nigg Bay modelled using the methodology described above are therefore likely to be precautionary.

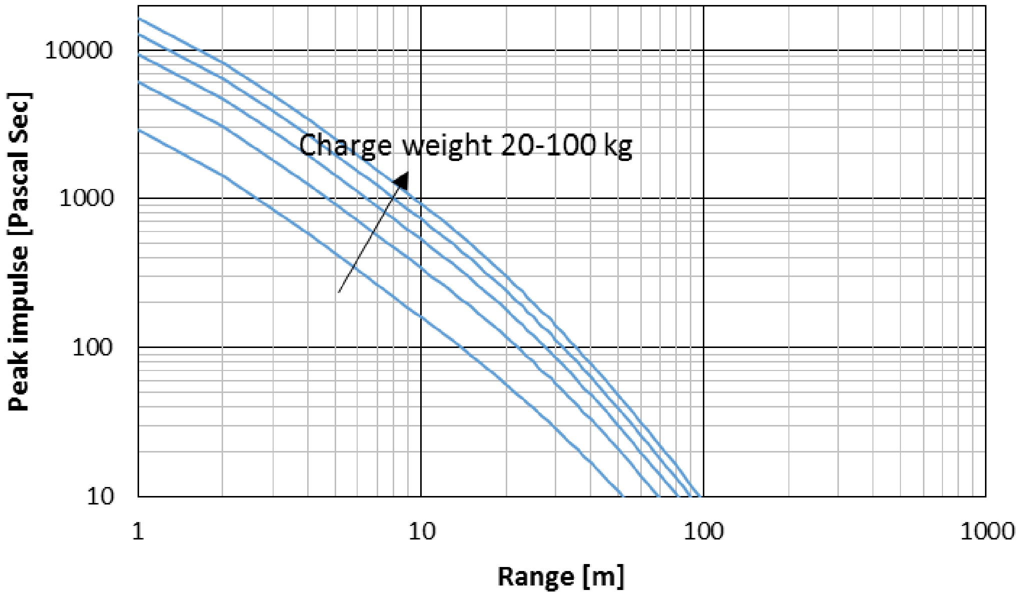

Figure 6.2: Predicted peak impulse levels using the underwater blast model

6.3 Peak particle velocity

The modified Confined-Blast model also generates peak particle velocities (PPV) on the surface of the seabed as a function of distance from the blast site. The relationship between PPV as a function of distance is illustrated in Figure 6.3 for the given selection of charge weights.

It will be seen that PPV decreases with increasing distance from the point of entry into

35 Gaspin, J. (1983), Safe swimmer ranges from bottom explosions, Naval Surface Weapons Center, NSWC TR 83-84.

the water. Beyond a distance of approximately 10 m, the PPV falls logarithmically with increasing distance. In addition, as charge weight increases from 20 kg to 100 kg there is approximately a four-fold increase in PPV values.

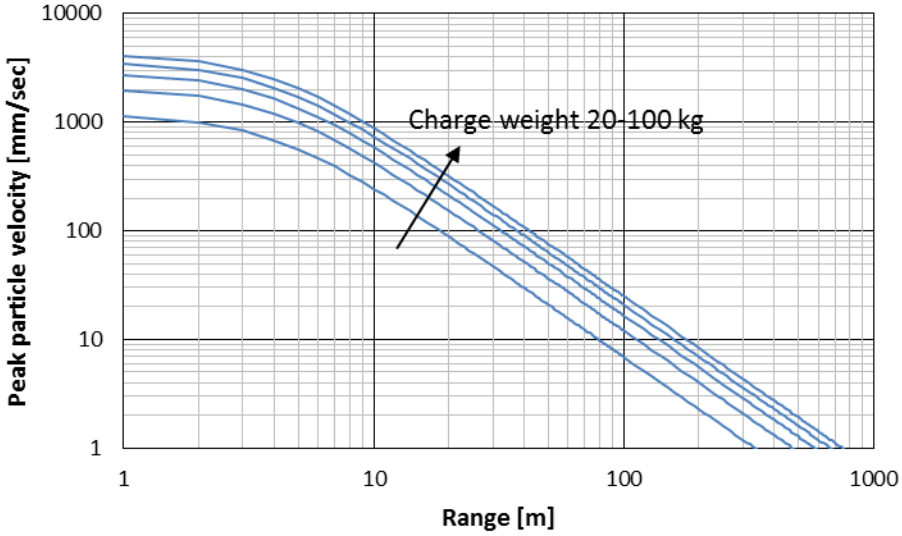

Figure 6.3: Predicted peak blast levels using the modified Confined-Blast model

7 ACOUSTIC IMPACT MODELLING RESULTS

7.1 Introduction

The levels of underwater noise generated by the detonation of charge weights in the range 20 kg to 100 kg during the AHEP blasting programme are used here to estimate impact ranges for a number of target marine species such as cetaceans, pinnipeds and fish. The distances at which each impact criterion is met may be determined by the application of the acoustic impact thresholds discussed in Section 4 to the results of the modified Confined-Blast modelling and Marsh-Schulkin shallow water model as discussed in Sections 5 and 6. Two scenarios are considered: bubble curtain absent; and bubble curtain present. For the latter case two examples are considered where:

(i) a bubble curtain is assumed to lie at a distance of 650 m from the blast site. This is representative of blasting taking place at the northern end of Nigg Bay while a double bubble curtain is located between the end of the northern breakwater and the southern edge of Nigg Bay. For this scenario, The layout is illustrated in Figure 7.1; and

(ii) a bubble curtain is assumed to lie at a distance of 100 m from the blast site. This is representative of blasting taking place at the southern end of Nigg Bay with a double bubble curtain lying to the east of the blast site and sealing the gap between the breakwater and the southern shore of Nigg Bay. The layout is shown in Figure 7.2.

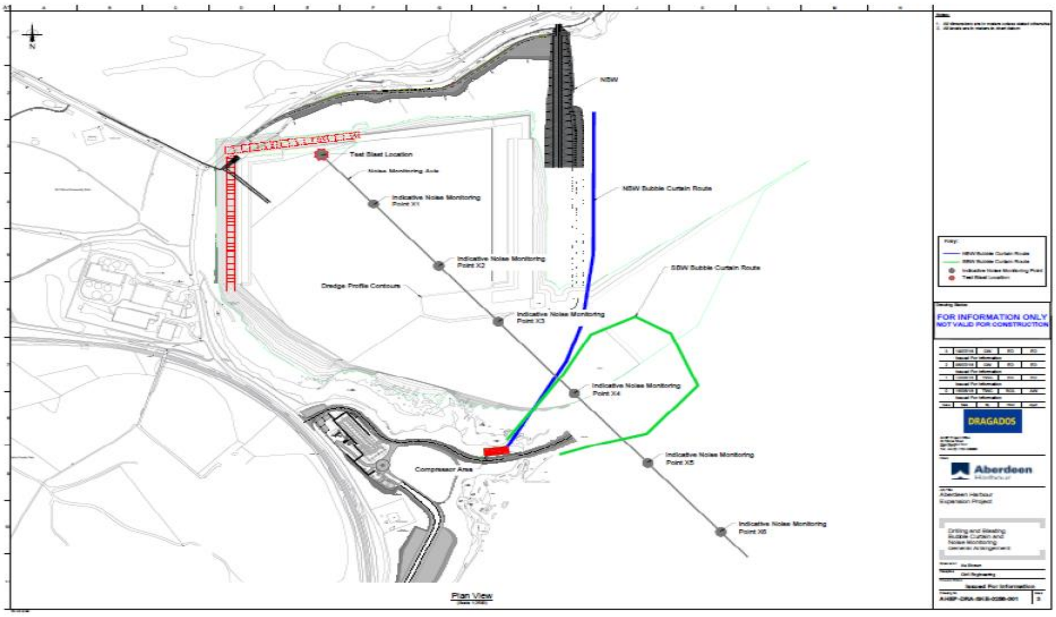

Figure 7.1: Bubble curtain arrangement when blasting in the north of Nigg Bay.

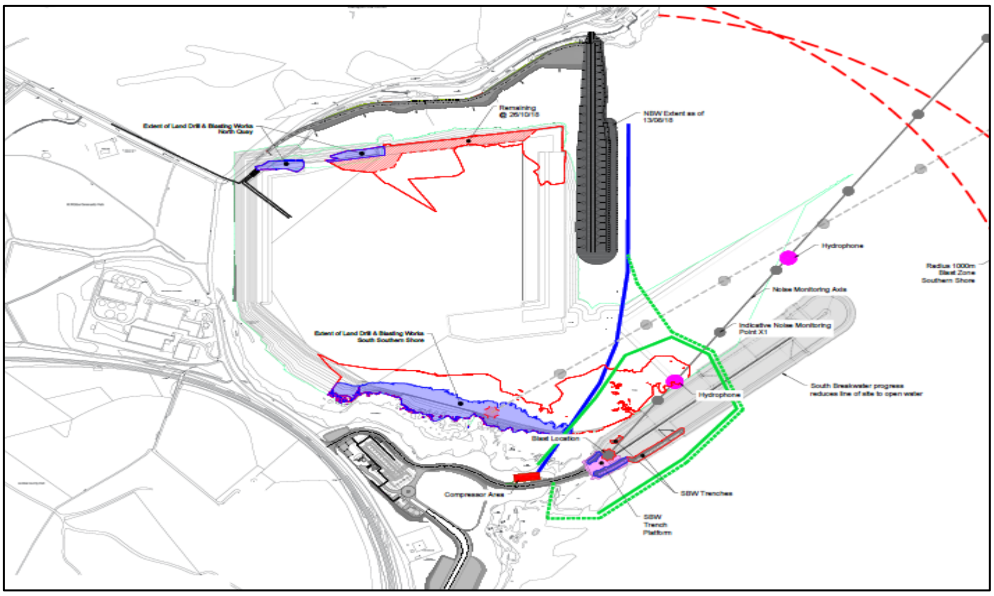

Figure 7.2: Bubble curtain arrangement when blasting in the south of Nigg Bay.

7.2 Blast noise – Bubble curtain absent

7.2.1 Cetaceans

Peak and RMS SPL metrics

The acoustic impact modelling shows that when low-frequency cetaceans are exposed to underwater blast noise arising from the use of a 20 kg maximum charge weight with no bubble curtain in place to absorb the acoustic energy, the impact criteria for PTS and TTS are met at distances of 340 m and 1.4 km respectively from the blast site. When a maximum charge of 60 kg is considered, the PTS and TTS impact criteria extend to distances of 2 km and 6.2 km respectively. Medium-frequency cetaceans appear less sensitive to underwater blast noise. For a 20 kg charge, the PTS and TTS impact criteria extend to distances of 27 m and 110 m respectively while the corresponding distances for high frequency cetaceans are increased to 8.8 km and 15 km. For a maximum charge weight of 60 kg, the PTS and TTS impact criteria are met at distances of 160 m and 610m respectively for medium frequency cetaceans while for high-frequency cetaceans the corresponding distances extend to 17 km and 26 km.

For both low- and medium-frequency cetaceans exposed to blast from a 20 kg charge the Strong Behavioural Response impact criterion is met at a maximum distance of 39 km from the blast site. For high-frequency cetaceans, the same criterion is met over distances varying between 80 km and 110 km for the smaller charge weight increasing to lie in the range 97 km to 120 km for the larger charge weight.

The No Behavioural Response impact criterion is met at distances from 110 km to 240 km.

A summary of the impact distances determined using SPL peak and rms metrics for low-, medium- and high-frequency cetaceans when exposed to blast noise are given in Tables 7.1-7.3 respectively. Modelled impact ranges using SPL peak and rms metrics for cetaceans as a function of charge weight from 20 kg to 100 kg when no bubble curtain is present are given in Annex A.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	219 dB re 1 μPa peak	340 m	640 m	1.10 km	1.50 km	2.0 km
TTS	213 dB re 1 μPa peak	1.4 km	2.6 km	4.0 km	5.4 km	6.2 km
Strong Behavioural Response	180 dB re 1 μPa rms	22 km	26 km	30 km	32 km	35 km
	170 dB re 1 μPa rms	39 km	45 km	49 km	52 km	54 km
No Behavioural Response	130 dB re 1 μPa rms	130 km	130 km	140 km	140 km	150 km
	120 dB re 1 μPa rms	150 km	160 km	160 km	170 km	170 km

Table 7.1: Summary of impact ranges for low-frequency cetaceans in the AHEP area when exposed to blast noise using SPL peak and rms metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	230 dB re 1 μPa peak	27 m	51 m	80 m	120 m	160 m
TTS	224 dB re 1 μPa peak	110 m	210 m	320 m	460 m	610 m
Strong Behavioural Response	180 dB re 1 μPa rms	22 km	26 km	30 km	32 km	35 km
	170 dB re 1 μPa rms	39 km	45 km	49 km	52 km	54 km
No Behavioural Response	140 dB re 1 μPa rms	110 km	110 km	120 km	120 km	120 km
	130 dB re 1 μPa rms	130 km	130 km	140 km	140 km	150 km

Table 7.2: Summary of impact ranges for medium-frequency cetaceans in the AHEP area when exposed to blast noise using SPL peak and rms metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	202 dB re 1 μPa peak	8.8 km	12 km	14 km	16 km	17 km
TTS	196 dB re 1 μPa peak	15 km	19 km	22 km	24 km	26 km
Strong Behavioural Response	150 dB re 1 μPa rms	80 km	86 km	91 km	94 km	97 km
	140 dB re 1 μPa rms	110 km	110 km	120 km	120 km	120 km
No Behavioural Response	100 dB re 1 μPa rms	200 km	200 km	210 km	210 km	210 km
	90 dB re 1 μPa rms	220 km	230 km	230 km	230 km	240 km

Table 7.3: Summary of impact ranges for high-frequency cetaceans in the AHEP area when exposed to blast noise using SPL peak and rms metrics

SEL metrics

Acoustic impacts can build up on a receptor following a period of continual exposure to a noise. For this, it was assumed that the cetaceans were exposed to blast noise for a total of 2.2 seconds – this being the mean duration of the outgoing pulse determined from the underwater noise measurements made during the 2018 blasting programme[9]. For the given exposure duration, the SEL is calculated from equation 2-3 using the data presented in Figure 6.1 and the M-weighting for the appropriate functional hearing group (Figure 4.1).

The acoustic impact modelling shows that following the detonation of a 20 kg charge weight and with no bubble curtain is in place to absorb the blast energy, the PTS impact criterion is not met for medium-frequency cetaceans – being the least sensitive of the cetacean groupings to blast noise when assessed using the SEL metric; and at a distance of 14 km for high-frequency cetaceans – being the most sensitive. For a maximum charge weight of 60 kg, the PTS impact criterion is still not met for medium-frequency cetaceans and up to 24 km for low-frequency cetaceans. The TTS impact criterion is met at a maximum distance of 51 km when blasting with the largest charge weight considered.

A summary of the impact distances determined using SEL metrics for low-, medium- and high-frequency cetaceans when exposed to blast noise are given in Tables 7.4-7.6 respectively. Modelled impact ranges using SEL metrics for cetaceans as a function of charge weight from 20 kg to 100 kg when no bubble curtain is present are given in Annex A.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	183 dB re 1 µPa peak	14 km	17 km	20 km	22 km	24 km
TTS	168 dB re 1 µPa peak	36 km	42 km	46 km	49 km	51 km

Table 7.4: Summary of impact ranges for low-frequency cetaceans in the AHEP area when exposed to blast noise using SEL metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	185 dB re 1 µPa peak	<1 m	<1 m	<1 m	<1 m	<1 m
TTS	170 dB re 1 µPa peak	4 m	7 m	12 m	16 m	22 m

Table 7.5: Summary of impact ranges for medium-frequency cetaceans in the AHEP area when exposed to blast noise using SEL metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	155 dB re 1 µPa peak	7 m	13 m	20 m	29 m	38 m
TTS	140 dB re 1 µPa peak	210 m	400 m	630 m	900 m	1.2 km

Table 7.6: Summary of impact ranges for high-frequency cetaceans in the AHEP area when exposed to blast noise using SEL metrics

7.2.2 Phocids

Peak and RMS SPL metrics

The acoustic impact modelling shows that when seals are exposed to underwater blast noise arising from the detonation of a 20 kg charge, the PTS and TTS impact criteria are met at distances from the blast site of 420 m and 1.7 km respectively. When the charge weight is increased to 60 kg, there is a corresponding increase in the distances to 2.5 km and 6.9 km respectively.

The criterion for Strong Behavioural Response is met over distances in the range of 2.1 km to 9.7 km from the blast site following the detonation of a 20 kg charge increasing to lie in the range 7.7 km to 19 km for a 60 kg charge weight. The No

Behavioural Response is met at distances from 22 km to 54 km depending on charge weight.

A summary of the impact distances determined using SPL peak and rms metrics for phocids when exposed to blast noise is given in Table 7.7. Modelled impact ranges using SPL peak and rms metrics for phocids as a function of charge weight from 20 kg to 100 kg when no bubble curtain is present are given in Annex A.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	218 dB re 1 μPa peak	420 m	800 m	1.3 km	1.9 km	2.5 km
TTS	212 dB re 1 μPa peak	1.7 km	3.2 km	5.1 km	6.0 km	6.9 km
Strong Behavioural Response	200 dB re 1 μPa rms	2.1 km	4.1 km	5.7 km	6.7 km	7.7 km
	190 dB re 1 μPa rms	9.7 km	13 km	15 km	17 km	19 km
No Behavioural Response	180 dB re 1 μPa rms	22 km	26 km	30 km	32 km	35 km
	170 dB re 1 μPa rms	39 km	45 km	49 km	52 km	54 km

Table 7.7: Summary of impact ranges for phocids in the AHEP area when exposed to blast noise using SPL peak and rms metrics

SEL metrics

Acoustic impacts can build up on a receptor following a period of continual exposure to a noise. For this, it was assumed that the phocids were exposed to blast noise for a total of 2.2 seconds.

The acoustic impact modelling showed that when no bubble curtain is in place, the PTS impact criterion extends to a distance of 480 m for a 20 kg charge weight and up to 2.8 km for a 60 kg charge weight. The TTS impact criterion extends to a maximum distance of 17 km for the maximum charge weight considered.

A summary of the impact distances determined using SEL metrics for phocids when exposed to blast noise is given in Table 7.8. Modelled impact ranges using SEL metrics for phocids as a function of charge weight from 20 kg to 100 kg when no bubble curtain is present are given in Annex A.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	185 dB re 1 μPa peak	480 m	920 m	1.5 km	2.1 km	2.8 km
TTS	170 dB re 1 μPa peak	8.5 km	12 km	14 km	15 km	17 km

Table 7.8: Summary of impact ranges for phocids in the AHEP area when exposed to blast noise using SEL metrics

7.2.3 Fish

Peak and RMS SPL metrics

Compared with cetaceans and phocids, the acoustic impact modelling indicates that fish of all functional hearing groups are relatively insensitive to the underwater blast noise.

The modelling shows that for a 20 kg charge, the Mortality and Potential Mortal Injury impact criterion extends over the distance 11 m to 34 m from the blast site for fish of all functional hearing groups. When a charge weight of 60 kg is considered, the distances increase to lie in the range 61-200 m.

By contrast, the distances over which the Recoverable Injury and TTS impact criteria are expressed qualitatively. These show that there is a high risk that both impact criteria will be met at distances near to the blast site and a low risk at far distances. The terms "near" and "far" are not defined quantitatively.

A summary of the impact distances determined using SPL peak metrics for fish of each functional hearing group when exposed to blast noise are given in Tables 7.9-7.11. Modelled impact ranges using SPL metrics for fish as a function of charge weight from 20 kg to 100 kg when no bubble curtain is present are given in Annex A.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
Mortality and Potential Mortal Injury	234 dB re 1 μPa peak	11 m	21 m	32 m	46 m	61 m
	229 dB re 1 μPa peak	34 m	64 m	110 m	150 m	200 m
Recoverable injury		High risk at near distance. Low risk at all other distances				
TTS		High risk at near distance. Moderate risk at intermediate distance. Low risk at far distance				

Table 7.9: Summary of impact ranges for hearing generalist ("low sensitivity") fish in the AHEP area when exposed to blast noise using SPL peak metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
Mortality and Potential Mortal Injury	234 dB re 1 μPa peak	11 m	21 m	32 m	46 m	61 m
	229 dB re 1 μPa peak	34 m	64 m	110 m	150 m	200 m
Recoverable injury		High risk at near and intermediate distances Low risk at far distance				
TTS		High risk at near distance Moderate risk at intermediate distance Low risk at far distance				

Table 7.10: Summary of impact ranges for hearing generalist ("medium sensitivity") fish in the AHEP area when exposed to blast noise using SPL peak metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
Mortality and Potential Mortal Injury	234 dB re 1 μPa peak	11 m	21 m	32 m	46 m	61 m
	229 dB re 1 μPa peak	34 m	64 m	110 m	150 m	200 m
Recoverable injury		High risk at near and intermediate distances Low risk at far distance				
TTS		High risk at near and intermediate distances Low risk at far distance				

Table 7.11: Summary of impact ranges for hearing specialist fish in the AHEP area when exposed to blast noise using SPL peak metrics

Particle velocity metrics

Impacts on fish eggs and larvae are given in terms of the PPV to which they may be exposed during blasting. The acoustic impact modelling shows that the Mortality and Potential Mortal Injury impact criterion increases from a distance of 68 m for a 20 kg charge up to a distance of 120 m for the maximum charge weight considered of 60 kg.

The distances over which the Recoverable Injury and the TTS impact criteria are expressed qualitatively where there is a high risk at near distances that both criteria will be met and a low risk at all other distances. The terms "high", "low", "near" and "far" are not defined quantitatively.

A summary of the impact distances determined using PPV metrics for fish eggs and larvae when exposed to blast noise is given in Table 7.12. Modelled impact ranges using PPV metrics for fish eggs and larvae as a function of charge weight from 20 kg to 100 kg when no bubble curtain is present are given in Annex A.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
Mortality and Potential Mortal Injury	13 mm/sec	68 m	83 m	96 m	110 m	120 m
Recoverable injury		High risk at near distance. Low risk at all other distances				
TTS		High risk at near distance. Low risk at all other distances				

Table 7.12: Summary of impact ranges for fish eggs and larvae in the AHEP area when exposed to blast noise using PPV metrics

7.2.4 Seabirds

Impulse metrics

Impacts on seabirds are quantified using impulse metrics. The acoustic impact modelling shows that the impacts are likely to occur over relatively short distances from the blast site. The 50% Mortality impact is met within maximum distances of 3 m to 8 m from the blast site over the range of charge weights modelled. By contrast, the Safe Level impact extends to a maximum distance of 19 m. It is noted that beyond this distance the seabirds are unharmed but may nevertheless be startled at the moment of detonation.

A summary of the impact distances determined using impulse metrics for seabirds when exposed to blast noise is given in Table 7.13. Modelled impact ranges using impulse metrics for seabirds as a function of charge weight from 20 kg to 100 kg when no bubble curtain is present are given in Annex A.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
50% mortality	896 Pas.sec	3 m	5 m	6 m	7 m	8 m
Mortality threshold	690 Pas.sec	4 m	6 m	7 m	8 m	9 m
Slight blast injuries	276 Pas.sec	7 m	10 m	12 m	14 m	16 m
Safe level	207 Pas.sec	9 m	12 m	15 m	17 m	19 m

Table 7.13: Summary of impact ranges for seabirds in the AHEP area when exposed to blast noise using impulse metrics

7.3 Blast noise – Bubble curtain at 650 m from blast site

7.3.1 Cetaceans

Peak and RMS SPL metrics

The acoustic impact modelling was repeated but this time including the absorptive effects of a bubble curtain located at a distance of 650 m from the blast site as illustrated in Figure 7.1. The results shows that the distances over which the longer range impacts are met are all significantly reduced.

When a 20 kg charge is detonated, for low-frequency cetaceans the PTS impact criterion is met (as before) at a distance of 340 m. The distance over which the TTS impact criterion is met is reduced from 1.4 km with no bubble curtain in place to 660 m with the curtain installed. For the maximum charge considered of 60 kg, both the PTS and TTS impact criteria are met at a distance of 660 m.

For medium-frequency cetaceans exposed to the blast from a 20 kg charge, the PTS and TTS impact criteria extend to distances of 27 m and 110 m respectively while for high frequency cetaceans the corresponding distances are 660 m for both criteria. When the charge weight is increased to 60 kg, the PTS and TTS impact criteria are met at distances of 160 m and 610 m respectively for medium frequency cetaceans while for high-frequency cetaceans the corresponding distances extend to 660 m and 2.5 km respectively.

For both low- and medium-frequency cetaceans exposed to blast from a 20 kg charge the Strong Behavioural Response impact criterion is met at a maximum distance of 8 km from the blast site. When the charge weight is increased to 60 kg, the impact criterion extends to a maximum distance of16 km from the blast site. For high-frequency cetaceans, the Strong Behavioural Response criterion is met over distances varying between 35 km and 55 km for the smaller charge weight increasing to lie in the range 50 km to 71 km for the larger charge weight.

The criterion for No Response criterion is met at distances between 55 km and 190 km depending on charge weight and the functional hearing group being considered.

A summary of the impact distances determined using SPL peak and rms metrics for low-, medium- and high-frequency cetaceans when exposed to blast noise with a bubble curtain in place are given in Tables 7.14-7.16 respectively. Modelled impact ranges using SEL metrics for cetaceans as a function of charge weight from 20 kg to 100 kg when the bubble curtain present are given in Annex B.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	219 dB re 1 μPa peak	340 m	640 m	660 m	660 m	660 m
TTS	213 dB re 1 μPa peak	660 m	660 m	660 m	660 m	660 m
Strong Behavioural Response	180 dB re 1 μPa rms	1.4 km	2.6 km	4.0 km	5.4 km	6.2 km
	170 dB re 1 μPa rms	8.0 km	11 km	13 km	15 km	16 km
No Behavioural Response	130 dB re 1 μPa rms	76 km	82 km	86 km	90 km	92 km
	120 dB re 1 μPa rms	98 km	110 km	110 km	120 km	120 km

Table 7.14: Summary of impact ranges for low-frequency cetaceans in the AHEP area when exposed to blast noise using SPL peak and rms metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	230 dB re 1 μPa peak	27 m	51 m	80 m	120 m	160 m
TTS	224 dB re 1 μPa peak	110 m	210 m	320 m	460 m	610 m
Strong Behavioural Response	180 dB re 1 μPa rms	1.4 km	2.6 km	4.0 km	5.4 km	6.2 km
	170 dB re 1 μPa rms	8.0 km	11 km	13 km	15 km	16 km
No Behavioural Response	140 dB re 1 μPa rms	55 km	61 km	65 km	68 km	71 km
	130 dB re 1 μPa rms	76 km	82 km	86 km	90 km	92 km

Table 7.15: Summary of impact ranges for medium-frequency cetaceans in the AHEP area when exposed to blast noise using SPL peak and rms metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	202 dB re 1 μPa peak	660 m	660 m	660 m	660 m	660 m
TTS	196 dB re 1 μPa peak	660 m	800 m	1.30 km	1.90 km	2.5 km
Strong Behavioural Response	150 dB re 1 μPa rms	35 km	41 km	45 km	48 km	50 km
	140 dB re 1 μPa rms	55 km	61 km	65 km	68 km	71 km
No Behavioural Response	100 dB re 1 μPa rms	150 km	150 km	160 km	160 km	160 km
	90 dB re 1 μPa rms	170 km	180 km	180 km	180 km	190 km

Table 7.16: Summary of impact ranges for high-frequency cetaceans in the AHEP area when exposed to blast noise using SPL peak and rms metrics

SEL metrics

When the acoustic impacts are given in SEL metrics, the PTS impact criterion is met at a distance of 660 m for low-frequency cetaceans when exposed to the blast from a 20 kg charge. By contrast, the PTS impact criterion is not met at all for medium-frequency cetaceans. When the charge size is increased to 60 kg, the TTS impact criterion extends to cover a distance of 15 km for low-frequency cetaceans, 22 m for medium frequency cetaceans and 660 m for high-frequency cetaceans.

A summary of the impact distances determined using SEL metrics for low-, medium- and high-frequency cetaceans when exposed to blast noise are given in Tables 7.17-7.19 respectively. Modelled impact ranges using SEL metrics for cetaceans as a function of charge weight from 20 kg to 100 kg when the bubble curtain is present at a distance of 650 m from the blast site are given in Annex B.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	183 dB re 1 μPa^2.sec	660 m	660 m	910 m	1.3 km	1.8 km
TTS	168 dB re 1 μPa^2.sec	6.9 km	9.2 km	11 km	13 km	15 km

Table 7.17: Summary of impact ranges for low-frequency cetaceans in the AHEP area when exposed to blast noise using SEL metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	185 dB re 1 μPa^2.sec	<1 m	<1 m	<1 m	<1 m	<1 m
TTS	170 dB re 1 μPa^2.sec	4 m	7 m	12 m	16 m	22 m

Table 7.18: Summary of impact ranges for medium-frequency cetaceans in the AHEP area when exposed to blast noise using SEL metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	155 dB re 1 μPa^2.sec	7 m	13 m	20 m	29 m	38 m
TTS	140 dB re 1 μPa^2.sec	210 m	400 m	630 m	660 m	660 m

Table 7.19: Summary of impact ranges for high-frequency cetaceans in the AHEP area when exposed to blast noise using SEL metrics

7.3.2 Phocids

Peak and RMS SPL metrics

The PTS impact criterion is met at distances between 420 m and 660 m depending on the charge weight while the TTS impact criterion is met at 660 m for all charge weights considered. The Strong Behavioural Response criterion covers the range 660 m to 770 m while the No Behavioural Response criterion extends to a maximum distance of 16 km.

A summary of the impact distances determined using SPL peak and rms metrics for phocids when exposed to blast noise is given in Table 7.20. Modelled impact ranges using SPL metrics for phocids as a function of charge weight from 20 kg to 100 kg when the bubble curtain is present at 650 m are given in Annex B.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	218 dB re 1 μPa peak	420 m	660 m	660 m	660 m	660 m
TTS	212 dB re 1 μPa peak	660 m	660 m	660 m	660 m	660 m
Strong Behavioural Response	200 dB re 1 μPa rms	660 m	660 m	660 m	660 m	660 m
	190 dB re 1 μPa rms	660 m	660 m	660 m	660 m	770 m
No Behavioural Response	180 dB re 1 μPa rms	1.4 km	2.6 km	4.0 km	5.4 km	6.2 km
	170 dB re 1 μPa rms	8 km	11 km	13 km	15 km	16 km

Table 7.20: Summary of impact ranges for phocids in the AHEP area when exposed to blast noise using SPL peak and rms metrics

SEL metrics

When expressed in SEL metrics, the PTS impact criterion is met at a distance of 660 m for charges weight in the range 20 kg to 60 kg. The TTS impact criterion is met at the same maximum distance regardless of charge weight.

A summary of the impact distances determined using SEL metrics for phocids when exposed to blast noise is given in Table 7.21. Modelled impact ranges using SEL metrics for phocids as a function of charge weight from 20 kg to 100 kg when the bubble curtain is present are given in Annex B.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	185 dB re 1 μPa peak	480 m	660 m	660 m	660 m	660 m
TTS	170 dB re 1 μPa peak	660 m	660 m	660 m	660 m	660 m

Table 7.21: Summary of impact ranges for phocids in the AHEP area when exposed to blast noise using SEL metrics

7.3.3 Fish

Peak and RMS SPL metrics

The distances over which the Mortality and Potential Mortal Injury criterion are met for all charge weights are so short that they fall at distances inside the bubble curtain when it is at a distance of 650 m from the blast site. Hence for this scenario, the impact distances are unaffected by the presence of the bubble curtain. As such they remain unchanged from those given in Table 7.9-7.11.

Particle velocity metrics

The presence of a bubble curtain has no effect on particle velocity. The distances at over which the PPV impact criterion are met are therefore unchanged from those given in Table 7.12.

7.3.4 Seabirds

Impulse metrics

The Mortality, Slight Blast Injury and Safe Level impact criteria are all met at distances inside the bubble curtain. As such the presence of the bubble curtain has no effect on these criteria and the corresponding impact distances are as given in Table 7.13.

7.4 Blast noise – Bubble curtain at 100 m from blast site

7.4.1 Cetaceans

Peak and RMS SPL metrics

The acoustic impact modelling was repeated but this time including the absorptive effects of a bubble curtain located at a distance of 100 m from the blast site as illustrated in Figure 7.2.

The impact modelling shows that for the low- and medium-frequency cetaceans, both the PTS and TTS impact criteria are met at a maximum distance of 100 m for all charge weights considered. For high-frequency cetaceans, the distance over which the PTS impact criterion extends varies from 110 m to 610 m over the range of charge weights considered while the TTS impact criterion is met at a maximum distance of 2.5 km.

For both low- and medium-frequency cetaceans the Strong Behavioural Response criterion is met at distances from 1.4 km to 16 km depending on charge weight while for high-frequency cetaceans the corresponding range is 35 km to 71 km.

A summary of the impact distances determined using SPL peak and rms metrics for low-, medium- and high-frequency cetaceans when exposed to blast noise with a bubble curtain in place are given in Tables 7.22-7.24 respectively. Modelled impact ranges using SEL metrics for cetaceans as a function of charge weight from 20 kg to 100 kg when the bubble curtain present at a distance of 100 m from the blast site are given in Annex C.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	219 dB re 1 µPa peak	100 m	100 m	100 m	100 m	100 m
TTS	213 dB re 1 µPa peak	100 m	100 m	100 m	100 m	100 m
Strong Behavioural Response	180 dB re 1 µPa rms	1.4 km	2.6 km	4.0 km	5.4 km	6.2 km
	170 dB re 1 µPa rms	8.0 km	11 km	13 km	15 km	16 km
No Behavioural Response	130 dB re 1 µPa rms	76 km	82 km	86 km	90 km	92 km
	120 dB re 1 µPa rms	98 km	110 km	110 km	120 km	120 km

Table 7.22: Summary of impact ranges for low-frequency cetaceans in the AHEP area when exposed to blast noise using SPL peak and rms metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	230 dB re 1 µPa peak	27 m	51 m	80 m	100 m	100 m
TTS	224 dB re 1 µPa peak	100 m	100 m	100 m	100 m	100 m
Strong Behavioural Response	180 dB re 1 µPa rms	1.4 km	2.6 km	4.0 km	5.4 km	6.2 km
	170 dB re 1 µPa rms	8.0 km	11 km	13 km	15 km	16 km
No Behavioural Response	140 dB re 1 µPa rms	55 km	61 km	65 km	68 km	71 km
	130 dB re 1 µPa rms	76 km	82 km	86 km	90 km	92 km

Table 7.23: Summary of impact ranges for medium-frequency cetaceans in the AHEP area when exposed to blast noise using SPL peak and rms metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	202 dB re 1 μPa peak	110 m	210 m	320 m	460 m	610 m
TTS	196 dB re 1 μPa peak	420 m	800 m	1.3 km	1.9 km	2.5 km
Strong Behavioural Response	150 dB re 1 μPa rms	35 km	41 km	45 km	48 km	50 km
	140 dB re 1 μPa rms	55 km	61 km	65 km	68 km	71 km
No Behavioural Response	100 dB re 1 μPa rms	150 km	150 km	160 km	160 km	160 km
	90 dB re 1 μPa rms	170 km	180 km	180 km	180 km	190 km

Table 7.24: Summary of impact ranges for high-frequency cetaceans in the AHEP area when exposed to blast noise using SPL peak and rms metrics

SEL metrics

When the acoustic impacts are given in SEL metrics, the PTS impact criterion is met at a distance of 300 m for low-frequency cetaceans when exposed to the blast from a 20 kg charge. By contrast, the PTS impact criterion is not met at all for medium-frequency cetaceans and at a maximum distance of 7 m for high-frequency cetaceans. When the charge size is increased to 60 kg, the TTS impact criterion extends to cover a distance of 15 km for low-frequency cetaceans, 22 m for medium frequency cetaceans and 100 m for high-frequency cetaceans.

A summary of the impact distances determined using SEL metrics for low-, medium- and high-frequency cetaceans when exposed to blast noise are given in Tables 7.25-7.27 respectively. Modelled impact ranges using SEL metrics for cetaceans as a function of charge weight from 20 kg to 100 kg when the bubble curtain is present at a distance of 100 m from the blast site are given in Annex C.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	183 dB re 1 μPa^2.sec	300 m	580 m	910 m	1.3 km	1.8 km
TTS	168 dB re 1 μPa^2.sec	6.9 km	9.2 km	11 km	13 km	15 km

Table 7.25: Summary of impact ranges for low-frequency cetaceans in the AHEP area when exposed to blast noise using SEL metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	185 dB re 1 μPa^2.sec	<1 m	<1 m	<1 m	<1 m	<1 m
TTS	170 dB re 1 μPa^2.sec	4 m	7 m	12 m	16 m	22 m

Table 7.26: Summary of impact ranges for medium-frequency cetaceans in the AHEP area when exposed to blast noise using SEL metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	155 dB re 1 μPa^2.sec	7 m	13 m	20 m	29 m	38 m
TTS	140 dB re 1 μPa^2.sec	100 m	100 m	100 m	100 m	100 m

Table 7.27: Summary of impact ranges for high-frequency cetaceans in the AHEP area when exposed to blast noise using SEL metrics

7.4.2 Phocids

Peak and RMS SPL metrics

Both the PTS and TTs impact criteria are met at distances of 100 m for all charge weights modelled.

The Strong Behavioural Response and No Behavioural Response impact criteria extend to maximum distances of 770 m and 16 km respectively for the largest charge weight considered.

A summary of the impact distances determined using SPL peak and rms metrics for phocids when exposed to blast noise is given in Table 7.28. Modelled impact ranges using SPL metrics for phocids as a function of charge weight from 20 kg to 100 kg when the bubble curtain is present at 100 m are given in Annex C.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	218 dB re 1 μPa peak	100 m	100 m	100 m	100 m	100 m
TTS	212 dB re 1 μPa peak	100 m	100 m	100 m	100 m	100 m
Strong Behavioural Response	200 dB re 1 μPa rms	100 m	100 m	100 m	100 m	100 m
	190 dB re 1 μPa rms	140 m	260 m	400 m	580 m	770 m
No Behavioural Response	180 dB re 1 μPa rms	1.4 km	2.6 km	4.0 km	5.4 km	6.2 km
	170 dB re 1 μPa rms	8.0 km	11 km	13 km	15 km	16 km

Table 7.28: Summary of impact ranges for phocids in the AHEP area when exposed to blast noise using SPL peak and rms metrics

SEL metrics

When assessed using SEL metrics, the PTS impact criterion is met at a maximum distance of 100 while the TTS impact criterion extends to 560 m.

A summary of the impact distances determined using SEL metrics for phocids when exposed to blast noise is given in Table 7.29. Modelled impact ranges using SEL metrics for phocids as a function of charge weight from 20 kg to 100 kg when the bubble curtain is present at 100 m are given in Annex C.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
PTS	185 dB re 1 μPa peak	100 m	100 m	100 m	100 m	100 m
TTS	170 dB re 1 μPa peak	100 m	190 m	290 m	420 m	560 m

Table 7.29: Summary of impact ranges for phocids in the AHEP area when exposed to blast noise using SEL metrics

7.4.3 Fish

Peak and RMS SPL metrics

The distances over which the Mortality and Potential Mortal Injury criterion are met for all charge weights are so short that they fall at distances inside or else up to the bubble curtain when it is at a distance of 100 m from the blast site.

A summary of the impact distances determined using SPL peak metrics for fish of each functional hearing group when exposed to blast noise are given in Tables 7.30-7.32. Modelled impact ranges using SPL metrics for fish as a function of charge weight from 20 kg to 100 kg when the bubble curtain is present at a distance of 100 m from the blast site are given in Annex C.

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
Mortality and Potential Mortal Injury	234 dB re 1 µPa peak	11 m	21 m	32 m	46 m	61 m
	229 dB re 1 µPa peak	34 m	64 m	100 m	100 m	100 m
Recoverable injury		High risk at near distance. Low risk at all other distances				
TTS		High risk at near distance. Moderate risk at intermediate distance. Low risk at far distance				

Table 7.30: Summary of impact ranges for hearing generalist ("low sensitivity") fish in the AHEP area when exposed to blast noise using SPL peak metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
Mortality and Potential Mortal Injury	234 dB re 1 µPa peak	11 m	21 m	32 m	46 m	61 m
	229 dB re 1 µPa peak	34 m	64 m	100 m	100 m	100 m
Recoverable injury		High risk at near and intermediate distances Low risk at far distance				
TTS		High risk at near distance Moderate risk at intermediate distance Low risk at far distance				

Table 7.31: Summary of impact ranges for hearing generalist ("medium sensitivity") fish in the AHEP area when exposed to blast noise using SPL peak metrics

		Charge weight				
Impact	**Threshold**	**20kg**	**30kg**	**40kg**	**50kg**	**60kg**
Mortality and Potential Mortal Injury	234 dB re 1 µPa peak	11 m	21 m	32 m	46 m	61 m
	229 dB re 1 µPa peak	34 m	64 m	100 m	100 m	100 m
Recoverable injury		High risk at near and intermediate distances Low risk at far distance				
TTS		High risk at near and intermediate distances Low risk at far distance				

Table 7.32: Summary of impact ranges for hearing specialist fish in the AHEP area when exposed to blast noise using SPL peak metrics

Particle velocity metrics

The presence of a bubble curtain has no effect on particle velocity. The distances at over which the PPV impact criterion are met are therefore unchanged from those given in Table 7.12.

7.4.4 Seabirds

Impulse metrics

The Mortality, Slight Blast Injury and Safe Level impact criteria are all met at distances inside the bubble curtain. As such the presence of the bubble curtain has no effect on these criteria and the corresponding impact distances are as given in Table 7.13.

8 SUMMARY AND CONCLUSIONS

Construction activity at AHEP involves the use of explosives detonated in boreholes that have been drilled into the seabed. The purpose of this task is to fracture and subsequently remove the bedrock in order to increase the water depth at key locations around Nigg Bay. The noise created from their installation has the potential to impact on sensitive biological receptors in the marine environment.

The current licensing agreement obtained through the regulatory authorities permit the use of a maximum charge weight of 20 kg. In order to meet project requirements, permission is being sought to increase the maximum charge beyond this limit.

Specific data on the sound levels appropriate to the detonation of a given charge weight of explosive in confined blasting do not exist. A model for estimating the peak blast levels from confined blasting was taken from the published literature and modified using acoustic data acquired during the blasting programme in Nigg Bay in 2018[9].

A number of marine species have been identified as being of specific interest to the AHEP area. Using the methodology described by Southall *et al*.[3] and Popper *et al*.[27] the corresponding functional hearing groups are given as: low-, medium- and high-frequency cetaceans; phocid pinnipeds; hearing generalist fish (both "low-" and "medium-sensitivity") and hearing specialist fish; and fish eggs and larvae.

The published literature was accessed to determine threshold values relating to potential acoustic impacts on each functional hearing group. The potential impacts considered were mortality; auditory impairment (PTS and TTS) and behavioural responses, which were based on peak and rms SPL and SEL metrics derived from studies by Southall *et al*.[3], NMFS[26] and Popper *et al*.[27].

The acoustic impact modelling draws on blast impact propagation modelling, shallow water propagation modelling, and M-weighting criteria for marine mammals and fish hearing sensitivity where relevant. Distances at which each acoustic impact are likely to be met were determined for a range of explosive charge weights given both the absence and presence (in two different locations) of a bubble curtain.

Bubble curtain absent - Peak SPL, RMS metrics

Cetaceans - For medium-frequency cetaceans, being the least sensitive of the cetacean functional hearing groups to blast noise, the distance over which the PTS impact criterion is met varies from 27 m to 160 m from the blast site depending on charge weight. TTS is met at a maximum distance of 610 m. For high-frequency cetaceans, being the most sensitive of the hearing groups, the PTS impact criterion is met at a distance of 17 km while the TTS impact criterion extends to 26 km. For all functional hearing groups, the Strong Behavioural Impact criterion is met at a maximum distance of 120 km.

Phocids – Phocids are generally less sensitive to blast noise than cetaceans. The PTS impact criterion is met at distances varying between 420 m to 2.5 km for the 20 kg and 60 kg charge weights respectively. The TTS impact criterion extends to a maximum distance of 6.9 km. The Strong Behavioural Response criterion is met over distances of 2.1 km to 19 km.

Fish - For fish of all hearing abilities, the Mortality and Potential Mortal Injury impact criterion is met at no more than 200 m from the blast site for the largest charge weight considered. There is the possibility of a high risk that both the Recoverable Injury and the TTS impact criteria will be met at near distances to the blast site.

Bubble curtain absent - SEL metrics

Cetaceans - Acoustic impacts can build up on a receptor following a period of continual exposure. When exposed to a pulse of 2.2 seconds (this being the mean duration of the outgoing pulse (derived from measurements made during the 2018 blasting programme[9]), the PTS and TTS impact criteria are met at maximum distances of 24 km and 51 km respectively for low-frequency cetaceans. This is the most sensitive of all the cetacean functional hearing groups considered when assessed using SEL metrics.

Phocids - The PTS impact criteria is met at distances between 480 m and 2.8 km depending on charge weight. The TTS impact criterion extends to a maximum distance of 17 km.

Bubble curtain absent - PPV metrics

Fish eggs and larvae - The Mortality and Potential Mortal Injury is also defined in terms of the Peak Particle Velocity. This impact extends to cover the range 68 m to 120 m for all the charge weights considered.

Bubble curtain absent - Impulse metrics

Seabirds - The 50% Mortality, Mortality, Slight Blast Injury and Safe Level impact criteria are defined in terms of the impulse. The 50% Mortality impact is met at distances from 3 m to 8 m for charge weights between 20 kg and 60 kg. The Safe Level impact criterion extends to a maximum, distance of 19 m from the blast site following detonation of the 60 kg charge.

Bubble curtain present at 650 m - Peak SPL, RMS metrics

Cetaceans – When the presence of a bubble curtain at a distance of 650 m from the blast site is included in the impact modelling, the PTS impact criterion is met at a maximum distance of 660 m for all functional hearing groups. The TTS impact criterion is met at a maximum distance of 2.5 km for the largest charge weight considered. The Strong Behavioural Response impact criterion extends to a maximum distance of 16 km for both low- and medium frequency cetaceans while for the high-frequency cetaceans, the criterion is met at a maximum distance of 71 km.

Phocids – Both the PTS and TTS impact criteria are met at maximum distances of 660 m from the blast site. The Strong Behavioural Response criterion covers the range 660 m to 770 m.

Fish - The distances over which the Mortality and Potential Mortal Injury criterion are met for all charge weights are so short that they fall at distances inside the bubble curtain hence they are unaffected by the presence of the bubble curtain when it is located at a distance of 650 m from the blast site. Hence for fish of all hearing abilities, the Mortality and Potential Mortal Injury impact criterion is met at no more than 200 m from the blast site for the largest charge weight considered. There is the possibility of a high risk that both the Recoverable Injury and the TTS impact criteria will be met at near distances to the blast site.

Bubble curtain present at 650 m - SEL metrics

Cetaceans – The PTS impact criterion extends to a maximum distance of 1.8 km from the blast site while the TTS impact criterion covers a maximum distance of 15 km for the largest charge weight modelled.

Phocids – Both the PTS and TTS impact criteria are met at a maximum distance of 660 m for all charge weights considered.

Bubble curtain present at 650 m - PPV metrics

Fish eggs and larvae - The presence of a bubble curtain has no effect on particle velocity. This impact extends to cover the range 68 m to 120 m for all the charge weights considered.

Bubble curtain present at 650 m - Impulse metrics

Seabirds - The presence of a bubble curtain has no effect on impulse. The Safe Level impact extends to a maximum distance of 19 m from the blast site for the maximum charge weight considered.

Bubble curtain present at 100 m - Peak SPL, RMS metrics

Cetaceans – When the presence of a bubble curtain at a distance of 100 m from the blast site is included in the impact modelling, both the PTS and TTS impact criteria are met at a distance of 100 m for low- and medium-frequency cetaceans. For high-frequency cetaceans, the maximum distance is 610 m. The TTS impact criterion is met at a maximum distance of 2.5 km for the largest charge weight considered. The Strong Behavioural Response impact criterion extends to a maximum distance of 16 km for both low- and medium frequency cetaceans while for the high-frequency cetaceans, the criterion is met at a maximum distance of 71 km.

Phocids – Both the PTS and TTS impact criteria are met at maximum distances of 100 m from the blast site. The Strong Behavioural Response criterion covers the range 100 m to 770 m.

Fish - For fish of all hearing abilities, the Mortality and Potential Mortal Injury impact criterion is met at no more than 100 m from the blast site for the largest charge weight considered. There is the possibility of a high risk that both the Recoverable Injury and the TTS impact criteria will be met at near distances to the blast site.

Bubble curtain present at 100 m - SEL metrics

Cetaceans – The PTS impact criterion extends to a maximum distance of 1.8 km from the blast site while the TTS impact criterion covers a maximum distance of 15 km for the largest charge weight modelled.

Phocids – The PTS impact criterion is met at a maximum distance of 100 m from the blast site. The TTS impact criterion extends to a maximum distance of 560 m when the largest charge weight is considered.

Bubble curtain present at 100 m - PPV metrics

Fish eggs and larvae - The presence of a bubble curtain has no effect on particle velocity. This impact extends to cover the range 68 m to 120 m for all the charge weights considered.

Bubble curtain present at 100 m - Impulse metrics

Seabirds - The presence of a bubble curtain has no effect on impulse. The Safe Level impact extends to a maximum distance of 19 m from the blast site for the maximum charge weight considered.

ANNEX A: NO BUBBLE CURTAIN

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Low-frequency cetaceans	PTS	219 dB re 1 μPa peak	340	640	1100	1500	2000	2500	3100	3700	4400
	TTS	213 dB re 1 μPa peak	1400	2600	4000	5400	6200	7000	7700	8400	9000
	Strong Behavioural Response	180 dB re 1 μPa rms	22000	26000	30000	32000	35000	37000	38000	40000	41000
		170 dB re 1 μPa rms	39000	45000	49000	52000	54000	56000	58000	60000	62000
	No Behavioural Response	130 dB re 1 μPa rms	130000	130000	140000	140000	150000	150000	150000	150000	150000
		120 dB re 1 μPa rms	150000	160000	160000	170000	170000	170000	170000	180000	180000

Table A.1: Ranges in metres at which SPL has fallen to threshold level for low-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Low-frequency cetaceans	PTS	183 dB re 1 μPa^2.sec	14000	17000	20000	22000	24000	25000	27000	28000	29000
	TTS	168 dB re 1 μPa^2.sec	36000	42000	46000	49000	51000	53000	55000	57000	59000

Table A.2: Ranges in metres at which SEL has fallen to threshold level for low-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Medium-frequency cetaceans	PTS	230 dB re 1 μPa peak	27	51	80	120	160	200	250	300	350
	TTS	224 dB re 1 μPa peak	110	210	320	460	610	780	970	1200	1400
	Strong Behavioural Response	180 dB re 1 μPa rms	22000	26000	30000	32000	35000	37000	38000	40000	41000
		170 dB re 1 μPa rms	39000	45000	49000	52000	54000	56000	58000	60000	62000
	No Behavioural Response	140 dB re 1 μPa rms	110000	110000	120000	120000	120000	130000	130000	130000	130000
		130 dB re 1 μPa rms	130000	130000	140000	140000	150000	150000	150000	150000	150000

Table A.3: Ranges in metres at which SPL has fallen to threshold level for medium-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Medium-frequency cetaceans	PTS	185 dB re 1 μPa^2.sec	<1 m	<1 m	<1 m	<1 m	<1 m	<1 m	2	2	2
	TTS	170 dB re 1 μPa^2.sec	4	7	12	16	22	27	34	41	48

Table A.4: Ranges in metres at which SEL has fallen to threshold level for medium-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
High-frequency cetaceans	PTS	202 dB re 1 μPa peak	8800	12000	14000	16000	17000	19000	20000	21000	22000
	TTS	196 dB re 1 μPa peak	15000	19000	22000	24000	26000	28000	29000	31000	32000
	Strong Behavioural Response	150 dB re 1 μPa rms	80000	86000	91000	94000	97000	99000	110000	110000	110000
		140 dB re 1 μPa rms	110000	110000	120000	120000	120000	130000	130000	130000	130000
	No Behavioural Response	100 dB re 1 μPa rms	200000	200000	210000	210000	210000	220000	220000	220000	220000
		90 dB re 1 μPa rms	220000	230000	230000	230000	240000	240000	240000	240000	250000

Table A.5: Ranges in metres at which SPL has fallen to threshold level for high-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
High-frequency cetaceans	PTS	155 dB re 1 μPa^2.sec	7	13	20	29	38	49	60	73	86
	TTS	140 dB re 1 μPa^2.sec	210	400	630	900	1200	1600	1900	2300	2800

Table A.6: Ranges in metres at which SEL has fallen to threshold level for high-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Phocid pinnipeds	PTS	218 dB re 1 μPa peak	420	800	1300	1900	2500	3100	3900	4700	5300
	TTS	212 dB re 1 μPa peak	1700	3200	5100	6000	6900	7700	8500	9200	9900
	Strong Behavioural Response	200 dB re 1 μPa rms	2100	4100	5700	6700	7700	8600	9400	11000	11000
		190 dB re 1 μPa rms	9700	13000	15000	17000	19000	20000	21000	23000	24000
	No Behavioural Response	180 dB re 1 μPa rms	22000	26000	30000	32000	35000	37000	38000	40000	41000
		170 dB re 1 μPa rms	39000	45000	49000	52000	54000	56000	58000	60000	62000

Table A.7: Ranges in metres at which SPL has fallen to threshold level for pinnipeds exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Pinnipeds	PTS	185 dB re 1 μPa^2.sec	480	920	1500	2100	2800	3600	4400	5200	5600
	TTS	170 dB re 1 μPa^2.sec	8500	12000	14000	15000	17000	18000	19000	21000	22000

Table A.8: Ranges in metres at which SEL has fallen to threshold level for pinnipeds exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Hearing generalist (“low-sensitivity”) fish	Mortality and Potential Mortal Injury	234 dB re 1 μPa peak	11	21	32	46	61	78	97	120	140
		229 dB re 1 μPa peak	34	64	110	150	200	250	310	370	440

Table A.9: Ranges in metres at which SPL has fallen to threshold level for fish exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Fish eggs and larvae	Mortality and Potential Mortal Injury	13 mm/sec	68 m	83 m	96 m	110 m	120 m	130 m	140 m	150 m	160 m

Table A.10: Ranges in metres at which PPV has fallen to threshold level for fish eggs and larvae exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Seabirds	50% mortality	896 Pas.sec	3 m	5 m	6 m	7 m	8 m	8 m	9 m	10 m	11 m
	Mortality threshold	690 Pas.sec	4 m	6 m	7 m	8 m	9 m	10 m	11 m	12 m	13 m
	Slight blast injuries	276 Pas.sec	7 m	10 m	12 m	14 m	16 m	18 m	19 m	20 m	22 m
	Safe level	207 Pas.sec	9 m	12 m	15 m	17 m	19 m	22 m	22 m	24 m	25 m

Table A.11: Ranges in metres at which at which impulse has fallen to threshold level for seabirds exposed to blast noise frpm the given charge weight

ANNEX B: BUBBLE CURTAIN AT 650 M

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Low-frequency cetaceans	PTS	219 dB re 1 µPa peak	340	640	660	660	660	660	660	660	660
	TTS	213 dB re 1 µPa peak	660	660	660	660	660	660	660	660	660
	Strong Behavioural Response	180 dB re 1 µPa rms	1400	2600	4000	5400	6200	7000	7700	8400	9000
		170 dB re 1 µPa rms	8000	11000	13000	15000	16000	18000	19000	20000	21000
	No Behavioural Response	130 dB re 1 µPa rms	76000	82000	86000	90000	92000	95000	97000	99000	100000
		120 dB re 1 µPa rms	98000	110000	110000	120000	120000	120000	120000	130000	130000

Table B.1: Ranges in metres at which SPL has fallen to threshold level for low-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Low-frequency cetaceans	PTS	183 dB re 1 μPa^2.sec	660	660	910	1300	1800	2300	2800	3400	4000
	TTS	168 dB re 1 μPa^2.sec	6900	9200	11000	13000	15000	16000	17000	18000	19000

Table B.2: Ranges in metres at which SEL has fallen to threshold level for low-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Medium-frequency cetaceans	PTS	230 dB re 1 μPa peak	27	51	80	120	160	200	250	300	350
	TTS	224 dB re 1 μPa peak	110	210	320	460	610	660	660	660	660
	Strong Behavioural Response	180 dB re 1 μPa rms	1400	2600	4000	5400	6200	7000	7700	8400	9000
		170 dB re 1 μPa rms	8000	11000	13000	15000	16000	18000	19000	20000	21000
	No Behavioural Response	140 dB re 1 μPa rms	55000	61000	65000	68000	71000	73000	75000	77000	78000
		130 dB re 1 μPa rms	76000	82000	86000	90000	92000	95000	97000	99000	100000

Table B.3: Ranges in metres at which SPL has fallen to threshold level for medium-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Medium-frequency cetaceans	PTS	185 dB re 1 μPa^2.sec	<1 m	<1 m	<1 m	<1 m	<1 m	<1 m	2	2	2
	TTS	170 dB re 1 μPa^2.sec	4	7	12	16	22	27	34	41	48

Table B.4: Ranges in metres at which SEL has fallen to threshold level for medium-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
High-frequency cetaceans	PTS	202 dB re 1 μPa peak	660	660	660	660	660	780	970	1200	1400
	TTS	196 dB re 1 μPa peak	660	800	1300	1900	2500	3100	3900	4700	5300
	Strong Behavioural Response	150 dB re 1 μPa rms	35000	41000	45000	48000	50000	52000	54000	56000	57000
		140 dB re 1 μPa rms	55000	61000	65000	68000	71000	73000	75000	77000	78000
	No Behavioural Response	100 dB re 1 μPa rms	150000	150000	160000	160000	160000	170000	170000	170000	170000
		90 dB re 1 μPa rms	170000	180000	180000	180000	190000	190000	190000	190000	200000

Table B.5: Ranges in metres at which SPL has fallen to threshold level for high-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
High-frequency cetaceans	PTS	155 dB re 1 μPa^2.sec	7	13	20	29	38	49	60	73	86
	TTS	140 dB re 1 μPa^2.sec	210	400	630	660	660	660	660	660	660

Table B.6: Ranges in metres at which SEL has fallen to threshold level for high-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Phocid pinnipeds	PTS	218 dB re 1 μPa peak	420	660	660	660	660	660	660	660	660
	TTS	212 dB re 1 μPa peak	660	660	660	660	660	660	660	660	660
	Strong Behavioural Response	200 dB re 1 μPa rms	660	660	660	660	660	660	660	660	660
		190 dB re 1 μPa rms	660	660	660	660	770	980	1300	1500	1800
	No Behavioural Response	180 dB re 1 μPa rms	1400	2600	4000	5400	6200	7000	7700	8400	9000
		170 dB re 1 μPa rms	8000	11000	13000	15000	16000	18000	19000	20000	21000

Table B.7: Ranges in metres at which SPL has fallen to threshold level for pinnipeds exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Phocid pinnipeds	PTS	185 dB re 1 μPa^2.sec	480	660	660	660	660	660	660	660	660
	TTS	170 dB re 1 μPa^2.sec	660	660	660	660	660	710	880	1100	1300

Table B.8: Ranges in metres at which SEL has fallen to threshold level for pinnipeds exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
All fish functional hearing groups	Mortality and Potential Mortal Injury	234 dB re 1 μPa peak	11	21	32	46	61	78	97	120	140
		229 dB re 1 μPa peak	34	64	110	150	200	250	310	370	440

Table B.9: Ranges in metres at which SPL has fallen to threshold level for hearing generalist ("low sensitivity") fish exposed to explosive blast noise from the given charge weight

ANNEX C: BUBBLE CURTAIN AT 100 M

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Low-frequency cetaceans	PTS	219 dB re 1 μPa peak	100	100	100	100	100	100	100	100	100
	TTS	213 dB re 1 μPa peak	100	100	100	100	100	100	100	100	110
	Strong Behavioural Response	180 dB re 1 μPa rms	1400	2600	4000	5400	6200	7000	7700	8400	9000
		170 dB re 1 μPa rms	8000	11000	13000	15000	16000	18000	19000	20000	21000
	No Behavioural Response	130 dB re 1 μPa rms	76000	82000	86000	90000	92000	95000	97000	99000	100000
		120 dB re 1 μPa rms	98000	110000	110000	120000	120000	120000	120000	130000	130000

Table C.1: Ranges in metres at which SPL has fallen to threshold level for low-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Low-frequency cetaceans	PTS	183 dB re 1 μPa^2.sec	300	580	910	1300	1800	2300	2800	3400	4000
	TTS	168 dB re 1 μPa^2.sec	6900	9200	11000	13000	15000	16000	17000	18000	19000

Table C.2: Ranges in metres at which SEL has fallen to threshold level for low-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Medium-frequency cetaceans	PTS	230 dB re 1 μPa peak	27	51	80	100	100	100	100	100	100
	TTS	224 dB re 1 μPa peak	100	100	100	100	100	100	100	100	100
	Strong Behavioural Response	180 dB re 1 μPa rms	1400	2600	4000	5400	6200	7000	7700	8400	9000
		170 dB re 1 μPa rms	8000	11000	13000	15000	16000	18000	19000	20000	21000
	No Behavioural Response	140 dB re 1 μPa rms	55000	61000	65000	68000	71000	73000	75000	77000	78000
		130 dB re 1 μPa rms	76000	82000	86000	90000	92000	95000	97000	99000	100000

Table C.3: Ranges in metres at which SPL has fallen to threshold level for medium-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Medium-frequency cetaceans	PTS	185 dB re 1 μPa^2.sec	<1 m	<1 m	<1 m	<1 m	<1 m	<1 m	2	2	2
	TTS	170 dB re 1 μPa^2.sec	4	7	12	16	22	27	34	41	48

Table C.4: Ranges in metres at which SEL has fallen to threshold level for medium-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
High-frequency cetaceans	PTS	202 dB re 1 μPa peak	110	210	320	460	610	780	970	1200	1400
	TTS	196 dB re 1 μPa peak	420	800	1300	1900	2500	3100	3900	4700	5300
	Strong Behavioural Response	150 dB re 1 μPa rms	35000	41000	45000	48000	50000	52000	54000	56000	57000
		140 dB re 1 μPa rms	55000	61000	65000	68000	71000	73000	75000	77000	78000
	No Behavioural Response	100 dB re 1 μPa rms	150000	150000	160000	160000	160000	170000	170000	170000	170000
		90 dB re 1 μPa rms	170000	180000	180000	180000	190000	190000	190000	190000	200000

Table C.5: Ranges in metres at which SPL has fallen to threshold level for high-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
High-frequency cetaceans	PTS	155 dB re 1 μPa^2.sec	7	13	20	29	38	49	60	73	86
	TTS	140 dB re 1 μPa^2.sec	100	100	100	100	100	100	100	100	100

Table C.6: Ranges in metres at which SEL has fallen to threshold level for high-frequency cetaceans exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Phocid pinnipeds	PTS	218 dB re 1 μPa peak	100	100	100	100	100	100	100	100	100
	TTS	212 dB re 1 μPa peak	100	100	100	100	100	100	100	120	140
	Strong Behavioural Response	200 dB re 1 μPa rms	100	100	100	100	100	100	130	150	180
		190 dB re 1 μPa rms	140	260	400	580	770	980	1300	1500	1800
	No Behavioural Response	180 dB re 1 μPa rms	1400	2600	4000	5400	6200	7000	7700	8400	9000
		170 dB re 1 μPa rms	8000	11000	13000	15000	16000	18000	19000	20000	21000

Table C.7: Ranges in metres at which SPL has fallen to threshold level for pinnipeds exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
Phocid pinnipeds	PTS	185 dB re 1 μPa^2.sec	100	100	100	100	100	100	100	100	100
	TTS	170 dB re 1 μPa^2.sec	100	190	290	420	560	710	880	1100	1300

Table C.8: Ranges in metres at which SEL has fallen to threshold level for pinnipeds exposed to explosive blast noise from the given charge weight

Functional hearing group	Impact	Threshold	20kg	30kg	40kg	50kg	60kg	70kg	80kg	90kg	100kg
All fish functional hearing groups	Mortality and Potential Mortal Injury	234 dB re 1 μPa peak	11	21	32	46	61	78	97	100	100
		229 dB re 1 μPa peak	34	64	100	100	100	100	100	100	100

Table C.9: Ranges in metres at which SPL has fallen to threshold level for hearing generalist (“low sensitivity”) fish exposed to explosive blast noise from the given charge weight

C. CONFINED BLAST MODEL CALIBRATION REPORT

Award Environmental Consultants Ltd

Calibration of the Confined-Blast model in connection with the blasting program in Nigg Bay for Aberdeen Harbour Expansion Project

P D Ward
Award Environmental Consultants Ltd

Rep: 201804-007-V3

16 November 2018

Administration Page

Customer Information	
Customer reference number	
Project title	Calibration of the Confined-Blast model in connection with the blasting program in Nigg Bay for Aberdeen Harbour Expansion Project
Customer Organisation	Dragados UK Limited AHEP Project Office St Fitticks Road, Nigg Bay Aberdeen, AB11 8TN
Customer contact	Peter Scott-Wilson
Contract number	AECL/201804-007-V3
Date due	16 November 2018

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Record of changes

Issue	**Date**	**Detail of Changes**
1	09 November 2018	Final report
2	13 November 2018	Addition of Section 4.5
3	16 November 2018	Incorporate client review comments

CONTENTS

EXECUTIVE SUMMARY

This report was commissioned in order to address the following points:

- to verify the existing Confined-Blast model predictions using blast noise data acquired during the blasting program that took place in Nigg Bay over the period August to October 2018;
- to support the proposal to increase the maximum permitted charge weight beyond 20 kg of explosive deployed during blasting;
- to support the assertion that blasting can be carried out without exceeding the noise benchmark of 170 dB re 1 μPa RMS at a location outside the bubble curtain;
- to show that where the bubble curtain is set closer than 400 m from the blast site, that the noise benchmark will not be exceeded at a location beyond 400 m from the blast site.

The underwater noise monitoring field data has been used to validate the Confined-Blast model predictions, including the generation and propagation of a waterborne component of the blast wave which arises following the detonation of an explosive charge contained in the subsea sediment.

The validated Confined-Blast model was used to predict peak and RMS blast levels expected to occur following the detonation of explosive charges in excess of 20 kg.

A requirement is given that RMS blast levels should not exceed the noise benchmark condition of 170 dB re 1 μPa RMS at a location just outside the bubble curtain when blasting takes place at the northern edge of Nigg Bay. In order to meet this requirement, the modified Confined-Blast model shows that maximum permitted charge weights can vary in the range 30-100 kg depending on:

(i) the level of attenuation provided by the bubble curtain; and

(ii) the level of risk deemed acceptable in exceeding the benchmark condition.

When blasting takes place at the southern edge of Nigg Bay and the bubble curtain is re-sited to a location approximately 100 m beyond the blast site, the modified Confined-Blast model indicates that RMS blast levels may remain above the benchmark at distances varying from 0 m to 360 m beyond the bubble curtain for charge weights in the range 20-70 kg and for a bubble curtain having an attenuation of 35 dB. For a bubble curtain having an attenuation of 45 dB, sufficient energy is removed from the blast wave such that the benchmark condition is not met at all.

1. INTRODUCTION

This document has been prepared by Award Environmental Consultants Ltd for Dragados UK Limited under the Aberdeen Harbour Expansion Project (AHEP) contract. Its objective is to describe a model which may be used to predict blast levels arising from the detonation of explosive charge weights that are in excess of the currently permitted maximum of 20 kg.

The report commences with an overview of the blast noise data acquired in Nigg Bay over the AHEP blasting program that took place from August through to October 2018. As an environmental impact mitigation measure, a double bubble curtain had been put in place so as to restrict the propagation of blast noise into the wider underwater environment. The resulting attenuation of the blast wave by the bubble curtain was determined from noise survey data acquired at locations either side of the curtain itself.

Given the additional blast data, the Confined-Blast model described in the Environmental Statement[1] was revisited and modifications were made which led to a higher level of agreement between predicted blast levels and the blast levels determined from the survey data. Subsequently, the modified Confined-Blast model was used to predict blast levels likely to arise following the detonation of explosive charge weights in excess of the current maximum of 20 kg.

In order to remain environmentally compliant, it is a requirement that a benchmark condition of 170 dB re 1 μPa at a location just outside the bubble curtain (or at 400 m if the bubble curtain is closer than 400 m to the blast site) should not be exceeded. Given this constraint, it is shown that maximum permissible charge weights are in the range 30-100 kg depending on:

(i) an acceptable bubble curtain attenuation given the uncertainty in the value determined from the preceding analysis; and

(ii) the maximum allowable level of risk in exceeding the benchmark condition just outside the bubble curtain.

Finally, a number of procedures are highlighted whereby the explosive charge weight is increased; a short blasting program is undertaken; and the resulting blast levels are compared against the benchmark condition and the peak levels calculated from the Confined-Blast model. Provided the benchmark condition is not exceeded, the charge weight is increased and the process repeated.

[1] Aberdeen Harbour Expansion Project, Volume 3: Technical Appendices - Appendix 13-B Underwater Noise Impact Study, November 2015 - "Underwater noise impact study for Aberdeen Harbour Expansion Project: Impact of construction noise", Kongsberg Report 35283-0004-V5.

2. BLAST DATA ANALYSIS SUMMARY

2.1 Data processing

An earlier report[2] provided an analysis of the blast data that had been acquired during the test blasting program in Nigg Bay that took place over August and September 2018. For each blast, acoustic noise data was acquired simultaneously at two various locations within Nigg Bay both inside and outside the bubble curtain. From blast to blast, the recording locations changed hence over the course of a number of blast days a general trend built up which showed variation of blast level with respect to distance from the blast site. A number of conclusions were drawn from the work presented therein:

- for recordings obtained at locations inside the bubble curtain, the model underestimated noise levels by up to 32 dB;
- for recordings made at locations outside the bubble curtain, the model overestimated noise levels by up to 30 dB;
- the bubble curtain attenuation was estimated at 30±22 dB.

The relatively large uncertainty in the attenuation of the bubble curtain was attributed at least in part, to the relatively few data points that were available at the time.

This last point was addressed when further data became available following a further round of blasting which took place during October 2018. In addition, the blast data acquired during August and September was revisited following the resolution of an issue surrounding the gain settings of the equipment used in the noise data acquisition chain. During each blast monitoring task in Nigg Bay, the key equipment parameters (notably hydrophone sensitivities and the settings of the terminal units (TU) which are used in the data acquisition chain[3]) are recorded by the Ecofish noise survey team. Over the course of a discussion between AECL and EcoFish, it was agreed that the information provided on the Day Logs (which are produced by the EcoFish noise survey team during each blast activity) was unclear and open to interpretation. As a consequence, this could have a resultant impact on the post-acquisition data processing from which blast noise levels are subsequently determined. In order to address this point of potential confusion, a report was issued[4] where the requisite gain settings for each hydrophone-TU combination were clarified. Following this, the blast data acquired during in August and September was re-processed using the correct gain settings. The outcome of the re-processing stage was that blast levels recorded inside the bubble curtain were increased by up to 2 dB; blast levels recorded outside the bubble curtain were increased by up to 12 dB; the overall

[2] Ward P. D., " Aberdeen Harbour Expansion Project: Results of underwater noise monitoring during test blasting, Award Environmental Consulting Ltd Technical Report 201804-004-V1, September 2018.
[3] "Aberdeen Harbour Expansion Project (AHEP) Underwater Noise + Passive Acoustic Monitoring Procedure", EcoFish Global Ltd Technical Report, Revision 6, July 2018.
[4] Harland E., " Acoustic calibration of equipment used in Nigg Bay, 2018", Chickerell BioAcoustics Technical Report CBA138/18 Iss 1, October 2018.

data spread was reduced slightly.

Figure 2.1 shows all the blast data acquired over the period August through to October compared against peak levels predicted using the Confined-Blast model as presented in the Environmental Statement[1]. It is seen that the blast levels recorded inside the bubble curtain exceed predicted levels by up to 40 dB. By contrast, the blast levels recorded at positions outside the bubble curtain tend to follow predicted peak levels when a bubble curtain having 60% attenuation is included in the model.

In line with the earlier report[2], Figure 2.2 shows the results of a linear-regression analysis on the data recorded both inside and outside the bubble curtain - which itself is located approximately 600-650 m from the blast site. This shows that the bubble curtain has an attenuation of 45 ± 10 dB. This revised value is largely consistent with the attenuation estimated previously but the level of uncertainty in the mean value as expressed by the tolerance is now much reduced.

The opportunity now exists to use the acquired data in order to refine the Confined-Blast model and to improve the fit between data and model output. This stage is discussed in the following section below.

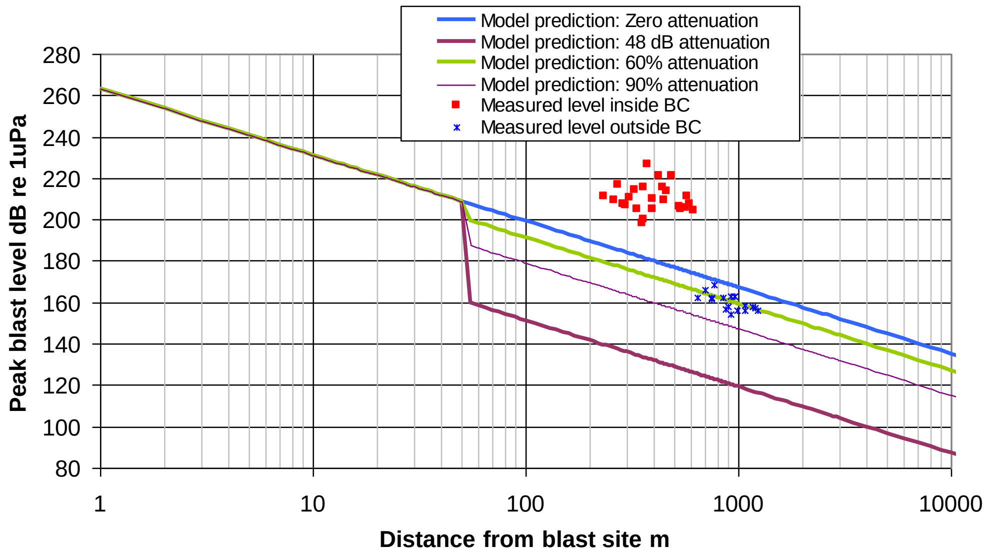

Figure 2.1: Peak blast levels as a function of distance from blast site recorded inside and outside the bubble curtain during Aug-Oct 2018

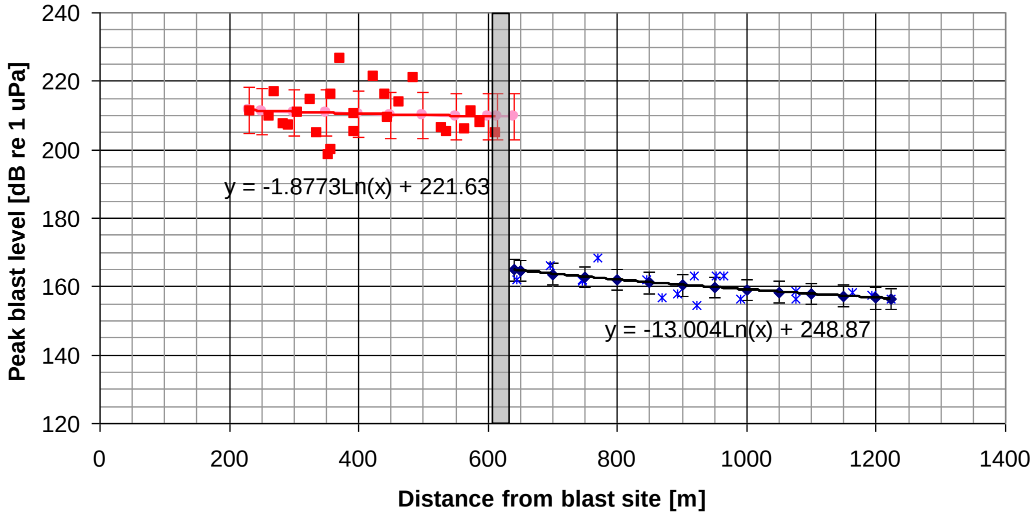

Figure 2.2: Regression analysis on datasets recorded during August through to October both inside and outside the bubble curtain

2.2 Data uncertainty

It is noted that the blast levels thus acquired show considerable variation and at least some of this may be attributed to uncertainties arising during the measurement procedure and discussed earlier[2]. It is also acknowledged that the noise levels recorded are partly dependent on the movement of the noise survey vessels which arises as a result of a combination of wind and tide within Nigg Bay both of which vary temporally and spatially. When working under such "real world" conditions, and especially given the nature of the weather in and around Nigg Bay, the resulting variation in blast levels is both inevitable and unavoidable and must therefore be taken into account in any subsequent data analysis.

An understanding of the propagation of blast waves that takes place in Nigg Bay is supported by the linear-regression analysis presented herein. The uncertainties associated with the results of the analysis therefore take into account the variation in environmental conditions prevailing over the entire noise survey period.

3. BLAST PROPAGATION MODELLING REFINEMENT

3.1 Rockborne wave

The underwater noise modelling technical study contained in the Environmental Statement (ES)[1] involved modelling the outgoing waterborne pressure wave and ground vibration that follows such an explosion. The modelling was based on the confined detonation of a 20 kg charge of explosive located in a borehole that had been drilled to a depth of 2.5 m into the subsea sediments. The underpinning model was based on a semi-empirical technique developed by Wright and Hopky[5] whereby the blast wave formed following detonation is attenuated by the surrounding bedrock. This may be illustrated further below in Figure 3.1.

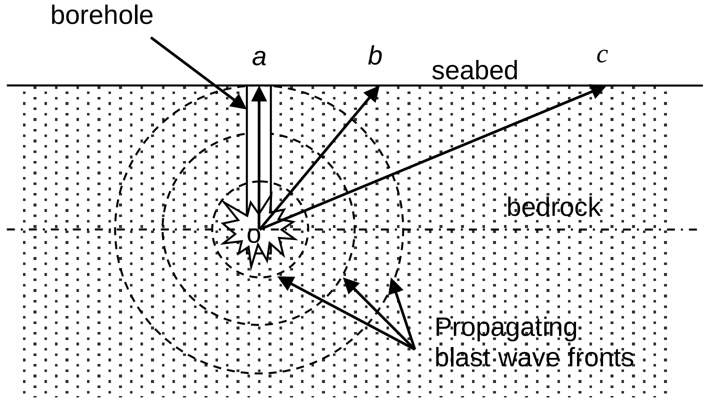

Figure 3.1: Schematic of confined blasting scenario

A detonation takes place at location *o* as indicated in Figure 3.1. The initial source level in the rock is given by SL dB re 1 μPa at 1 m. The blast wave propagates through the surrounding bedrock and it undergoes a degree of attenuation which is proportional to the path length over which it has travelled.

At location *a* on the seabed immediately above the detonation site, the blast wave has travelled through the distance *oa*. The attenuating nature of the bedrock ensures that acoustic energy is absorbed and dissipated into the rock thereby reducing the blast wave pressure level by an amount equal to $\alpha(oa)$ dB. The blast wave pressure level (BPL) at location *a* is thus given by:

$$BPL_{oa} = SL - \alpha(oa) \quad \text{(i)}$$

At some lateral distance *b* from the detonation site, the blast wave has travelled over a longer path given by *ob*. Hence the attenuation in the bedrock is given by $\alpha(xb)$ dB and the blast wave pressure level at location *b* is given by

$$BPL_{ob} = SL - \alpha(ob) \quad \text{(ii)}$$

Similarly, the blast wave pressure level at location *c* is given by

$$BPL_{oc} = SL - \alpha(oc) \quad \text{(iii)}$$

[5] Wright D.G., Hopky G.E., (1998), "Guidelines for the Use of Explosives In or Near Canadian Fisheries Waters", Canadian Technical Report of Fisheries and Aquatic Sciences 2107, Department of Fisheries and Oceans, Canada.

It is noted that the further the wavefront propagates through the rock the smaller the BPL at the seabed hence $BPL_{oc} < BPL_{ob} < BPL_{oa}$.

Using the equations developed by Wright and Hopky[5], the explosive blast peak pressure level as a function of distance from the detonation site may be calculated and the results are shown in Figure 3.2. This shows that the instantaneous peak level at a distance of 1 m from the detonation site is 263 dB re 1 μPa falling to approximately 200 dB re 1 μPa at a distance of 100 m and 167 dB re 1 μPa at a distance of 1000 m.

It is important to caveat these results: the blast propagation model assumes a very simple representation of the environment whereby the bedrock is single-layered and homogenous in nature. In practice, it is known that the seabed sediments at Nigg Bay consists of sandstone of varying thickness and which overlays a metamorphic bedrock. The effect of such layering on the propagation of the blast wave is not known but is thought likely that the amplitude of the peak blast level will be reduced though the introduction of further acoustic losses as the wave front propagates over the interface between the two layers.

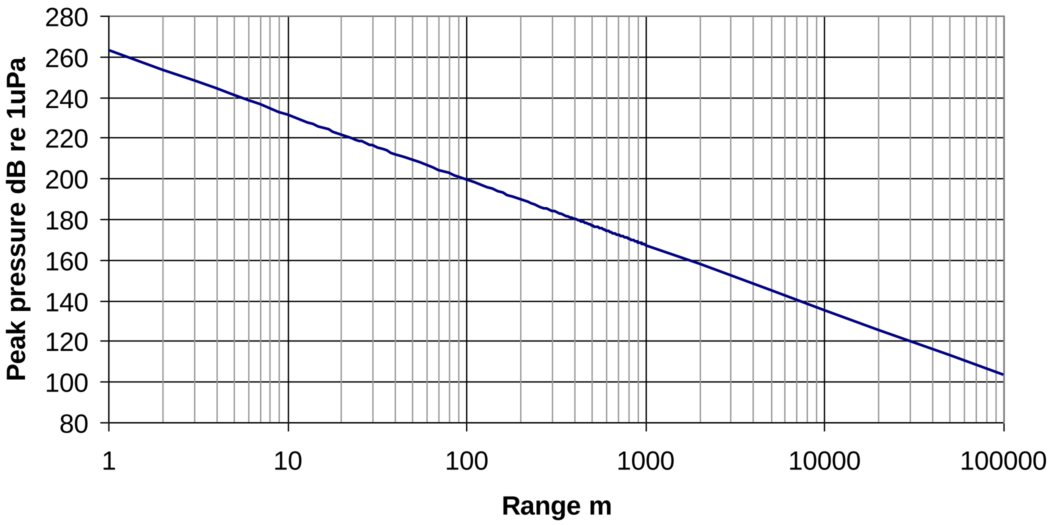

Figure 3.2: Rockborne blast levels for a 20 kg charge weight in a borehole 2.5 m deep, as a function of distance from the detonation site

3.2 Waterborne wave

Now consider the schematic diagram shown in Figure 3.3 where, it is assumed, each location on the seabed *oa, ob, oc etc*. acts as a point source radiating sound into the water. In effect, the blast pressure level in the bedrock at *oa* represents the source level of the waterborne blast wave. Subsequently, instead of propagating at the speed of sound in the bedrock, the wave front now propagates at the speed of sound in the water. The waterborne wave is attenuated in the water at some given constant rate - excluding any effect from, say, a bubble curtain. An example given in Figure 3.4 shows the rockborne wave and also the waterborne wave both as a function of distance from the point of detonation. It is noted that the waterborne wave is the component that is actually measured in the water. The rockborne component merely provides the source level term from which the waterborne component subsequently attenuates during propagation. The question now arises as to what degree of attenuation due to propagation is appropriate.

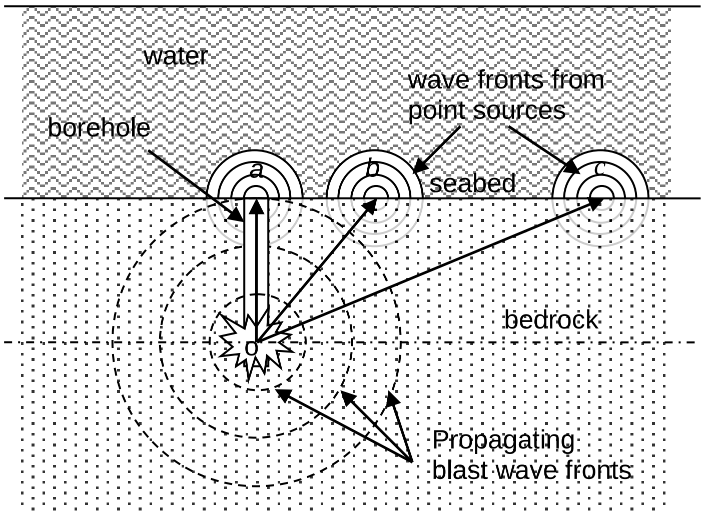

Figure 3.3: Schematic of confined blasting scenario

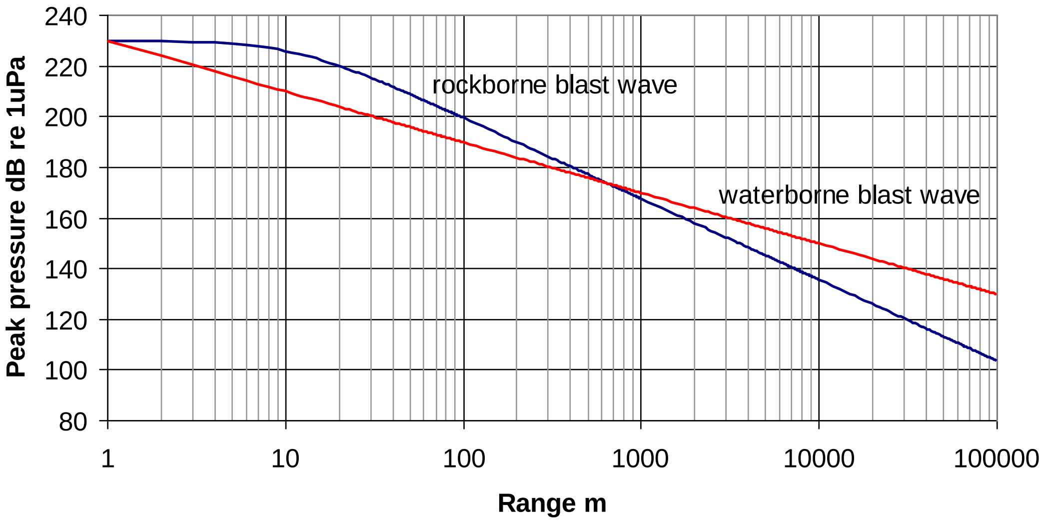

Figure 3.4: Rockborne and waterborne blast wave levels as a function of distance from the detonation site.

3.3 Propagation modelling

In general terms, underwater acoustic propagation may be modelled as N Log10[R] where N is the propagation constant and R is the distance in metres between the blast site and the noise recording location.

If it is assumed that the waterborne wave decays as 20 Log_{10}[R], this indicates that the wavefront expands equally in all directions. Simply by considering the geometry of the acoustic environment in Nigg Bay, spherical spreading can be ruled out. Spectral data of the blast provided by the EcoFish noise survey team show that the explosive blast is predominantly a low-frequency sound source. In addition, the water depths in the vicinity of the blast site in Nigg Bay are very small - ranging from 1 m or so at the point at which the waterborne wave enters the water down to 15-20 m at a distance of 1000 m or so from the blast site. Given the low-frequency components contained in the blast wave, such shallow water depths will not permit the uniform expansion in all directions of the blast wavefront[6].

A more appropriate acoustic propagation law for shallow waters is given by cylindrical spreading where the wave front decays as 10 $Log_{10}[R]$. It can be shown that this gives a much closer fit to the blast level data. Further slight adjustments may be made to the propagation constant: a 13 $Log_{10}[R]$ decay law fits within the statistical standard errors determined using a linear-regression analysis on the data points and this is shown in Figure 3.5. The nominal location of the bubble curtain is included. This lies approximately 650 m from the blast site and is approximately 15 m in width[7].

Given that the Confined-Blast model has now been calibrated using actual blast data, the model may be used to calculate peak blast levels given a range of explosive charge weights. This is explored in Section 4 below.

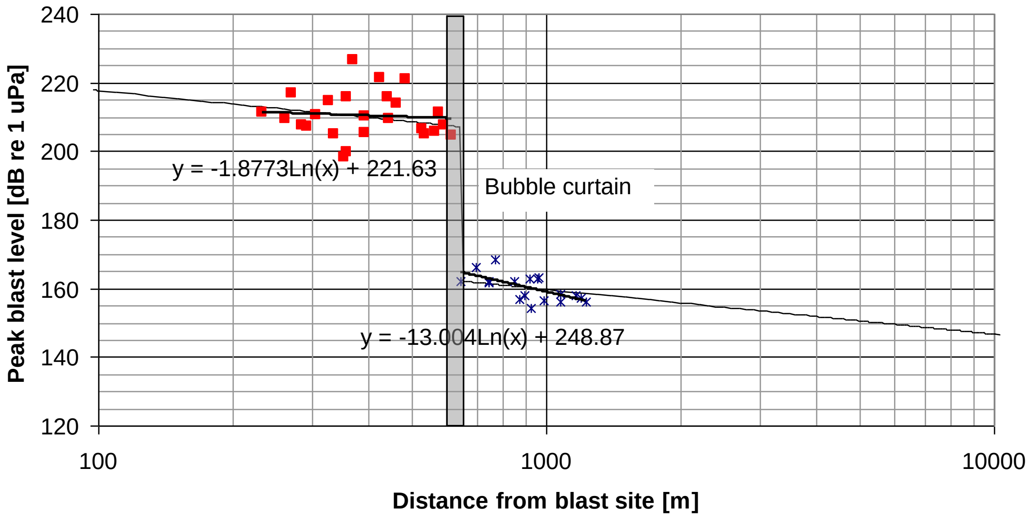

Figure 3.5: Linear regression analysis on blast data compared with a 13Log10[R] acoustic propagation law

[6] Urick, Robert J. (1983), Principles of Underwater Sound, 3rd Edition. New York. McGraw-Hill.
[7] A double bubble curtain is in operation in Nigg Bay.

4. REVISED BLAST PROPAGATION MODELLING

4.1 Confined-Blast modelling

The Confined-Blast model, calibrated using the blast data acquired following the detonation of 20 kg charge weights, may be used to determine suitable peak blast levels for a variety of charge weights.

Figure 4.1 shows peak blast levels calculated for charge weights increasing from 20 kg to 70 kg. Also included is the bubble curtain at a distance of 650 m from the blast site and over which, it is shown, there is an attenuation of 45 dB over a distance of approximately 15 m (representing the nominal width of the bubble curtain).

The figure shows that in increasing the charge weight from 20 kg to 70 kg, there is a predicted increase in peak blast levels of approximately 9 dB.

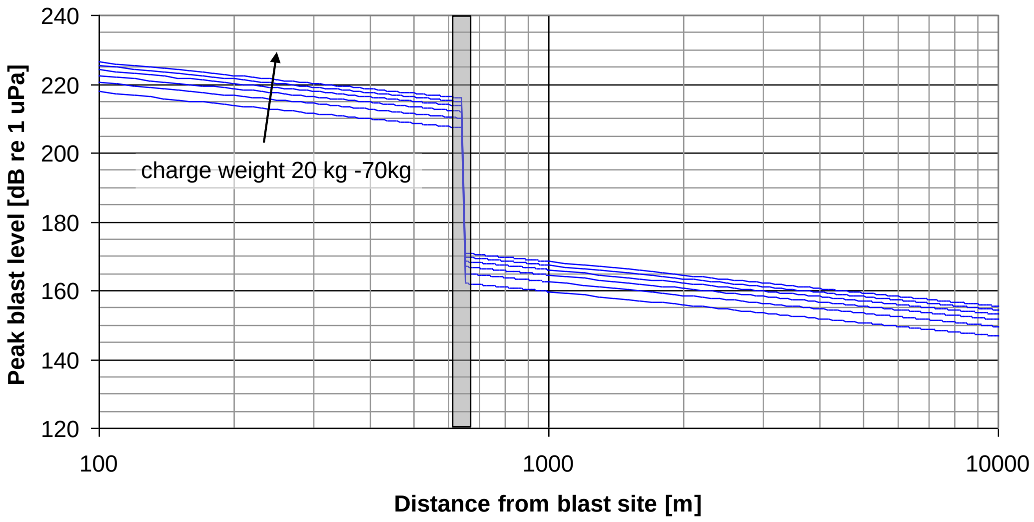

Figure 4.1: Predicted peak blast levels using the modified Confined-Blast model

4.2 Peak level to RMS level

The output from the Confined-Blast model may be used to determine a suitable upper limit of charge weight from which the resulting peak blast level meets a specific threshold. A sound level of 170 dB re 1 μPa RMS has been adopted as a benchmark condition for blast levels recorded at a location just beyond the bubble curtain (or at 400 m if the bubble curtain is closer than 400 m to the blast site). The Confined-Blast model gives output in peak levels whereas the benchmark is given in terms of RMS levels. It is necessary first therefore to convert the peak level into an RMS equivalent.

Peak levels may be converted to equivalent RMS levels following consideration of the nature of the signal. For a sinusoidal signal, the relationship between peak level signal and its RMS equivalent is given by peak level – 3dB. Blast noise signals are not sinusoidal in shape so this conversion is not valid. Furthermore, during propagation the outgoing source signal stretches out in time (see *e.g.* Urick[6]) and this is attributed to the sound travelling along multiple paths and each arriving at a given location at a slightly different time. As a result, the difference between peak level and RMS varies with distance. Various studies[8,9,10] suggest a range of values between 2 dB and 20 dB. It is noted that these values come from impact piling noise and seismic airgun array noise. It is further noted that the greater the degree of asymmetry in the outgoing wave the higher the conversion factor necessary. The blast pulses identified in the acoustic data recorded during the noise surveys were analysed in order to determine an appropriate conversion factor. For the purpose of continuing the analysis undertaken in the current study, it is suggested that for data acquired inside the bubble curtain, the subtraction of a range-invariant 23.4±5.4 dB be used to convert all to peak level metrics to their RMS equivalents. For data acquired outside the bubble curtain, the equivalent conversion factor is 12.9±2.3 dB. Such values are consistent with those obtained from the studies referenced above and furthermore, take into account the asymmetry in the blast signal train.

The peak levels given in Figure 4.1 are therefore re-plotted as RMS equivalents and these are shown in Figure 4.2 together with the 170 dB re 1 μPa benchmark condition.

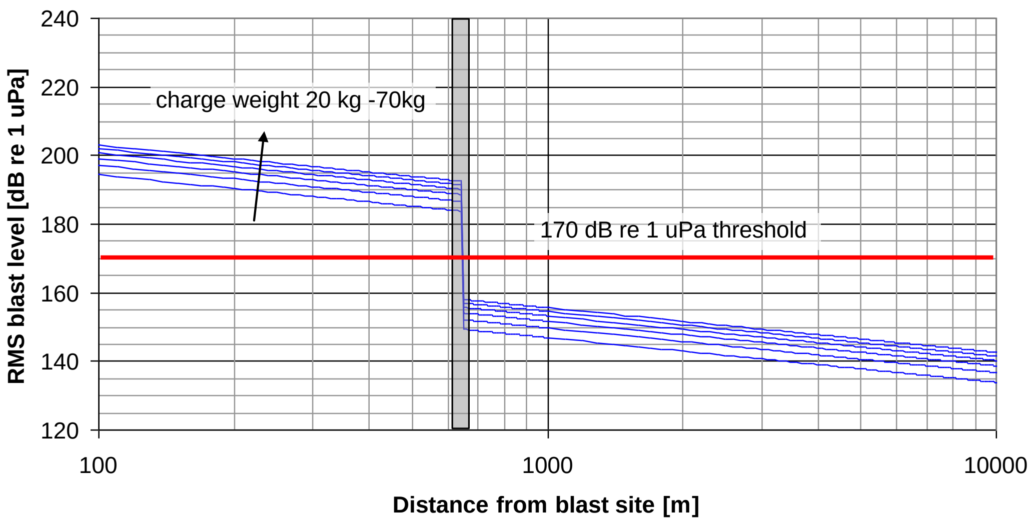

Figure 4.2: Predicted RMS blast levels converted from the modified Confined-Blast output using RMS to peak level conversion factor

[8] Madsen P.T., (2005), "Marine mammals and noise: Problems with root mean square sound pressure levels for transients", J. Acoust. Soc. Am. 117(6), 3952.
[9] Greene Jnr C.R.,"Physical acoustics measurements". In: W.J. Richardson (ed.) Northstar Marine Mammal Monitoring Program 1996: Marine Mammal and Acoustical Monitoring of a Seismic Program in the Alaskan Beaufort Sea. LGL Rep 2121-2, LGL Ltd, Canada and Greeneridge Sciences Inc. USA for BP (Alaska) Inc. and Nat. Mar. Fish Serv. Alaska. 245 pp.
[10] McCauley, R.D., Fewtrell, J., Duncan, A.J., Jenner, C., Jenner, M.N., Penrose, J.D., Prince, R.I.T., Adhitya, A., Murdoch, J. and McCabe, K. (2000). Marine seismic surveys – a study of environmental implications. APPEA Journal 2000:692-708.

4.3 Predicted mean bubble curtain attenuation (north side of Nigg Bay)

The modified Confined-Blast model, which is now supported by the linear regression analysis discussed in Section 2, is run each time with increasing charge weight until the modelled RMS level at a location just outside the bubble curtain is equal to the benchmark condition of 170 dB re 1μPa. The data presented in Table 4.1 shows the modelled RMS level at a distance of 650 m calculated for a range of charge weights and a bubble curtain attenuation of 45 dB. The table shows that the modelled RMS level increases gradually as charge weight increases. If the charge weight is increased, eventually the modelled RMS level meets the benchmark level and Table 4.1 indicates that this condition would be met for a charge weight somewhat in excess of 100 kg.

It is necessary now to include the inherent statistical uncertainties into the analysis. If a charge weight of 100 kg is detonated, Table 4.1 shows that the resulting RMS level, converted from the Peak level using the mean conversion factor given in Section 4.1 above, is 160.9 dB re 1 μPa. However, Section 4.1 also shows that the conversion factor can lie in the range 10.6±2.3 dB. Such variation may be accounted for by including in Table 4.1 the effect of the standard deviation σ given thus. If the conversion factor is (12.9 - 2.3) = 10.6 dB *i.e.* 1σ down on the mean value, the RMS level becomes 163.2 dB re 1 μPa. In statistical terms this means that 84.1% of the peak level data may be converted to RMS equivalents using a conversion factor of 10.6 dB. However, this also means that 15.9% of measurements are likely to have an RMS level greater than 163.2 dB re 1 μPa.

Table 4.1 shows the effect of incorporating the additional uncertainty in the peak level-to-RMS conversion factor by including RMS levels calculated using 1σ and 2σ of uncertainty. In practice, this shows that for a charge weight of 40 kg, approximately 84 out of 100 measurements of blast levels recorded just outside the bubble curtain will have an RMS level of 156.8 dB re 1 μPa or less while approximately 16 measurements in every 100 will have blast levels greater than 156.8 dB re 1 μPa. Similarly, for a charge weight of 100 kg, approximately 98 measurements of blast levels in 100 will be at 165.4 dB re 1 μPa or less and approximately 2 in every 100 will be above that level.

		RMS level at given confidence limit	
Charge Weight kg	RMS dB at 650 m	84.1%	97.7%
		1σ dB	2σ dB
20	149.7	152.0	154.2
30	152.5	154.8	157.0
40	154.5	156.8	159.0
50	156.1	158.4	160.6
60	157.3	159.6	161.8
70	158.4	160.7	162.9
80	159.3	161.6	163.8
90	160.2	162.5	164.7
100	160.9	163.2	165.4

Table 4.1: RMS levels calculated for a range of explosive charge weights and confidence limits based on a bubble curtain attenuation of 45 dB.

4.4 Predicted minimum bubble curtain attenuation (north side of Nigg Bay)

Section 2 showed that there is a significant amount of scatter in the blast levels calculated from the data acquired during the noise survey. Taking into account the scatter, the bubble curtain attenuation was found to be 45±10 dB. The analysis discussed above was based on a bubble curtain attenuation of 45 dB. However, within 1σ of uncertainty, the bubble curtain may have an attenuation of 35 dB. In which case, a more precautionary RMS level may be recalculated using the reduced bubble curtain attenuation and the revised data for this are given in Table 4.2 below.

Table 4.2 indicates that for a charge weight of 60 kg, approximately 84 blast level measurements in 100 will have RMS levels of 169.3 dB re 1 μPa or less. For the same charge weight, approximately 98 measurements in 100 will have a RMS blast levels of 171.5 dB re 1 μPa or less while 2 measurements in 100 will exceed this level.

		RMS level at given confidence limit	
Charge Weight kg	RMS dB at 650 m	84.1%	97.7%
		1σ dB	2σ dB
20	159.4	161.6	163.9
30	162.2	164.4	166.7
40	164.2	166.4	168.7
50	165.7	168.0	170.3
60	167.0	169.3	171.5
70	168.1	170.3	172.6
80	169.0	171.3	173.5
90	169.8	172.1	174.3
100	170.5	172.8	175.1

Table 4.2: RMS levels calculated for a range of explosive charge weights and confidence limits based on a bubble curtain attenuation of 35 dB.

4.5 Predicted bubble curtain attenuation (south side of Nigg Bay)

To date (November 2018), blasting has taken place on the north side of Nigg Bay. The bubble curtain construction has been located in the gap between the end of the northern breakwater and the southern edge of Nigg Bay as shown in Figure 4.3. The distance from the point of blasting to the bubble curtain varies in the range 600-650 m or thereabouts. The reduction in RMS blast level for this scenario is shown in Figure 4.2 where the position of the bubble curtain at 620 m is as indicated.

The blasting program is scheduled to relocate to the southern edge of Nigg Bay thus there is a need to relocate the bubble curtain. Due to logistical constraints the bubble curtain is likely to be somewhat closer to the blast site - in the range 100- 120 m. It is assumed that the attenuation of the bubble curtain remains unchanged. It is further assumed that the integrity of the bubble curtain itself is not affected by its proximity to the blast site. (A literature search[11,12,13] revealed that where bubble curtains have been used to contain either impulsive noise from impact piling sites or explosive noise from blasting sites, the distance from the noise source to the bubble curtain varies from a few tens of metres out to several hundreds of metres. From this, it may be concluded that the blast site - bubble curtain separation distance does not appear to be a critical parameter in determining the bubble curtain effectiveness.)

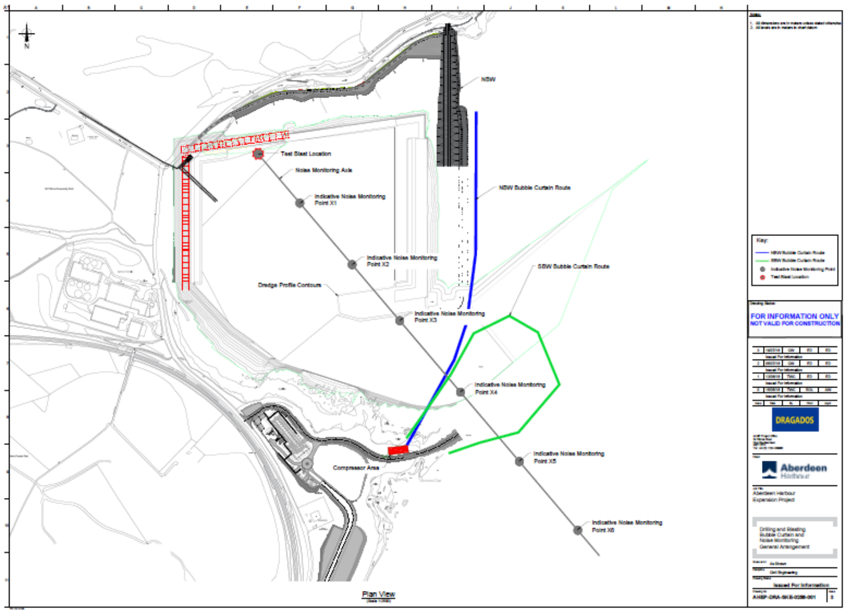

Figure 4.3: Plan view of Nigg Bay showing bubble curtain construction (blue and green lines)

Figure 4.4 shows the modelled RMS blast levels either side of the bubble curtain for a range of explosive charge weights. The bubble curtain, having a minimum expected attenuation of 35 dB (see Section 4.4), is located 100 m from the blasting site. For this model realisation to be valid, it is assumed that the propagation characteristic of the waterborne wave generated following detonation at the south blast site is the same as that generated at the north blast site. The figure shows that, even though a considerable amount of acoustic energy has been removed from the blast wave by the bubble curtain, the RMS blast level nevertheless remains above the benchmark of 170 dB re 1 μPa RMS out to distances beyond the bubble curtain varying between 0 m to 360 m depending on charge weight considered. If it is assumed that the bubble curtain has an attenuation of 45 dB, Figure 4.5 shows that sufficient acoustic energy is absorbed from the blast wave such that the limiting benchmark is nowhere exceeded beyond the bubble curtain for the charge weights considered.

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[11] Würsig B., C.R. Greene Jr., T.A. Jefferson, "Development of an air bubble curtain to reduce underwater noise of percussive piling", Marine Environmental Research Volume 49, Issue 1, Pages 79-93, 2000.
[12] CALTRANS (2007), "Compendium of Pile Driving Sound Data". Prepared by Illingworth & Rodkin, Inc. for The California Department of Transportation. 129pp. http://www.dot.ca.gov/hq/env/bio/files/pile_driving_snd_comp9_27_07.pdf
[13] Dähne M., J. Tougaard, J. Carstensen, A. Rose, J. Nabe-Nielsen, "Bubble curtains attenuate noise from offshore wind farm construction and reduce temporary habitat loss for harbour porpoises", Marine Ecology Progress Series, Vol. 580: 221–237, 2017.

Section 4.2 above recommends that a RMS level of 170 dB re 1 μPa be the limiting benchmark condition for blast levels outside the bubble curtain when the blast site is at the north end of Nigg Bay and the bubble curtain is as indicated in Figure 4.3. When the bubble curtain is relocated to the southern edge of Nigg Bay, it is suggested that the recording location is 400m, which is in accordance with the noise level predicted in the Environmental Statement[1].

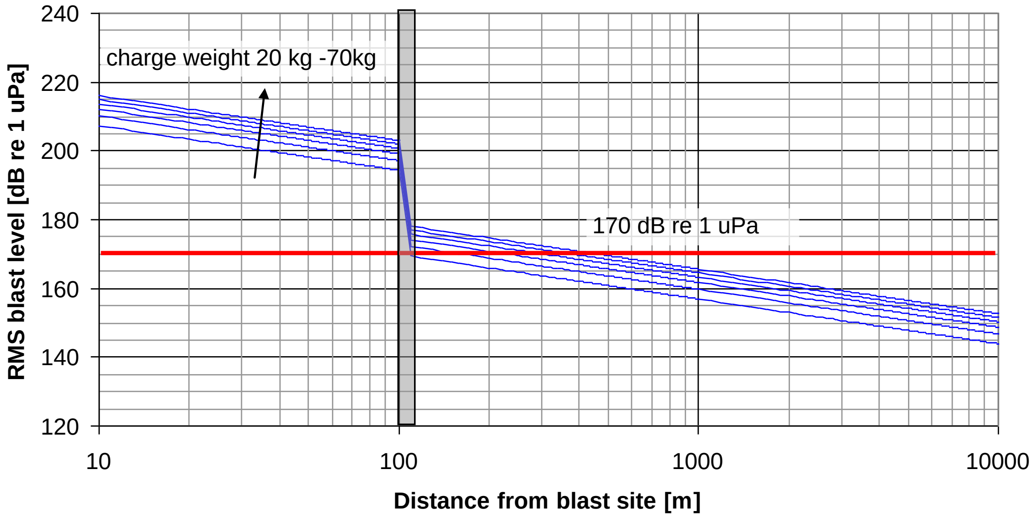


Figure 4.4: Modelled RMS blast levels when a 35 dB bubble curtain is located 100 m from the blast site

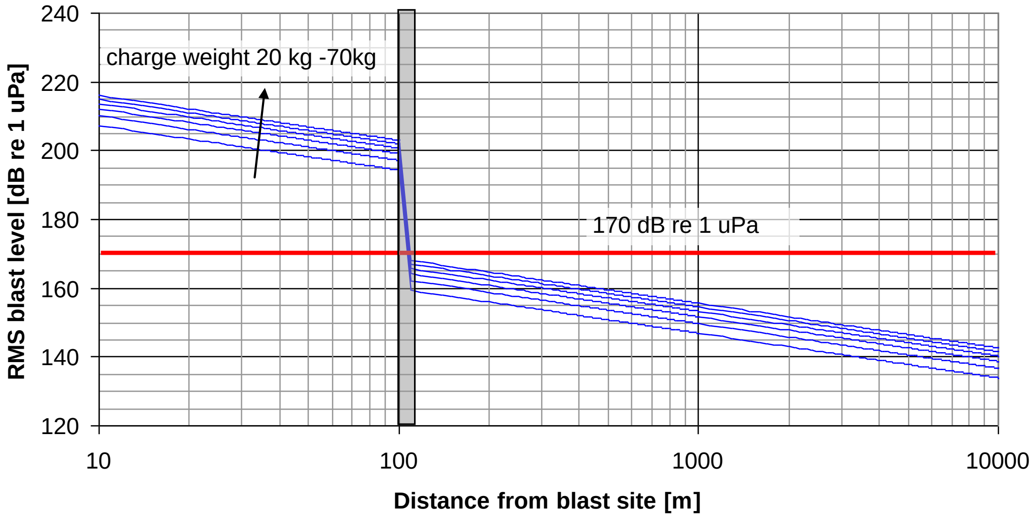
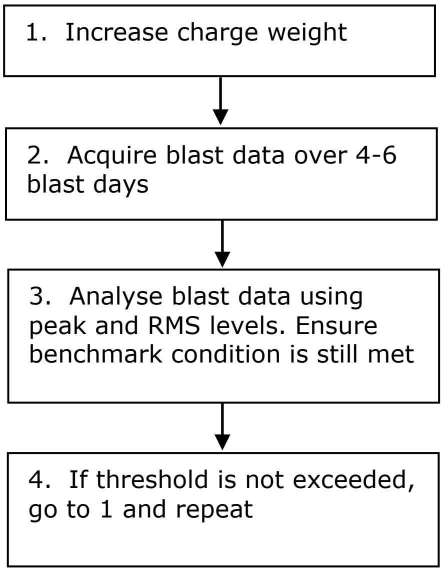


Figure 4.5: Modelled RMS blast levels when a 45 dB bubble curtain is located 100 m from the blast site

5. MODEL VERIFICATION

In order to verify the predicted levels derived from the revised Confined-Blast model, it is recommended that recordings of blasting noise continue to be made at distances from the blast site and at either side of the bubble curtain. Recordings should be made at distances concentrating in the range 200 m to 1100 m.

A simple flow chart of the processes to follow in increasing the explosive charge weights up to a charge size that is still acceptable in terms of acoustic impact is given as follows:



Supplementary notes to flow chart:

Step 1 - Select a charge weight above 20 kg. It is suggested that initial revised charge weights are 30 kg and 40 kg. Subsequent increases are recommended to be 5 kg.

Step 2 - Noise measurements taken at locations inside and outside the bubble curtain will be recorded during every blast.

Step 3 - Ideally the measured data should overlie the "waterborne" curve with as good a fit as possible. This would show that the existing blast model is "fit for purpose". If the measured data shows appreciable departure from the modelled data, it is then necessary to further revise the model based on the measured data.

6. SUMMARY AND CONCLUSIONS

Noise data has been acquired during the blasting program in Nigg Bay over the period of August through to October 2018.

The analysis undertaken and reported earlier[2] has been supported and enhanced by significantly more data acquired during the subsequent blasting program.

The data processing procedure was revised following the availability of additional data from the EcoFish noise survey team. The data acquired during the earlier part of the survey (Aug-Sep 2018) was reprocessed. Subsequently, peak blast levels acquired inside the bubble curtain were revised upwards by no more than 2 dB while blast levels acquired outside the bubble curtain were revised upwards by approximately 12 dB.

Together with the data acquired during October 2018, the attenuation of the bubble curtain was found to be 45±10 dB.

The resulting noise survey data was compared with predictions of blast levels determined from the Confined-Blast model. The structure of the model itself was revised thus leading to a more convincing fit between predicted blast levels and actual blast levels.

The modified Confined Blast model predicts that the maximum permitted explosive charge weight can be increased from the current 20 kg while still remaining compliant with the benchmark condition not exceeding 170 dB re 1 μPa RMS at a maximum distance of 400 m from the blast site.

The maximum charge weight permissible such that the benchmark condition is not exceeded varies between 30-40 kg and over 100 kg depending on the uncertainty in the value given to the bubble curtain attenuation as well as the level of risk deemed acceptable in exceeding the benchmark condition.

When blasting takes place at the southern edge of Nigg Bay, a bubble curtain is proposed to be constructed at a distance of approx 100 m from the blast site. The modified Confined-Blast model shows that for a bubble curtain having an attenuation of 35 dB, the potential exists for RMS blast levels to be in excess of the stated benchmark level of 170 dB re 1 μPa at distances up to 360 m beyond the outside edge of the bubble curtain. If it is assumed that the bubble curtain has an attenuation of 45 dB, the benchmark condition is met at all at locations outside the bubble curtain.

A number of steps to be followed are suggested whereby the maximum charge weight is incremented. A short blasting program ensues following which the acquired data is analysed. The analysis includes a comparison of blast levels with predicted levels from the Confined-Blast model and also a comparison with the 170 dB re 1 μPa RMS benchmark. If the benchmark is not exceeded then the charge weight is increased further and the process repeated.

D. UNDERWATER NOISE MONITORING FULL RESULTS AUGUST – NOVEMBER 2018.

Commercial in Confidence

Aberdeen Harbour Expansion Project: Results of underwater noise monitoring during test blasting 2018

P D Ward
Award Environmental Consultants Ltd

Rep: 201804-005-V0

7 December 2018

Administration Page

Customer Information	
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EXECUTIVE SUMMARY

The report provides an analysis of underwater noise recordings obtained during a program of confined-blasting in Nigg Bay which forms part of the construction activities of the Aberdeen Harbour Expansion Project (AHEP).

A bubble curtain was assembled at the mouth of Nigg Bay the purpose of which was to contain the acoustic energy arising from the explosive blast and to prevent it from propagating into the wider area. Each blasting schedule involved a number of explosive charges of weight up to 20 kg which were detonated sequentially. Recordings of blast noise were made at various locations both inside and outside the bubble curtain.

Underwater noise generated from the seabed blasting was recorded over the period August through to November 2018.

The blast noise data was processed in order to obtain both peak levels (dB re 1 μPa peak) and root-mean-square levels (dB re 1 μPa rms).

The noise levels derived from each recording were compared with maximum blast levels obtained from the original confined-blast propagation model and also the calibrated confined-blast model. It was found that:

- for recordings obtained at locations inside the bubble curtain, the original model consistently underestimated peak blast noise levels by up to 45 dB;
- measured peak blast noise levels are seen to lie within ±27 dB of the predicted levels from the calibrated model;
- for recordings made at locations outside the bubble curtain, the original model overestimated noise levels by up to 14 dB;
- measured peak blast levels are approximately 40 dB lower than the levels predicted using the calibrated model assuming no bubble curtain attenuation.

Following discussions with the regulatory bodies, it was agreed that blasting would cease should recorded blasting levels exceed a critical threshold of 170 dB re 1 μPa rms at a distance of 400 m from the blasting. The results showed that:

- at locations inside the bubble curtain and at distances of 400 m and beyond, the rms blast levels varied between 40 dB above and 18 dB below the critical threshold level;
- more significantly, beyond the bubble curtain rms levels were consistently lower than the critical threshold level by 17-32 dB.

1. INTRODUCTION

As part of the construction activities carried out in pursuit of the Aberdeen Harbour Expansion Project (AHEP), a key objective is to increase the depth of water depth in Nigg Bay. This is carried out by drilling a number of boreholes in the seabed and packing them with explosives. Upon detonation, the seabed is fractured and the overburden is subsequently removed with the aid of a dredging vessel. The underwater noise arising from the explosive blast has the potential to impact on species of marine life in and around Nigg Bay. In order to contain and restrict the propagation of sound into the wider undersea environment, a bubble-curtain arrangement is constructed at the mouth of the bay. At the moment of detonation, noise measurements are made at locations both inside and outside the bubble curtain. Following each blast, there is a requirement to monitor the blast noise levels and to report back to the regulatory bodies.

This report presents the results and analysis of the underwater noise data recorded during test blasting in Nigg Bay over the period August to November 2018. Following the completion of the first phase of blasting in September 2018, a report was issued[1] which summarised the blast noise levels to date and also provided an estimate of the attenuation afforded by the bubble curtain. In addition, the report allowed for a first comparison between recorded noise levels and expected levels calculated using a confined-blast model which was first presented in the Environmental Statement[2] (ES). It was found that there was a considerable discrepancy between the two data sets with the recorded levels being 20-40 dB higher than modelled levels. However, the availability of the recorded noise data supported the reassessment of the confined-blast model and this was discussed in the calibration report[3]. Furthermore, since the issuing of the first blast summary report[1], additional information became available regarding the data acquisition equipment settings as used by the Ecofish noise survey team. As a result, it was necessary to reprocess the noise data that had been acquired over the period August to October 2018. The outcome was that peak blast levels recorded inside the bubble curtain were increased by no more than 2 dB while levels recorded outside the bubble curtain increased by up to 12 dB. In addition, the data variability was reduced considerably. This was discussed at length in the calibration report[3].

The current report commences with an overview of the noise recording and subsequent data processing procedures and this is followed with a summary of all blast noise levels obtained from recording stations located on either side of the bubble curtain. Comparisons are drawn between the results obtained from the recorded acoustic data with those obtained from the confined-blasting model discussed in the Environmental Statement and with those discussed in the calibration report[3]. It is inevitable that in

[1] Ward P. D., “Aberdeen Harbour Expansion Project: Results of underwater noise monitoring during test blasting”, Award Environmental Consultants Ltd Technical Report AECL/201804-004-V1, Sep 2018.
[2] Aberdeen Harbour Expansion Project, Volume 3: Technical Appendices - Appendix 13-B Underwater Noise Impact Study, November 2015 - "Underwater noise impact study for Aberdeen Harbour Expansion Project: Impact of construction noise", Kongsberg Report 35283-0004-V5.
[3] Ward P. D., “Calibration of the Confined-Blast model in connection with the blasting program in Nigg Bay for Aberdeen Harbour Expansion Project”, Award Environmental Consultants Ltd Technical Report AECL/201804-007-V3, Nov 2018.

any comparison with recorded data against modelled results discrepancies will be seen between the two data sets. Furthermore, the recorded datasets themselves will contain internal variability due to the continually changing at-sea environment. Sources of variability relevant to this project are discussed. The results from each day's blasting are presented in Appendices A-L.

2. NIGG BAY BLASTING

2.1 Blast field location

The key engineering objective is to increase the water depth in certain locations of Nigg Bay. The client planning engineers have delineated blast sites along the north and north-west shore of Nigg Bay. Within each blast field, a number of boreholes are drilled down to depths varying between 2 m and 11 m – depending on the amount of overburden that must be removed in order to achieve design depth. The blasting engineers determine the numbers of charge weights and the size of each charge weight such that the resulting detonation successfully fractures the overburden over the entire blast field. Afterwards, the blast rubble is further broken up using a hydraulically-driven ripper tool prior to being removed with the aid of a backhoe dredging vessel.

In order to constrain the propagation of explosive noise into the wider undersea environment, a bubble curtain arrangement has been constructed. This sits between the end of the partially-constructed northern breakwater and the southern shore of Nigg Bay. A schematic showing the approximate locations is given in Figure 2.1 and it will be seen that the bubble curtain construction actually consists of 2 to 3 (depending on location) individual bubble curtains that effectively seal up the open end of the bay.

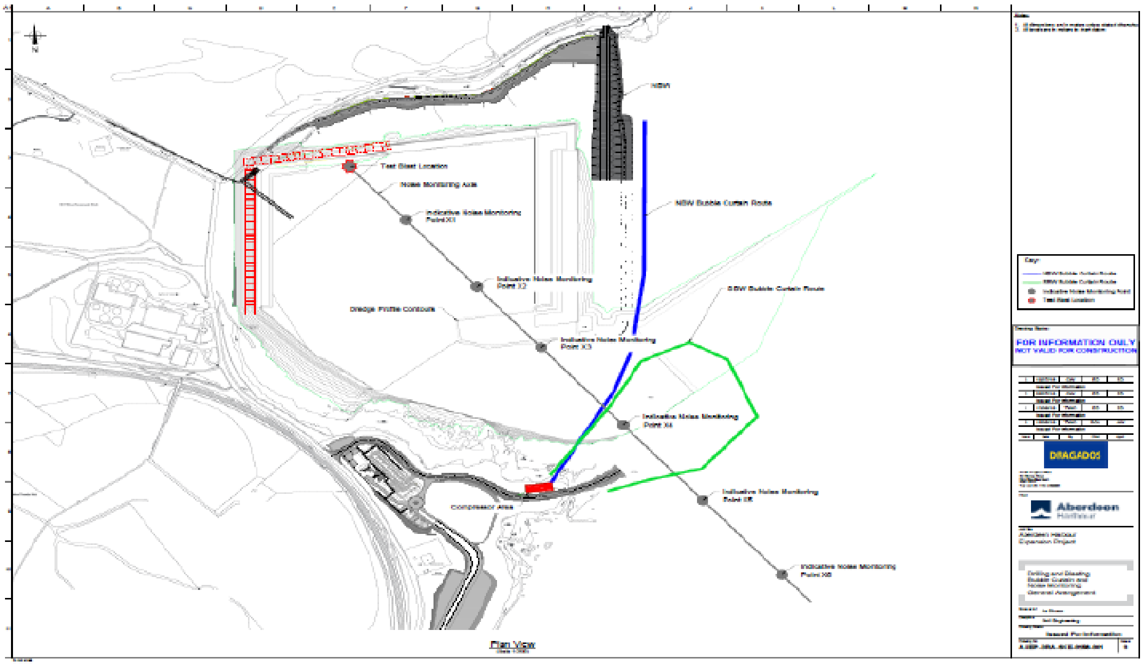

Figure 2.1: Schematic of Nigg Bay showing blast sites, northern breakwater and bubble curtain arrangement.

2.2 Noise data collection

In order to monitor underwater noise levels during blasting, measurements of blast noise were recorded simultaneously at locations on either side of the bubble curtain. The objective was to ensure that all recording stations lay along a direct line-of-sight transect commencing at the blast field. The survey line along which the measurements were made is indicated in Figure 2.1.

Prior to each blasting schedule, the EcoFish noise survey team liaised with the blasting engineers to ensure that the two survey vessels were "on-station" in good time. Noise data, which was collected at each recording station over durations ranging from a few minutes to 1 hour or more, consisted of general background noise, calibration tones which were injected into the data acquisition system so as to provide a standardised noise level against which all subsequent measurements would be compared; and the blast noise itself.

In addition to the noise data, the EcoFish noise survey team also collated log sheets indicating which blast field was being fitted out; the numbers of boreholes prepared the numbers of charges that were successfully detonated; state of weather and tide; and any other sources of noise that were present in the bay from time to time. All data was then made available for subsequent data processing and analysis.

2.3 Noise data processing and analysis

The noise data were supplied as voltage-time series in one or more .WAV files. The EcoFish log sheets which were completed during and after each blast, noted the hydrophone which had been used to collect the noise recording and also the gain settings deployed on the data acquisition terminal units[4].

The proprietary data processing package MATLAB was used to access the .WAV file and an example of this is given in Figure 2.2. The calibration tones were identified: in this example, the calibration tone was injected near to the commencement of data acquisition. The root-mean-square amplitude was computed and this was compared with the amplitude of the calibration tone that was injected into the system. It is noted that a range of different amplitude input signals were used depending on the specific combination of hydrophone and terminal unit deployed[4]. Subsequently, a calibration adjustment factor related to the ratio of the output signal amplitude to the input signal amplitude needed to be applied to the blast wave data.

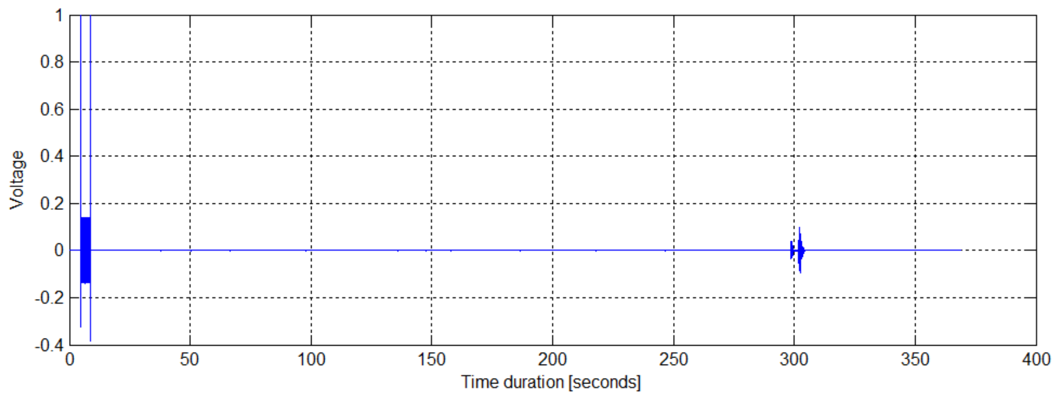

Figure 2.2: Hydrophone output in volts as a function of time in seconds

The blast wave sequence was next identified in the record and an example of this is shown in Figure 2.3. It is seen that there are two clear blast events separated by approximately 3 seconds. Each event can be correlated with the blast field detonation

[4] "Aberdeen Harbour Expansion Project (AHEP) – Underwater noise + passive acoustic monitoring procedure July 2018", EcoFish Global Ltd Technical Report Rev. 6, July 2018.

record as compiled in the Field Contractor's Log[5].

The blast data is converted into a pressure-time series after taking into account the hydrophone frequency sensitivity; the terminal unit gain settings; and the calibration factor and this is shown in Figure 2.4. The maximum amplitude of each blast event is transcribed from the figure thus giving the peak blast level. The rms blast level is determined by noting the start and end times of each blast sequence (the two blast sequences shown have durations of approximately 1.3 seconds and 2.5 seconds respectively). The rms value is then ascertained over each time duration.

From the positional data contained within both the Field Contractor’s Log and the EcoFish Log, the distance between the blast site and each recording station is determined. The confined-blast model is used to determine the peak blast level expected at a given distance from the blast site and this is compared to the blast level determined above. Similarly, the 170 dB re 1 μPa threshold condition at a reference distance of 400 m from the blast site[1] is compared with the rms blast level computed at the given distance. This is achieved by determining the equivalent blast level that would be measured if the recording station was at a distance of 400 m[6].

Summaries of the peak and rms noise levels both inside and outside the bubble curtain recorded to date are given in Tables 2.1 and 2.2 respectively.

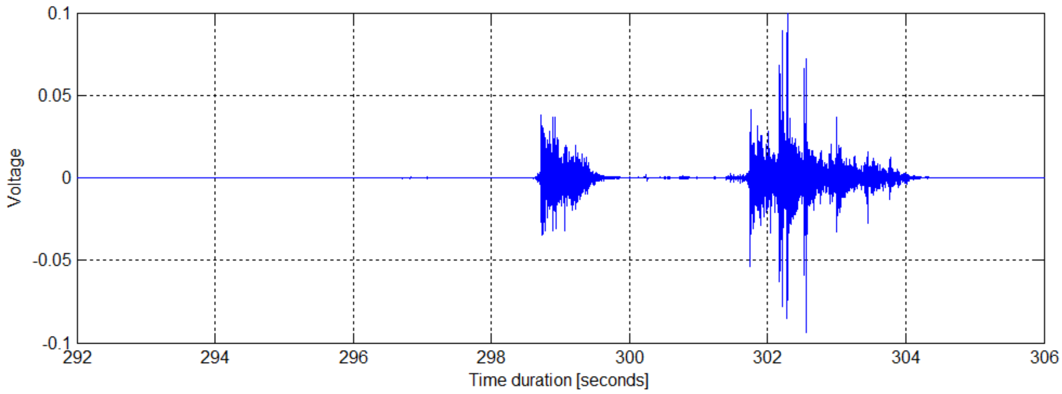

Figure 2.3: Hydrophone output in volts as a function of time in seconds around blast sequence

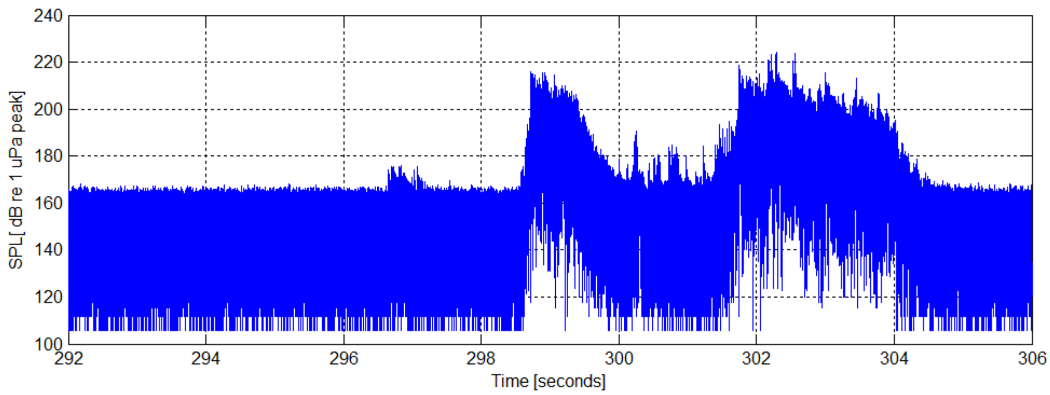

Figure 2.4: Sound pressure level in dB re 1 μPa peak as a function of time in seconds around blast sequence

[5] The Field Contractor’s Log was compiled by the blasting engineers and recorded the location and depth of each borehole in the blast field as well as the quantities and masses of charge weights deployed in each borehole.
[6] A distance-related factor is applied that accounts for the additional geometrical spreading which takes place between a distance of 400 m and the recording station.

Inside Bubble Curtain

Blast Date	Blast No.	Field	Charges detonated/primed	Dist. from blast site m	Blast level dB re 1 μPa			
					Peak modelled	Peak recorded	rms equivalent‡	rms recorded
20 Aug 18	B1	1	42/45†	437	174.0	183.6	165.4	168.0
20 Aug 18	B2	2	90/90	442	178.5	215.9	169.7	199.9
24 Aug 18	B3	1	3/3†	457	173.4	160.0	157.8	135.8
24 Aug 18	B4	3	63/63	424	179.2	221.2	169.9	198.9
06 Sep 18	B5	4	65/65	285	184.8	207.4	171.2	188.1
06 Sep 18	B6	5	86/86	262	185.9	209.5	171.5	185.8
12 Sep 18	B7	6	92/132	232	187.6	211.3	172.0	185.6
12 Sep 18	B8	7	30/77	270	185.5	216.9	171.4	190.1
12 Sep 18	B7*	6	40/40	252	186.5	191.1	171.7	162.9
12 Sep 18	B8*	7	47/47	293	184.4	207.1	171.1	196.1
14 Sep 18	B9	8	59/99	326	182.9	214.5	170.7	191.8
14 Sep 18	B10	9	53/53	358	181.6	215.9	170.4	190.6
14 Sep 18	B10	9	53/53	358	181.6	199.9	170.4	177.1
14 Sep 18	B9*	8	40/40	336	182.5	183.1	170.6	152.5
14 Sep 18	B10*	8	40/40	336	182.5	204.9	170.6	185.3
17 Sep 18	B11	10	134/134	565	175.3	205.9	169.0	176.9
17 Sep 18	B12	11	47/47	589	174.7	207.6	168.8	175.5
08 Oct 18	B13	12	100/100	306	183.8	210.6	170.9	196.8
08 Oct 18	B14	13	48/48	463	178.0	213.8	169.5	198.9
08 Oct 18	B15	14	119/149	393	180.3	210.3	170.1	188.5
08 Oct 18	B15*	14	30/30	393	180.3	205.2	170.1	180.1
13 Oct 18	B16	15	84/84	446	178.5	209.3	169.6	180.3
17 Oct 18	B17	16	38/38	354	181.8	198.3	170.4	168.5
17 Oct 18	B18	17	49/49	371	181.1	226.5	170.2	197.9
25 Oct 18	B19	18	51/51	575	175.0	211.2	168.9	185.9
25 Oct 18	B20	20	12/69	613	174.1	204.7	168.7	181.7
25 Oct 18	B21	19	36/72	537	176.0	205.1	169.1	183.8
25 Oct 18	B21*	19	36/72	486	177.3	220.9	169.4	190.5
25 Oct 18	B20*	20	57/57	528	176.2	206.4	169.1	180.0
17 Nov 18	B22	21	121/121	257	186.2	231.3	171.5	208.3
17 Nov 18	B23	22	55/55	262	185.9	237.6	171.5	211.9
17 Nov 18	B24	23	70/70	245	186.9	234.8	171.7	208.8
17 Nov 18	B25	LSS1	3/3††	255	177.9	214.9	171.6	196.4
24 Nov 18	B26	24	217/217	459	178.1	186.2	169.6	158.5
24 Nov 18	B27	25	198/198	459	178.1	187.6	169.6	162.3

Table 2.1: Summary of peak and rms blast levels for each days blasting of 20kg charges (except †10kg, ††6kg) recorded inside the bubble curtain
* Repeat blasting due to earlier non-detonations
‡ Calculated equivalent dB re 1 μPa rms based on the threshold of 170 dB re 1 μPa rms at 400m

Outside Bubble Curtain

Blast Date	Blast No.	Field	Charges detonated/primed	Dist. from blast site m	Blast level dB re 1 μPa			
					Peak modelled 0% att	Peak modelled 60% att	Peak recorded	rms recorded
20 Aug 18	B1	1	42/45†					
20 Aug 18	B2	2	90/90					
24 Aug 18	B3	1	3/3†	806	165.5	157.5	‡	138.9‡
24 Aug 18	B4	3	63/63	769	171.0	163.0	168.5	153.7
06 Sep 18	B5	4	65/65					
06 Sep 18	B6	5	86/86					
12 Sep 18	B7	6	92/132					
12 Sep 18	B8	7	30/77					
12 Sep 18	B7*	6	40/40					
12 Sep 18	B8*	7	47/47					
14 Sep 18	B9	8	59/99	893	168.9	161.0	158.0	146.2
14 Sep 18	B10	9	53/53	922	168.4	160.5	154.4	137.6
14 Sep 18	B10	9	53/53				154.0	138.5
14 Sep 18	B9*	8	40/40	869	169.3	161.4	156.8	144.6
14 Sep 18	B10*	8	40/40	899	168.8	160.9	*126*	*115.3*
17 Sep 18	B11	10	134/134	964	167.8	159.9	163.2	152.4
17 Sep 18	B12	11	47/47	990	167.5	159.6	156.4	146.1
08 Oct 18	B13	12	100/100	644	173.4	165.4	162.1	149.8
08 Oct 18	B14	13	48/48	846	169.6	161.6	162.1	152.3
08 Oct 18	B15	14	119/149	746	171.4	163.4	162.1	152.3
08 Oct 18	B15*	14	30/30	746	171.4	163.4	161.8	146.1
13 Oct 18	B16	15	84/84	696	172.4	164.4	166.3	151.2
17 Oct 18	B17	16	38/38	919	168.5	160.5	163.0	151.6
17 Oct 18	B18	17	49/49	953	168.0	160.0	163.0	151.6
25 Oct 18	B19	18	51/51	1163	165.2	157.2	158.1	146.2
25 Oct 18	B20	20	12/69	1224	164.5	156.5	156.3	144.5
25 Oct 18	B21	19	36/72	1075	166.3	158.3	156.3	140.9
25 Oct 18	B21*	19	36/72	1075	166.3	158.3	158.5	142.7
25 Oct 18	B20*	20	57/57	1194	164.9	156.9	157.4	143.2
17 Nov 18	B22	21	121/121					
17 Nov 18	B23	22	55/55					
17 Nov 18	B24	23	70/70					
17 Nov 18	B25	LSS1	3/3††					
24 Nov 18	B26	24	217/217	860	169.4	161.4	166.0	151.9
24 Nov 18	B27	25	198/198	831	169.9	161.9	165.9	150.8

Table 2.2: Summary of peak and rms blast levels for each days blasting of 20kg charges (except †10kg, ††6kg) recorded outside the bubble curtain
* Repeat blasting due to earlier non-detonations
‡ Not evident in acoustic record: estimated rms level only

3. CUMULATIVE RECORD OF BLASTING

Figure 3.1 shows the peak blast levels recorded for the 20 kg blasts undertaken at locations both inside and outside (when available) the bubble curtain, compared with the confined-blast modelling undertaken using the same charge weight as discussed in the ES[2]. Locations inside the bubble curtain vary from 232 m to 613 m from the blast sites while outside the bubble curtain, the distances vary from 644 m to 1224 m. Also included are the modelled levels of blast expected given various degrees of attenuation afforded by bubble curtains and reported on in the AHEP Clarification Note[7]. The results show that the peak blast levels recorded at locations inside the bubble curtain are up to 45 dB higher than those levels predicted by the modelling. By contrast, the levels recorded at locations outside the bubble curtain are up to 14 dB lower than levels in the absence of a bubble curtain. When the data are compared with the calibrated confined-blast model[3], Figure 3.2 shows that the levels recorded on both sides of the bubble curtain, are a much closer fit. Measured blast noise levels inside the bubble curtain are seen to lie within ±27 dB of the predicted levels while blast noise levels outside the bubble curtain closely follow the "48 dB attenuation" model prediction.

As a mitigation procedure and following discussions with the regulatory bodies, it was agreed that blasting would cease should recorded blast levels exceed a critical threshold of 170 dB re 1 μPa rms at a distance of 400 m from the blasting site. Figure 3.3 shows the calculated rms levels plotted as a function of distance from the blasting site for recordings made both inside and outside the bubble curtain. Considering first just the data recorded at locations inside the bubble curtain, it will be seen that for those distances in excess of 400 m from the blast site, the calculated rms levels exceed the critical threshold by up to 30 dB. At those locations closer than 400 m, the threshold is exceeded by up to 40 dB. More significantly, all of the data recorded outside the bubble curtain yielded rms levels below the threshold by up to 32 dB.

The results suggest that sufficient acoustic energy may be removed from the water column such that the 170 dB re 1 μPa rms level is not likely to be breached anywhere outside the bubble curtain.

[7] "Aberdeen Harbour Expansion Project - Clarification Note: Blasting methodology and mitigation", AHEP Internal Report 2018.

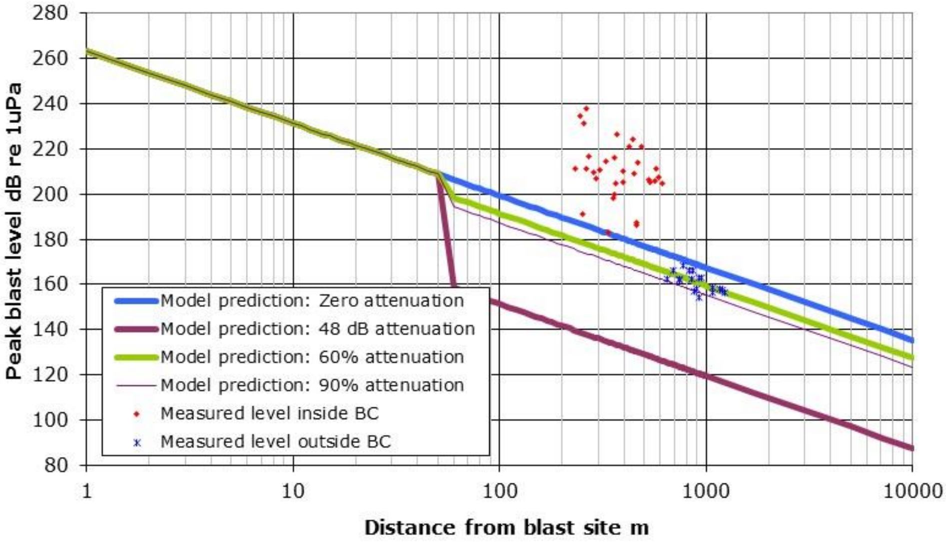

Figure 3.1: Cumulative record of measured peak blast levels from a 20 kg charge weight compared with original confined-blast model predictions (red diamond indicates a position inside the bubble curtain, blue cross indicates a position outside the bubble curtain)

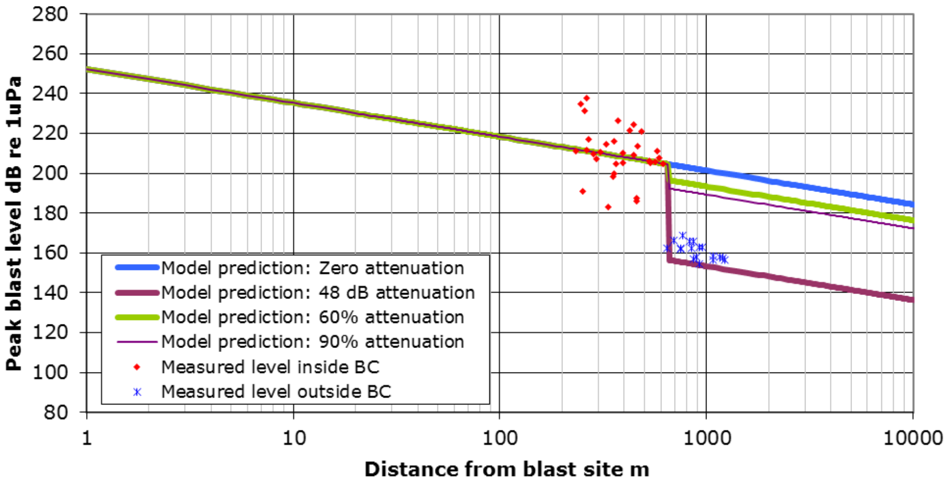

Figure 3.2: Cumulative record of measured peak blast levels from a 20 kg charge weight compared with calibrated confined-blast model predictions (red diamond indicates a position inside the bubble curtain, blue cross indicates a position outside the bubble curtain)

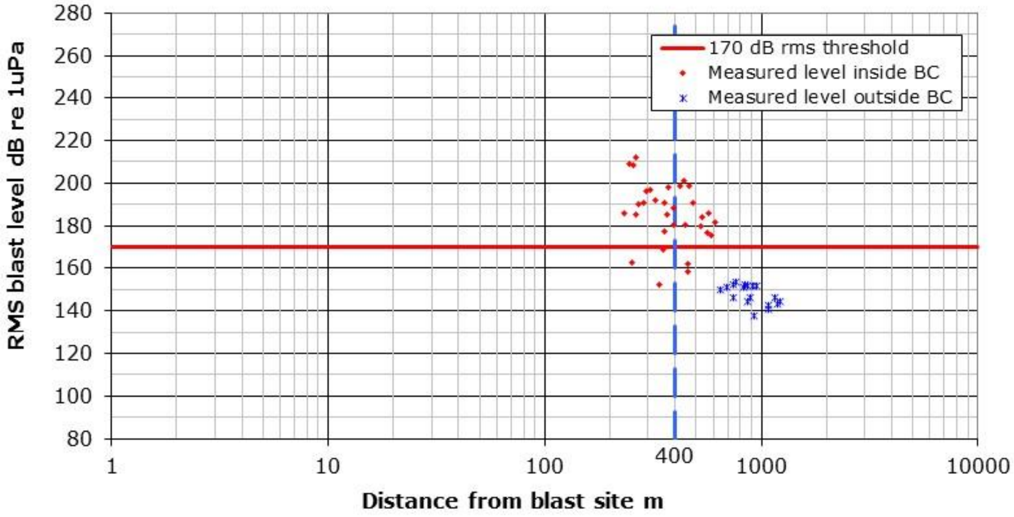

Figure 3.3: Cumulative record of rms blast levels from a 20 kg charge weight (red diamond indicates a position inside the bubble curtain, blue cross indicates a position outside the bubble curtain)

4. DISCUSSION

The original confined-blast model discussed in the Environmental Statement[2] and the calibration report[3] allows the user to estimate maximum blast levels from detonations of explosives that have been packed into boreholes drilled into the seabed. The surrounding bedrock attenuates the acoustic energy arising from the ensuing explosion until, at a given distance from the centre of detonation, the propagating acoustic wave front enters the water.

The confined-blast model draws on a relatively simple model of the underwater environment. It assumes a single layer of bedrock having uniform sound speed and density being overlain by a semi-infinite layer of water hence the water depth is not a model parameter. The seabed structure of Nigg Bay is known to consist of multiple layers of sedimentary rock, overtopped by varying coverage of sand[2]. In addition, the water is shallow with depths increasing from 2 m near to the head of the bay to 15-20 m beyond the mouth. Such a complicated structure is beyond the capabilities of the model hence it was assumed that the modelled blast levels would very likely be under- or over-estimated by some amount. The data presented in this report shows that, in the event, the original model consistently under-estimated the recorded levels by up to 40 dB while the calibrated model provided a much better fit.

The results shown in Figure 4.1 suggest that the bubble curtain absorbs a considerable amount of acoustic energy. A linear-regression analysis was carried out on the data recorded both before and after the bubble curtain - which was assumed to be located 650 m from the blast site. For each dataset the regression line and its standard error (corresponding approximately to the standard deviation of the underlying data) showed that the bubble curtain has an attenuation of 38 ± 16 dB. It is noted that these range of values are largely consistent with those reported earlier even though the previous linear-regression analyses were carried out on somewhat smaller sample sizes[1,3]. The uncertainty in the attenuation level is driven principally by the relatively large scatter in the data points recorded before the bubble curtain. The causes of the variability are discussed below.

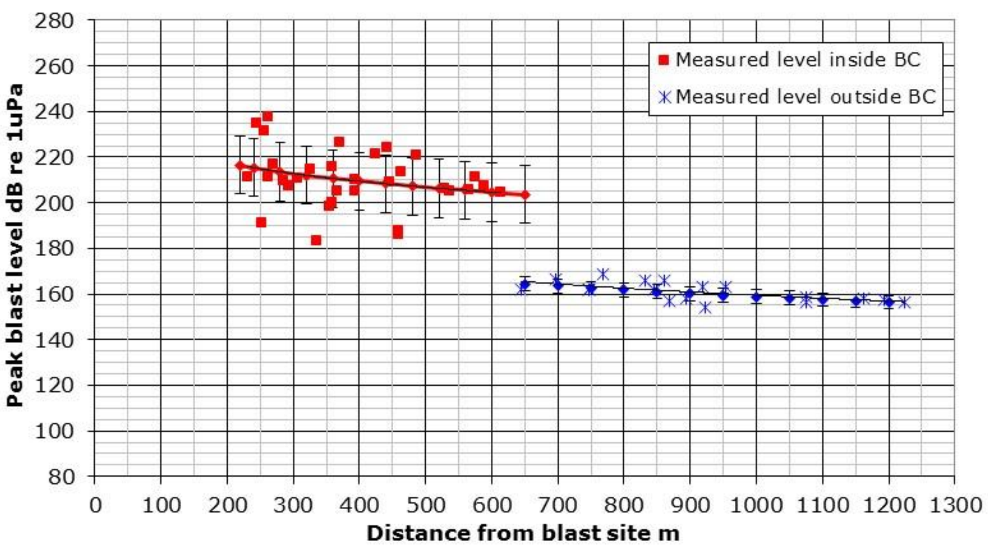

Figure 4.1: Regression analysis on datasets recorded before and after the bubble curtain

5. RECORDED LEVEL VARIABILITY

The variability in recorded blast levels for successive measurements at nominally the same distance from the blast site may be attributed to a number of factors and these are discussed below.

The distribution and number of charge weights during any given blasting schedule is determined by the blasting engineers and reflects the amount of bedrock that needs to be removed during the construction programme. Each blasting schedule has involved different numbers of charge weights where, for each blast sequence, the charge weights vary between 5 kg and a maximum of 20 kg. Between 30 and 200 charges have been detonated during each blasting schedule. It is assumed that the seabed properties (such as density, sound speed and geological layering) vary from location to location in Nigg Bay and these affect how well (or otherwise) the acoustic energy is firstly, coupled into the seabed and secondly, subsequently propagates to any distance. The levels of blast noise as recorded in the water are therefore dependent on the charge weight distribution, the underlying geology and structure of the seabed and the water depth.

The recorded blast noise level is dependent on the positioning of the hydrophone in the water column. In the shallow waters of Nigg Bay, the positioning can be critical. A key objective is to ensure that the hydrophone is located at mid-water depth so that the influence of acoustic reflections from either the sea surface or the seabed are minimised. However, prevailing weather conditions often ensure that this requirement is not met. It is noted that visual monitoring for marine wildlife is not possible when wind speeds exceed Beaufort No 3 (approximately 4-6 m/s) but even in such relatively benign conditions, there could be choppy water (where the wind and tidal stream flow are moving in opposite directions and from which produces a disturbed sea surface) or else a good swell (remnants of a passing storm at sea some days earlier). Both of these conditions could cause the hydrophone to travel up and down in the water column and hence any planned accuracy in vertical positioning is lost.

6. CONCLUSIONS

The key objective of the work described herein was to analyse underwater noise recordings obtained in Nigg Bay following a program of confined-blasting. For each blast schedule, noise recordings were made at two locations, one either side of a bubble curtain whose purpose it was to impede the propagation of acoustic energy in to the wider area beyond Nigg Bay. The analysis consisted of comparisons between:

(i) the actual blast noise levels with estimated noise levels obtained from a predictive model and

(ii) the actual blast noise levels with a threshold condition of 170 dB re 1 μPa rms at a distance of 400 m from the blast site.

The results showed that:

(i) for recordings obtained at locations inside the bubble curtain, the original confined-blast model consistently underestimated peak blast noise levels by up to 45 dB while for recordings made at locations outside the bubble curtain, the model overestimated peak noise levels by up to 14 dB;

(ii) when compared with the calibrated confined-blast model, blast levels recorded inside the bubble curtain are seen to lie within ±27 dB of the predicted levels while blast noise levels outside the bubble curtain closely follow the "48 dB attenuation" model prediction;

(iii) at locations inside the bubble curtain and at distances of 400 m and beyond, the rms blast levels exceed the critical threshold by up to 30 dB. Beyond the bubble curtain, rms levels were up to 32 dB lower than the critical threshold level.

APPENDIX A: BLASTING RESULTS - 20TH AUGUST 2018

A.1 Overview - Inside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
20 Aug 2018	1951hrs BST	10 kg	H0	Inside	437 m/Field1	180820_01
20 Aug 2018	1951hrs BST	20 kg	H0	Inside	442m/Field2	180820_01

A.2 Ecofish Observations

Detonation noise recording. 10 kg field (45 holes) of charges followed by 20kg field (90 holes) of charges. The 10kg field failed to detonate completely leaving three of the 45 charge holes unexploded. Hydrophone H0 deployed inside of the bubble curtain. Vessel drifting with engines and sounder off. Following a quality check by Ecofish, the acoustic recording obtained from the hydrophone positioned outside the bubble curtain was deemed unusable, so it has not been possible to make a comparison between inside and outside the bubble curtain for this blast.

A.3 Data Processing:

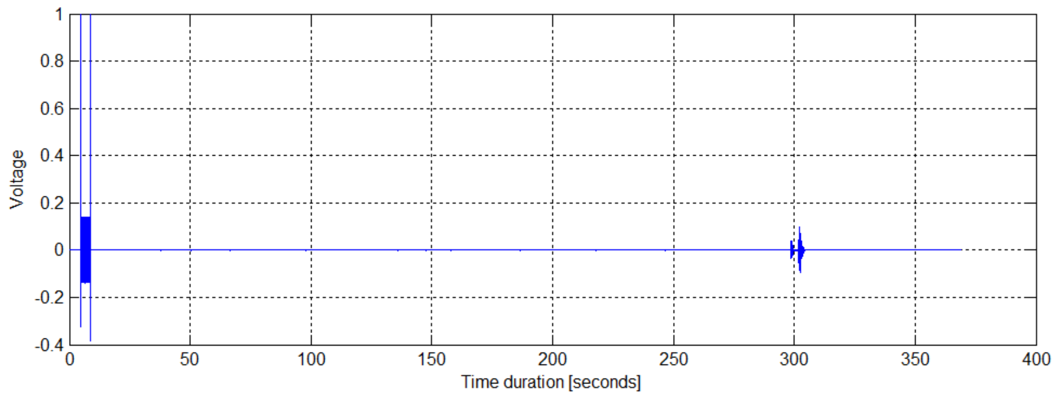

Figure A.1: Hydrophone output in volts as a function of time in seconds

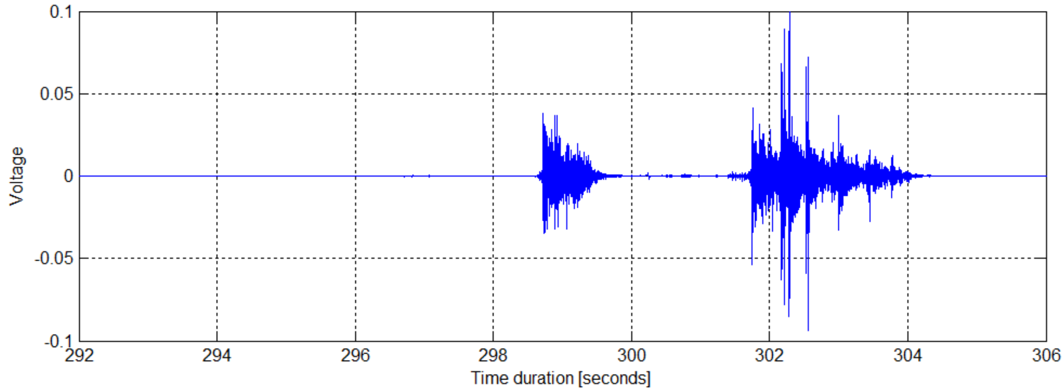

Figure A.2: Hydrophone output in volts as a function of time in seconds around blast sequence

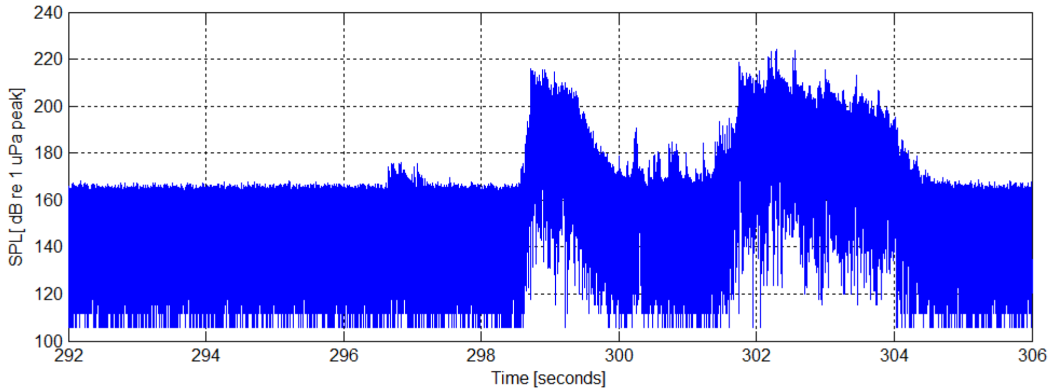

Figure A.3: Sound pressure level in dB re 1 μPa peak as a function of time in seconds around blast sequence

A.4 Discussion

Figures A.1 and A.2 show the hydrophone output displayed in units of volts.

Figure A.1 shows a feature at around 10 seconds. From the information given in the Ecofish Log, this event is correlates with the injection of the calibration tone. The features around 300 seconds are identified as a sequence of detonations.

Figure A.2 shows the detonation record more clearly. From discussions with Dragados UK, it is understood that the first feature at 299 seconds is due to the detonation of a sequence (42 charges detonated out of 45 boreholes primed) of 10 kg charges while the second feature is attributed to the detonation of a sequence (90 detonations out of 90 boreholes primed) of 20 kg charges. The event at 297 seconds corresponds to a single detonation charge.

Figures A.3 shows the corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 μPa for the blast events discussed in Figure A.2.

When a confined detonation occurs in shallow water, the initial impulse will be reflected from both the water surface and the sea surface as it propagates through the water. Such a series of reverberations will become superimposed on the outgoing impulses from the subsequent sequence of detonations each of which also sets up a series of reverberations. The result is that the acoustic record of events becomes somewhat confused in that it is difficult to pick out what is a reverberation feature and what is a subsequent detonation (see *eg*. the time history over the range 302-304 seconds in Figure A.2).

From Figure A.3, for the 10 kg charge event, there are a series of peak blast levels in excess of 210 dB re 1 μPa peak with the maximum being at 215.9 dB re 1 μPa peak. RMS levels are 198.3 dB re 1 μPa over a 1.6 second duration.

For the 20 kg charge event, there are a series of peak blast levels in excess of 220 dB re 1 μPa peak with the maximum being at 224.3 dB re 1 μPa peak. RMS levels are 201.0 dB re 1 μPa over a 3.0 second duration.

A.5 Results

For both charge weights and the given distances from the blast site, the expected peak blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent root-mean-square (rms) levels calculated using durations sufficiently long enough to capture the entire blasting sequence together with the following reverberations from each detonation. It is noted that the confined blasting model give peak blast levels only; rms levels are not calculated.

The data presented in Table A.1 show that the modelled blast levels are lower than those obtained from the acoustic data acquired during the blasting schedule. Currently, it is considered too early to comment on whether this discrepancy arises as a result of the small sample size of recorded data or else from the assumptions and simplifications inherent in the blast modelling process itself[2]. In addition, it is seen that the measured rms levels are all below the behavioural threshold of 170 dB re 1 μPa (rms).

Charge weight	Distance from blast site	Modelled blast levels	Measured blast levels
10 kg	437 m	174.0 dB re 1 μPa peak	215.9 dB re 1 μPa 198.3 dB re 1 μPa $rms_{1.6sec}$
20 kg	442 m	178.5 dB re 1 μPa peak	224.3 dB re 1 μPa 201.0 dB re 1 μPa $rms_{3.0sec}$

Table A.1: Comparison of peak and rms modelled blast levels with peak and rms recorded blast levels

APPENDIX B: BLASTING RESULTS - 24TH AUGUST 2018

B.1 Overview - Inside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
24 Aug 2018	1303hrs BST	10 kg	H0	Inside	457 m/Field1	180824_03
24 Aug 2018	1303hrs BST	20 kg	H0	Inside	425 m/Field3	180824_03

B.2 Ecofish Observations

Detonation noise recording. 3 holes of 10kg charges, followed by 63 holes of up to 20kg charges. Hydrophone H0 deployed inside of the bubble curtain.

The detonation was delayed for three days due to grey seal presence in Nigg Bay. The animals were eventually shepherded out using a Lofitech Seal Scarer Acoustic Deterrent Device (ADD) deployed from a fast recovery vessel. Due to these circumstances, the bubble curtain was left on during the entirety of the 30 minutes leading to the detonation in an attempt to deter the animals from returning. The PAM ops asked the vessel skipper to adjust his vessel's position shortly before the blast due to a drift towards the bubble curtain. The blast was detonated approximately 2.5 minutes ahead of schedule therefore some of the engine noise may be present on the recording just before the detonation.

B.3 Data Processing:

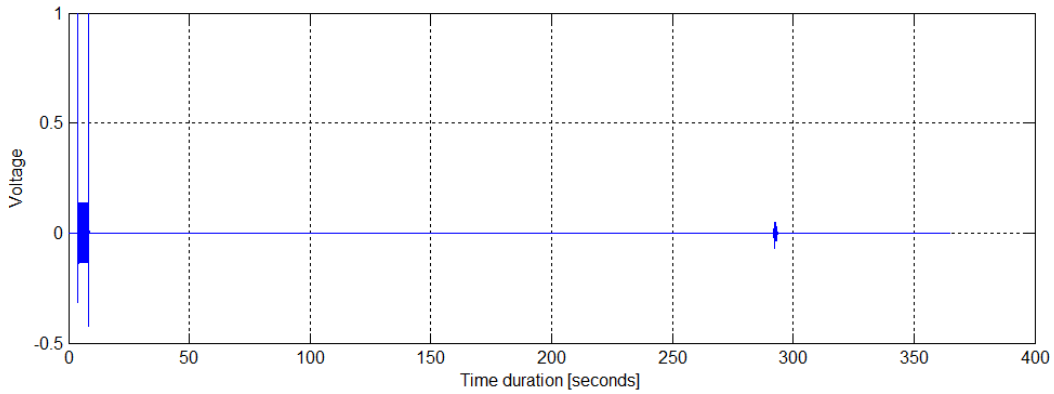

Figure B.1: Hydrophone output in volts as a function of time in seconds

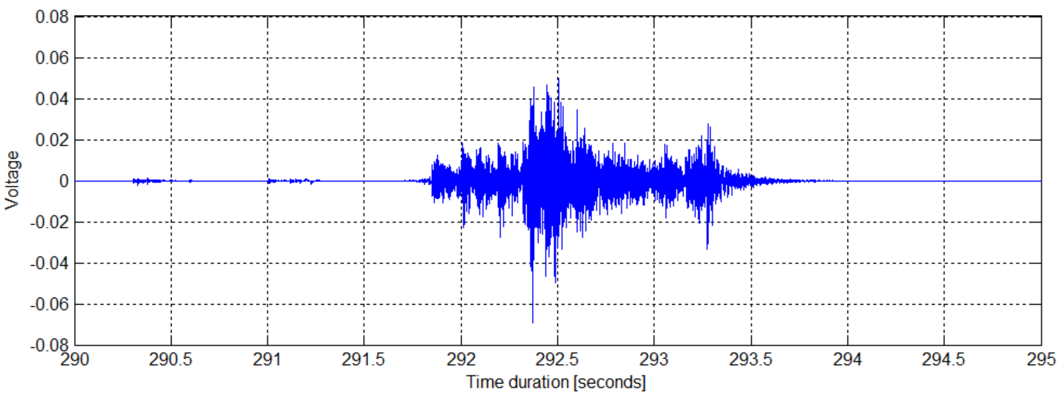

Figure B.2: Hydrophone output in volts as a function of time in seconds around blast sequence

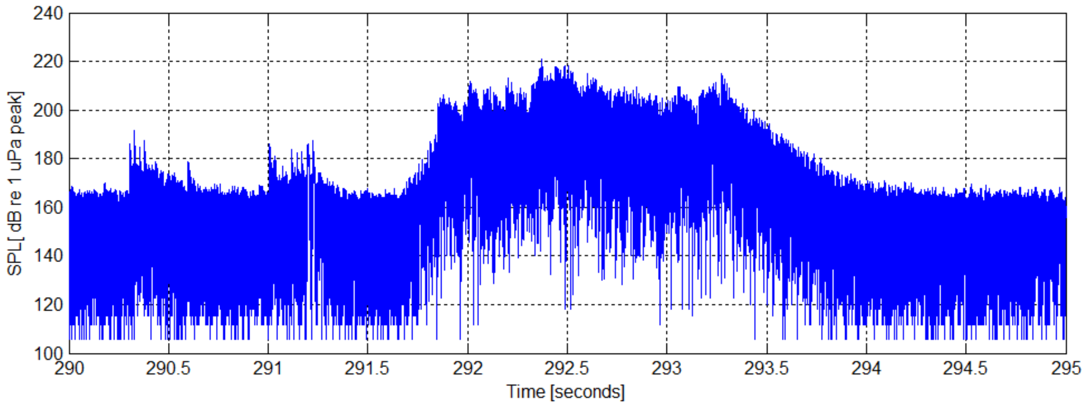

Figure B.3 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

B.4 Discussion

Figure B.1 shows the full hydrophone output time series displayed in units of volts. A total of three detonation sequences are identified commencing around 290 seconds and are seen more clearly in Figure B.2. From 290.3 sec to 291.3 sec there are a total of 3 detonations of the 10 kg charge weights that failed to detonate on 20 August. This is followed by the main detonation sequence consisting of the 20 kg charge weights.

The Field Contractor's Log shows that there were 63 detonations in the main blast sequence where each detonation is separated by a time of approximately 25 msec. This gives an overall blast event duration of 1.55 sec. When a confined detonation occurs in shallow water, the initial impulse will be reflected from both the water surface and the sea surface as it propagates through the water. Such a series of reverberations will become superimposed on the outgoing impulses from the subsequent sequence of detonations each of which also sets up a series of reverberations. The result is that the acoustic record of events becomes stretched out in time. Figure B.2 shows that the blast sequence lasts approximately 1.75 sec. The additional time is attributed to the time required for all reverberations to decay back to background level.

Figures B.3 shows the sound pressure level (SPL) time series displayed in units of decibels re 1 μPa. For the 10 kg charge weights, the maximum blast level is 160 dB re 1 μPa peak. This is equivalent to 135 dB re 1 μPa rms over a period of 0.22 sec.

For the 20 kg charge event, there are a series of peak blast levels in excess of 180 dB re 1 μPa peak with the maximum being at 188.8 dB re 1 μPa peak. This is equivalent to 168.5 dB re 1 μPa rms over a period of 1.76 sec.

B.5 Results

For both charge weights and the given distances from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table B.1, shows that for the 10 kg charge, the maximum blast level measured during the current blasting sequence is approximately 13 dB lower than the modelled level while for the 20 kg charge the recorded level is approximately 40 dB higher than the modelled level.

The rms level for the 20 kg charge is 29 dB above the critical threshold of 170 dB re 1 μPa rms.

Charge weight	Distance from blast site	Modelled blast level	Measured blast level
10 kg	457 m	173.4 dB re 1 μPa peak	160.0 dB re 1 μPa peak 135.8 dB re 1 μPa $rms_{0.22sec}$
20 kg	425 m	179.2 dB re 1 μPa peak	221.2 dB re 1 μPa peak 198.9 dB re 1 μPa $rms_{1.76sec}$

Table B.1: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

B.6 Overview - Outside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
24 Aug 2018	1303hrs BST	10 kg	H10	Outside	806 m/Field1	180820_130015
24 Aug 2018	1303hrs BST	20 kg	H10	Outside	769 m/Field3	180820_130015

B.7 Ecofish Observations

Detonation noise recording Hydrophone H10 deployed outside of the bubble curtain. Vessel stationary outside of BC.

After initial calibration tone H/P gain was set to High for 30 seconds and then changed to Low in order to provide a comparison. A further Calibration tone was injected after the gain change.

B.8 Data Processing:

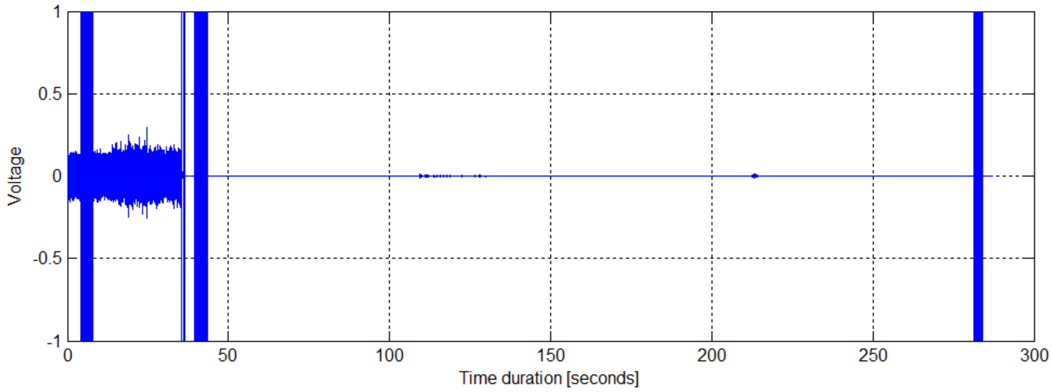

Figure B.4: Hydrophone output in volts as a function of time in seconds

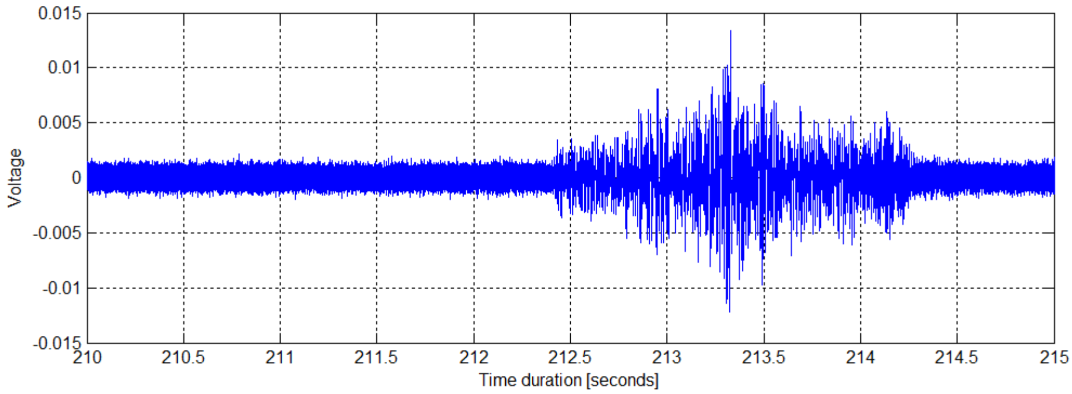

Figure B.5: Hydrophone output in volts as a function of time in seconds around blast sequence

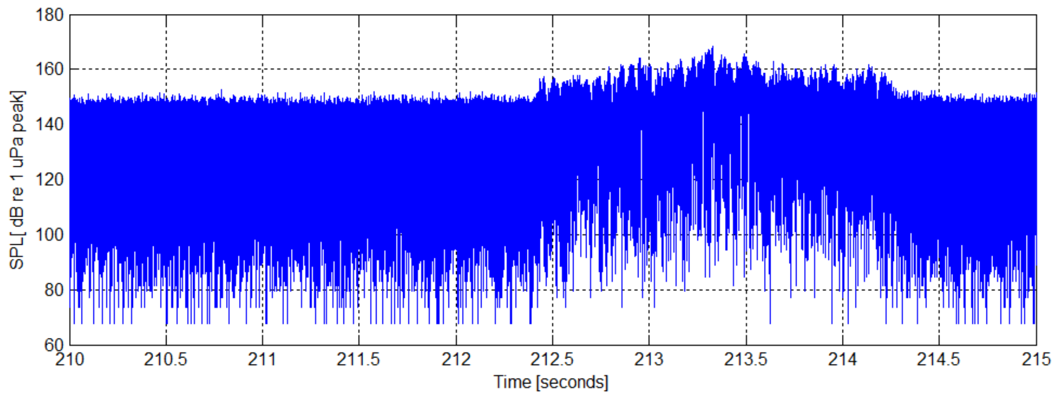

Figure B.6: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

B.9 Discussion

Figures B.4 and B.5 show the hydrophone output displayed in units of volts.

Figure B.4 shows over the first 40 seconds, the injection of the calibration tones and the switching of the amplifier between High Gain and Low Gain. The detonation sequence consisting of the 20 kg charges is identified as occurring around 212 seconds and this is seen more clearly in Figure B.5. The 3 x 10 kg detonation sequence is not found in the time-series. It is assumed that these events have become submerged in the background noise.

Earlier, it was discussed how the recorded blast sequence becomes stretched out in time due to the blast waves being reflected from the sea surface and seabed. For the hydrophone H0, located inside the bubble curtain, the blast sequence was 1.75 sec in duration. For the hydrophone H10, located outside the bubble curtain, Figure B.6 indicates that the blast sequence is increased to approximately 1.85 sec in duration. This increase can be attributed to the longer acoustic paths lengths associated with propagation between the blast site and hydrophone H10.

Figures B.6 shows the sound pressure level (SPL) time series centred on the blast sequence displayed in units of decibels re 1 μPa. For the 20 kg charge event, there are a series of peak blast levels in excess of 160 dB re 1 μPa peak with the maximum being at 168.5 dB re 1 μPa peak corresponding to 153.7 dB re 1 μPa $rms_{1.85sec}$.

B.10 Results

For both charge weights and the given distances from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. The effect of a bubble curtain is modelled using the modified confined blasting model presented in the Clarification Note[7].

The results, summarised in Table B.2, show that the maximum blast level measured during the 20 kg blasting sequence is 2.5 dB lower than the level modelled using a bubble curtain having zero attenuation and 5.5 dB higher than when modelled using a bubble curtain having 60% attenuation. Currently, due to lack of data, it is considered too early to comment in detail on the attenuation characteristics provided by the bubble curtain.

The 10 kg blasting sequence is not evident in the acoustic record: it is assumed that the blast noise has fallen into the general background noise. Nevertheless, the maximum rms levels from the 10 kg blast may still be estimated by calculating the rms levels for a 1.9 second period immediately prior to the 20 kg blast. In this case, the level is 138.9 dB re 1 μPa rms.

Charge weight	Distance from blast site	Modelled blast level		Measured blast level
		Zero attenuation	60% attenuation	
10 kg	806 m	165.5 dB re 1 μPa peak	157.5 dB re 1 μPa peak	†138.9 dB re 1 μPa $rms_{1.9sec}$
20 kg	769 m	171.0 dB re 1 μPa peak	163 dB re 1 μPa peak	168.5 dB re 1 μPa peak 153.7 dB re 1 μPa $rms_{1.9sec}$

Table B.2: Comparison of modelled peak and rms blast levels involving bubble curtains with two attenuation properties with recorded peak and rms blast levels. † Not evident in acoustic record: estimated rms level only

APPENDIX C: BLASTING RESULTS: 06TH SEPTEMBER 2018

C.1 Overview - Inside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
06 Sep 2018	0901hrs BST	20 kg	H0	Inside	285 m/Field4	180906-085634
06 Sep 2018	0901hrs BST	20 kg	H0	Inside	262 m/Field5	180906-085634

C.2 Ecofish Observations

Detonation noise recording: 65 holes of up to 20kg charges, followed by 86 holes of up to 20kg charges.

Hydrophone H0 deployed inside of the bubble curtain.

H10 TU used with H0 hydrophone due to damage caused to the h10 hydrophone earlier in the week.

C.3 Data Processing

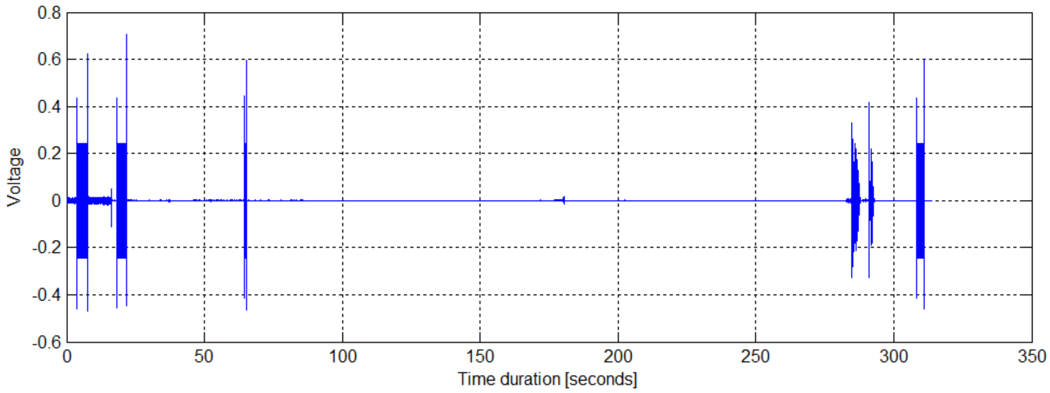

Figure C.1: Hydrophone output in volts as a function of time in seconds

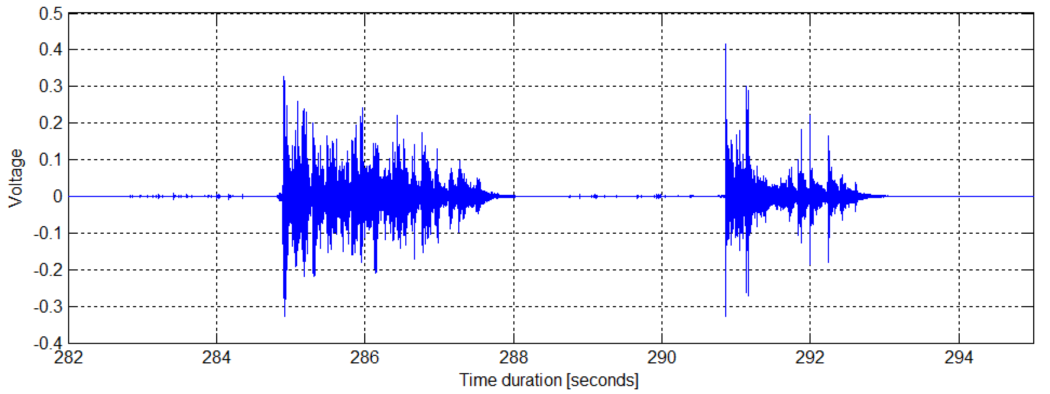

Figure C.2: Hydrophone output in volts as a function of time in seconds around blast sequence

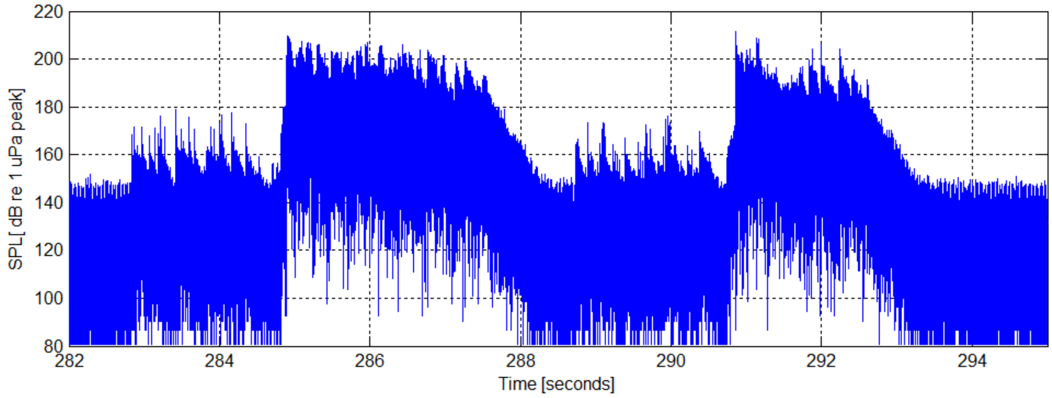

Figure C.3 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

C.4 Discussion

The Field Contractor's Log shows that there were two blast sequences of 65 detonations and 86 detonations respectively. For both sequences, the maximum charge weight was 20 kg. The acoustic record displayed in units of volts as a function of time as given in Figures C.1 and C.2, show that these two sequences occurred around 280 seconds from the commencement of recording.

Figure C.3 indicates that the first blast sequence lasted for a period of 3.8 seconds. Over this sequence, the maximum blast level was 209.4 dB re 1 μPa peak, equivalent to 190.5 dB re 1 μPa rms over a period of 3.8 sec. The second blast sequence was seen to have a slightly shorter duration. The maximum blast level was 211.5 dB re 1 μPa peak, equivalent to 185.4 dB re 1 μPa rms over a period of 3.4 sec.

C.5 Results

For both charge weights and the given distances from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table C.1, shows that for the 20 kg charges, the recorded levels are approximately 23 dB higher than the corresponding modelled levels.

The equivalent rms levels for both the blast sequences are in the range 15-20 dB above the critical threshold of 170 dB re 1 μPa rms.

Charge weight	Distance from blast site	Modelled blast level	Measured blast level
20 kg	285 m	184.8 dB re 1 μPa peak	209.4 dB re 1 μPa peak 190.5 dB re 1 μPa $rms_{3.8sec}$
20 kg	262 m	185.9 dB re 1 μPa peak	211.5 dB re 1 μPa peak 185.4 dB re 1 μPa $rms_{3.4sec}$

Table C.1: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

APPENDIX D: BLASTING RESULTS - 12TH SEPTEMBER 2018

D.1 Overview - Inside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
12 Sep 2018	1030 hrs BST	20 kg	H0	Inside	232 m /Field6	180912-112955
12 Sep 2018	1030 hrs BST	20 kg	H0	Inside	270 m /Field7	180912-112955

D.2 Ecofish Observations

Blast recording inside bubble curtain ~160 meters from centre of blast zone.

PAM system utilised H10 TU with H0 hydrophone. Vertical static, deployed over port side of vessel.

Vessel had no sea anchor and as such was drifting with the tide. Our position for the blast was achieved by attempting to estimate potential drift (>1.5knts current) and wind direction to maintain correct position with engines off for the blast recording.

As the blast occurred 3 minutes late (8 minutes after the initial 5 minute warning given) we had drifted beyond the required position and did not maintain correct line of sight with Forth Fighter (2nd recording vessel)

Starting the engines to move position may have been detrimental to any data acquisition with no indication of blast timing.

D.3 Data Processing

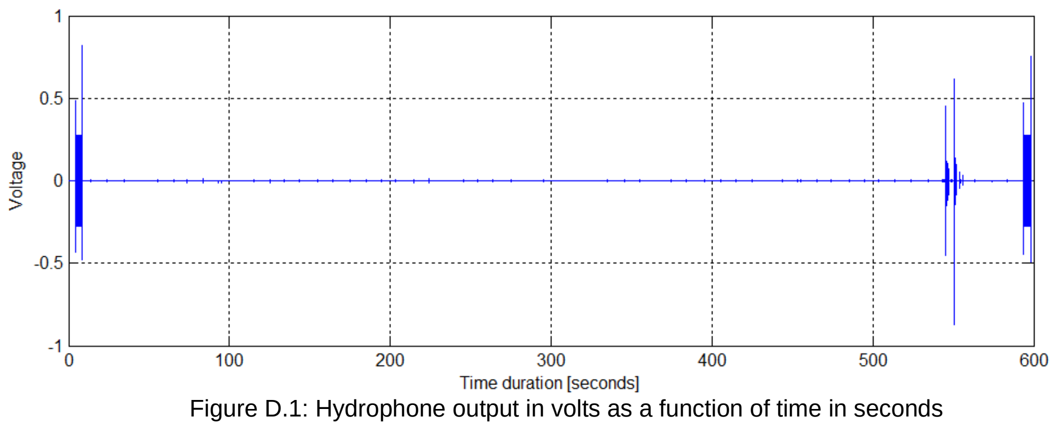

Figure D.1: Hydrophone output in volts as a function of time in seconds

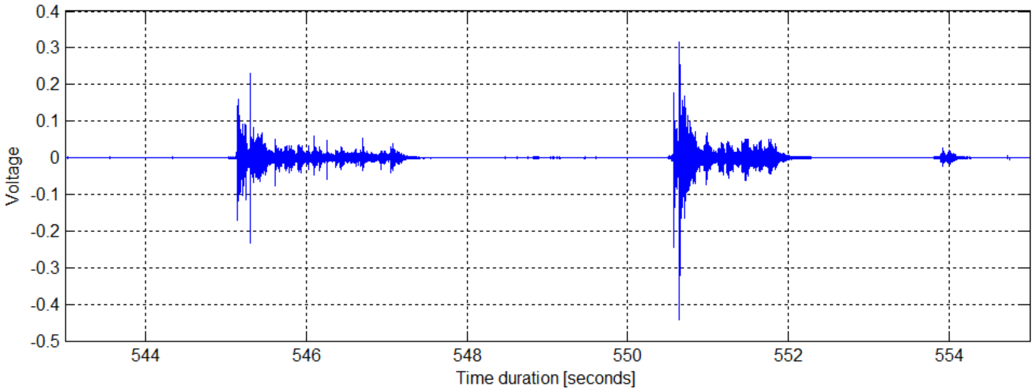

Figure D.2: Hydrophone output in volts as a function of time in seconds around blast sequence

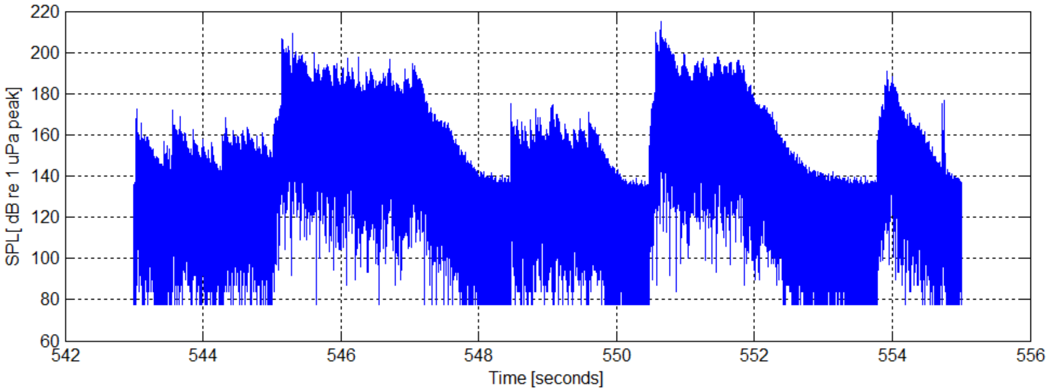

Figure D.3 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

D.4 Discussion

The Field Contractor's Log shows that two blasting sites were prepared: Field 6 had a total of 132 boreholes primed with explosives while Field 7 had 77 boreholes primed. At the moment of blasting, a total of 92 charges were detonated in Field 6 while around 30 charges were detonated in Field 7. For both sequences, the maximum charge weight was 20 kg. The acoustic record displayed in units of volts as a function of time as given in Figure D.1, shows that these two sequences occurred around 545 seconds from the commencement of recording.

Figure D.2 indicates that the first blast sequence lasted for a period of 2.38 seconds. Over this sequence, Figure D.3 shows that the maximum blast level was 211.3 dB re 1 μPa peak, equivalent to 185.6 dB re 1 μPa rms over a period of 2.38 sec. The second blast sequence was seen to have a slightly shorter duration. The maximum blast level was 216.9 dB re 1 μPa peak, equivalent to 190.1 dB re 1 μPa rms over a period of 1.65 sec.

D.5 Results

For both charge weights and the given distances from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The result, summarised in Table D.1, shows that for the 20 kg charges, the recorded levels are between 24 dB and 30 dB higher than the corresponding modelled levels.

The equivalent rms levels for both the blast sequences are in the range 15-20 dB above the critical threshold of 170 dB re 1 μPa rms. However, the rms levels have been computed from data recorded at distances much closer to the blast sites than the 400 m specified.

Charge weight	Distance from blast site	Modelled blast level	Measured blast level
20 kg	232 m from Field 6	187.6 dB re 1 μPa peak	211.3 dB re 1 μPa peak 185.6 dB re 1 μPa $rms_{2.38sec}$
20 kg	270 m from Field 7	185.5 dB re 1 μPa peak	216.9 dB re 1 μPa peak 190.1 dB re 1 μPa $rms_{1.65sec}$

Table D.1: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

D.6 Overview - Outside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
12 Sep 2018	1030 hrs BST	20 kg	H4	Outside	-	180912_01
12 Sep 2018	1030 hrs BST	20 kg	H4	Outside	-	180912_02

D.7 Ecofish Observations

The acoustic data recordings were found to be unusable. Investigations as to why are ongoing.

D.8 Overview - Inside bubble curtain (repeat blasting)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
12 Sep 2018	1200 hrs BST	20 kg	H0	Inside	252 m/Field6	180912-125638
12 Sep 2018	1200 hrs BST	20 kg	H0	Inside	293 m/Field7	180912-125638

D.9 Ecofish Observations

Blast recording inside bubble curtain ~160 meters from centre of blast zone.

PAM system utilised H10 TU with H0 hydrophone. Vertical static, deployed over port side of vessel.

Blast 4.5 Detonation. 12:00 UTC (Partial detonation occurred previously – awaiting information on potential/estimated charge weight successfully detonated on repeat blast)

Survey vessel moved drastically in the initial 2 minutes of the 5 minute warning provided, as such the engines were started and position hastily moved. Calibration tone injected again. Position was 'borderline' linear with blast and Forth Fighter Rec vessel.

D.10 Data Processing

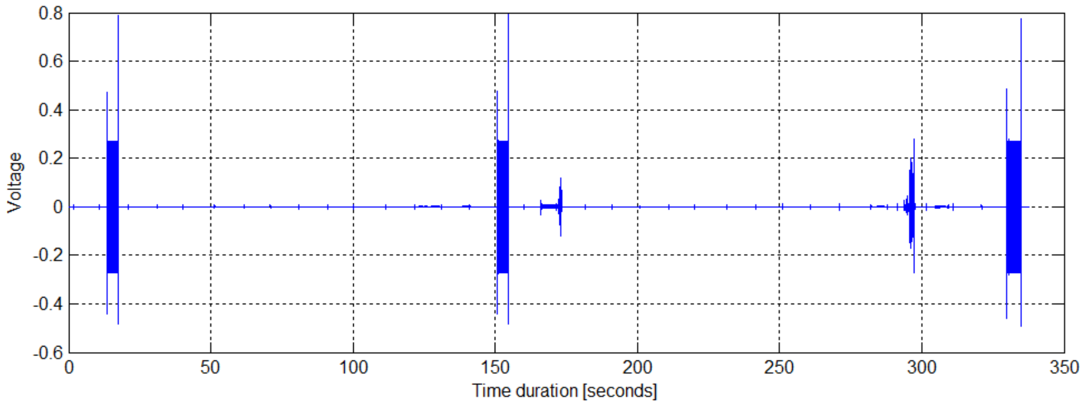

Figure D.4: Hydrophone output in volts as a function of time in seconds

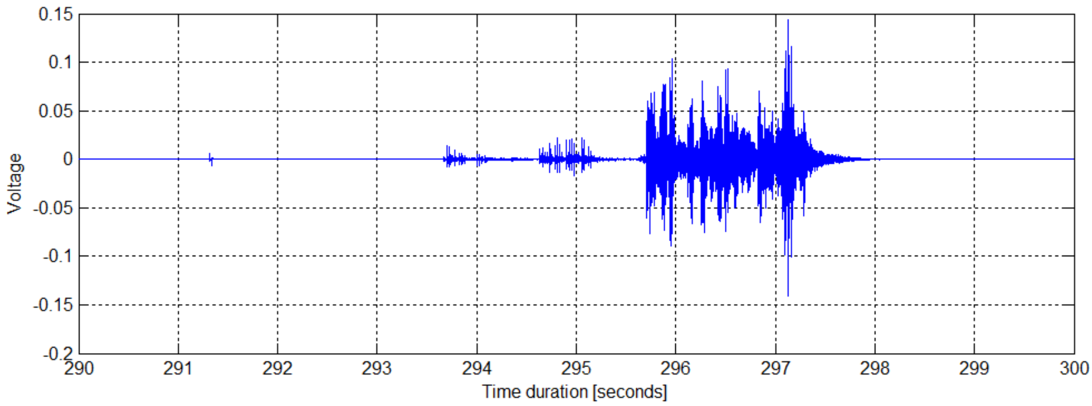

Figure D.5: Hydrophone output in volts as a function of time in seconds around blast sequence

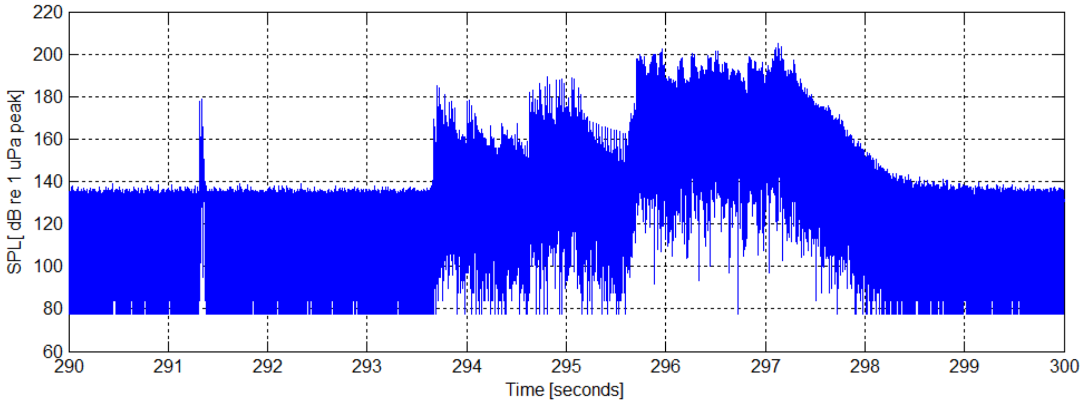

Figure D.6 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

D.11 Discussion

The blast sequence commencing 293 sec consisted of 40 detonations from Field 6 and an unknown number from Field 7 that failed to detonate at 1030 hrs. It is assumed that the sequence from 293.6 sec to 295.5 sec are the detonations from Field 6 while the sequence from 293.6 sec to 298.2 sec are the detonations from Field 7.

Figure D.6 indicates that during the first blast sequence the maximum blast level was 191.1 dB re 1 μPa peak, equivalent to 162.9 dB re 1 μPa rms over a period of 1.85 sec. The second blast sequence lasted slightly longer. The maximum blast level was 207.1 dB re 1 μPa peak, equivalent to 196.1 dB re 1 μPa rms over a period of 2.55 sec.

D.12 Results

For both charge weights and the given distances from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The result, summarised in Table D.2, shows that for the 20 kg charges, the recorded levels are between 3 dB and 23 dB higher than the corresponding modelled levels.

The equivalent rms levels for both the blast sequences vary from 7 dB below to 26 dB above the critical threshold of 170 dB re 1 μPa rms. In each case, the rms levels have been computed from data recorded at distances much closer to the blast sites than the 400 m specified.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
20 kg	6	252 m	186.5 dB re 1 μPa peak	191.1 dB re 1 μPa peak 162.9 dB re 1 μPa $rms_{1.85sec}$
20 kg	7	293 m	184.4 dB re 1 μPa peak	207.1 dB re 1 μPa peak 196.1 dB re 1 μPa $rms_{2.55sec}$

Table D.2 Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

D.13 Overview - Outside bubble curtain (repeat blasting)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
12 Sep 2018	1200 hrs BST	20 kg	H4	Outside		180912_04

D.14 Ecofish Observations

Blast recording outside bubble curtain ~750 meters from centre of blast zone.

Blast 4.5 Detonation. 12:00 UTC (Partial detonation occurred previously – awaiting information on potential/estimated charge weight successfully detonated on repeat blast)

PAM system utilised H4 TU with H4 hydrophone. Vertical static, deployed over port side of vessel.

Vessel was sea anchored.

5 calibrations done in total. 1st Calibration on mitigation settings, +10 TU gain and HPF 1kHz, 2nd Calibration +10 TU gain, 3rd Calibration 0 TU gain, 4th Calibration +10 TU gain. 5th calibration at the end of the recording.

Ocean Spartan's position was 'borderline' linear with blast and Forth Fighter Rec. vessel.

Currently waiting for information on charge that detonated successfully during the 2nd blasting sequence.

D.15 Data Processing

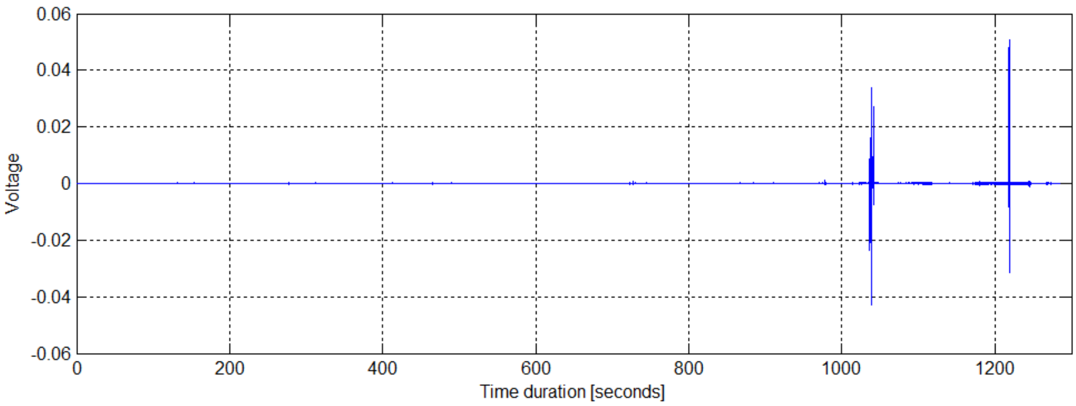

Figure D.7: Hydrophone output in volts as a function of time in seconds

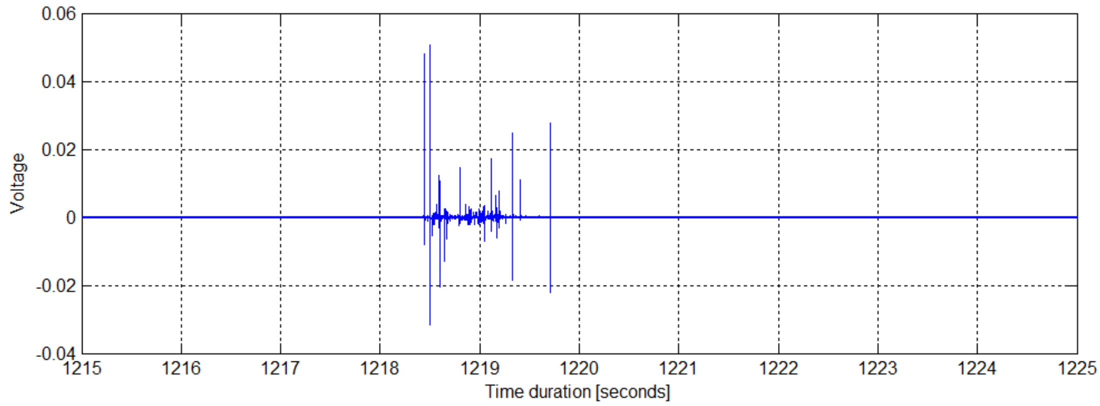

Figure D.8: Hydrophone output in volts as a function of time in seconds around blast sequence

D.16 Discussion

The event in the acoustic record that was identified as the blast signal appeared to be contaminated with interference noise and was subsequently deemed unusable.

APPENDIX E: BLASTING RESULTS - 14TH SEPTEMBER 2018

E.1 Overview - Inside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
14 Sep 2018	1305 hrs BST	20 kg	H0	Inside	326 m/Field8	180914_124350
14 Sep 2018	1305 hrs BST	20 kg	H0	Inside	358 m/Field9	180914_124350

E.2 Ecofish Observations

Blast recording inside bubble curtain ~300 meters from centre of blast zone. Partial detonation.

Blast 5 Detonation 12:05 UTC

Vertical static and using anchor. Hydrophone deployed over port bow of vessel. Sea earth deployed over portside astern to depth ~1.5 meters

PAM system utilised h10 TU with h0 hydrophone. All systems checked before recording. Terminal unit kept in a position far away as possible from any RF or mobile phone etc. Radio possible interference etc. Engine running slight power until T-5 mins before blast.

E.3 Data Processing

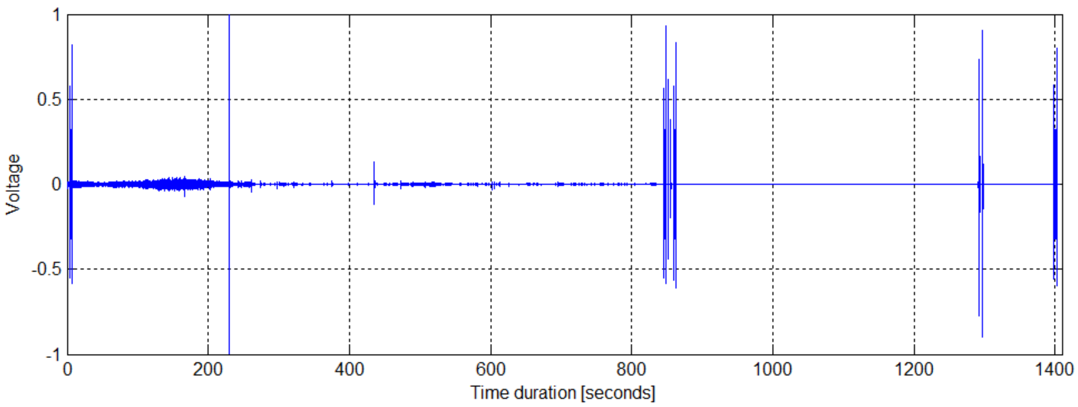

Figure E.1: Hydrophone output in volts as a function of time in seconds

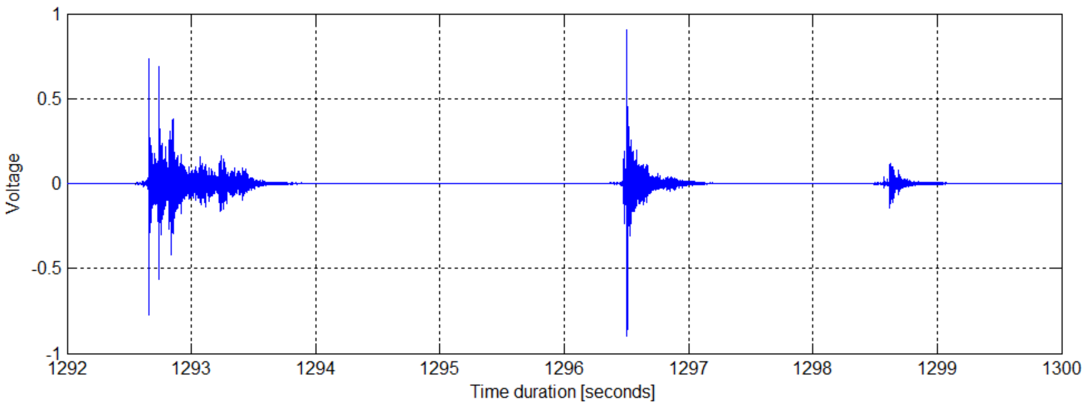

Figure E.2: Hydrophone output in volts as a function of time in seconds around blast sequence

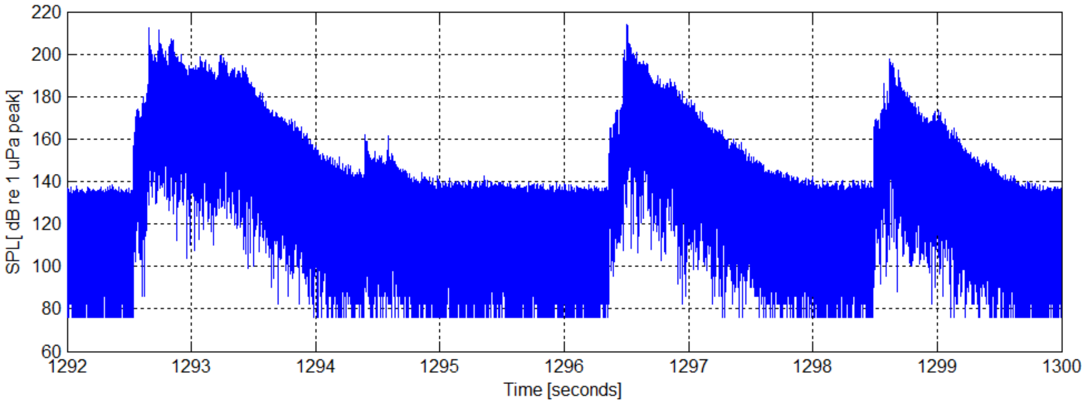

Figure E.3 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

E.4 Discussion

The Field Contractor's Log shows that two blasting sites were prepared: Field 8 had a total of 99 boreholes primed with explosives while Field 9 had 53 boreholes primed. It is understood that not all charges were successfully detonated. However it has not been possible to determine the numbers of charges that were undetonated. For both sequences, the maximum charge weight was 20 kg. The acoustic record displayed in units of volts as a function of time as given in Figures E.1 and E.2, shows that these two sequences occurred around 1292 seconds from the commencement of recording. It is assumed that the sequence from 1292.5 sec to 1293.5 sec are the detonations from Field 8 while the sequence commencing 1295.5 sec are the detonations from Field 9.

Figure E.3 indicates that during the first blast sequence the maximum blast level was 214.5 dB re 1 μPa peak, equivalent to 191.8 dB re 1 μPa rms over a period of 1.06 sec. The blasting from Field 9 appears to extend over two discrete periods separated by approximately 1.5 seconds. The first part has a maximum blast level of 215.9 dB re 1 μPa peak, equivalent to 190.6 dB re 1 μPa rms over a period of 0.63 sec while the second part has a maximum blast level of 199.9 dB re 1 μPa peak, equivalent to 177.1 dB re 1 μPa rms over a period of 0.73 sec.

E.5 Results

For the charge weights and their corresponding distances from the blast sites, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The result, summarised in Table E.1, shows that for the 20 kg charges, the recorded levels are between 15 dB and 33 dB higher than the corresponding modelled levels.

The equivalent rms levels for both the blast sequences vary from 7 dB to 20 dB above the critical threshold of 170 dB re 1 μPa rms. In each case, the rms levels have been computed from data recorded at distances much closer to the blast sites than the 400 m specified.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
20 kg	8	326 m	182.9 dB re 1 µPa peak	214.5 dB re 1 µPa peak 191.8 dB re 1 µPa $rms_{1.06sec}$
20 kg	9	358 m	181.6 dB re 1 µPa peak	215.9 dB re 1 µPa peak 190.6 dB re 1 µPa $rms_{0.63sec}$
20 kg	9	358 m	181.6 dB re 1 µPa peak	199.9 dB re 1 µPa peak 177.1 dB re 1 µPa $rms_{0.73sec}$

Table E.1: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

E.6 Overview - Outside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
14 Sep 2018	1305 hrs BST	20 kg	H4	Outside	893 m/Field8	180914_02
14 Sep 2018	1305 hrs BST	20 kg	H4	Outside	922 m/Field9	180914_02

E.7 Ecofish Observations

Blast recording outside bubble curtain ~750 meters from centre of blast zone. Partial detonation so no charge amount known.

Blast 5 Detonation 12:05 UTC

Vertical static and using anchor. Hydrophone deployed over port bow of vessel. Sea earth deployed over portside astern to depth ~1.5 meters.

PAM system utilised h4 TU with h4 hydrophone. All systems checked before recording. Terminal unit kept in a position far away as possible from any RF or mobile phone etc.

E.8 Data Processing

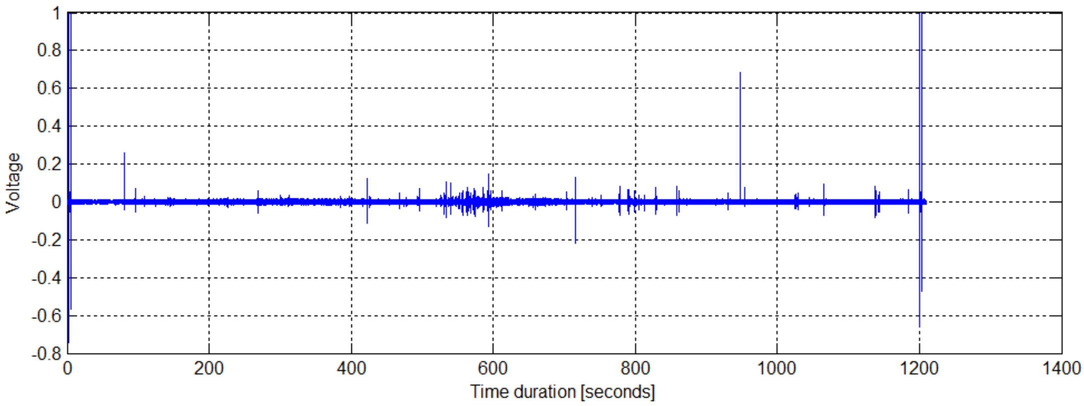

Figure E.4: Hydrophone output in volts as a function of time in seconds

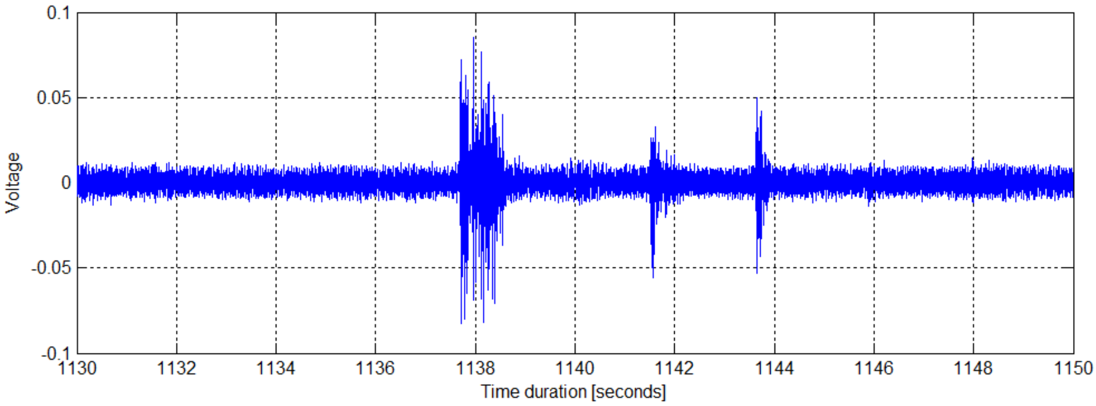

Figure E.5: Hydrophone output in volts as a function of time in seconds around blast sequence

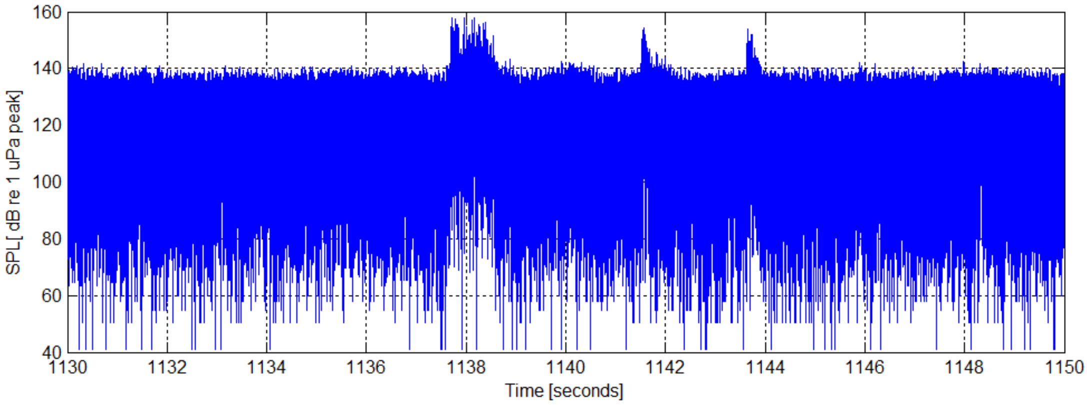

Figure E.6 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

E.9 Discussion

As discussed earlier, there was a partial detonation of the charges in Fields 8 and 9. The blast noise was recorded at a location outside the bubble curtain and the corresponding voltage-time series is shown in Figure E.4. The recording shows that there are a number of spurious clicks at *eg*. 80 seconds; 420 seconds; and 930 seconds while other unidentified noise events are apparent from 530 seconds to 580 seconds; and 1025 seconds to 1029 seconds. A series of low-amplitude events attributed to the blasting sequence at the two fields have been identified over the time period 1137-1144 seconds and this is shown more clearly in Figure E.5. The first event, lasting for just over 1 second, is assumed to be from Field 8. Figure E.6 shows that this has a maximum blast level of 158 dB re 1 μPa peak, equivalent to 146.2 dB re 1 μPa rms over a period of 1.1 sec. The blasting from Field 9 appears to extend over two discrete periods separated by approximately 3 seconds. The maximum blast level is 154.4 dB re 1 μPa peak, equivalent to 137.6 dB re 1 μPa rms over a period of 2.7 sec.

E.10 Results

For the charge weights and their corresponding distances from the blast sites, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The result, summarised in Table E.2, shows that for the 20 kg charges, the recorded levels are between 26 dB and 30 dB lower than the corresponding modelled levels assuming no bubble curtain. When a bubble curtain having a 60% attenuation is included, the recorded peak levels are 3-6 dB down on the modelled levels.

The equivalent rms levels for both the blast sequences are 24-33 dB below the critical threshold of 170 dB re 1 μPa rms. It is noted that the rms levels have been computed from data recorded at distances much greater to the blast sites than the 400 m specified.

Charge weight	Distance from blast site	Modelled blast level		Measured blast level
		Zero attenuation	60% attenuation	
20 kg	893 m	168.9 dB re 1 μPa peak	161.0 dB re 1 μPa peak	158.0 dB re 1 μPa peak 146.2 dB re 1 μPa $rms_{1.1sec}$
20 kg	922 m	168.4 dB re 1 μPa peak	160.5 dB re 1 μPa peak	154.4 dB re 1 μPa peak 137.6 dB re 1 μPa $rms_{2.7sec}$

Table E.2: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

E.11 Overview - Inside bubble curtain (repeat blasting)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
14 Sep 2018	1231 hrs BST	20 kg	H0	Inside	336 m/Field8	180914-131739
14 Sep 2018	1231 hrs BST	20 kg	H0	Inside	366 m/Field9	180914-131739

E.12 Ecofish Observations

Blast recording inside bubble curtain ~300 meters from centre of blast zone. 2nd sequence of blast due to earlier partial detonation.

Blast 5.5 Detonation 12:31 UTC

Vertical static and using anchor. Hydrophone deployed over portside bow of vessel. Sea earth deployed over portside astern to depth ~1.5 meters

PAM system utilised H10 TU with H0 hydrophone. Terminal unit kept in a position far away as possible from any RF or mobile phone etc. Radio possible interference etc.

E.13 Data Processing

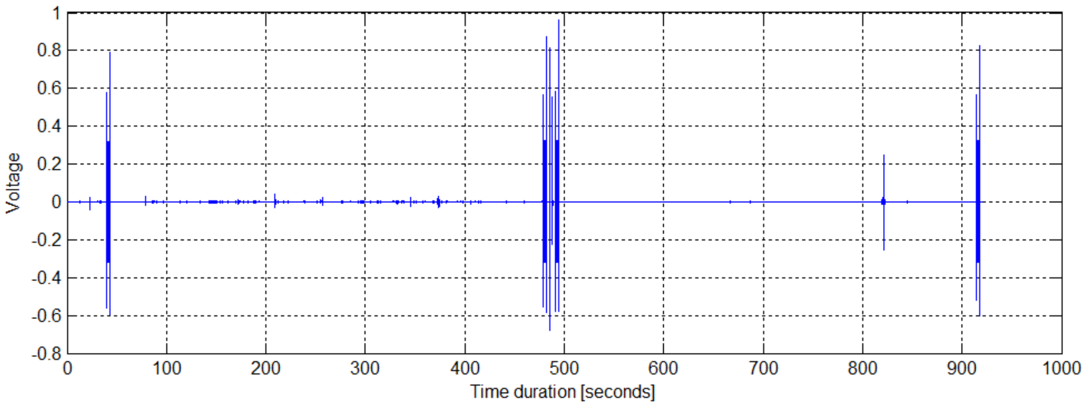

Figure E.7: Hydrophone output in volts as a function of time in seconds

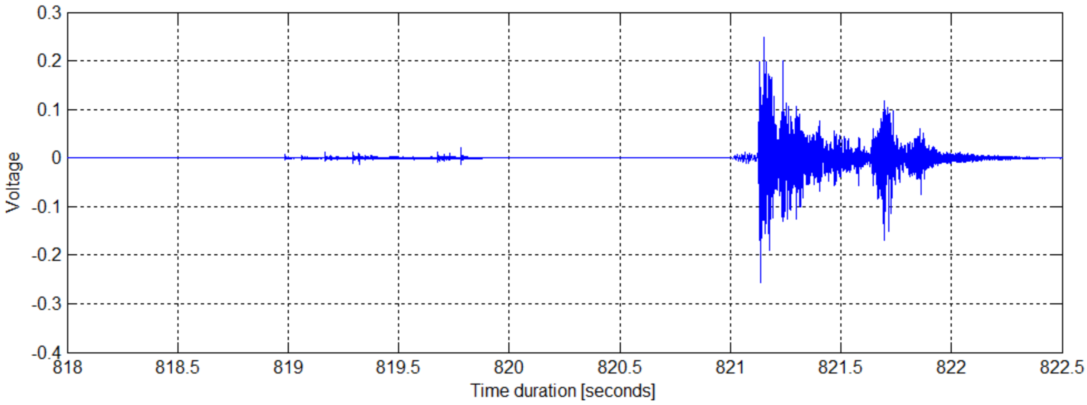

Figure E.8: Hydrophone output in volts as a function of time in seconds around blast sequence

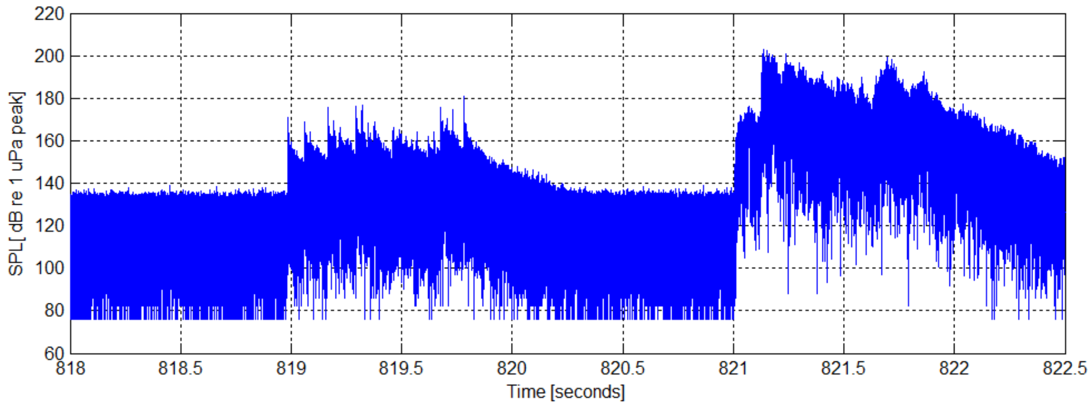

Figure E.9 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

E.14 Discussion

The blast sequence shown in Figure E.7 shows the noise recording at a location inside the bubble curtain and this consisted of the remaining charges that failed to detonate from Fields 8 and 9 during the blasting sequence scheduled for 1200 hrs. Figure E.8 shows a number of blast events. The blast sequence commencing 819 sec consisted of the remaining charges that failed to detonate from Fields 8 and 9 during the blasting sequence scheduled for 1200 hrs. It is assumed that the sequence from 819 sec to 820 sec are the detonations from Field 8 while the sequence from 821 sec to 822.3 sec are the detonations from Field 9.

Figure E.9 indicates that during the first blast sequence the maximum blast level was 183.1 dB re 1 μPa peak, equivalent to 152.5 dB re 1 μPa rms over a period of 1.15 sec. The second blast sequence had a maximum blast level of 204.9 dB re 1 μPa peak, equivalent to 185.3 dB re 1 μPa rms over a period of 1.2 sec.

E.15 Results

For the charge weights and their corresponding distances from the blast sites, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table E.3, show that for the 20 kg charges, the recorded levels are between 1 dB lower and 21 dB higher than the corresponding modelled levels.

The equivalent rms levels for both the blast sequences vary from 19 dB below to 13 dB above the critical threshold of 170 dB re 1 μPa rms. In each case, the rms levels have been computed from data recorded at distances slightly closer to the blast sites than the 400 m specified.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
20 kg	8	336 m	182.5 dB re 1 μPa peak	183.1 dB re 1 μPa peak 152.5 dB re 1 μPa $rms_{1.15sec}$
20 kg	9	366 m	181.3 dB re 1 μPa peak	204.9 dB re 1 μPa peak 185.3 dB re 1 μPa $rms_{1.2sec}$

Table E.3: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

E.16 Overview - Outside bubble curtain (repeat blasting)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
14 Sep 2018	1231 hrs BST	20 kg	H4	Outside	869 m/Field8	180914_03
14 Sep 2018	1231 hrs BST	20 kg	H4	Outside	899 m/Field9	180914_03

E.17 Ecofish Observations

Blast recording outside bubble curtain ~750 meters from centre of blast zone. Partial detonation so no charge amount known.

Blast 5.5 Detonation 12:30 UTC

Vertical static and using anchor. Hydrophone deployed over port bow of vessel. Sea earth deployed over portside astern to depth ~1.5 meters.

PAM system utilised h4 TU with h4 hydrophone. All systems checked before recording. Terminal unit kept in a position far away as possible from any RF or mobile phone etc. 13 minute recording due to not having information for this blast schedule. Bubble curtain turned on little before start of blast.

E.18 Data Processing

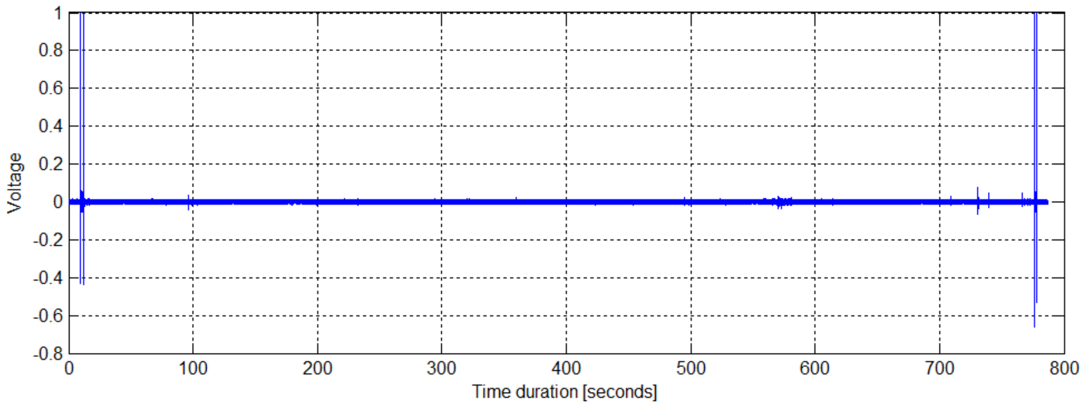

Figure E.10: Hydrophone output in volts as a function of time in seconds

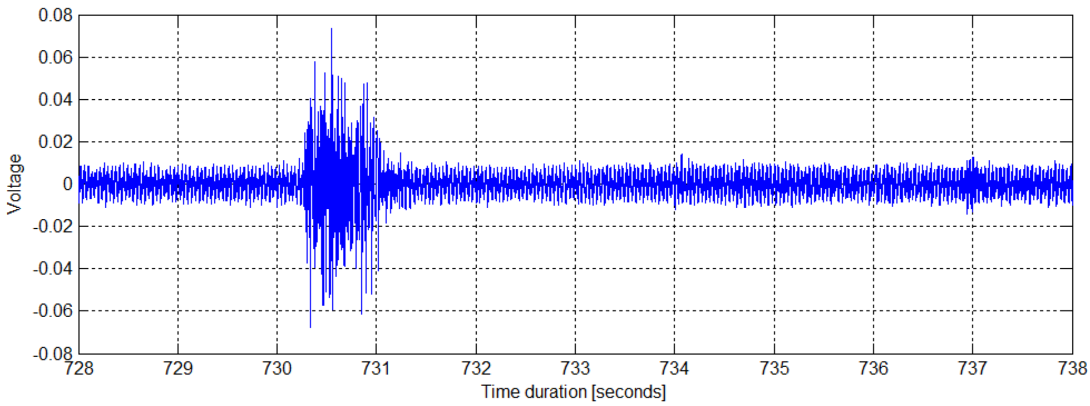

Figure E.11: Hydrophone output in volts as a function of time in seconds around blast sequence

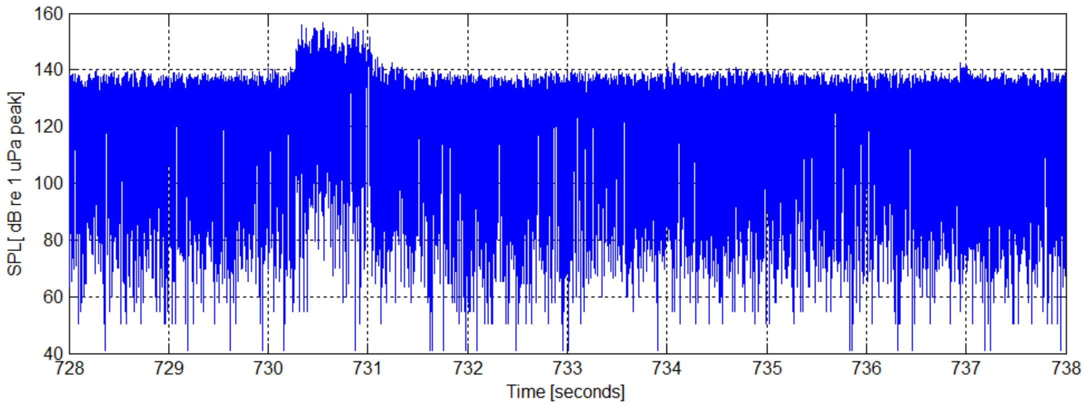

Figure E.12 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

E.19 Discussion

The blast sequence shown in Figure E.10 shows the noise recording at a location outside the bubble curtain and this consisted of the remaining charges that failed to detonate from Fields 8 and 9 during the blasting sequence scheduled for 1305 hrs. Figure E.11 shows two clear blast events. It is assumed that the first blast sequence commencing 730 sec consisted of the remaining charges that failed to detonate from Field 8 while the sequence at 737 seconds sec consisted of the remaining charges from Field 9.

Figure E.12 shows that during the first blast sequence the maximum blast level was 156.8 dB re 1 μPa peak, equivalent to 144.6 dB re 1 μPa rms over a period of 1.3 sec. The second blast sequence had a maximum blast level of 126.0 dB re 1 μPa peak, equivalent to 115.3 dB re 1 μPa rms over a period of 1.0 sec.

E.20 Results

For the charge weights and their corresponding distances from the blast sites, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table E.4, shows that for the 20 kg charges, the recorded levels are between 28 dB and 42 dB lower than the corresponding modelled levels assuming no bubble curtain. When a bubble curtain having 60% attenuation is included, recorded levels are 5-35 dB down on modelled levels.

The equivalent rms levels for both the blast sequences are up to 55 dB below the critical threshold of 170 dB re 1 μPa rms. It is noted that the rms levels have been computed from data recorded at distances to the blast sites much greater than the 400 m specified. In addition, the bubble curtain has absorbed significant levels of acoustic energy.

Charge weight	Distance from blast site	Modelled blast level		Measured blast level
		Zero attenuation	60% attenuation	
20 kg	869 m	169.3 dB re 1 μPa peak	161.4 dB re 1 μPa peak	156.8 dB re 1 μPa peak 144.6 dB re 1 μPa $rms_{1.1sec}$
20 kg	899 m	168.8 dB re 1 μPa peak	160.9 dB re 1 μPa peak	126.0 dB re 1 μPa peak 115.3 dB re 1 μPa $rms_{2.7sec}$

Table E.4: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

APPENDIX F: BLASTING RESULTS - 17TH SEPTEMBER 2018

F.1 Overview - Inside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
17 Sep 2018	1642 hrs BST	20 kg	H0	Inside	565 m/Field10	180917-160821
17 Sep 2018	1642 hrs BST	20 kg	H0	Inside	589 m/Field11	180917-160821

F.2 Ecofish Observations

Blast 6 recording inside bubble curtain (approx. 100 meters away). Hydrophone was ~575 meters from source.

Vertical static. Hydrophone deployed over port bow of vessel. Sea earth deployed over portside astern to depth ~1.5 meters

PAM system utilised h10 TU with h0 hydrophone. Overall system calibration -226 dB re 1 Volt/uPa

All systems checked before recording. Terminal unit kept in a position far away as possible from any RF or mobile phone etc. Radio possible interference etc. Vessel engine running (not possible to anchor).

There is UHF radio interference from communications and some boat traffic.

F.3 Data Processing

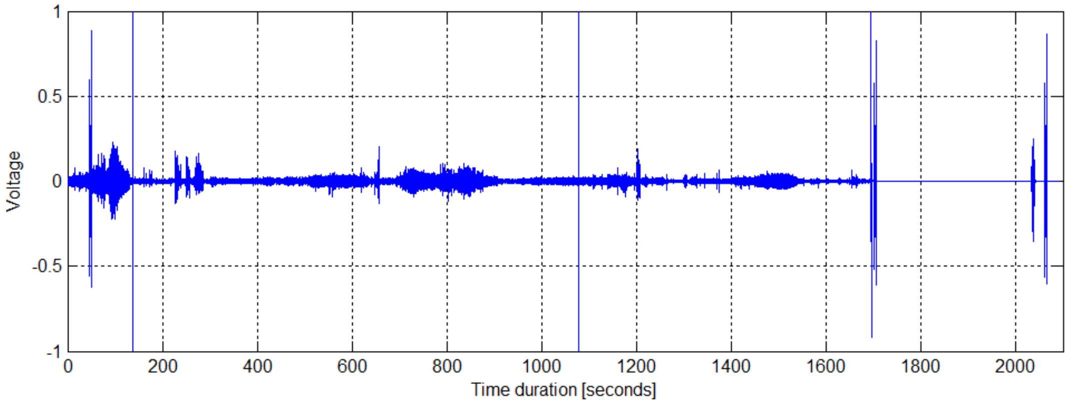

Figure F.1: Hydrophone output in volts as a function of time in seconds

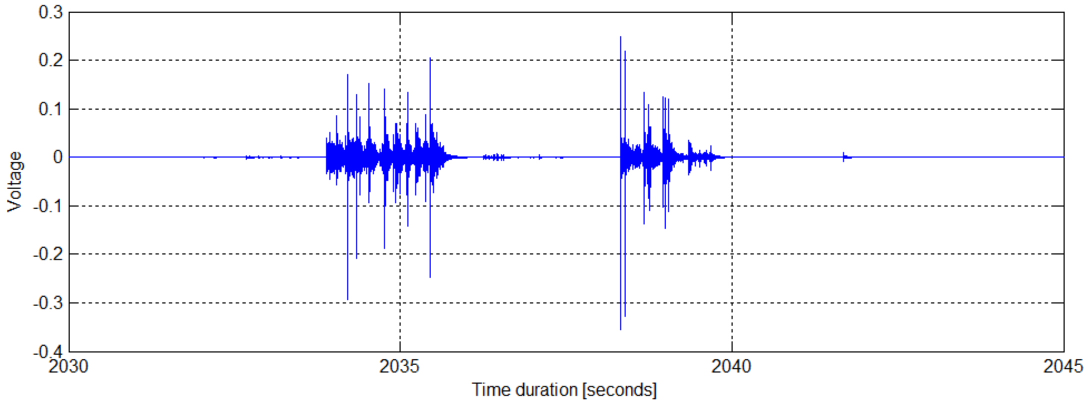

Figure F.2: Hydrophone output in volts as a function of time in seconds around blast sequence

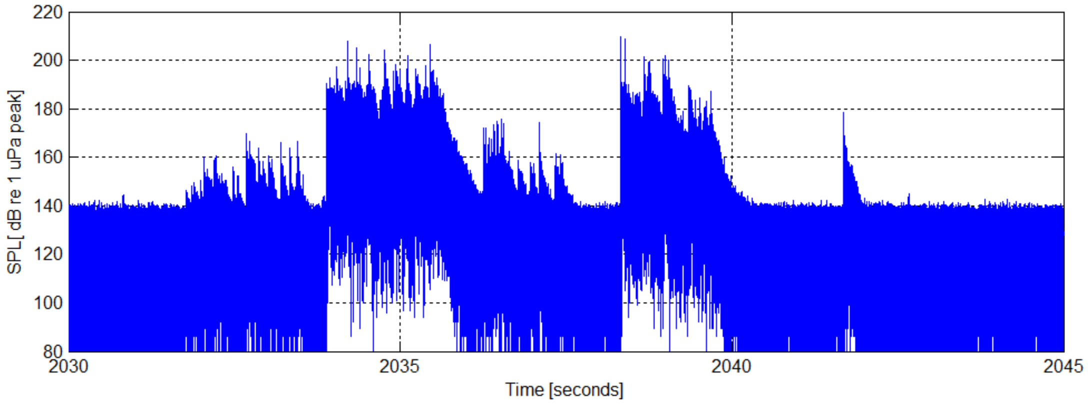

Figure F.3 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

F.4 Discussion

The blast sequence shown in Figure F.1 shows the noise recording at a location inside the bubble curtain. Figure F.2 shows two clear blast events. It is assumed that the first blast sequence commencing 2034 sec consisted of the detonation of the 134 charge weights located in Field 10 while the sequence commencing at approximately 2038 seconds consisted of the detonation of the 47 charge weights from Field 11.

Figure F.3 shows that the maximum blast level from Field 10 was 205.9 dB re 1 μPa peak, equivalent to 176.9 dB re 1 μPa rms over a period of 4.0 sec. The maximum blast level from Field 11 was 207.6 dB re 1 μPa peak, equivalent to 175.5 dB re 1 μPa rms over a period of 3.7 sec.

F.5 Results

For the charge weights and their corresponding distances from the blast sites, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table F.1, shows that for the 20 kg charges, the recorded levels are approximately 30 dB higher than the corresponding modelled levels.

The equivalent rms levels for both the blast sequences are up to 7 dB above the critical threshold of 170 dB re 1 μPa rms. It is noted that the rms levels have been computed from data recorded at distances to the blast sites greater than the 400 m specified.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
20 kg	10	565 m	175.3 dB re 1 μPa peak	205.9 dB re 1 μPa peak 176.9 dB re 1 μPa $rms_{4.0sec}$
20 kg	11	589 m	174.7 dB re 1 μPa peak	207.6 dB re 1 μPa peak 175.5 dB re 1 μPa $rms_{3.7sec}$

Table F.1: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

F.6 Overview - Outside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
17 Sep 2018	1642 hrs BST	20 kg	H4b	Outside	964m/Field10	180917_01
17 Sep 2018	1642 hrs BST	20 kg	H4b	Outside	990m/Field11	180917_01

F.7 Ecofish Observations

Blast recording outside bubble curtain ~1000 meters from centre of blast zone.

Blast 6 Detonation 15:41 UTC

Vertical static and using anchor. Hydrophone deployed over port bow of vessel. Sea earth deployed over portside astern to depth ~1.5 meters at 8:20 min in the recording.

The wet end is a calibrated Reson TC4032 hydrophone. The hydrophone and preamplifier have a nominal sensitivity of -164dB re 1V/µPa.

TU Gain +10 dB.

F.8 Data Processing

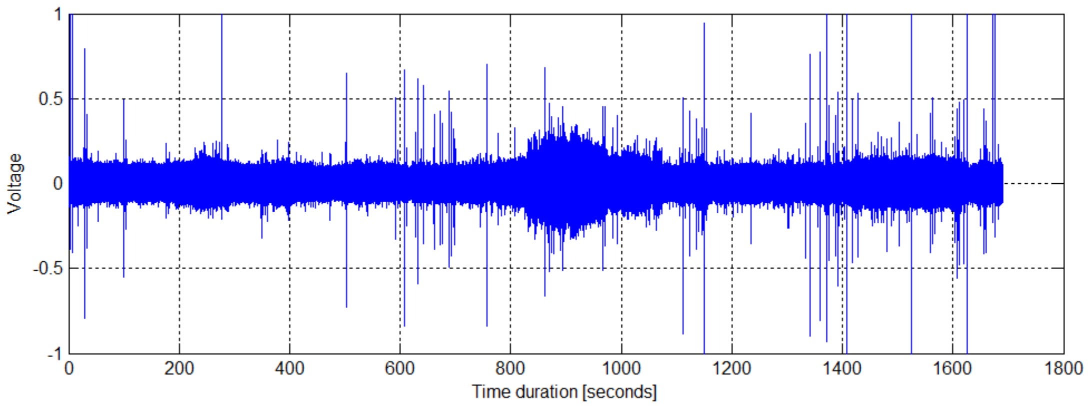

Figure F.4: Hydrophone output in volts as a function of time in seconds

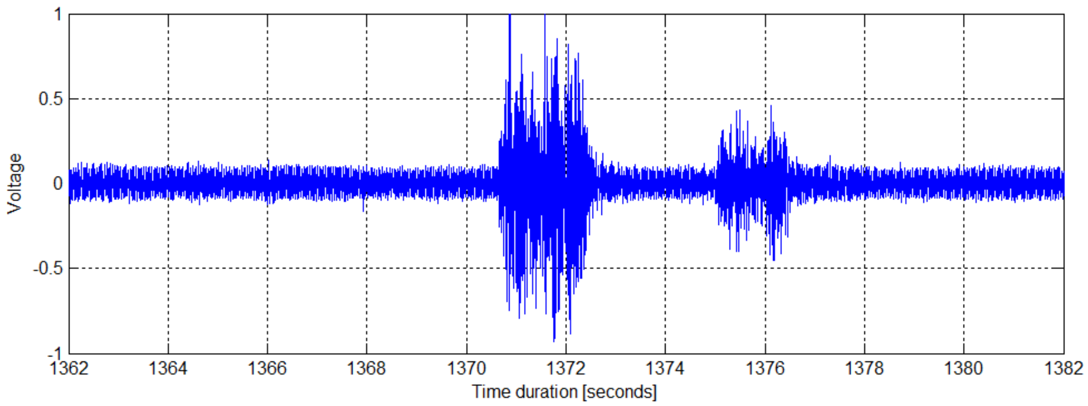

Figure F.5: Hydrophone output in volts as a function of time in seconds around blast sequence

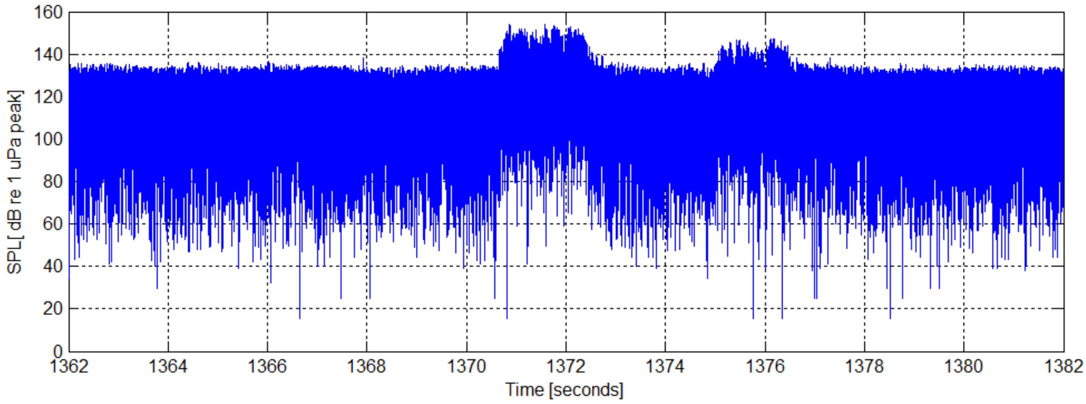

Figure F.6 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

F.9 Discussion

Figure F.4 shows the blast sequence recorded at a location outside the bubble curtain. The recording shows a number of transient events and other raised levels however the blast events were identified around 1370 seconds (see Figure F.5).

The first blast event commencing at 1371 seconds is assumed to be from the detonations in Field 10 while the second event, commencing 1375 seconds is assumed to be from the detonations in Field 11.

Figure F.6 shows that the maximum blast level from Field 10 was 154.0 dB re 1 μPa peak, equivalent to 143.2 dB re 1 μPa rms over a period of 4.0 sec. The maximum blast level from Field 11 was 147.2 dB re 1 μPa peak, equivalent to 135.9 dB re 1 μPa rms over a period of 3.7 sec.

F.10 Results

For the charge weights and their corresponding distances from the blast sites, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table F.2, shows that for the 20 kg charges, the recorded levels are 14-20 dB lower than the corresponding modelled levels assuming no bubble curtain. When a bubble curtain having 60% attenuation is included, recorded levels are 5-13 dB down on modelled levels.

The equivalent rms levels for both the blast sequences are 22-35 dB below the critical threshold of 170 dB re 1 μPa rms. It is noted that the rms levels have been computed from data recorded at distances to the blast sites much greater than the 400 m specified. In addition, the bubble curtain has absorbed significant levels of acoustic energy.

Charge weight	Field	Distance from blast site	Modelled blast level		Measured blast level
			Zero attenuation	60% attenuation	
20 kg	10	964 m	167.8 dB re 1 μPa peak	159.9 dB re 1 μPa peak	154.0 dB re 1 μPa peak 143.2 dB re 1 μPa $rms_{4.0sec}$
20 kg	11	990 m	167.5 dB re 1 μPa peak	159.6 dB re 1 μPa peak	147.2 dB re 1 μPa peak 135.9 dB re 1 μPa $rms_{3.7sec}$

Table F.2: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

APPENDIX G: BLASTING RESULTS - 08TH OCTOBER 2018

G.1 Overview - Inside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
08 Oct 2018	1701 hrs UTC	20 kg	H0	Inside	306 m/Field12	181008_170136
08 Oct 2018	1701 hrs UTC	20 kg	H0	Inside	463 m/Field13	181008_170136
08 Oct 2018	1701 hrs UTC	20 kg	H0	Inside	393 m/Field14	181008_170136

G.2 Ecofish Observations

Blast 7 recording inside bubble curtain (approx. 150m). Hydrophone was ~350 to 400 meters from source.

Vertical static. Hydrophone deployed over port bow of vessel. Sea earth deployed over portside astern to depth ~1.5 meters.

PAM system utilised H10 TU with H0 hydrophone. All systems checked before recording. Terminal unit kept in a position far away as possible from any RF or mobile phone etc. Radio possible interference etc. Vessel engines running (not possible to anchor).

There is UHF radio interference from communications and some boat traffic.

Wind South Easterly Force 4. Rough sea state. High swell.

G.3 Data Processing

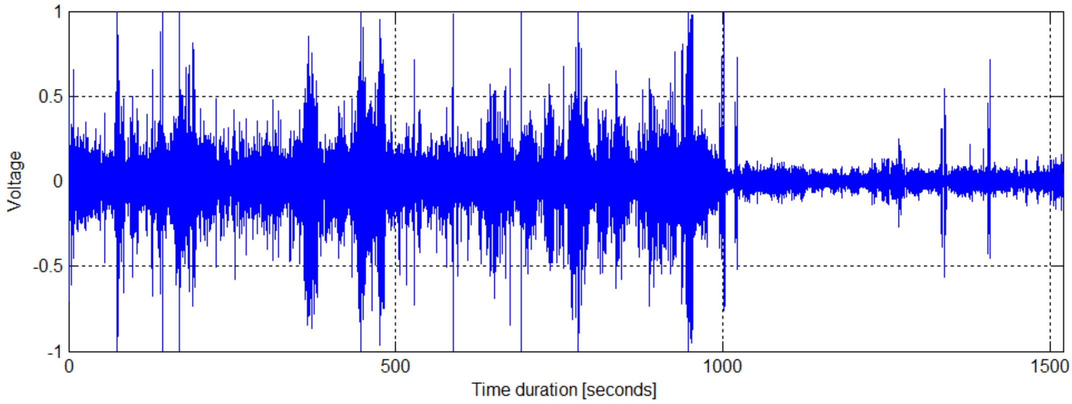

Figure G.1: Hydrophone output in volts as a function of time in seconds

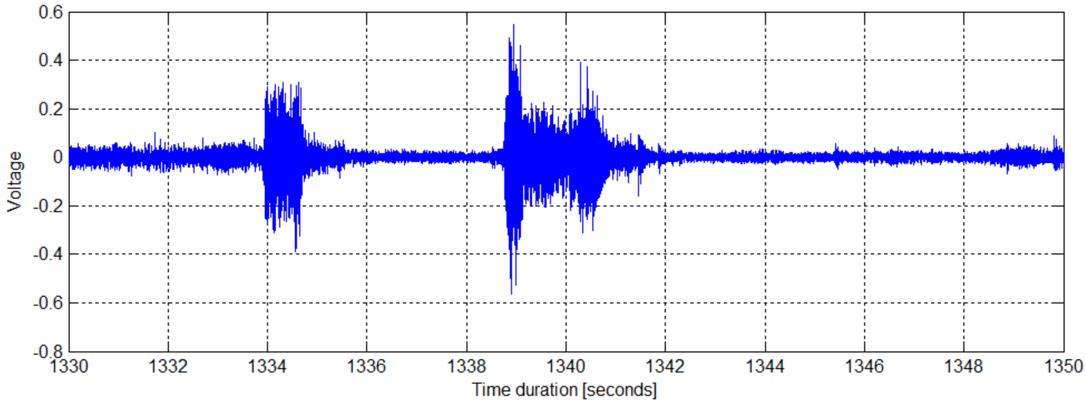

Figure G.2: Hydrophone output in volts as a function of time in seconds around blast sequence

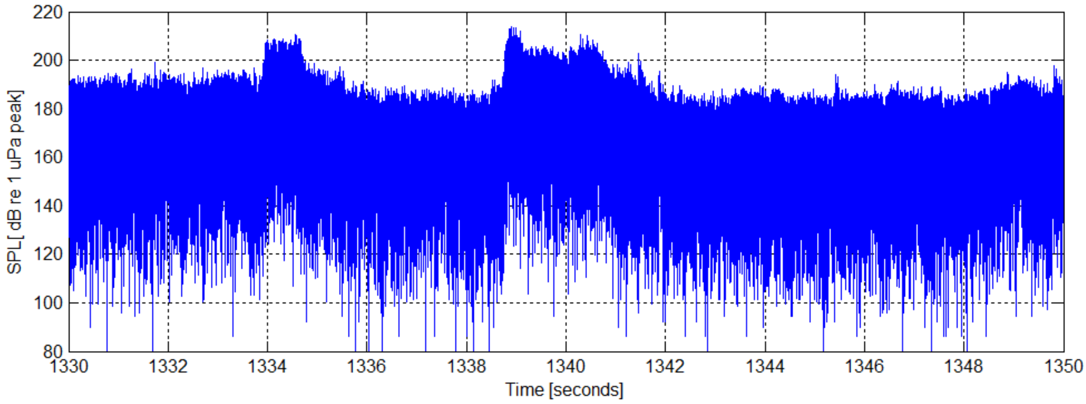

Figure G.3: Sound pressure level in dB re 1 μPa peak as a function of time in seconds around blast sequence

G.4 Discussion

Figures G.1 and G.2 show the hydrophone output displayed in units of volts.

Figure G.1 shows the complete acoustic recording made around the time of the first blast sequence. Calibration tones of a few seconds duration were injected at 1018 seconds and at 1405 seconds. A sequence of features commencing 1334 seconds are identified as the detonations arising from Fields 12-14.

Figure G.2 shows the detonation record more clearly. It is assumed that the feature commencing 1334 seconds consists of the detonations in Field 12 where the Field Contractor's Log shows that a total of 100 boreholes were primed with charge weights up to a maximum of 20 kg of explosive. All 100 charges were successfully detonated. Given a nominal time delay between each detonation of 0.025 seconds, this gives an overall blast duration of 2.5 seconds excluding the time required for the reverberations to die down and this is borne out in the acoustic record.

When a confined detonation occurs in shallow water, the initial impulse will be reflected from both the water surface and the sea surface as it propagates through the water. Such a series of reverberations will become superimposed on the outgoing impulses from the subsequent sequence of detonations each of which also sets up a series of reverberations. The result is that the acoustic record of events becomes somewhat confused in that it is difficult to pick out what is a reverberation feature and what is a subsequent detonation (see *e.g*. the time history over the range 1339-1342 seconds in Figure G.3).

The blast sequence from Field 13 is assumed to commence at 1338.5 seconds. The charges in all 48 boreholes were successfully detonated giving a blast sequence of at least 1.2 seconds excluding reverberation time. The blast sequence from Field 14 is assumed to commence at 1340.3 seconds. A total of 149 boreholes were primed but only 119 were successfully detonated. The ensuing pulse would have a duration of approximately 3.0 seconds excluding reverberation time. In support of this, the acoustic record show evidence of low-level blast-like features occurring up to 1344.5 seconds.

Figures G.3 shows the corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 μPa for the blast events discussed in Figure G.2.

Figure G.3 indicates that the peak blast level from Field 12 is 210.6 dB re 1 μPa with a corresponding rms level of 196.8 dB re 1 μPa over a duration of 1.6 seconds. Peak blast levels from Fields 13 and 14 are 213.8 dB re 1 μPa and 210.3 dB re 1 μPa respectively while the corresponding rms levels are 198.9 dB re 1 μPa over 1.5 seconds and 188.5 dB re 1 μPa over 4.2 seconds.

G.5 Results

For the charge weights of 20 kg and the given distances from each blast site, the expected peak blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent root-mean-square (rms) levels calculated using durations sufficiently long enough to capture the entire blasting sequence together with the following reverberations from each detonation. It is noted that the confined blasting model give peak blast levels only; rms levels are not calculated.

The results summarised in Table G.1, show that for the 20 kg charges, the recorded levels are between 27 dB and 36 dB higher than the corresponding modelled levels. These offsets are consistent with those reported following the blasting program that took place in August and September 2018.

The equivalent rms levels for each blast sequence may be compared with the critical threshold of 170 dB re 1 μPa rms at a distance of 400 m from the blast site. In each case, the computed rms levels exceeded the critical threshold by 19-29 dB. In addition, Table G.1 shows that the distance from the recording location and the blast from Field 14 was 393 m *i.e.* very close to the critical distance of 400 m. In this case, the equivalent rms levels exceeded the critical level by 19 dB.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
20 kg	12	306 m	183.8 dB re 1 μPa peak	210.6 dB re 1 μPa peak 196.8 dB re 1 μPa $rms_{1.6sec}$
20 kg	13	463 m	178.0 dB re 1 μPa peak	213.8 dB re 1 μPa peak 198.9 dB re 1 μPa $rms_{1.5sec}$
20 kg	14	393 m	180.3 dB re 1 μPa peak	210.3 dB re 1 μPa peak 188.5 dB re 1 μPa $rms_{4.2sec}$

Table G.1: Comparison of peak and rms modelled blast levels with peak and rms recorded blast levels

G.6 Overview - Outside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
08 Oct 2018	1701 hrs UTC	20 kg	H4	Outside	644 m/Field12	181008_02
08 Oct 2018	1701 hrs UTC	20 kg	H4	Outside	846 m/Field13	181008_02
08 Oct 2018	1701 hrs UTC	20 kg	H4	Outside	746 m/Field14	181008_02

G.7 Ecofish Observations

Blast recording outside bubble curtain ~1000 meters from centre of blast zone. Not in the line of sight from the blast.

Blast 7 Detonation 17:22 UTC.

Vertical static and using anchor. Hydrophone deployed over port bow of vessel.

PAM system utilised H4b TU with h4b hydrophone. All systems checked before recording. Terminal unit kept in a position far away as possible from any RF or mobile phone etc.

Wind South Easterly force 4. Rough sea state. High swell.

G.8 Data Processing

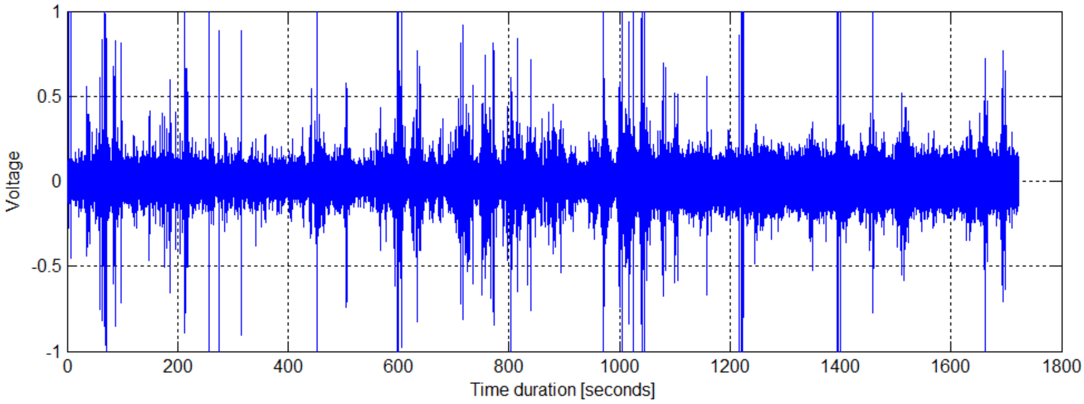

Figure G.4: Hydrophone output in volts as a function of time in seconds

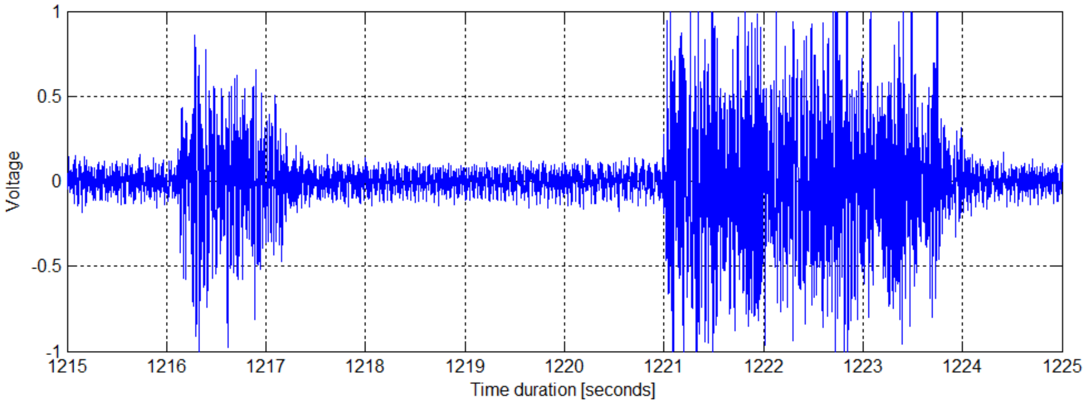

Figure G.5: Hydrophone output in volts as a function of time in seconds around blast sequence

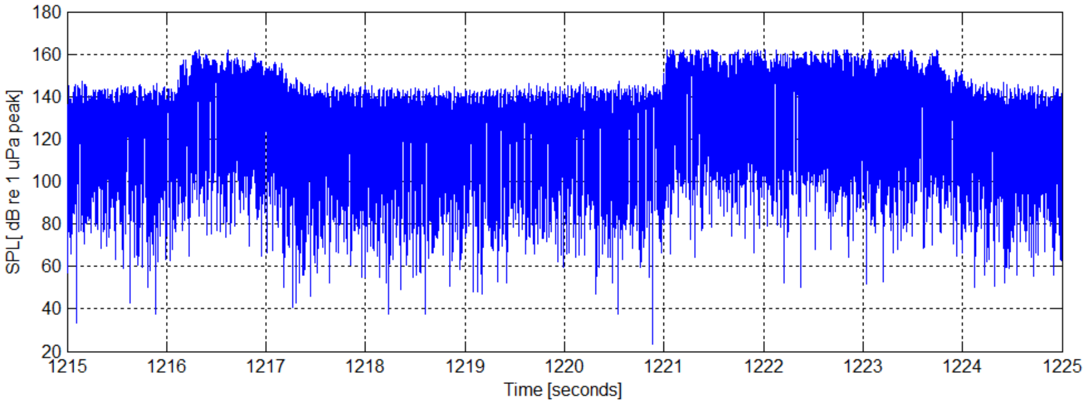

Figure G.6 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

G.9 Discussion

Figure G.4 shows the voltage-time series recorded at a location outside the bubble curtain during the detonation of the charges in Fields 12, 13 and 14. The recording shows that there are a number of spurious clicks and other transient events throughout the record. A series of events attributed to the blasting sequence at the three fields have been identified over the time period 1216-1225 seconds and this is shown more clearly in Figure G.5. The first event, lasting for approximately 1.5 seconds, is assumed to be from Field 12. Figure G.6 shows that this has a maximum blast level of 162.1 dB re 1 μPa peak, equivalent to 149.8 dB re 1 μPa rms over a period of 1.5 sec. The next sequence lasting over the period 1221-1225 seconds is assumed to consist of the blast from both Field 13 and 14 combined. It is likely that the blast waves from the sequence detonated in Field 13 along with its associated reverberation events are still arriving at the hydrophone when the blast events from Field 14 are also being detected. It is thus impossible to discriminate between the arrivals from either blast field. Over this sequence, the maximum blast level is 162.1 dB re 1 μPa peak, equivalent to 152.3 dB re 1 μPa rms over a period of 4.1 sec. It is noted that this waveform sequence has probably saturated the hydrophone. The peak and rms levels thus obtained must be treated with some caution.

G.10 Results

For the charge weights and their corresponding distances from the blast sites, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. The effect of a bubble curtain is modelled using the modified confined blasting model presented in the Clarification Note[7]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table G.2, show that the recorded levels are between 7.5 dB and 11 dB lower than the corresponding modelled levels assuming no bubble curtain. When a bubble curtain having 60% attenuation is included, the recorded levels are between 0.5 dB above and 3.3 dB below the corresponding modelled levels.

The equivalent rms levels for both the blast sequences are around 20 dB below the critical threshold of 170 dB re 1 μPa rms. It is noted that the rms levels have been computed from data recorded at distances much greater to the blast sites than the 400 m specified. In addition, it is apparent that the bubble curtain has absorbed significant levels of acoustic energy.

Charge weight	Field	Distance from blast site	Modelled blast level		Measured blast level
			Zero attenuation	60% attenuation	
20 kg	12	644 m	173.4 dB re 1 μPa peak	165.4 dB re 1 μPa peak	162.1 dB re 1 μPa peak 149.8 dB re 1 μPa $\mathrm{rms}_{1.5sec}$
20 kg	13	846 m	169.6 dB re 1 μPa peak	161.6 dB re 1 μPa peak	162.1 dB re 1 μPa peak 152.3 dB re 1 μPa $\mathrm{rms}_{4.1sec}$
20 kg	14	746 m	171.4 dB re 1 μPa peak	163.4 dB re 1 μPa peak	162.1 dB re 1 μPa peak 152.3 dB re 1 μPa $\mathrm{rms}_{4.1sec}$

Table G.2: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

G.11 Overview - Inside bubble curtain (repeat blasting)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
08 Oct 2018	1701 hrs UTC	20 kg	H0	Inside	393 m/Field14	181008-173741

G.12 Ecofish Observations

Blast recording inside bubble curtain.

Vertical static. Hydrophone deployed over port bow of vessel. Sea earth deployed over portside astern to depth ~1.5 meters.

PAM system utilised H10 TU with H0 hydrophone. All systems checked before recording. Terminal unit kept in a position far away as possible from any RF or mobile phone etc. Radio possible interference etc. Vessel engines running (not possible to anchor).

There is UHF radio interference from communications and some boat traffic.

Wind South Easterly Force 4. Rough sea state. High swell.

G.13 Data Processing

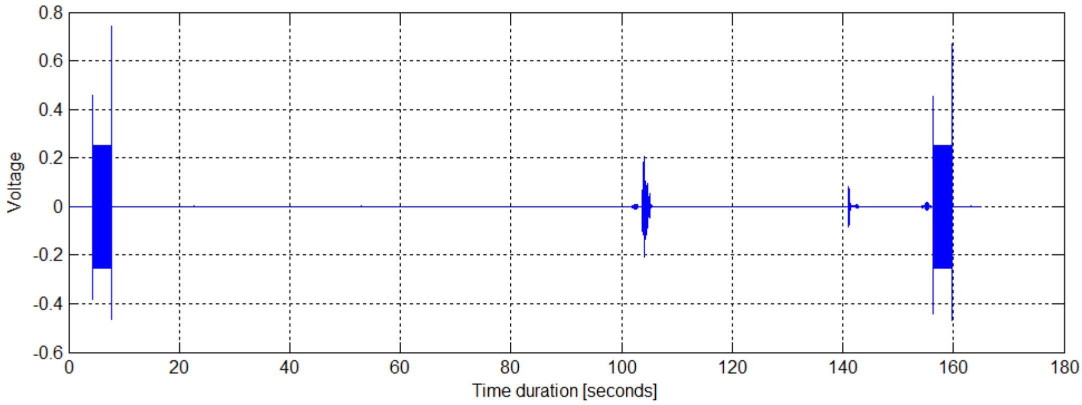

Figure G.7: Hydrophone output in volts as a function of time in seconds

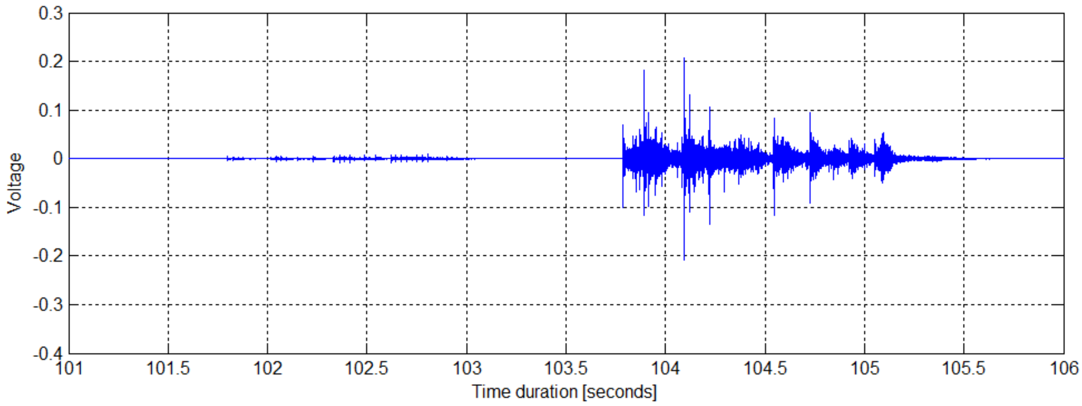

Figure G.8: Hydrophone output in volts as a function of time in seconds around blast sequence

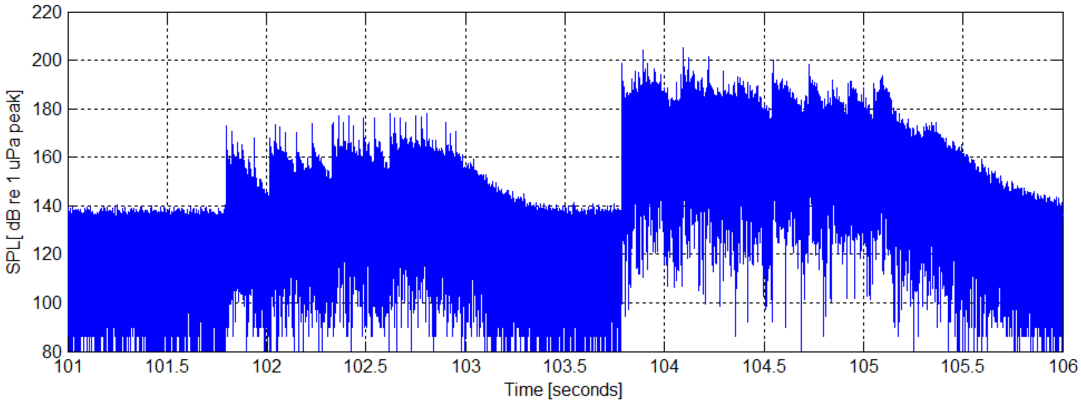

Figure G.9: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

G.14 Discussion

Discussions with the blasting engineers revealed that a total of 30 charges from Field 14 failed to detonate earlier in the day. All charges were successfully detonated during the reblast that took place around 40 minutes after the earlier session. Figure G.7 shows the time-series that was subsequently recorded. Two discrete blast sequences were identified and these are shown more clearly in Figure G.8. The first sequence commencing at 101.7 seconds lasted for 1.6 seconds. Figure G.9 shows that the peak level was 178.0 dB re 1 μPa and the rms level was 153.1 dB re 1 μPa over a period of 1.6 seconds. The second sequence commencing at 103.7 seconds has a peak level of 205.2 dB re 1 μPa with a corresponding rms equivalent level of 180.1 dB re 1 μPa over 1.52 seconds.

G.15 Results

For the given charge weights and distances from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The result, summarised in Table G.3, shows that for the 20 kg charges, the recorded level is 25 dB higher than the corresponding modelled level. However, the distance at which this measurement was made is currently uncertain so the precise offset is unclear.

The equivalent rms level for both the blast sequences is 10 dB above the critical threshold of 170 dB re 1 μPa rms. For this measurement the recording was made close to the critical distance of 400 m.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
20 kg	Field14	393 m	180.3 dB re 1 μPa peak	205.2 dB re 1 μPa peak 180.1 dB re 1 μPa $rms_{1.5sec}$

Table G.3: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

G.16 Overview - Outside bubble curtain (repeat blasting)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
08 Oct 2018	1701 hrs UTC	20 kg	H4	Outside	746 m	181008-03

G.17 Ecofish Observations

Blast recording outside bubble curtain.

Blast 7 Detonation 17:41 UTC.

Vertical static and using anchor. Hydrophone deployed over port bow of vessel.

PAM system utilised H4b TU with H4b hydrophone. All systems checked before recording. Terminal unit kept in a position far away as possible from any RF or mobile phone etc.

Wind South Easterly force 4. Rough sea state. High swell.

G.18 Data Processing

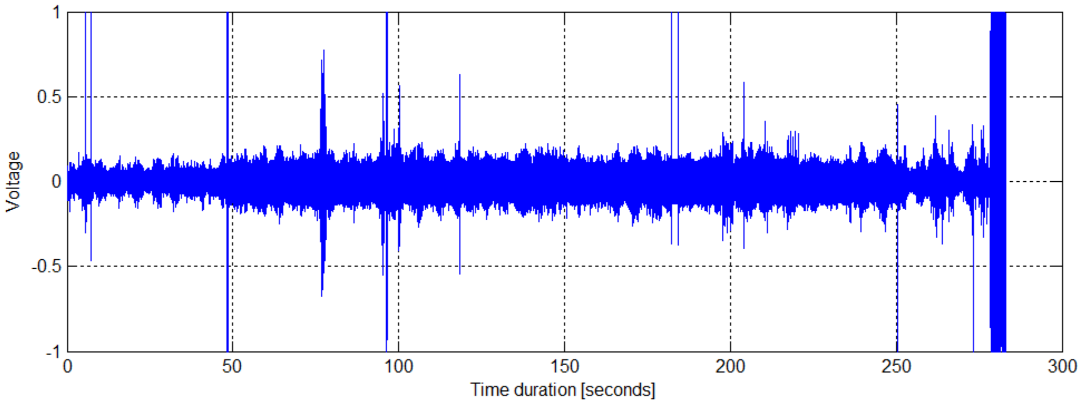

Figure G.10: Hydrophone output in volts as a function of time in seconds

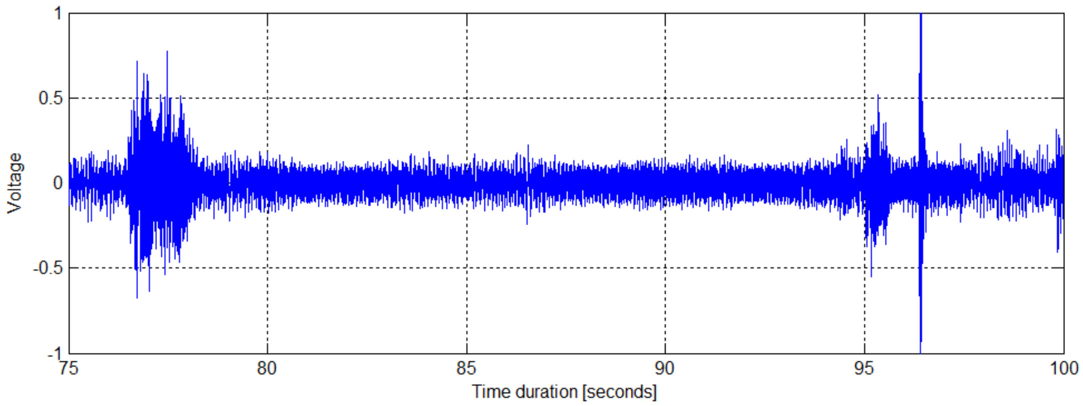

Figure G.11: Hydrophone output in volts as a function of time in seconds around blast sequence

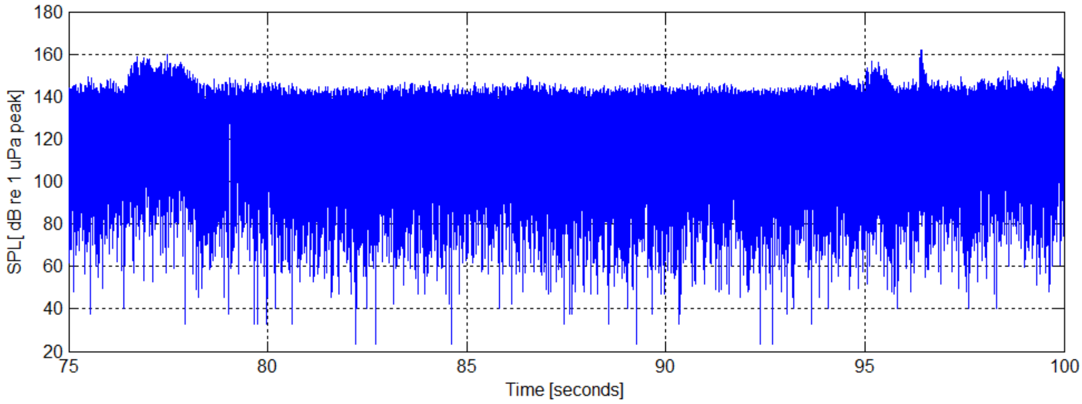

Figure G.12: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

G.19 Discussion

Figure G.10 shows the voltage-time series recorded during the reblast at a location outside of the bubble curtain. Calibration tones of a few seconds duration were injected at 5.7 seconds and 182.2 seconds. Two blast sequences were identified in the series and these are shown in Figure G.11 while Figure G.12 shows the corresponding peak sound levels. The first sequence, occurring at 76.4 seconds, had a peak level of 159.6 dB re 1 μPa and an equivalent rms level of 147.2 dB re 1 μPa over a duration of 2.1 seconds. The second sequence occurred 20 seconds later; it had a peak level of 161.8 dB re 1 μPa and an equivalent rms level of 146.1 dB re 1 μPa over 0.25 seconds.

G.20 Results

For the given charge weight and distance from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table G.2, show that the recorded levels are 10-12 dB lower than the corresponding modelled levels assuming no bubble curtain. When a bubble curtain having 60% attenuation is included, the recorded levels are 2-4 dB lower than the corresponding modelled levels.

The equivalent rms levels for both the blast sequences are around 23 dB below the critical threshold of 170 dB re 1 μPa rms. It is noted that the rms levels have been computed from data recorded at distances much greater to the blast sites than the 400 m specified. In addition, it is apparent that the bubble curtain has absorbed significant levels of acoustic energy.

The distance at which this measurement was made is currently uncertain so the results must be treated with some caution.

Charge weight	Field	Distance from blast site	Modelled blast level		Measured blast level
			Zero attenuation	60% attenuation	
20 kg	14	746 m	171.4 dB re 1 μPa peak	163.4 dB re 1 μPa peak	159.6 dB re 1 μPa peak 147.2 dB re 1 μPa $rms_{2.1sec}$
20 kg	14	746 m	171.4 dB re 1 μPa peak	163.4 dB re 1 μPa peak	161.8 dB re 1 μPa peak 146.1 dB re 1 μPa $rms_{0.3sec}$

Table G.4: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

APPENDIX H: BLASTING RESULTS - 13TH OCTOBER 2018

H.1 Overview - Inside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
13 Oct 2018	0942 hrs UTC	20 kg	H0	Inside	446 m/Field15	181013-094258

H.2 Ecofish Observations

Explosives detonation noise recording made by Hydrophone H10_H0 inside of the bubble curtain.

Vertical static, deployed over the port side of fiber hulled vessel. Sea earth cable deployed from start to end.

Vessel inside the bubble curtain (200 meters approx.), drifting with engines running due to adverse weather conditions.

Heavy precipitation, light winds, high swell (2 meters). Wind W.

H.3 Data Processing

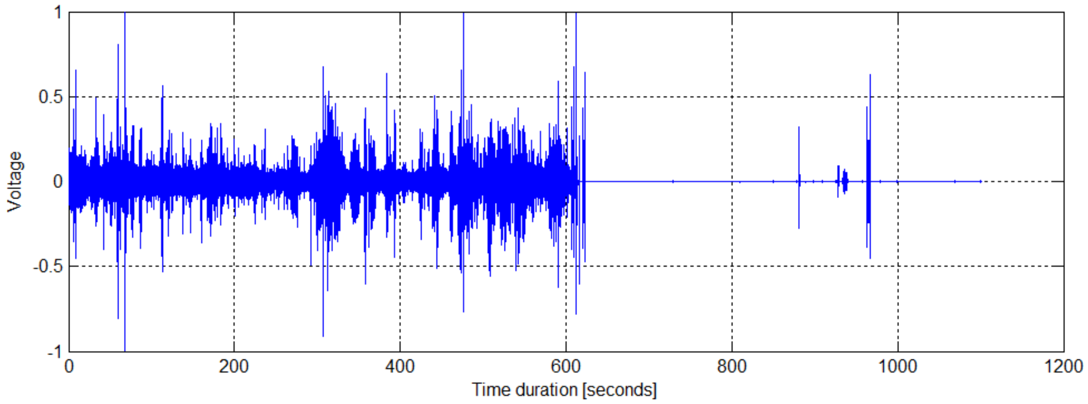

Figure H.1: Hydrophone output in volts as a function of time in seconds

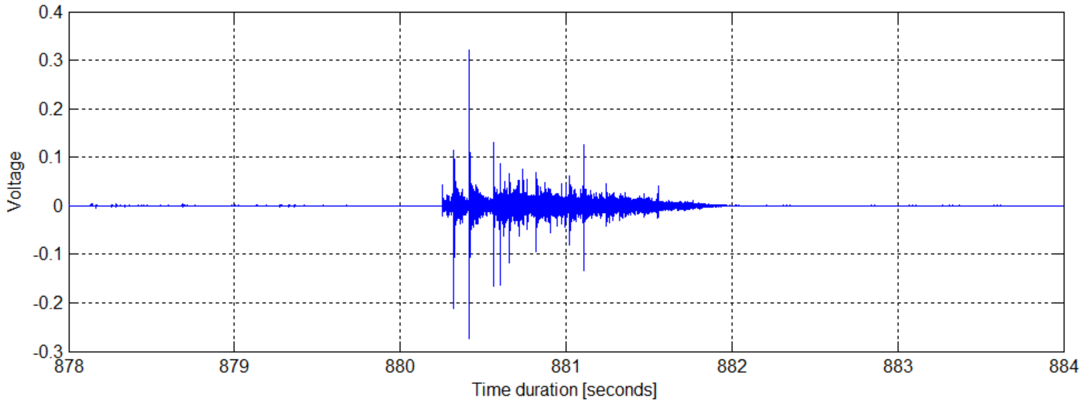

Figure H.2: Hydrophone output in volts as a function of time in seconds around blast sequence

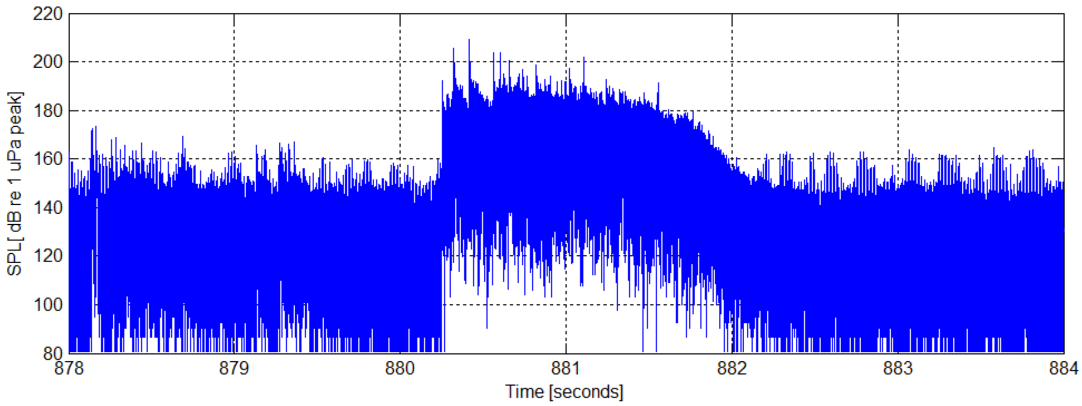

Figure H.3: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

H.4 Discussion

Figure H.1 shows the complete voltage-time series recorded around the time of the first blast sequence. Calibration tones of a few seconds duration were injected at 620 seconds and at 960 seconds. A sequence of features commencing 880 seconds are identified as the detonations arising from Field 15.

The Field Contractor's Log shows that in Field 15 a total of 84 boreholes were primed with charge weights up to a maximum of 20 kg of explosive. All 84 charges were successfully detonated. Given a nominal time delay between each detonation of 0.025 seconds, this gives an overall blast duration of 2.1 seconds excluding the time required for the reverberations to die down and this is borne out in the voltage-time series around the time of the blast itself and as shown in Figure H.2.

Figures H.3 shows the corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 μPa for the blast record shown in Figure H.2.

Figure H.3 indicates that the peak blast level from Field 15 is 209.3 dB re 1 μPa with a corresponding rms level of 180.4 dB re 1 μPa over a duration of 2.0 seconds.

H.5 Results

For the charge weights of 20 kg and the given distances from each blast site, the expected peak blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent root-mean-square (rms) levels calculated using durations sufficiently long enough to capture the entire blasting sequence together with the following reverberations from each detonation. It is noted that the confined blasting model give peak blast levels only; rms levels are not calculated.

The results summarised in Table H.1, show that for the 20 kg charges, the recorded level is over 30 dB higher than the corresponding modelled level. This offset is consistent with those reported following the blasting program that took place in August and September 2018.

The equivalent rms level for the blast sequence may be compared with the critical threshold of 170 dB re 1 μPa rms at a distance of 400 m from the blast site. It is seen that for this blast, the computed rms level exceeded the critical threshold by 10 dB. In addition, Table H.1 shows that the distance between the recording location and the blast from Field 15 was 446 m *i.e.* greater than the critical distance of 400 m. It is noted from the results reported following the blasting program that took place in August and September 2018, rms levels were below 170 dB re 1 μPa whenever the blast-recorder distance was greater than 400 m.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
20 kg	15	446 m	178.5 dB re 1 μPa peak	209.3 dB re 1 μPa peak 180.3 dB re 1 μPa $rms_{2.0sec}$

Table H.1: Comparison of peak and rms modelled blast levels with peak and rms recorded blast levels

H.6 Overview - Outside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
13 Oct 2018	0942 hrs UTC	20 kg	H4	Outside	696 m/Field15	181013_01

H.7 Ecofish Observations

Explosives detonation noise recording total 16 min made by Hydrophone H4B outside of the bubble curtain.

Vessel stationary outside the bubble curtain (300 meters approx.), anchored with engine running due to adverse weather conditions.

Vertical static, deployed over the stern of metal hulled vessel. Sea earth cable deployed from start to end.

Only other vessels in Nigg Bay was Ocean Spartan (inside BBC- recording vessel) with both engines running and blast vessel Delfi.

Heavy precipitation, light winds, high swell (2 meters). Wind W.

H.8 Data Processing

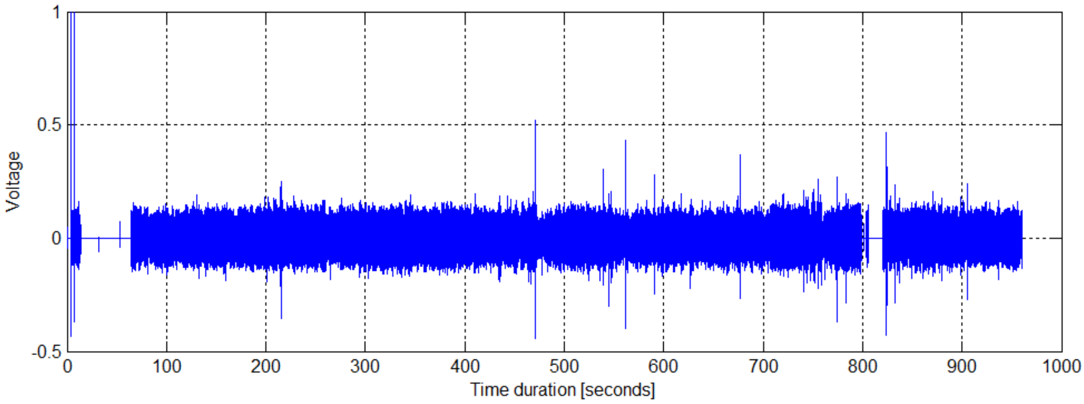

Figure H.4: Hydrophone output in volts as a function of time in seconds

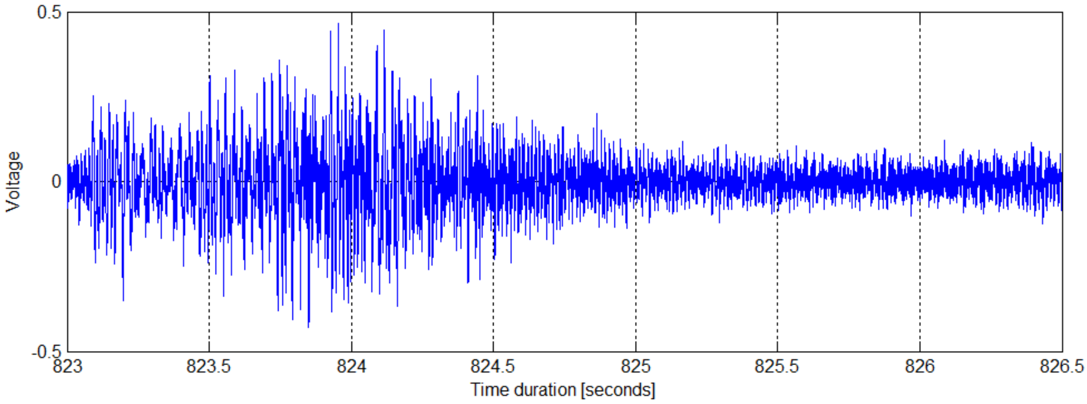

Figure H.5: Hydrophone output in volts as a function of time in seconds around blast sequence

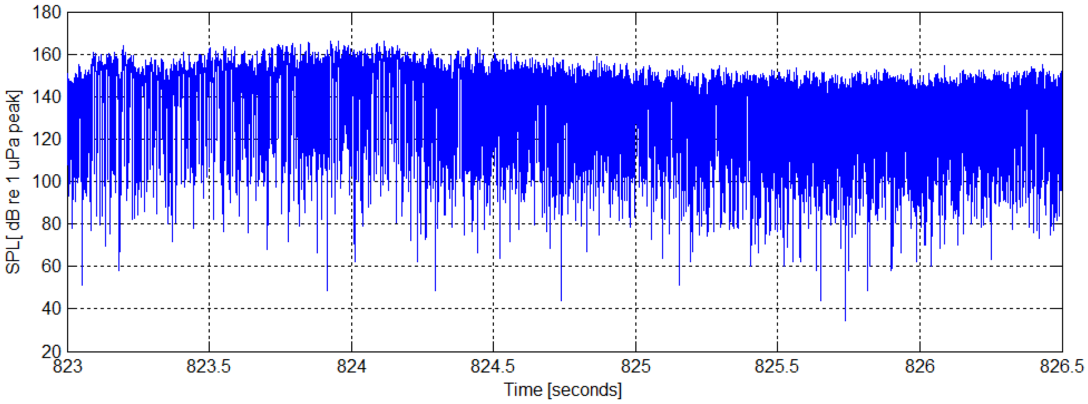

Figure H.6 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

H.9 Discussion

Figure H.4 shows the voltage-time series recorded at a location outside the bubble curtain during the detonation of the charges in Field 15. The Ecofish log noted that the acoustic recorder channel gain was changed at approximately 800 seconds and that the blast was recorded shortly after. A series of events attributed to the blasting sequence at Field15 has been identified over the time period 823-826.5 seconds and this is shown more clearly in Figure H.5. The blast duration of 3.5 seconds is around 1.5 seconds longer than the series recorded inside the bubble curtain and as discussed above. The additional duration is due to a combination of the blast signals reverberating around the shallow waters of Nigg Bay as well as acoustic reflection and attenuation inside the bubble cloud. Figure H.6 shows that there is a maximum blast level of 166.3 dB re 1 μPa peak, equivalent to 151.2 dB re 1 μPa rms over a period of 3.5 sec.

H.10 Results

For the charge weights and their corresponding distances from the blast sites, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. The effect of a bubble curtain is modelled using the modified confined blasting model presented in the Clarification Note[7]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table H.2, show that the recorded level is approximately 8 dB lower than the corresponding modelled level assuming no bubble curtain. When a bubble curtain having 60% attenuation is included, the recorded level is approximately 2 dB higher than the corresponding modelled level.

The equivalent rms levels for the blast sequence is 19 dB below the critical threshold of 170 dB re 1 μPa rms. It is noted that the rms level has been computed from data recorded at a distance much greater to the blast site than the 400 m specified. In addition, it is apparent that the bubble curtain has absorbed significant levels of acoustic energy.

Charge weight	Field	Distance from blast site	Modelled blast level		Measured blast level
			Zero attenuation	60% attenuation	
20 kg	15	696 m	172.4 dB re 1 μPa peak	164.4 dB re 1 μPa peak	166.3 dB re 1 μPa peak 151.2 dB re 1 μPa $rms_{3.5sec}$

Table H.2: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

APPENDIX I: BLASTING RESULTS - 17TH OCTOBER 2018

I.1 Overview - Inside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
17 Oct 2018	1149 hrs UTC	20 kg	H11	Inside	354 m/Field16	181017-114548
17 Oct 2018	1149 hrs UTC	20 kg	H11	Inside	371 m/Field17	181017-114548

I.2 Ecofish Observations

Detonation noise recording. Hydrophone H11 deployed inside the bubble curtain close to the end of the north breakwater.

Vertical static, deployed aft of vessel on the port side.

There was no scheduled pre-detonation charge heard during the run in to the detonation however "Wasa have confirmed they detonated the fish scare charges 1 min before blast". Vessel motors idle. 1 excavator operational on end of breakwater, west side.

Beaufort scale 2 from the west. Calm seas, low swell, no precipitation

I.3 Data Processing

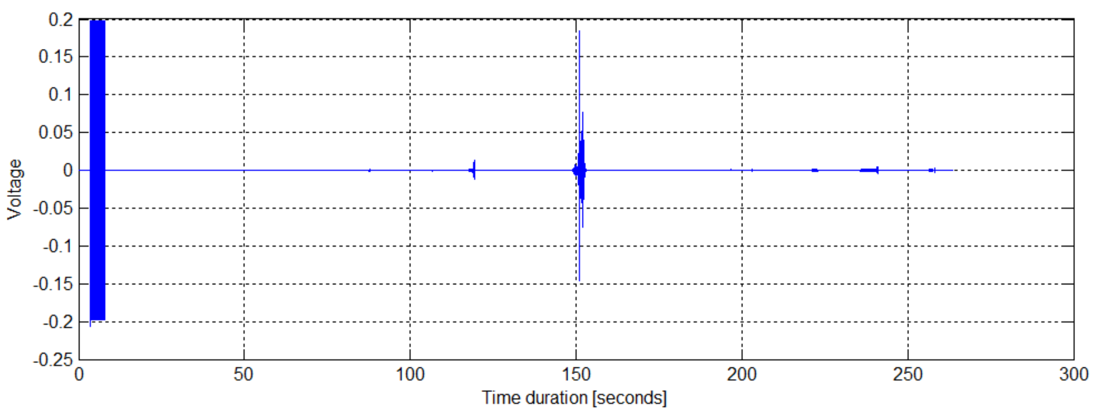

Figure I.1: Hydrophone output in volts as a function of time in seconds

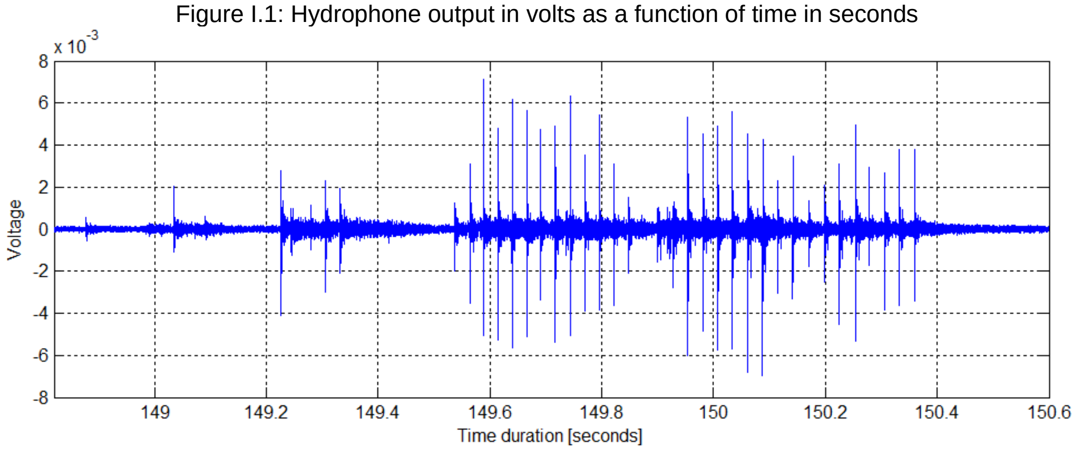

Figure I.2: Hydrophone output in volts as a function of time in seconds around blast sequence from Field 16

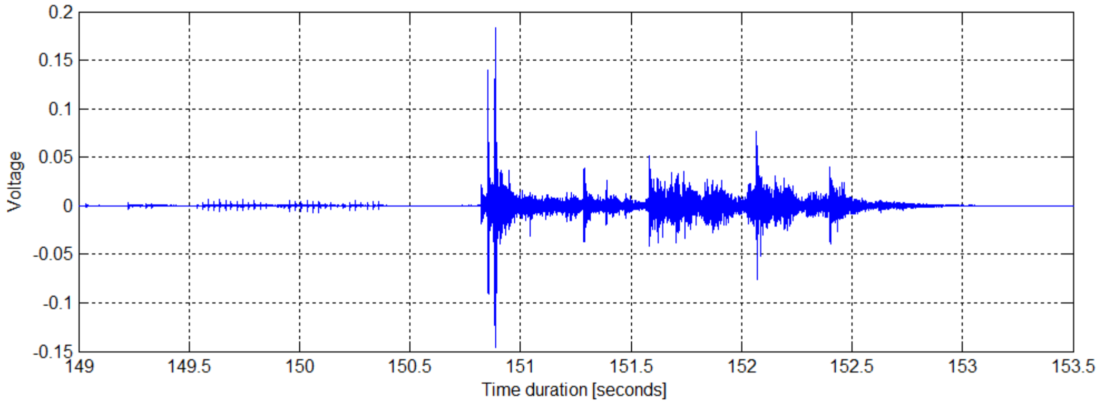

Figure I.3: Hydrophone output in volts as a function of time in seconds around blast sequence

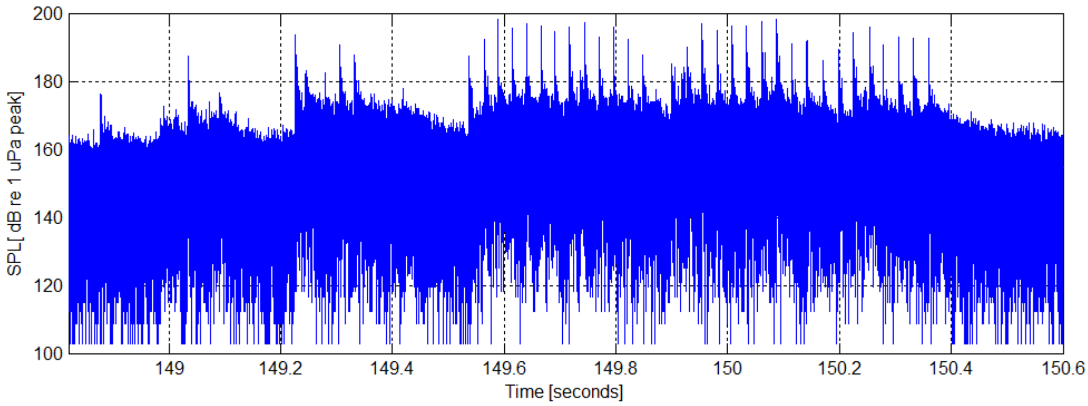

Figure I.4: Sound pressure level in dB re 1 μPa peak as a function of time in seconds for Field 16

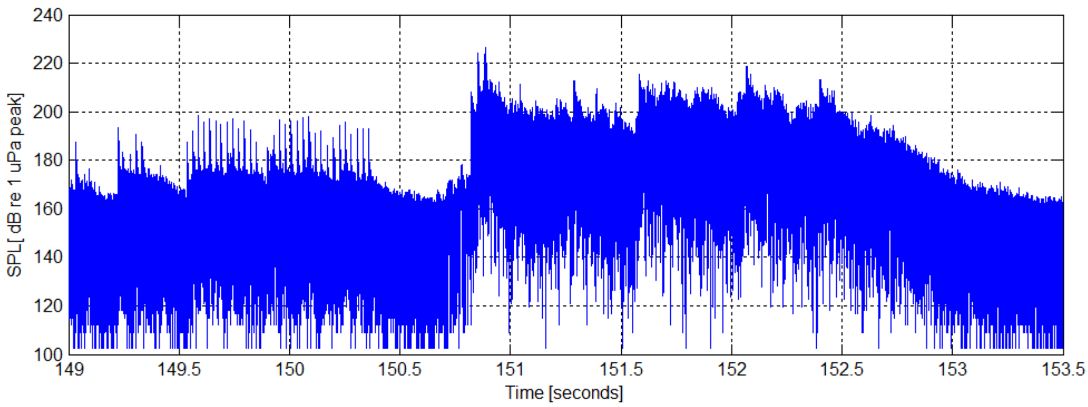

Figure I.5: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

I.4 Discussion

Figure I.1 shows the complete voltage-time series recorded around the time of the blast sequence. A calibration tone of a few seconds duration was injected at 3.5 seconds. The Ecofish log noted that fish scarers were detonated about 1 minute before the main blast sequence. The fish scarer usually consists of a few grammes of explosive which is detonated in the water. The resulting blast may just be discerned in the voltage-time series around 90 seconds. A sequence of features commencing 149 seconds are identified as the detonations arising from Field 16 while the sequence commencing 150.8 seconds are identified as those from Field 17. The voltage-time series centred around the blasts from Fields 16 and 17 are shown in Figures I.2 and I.3 respectively.

The Field Contractor's Logs shows that Fields 16 and 17 consisted of 38 and 49 boreholes respectively primed in each case with up to 20 kg of explosive. In both fields, all charges were successfully detonated. Given a nominal time delay between each detonation of 0.025 seconds, Field 16 gives an overall blast duration of 0.93 seconds while Field 17 has an overall duration of 1.23 seconds - in each case excluding the time required for the reverberations to die down.

Figure I.4 shows the corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 μPa for the blast records arising from Field 16. It shows that the peak blast level is 198.3 dB re 1 μPa with a corresponding rms level of 168.5 dB re 1 μPa over a duration of 1.78 seconds. Figure I.5 shows the SPL time series for Field 17. The peak blast level is 226.5 dB re 1 μPa with a corresponding rms level of 197.9 dB re 1 μPa over a duration of 2.49 seconds.

I.5 Results

For the charge weights of 20 kg and the given distances from each blast site, the expected peak blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent root-mean-square (rms) levels calculated using durations sufficiently long enough to capture the entire blasting sequence together with the following reverberations from each detonation. It is noted that the confined blasting model give peak blast levels only; rms levels are not calculated.

The results summarised in Table I.1, show that for the 20 kg charges, the recorded levels are between 17 dB and 45 dB higher than the corresponding modelled levels. These offsets are consistent with those reported following the blasting program that took place in August and September 2018.

The equivalent rms levels for each blast sequence may be compared with the critical threshold of 170 dB re 1 μPa rms at a distance of 400 m from the blast site. The computed rms levels are between 1.5 dB lower and 28 dB higher than the critical threshold. In addition, Table B.1 shows that the distances between the recording locations and the blast sites were both less than the critical distance of 400 m.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
20 kg	16	354 m	181.8 dB re 1 μPa peak	198.3 dB re 1 μPa peak 168.5 dB re 1 μPa $rms_{1.78sec}$
20 kg	17	371 m	181.1 dB re 1 μPa peak	226.5 dB re 1 μPa peak 197.9 dB re 1 μPa $rms_{2.49sec}$

Table I.1: Comparison of peak and rms modelled blast levels with peak and rms recorded blast levels

I.6 Overview - Outside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
17 Oct 2018	1149 hrs UTC	20 kg	H4	Outside	919 m/Field16	181017_03
17 Oct 2018	1149 hrs UTC	20 kg	H4	Outside	953 m/Field17	181017_03

I.7 Ecofish Observations

Detonation noise recording. Hydrophone H4b deployed outside the bubble curtain. GPS way point 128 provided.

Vertical static. Deployed middle of vessel on the starboard side.

Calm sea. BF 2 Westerly

I.8 Data Processing

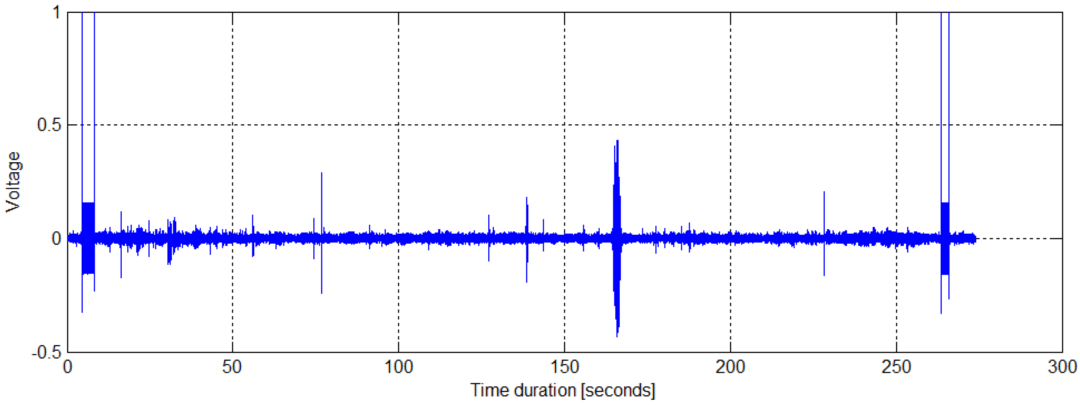

Figure I.6: Hydrophone output in volts as a function of time in seconds

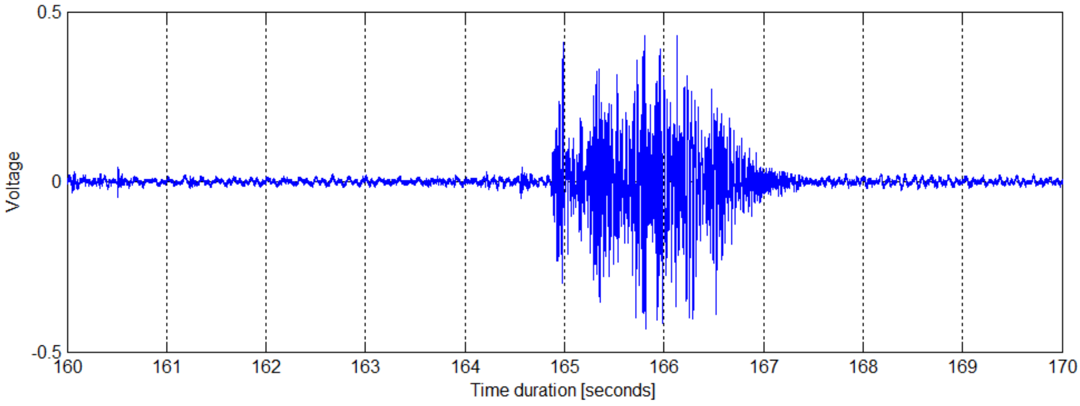

Figure I.7: Hydrophone output in volts as a function of time in seconds around blast sequence

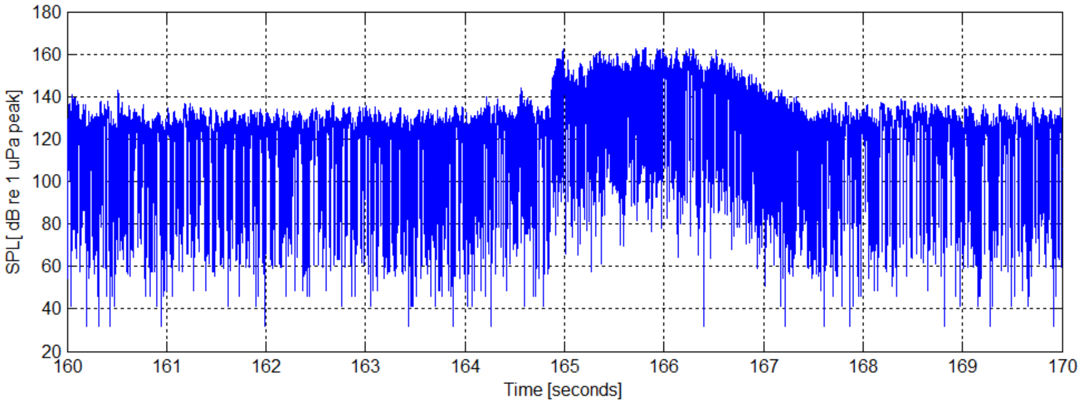

Figure I.8 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

I.9 Discussion

Figure I.6 shows the voltage-time series recorded at a location outside the bubble curtain during the detonation of the charges in Fields 16 and 17. Calibration tones of a few seconds duration were injected at 5 seconds and 263 seconds. A blast signature was identified commencing at 165 seconds and this is shown in detail in Figure I.7. The voltage-time series recorded inside the bubble curtain (Figure I.3) showed that there was approximately 0.5 seconds between the end of the blast sequence from Field 16 and the start of the blast sequence from Field 17. By the time the blast signals and their corresponding reverberation components have propagated over the additional distance to the recorder located outside the bubble curtain, it has become impossible to discriminate between the arrivals from either blast field. Figure I.8 shows that there is a maximum blast level of 163.0 dB re 1 μPa peak, equivalent to 151.6 dB re 1 μPa rms over a period of 2.55 sec.

I.10 Results

For the charge weights and their corresponding distances from the blast sites, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. The effect of a bubble curtain is modelled using the modified confined blasting model presented in the Clarification Note[7]. Also given are the equivalent rms levels calculated using durations discussed above.

Although it is not possible in practice to separate the blast arrivals coming from either field, the results given in Table I.2 assume that this can nevertheless be achieved. Hence it becomes possible to compare the recorded peak and rms blast levels with the modelled equivalents.

The results, summarised in Table I.2, show that the recorded level is approximately 5 dB lower than the corresponding modelled level assuming no bubble curtain. When a bubble curtain having 60% attenuation is included, the recorded level is approximately 2.5-3 dB higher than the corresponding modelled level.

The equivalent rms levels for the blast sequence is 19 dB below the critical threshold of 170 dB re 1 μPa rms. It is noted that the rms level has been computed from data recorded at a distance much greater to the blast site than the 400 m specified. In addition, it is apparent that the bubble curtain has absorbed significant levels of acoustic energy.

Charge weight	Field	Distance from blast site	Modelled blast level		Measured blast level
			Zero attenuation	60% attenuation	
20 kg	16	919 m	168.5 dB re 1 μPa peak	160.5 dB re 1 μPa peak	163.0 dB re 1 μPa peak 151.6 dB re 1 μPa $\text{rms}_{2.5\text{sec}}$
20 kg	17	953 m	168.0 dB re 1 μPa peak	160.0 dB re 1 μPa peak	163.0 dB re 1 μPa peak 151.6 dB re 1 μPa $\text{rms}_{2.5\text{sec}}$

Table I.2: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

APPENDIX J: BLASTING RESULTS - 25TH OCTOBER 2018

J.1 Overview - Inside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
25 Oct 2018	0813 hrs UTC	20 kg	H11	Inside	575 m/Field18	181025-081346
25 Oct 2018	0813 hrs UTC	20 kg	H11	Inside	613 m/Field20	181025-081346

J.2 Ecofish Observations

Detonation noise recording Hydrophone deployed inside of the bubble curtain.

H11 hydrophone was used with h10 TU due to previous damage to the h10 hydrophone cable.

Vertical static, deployed forward of vessel on the port side over rubber sponson.

Blast 10 incomplete detonation (10a). Fields 18 and 19 were blasted however field 19 resulted in a misfire.

One excavator working on end of North breakwater.

North-easterly wind force 3, sea state 3, low swell, no precipitation.

J.3 Data Processing

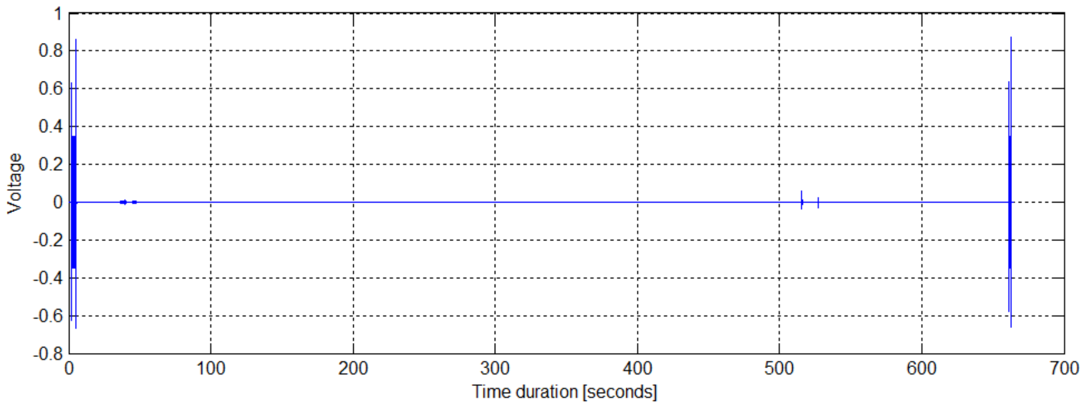

Figure J.1: Hydrophone output in volts as a function of time in seconds

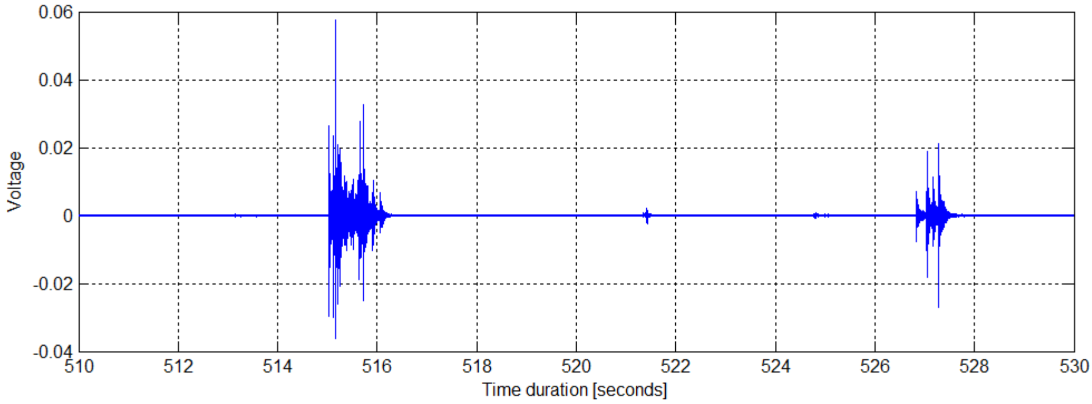

Figure J.2: Hydrophone output in volts as a function of time in seconds around blast sequence

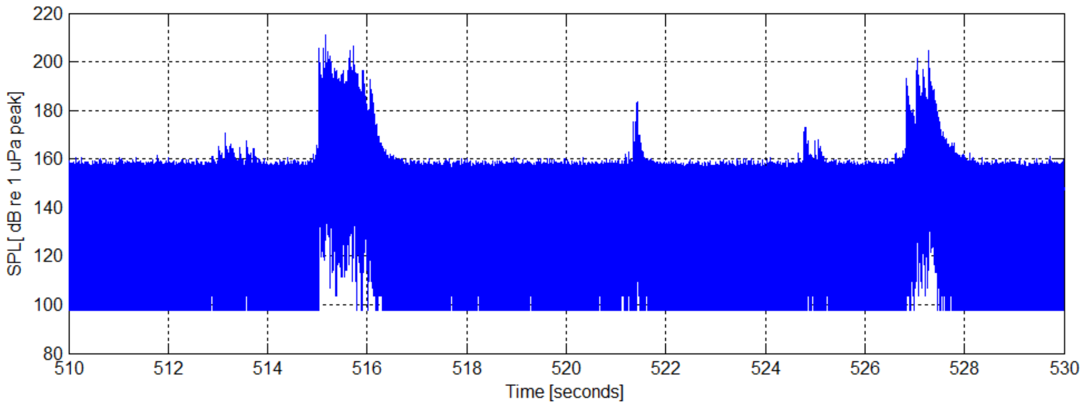

Figure J.3: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

J.4 Discussion

Figure J.1 shows the complete voltage-time series recorded around the time of the blast sequence. Calibration tones of a few seconds duration were injected at 2 seconds and 661 seconds. Two blast sequences were identified commencing at 515 seconds and 527 seconds and the voltage-time series for these are shown in more detail in Figure J.2.

The Field Contractor's Logs shows that Fields 18, 19 and 20 were prepared with 51, 72 and 69 boreholes respectively where each was primed with up to 20 kg of explosive. All the charges in Field 18 were detonated successfully; none in Field 19; and 12 in Field 20. Thus the blast waveforms shown in Figure J.2 and attributed to the blast sequences from Fields 18 and 20.

Following discussions with the blasting engineers it was agreed to set up the detonation sequence in each field so that following the detonation of the first charge there would be a time delay of 42 milliseconds (msec) before the second charge was detonated. The purpose of this was to facilitate the identification of the first two blasts in the recorded data and thus to identify a blast feature with a specific charge weight and position as given in the Field Contractors log. The remainder of the charges had delays of 25 msec between each. Given these time delays, Field 16 gives an overall blast duration of 1.3 seconds while Field 20 has an overall duration of 0.32 seconds - in each case excluding the time required for the reverberations to die down.

Figure J.3 shows the corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 μPa for the blast records arising from Fields 18 and 20. It shows that from Field 18, the first detonation peak in the blast sequence has a peak level of 203.2 dB re 1 μPa and is attributed to the detonation of a charge weight of 10 kg. Field 18 has a peak blast level of 211.2 dB re 1 μPa with an equivalent rms level of 185.9 dB re 1 μPa over a duration of 1.5 seconds. Similarly, the first peak in the blast sequence from Field 20 has a level of 193.7 dB re 1 μPa and this is attributed to the detonation of a 15 kg charge weight. Overall, from Field 20 the peak blast level is 204.7 dB re 1 μPa with a corresponding rms level of 181.7 dB re 1 μPa over a duration of 0.88 seconds.

J.5 Results

For the charge weights of 20 kg and the given distances from each blast site, the expected peak blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent root-mean-square (rms) levels calculated using durations sufficiently long enough to capture the entire blasting sequence together with the following reverberations from each detonation. It is noted that the confined blasting model give peak blast levels only; rms levels are not calculated.

The results summarised in Table J.1, show that for the 20 kg charges, the recorded levels are between 30 dB and 36 dB higher than the corresponding modelled levels. These offsets are consistent with those reported following the blasting program that took place in August and September 2018. Similarly, for the 10 kg and 15 kg charges, recorded levels are 21-33 dB higher than the corresponding modelled levels.

The equivalent rms levels for each blast sequence may be compared with the critical threshold of 170 dB re 1 μPa rms at a distance of 400 m from the blast site. The computed rms levels are 11-16 dB higher than the critical threshold. In addition, Table J.1 shows that the distances between the recording locations and the blast sites were greater than the critical distance of 400 m. Equivalent rms levels for the first peak in the blast sequence are not calculated owing to the difficulty in discriminating between the arrivals from the first and second blasts (see Figure J.2).

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
10 kg	18	567 m	170.4 dB re 1 μPa peak	203.2 dB re 1 μPa peak
20 kg	18	575 m	175.0 dB re 1 μPa peak	211.2 dB re 1 μPa peak 185.9 dB re 1 μPa $rms_{1.5sec}$
15 kg	20	608 m	172.2 dB re 1 μPa peak	193.7 dB re 1 μPa peak
20 kg	20	613 m	174.1 dB re 1 μPa peak	204.7 dB re 1 μPa peak 181.7 dB re 1 μPa $rms_{0.88sec}$

Table J.1: Comparison of peak and rms modelled blast levels with peak and rms recorded blast levels

J.6 Overview - Outside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
25 Oct 2018	0813 hrs UTC	20 kg	H4	Outside	1163 m/Field18	181025_01
25 Oct 2018	0813 hrs UTC	20 kg	H4	Outside	1224 m/Field20	181025_01

J.7 Ecofish Observations

Detonation noise recording. Hydrophone H4b deployed outside the bubble curtain. GPS way point 140 provided.

Detonation field charge blast 10. (3 X field were charged for this blasting operation there was some operational issues with the detonation sequencing).

Vertical static. deployed aft of vessel on the starboard side in favourable position for current.

Vessel was anchored. Engines were off a generator was running on the deck during recording. Note there was a small survey craft present ~150 meters north of our position periodically engaging their engines throughout the recording producing interference. They were not responding to radio communication however their engines were observed idling during the critical part of the blast recording.

Calm sea. BF 3 North Easterly.

J.8 Data Processing

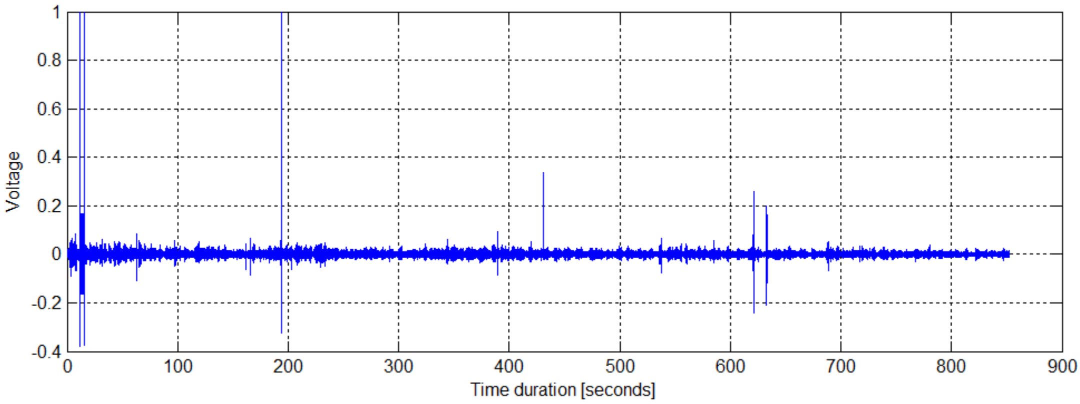

Figure J.4: Hydrophone output in volts as a function of time in seconds

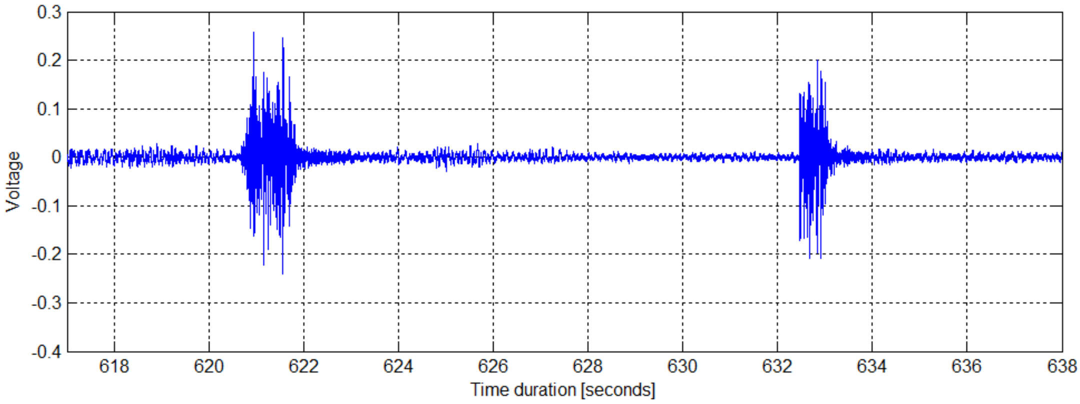

Figure J.5: Hydrophone output in volts as a function of time in seconds around blast sequence

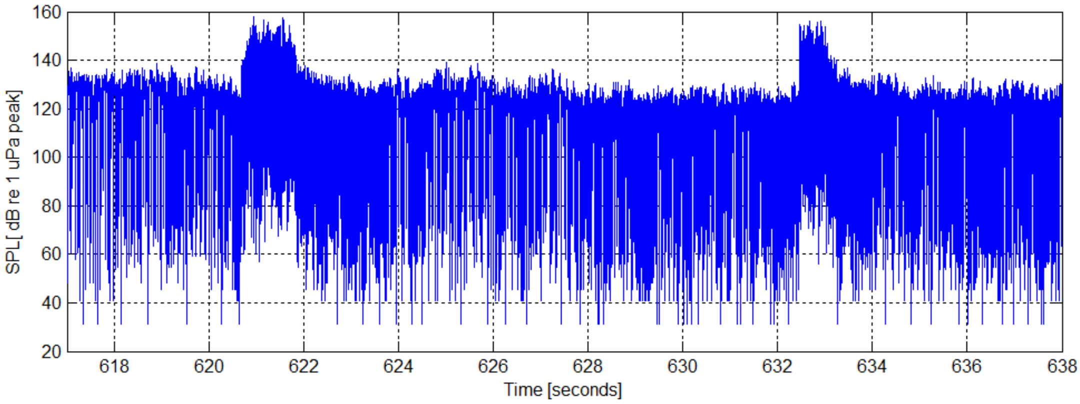

Figure J.6 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

J.9 Discussion

Figure J.4 shows the voltage-time series recorded at a location outside the bubble curtain during the detonation of the charges in Fields 18 and 20. Calibration tones of a few seconds duration were injected at 11 seconds and immediately afterwards in a post calibration-tone file. Two blast signatures were identified commencing at 620 seconds and 632 seconds and are shown in detail in Figure J.5. These were attributed to the blasts arising from Fields 18 and 20 respectively.

It is noted that the duration of each blast event is slightly shorter than the durations noted at the recorder inside the bubble curtain. It is assumed that the additional propagation distance together with the absorptive properties of the bubble curtain have resulted in their removing considerable levels of acoustic energy from each blast wave. Figure J.6 shows that from Field 18 there is a maximum blast level of 158.1 dB re 1 μPa peak, equivalent to 146.2 dB re 1 μPa rms over a period of 1.35 sec and from Field 20 the maximum blast level is 156.3 dB re 1 μPa peak, equivalent to 144.5 dB re 1 μPa rms over a period of 1.16 sec.

J.10 Results

For the charge weights and their corresponding distances from the blast sites, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. The effect of a bubble curtain is modelled using the modified confined blasting model presented in the Clarification Note[7]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table J.2, show that recorded levels are 7-8 dB lower than the corresponding modelled levels assuming no bubble curtain. When a bubble curtain having 60% attenuation is included, the recorded levels are no more than 1 dB higher than the corresponding modelled levels.

The equivalent rms levels for the blast sequence are approximately 25 dB lower than the critical threshold of 170 dB re 1 μPa rms. It is noted that the rms level has been computed from data recorded at a distance much greater to the blast site than the 400 m specified. In addition, it is apparent that the bubble curtain has absorbed significant levels of acoustic energy.

Charge weight	Field	Distance from blast site	Modelled blast level		Measured blast level
			Zero attenuation	60% attenuation	
20 kg	18	1163 m	165.2 dB re 1 μPa peak	157.2 dB re 1 μPa peak	158.1 dB re 1 μPa peak 146.2 dB re 1 μPa $rms_{1.3sec}$
20 kg	20	1224 m	164.5 dB re 1 μPa peak	156.5 dB re 1 μPa peak	156.3 dB re 1 μPa peak 144.5 dB re 1 μPa $rms_{1.1sec}$

Table J.2: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

J.11 Overview - Inside bubble curtain (first repeat blasting)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
25 Oct 2018	0836 hrs UTC	20 kg	H11	Inside	537 m/Field19	181025-083618

J.12 Ecofish Observations

Detonation noise recording Hydrophone deployed inside of the bubble curtain.

H11 hydrophone was used with h10 TU due to previous damage to the h10 hydrophone cable.

Vertical static, deployed forward of vessel on the port side over rubber sponson.

Blast 10 incomplete detonation. Second attempt to detonate Field 19 (10b).

One excavator working on end of North breakwater.

Northeasterly wind force 3, sea state 3, low swell, no precipitation.

J.13 Data Processing

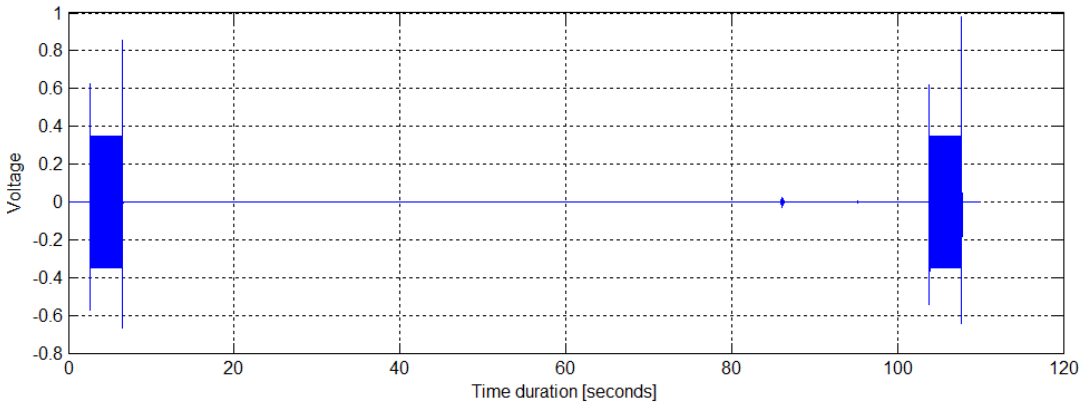

Figure J.7: Hydrophone output in volts as a function of time in seconds

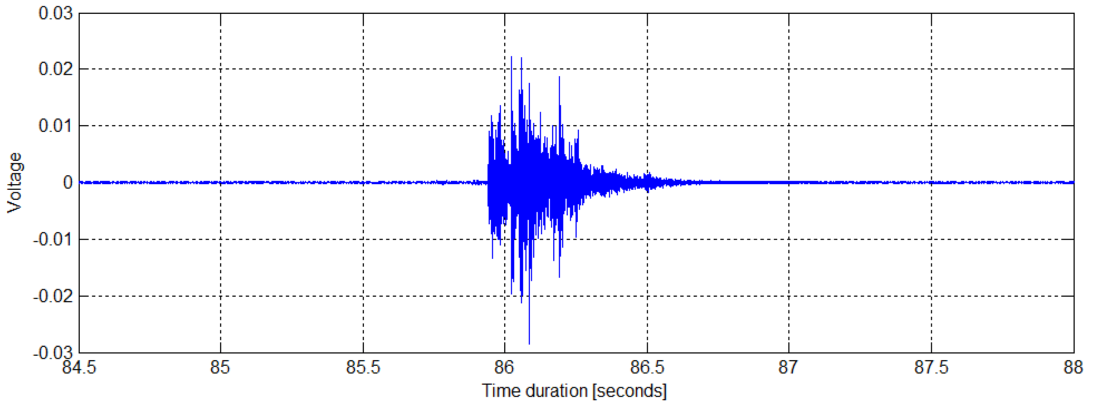

Figure J.8: Hydrophone output in volts as a function of time in seconds around blast sequence

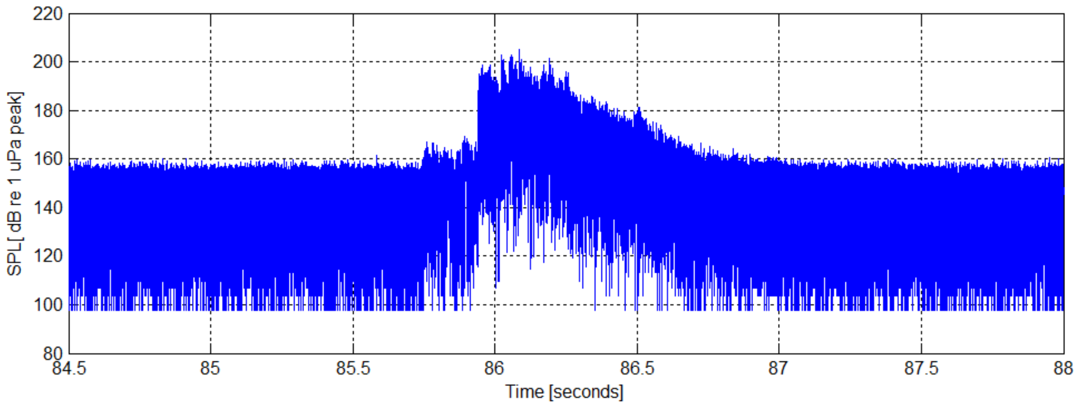

Figure J.9: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

J.14 Discussion

Discussions with the blasting engineers revealed that none of the 72 charges from Field 19 detonated during the blasting schedule earlier in the day. A total of 36 charges were successfully detonated during the reblast that took place around 30 minutes after the earlier session. Figure J.7 shows the voltage-time series that was subsequently recorded at a location inside the bubble curtain. Calibration tones of a few seconds duration were injected at 2.5 seconds and 104 seconds. A blast signature was identified commencing at approximately 86 seconds and this is shown in detail in Figure J.8. Figure J.9 shows the corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 μPa for the blast record arising from Field 19. The peak level was 205.1 dB re 1 μPa and the rms level was 183.8 dB re 1 μPa over a period of 3.5 seconds. The voltage-time series in Figure J.8 shows that it is not possible to discriminate clearly the peaks in the blast sequence and hence they cannot be attributed uniquely to the detonation of a specific charge.

J.15 Results

For the given charge weights and distances from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above. It is noted that the confined blasting model give peak blast levels only; rms levels are not calculated.

The result, summarised in Table J.3, shows that for the 20 kg charge, the recorded level is 29 dB higher than the corresponding modelled level. This offset is consistent with those reported following the blasting program that took place in August and September 2018.

The equivalent rms levels for each blast sequence may be compared with the critical threshold of 170 dB re 1 μPa rms at a distance of 400 m from the blast site. The computed rms level is 14 dB higher than the critical threshold. In addition, Table J.3 shows that the distance between the recording location and the blast site was greater than the critical distance of 400 m.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
20 kg	Field19	537 m	176.0 dB re 1 μPa peak	205.1 dB re 1 μPa peak 183.8 dB re 1 μPa $rms_{3.5sec}$

Table J.3: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

J.16 Overview - Outside bubble curtain (first repeat blasting)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
25 Oct 2018	0836 hrs UTC	20 kg	H4	Outside	1075 m	181025_03

J.17 Ecofish Observations

Detonation noise recording. Hydrophone H4b deployed outside the bubble curtain. GPS way point 140 provided.

Vertical static. deployed aft of vessel on the starboard side in favourable position for current.

Partial Detonation occurred initially (Blast 1A) this recording contains the subsequent detonation sequence. (Blast 1B).

Vessel was anchored. Engines were off a generator was running on the deck during recording

Calm sea. BF 3 North Easterly

J.18 Data Processing

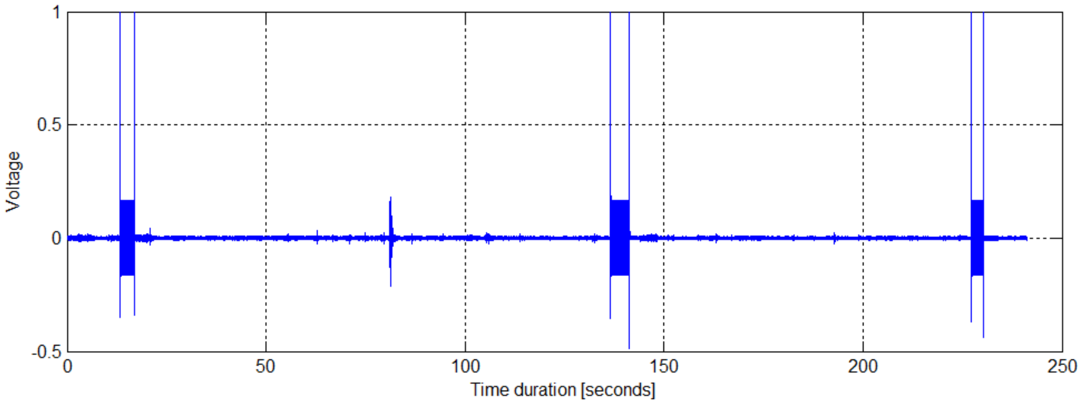

Figure J.10: Hydrophone output in volts as a function of time in seconds

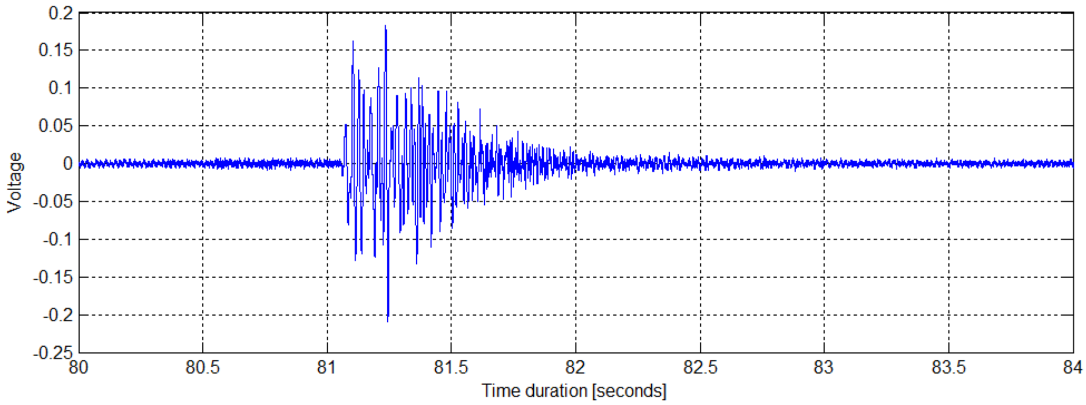

Figure J.11: Hydrophone output in volts as a function of time in seconds around blast sequence

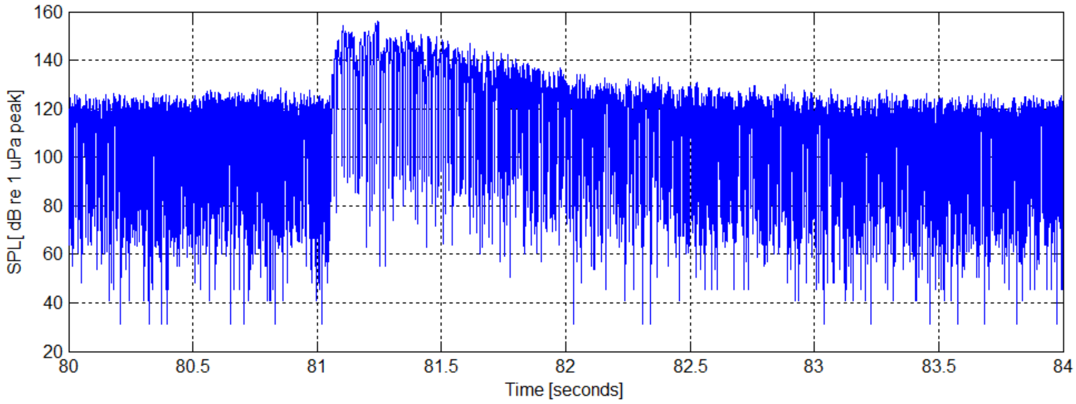

Figure J.12: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

J.19 Discussion

Figure J.10 shows the voltage-time series recorded at a location outside of the bubble curtain following the detonation of the 36 charges in Field 19. Calibration tones of a few seconds duration were injected at 13 seconds, 136 seconds and 227 seconds. A blast sequence was identified in the series commencing at 81 seconds and this is shown in detail in Figure J.11. Figure J.12 shows the corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 μPa for the blast records arising from Field 19. It will be seen that there is a blast level of 156.3 dB re 1 μPa peak equivalent to an rms level of 140.9 dB re 1 μPa over 1.66 seconds.

J.20 Results

For the given charge weight and distance from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table J.4, show that the recorded level is 10 dB lower than the corresponding modelled level assuming no bubble curtain. When a bubble curtain having 60% attenuation is included, the recorded level is 2 dB lower than the corresponding modelled levels.

The equivalent rms level for the blast sequence from Field 19 is 30 dB below the critical threshold of 170 dB re 1 μPa rms. It is noted that the rms levels have been computed from data recorded at distances much greater to the blast sites than the 400 m specified. In addition, it is apparent that the bubble curtain has absorbed significant levels of acoustic energy.

Charge weight	Field	Distance from blast site	Modelled blast level		Measured blast level
			Zero attenuation	60% attenuation	
20 kg	19	1075 m	166.3 dB re 1 μPa peak	158.3 dB re 1 μPa peak	156.3 dB re 1 μPa peak 140.9 dB re 1 μPa $\text{rms}_{1.6sec}$

Table J.4: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

J.21 Overview - Inside bubble curtain (second repeat blasting)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
25 Oct 2018	0855 hrs UTC	20 kg	H11	Inside	486 m/Field19	181025-085425

J.22 Ecofish Observations

Detonation noise recording Hydrophone deployed inside of the bubble curtain.

H11 hydrophone was used with h10 TU due to previous damage to the h10 hydrophone cable.

Vertical static, deployed forward of vessel on the port side over rubber sponson.

Blast 10 incomplete detonation. Safety blast of field 19 (10c). Field 19 initially resulted in a misfire and further incomplete detonation. This log sheet refers to a safety blast which was carried out to ensure there were no live explosives remaining in the water.

One excavator working on end of North breakwater.

Northeasterly wind force 3, sea state 3, low swell, no precipitation.

J.23 Data Processing

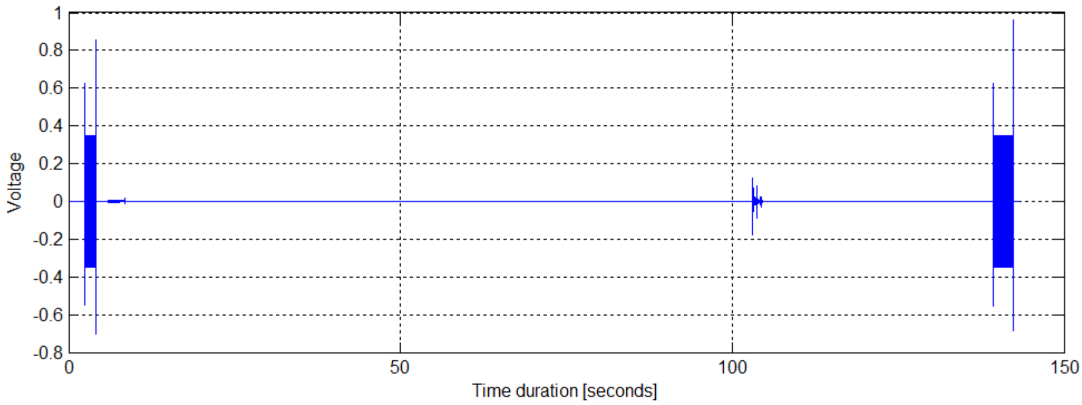

Figure J.13: Hydrophone output in volts as a function of time in seconds

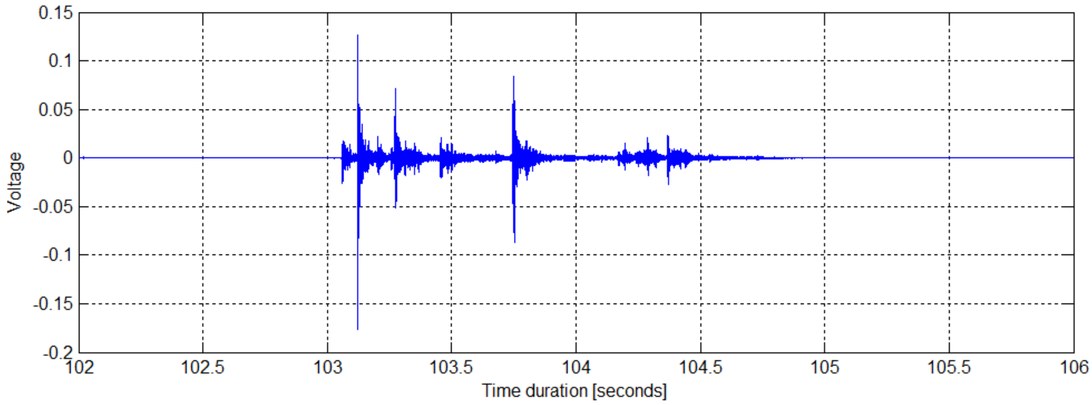

Figure J.14: Hydrophone output in volts as a function of time in seconds around blast sequence

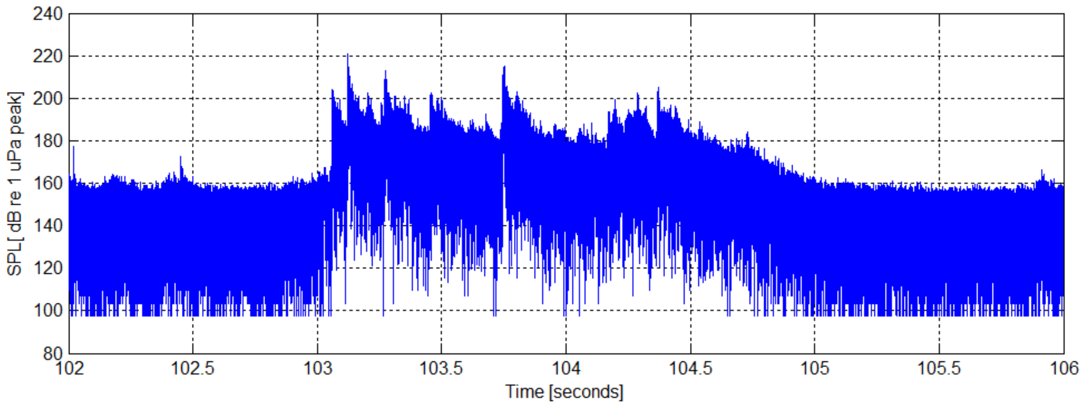

Figure J.15: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

J.24 Discussion

During the second reblast which took place around 20 minutes after the first, 36 charges out of 72 boreholes primed in Field 19 were successfully detonated. Figure J.13 shows the voltage-time series that was subsequently recorded at a location inside the bubble curtain. Calibration tones of a few seconds duration were injected at 2.5 seconds and 139 seconds. The blast signature was identified commencing at 103 seconds and this is shown in detail in Figure J.14. The corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 μPa for the blast records arising from Field 19 as seen in Figure J.15 shows that the peak level was 220.9 dB re 1 μPa and the rms level was 190.5 dB re 1 μPa over a duration of 1.95 seconds.

J.25 Results

For the given charge weights and distances from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above. . It is noted that the confined blasting model give peak blast levels only; rms levels are not calculated.

The result, summarised in Table J.5, shows that for the 20 kg charge, the recorded level is 44 dB higher than the corresponding modelled level. This offset is somewhat higher than those reported following the blasting program that took place in August and September 2018.

The equivalent rms levels for each blast sequence may be compared with the critical threshold of 170 dB re 1 μPa rms at a distance of 400 m from the blast site. The computed rms level is 20 dB higher than the critical threshold. In addition, Table J.5 shows that the distance between the recording location and the blast site was greater than the critical distance of 400 m.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
20 kg	Field19	486 m	177.3 dB re 1 μPa peak	220.9 dB re 1 μPa peak 190.5 dB re 1 μPa $rms_{1.95sec}$

Table J.5: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

J.26 Overview - Outside bubble curtain (second repeat blasting)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
25 Oct 2018	0855 hrs UTC	20 kg	H4	Outside	1075 m	181025_04

J.27 Ecofish Observations

Detonation noise recording. Hydrophone H4b deployed outside the bubble curtain. GPS way point 140 provided.

Vertical static. deployed aft of vessel on the starboard side in favourable position for current.

Partial Detonation occurred initially (Blast 1A followed by Blast 1B this recording contains the subsequent detonation sequence. (Blast 1C).

Vessel was anchored. Engines were off a generator was running on the deck during recording. Some heavy plant machinery was active on the point of the south shore which introduced some impulsive sound into the recording. The operator was asked to cease operation for further blasting.

Calm sea. BF 3 North Easterly

J.28 Data Processing

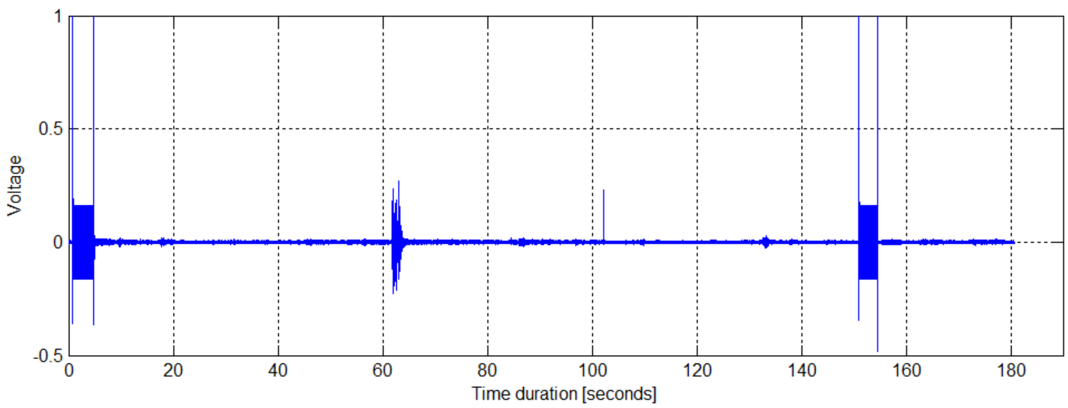

Figure J.16: Hydrophone output in volts as a function of time in seconds

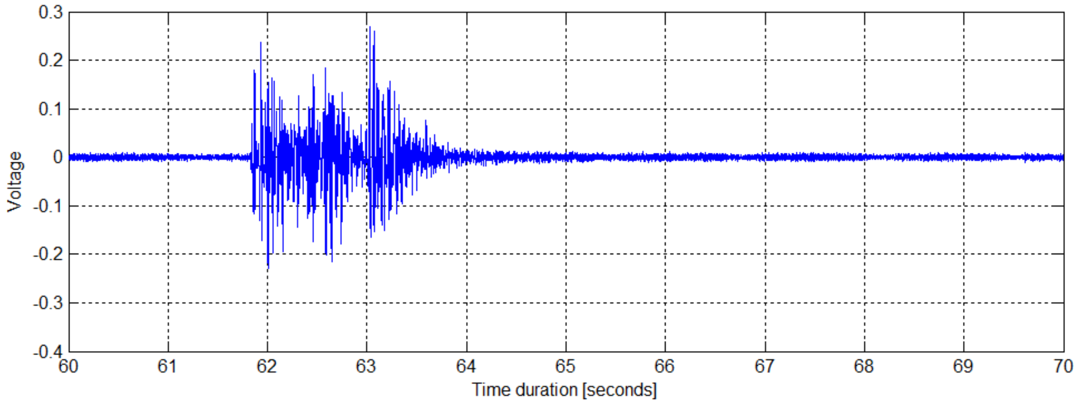

Figure J.17: Hydrophone output in volts as a function of time in seconds around blast sequence

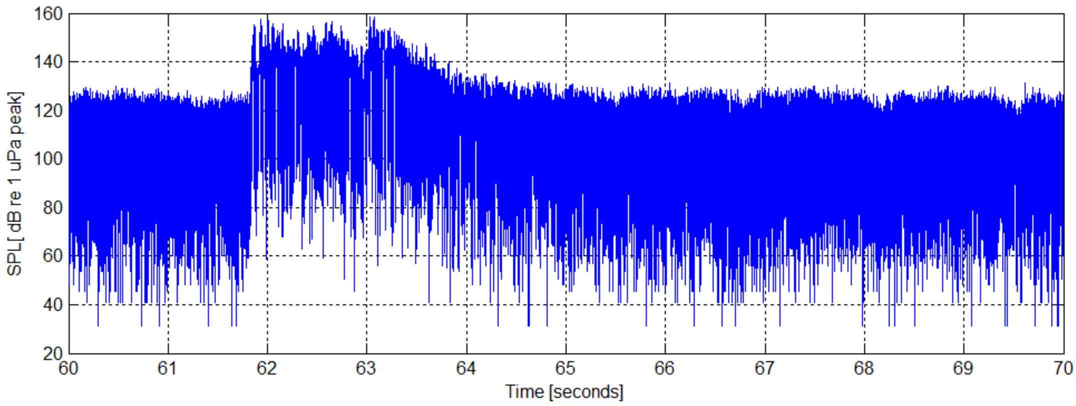

Figure J.18: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

J.29 Discussion

Figure J.16 shows the voltage-time series recorded at a location outside of the bubble curtain following the second repeat detonation of the charges in Field 19 that failed to go off 20 minutes earlier. Calibration tones of a few seconds duration were injected at 1 second and 151 seconds. A blast sequence was identified in the series commencing at 62 seconds and this is shown in detail in Figure J.17. Figure J.18 shows the corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 μPa for the blast record arising from Field 19. It will be seen that there is a blast level of 158.5 dB re 1 μPa peak equivalent to an rms level of 142.7 dB re 1 μPa over 4.2 seconds.

J.30 Results

For the given charge weight and distance from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table J.6, show that the recorded level is 8 dB lower than the corresponding modelled level assuming no bubble curtain. When a bubble curtain having 60% attenuation is included, the recorded level is within 0.5 dB of the corresponding modelled level.

The equivalent rms level for the blast sequence from Field 19 is 17 dB below the critical threshold of 170 dB re 1 μPa rms. It is noted that the rms levels have been computed from data recorded at distances much greater to the blast sites than the 400 m specified. In addition, it is apparent that the bubble curtain has absorbed significant levels of acoustic energy.

Charge weight	Field	Distance from blast site	Modelled blast level		Measured blast level
			Zero attenuation	60% attenuation	
20 kg	19	1075 m	166.3 dB re 1 μPa peak	158.3 dB re 1 μPa peak	158.5 dB re 1 μPa peak 142.7 dB re 1 μPa $rms_{4.2sec}$

Table J.6: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

J.31 Overview - Inside bubble curtain (third repeat blasting)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
25 Oct 2018	0917 hrs UTC	20 kg	H11	Inside	528 m/Field20	181025-091723

J.32 Ecofish Observations

Detonation noise recording Hydrophone deployed inside of the bubble curtain.

H11 hydrophone was used with h10 TU due to previous damage to the h10 hydrophone cable.

Vertical static, deployed forward of vessel on the port side over rubber sponson.

Blast 10 detonation. Detonation of field 20 (10d).

One excavator working on end of North breakwater.

Northeasterly wind force 3, sea state 3, low swell, no precipitation.

J.33 Data Processing

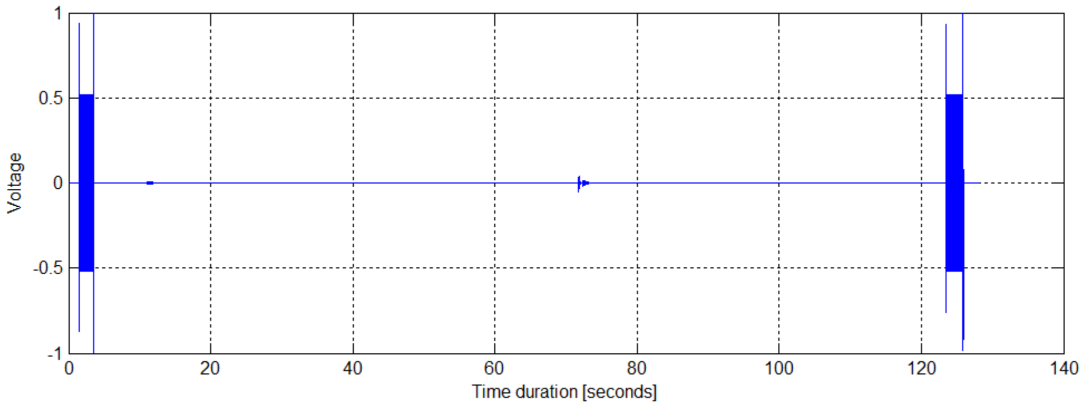

Figure J.19: Hydrophone output in volts as a function of time in seconds

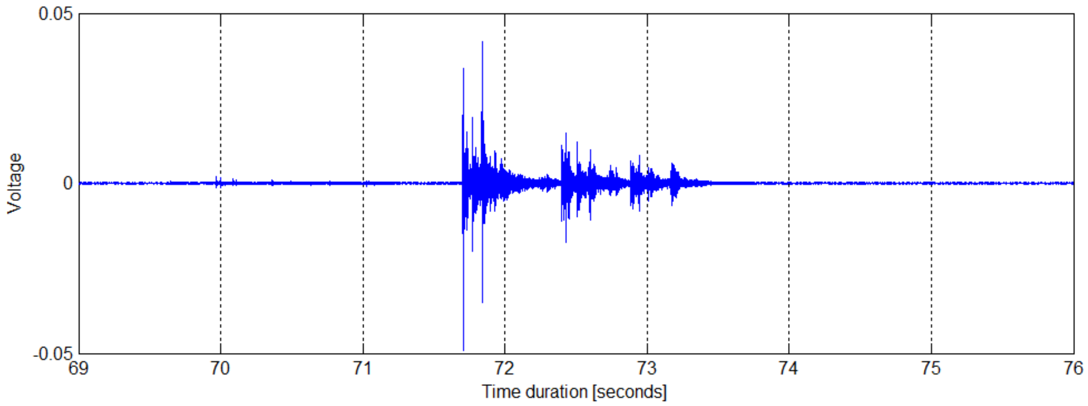

Figure J.20: Hydrophone output in volts as a function of time in seconds around blast sequence

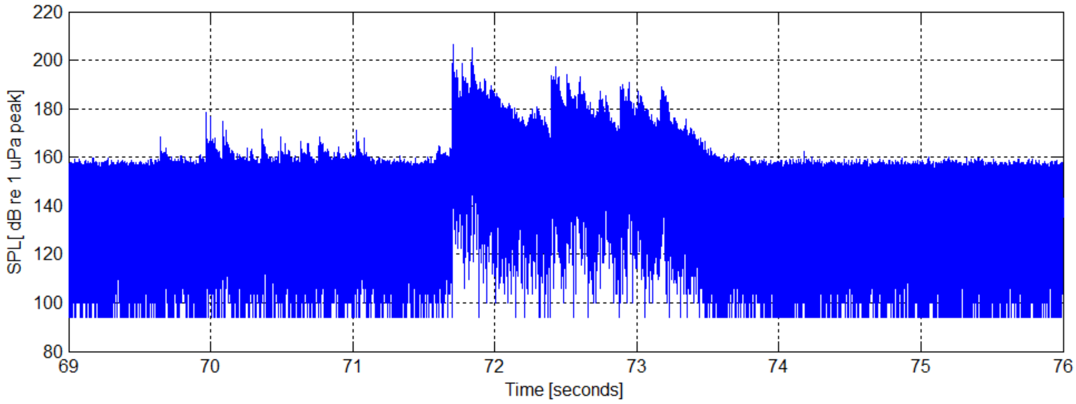

Figure J.21: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

J.34 Discussion

During the third reblast which took place around 20 minutes after the previous, the 57 charges in Field 20 that failed to go off earlier were all successfully detonated. Figure J.19 shows the voltage-time series that was subsequently recorded at a location inside the bubble curtain. Calibration tones of a few seconds duration were injected at 1.4 seconds and 124 seconds. The blast signature was identified commencing at 71 seconds and this is shown in detail in Figure J.20. The corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 μPa for the blast record arising from Field 20 as seen in Figure J.21 shows that the peak level was 206.4 dB re 1 μPa and the rms level was 180.0 dB re 1 μPa over a duration of 1.81 seconds.

J.35 Results

For the given charge weights and distances from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above. . It is noted that the confined blasting model give peak blast levels only; rms levels are not calculated.

The result, summarised in Table J.7, shows that for the 20 kg charge, the recorded level is 30 dB higher than the corresponding modelled level. This offset is consistent with those reported following the blasting program that took place in August and September 2018.

The equivalent rms levels for each blast sequence may be compared with the critical threshold of 170 dB re 1 μPa rms at a distance of 400 m from the blast site. The computed rms level is 10 dB higher than the critical threshold. In addition, Table J.7 shows that the distance between the recording location and the blast site was greater than the critical distance of 400 m.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
20 kg	Field20	528 m	176.2 dB re 1 μPa peak	206.4 dB re 1 μPa peak 180.0 dB re 1 μPa $rms_{1.81sec}$

Table J.7: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

J.36 Overview - Outside bubble curtain (third repeat blasting)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
25 Oct 2018	0917 hrs UTC	20 kg	H4	Outside	1194 m	181025_05

J.37 Ecofish Observations

Detonation noise recording. Hydrophone H4b deployed outside the bubble curtain. GPS way point 140 provided.

Vertical static. deployed aft of vessel on the starboard side in favourable position for current.

Partial Detonations occurred (Blast 1A was followed by Blast 1B & Blast 1C this recording contains the subsequent detonation sequence. (Blast 1D).

Vessel was anchored. Engines were off a generator was running on the deck during recording. During the recording the RNLI rescue service was conducting a live operation in very close proximity (<500 meters at high speeds) to our vessel. The interference on the recording was severe however was unavoidable due to the nature of the rescue operation in progress.

Calm sea. BF 3 North Easterly

J.38 Data Processing

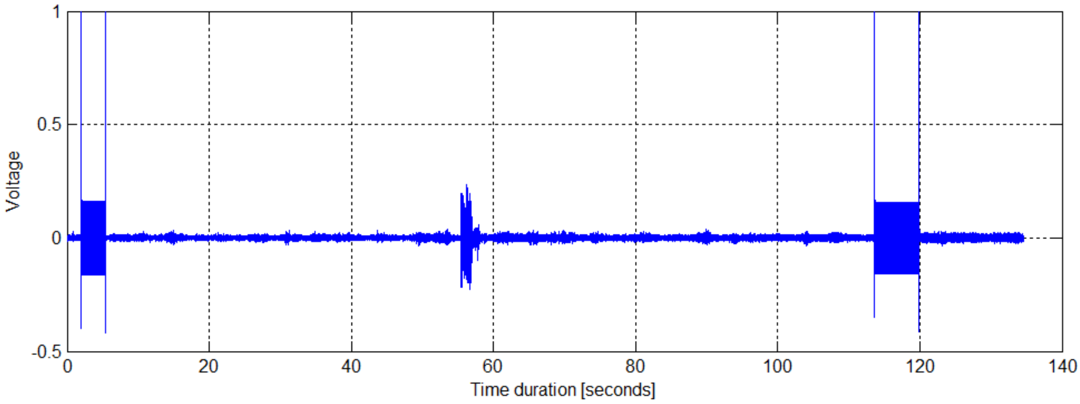

Figure J.22: Hydrophone output in volts as a function of time in seconds

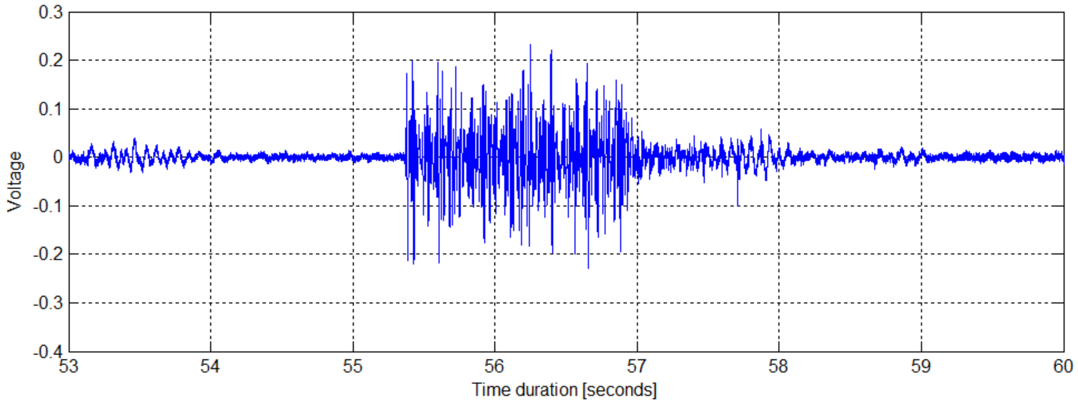

Figure J.23: Hydrophone output in volts as a function of time in seconds around blast sequence

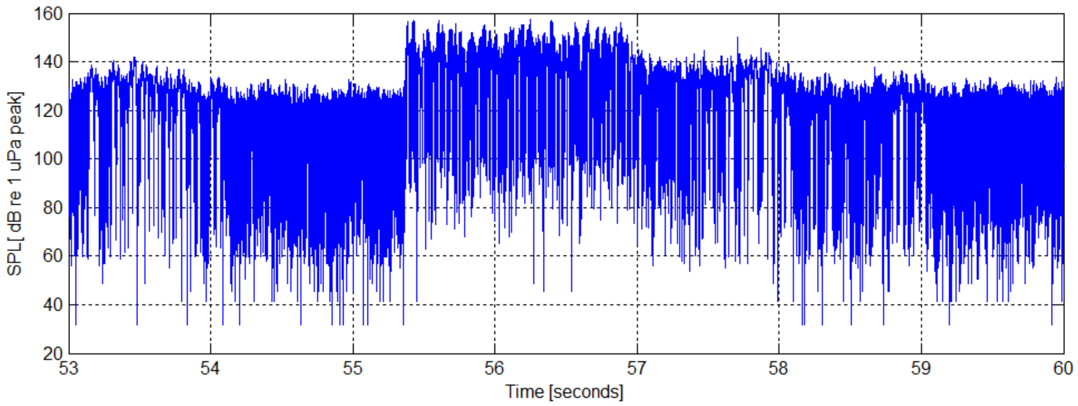

Figure J.24: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

J.39 Discussion

Figure J.22 shows the voltage-time series recorded at a location outside of the bubble curtain following the third repeat detonation of the charges in Field 20 that failed to go off earlier. Calibration tones of a few seconds duration were injected at 2 second and 113 seconds. A blast sequence was identified in the series commencing at 55.5 seconds and this is shown in detail in Figure J.23. Figure J.24 shows the corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 μPa for the blast record arising from Field 19. It will be seen that there is a blast level of 157.4 dB re 1 μPa peak equivalent to an rms level of 143.2 dB re 1 μPa over a duration of 4.65 seconds.

J.40 Results

For the given charge weight and distance from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table J.8, show that the recorded level is 7.5 dB lower than the corresponding modelled level assuming no bubble curtain. When a bubble curtain having 60% attenuation is included, the recorded level is within 0.5 dB of the corresponding modelled level.

The equivalent rms level for the blast sequence from Field 20 is 17 dB below the critical threshold of 170 dB re 1 μPa rms. It is noted that the rms levels have been computed from data recorded at distances much greater to the blast sites than the 400 m specified. In addition, it is apparent that the bubble curtain has absorbed significant levels of acoustic energy.

Charge weight	Field	Distance from blast site	Modelled blast level		Measured blast level
			Zero attenuation	60% attenuation	
20 kg	20	1194 m	164.9 dB re 1 μPa peak	156.9 dB re 1 μPa peak	157.4 dB re 1 μPa peak 143.2 dB re 1 μPa $rms_{4.6sec}$

Table J.8: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

APPENDIX K: BLASTING RESULTS - 17TH NOVEMBER 2018

K.1 Overview - Inside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
17 Nov 2018	1358 hrs UTC	20 kg	H11	Inside	257 m/Field21	181117-135848
17 Nov 2018	1358 hrs UTC	20 kg	H11	Inside	262 m/Field22	181117-135848
17 Nov 2018	1358 hrs UTC	20 kg	H11	Inside	245 m/Field23	181117-135848

K.2 Ecofish Observations

Detonation underwater noise recording.

Detonation of field charge blasts 21, 22, and 23, inside the bubble curtain.

Vessel at anchor. Hydrophone deployed from forward port side of vessel over rubber sponson.

There was one additional blast to clear the field which was not communicated to the MMOs. It was not possible to record this charge.

The second detonation appeared to clip the recording. This was due to the operator trying to optimise the recorder settings following a relatively low signal from the previous blasts when using this equipment.

Wind and sea state force 4 on the Beaufort scale, wind direction SE, sea surface slight to choppy, swell low, no precipitation.

K.3 Data Processing

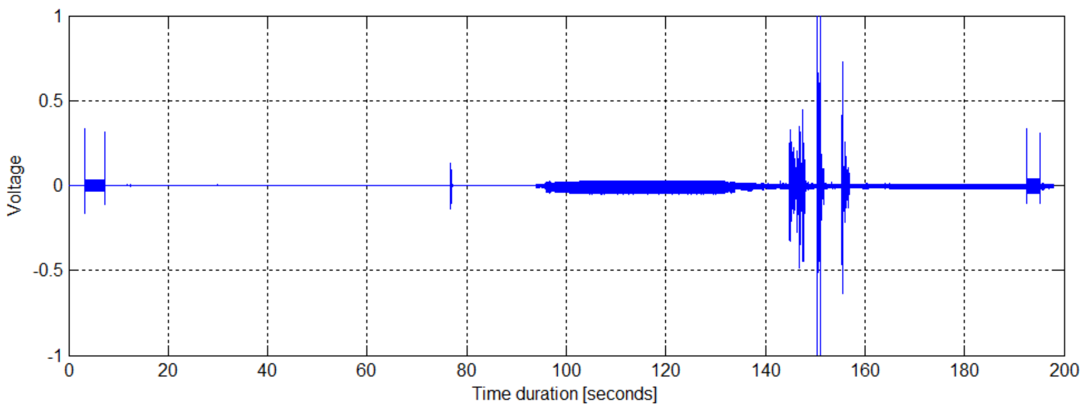

Figure K.1: Hydrophone output in volts as a function of time in seconds

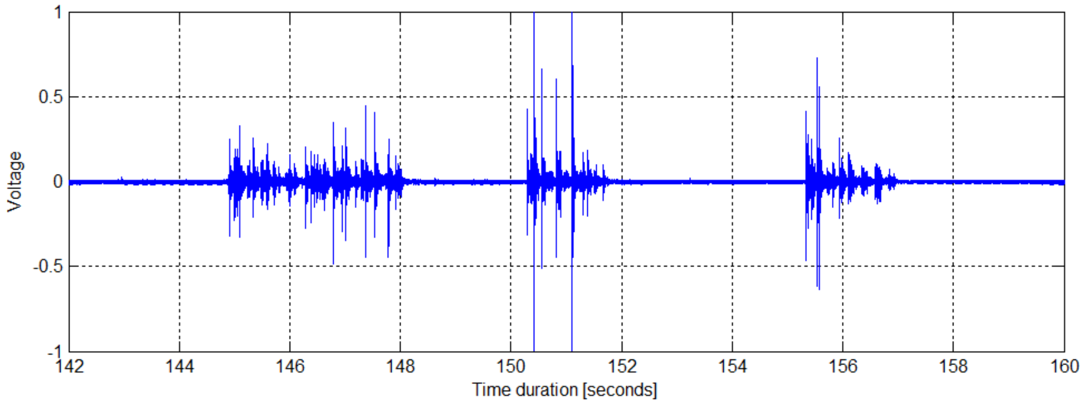

Figure K.2: Hydrophone output in volts as a function of time in seconds around blast sequence

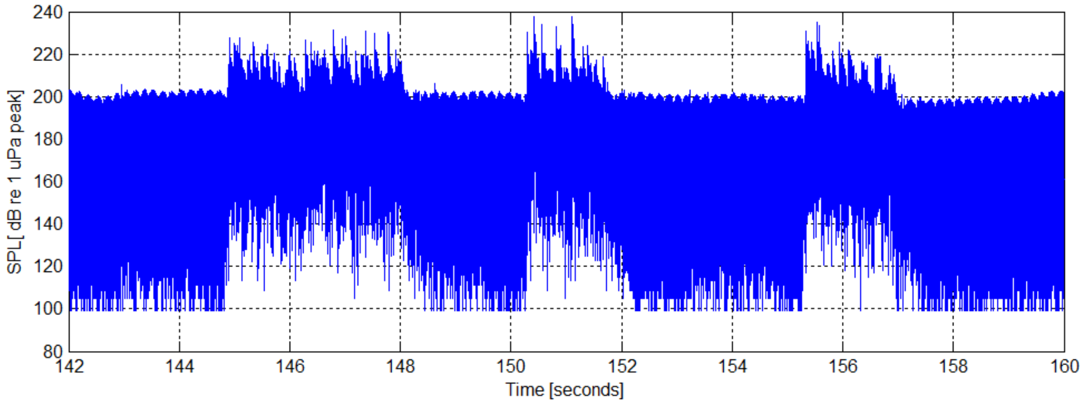

Figure K.3: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

K.4 Discussion

Figure K.1 shows the complete voltage-time series recorded around the time of the blast sequence. Calibration tones of a few seconds duration were injected at 3 seconds and 192 seconds. Three blast sequences were identified commencing at 145 seconds, 150 seconds and 155 seconds and the voltage-time series for these are shown in more detail in Figure K.2.

The Field Contractor's Logs show that Fields 21, 22 and 23 were prepared with 121, 55 and 70 boreholes respectively where each was primed with up to 20 kg of explosive. It is understood that all charges were successfully detonated. Given a nominal time delay between each detonation of 0.025 seconds, this gives overall blast durations of 3 seconds, 1.3 seconds and 1.7 seconds respectively excluding the time required for the reverberations to die down and these are borne out in the voltage-time series around the time of the blast itself and as shown in Figure K.2.

Figure K.3 shows the corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 μPa for the blast records arising from Fields 21, 22 and 23. It shows that from Field 21, the peak blast level is 231.3 dB re 1 μPa with a corresponding rms level of 208.3 dB re 1 μPa over a duration of 3.4 seconds. The detonation of the charges in Field 22 produced a peak blast level of 237.6 dB re 1 μPa with a corresponding rms level of 211.9 dB re 1 μPa over a duration of 1.6 seconds and the corresponding levels from Field 23 were 234.8 dB re 1 μPa peak and 208.8 dB re 1 μPa rms over a duration of 1.9 seconds.

K.5 Results

For the charge weights of 20 kg and the given distances from each blast site, the expected peak blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent root-mean-square (rms) levels calculated using durations sufficiently long enough to capture the entire blasting sequence together with the following reverberations from each detonation. It is noted that the confined blasting model give peak blast levels only; rms levels are not calculated.

The results summarised in Table K.1, show that for the 20 kg charges, the recorded levels are 45-50 dB higher than the corresponding modelled levels. These offsets are slightly in excess of those reported following the blasting program that took place in August and September 2018.

The equivalent rms levels for each blast sequence may be compared with the critical threshold of 170 dB re 1 μPa rms at a distance of 400 m from the blast site. The computed rms levels are 38-42 dB higher than the critical threshold. In addition, Table K.1 shows that the distances between the recording locations and the blast sites were much shorter than the critical distance of 400 m.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
20 kg	21	257 m	186.2 dB re 1 μPa peak	231.3 dB re 1 μPa peak 208.3 dB re 1 μPa $rms_{3.4sec}$
20 kg	22	262 m	185.9 dB re 1 μPa peak	237.6 dB re 1 μPa peak 211.9 dB re 1 μPa $rms_{1.6sec}$
20 kg	23	245 m	186.9 dB re 1 μPa peak	234.8 dB re 1 μPa peak 208.8 dB re 1 μPa $rms_{1.9sec}$

Table K.1: Comparison of peak and rms modelled blast levels with peak and rms recorded blast levels

K.6 Overview - Outside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
17 Nov 2018	1358 hrs UTC	20 kg	H4	Outside	707 m/Field21	181117_01
17 Nov 2018	1358 hrs UTC	20 kg	H4	Outside	771 m/Field22	181117_01
17 Nov 2018	1358 hrs UTC	20 kg	H4	Outside	740 m/Field23	181117_01

K.7 Ecofish Observations

Underwater noise recording of marine blast outside of the bubble curtain.

Marine blasting of Fields 21, 22, and 23.

Vertical static. deployed aft of vessel on the starboard side in favourable position for current.

Vessel was anchored. Anchor chain and Swell noise present. Engines were off a generator was running on the deck during recording. There was no notable vessel movement during this time. An additional charge was detonated to clear Field 22 which was not communicated to the MMO team.

Wind and sea state force 4 on the Beaufort scale, wind direction SE, sea surface slight to choppy, swell low, no precipitation.

K.8 Data Processing

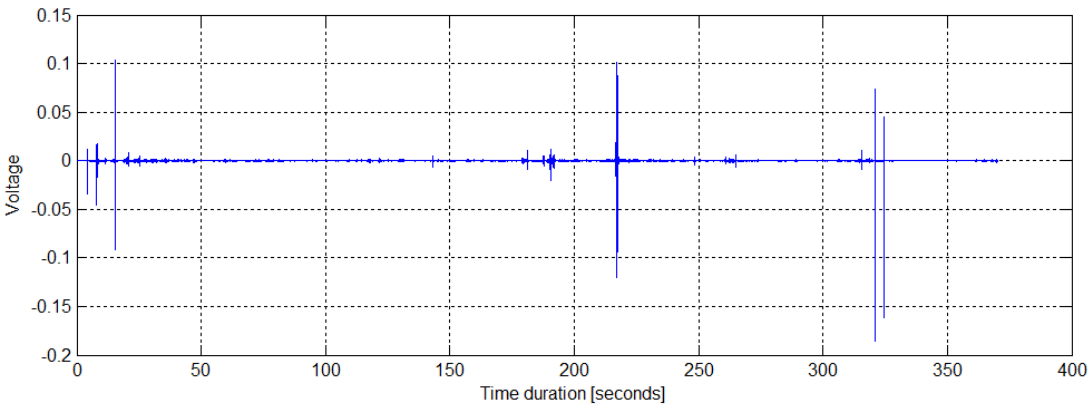

Figure K.4: Hydrophone output in volts as a function of time in seconds

K.9 Discussion

Figure K.4 shows the voltage-time series recorded at a location outside the bubble curtain during the detonation of the charges in Fields 21, 22 and 23.

Acoustic data including the calibration tone signals were found to be missing on the recordings made. This appears to be due to either a faulty cable to the recorder or a faulty connector on the recorder. The data were thus deemed to be unusable for subsequent analysis.

K.10 Overview - Inside bubble curtain (land test blast)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
17 Nov 2018	1540 hrs UTC	6 kg	H11	Inside	1305 m/LTB	181117-154032

K.11 Ecofish Observations

Detonation noise recording.

First land test blast for the purpose of testing vibration measuring equipment. For this blast the original bubble curtain layout was used whereby the double bubble curtain stretches across the mouth of the bay.

The blast consisted of 3 charges, two of 3kg, and one of 6kg, detonated in sequence with a 25 millisecond interval.

Vessel holding position on engines. Hydrophone deployed from forward port side of vessel over rubber sponson.

Echosounder present in background probably from the Hector barge.

Wind and sea state force 4 on the Beaufort scale, wind direction SE, sea surface slight to choppy, swell low, no precipitation.

K.12 Data Processing

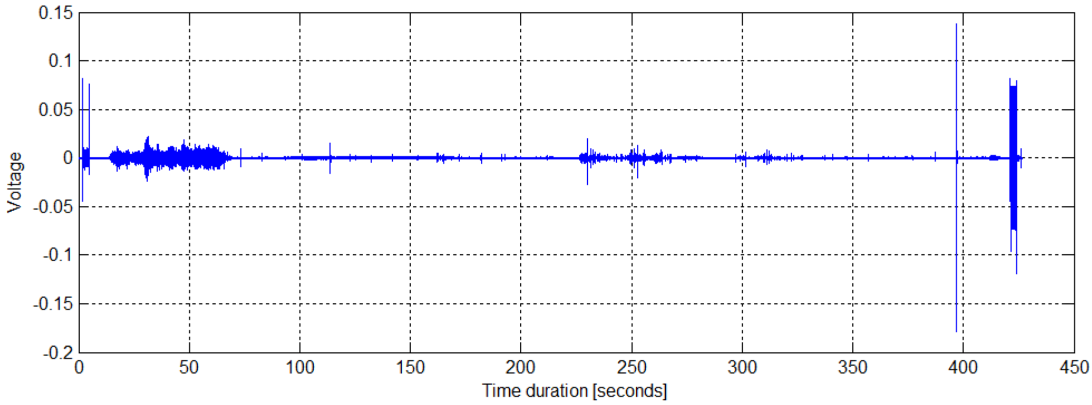

Figure K.5: Hydrophone output in volts as a function of time in seconds

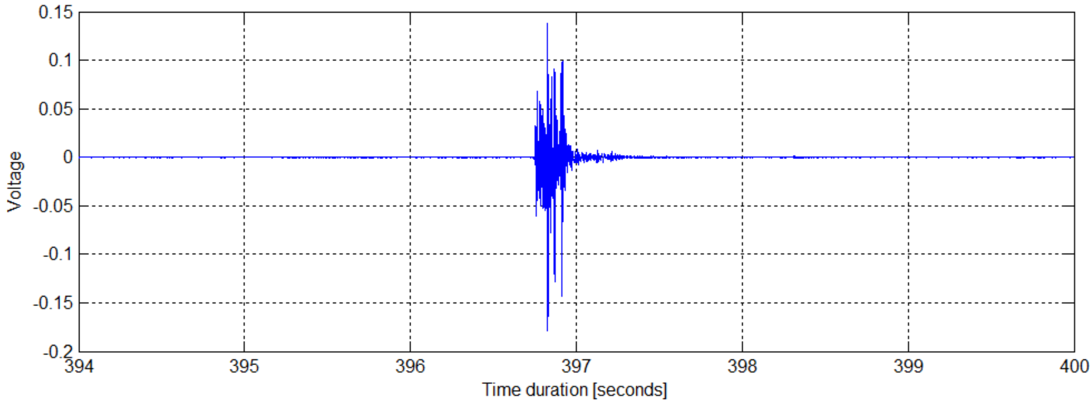

Figure K.6: Hydrophone output in volts as a function of time in seconds around blast sequence

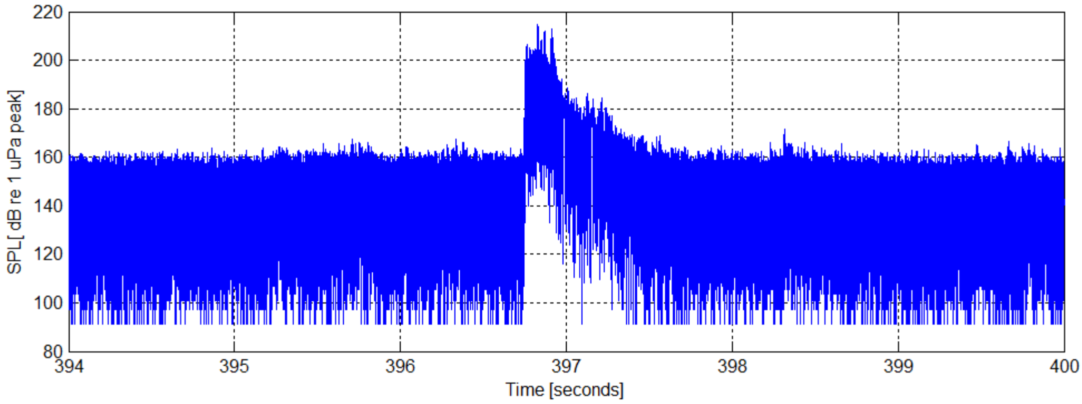

Figure K.7: Sound pressure level in dB re 1 μPa peak as a function of time in seconds

K.13 Discussion

A test blast sequence took place on the south shore of Nigg Bay. A total of 3 boreholes were primed with between 3 kg and 6 kg of explosive, all of which were subsequently detonated. Figure K.5 shows the resulting voltage-time series that was recorded at a location inside the bubble curtain. A calibration tone of a few seconds duration was injected at 420 seconds. The blast signature was identified commencing at approximately 396.5 seconds. Given a nominal time delay between each detonation of 0.025 seconds, this gives an overall blast duration of 0.05 seconds excluding the time required for the reverberations to die down and this is borne out in the voltage-time series around the time of the blast itself and as shown in detail in Figure K.6. The corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 μPa for the blast records arising from the detonation sequence as seen in Figure K.7 shows that the peak level was 214.9 dB re 1 μPa while the corresponding rms level was 196.4 dB re 1 μPa over a duration of 0.90 seconds.

K.14 Results

For the given charge weights and distances from the blast site, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent rms levels calculated using durations discussed above. . It is noted that the confined blasting model give peak blast levels only; rms levels are not calculated.

The result, summarised in Table K.5, shows that for the 6 kg charge, the recorded level is approximately 38 dB higher than the corresponding modelled level.

The equivalent rms levels for each blast sequence may be compared with the critical threshold of 170 dB re 1 μPa rms at a distance of 400 m from the blast site. The computed rms level is 26 dB higher than the critical threshold. In addition, Table D.5 shows that the distance between the recording location and the blast site was greater than the critical distance of 400 m.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
6 kg	LTB	255 m	177.9 dB re 1 μPa peak	214.9 dB re 1 μPa peak 196.4 dB re 1 μPa $rms_{0.90sec}$

Table K.2: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

K.15 Overview - Outside bubble curtain (land test blast)

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
17 Nov 2018	1540 hrs UTC	6 kg	H4	Outside	302 m	181117_04

K.16 Ecofish Observations

Underwater noise recording of land test blast outside of the bubble curtain.

Land blasting of first test field. The blast consisted of 3 charges, two of 3kg, and one of 6kg, detonated in sequence with a 25 millisecond interval.

Vertical static. deployed aft of vessel on the starboard side in favourable position for current.

Vessel was anchored. Engines were off a generator was running on the deck during recording. Swell and anchor chain noise present throughout recording.

Wind and sea state force 4 on the Beaufort scale, wind direction SE, sea surface slight to choppy, swell low, no precipitation.

K.17 Data Processing

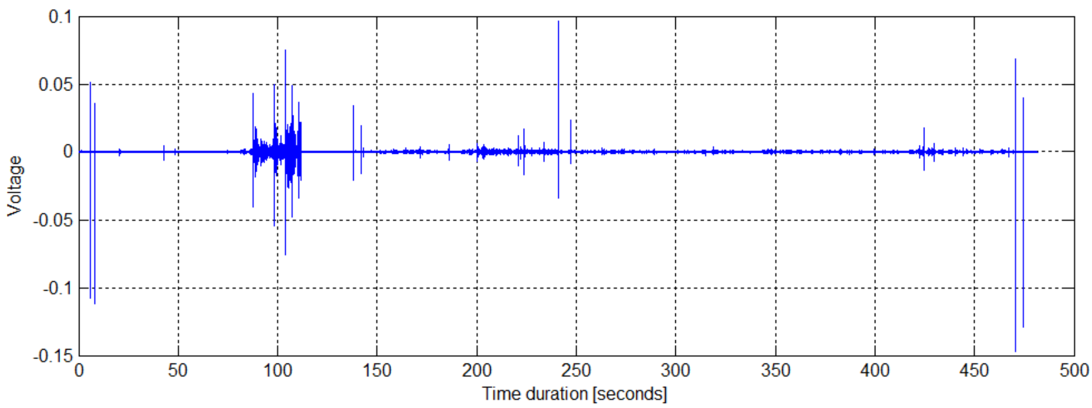

Figure K.8: Hydrophone output in volts as a function of time in seconds

K.18 Discussion

Figure K.8 shows the voltage-time series recorded at a location outside of the bubble curtain following the detonation of the charges in the test site located on the south shore of Nigg Bay.

Acoustic data including the calibration tone signals were found to be missing on the recordings made. This appears to be due to either a faulty cable to the recorder or a faulty connector on the recorder. The data were thus deemed to be unusable for subsequent analysis.

APPENDIX L: BLASTING RESULTS - 24TH NOVEMBER 2018

L.1 Overview - Inside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
24 Nov 2018	1050 hrs UTC	20 kg	H10	Inside	459 m/Field24	181124-105016
24 Nov 2018	1050 hrs UTC	20 kg	H10	Inside	459 m/Field25	181124-105016

L.2 Ecofish Observations

Detonation underwater noise recording.

Hydrophone deployed forward of midships on port side over rubber sponson.

The echosounder on the split-hopper barge Boann contributed as a source of contamination.

Force 2 to 3 from the East Northeast. Seas slight, low swell, good visibility, no precipitation.

L.3 Data Processing

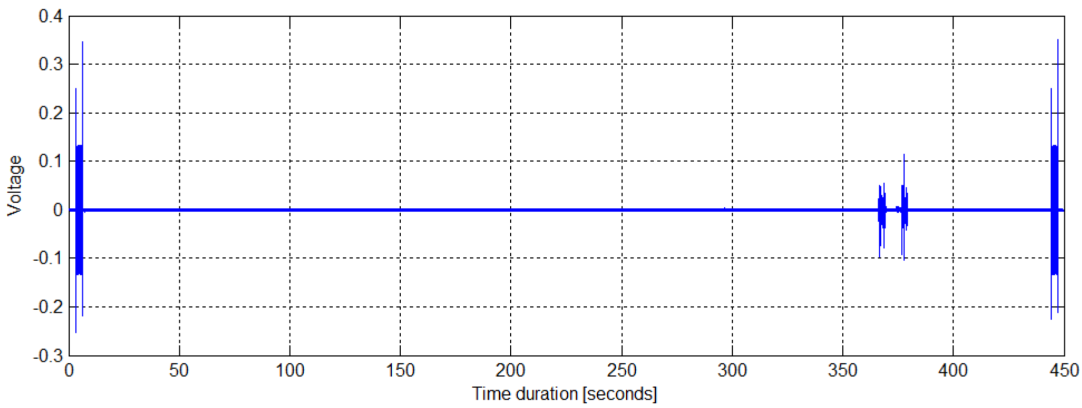

Figure L.1: Hydrophone output in volts as a function of time in seconds

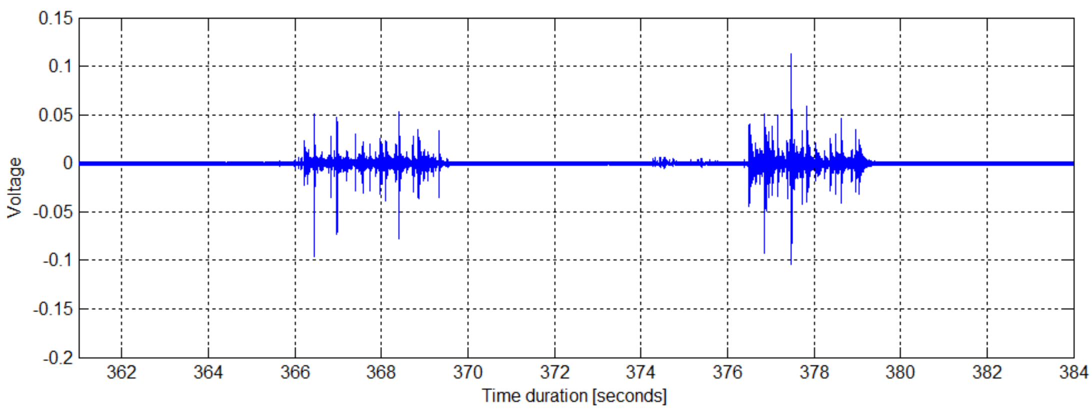

Figure L.2: Hydrophone output in volts as a function of time in seconds around blast sequence

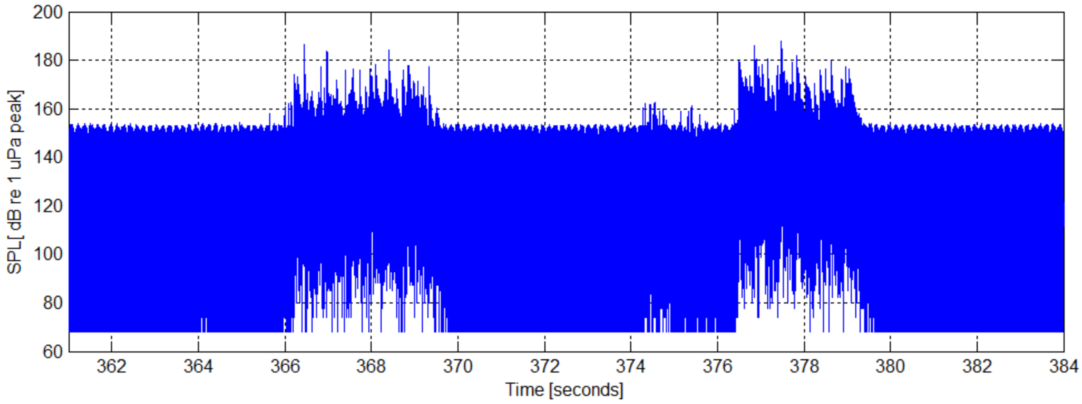

Figure L.3: Sound pressure level in dB re 1 µPa peak as a function of time in seconds

L.4 Discussion

Figure L.1 shows the complete voltage-time series recorded around the time of the blast sequence. Calibration tones of a few seconds duration were injected at 3 seconds and 444 seconds. Two blast sequences were identified commencing at 366 seconds and 376 seconds and the voltage-time series for these are shown in more detail in Figure L.2.

The Field Contractor's Logs show that Fields 24 and 25 were prepared with 217 and 198 charges respectively of up to 20 kg of explosive. It is understood that all charges were successfully detonated. Given a nominal time delay between each detonation of 0.025 seconds, this gives overall blast durations of 5.4 seconds and 4.9 seconds respectively excluding the time required for the reverberations to die down and these are largely borne out in the voltage-time series around the time of the blast itself and as shown in Figure L.2. Figure L.3 shows the corresponding sound pressure level (SPL) time series displayed in units of decibels re 1 µPa for the blast records arising from Fields 24 and 25. It shows that from Field 24, the peak blast level is 186.2 dB re 1 µPa with a corresponding rms level of 158.5 dB re 1 µPa over a duration of 3.6 seconds. The detonation of the charges in Field 25 produced a peak blast level of 187.6 dB re 1 µPa with a corresponding rms level of 162.3 dB re 1 µPa over a duration of 3.1 seconds.

L.5 Results

For the charge weights of 20 kg and the given distances from each blast site, the expected peak blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. Also given are the equivalent root-mean-square (rms) levels calculated using durations sufficiently long enough to capture the entire blasting sequence together with the following reverberations from each detonation. It is noted that the confined blasting model give peak blast levels only; rms levels are not calculated.

The results summarised in Table L.1, show that for the 20 kg charges, the recorded levels are around 9 dB higher than the corresponding modelled levels. These offsets are consistent with those reported following the blasting program that took place in August and September 2018.

The equivalent rms levels for each blast sequence may be compared with the critical threshold of 170 dB re 1 μPa rms at a distance of 400 m from the blast site. The computed rms levels are in the range 8-12 dB lower than the critical threshold. In addition, Table L.1 shows that the distances between the recording locations and the blast sites are somewhat in excess of the critical distance of 400 m.

Charge weight	Field	Distance from blast site	Modelled blast level	Measured blast level
20 kg	24	459 m	178.1 dB re 1 μPa peak	186.2 dB re 1 μPa peak 158.5 dB re 1 μPa $rms_{3.6sec}$
20 kg	25	459 m	178.1 dB re 1 μPa peak	187.6 dB re 1 μPa peak 162.3 dB re 1 μPa $rms_{3.1sec}$

Table L.1: Comparison of peak and rms modelled blast levels with peak and rms recorded blast levels

L.6 Overview - Outside bubble curtain

Date of blast	Time of blast	Charge weight	Hydrophone	Location re. bubble curtain	Distance from blast	Wav file
24 Nov 2018	1050 hrs UTC	20 kg	H4	Outside	860 m/Field24	181124_02
24 Nov 2018	1050 hrs UTC	20 kg	H4	Outside	831 m/Field25	181025_02

L.7 Ecofish Observations

Underwater noise recording of marine blast. Hydrophone H4b deployed outside of the bubble curtain.

Vertical static. deployed aft of vessel on the starboard side in favourable position for current.

Anchor chain and Swell noise present. Engines were off a generator was running on the deck during recording. There was no notable vessel movement during this time. There were possible issues with the bubble curtain.

Wind and sea state force 3 on the Beaufort scale, wind direction E, sea surface slight , swell low, intermittent precipitation, not across blast.

L.8 Data Processing

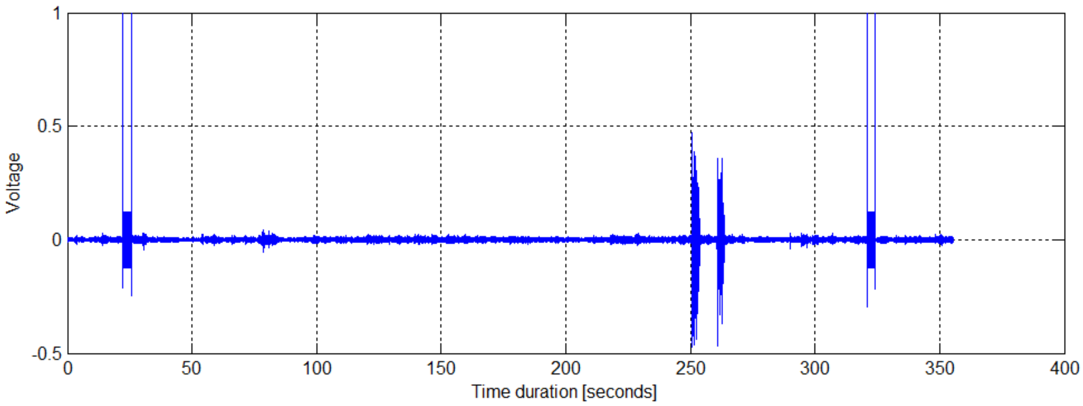

Figure L.4: Hydrophone output in volts as a function of time in seconds

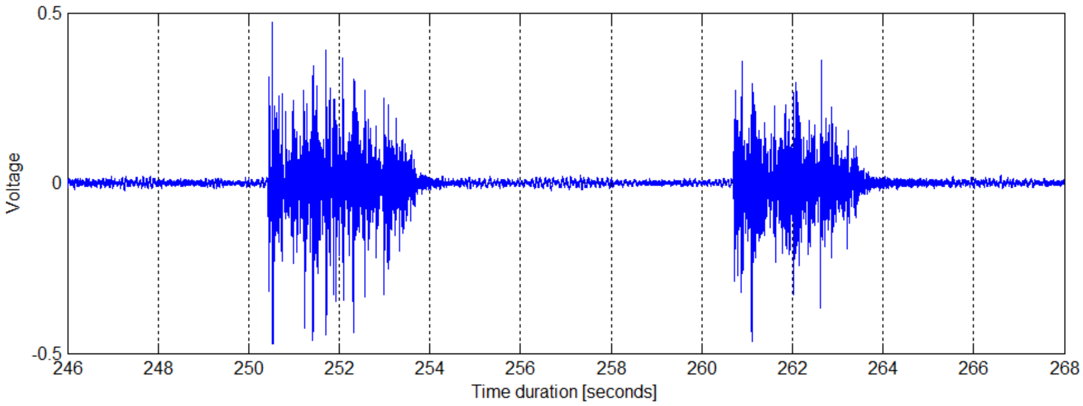

Figure L.5: Hydrophone output in volts as a function of time in seconds around blast sequence

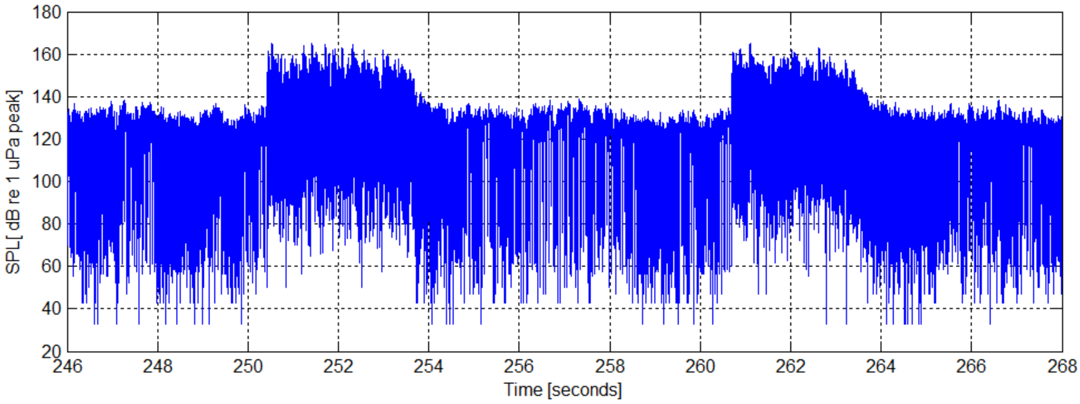

Figure L.6 Sound pressure level in dB re 1 μPa peak as a function of time in seconds

L.9 Discussion

Figure L.4 shows the voltage-time series recorded at a location outside the bubble curtain during the detonation of the charges in Fields 24 and 25. Calibration tones of a few seconds duration were injected at 22 seconds and 26 seconds. Two blast signatures were identified commencing at 250 seconds and 260 seconds and are shown in detail in Figure L.5. These were attributed to the blasts arising from Fields 24 and 25 respectively. It is noted that the duration of each blast event is approximately 0.5 seconds longer than the corresponding durations recorded inside the bubble curtain. The slightly greater times are attributed to the longer propagation paths between blast sites and the outside recorder (compared with the shorter paths between blast sites and the inside recorder) and over which additional reverberations are induced in the shallow waters of Nigg Bay. Figure L.6 shows that from Field 24 there is a maximum blast level of 166.0 dB re 1 μPa peak, equivalent to 151.9 dB re 1 μPa rms over a period of 4.1 seconds and from Field 25 the maximum blast level is 165.9 dB re 1 μPa peak, equivalent to 150.8 dB re 1 μPa rms over a period of 3.4 seconds.

L.10 Results

For the charge weights and their corresponding distances from the blast sites, the expected blast levels may be modelled using the confined blasting model undertaken for the Environmental Statement[2]. The effect of a bubble curtain is modelled using the modified confined blasting model presented in the Clarification Note[7]. Also given are the equivalent rms levels calculated using durations discussed above.

The results, summarised in Table L.2, show that recorded levels are 3.5-4 dB lower than the corresponding modelled levels assuming no bubble curtain. When a bubble curtain having 60% attenuation is included, the recorded levels are 4-5 dB higher than the corresponding modelled levels.

The equivalent rms levels for the blast sequence are 18-19 dB lower than the critical threshold of 170 dB re 1 μPa rms. It is noted that the rms level has been computed from data recorded at a distance much greater to the blast site than the 400 m specified. In addition, it is apparent that the bubble curtain has absorbed significant levels of acoustic energy.

Charge weight	Field	Distance from blast site	Modelled blast level		Measured blast level
			Zero attenuation	60% attenuation	
20 kg	24	860 m	169.4 dB re 1 μPa peak	161.4 dB re 1 μPa peak	166.0 dB re 1 μPa peak 151.9 dB re 1 μPa $rms_{1.3sec}$
20 kg	25	831 m	169.9 dB re 1 μPa peak	161.9 dB re 1 μPa peak	165.9 dB re 1 μPa peak 150.8 dB re 1 μPa $rms_{3.4sec}$

Table L.2: Comparison of modelled peak blast levels with recorded peak blast levels and rms equivalent levels

E. RESULTS OF THE INTERIM POPULATION CONSEQUENCES OF DISTURBANCE MODELLING

INTERIM POPULATION CONSEQUENCES OF DISTURBANCE (iPCOD) FOR THE HARBOUR PORPOISE, BOTTLENOSE DOLPHIN, MINKE WHALE, AND GREY SEAL FROM ABERDEEN HARBOUR EXPANSION PROJECT (AHEP)

Prepared on behalf of

DRAGADOS

TECHNICAL REPORT 7

May 2019

OSC
OCEAN SCIENCE CONSULTING

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LIST OF ACRONYMS/ABBREVIATIONS/UNITS/TERMS

A-weighting	Sound weighting system for humans for quiet sounds
AHEP	Aberdeen Harbour Expansion Project
BC	Bubble Curtain
BD	Behavioural Disturbance
BOWL	Beatrice Offshore Windfarm Limited
BND	BottleNose Dolphin
C-weighting	Sound weighting system for humans for noisy conditions
D-weighting	Sound weighting system for humans for intense sounds
dB	DeciBels
DUK	Dragados UK
g	gram
GS	Grey Seal
HF	High Frequency
HP	Harbour Porpoise
Hz	Hertz
iPCOD	interim Population Consequences of Disturbance
kg	Kilogram
km^2	Square kilometre
lb	Pound
LF	Low Frequency
µPa	Micro Pascale
M-weighting	Sound weighting system for marine mammals (similar to C-weighting)
MF	Mid Frequency
Mhf	High-frequency cetaceans (Southall criteria)
ML	Marine Licence
Mlf	Low-frequency cetaceans (Southall criteria)
Mmf	Mid-frequency cetaceans (Southall criteria)
MMO	Marin Mammal Observer
Mpa	Pinnipeds in air (Southall criteria)
Mpw	Pinnipeds in water (Southall criteria)
MS-LOT	Marine Scotland Licensing and Operations Team
MSS	Marine Scotland Science

MW	Minke Whale
N_{min}	Minimum population size estimate
NOAA	National Oceanic and Atmospheric Administration
OSC	Ocean Science Consulting Limited
OW	Otariid pinnipeds in Water (NOAA criteria)
PCoD	Population Consequences of Disturbance
PTS	Permanent Threshold Shift
PW	Phocid pinnipeds in Water (NOAA criteria)
SCANS	Small Cetaceans in the European Atlantic and North Sea
SCOS	Special Committee on Seals
SEL	Sound Exposure Level
SL	Source Level
SNH	Scottish Natural Heritage
TTS	Temporary Threshold Shift
UK	United Kingdom of Great Britain and Northern Ireland
UXO	Unexploded Ordnance
VHF	Very-High Frequency

1. SUMMARY

Construction of the Aberdeen Harbour Expansion Project (AHEP) during 2018 was delayed; therefore, Dragados UK (DUK) has applied for a variation to their Marine Licence (ML) to extend the period over which rock blasting for harbour construction can occur. A requirement of the ML application is to perform population viability analysis for four species of marine mammals: harbour porpoise (HP, *Phocoena phocoena*), bottlenose dolphin (BND, *Tursiops truncatus*), minke whale (MW, *Balaenoptera acutorostrata*), and grey seal (GS, *Halichoerus grypus*) using the interim Population Consequences Of Disturbance (iPCOD) modelling framework.

DUK contracted Ocean Science Consulting Limited (OSC) to perform this analysis for several potential development strategies (with and without double-bubble curtain and different charge sizes) as well as cumulatively with other port and windfarm construction projects along the east coast of Scotland.

When using a double-bubble curtain, blasting at AHEP with the largest charge size modelled (100 kg) was not predicted to significantly affect population size of any species of marine mammals studied. When the bubble curtain was not used, disturbance from a charge of 100 kg did not significantly affect HP, BND or GS population sizes; however, it did cause a significant decrease to MW population sizes. This decrease became insignificant for MW if the charge was reduced to 50 kg.

Cumulative models resulted in a decrease in population size to all species, which was significant for BND, MW and GS. However, cumulative models which included AHEP were not significantly different than those that did not include AHEP. Therefore, construction at AHEP is not expected to create additional disturbance for these four species of marine mammals than is expected from other developments.

It is recommended that any blasting at AHEP only occurs with a double-bubble curtain in place to reduce acoustic emissions. According to modelling results presented here, this should be sufficient to reduce population-level consequences to the investigated species of marine mammals arising from AHEP alone at any

charge size tested. If blasting was undertaken without a bubble curtain, the charge size would need to be reduced to a maximum of 50 kg to prevent population level consequences for any species.

2. INTRODUCTION

The loudest sounds generated by human activities at sea are caused by explosions for removal of seabed for construction or seabed clearance (UneXploded Ordnance, UXO). Underwater explosions are characterised by a near-instantaneous rise from ambient pressure to an extremely high peak pressure generating an explosive shock wave. Farther from the explosion, the peak pressure decays and the explosive wave propagates as an impulsive, broadband sound.

The source level of explosions scales according to size of the charge. For example, a 10,000 lb explosive produces sound with a (back-calculated) source level (SL) of 304 dB re 1 µPa and frequency of 0.5–50 Hz while a 98 lb explosive produces sound with an SL of 289 dB re 1 µPa at 10–200 Hz (Hildebrand, 2009). Much smaller charges used in seal bombs (to deter marine mammals) of only 2.3 g can still produce sound with SL of 205 dB re 1 µPa at 15–100 Hz (Hildebrand, 2009). The sound produced from these explosions has capacity to impact marine mammals.

2.1. Marine mammals & sound

Marine mammals, and in particular cetaceans (whales, dolphins, and porpoises), use different sound-frequency bands for a number of activities, which include, but are not limited to: communication, navigation, foraging, and a range of activities within the wider social group such as cohesive actions, warnings, and maternal relationships (Southall et al., 2007; André et al., 2010). Sound perception and production is also an important sensory modality for pinnipeds – seals and sea lions (Schusterman and Van Parijs, 2003). In most cases, hearing range of cetaceans is less well understood than that of pinnipeds (due to logistical difficulties with studying them), but it is assumed generally that they hear over similar frequency ranges to sounds that they produce. Odontocete (toothed) cetaceans are considered to be more sensitive to underwater sound and produce sound at higher frequencies than baleen whales and pinnipeds (Southall et al., 2007; NOAA, 2018).

Underwater noise generated by marine activities (anthropogenic noise) has capacity to impact wildlife. Potential direct effects include damage to auditory systems, avoidance of habitats, behavioural alterations, and masking of biologically important sounds (Southall et al., 2007; Branstetter et al., 2013; Tougaard et al., 2016; Mikkelsen et al., 2017). Anthropogenic noise can also affect marine mammals indirectly through impact to both adult and juvenile/larval stages of prey such as fish and invertebrates (Packard et al., 1990; Mooney et al., 2010; Simpson et al., 2010; Radford et al., 2011; Holles et al., 2013).

There is little doubt that some noisy activities are detrimental to marine mammals (and, in some cases, likely cause death), but quantifying this doubt is difficult (Todd, 2016). Consequently, exact effects of anthropogenic sound on marine mammals are unknown, but reviews (e.g., Richardson et al., 1995; Nowacek et al., 2007; Southall et al., 2007; Wright et al., 2007; Andersen et al., 2012; Johnston et al., 2012) highlight that increased background noise and certain sound sources might impact marine mammals in several ways: (1) death; (2) masking of important sounds (including communication signals, echolocation, sounds associated with finding prey or avoiding predators, and human threats such as shipping); (3) alterations in behaviour (including displacement from feeding/breeding/migration habitat); (4) hearing loss; (5) chronic stress; and, (6) indirect effects including displacement of prey species. Hearing loss is often defined as either a Permanent or Temporary Threshold Shift (PTS or TTS respectively) with which the animal's hearing sensitivity is reduced at a specific frequency. This reduction in sensitivity will either not recover or take a certain amount of time to recover.

Effects of sounds on marine mammals depend greatly on the characteristics of the sound. A useful distinction can be made between continuous (long duration), transient (short duration), and repeated transient sounds (de Jong et al., 2011). According to Southall et al. (2007), there are mainly two sound types that are relevant for marine mammal noise exposure criteria: pulse (single or multiple) and non-pulses. Sound from blasting at AHEP would be classified as single pulsed.

2.2. Marine mammals & noise criteria

Species and individuals are sensitive to sound at different frequencies. In humans, it has been shown that variance in sensitivity is related to an individual's perception of loudness of a sound (the sensation of loudness is expressed in phons). To account for differential sensitivity in humans, measures of sound may be normalised or 'weighted' by applying a filter that matches plots of perceived loudness. Weightings are applied numerically by adding or subtracting specific values on the decibel scale. There are three weighting systems used for humans: A-weighting (for quiet signals), C-weighting (for noisy conditions), and D-weighting (for intense sounds). Most commercial studies of potential effects of underwater noise on marine mammals use the Southall et al. (2007) criteria, which until recently, was the most widely used benchmark to assess effects of noise on marine mammals. An updated version of these criteria was published in March 2019 (Southall et al., 2019); however, noise modelling performed by Fugro (which generated many of the inputs used in this report) was performed prior to its publication. Therefore, details of this updated version are not reported here; instead, potential differences are presented in the discussion.

Southall and his colleagues (2007) produced a comprehensive review of impacts of underwater noise on marine mammals and proposed criteria for preventing injury based on both peak sound level and Sound Exposure Level, SEL (Southall et al., 2007). SEL is the time integral of the square pressure over a time window long enough to include the entire pressure pulse of the sound. SEL is therefore sum of the acoustic energy over a measurement period, and effectively takes account of both sound level, and duration over which the sound is present in the acoustic environment. These SEL criteria can then be applied to either a single transient pulse or cumulative energy from multiple pulses. To account for wide frequency dependence in the auditory response of marine species, M-Weighting (related to C-weighting) frequency functions were proposed for five functional hearing groups of marine mammals: low (Mlf), mid (Mmf), and high (Mhf) frequency hearing cetaceans and for pinnipeds in water (Mpw) and air (Mpa). A useful synopsis of functional hearing groups and definitions of terms is provided in Section 1.5.3. of OSC's Marine Mammal Observer and Passive Acoustic Monitoring Handbook (Todd et al., 2015). The Southall et al. (2007) criteria were developed using this weighting scheme and onset of TTS and PTS has been estimated for these groups based on measurements and extrapolation from terrestrial mammals. A caveat is that these criteria are based on audiograms of only a few species.

More recently, many of the authors of Southall et al. (2007) updated their criteria for assessing risk of marine mammal auditory injury and produced the NOAA (2016) then NOAA (2018) criteria, which also group marine mammals into five functional hearing groups: Low-frequency (LF), Mid-frequency (MF), and High-frequency (HF) cetaceans, Phocid pinnipeds (PW), and Otariid pinnipeds (OW), the latter of which are not present in significant numbers in UK waters. These criteria also apply filters to unweighted noise in order to approximate hearing sensitivity of the receptor.

Estimates of the number of animals expected to be exposed to PTS and TTS from blasting at AHEP were calculated by Fugro (2019) using the NOAA (2018) criteria.

Animals are expected generally to move away from noise and disturbing sound sources thereby reducing their exposure; however, there are a variety of reasons why this might not be the case. One of which is the 'dinner gong' or 'dinner bell' effect, in which adding acoustic alarms or pingers to, for example, fishing nets, can signal locations of prey availability and attract predators (Dawson, 1994). California sea lions (*Zalophus californianus*) have been shown to be attracted to fishing nets equipped with pingers (Carretta and Barlow, 2011); this result has also been suggested for bottlenose dolphins, *Tursiops truncatus* (López and Mariño, 2011). In addition, it has been suggested that grey seals (*Halichoerus grypus*) may use sound signals produced by acoustically tagged fish to locate prey (Stansbury et al., 2015).

2.3. Population consequences of disturbance

The Population Consequences of Disturbance (PCoD) approach is a methodology developed to estimate and quantify the potential consequences of offshore energy developments and other activities on marine mammals (Harwood et al., 2013). This method is aimed at assisting with decision-making when there is limited information available about the potential effects of developments. A methodology has been developed to implement this framework, called the interim Population Consequences Of Disturbance (iPCOD) framework (Booth et al., 2017). By combining information on population size, growth rate, age of reproduction, fertility rates, etc., as well as estimates of animals' responses to disturbance generated from expert elicitation (Booth and Heinis, 2018; Booth et al., 2019), this iPCOD framework allows efficient estimation of disturbance for several species of marine mammal.

The primary aim of the iPCOD framework is to investigate disturbance from renewable energy development (e.g. sound from impact piling during the construction of offshore windfarms). However, it can also be applied to other development projects where the number of animals exposed to PTS, TTS or behavioural disturbance can be estimated, such as blasting at AHEP.

2.4. Previous OSC work at AHEP

OSC has previously been contracted by DUK to monitor dolphin and harbour porpoise activity around AHEP using two cetacean echolocation click detectors (C-PODs), which have been deployed outside the harbour continuously since August 2018 (OSC, 2019a; OSC, 2019b). Results from these deployments have been used to inform the duration of disturbance from previous blasting events for porpoises (Section 4.7).

2.5. Rationale

Due to delays in construction, blasting at AHEP will no-longer be completed during the period of the original marine licence. A constraint of Marine Scotland issuing an updated licence, which would allow blasting to continue for approximately one more year, is that DUK assess the potential population-level impacts of this development on four species of marine mammal. These species include the harbour porpoise (HP), bottlenose dolphin (BND), minke whale (MW, *Balaenoptera acutorostrata*), and grey seal (GS). This report is intended to address knowledge gaps for these species and assess if AHEP is likely to cause significant disturbance at a population-level for each species. This will be achieved using iPCOD v5.0.

3. METHODOLOGY

3.1. Location

AHEP is located just south of Aberdeen in North East Scotland (**Figure 1**).

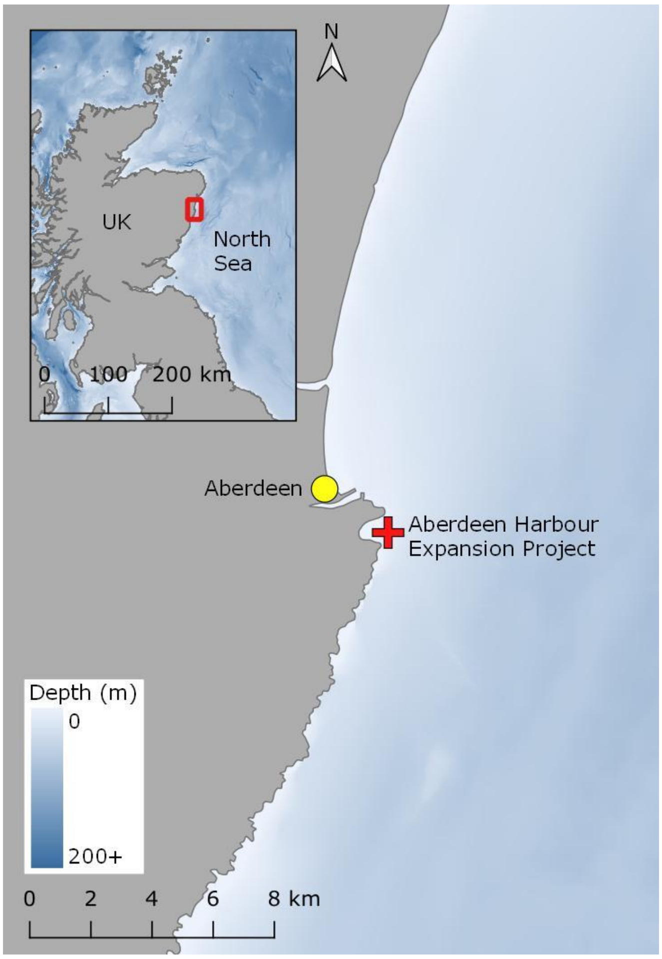

Figure 1: Location of Aberdeen Harbour Expansion Project (AHEP) in relation to Aberdeen (Scotland, UK). *Source*: OSC (2019).

3.2. Modelling scenarios

Modelling was performed for 17 scenarios:

- Four species (HP, BND, MW, GS);
- Four mitigation and cumulative stressor scenarios;
    - AHEP only with double-bubble curtain;
    - AHEP only without bubble curtain;
    - Cumulative impacts of east coast harbour and windfarm developments excluding AHEP.
    - Cumulative impacts of other developments and AHEP with double-bubble curtain;
- Charge size of 100 kg;
    - In one case a charge of 50 kg was used.

Modelling was performed in R v3.5.1 (R Core Team, 2018) using iPCOD v5.0 (Harwood et al., 2013; Sinclair et al., 2019). The input parameters used for iPCOD modelling are detailed in Section 4, and modelling was repeated 1,000 times for each scenario to gain an accurate representation of population trends. After models were run, two-sample t-tests were used to determine if impacted vs. unimpacted populations were significantly different after 24 years as per Smith (2018).

4. iPCOD INPUT PARAMETERS

4.1. Population size

Recent estimates of population size were sourced for each species from the literature (**Table 1**). The population size used for GS in models of AHEP only was the minimum population estimate (N_{min}) in the East Scotland management unit SCOS (2017).

Species	Population estimate	Source
HP	345,373 (246,526–495,752)	Hammond et al. (2017)
BND	195 (162–53)	Cheney et al. (2013)
MW	14,759 (7,908–27,544)	Hammond et al. (2017)
GS	14,717	SCOS (2017)

Table 1: Population sizes used for iPCOD modelling. *Source*: as above.

4.2. Demographic parameters

Demographic parameters used in the iPCOD model were from Sinclair et al. (2019).

Species	Management unit	Age calf/pup becomes independent (age1)	Age of first birth (age2)	Calf/pup survival (surv[1])	Juvenile survival (surv[7])	Adult survival (surv[13])	Fertility	Growth rate
HP	North Sea high adult survival	1	5	0.6	0.85	0.925	0.479	1.0000
BND	Coastal East Scotland	2	9	0.9	0.94	0.9497	0.3	1.0180
MW	European waters	1	9	0.72	0.77	0.96	0.90	1.0000
GS	All	1	5	0.222	0.94	0.94	0.84	1.0100

Table 2: Demographic parameters to be inputted into iPCOD modelling. *Modified from*: Sinclair et al. (2019).

4.3. Number of animals with PTS

Number of animals predicted to be close enough to suffer Permanent Threshold Shift (PTS) in each blasting scenario were provided by Fugro (2019). The number of animals potentially exposed to sound levels exceeding the PTS and TTS thresholds was calculated by multiplying the area in which these thresholds were breached by the relevant SCANS III density data. The affected areas were calculated as the area of sea covered by the radius of a circle centred on AHEP. The numbers of animals within each 'circle' or 'semi-circle' represents those potentially affected by each charge size and is regarded as a very conservative estimate, as no account was made of the potential noise attenuation from the rocky headlands and breakwater(s).

These values were calculated for each of the different charge sizes predicted to be used (20, 50 and 100 kg; **Table 3**).

Species	Mitigation	Charge Size (kg)	PTS Range (m)	PTS Area (km^2)	Number individuals present	% of population
HP	No BC	20	8800	147.970	88.6340	0.02566
HP	No BC	50	16000	453.730	271.7843	0.07869
HP	No BC	100	22000	838.490	502.2555	0.14542
HP	With BC	20	110	0.038	0.0228	0.00001
HP	With BC	50	460	0.490	0.2935	0.00008
HP	With BC	100	1400	3.300	1.9767	0.00057
BND	No BC	20	27	0.002	0.0001	0.00003
BND	No BC	50	120	0.045	0.0014	0.00068
BND	No BC	100	350	0.385	0.0115	0.00577
BND	With BC	20	27	0.002	0.0001	0.00003
BND	With BC	50	100	0.031	0.0009	0.00047
BND	With BC	100	100	0.031	0.0009	0.00047
MW	No BC	20	340	0.363	0.0142	0.00010
MW	No BC	50	1500	3.900	0.1521	0.00103
MW	No BC	100	4400	37.130	1.4481	0.00981
MW	With BC	20	100	0.031	0.0012	0.00001
MW	With BC	50	100	0.031	0.0012	0.00001
MW	With BC	100	100	0.031	0.0012	0.00001
GS	No BC	20	420	0.460	0.9200	0.00066
GS	No BC	50	1900	6.690	13.3800	0.00957
GS	No BC	100	5300	35.520	107.0400	0.07657
GS	With BC	20	100	0.031	0.0628	0.00004
GS	With BC	50	100	0.031	0.0628	0.00004
GS	With BC	100	100	0.031	0.0628	0.00004

Table 3: Details of Permanent Threshold Shift (PTS) ranges and number of animals impacted for each species in all potential development scenarios considered. Mitigation measures include the use of a double-bubble curtain (BC) or no bubble curtain. *Source*: Fugro (2019).

4.4. Number of animals with TTS

Number of animals predicted to be exposed to TTS was calculated using the same methodology as for PTS explained in Section 4.3 (**Table 4**).

Species	Mitigation	Charge size (kg)	TTS range (m)	TTS area (km^2)	Number individuals present	% of population
HP	No BC	20	15000	399.61	239.3664	0.06931
HP	No BC	50	24000	989.73	592.8483	0.17165
HP	No BC	100	32000	1692.60	1013.8674	0.29356
HP	With BC	20	420	0.46	0.2755	0.00008
HP	With BC	50	1900	6.69	4.0073	0.00116
HP	With BC	100	5300	53.50	32.0465	0.00928
BND	No BC	20	110	0.04	0.0011	0.00057
BND	No BC	50	460	0.49	0.0147	0.00735
BND	No BC	100	1400	3.30	0.0990	0.04950
BND	With BC	20	100	0.03	0.0009	0.00047
BND	With BC	50	100	0.03	0.0009	0.00047
BND	With BC	100	100	0.03	0.0009	0.00047
MW	No BC	20	1400	3.26	0.1271	0.00086
MW	No BC	50	5400	55.86	2.1785	0.01476
MW	No BC	100	9000	148.75	5.8013	0.03931
MW	With BC	20	100	0.03	0.0012	0.00001
MW	With BC	50	100	0.03	0.0012	0.00001
MW	With BC	100	110	0.04	0.0015	0.00001
GS	No BC	20	1700	5.24	10.4800	0.00750
GS	No BC	50	6000	68.31	136.6200	0.09773
GS	No BC	100	9900	179.50	359.0000	0.25680
GS	With BC	20	100	0.03	0.0628	0.00004
GS	With BC	50	100	0.03	0.0628	0.00004
GS	With BC	100	140	0.06	0.1232	0.00009

Table 4: Details of Temporary Threshold Shift (TTS) ranges and number of animals impacted for each species in all potential development scenarios considered. Mitigation measures include the use of a double-bubble curtain (BC) or no bubble curtain. *Source*: Fugro (2019).

4.5. Vulnerable subpopulations

It is unlikely that all individuals within a population will be vulnerable to disturbance from any particular development; therefore, vulnerable groups can be specified in the iPCOD modelling framework.

For HP in the southern North Sea, Booth et al. (2017) used the estimated number of porpoise in the corresponding Small Cetaceans in the European Atlantic and North Sea (SCANS) II block as the vulnerable subpopulation, which resulted in 51% of the total population. The same methodology was employed here, in which AHEP and other Firth of Forth and Tay developments fell within SCANS III region R and Moray Firth developments were in region S (**Figure 2**). For models of AHEP only, the vulnerable subpopulation was considered to be individuals in block R, and for cumulative models, the vulnerable subpopulation was those in blocks R and S. The same method was used for MW (**Table 5**).

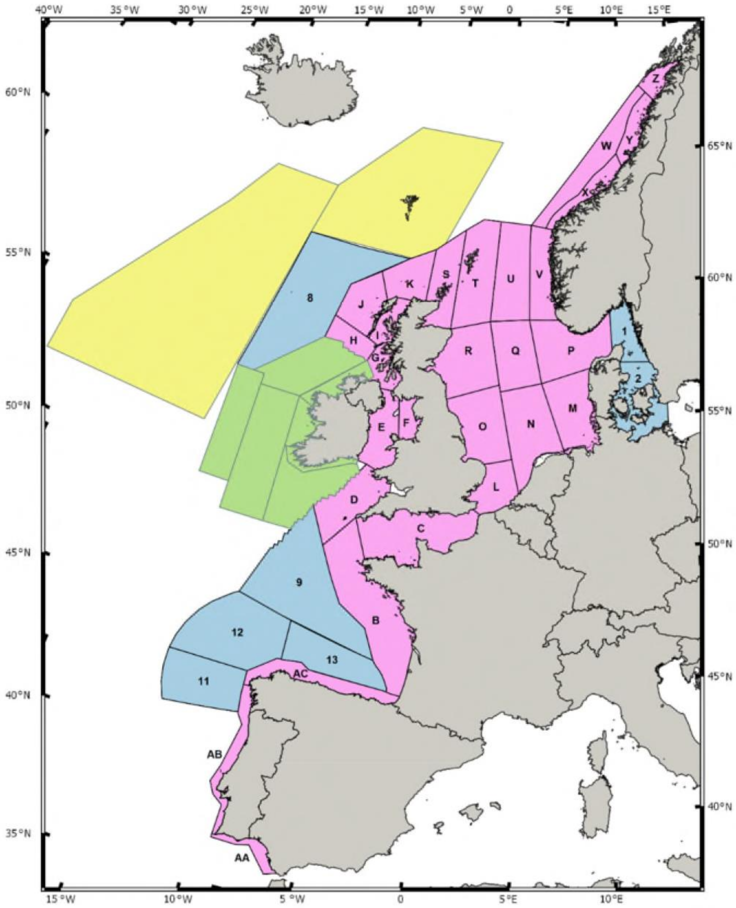

Figure 2: Survey blocks (letters and numbers) from SCANS III surveys. Pink blocks were surveyed by air and blue by ship. Green blocks were surveyed by the ObSERVE project and yellow by the Faroe Islands. *Source*: Hammond et al. (2017).

Species	East Coast or SCANS III block R (% of total population)	Moray Firth or SCANS III block S (% of total population)
Harbour porpoise	38,646 (11.2%)	6,147 (1.2%)
Bottlenose dolphin	98 (50%)	98 (50%)
Minke whale	2,498 (16.9%)	383 (2.6%)
Grey seal	14,717 (75.27%)	4,833 (24.72%)

Table 5: Vulnerable subpopulations of marine mammals used for modelling. Source *(values)*: Hammond et al. (2017) and SCOS (2017).

Twenty-five percent of the BND population along the east coast of Scotland have been estimated to use the area between Aberdeen and Stonehaven and 60% use the area between Aberdeen and the Firth of Forth. Previous modelling has assumed 50% of the population was vulnerable to developments along the East Coast and 50% to developments within the Moray Firth (e.g., Neart na Gaoithe, 2018a; Smith, 2018). For consistency, the same 50-50 split was used here (**Table 5**).

The entire population of GS within the East Scotland Seal Management Area was considered to be vulnerable to disturbance from developments along the East Coast; therefore, models of AHEP alone used a population size of 14,717 individuals and assumed 100% would be vulnerable to disturbance. For cumulative GS models, the AHEP development was considered to be close enough to the Moray Firth to potentially impact individuals within that management unit; therefore, both populations were considered for cumulative scenarios for GS (**Table 5**).

4.6. Seasonality

Some species exhibit seasonal shifts in distribution; therefore, seasonality can be specified in models. However, seasonality was not implemented into these models to be consistent with the approach taken by windfarm developers and as advised by Scottish Natural Heritage (SNH), Marine Scotland Science (MSS) and Marine Scotland Licencing and Operations Team (MS-LOT).

4.7. Duration of disturbance

One residual day of disturbance was used for each species; however, this is likely an overestimate, particularly for HP and GS. This means that there is one day of actual disturbance and one subsequent day of disturbance afterward.

Using moored echolocation click detectors (C-PODS), the duration between a blast and the next subsequent detection on C-PODs was calculated and found that porpoises are detected approximately 3.24 hours after blasting events (**Figure 3** and **Figure 4**). The same procedure was used to estimate duration of disturbance for GS, except using times of sightings from Marine Mammal Observer (MMO) spreadsheets provided by Fugro. This resulted in an average of 12 hours between blast and the next detection. This is likely an overestimate because MMOs cannot record at night, so some blasting events that occurred in the evening or afternoon had little subsequent MMO effort until the next day.

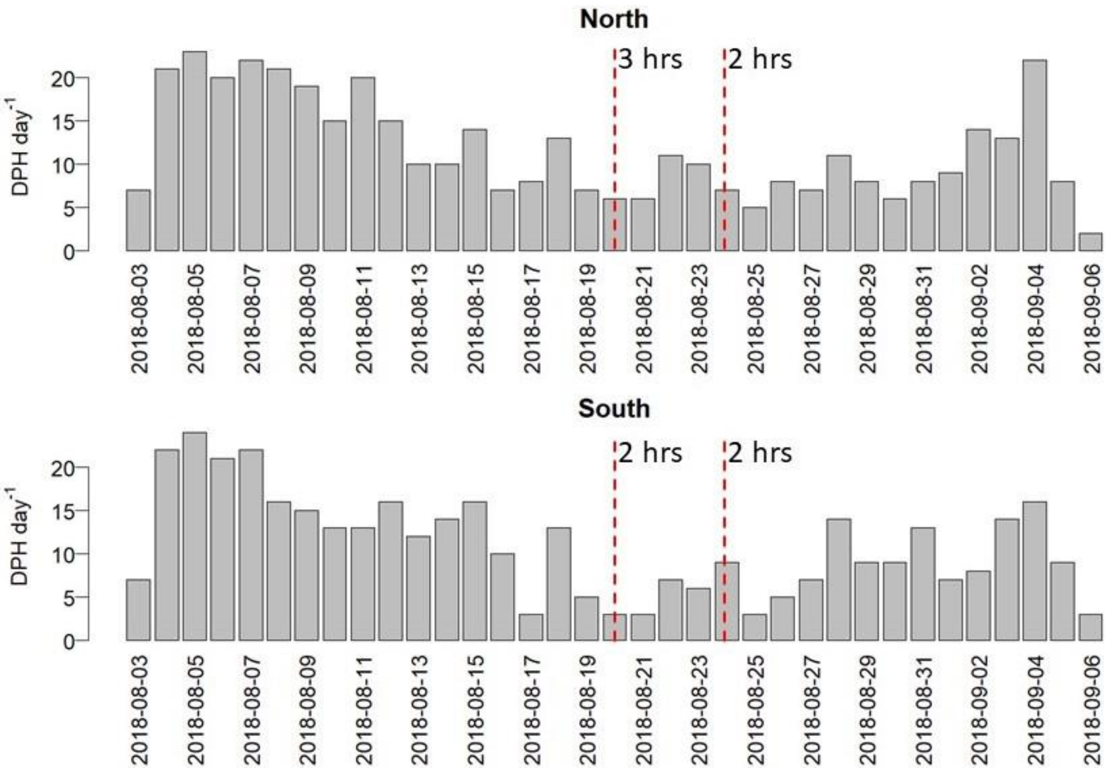

Figure 3: Harbour porpoise detections during C-POD deployment two showing AHEP blast days (red dotted lines) and hours until the subsequent porpoise detection (number next to line). *Source*: OSC (2019a).

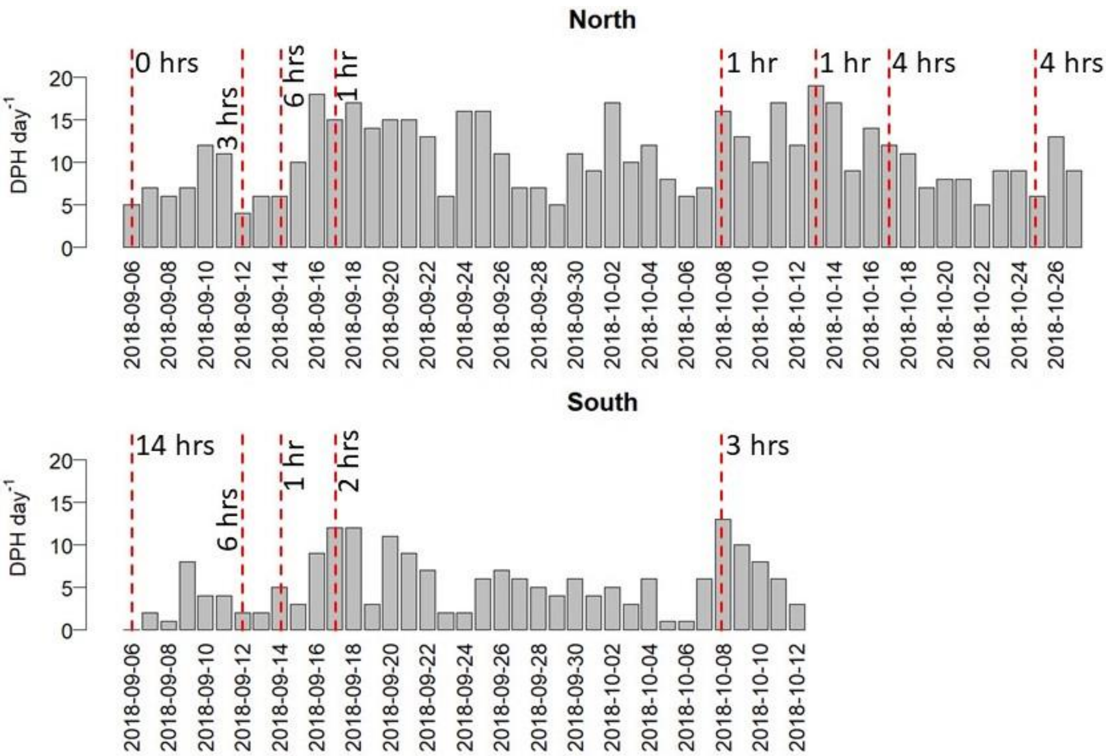

Figure 4: Harbour porpoise detections during C-POD deployment three showing AHEP blast days (red dotted lines) and hours until the subsequent porpoise detection (number next to line). *Source*: OSC (2019b).

4.8. AHEP blasting schedule

AHEP have applied to extend the blasting until 30 September 2020. A maximum of 211 days of blasting are expected to occur during this period, commencing in summer 2019. Blasting is predicted to occur every day during the summer campaign, then every other day thereafter. Consequently, as a model input, it was assumed that blasting would commence on 1 May 2019 and occur every single day until 27 August 2019, after which blasting would occur every other day until 27 February 2020 (totalling 211 days). In addition, every day of blasting that occurred during 2018 (12 days) has been included in the model. Any minor variation in the actual blasting dates are unlikely to significantly alter results, as seasonality is not included in the models. For cumulative models of impacts, any small change in blasting dates is again unlikely to cause a significant change in results unless it causes developments to overlap in time that did not previously overlap.

4.9. Model start date

The model start date was 1 January 2017 so that the full duration of piling at Beatrice Offshore Windfarm Limited (BOWL) could be included in the model.

4.10. Cumulative effects

Potential effects of AHEP were also considered cumulatively with other developments occurring or scheduled to occur on the east coast of Scotland during the next few years. Numbers of each species predicted to be affected by PTS or Behavioural Disturbance (BD) for each of the relevant developments were sourced from reports (**Table 6**). Estimates of number of animals expected to suffer BD from Moray East were obtained from the Seagreen report (Seagreen, 2018a). Estimates of PTS and TTS for Beatrice were obtained from (Neart na Gaoithe, 2018a), Smith (2018), and MORL (2012b).

Worst-case scenarios have been used for the assessment. When estimates of number of animals expected to exhibit a behavioural response were unavailable, the estimates of TTS were used instead. When estimates of PTS/BD were provided as a range (distance), this was assumed to relate to a circular area for all developments and the number of animals impacted was estimated as described in Section 4.3. These values are likely to be an over-estimate of disturbance for port developments.

Development	HP		BND		MW		GS	
	PTS	BD /TTS	PTS	BD /TTS	PTS	BD /TTS	PTS	BD /TTS
Seagreen Alpha and Bravo windfarm (concurrent)	0	1,177	0	4	0	76	0	24
Beatrice Offshore Windfarm Ltd.	9	3,191	0	19	36	177	78	347.5
Inch Cape Round 3	0	302	0	8	7	158	0	1,236
Neart na Gaoithe Round 3	77	1,177	0	2	14	77	1	821
Moray East	0	3442	0	19	0	185	0	1,184
Moray West	0	1609	0	15	0	30	0	207
Port of Cromarty	0.90	14.23	0	0	0.06	6.00	0.05	3.02

Table 6: Estimated number of animals expected to be exposed to Permanent Threshold Shift (PTS) or Behavioural Disturbance (BD) or Temporary Threshold Shift (TTS) by nearby developments. Developments within the Moray Firth are not included in this analysis as they relate to a different seal management unit. *Source (values)*: MORL (2012a); MORL (2012b); Inch Cape (2018b); Moray West (2018); Neart na Gaoithe (2018b); Port of Cromarty Firth (2018); Seagreen (2018a); Seagreen (2018b); and Smith (2018).

Approximate dates of piling/blasting of relevant developments are presented in **Table 7**. Piling for BOWL began in Q2 2017 and should have been completed in September 2018 (Beatrice, 2015; Smith, 2018). Piling for construction of Moray East is expected to begin in Q3 2019 and be completed by the end of Q2 2021. Piling every day during this period has been assumed. There is expected to be piling at Moray West between the beginning of Q2 2022 and the end of Q1 2023 (Moray West, 2018).

Piling for Neart na Gaoithe Round 3 offshore windfarm is expected to commence in January 2020 and be complete at the end of October 2020 (Neart na Gaoithe, 2017). It has been assumed that piling will occur on every day between 1 January 2020 and 31 October 2020.

Piling for the Inch Cape Round 3 offshore windfarm is expected to begin in September 2021 and last for approximately nine months (Inch Cape, 2018a). It is expected that actual piling will occur during 30% of the time; however, for the purposes of this assessment it is assumed that piling will occur on every day for the entire nine months.

Piling for construction of Seagreen Alpha and Bravo is expected to take 140 days of piling in 2022 and 2023 (Seagreen, 2018b). For the purpose of this assessment, each year it is assumed that piling will occur predominantly during summer time every day from 1 May until 17 September (140 days later).

Piling for Port of Cromarty should be completed by the end of June 2019 (Port of Cromarty Firth, 2018); therefore, it is assumed that this will occur every day from 1 January 2019 until 30 June 2019.

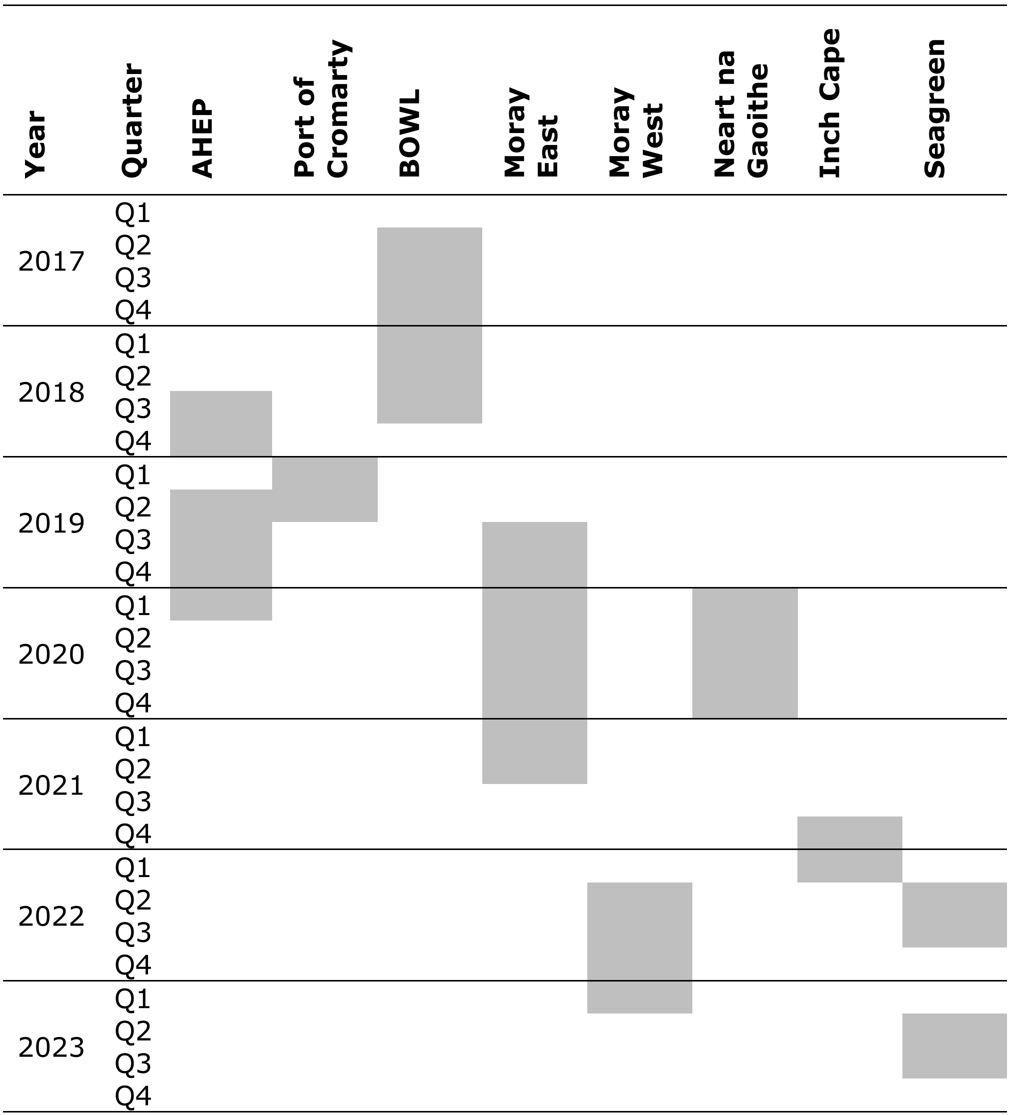

Table 7: Expected times of relevant development projects for cumulative impact assessment. *Source (dates)*: Neart na Gaoithe (2017); Inch Cape (2018b); Moray West (2018); Port of Cromarty Firth (2018); and Seagreen (2018b).

5. RESULTS

In the presentation of results, year one is the start of year one (prior to disturbance), year two is after one year of disturbance, year seven is after six years of disturbance, etc.

5.1. AHEP with double-bubble curtain

When using a 100 kg charge with a double bubble curtain, no population-level consequences of disturbance were predicted for any of the species investigated (**Table 8, Table 9** and **Table 10**). The unimpacted and impacted population sizes are between zero and four animals different after 25 years for each species (**Table 8**).

Year	Unimpacted population	Impacted population
	Harbour porpoise	
2	346,528 (318,247-369,214)	346,528 (318,247-369,214)
7	347,456 (296,302-400,225)	347,452 (296,298-400,224)
13	347,833 (277,798-419,811)	347,829 (277,799-419,802)
19	348,383 (266,472-444,410)	348,379 (266,472-444,405)
25	349,021 (253,538-459,087)	349,017 (253,540-459,071)
	Bottlenose dolphin	
2	204 (180-218)	204 (180-218)
7	233 (188-270)	233 (188-270)
13	265 (192-326)	265 (192-326)
19	297 (206-398)	297 (206-398)
25	334 (222-468)	335 (222-468)
	Minke whale	
2	14,778 (13,145-16,058)	14,778 (13,145-16,058)
7	14,771 (12,404-17,808)	14,771 (12,404-17,808)
13	14,698 (11,590-18,750)	14,698 (11,590-18,750)
19	14,719 (10,942-19,288)	14,720 (10,942-19,284)
25	14,670 (10,499-19,759)	14,670 (10,499-19,759)
	Grey seal	
2	14,872 (13,633-15,853)	14,872 (13,633-15,853)
7	15,601 (13,160-18,022)	15,602 (13,160-18,022)
13	16,632 (13,144-20,145)	16,632 (13,149-20,146)
19	17,767 (13,404-23,006)	17,768 (13,413-22,992)
25	18,825 (13,576-24,982)	18,826 (13,576-24,982)

Table 8: Unimpacted and impacted population sizes (mean and 95% confidence interval) of marine mammals with AHEP using a 100 kg charge with a double bubble curtain. *Source:* OSC (2019).

Year	Median of impacted to unimpacted population ratio	Median of ratio of impacted to unimpacted annual growth rate
	Harbour porpoise	
2	1	1
7	0.999994	0.999999
13	0.999994	1
19	1	1
25	1	1
	Bottlenose dolphin	
2	1	1
7	1	1
13	1	1
19	1	1
25	1	1
	Minke whale	
2	1	1
7	1	1
13	1	1
19	1	1
25	1	1
	Grey seal	
2	1	1
7	1	1
13	1	1
19	1	1
25	1	1

Table 9: Mean ratio of impacted to unimpacted population size and annual growth rate when using a 100 kg charge and a double-bubble curtain. Values less than one imply decline in population size or growth rate, values equal to one imply no impact and values greater than one imply increase. *Source*: OSC (2019).

Species	T statistic	Degrees of freedom	p-value
Harbour porpoise	-0.0018351	1998	0.9985
Bottlenose dolphin	0.032208	1998	0.9743
Minke whale	0.0025164	1998	0.9980
Grey seal	0.0080911	1998	0.9935

Table 10: Results of t-tests on the impacted vs. unimpacted populations of marine mammals for AHEP using a 100 kg charge with a double-bubble curtain after 24 years. *Source*: OSC (2019).

Harbour porpoise and MW have population growth rates of 1.0 (**Table 2**). Since there was no significant effect of AHEP when using a double-bubble curtain, HP and MW population sizes are predicted to remain stable over the 25-year study period (**Figure 5**). BND and GS have population growth rates of 1.018 and 1.01 respectively; therefore, their populations showed an overall increasing trend over the 25-year study period (**Figure 5**).

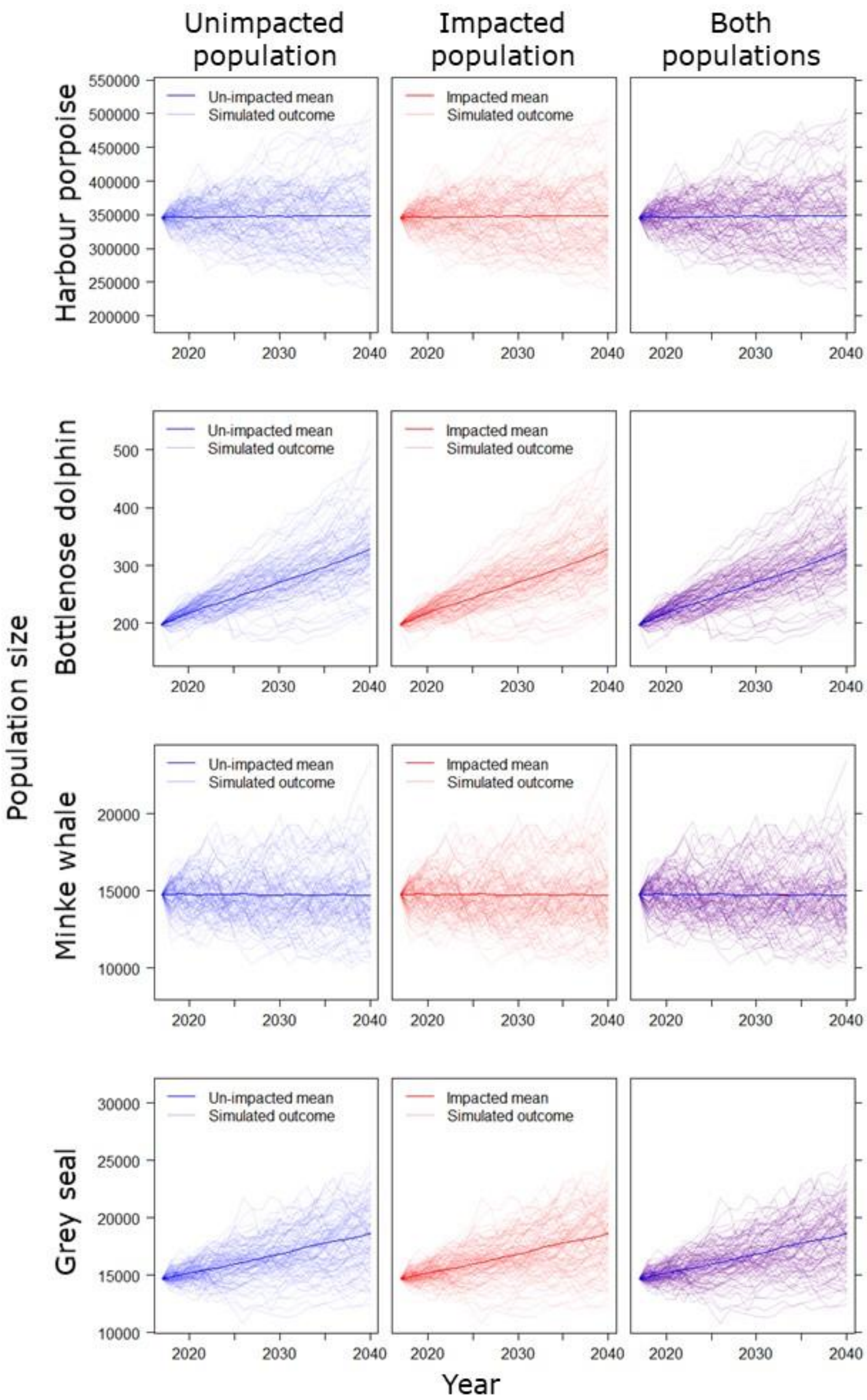

Figure 5: Population trajectories for each species for unimpacted and impacted populations over the 25-year study period when AHEP uses a 100 kg charge with a double-bubble curtain. *Source*: OSC (2019).

Models using a charge size smaller than 100 kg with a doubl-bubble curtain were not run, because they would have an even smaller effect than those with the 100 kg charge and double-bubble curtain, which was not significant for any species.

5.2. AHEP without bubble curtain

A small yet insignificant, decrease in HP and GS populations was predicted (404-167 individuals respectively), when AHEP blasting was modelled using 100 kg charges with no bubble curtain (**Table 11, Table 12,** and **Table 13**). In this scenario there was no effect on bottlenose dolphins (a difference of one individual). For MW, the impact was significant (**Table 13**), with a decrease of 264 individuals after 25 years (**Table 11**). Therefore, for MW, models were run testing smaller charge sizes with no bubble curtain. The effect reduced to insignificance ($T=-0.20348$, $p=0.8388$) when a charge size of 50 kg was used (**Table 11** and **Figure 7**).

Year	Unimpacted population	Impacted population
	Harbour porpoise – 100 kg	
2	344,937 (316,657-368,253)	344,937 (316,657-368,253)
7	344,568 (290,468-399,550)	344,172 (290,162-399,090)
13	344,796 (277,061-420,046)	344,394 (276,891-419,935)
19	343,605 (267,044-436,294)	343,202 (266,681-435,874)
25	344,067 (250,987-449,871)	343,663 (250,882-448,586)
	Bottlenose dolphin – 100 kg	
2	204 (180-218)	204 (180-218)
7	233 (188-270)	233 (188-270)
13	263 (194-326)	264 (196-328)
19	298 (204-390)	299 (208-394)
25	336 (220-458)	337 (220-460)
	Minke whale – 100 kg	
2	14,761 (13,245-16,100)	14,761 (13,245-16,100)
7	14,769 (12,254-17,492)	14,646 (12,182-17,412)
13	14,798 (11,648-18,629)	14,578 (11,445-18,394)
19	14,833 (11,150-19,331)	14,578 (10,914-19,062)
25	14,867 (10,761-20,339)	14,603 (10,514-20,086)
	Minke whale – 50 kg	
2	14,746 (13,002-16,056)	14,746 (13,002-16,056)
7	14,769 (12,262-17,607)	14,759 (12,260-17,604)
13	14,728 (11,530-18,573)	14,708 (11,528-18,540)
19	14,747 (11,254-19,409)	14,724 (11,218-19,388)
25	14,707 (10,796-20,508)	14,685 (10,780-20,451)
	Grey seal – 100 kg	
2	14,857 (13,576-15,848)	14,857 (13,576-15,848)
7	15,649 (13,290-18,215)	15,524 (13,146-18,104)
13	16,611 (13,088-20,229)	16,457 (13,057-20,106)
19	17,581 (13,170-22,567)	17,416 (13,104-22,244)
25	18,678 (13,214-24,723)	18,503 (13,063-24,577)

Table 11: Unimpacted and impacted population sizes (mean and 95% confidence interval) of marine mammals with AHEP for 100 and 50 kg charges with no bubble curtain. *Source:* OSC (2019).

Year	Median of impacted to unimpacted population ratio	Median of ratio of impacted to unimpacted annual growth rate
Harbour porpoise – 100 kg		
2	1	1
7	0.999177	0.999863
13	0.999182	0.999932
19	0.999194	0.999955
25	0.999193	0.999966
Bottlenose dolphin – 100 kg		
2	1	1
7	1	1
13	1	1
19	1	1
25	1	1
Minke whale – 100 kg		
2	1	1
7	0.993157	0.998856
13	0.986820	0.998895
19	0.984712	0.999144
25	0.983964	0.999327
Minke whale – 50 kg		
2	1	1
7	0.999489	0.999915
13	0.998856	0.999905
19	0.998684	0.999927
25	0.998746	0.999948
Grey seal – 100 kg		
2	0.999806	1
7	0.996968	0.999311
13	0.996994	0.999607
19	0.997022	0.999738
25	0.996972	0.999805

Table 12: Mean ratio of impacted to unimpacted population sizes and annual growth rate for AHEP when using a 100 or 50 kg charge without a bubble curtain. Values less than one imply decline in population size or growth rate, values equal to one imply no impact and values greater than one imply increase. *Source*: OSC (2019).

Species	T statistic	Degrees of freedom	p-value
Harbour porpoise	-0.17503	1998	0.8611
Bottlenose dolphin	0.41304	1998	0.67960
Minke whale	-2.5456	1998	0.01098
Grey seal	-1.3808	1998	0.16750

Table 13: Results of t-tests on the impacted vs. unimpacted populations of marine mammals for AHEP using a 100 kg charge without a bubble curtain after 24 years. *Source*: OSC (2019).

Plots of both impacted and unimpacted populations combined show that there is no difference for HP, BND, and GS for a 100 kg charge with no bubble curtain; however, the impacted MW population is slightly smaller than the unimpacted population (**Figure 6**). This decrease in impacted MW population disappears when a 50 kg charge is used instead (**Figure 7**).

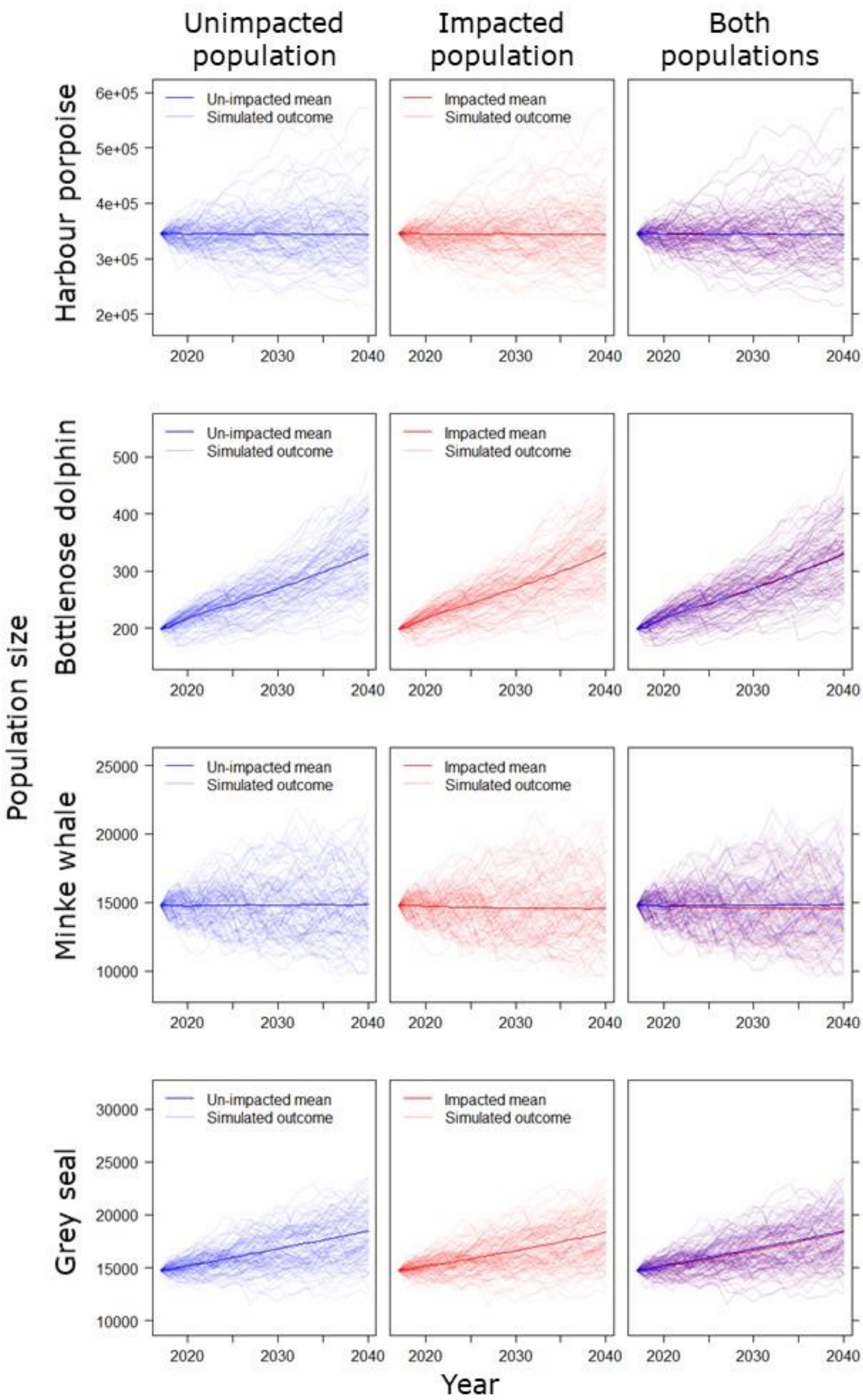

Figure 6: Population trajectories for each species for unimpacted and impacted populations over the 25-year study period when AHEP uses a 100 kg charge without a bubble curtain. *Source*: OSC (2019).

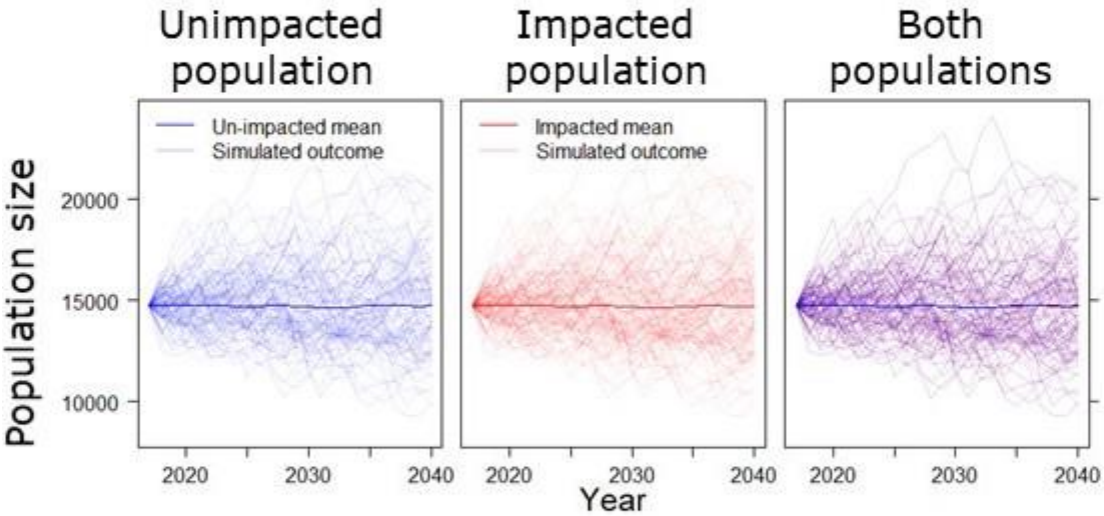

Figure 7: Population trajectories for minke whale for unimpacted and impacted populations over the 25-year study period when AHEP uses a 50 kg charge without a bubble curtain. *Source*: OSC (2019).

5.3. Cumulative East Coast and Moray Firth developments excluding AHEP

The HP population is expected to decrease by approximately 2,685 individuals if all developments (Beatrice, Moray East and West, Inch Cape, Seagreen, Neart na Gaoithe, and Port of Cromarty – AHEP not included in these models) occur (**Table 14** and **Table 15**). For HP, this decrease was not predicted to be significant at a population level (**Table 16**). The population size of each of the other species was also predicted to decrease (**Table 14**), and these decreases were predicted to be significant; most strongly for BND and MW (**Table 16** and **Figure 8**).

Year	Unimpacted population	Impacted population
	Harbour porpoise	
2	345,133 (317,099-369,347)	345,015 (316,864-369,096)
7	345,181 (294,901-400,087)	342,786 (293,157-396,397)
13	344,177 (279,376-421,106)	341,507 (276,680-418,325)
19	345,728 (264,101-435,113)	343,043 (262,962-431,546)
25	345,387 (248,335-454,803)	342,702 (246,086-450,498)
	Bottlenose dolphin	
2	204 (180-218)	201 (176-216)
7	234 (186-274)	203 (148-258)
13	266 (194-332)	233 (166-306)
19	301 (210-396)	262 (178-358)
25	339 (228-460)	296 (190-414)
	Minke whale	
2	14,765 (13,204-16,000)	14,701 (13,144-15,936)
7	14,684 (12,314-17,651)	13,717 (11,202-16,574)
13	14,703 (11,785-18,500)	12,984 (10,164-16,668)
19	14,793 (11,146-19,460)	12,771 (9,492-16,840)
25	14,836 (10,783-20,386)	12,713 (9,072-17,447)
	Grey seal	
2	19,729 (18,096-20,930)	19,717 (18,072-20,914)
7	20,848 (17,658-23,691)	20,586 (17,490-23,357)
13	22,085 (17,553-26,963)	21,780 (17,298-26,384)
19	23,465 (17,588-29,773)	23,143 (17,298-29,159)
25	24,848 (17,513-32,614)	24,508 (17,291-32,202)

Table 14: Unimpacted and impacted population sizes (mean and 95% confidence interval) of cumulative models of marine mammals when AHEP is excluded. *Source*: OSC (2019).

Year	Median of impacted to unimpacted population ratio	Median of ratio of impacted to unimpacted annual growth rate
	Harbour porpoise	
2	0.999988	0.999700
7	0.999636	0.998924
13	0.999618	0.999405
19	0.999614	0.999604
25	0.999618	0.999704
	Bottlenose dolphin	
2	1	1
7	0.887514	0.980308
13	0.901086	0.991358
19	0.899305	0.994121
25	0.899408	0.995592
	Minke whale	
2	0.996834	0.996834
7	0.940403	0.989811
13	0.880642	0.989464
19	0.855554	0.99137
25	0.84868	0.993187
	Grey seal	
2	0.999607	0.999607
7	0.990248	0.998368
13	0.989638	0.999132
19	0.989663	0.999423
25	0.989719	0.999569

Table 15: Mean ratio of impacted to unimpacted population size and annual growth rate for cumulative models when AHEP is excluded. Values less than one imply decline in population size or growth rate, values equal to one imply no impact and values greater than one imply increase. *Source*: OSC (2019).

Species	T statistic	Degrees of freedom	p-value
Harbour porpoise	-1.1942	1998	0.2325
Bottlenose dolphin	-16.826	1998	< 2.2e-16
Minke whale	-20.563	1998	< 2.2e-16
Grey seal	-1.9808	1998	0.04775

Table 16: Results of t-tests on the impacted vs. unimpacted populations of marine mammals for cumulative scenarios when AHEP is excluded after 24 years. *Source*: OSC (2019).

The significant decrease in population size can be seen most clearly for BND and MW, where the red line representing the mean of the impacted population estimates lies well below the corresponding blue line for the unimpacted populations in the right-hand plots of both populations together (**Figure 8**).

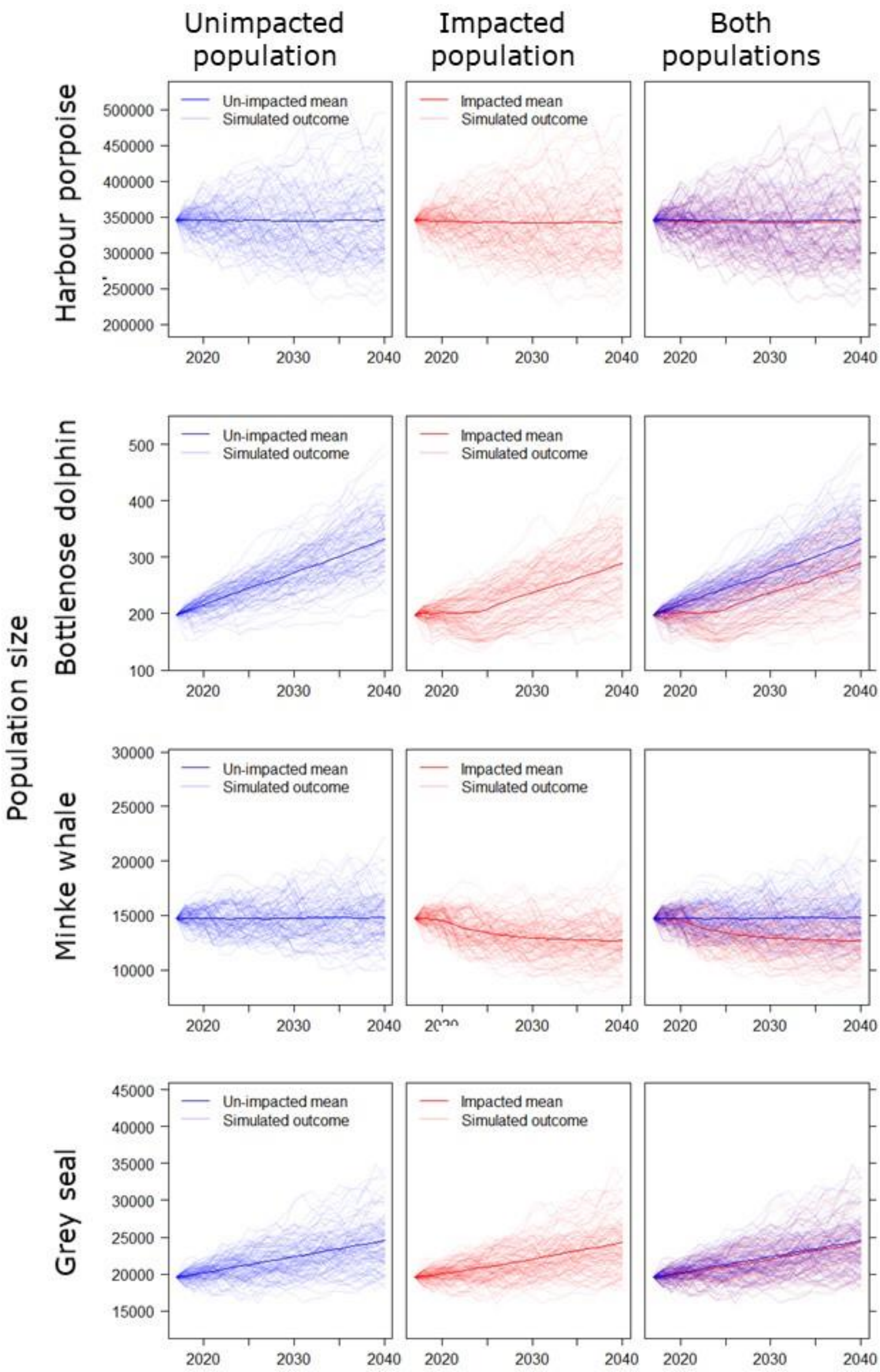

Figure 8: Population trajectories for each species for unimpacted and impacted populations over the 25-year study period for cumulative east coast and Moray Firth developments excluding AHEP. *Source*: OSC (2019).

5.4. Cumulative East Coast and Moray Firth developments including AHEP

Cumulative models of all developments including AHEP using a 100 kg charge with a double-bubble curtain show similar results to those obtained from cumulative models excluding AHEP. Each species exhibits a decrease in population size (**Table 17**, **Table 18**, and **Figure 9**); however, this decrease is not significantly different than the decrease predicted in cumulative models that exclude AHEP for any species (**Table 19**).

Year	Unimpacted population	Impacted population
	Harbour porpoise	
2	344,462 (312,425-369,455)	344,359 (312,353-369,391)
7	345,551 (294,005-401,174)	343,055 (291,428-397,302)
13	345,981 (275,844-420,915)	343,237 (274,255-418,933)
19	346,424 (261,073-442,433)	343,670 (259,569-435,964)
25	346,141 (259,506-453,595)	343,386 (256,727-449,465)
	Bottlenose dolphin	
2	204 (180-216)	201 (174-216)
7	234 (186-272)	204 (144-254)
13	265 (194-326)	233 (162-304)
19	298 (204-390)	261 (168-362)
25	337 (220-460)	296 (182-418)
	Minke whale	
2	14,764 (13,218-16,004)	14,702 (13,142-15,952)
7	14,709 (12,263-17,552)	13,757 (11,192-16,552)
13	14,769 (11,786-18,704)	13,065 (10,176-16,675)
19	14,751 (10,962-19,437)	12,764 (9,304-17,015)
25	14,743 (10,579-20,241)	12,665 (8,930-17,759)
	Grey seal	
2	19,734 (18,144-21,090)	19,720 (18,122-21,081)
7	20,714 (17,634-23,761)	20,452 (17,444-23,502)
13	22,204 (17,648-27,207)	21,894 (17,441-26,879)
19	23,569 (17,617-30,194)	23,239 (17,494-29,655)
25	25,025 (17,818-33,256)	24,674 (17,592-32,744)

Table 17: Unimpacted and impacted population sizes (mean and 95% confidence interval) of cumulative models of marine mammals when AHEP is using a 100 kg charge with a double-bubble curtain. *Source*: OSC (2019).

Year	Median of impacted to unimpacted population ratio	Median of ratio of impacted to unimpacted annual growth rate
Harbour porpoise		
2	0.999741	0.999741
7	0.993569	0.998925
13	0.992904	0.999407
19	0.992907	0.999605
25	0.992917	0.999704
Bottlenose dolphin		
2	1	1
7	0.901786	0.982918
13	0.909895	0.992162
19	0.908186	0.994664
25	0.910413	0.996097
Minke whale		
2	0.996896	0.996896
7	0.940817	0.989884
13	0.881294	0.989525
19	0.856413	0.991426
25	0.849632	0.993233
Grey seal		
2	0.999613	0.999613
7	0.98953	0.998247
13	0.988695	0.999053
19	0.98868	0.999368
25	0.988678	0.999526

Table 18: Mean ratio of impacted to unimpacted population size and annual growth rate for cumulative models when AHEP is using a 100 kg charge with a double-bubble curtain. Values less than one imply decline in population size or growth rate, values equal to one imply no impact, and values greater than one imply increase. *Source*: OSC (2019).

Species	T statistic	Degrees of freedom	p-value
Harbour porpoise	-0.38532	1998	0.7000
Bottlenose dolphin	-0.28638	1998	0.7746
Minke whale	0.37563	1998	0.7072
Grey seal	-0.7475	1998	0.4549

Table 19: Results of t-tests on the impacted populations of marine mammals for cumulative scenarios when AHEP is excluded vs. when AHEP is included using a 100 kg charge with a double-bubble curtain after 24 years. *Source*: OSC (2019).

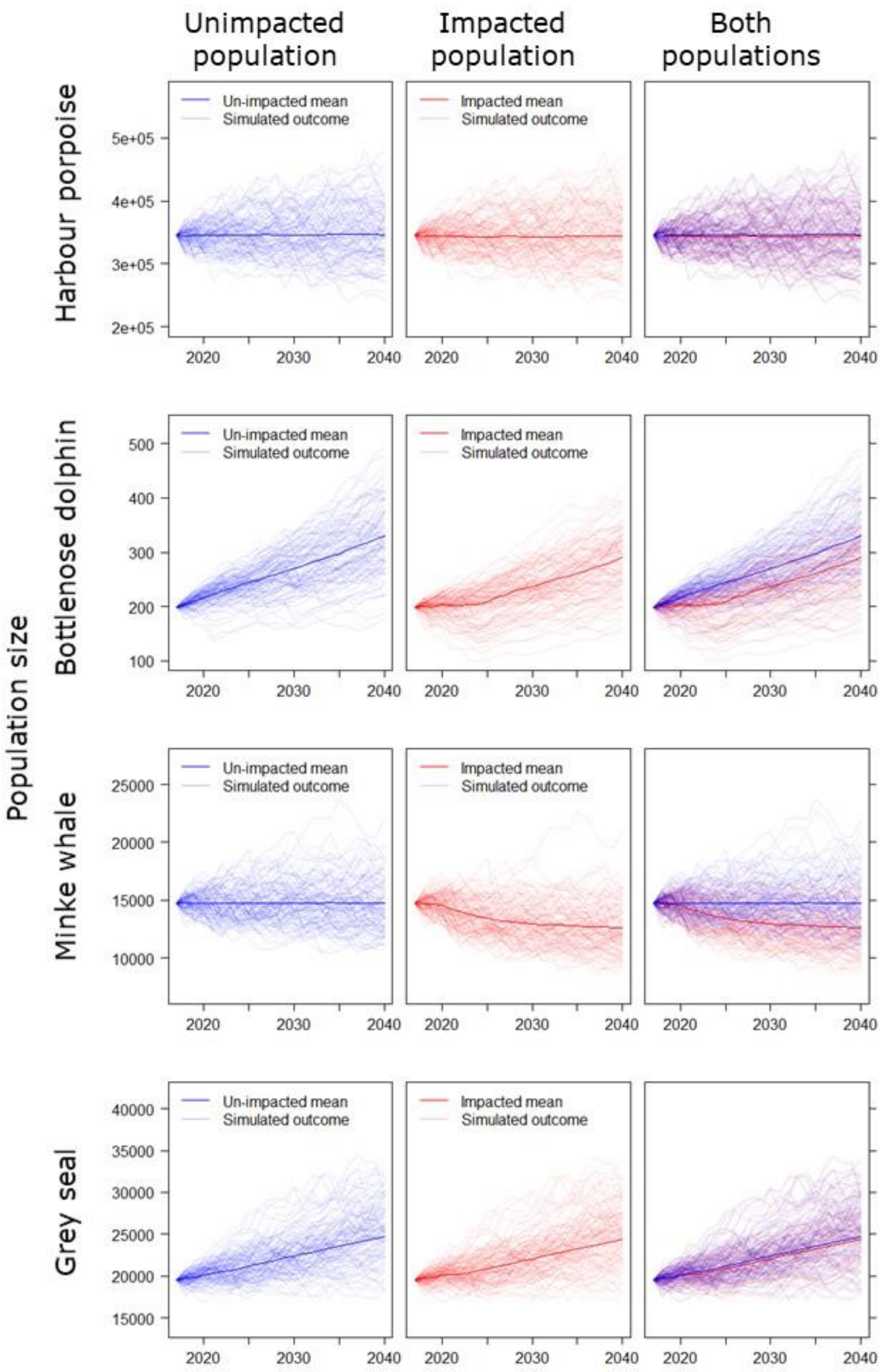

Figure 9: Population trajectories for each species for unimpacted and impacted populations over the 25-year study period when cumulative effects of other developments are included and AHEP uses a 100 kg charge with a double bubble curtain. *Source*: OSC (2019).

6. DISCUSSION

iPCOD modelling was performed for HP, BND, MW and GS to investigate potential impacts of blasting for construction of AHEP. This was performed for AHEP under several potential development strategies (with and without double-bubble curtain and different charge sizes) as well as cumulatively with other port and windfarm construction projects along the east coast of Scotland.

When using a double-bubble curtain, blasting at AHEP using the largest charge size modelled (100 kg) was not predicted to significantly affect population size of any of the species of marine mammals studied. When the bubble curtain was not used, disturbance from a charge of 100 kg did not significantly affect HP, BND or GS population size; however, it did cause a decrease to MW population sizes, which became insignificant if the charge was reduced to 50 kg.

Cumulative models resulted in a decrease in population size for all species, which was significant for BND, MW and GS. However, the addition of AHEP to cumulative models did not significantly change the results compared to those that did not include AHEP. Therefore, construction at AHEP is not expected to significantly affect these four species of marine mammals in combination with other developments. Cumulative modelling was performed on worst-case scenarios of each development; therefore, the actual impact of these developments is unlikely to be this extreme.

Results of modelling presented here are likely to represent a precautionary estimate of disturbance. Though population-level impacts from disturbance were not significant for HP under any scenario, in reality, the duration of disturbance is expected to be shorter than that used for modelling. Expert elicitation used to inform iPCOD modelling states HP will likely be disturbed by low-frequency broadband-pulsed noises like piling for approximately six hours (Booth et al., 2019). This is much less than the two days (one original day of disturbance and one day of residual disturbance) used in the current modelling, meaning these results are very precautionary. In addition, cetacean echolocation click detectors moored outside the harbour recorded porpoise back at the site a mean of 3.24 hours after blasting.

Similarly, for GS, MMOs reported them back in the site a mean of 12 hours after blasting. The iPCOD expert elicitation also suggested disturbance would last for much less than 24 hours, but an actual duration could not be determined due to a lack of knowledge (Booth et al., 2019).

MW appear to be more susceptible to disturbance from blasting at AHEP than the other species investigated (e.g. requiring the charge size to be reduced to 50 kg when no bubble curtain is used). However, this is likely an overestimate of the impact to MW. The number of individuals estimated to be affected by PTS or TTS by Fugro (2019) was calculated using the average density throughout the entire SCANS III region R. However, this does not take into account regional differences in animal density. MW are more abundant offshore; therefore, it is likely that fewer will actually be within the range of disturbance than predicted. The significant decline in MW population in the cumulative models likely stems from windfarm developments which are farther offshore in areas more frequently inhabited by MW. In addition, MW exhibit seasonal shifts in distribution and are more often present in the area during the summer (Reid et al., 2003; Risch et al., 2019). This would reduce the actual disturbance experienced by the species as they would not be present during part of the year.

In cumulative modelling scenarios, the BND population size stops increasing and remains constant for the duration of developments (seven years); however, it begins to increase again once the developments are complete. The impacted BND population increases at the same rate as the unimpacted population; therefore, the population size remains approximately seven years behind that of the unimpacted population. Conversely, the MW population, which is constant in unimpacted scenarios, exhibits a decline which then levels off after the completion of developments, but the population remains reduced for the entire 25-year study period and does not increase back to baseline levels.

6.1. Updated sound exposure criteria

The results presented here are based on modelling by Fugro which estimated the number of animals affected by various blasting and mitigation options at AHEP Fugro (2019). This modelling was performed using best-available guidance at the time, which was the NOAA (2018) criteria. Since this modelling was performed, updated guidance has been published (Southall et al., 2019). This updated guidance built on previously proposed recommendations for PTS and TTS onset (Southall et al., 2007) using over a decade of new research. These updated criteria are very similar to the NOAA (2018) criteria, and have the same limits for PTS and TTS onset. Therefore, modelling performed using the updated Southall et al. (2019) guidelines would be expected to generate the same results as the NOAA (2018) criteria.

6.2. Limitations of iPCOD

Difficulties were encountered during the modelling process when running the cumulative scenarios. These models originally failed to run for BND and MW (originally using two days of residual disturbance). Increasing the population size allowed the models to run, and they also ran successfully when using one day of residual disturbance. The developers of the package were notified of these inconsistencies and have since provided code which should address these errors; however, this was not received with enough time to repeat all the modelling. The cumulative models for GS each took several hours to run and approximately 24 hours for HP cumulative models. Developers advised that the error was caused when there was a lot of piling that occurred late in the year. This updated code has not yet been publicly released and is still undergoing testing by the developers.

7. CONCLUSIONS

Modelling indicates that blasting at AHEP will not significantly affect the populations of HP, BND, MW or GS individually or cumulatively with other developments at the largest charge size investigated when a double-bubble curtain is used.

8. RECOMMENDATIONS

It is recommended that blasting at AHEP only occurs with a double-bubble curtain in place to reduce acoustic emissions. According to modelling results presented here, this should be sufficient to reduce population-level consequences to the investigated species of marine mammals arising from AHEP alone at any charge size tested. If blasting were to happen without a bubble curtain (which is not expected), the charge size would need to be reduced to a maximum of 50 kg to prevent population level consequences of disturbance for any of the four species.

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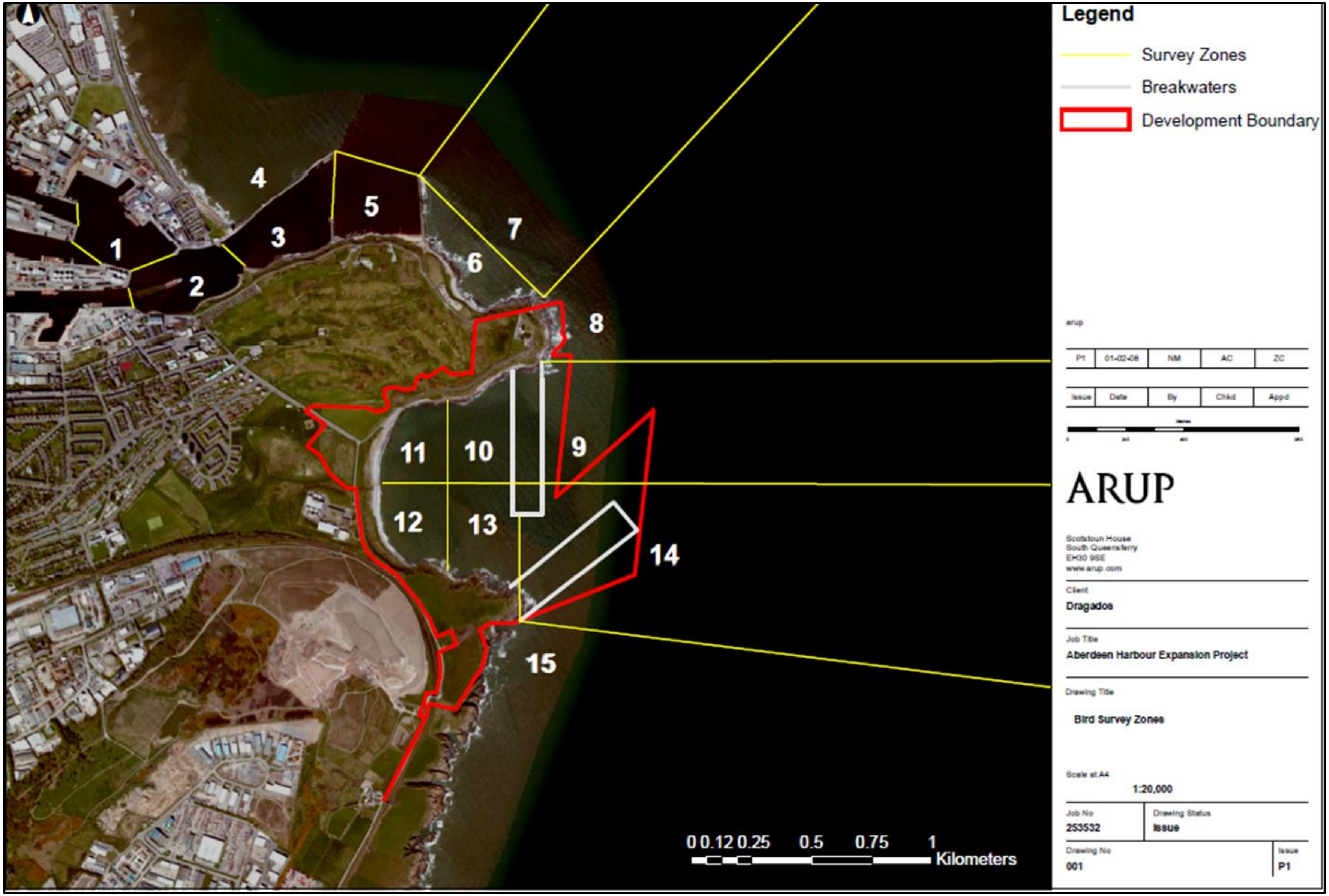
F. RESULTS OF THE POST CONSENT EIDER DUCK MONITORING (2017 TO 2019)


Legend
Survey Zones
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Kilometers
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South Queensferry
EH30 9SE
www.arup.com
Client
Dragados
Job Title
Aberdeen Harbour Expansion Project
Drawing Title
Bird Survey Zones
Scale at A4
1:20,000
Job No
253532
Drawing Status
Issue
Drawing No
001
Issue
P1

Date	Zone															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
20/06/2017	0	0	9	0	13	240	0	38	1	2	6	0	69	0	0	378
21/06/2017	0	0	22	0	14	431	0	1	0	0	0	11	67	0	0	546
22/06/2017	0	0	0	0	21	75	0	296	3	14	40	61	30	0	0	540
26/06/2017	0	0	2	0	20	99	0	48	14	0	80	81	22	19	0	385
28/06/2017	0	0	1	0	27	62	0	117	13	0	7	82	46	12	0	367
03/07/2017	0	0	0	0	8	130	0	114	5	0	57	19	9	4	0	346
05/07/2017	0	0	4	0	28	154	0	40	0	0	0	45	21	0	0	292
06/07/2017	0	0	0	0	44	242	0	2	0	0	0	30	40	0	0	358
09/07/2017	0	0	0	0	31	128	22	48	26	5	53	0	18	4	0	335
10/07/2017	0	0	0	0	29	93	0	99	35	0	43	7	24	0	0	330
12/07/2017	0	0	0	0	12	46	3	104	44	6	8	4	16	4	0	247
13/07/2017	0	0	0	0	14	157	76	0	0	0	3	0	2	0	0	252
14/07/2017	0	0	0	0	5	179	0	54	0	0	26	2	0	0	0	266
16/07/2017	0	0	0	0	14	213	0	0	0	0	26	29	2	0	0	284
08/08/2017	0	0	3	0	24	103	0	4	0	0	3	0	3	0	0	140
09/08/2017	0	0	0	0	10	0	4	75	167	3	0	0	26	0	0	285
10/08/2017	0	0	2	0	19	247	6	8	2	0	0	0	9	0	0	293
11/08/2017	0	0	3	0	0	141	0	32	29	2	0	2	0	0	0	209
13/08/2017	0	0	0	0	4	62	0	143	0	0	0	1	11	0	0	221
14/08/2017	0	0	5	0	18	118	0	44	0	0	0	0	38	0	0	223
15/08/2017	0	0	1	0	20	117	0	159	0	0	0	0	0	0	0	297
16/08/2017	0	0	0	0	24	147	0	60	0	0	0	6	0	0	0	237
19/08/2017	0	0	9	0	21	170	0	49	0	0	0	0	3	0	0	252
20/08/2017	0	0	1	0	24	39	0	88	128	0	0	0	2	0	0	282
21/08/2017	0	0	10	0	19	75	19	8	46	0	0	0	5	0	0	182
23/08/2017	0	0	12	0	11	45	0	36	76	0	0	0	1	0	0	181
24/08/2017	0	0	1	0	8	61	0	51	50	0	0	0	6	12	0	189
25/08/2017	0	0	0	0	16	105	0	165	0	0	0	0	0	0	0	286
26/08/2017	0	0	0	0	27	55	85	117	0	0	0	0	9	0	0	293
28/08/2017	0	0	3	0	35	128	0	63	49	0	0	0	20	16	0	314
29/08/2017	0	0	0	0	28	117	0	141	0	0	0	0	19	0	0	305
13/09/2017	0	0	2	0	3	34	0	43	0	0	0	0	0	0	0	82
14/09/2017	0	0	2	0	0	3	0	83	0	0	0	0	0	0	0	88
16/09/2017	0	0	0	0	0	2	0	84	0	0	0	0	0	0	0	86
17/09/2017	0	0	0	0	3	0	0	67	0	0	0	0	0	0	0	70
18/09/2017	0	0	0	0	0	0	0	84	0	0	0	0	0	0	0	84
19/09/2017	0	0	1	0	6	24	0	51	0	0	0	0	0	0	0	82
20/09/2017	0	0	0	0	5	30	0	48	0	0	0	0	0	0	0	83
21/09/2017	0	0	0	0	4	7	0	72	0	0	0	0	0	0	0	83
22/09/2017	0	0	3	0	0	22	0	42	0	0	0	0	0	0	0	67
25/09/2017	0	0	0	0	3	7	0	58	0	0	0	0	0	0	0	68
26/09/2017	0	0	0	0	2	6	0	61	0	0	0	0	0	0	0	69
27/09/2017	0	0	1	0	4	2	0	59	0	0	0	0	0	0	0	66
09/10/2017	0	0	0	0	0	11	0	14	0	0	0	0	0	0	0	25
10/10/2017	0	0	0	0	3	5	0	12	0	0	0	0	0	0	0	20
11/10/2017	0	0	0	0	0	2	0	7	0	0	0	0	0	0	0	9

Date	Zone															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
12/10/2017	0	0	0	0	0	0	1	19	0	0	0	0	0	0	0	20
13/10/2017	0	0	1		2	3	0	8	0	0	0	0	0	0	0	14
15/10/2017	0	0	0	0	1	4	0	3	0	0	0	0	0	0	0	8
17/10/2017	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	8
18/10/2017	0	0	0	0	0	2	2	8	0	0	0	0	0	0	0	12
20/10/2017	0	0	0	0	1	7	0	3	0	0	0	0	0	0	0	11
22/10/2017	0	0	0	0	0	5	0	4	0	0	0	0	0	0	0	9
24/10/2017	0	0	0	0	0	2	0	6	0	0	0	0	0	0	0	8
25/10/2017	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	18
26/10/2017	0	0	0	0	0	0	0	28	0	0	0	0	0	0	0	28
28/10/2017	0	0	0	0	0	0	0	26	0	0	0	0	0	1	0	27
11/02/2017	0	0	0	0	0	1	0	21	0	0	0	0	0	0	0	22
11/05/2017	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	22
11/10/2017	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	20
11/11/2017	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	25
11/12/2017	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	15
13/11/2017	0	0	1	0	0	0	0	22	0	0	0	0	0	0	0	23
15/11/2017	0	0	0	0	0	0	1	34	0	0	0	0	0	0	0	35
16/11/2017	0	0	0	0	0	0	2	28	0	0	0	0	0	0	0	30
17/11/2017	0	0	0	0	0	1	0	32	0	0	0	0	0	0	0	33
19/11/2017	0	0	3	0	0	0	0	23	0	0	0	0	0	0	0	26
25/11/2017	0	1	0	0	0	0	0	26	0	0	0	0	0	0	0	27
26/11/2017	0	1	0	0	0	0	0	33	0	0	0	0	0	0	0	34
28/11/2017	0	2	0	0	0	0	0	30	0	0	0	0	0	0	0	32
29/11/2017	0	1	2	0	0	0	0	34	0	0	0	0	0	0	0	37
30/11/2017	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	11
12/01/2017	0	0	6	0	0	0	0	25	0	0	0	0	0	0	0	31
12/05/2017	0	0	4	0	3	1	0	18	0	0	0	0	0	0	0	26
12/06/2017	0	0	3	0	0	0	0	49	0	0	0	0	0	0	0	52
12/09/2017	0	0	6	0	0	1	0	18	0	0	0	0	0	0	0	25
12/10/2017	0	4	0	0	0	4	0	25	0	0	0	0	0	0	0	33
12/12/2017	0	0	2	0	1	9	0	33	0	0	0	0	0	0	0	45
13/12/2017	0	0	5	0	5	5	8	40	0	0	0	0	0	0	0	63
14/12/2017	0	0	8	0	1	2	0	56	0	0	0	0	0	0	0	67
15/12/2017	0	0	3	0	0	0	0	28	0	0	0	0	0	0	0	31
17/12/2017	0	0	10	0	4	0	0	17	0	0	0	0	0	0	0	31
18/12/2017	0	5	3	0	0	0	0	48	0	0	0	0	0	0	0	56
20/12/2017	0	0	0	0	6	0	0	31	0	0	0	0	0	8	0	45
01/02/2018	0	4	2	0	0	0	0	43	0	0	0	0	0	0	0	49
01/03/2018	1	0	0	0	5	2	0	41	0	0	0	0	0	0	0	49
01/04/2018	4	0	0	0	0	0	0	23	0	0	0	0	0	0	0	27
01/06/2018	0	16	0	0	0	0	0	8	0	0	0	0	0	0	0	24
01/07/2018	0	1	0	0	0	1	0	29	0	0	0	0	0	0	0	31
01/08/2018	0	9	0	0	0	10	7	6	0	0	0	0	0	0	0	32
01/09/2018	0	18	3	0	0	0	0	8	0	0	0	0	0	0	0	29
01/10/2018	0	0	23	0	8	0	0	44	0	0	0	0	0	0	0	75

Date	Zone															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
01/11/2018	0	11	0	0	0	14	3	28	0	0	0	0	0	0	0	56
01/12/2018	0	10	0	0	4	1	0	21	0	0	0	0	0	0	0	36
14/01/2018	0	6	2	0	9	0	0	6	0	0	0	0	26	0	0	49
15/01/2018	17	0	2	0	3	0	0	13	0	0	0	0	0	0	0	35
16/01/2018	0	9	0	0	6	5	0	24	0	0	0	0	0	0	0	44
17/01/2018	0	0	1	0	5	8	7	16	0	0	0	0	0	0	0	37
18/01/2018	0	3	1	0	0	5	4	26	0	0	0	0	9	0	0	48
19/01/2018	0	6	0	0	0	3	0	36	9	0	0	0	0	0	0	54
21/01/2018	3	0	0	0	0	2	0	46	0	0	0	0	0	0	0	51
22/01/2018	0	8	11	0	0	0	0	37	0	0	0	0	0	0	0	56
23/01/2018	0	2	0	0	1	0	3	32	0	0	0	0	0	0	0	38
24/01/2018	0	5	2	0	2	14	4	11	0	0	0	0	0	0	0	38
25/01/2018	0	12	0	0	2	3	0	27	1	0	0	0	0	0	0	45
26/01/2018	0	5	0	0	0	0	0	61	0	0	0	0	0	0	0	66
27/01/2018	0	10	0	0	3	9	7	18	0	0	0	0	0	0	0	47
28/01/2018	0	3	0	0	3	0	11	48	0	0	0	0	0	0	0	65
29/01/2018	0	2	1	0	0	0	1	43	0	0	0	0	0	0	0	47
30/01/2018	0	1	1	0	0	0	1	21	0	0	0	0	0	0	0	24
02/01/2018	0	4	6	0	0	0	0	15	0	0	0	0	0	0	0	25
02/02/2018	0	2	0	0	0	2	0	26	0	0	0	0	0	0	0	30
02/03/2018	0	18	0	0	1	0	1	44	0	0	0	0	0	0	0	64
02/12/2018	0	22	0	0	0	3	0	33	0	0	0	0	0	0	0	58
13/02/2018	0	19	0	0	3	3	0	30	0	0	0	0	0	0	0	55
15/02/2018	0	15	0	1	1	0	0	27	0	0	0	0	0	0	0	44
16/02/2018	0	23	0	0	2	2	0	17	0	0	0	0	0	0	0	44
17/02/2018	0	18	2	0	0	6	1	13	0	0	0	0	9	0	0	49
18/02/2018	0	4	3	0	0	0	7	39	0	0	0	0	2	0	0	55
19/02/2018	0	4	0	0	1	1	0	34	1	0	0	0	0	0	0	41
20/02/2018	0	7	0	0	0	2	0	43	0	0	0	0	0	0	0	52
21/02/2018	0	8	0	0	3	3	0	33	0	0	0	0	0	0	0	47
22/02/2018	0	23	0	0	0	1	5	30	0	0	0	0	0	0	0	59
23/02/2018	0	21	0	0	0	4	0	30	0	0	0	0	0	0	0	55
25/02/2018	0	24	0	0	2	5	0	15	0	0	0	6	4	0	0	56
26/02/2018	0	24	1	0	9	1	0	11	0	0	0	0	0	0	0	46
27/02/2018	0	36	0	0	0	0	0	12	0	0	0	0	0	0	0	48
03/03/2018	0	11	8	0	0	0	0	6	0	0	0	0	0	0	0	25
03/07/2018	0	4	2	0	1	0	0	21	0	0	0	0	0	0	0	28
03/08/2018	0	0	8	0	0	0	0	25	0	0	0	0	19	0	0	52
03/09/2018	0	0	8	0	0	0	0	49	0	0	0	0	0	0	0	57
03/10/2018	0	0	2	0	0	6	0	45	0	0	0	0	0	0	0	53
03/12/2018	0	1	0	1	0	0	25	4	0	0	0	0	0	17	0	48
13/03/2018	0	5	0	0	1	36	0	0	0	0	0	0	6	0	0	48
14/03/2018	0	6	0	0	0	7	0	34	0	0	0	0	0	0	0	47
15/03/2018	0	16	1	0	4	0	0	23	0	0	0	0	0	0	0	44
17/03/2018	0	15	3	0	0	0	0	27	0	0	0	0	0	0	0	45
19/03/2018	0	18	4	0	4	0	0	0	4	0	0	0	0	5	0	35

Date	Zone															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
20/03/2018	0	6	5	0	0	0	0	19	3	0	0	0	7	0	0	40
21/03/2018	0	0	4	0	1	2	0	44	0	0	0	0	18	0	0	69
22/03/2018	0	11	0	0	0	32	8	7	0	0	0	0	7	0	0	65
23/03/2018	0	7	0	0	0	0	0	8	0	0	0	0	13	0	0	28
24/03/2018	0	23	0	0	1	8	2	20	0	0	0	0	2	0	0	56
25/03/2018	0	29	0	0	3	0	13	33	2	0	0	0	0	0	0	80
26/03/2018	0	21	0	0	0	0	25	3	0	0	0	0	0	0	0	49
30/03/2018	0	27	0	0	0	0	0	21	0	0	0	0	0	7	0	55
31/03/2018	0	37	4	0	0	0	0	7	1	0	0	0	0	0	0	49
04/01/2018	0	37	1	1	0	3	0	0	0	0	0	0	0	5	0	47
04/07/2018	0	45	0	0	0	0	0	14	0	0	6	0	0	0	0	65
04/08/2018	0	22	8	0	11	18	0	9	0	4	0	2	3	0	0	77
04/09/2018	0	35	3	0	15	0	0	19	0	0	0	0	0	0	0	72
04/10/2018	0	26	0	0	0	0	0	7	0	7	0	0	0	0	0	40
04/11/2018	0	31	1	0	0	0	0	8	0	7	0	0	0	0	0	47
04/12/2018	0	36	6	0	0	0	0	7	0	6	0	0	0	0	0	55
13/04/2018	0	22	0	1	1	0	0	4	0	6	0	0	0	0	0	34
14/04/2018	0	32	0	0	1	8	0	9	0	0	0	0	0	0	0	50
15/04/2018	0	27	0	0	0	0	0	20	0	1	7	0	0	0	0	55
16/04/2018	0	46	3	0	0	3	0	35	0	0	0	0	0	0	0	87
18/04/2018	0	44	0	0	0	9	0	21	0	0	0	0	0	0	0	74
19/04/2018	0	40	1	0	1	9	0	13	0	0	0	0	0	0	0	64
20/04/2018	0	21	0	2	0	10	0	28	0	0	0	0	0	0	0	61
21/04/2018	0	12	0	0	0	2	0	16	0	0	8	0	4	0	0	42
23/04/2018	0	11	0	0	0	4	0	14	0	0	0	0	0	0	0	29
25/04/2018	0	14	1	1	1	0	0	13	0	0	0	0	0	0	0	30
27/04/2018	0	0	0	1	5	0	0	3	0	0	0	0	9	0	0	18
29/04/2018	0	0	1	0	5	0	0	3	0	1	2	0	0	2	0	14
30/04/2018	0	8	0	0	0	1	0	2	0	0	0	2	0	0	0	13
05/01/2018	0	6	1	0	0	3	0	9	0	0	0	0	0	0	0	19
05/02/2018	0	3	6	0	3	0	0	1	0	0	0	8	0	0	0	21
05/03/2018	0	14	2	0	4	7	0	3	0	0	0	0	0	0	0	30
05/04/2018	0	7	2	0	5	3	0	4	0	0	0	1	0	0	0	22
05/12/2018	0	9	0	3	5	6	0	9	0	0	6	0	0	0	0	38
13/5/2018	0	4	3	0	0	0	0	12	0	0	0	0	5	0	0	24
14/05/2018	0	4	0	0	0	2	0	4	0	0	7	0	0	0	0	17
15/05/2018	0	0	2	0	4	3	0	2	0	0	6	0	0	1	0	18
17/05/2018	0	5	0	0	0	4	0	4	0	0	5	0	0	0	0	18
19/05/2018	0	7	0	0	0	2	0	0	0	0	0	7	0	0	0	16
21/05/2018	0	8	4	0	0	2	0	0	0	0	0	5	0	0	0	19
22/05/2018	0	4	0	0	1	0	0	5	0	8	0	0	0	0	0	18
23/05/2018	0	5	0	0	6	5	0	3	0	0	4	2	0	0	0	25
24/05/2018	0	4	0	2	0	3	0	4	0	1	6	0	0	0	0	20
23/06/2018	0	3	0	0	24	27	0	9	9	0	0	0	2	0	0	74
24/06/2018	0	0	0	6	25	70	0	5	0	0	0	0	1	0	0	107
25/06/2018	0	0	8	0	23	90	0	2	0	0	0	0	0	0	0	123

Date	Zone															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
27/06/2018	0	0	0	0	46	72	0	8	0	0	0	0	0	0	0	126
28/06/2018	0	2	1	0	53	83	5	20	0	0	0	2	0	0	0	166
29/06/2018	0	0	47	0	12	56	0	4	0	0	0	0	0	0	0	119
07/01/2018	0	4	22	0	35	36	0	11	0	0	0	0	0	0	0	108
07/02/2018	0	0	21	0	12	45	0	22	0	0	0	0	0	0	0	100
07/03/2018	0	1	9	0	32	45	0	9	0	0	0	0	0	0	0	96
07/04/2018	0	0	10	0	52	69	0	15	0	0	0	0	0	0	0	146
07/05/2018	0	4	36	0	0	67	0	17	0	0	0	0	0	0	0	124
07/06/2018	0	0	13	0	51	55	0	14	0	0	0	0	0	0	0	133
07/08/2018	0	0	5	2	50	82	0	17	0	0	0	0	0	0	0	156
07/09/2018	0	0	31	0	20	68	0	84	0	0	0	0	0	0	0	203
07/10/2018	0	0	2	0	46	44	0	64	0	0	0	0	0	0	0	156
07/11/2018	0	0	40	0	15	67	0	28	0	0	0	0	0	0	0	150
07/12/2018	0	0	25	0	28	51	0	66	0	0	0	0	0	0	0	170
21/07/2018	0	0	33	0	34	68	0	107	0	0	0	0	0	0	0	242
22/07/2018	0	0	0	0	54	111	0	41	0	0	0	0	0	0	0	206
23/07/2018	0	0	13	0	49	105	0	59	0	0	0	0	0	0	0	226
25/07/2018	0	0	13	0	57	101	0	78	0	0	0	0	0	0	0	249
26/07/2018	0	0	6	0	63	125	0	53	0	0	0	0	18	0	0	265
27/07/2018	0	0	22	0	36	104	0	74	0	0	0	0	5	0	0	241
28/07/2018	0	0	0	0	25	63	0	101	0	0	0	0	0	0	0	189
30/07/2018	0	5	7	0	40	137	0	24	0	0	0	0	0	0	0	213
31/07/2018	0	1	8	0	34	139	0	47	0	0	0	0	0	0	0	229
08/01/2018	0	1	4	0	38	145	0	69	0	0	0	0	0	0	0	257
08/02/2018	0	0	12	29	0	95	0	83	0	0	0	0	0	0	0	219
08/03/2018	0	0	10	0	68	176	0		0	0	0	0	0	0	0	254
08/06/2018	0	0	5	0	91	128	0	46	0	0	0	0	0	0	0	270
08/07/2018	0	0	14	0	82	153	0	8	0	0	0	0	0	0	0	257
08/08/2018	0	0	4	0	101	154	0	16	0	0	0	0	0	0	0	275
08/09/2018	0	0	9	0	84	157	0	13	0	0	0	0	0	0	0	263
14/08/2018	0	0	0	27	51	122	0	51	0	0	0	0	0	0	0	251
15/08/2018	0	0	3	0	47	42	0	107	0	0	0	0	0	0	0	199
17/08/2018	0	0	6	0	66	139	0	12	0	0	0	0	0	0	0	223
18/08/2018	0	1	25	0	46	72	0	69	0	0	0	0	5	0	0	218
19/08/2018	0	0	33	0	50	117	0	27	0	0	0	0	0	0	0	227
25/08/2018	0	0	0	0	40	11	0	87	0	0	0	0	0	0	0	138
27/08/2018	0	0	1	0	21	29	0	117	0	0	0	0	0	0	0	168
28/08/2018	0	0	3	0	42	65	0	81	0	0	0	0	0	0	0	191
19/09/2018	0	1	4	0	9	30	47	1	0	0	0	0	0	0	0	92
20/09/2018	0	0	1	0	5	10	0	48	0	0	0	0	0	0	0	64
24/09/2018	0	0	0	0	5	0	0	49	0	0	0	0	0	0	0	54
08/10/2018	0	0	0	0	0	2	0	14	0	0	0	0	0	0	0	16
09/10/2018	0	0	0	0	0	9	0	1	0	0	0	0	0	0	0	10
10/10/2018	0	0	0	0	1	1	0	9	0	0	0	0	0	0	0	11
11/10/2018	0	0	3	0	0	0	0	8	0	0	0	0	0	0	0	11
12/10/2018	0	0	0	0	0	5	0	9	0	0	0	0	0	0	0	14

Date	Zone															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
22/10/2018	0	0	1	0	0	1	0	24	0	0	0	0	0	0	0	26
23/10/2018	0	0	3	0	0	0	0	23	0	0	0	0	0	0	4	30
24/10/2018	0	0	0	0	0	0	0	37	0	0	0	0	0	0	0	37
25/10/2018	0	0	0	0	1	0	0	25	0	0	0	0	0	0	0	26
26/10/2018	0	0	2	0	0	0	0	26	0	0	0	0	0	0	0	28
27/10/2018	0	0	0	0	3	0	0	10	0	0	0	0	0	0	0	13
28/10/2018	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	20
29/10/2018	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	11
30/10/2018	0	0	1	0	0	0	0	13	0	0	0	0	0	0	0	14
31/10/2018	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	25
01/11/2018	0	0	2	0	0	1	0	13	0	0	0	0	0	0	0	16
06/11/2018	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	17
08/11/2018	0	0	0	0	2	0	0	16	0	0	0	0	0	0	0	18
09/11/2018	0	0	0	0	4	0	0	2	0	0	0	0	0	0	0	6
10/11/2018	0	1	0	0	3	0	0	3	0	0	0	0	0	0	0	7
11/11/2018	0	1	0	0	0	0	0	17	0	0	0	0	0	0	0	18
12/11/2018	0	1	0	0	0	4	0	9	0	0	0	0	0	0	0	14
13/11/2018	0	0	0	0	1	0	0	26	0	0	0	0	0	0	0	27
14/11/2018	0	2	0	0	1	2	0	16	0	0	0	0	0	0	0	21
16/11/2018	0	0	0	0	1	0	0	24	0	0	0	0	0	0	0	25
18/11/2018	0	1	0	0	0	2	0	26	0	0	0	0	0	0	0	29
19/11/2018	0	0	0	0	0	1	0	26	0	0	0	0	0	0	0	27
26/11/2018	0	1	0	0	0	0	0	13	0	0	0	0	0	0	0	14
27/11/2018	0	4	0	0	0	2	0	9	0	0	0	0	0	0	0	15
05/12/2018	0	6	0	0	0	4	0	47	0	0	0	0	0	0	0	57
06/12/2018	0	1	8	3	1	9	0	41	0	0	0	0	0	0	0	63
07/12/2018	0	1	0	0	2	16	0	38	0	0	0	0	0	0	0	57
08/12/2018	0	8	0	0	0	6	0	37	0	0	0	0	0	0	0	51
09/12/2018	0	5	0	0	0	4	0	22	0	0	0	0	0	0	0	31
10/12/2018	0	5	0	0	3	0	0	22	0	0	0	0	0	0	0	30
11/12/2018	0	6	0	0	0	6	0	25	0	0	0	0	0	0	0	37
12/12/2018	0	9	0	0	4	18	2	16	0	0	0	0	0	0	0	49
17/12/2018	0	7	0	0	0	1	0	64	0	0	0	0	0	0	0	72
19/12/2018	0	1	0	2	0	0	23	23	0	0	0	0	0	0	0	49
20/12/2018	0	0	0	0	0	3	4	37	0	0	0	0	0	0	0	44
24/12/2018	0	0	6	0	2	0	0	32	0	0	0	0	0	0	0	40
26/12/2018	0	4	5	0	0	0	4	24	0	0	1	0	0	0	0	38
27/12/2018	0	2	2	2	6	2	1	35	0	2	0	0	9	0	0	61
28/12/2018	0	6	4	0	1	22	0	16	5	0	1	0	0	0	0	55
29/12/2018	0	15	0	0	0	4	0	20	0	0	0	0	0	0	0	39
02/01/2019	0	2	15	0	0	0	0	55	0	0	0	0	0	0	0	72
03/01/2019	0	2	9	0	0	0	3	27	0	0	0	0	0	0	0	41

Date	Zone															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
04/01/2019	0	9	0	0	2	9	1	17	0	0	0	0	0	0	0	38
05/01/2019	0	6	0	0	0	1	0	30	0	3	0	0	0	0	0	40
06/01/2019	0	5	0	0	0	8	0	19	0	0	0	0	0	1	0	33
07/01/2019	0	3	0	7	0	3	0	16	0	0	0	0	0	0	0	29
08/01/2019	0	18	0	0	1	0	0	5	0	0	0	0	0	0	0	24
09/01/2019	0	4	6	0	0	0	0	13	0	0	0	0	0	0	0	23
10/01/2019	0	4	0	0	0	0	0	10	0	0	0	0	0	0	0	14
11/01/2019	0	7	1	0	1	4	0	30	3	0	0	0	0	0	0	46
13/01/2019	0	10	0	0	0	0	0	11	2	0	0	0	0	0	0	23
14/01/2019	0	15	0	0	1	1	0	28	0	0	0	0	0	0	0	45
15/01/2019	0	9	2	0	2	15	0	16	0	0	0	2	0	0	0	46
16/01/2019	0	3	0	0	5	36	0	6	0	0	0	0	0	0	0	50
17/01/2019	0	21	0	0	0	4	0	11	0	0	0	0	0	0	0	36
18/01/2019	0	18	0	0	0	13	0	8	0	0	0	0	0	0	0	39
19/01/2019	0	3	3	0	0	17	0	14	4	0	0	0	0	2	0	43
20/01/2019	0	0	0	0	0	2	0	29	0	0	0	0	0	0	0	31
21/01/2019	0	3	1	0	0	8	0	10	0	0	0	2	0	0	0	24
22/01/2019	0	10	3	0	4	9	0	25	0	0	0	0	0	0	0	51
24/01/2019	0	4	0	0	0	10	0	20	0	0	0	0	0	0	0	34
25/01/2019	0	15	1	0	0	10	0	30	0	0	0	0	0	0	0	56
26/01/2019	0	5	0	0	0	18	0	19	0	0	0	0	0	0	0	42
27/01/2019	0	6	0	0	0	0	0	6	0	0	0	0	0	0	0	12
28/01/2019	0	19	0	1	0	15	0	14	0	0	0	0	0	0	0	49
29/01/2019	0	16	0	0	0	11	0	31	0	0	0	0	0	0	0	58
31/01/2019	0	9	0	0	0	24	0	9	0	0	0	0	0	0	0	42
01/02/2019	0	1	1	0	0	23	0	18	0	0	0	0	0	0	0	43
02/02/2019	0	24	1	0	0	5	0	26	0	0	0	2	6	0	0	64
03/02/2019	0	9	0	0	0	11	0	33	0	0	0	0	0	0	0	53
04/02/2019	0	9	0	0	0	10	0	24	0	0	0	0	0	0	0	43
05/02/2019	0	16	0	0	5	6	0	37	0	0	0	0	0	0	0	64
06/02/2019	0	17	0	0	0	11	0	27	0	0	0	0	0	0	0	55
07/02/2019	0	11	0	0	0	7	0	30	0	0	0	0	0	0	0	48
08/02/2019	0	8	0	0	0	17	0	19	0	0	0	0	0	0	0	44
14/02/2019	0	16	0	0	0	19	0	22	0	0	0	0	0	0	0	57
15/02/2019	0	19	0	0	0	19	0	10	0	0	0	0	0	0	0	48
16/02/2019	0	19	0	0	0	33	0	15	0	0	0	0	0	0	0	67
17/02/2019	0	18	0	0	2	12	0	12	0	0	0	0	0	0	0	44
18/02/2019	0	17	0	0	16	21	0	23	0	0	0	0	0	7	0	84
19/02/2019	0	23	0	0	0	3	0	28	0	0	0	0	0	0	0	54
20/02/2019	0	24	0	0	0	6	0	23	8	0	0	0	0	0	0	61
21/02/2019	0	24	0	0	0	5	0	29	0	0	0	0	0	0	0	58

Date	Zone															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
22/02/2019	0	31	0	0	2	13	0	29	0	0	0	0	0	0	0	75
23/02/2019	0	24	2	0	1	14	0	11	0	0	0	0	0	0	0	52
24/02/2019	0	33	0	0	3	9	0	13	0	2	0	0	0	0	0	60
28/02/2019	0	30	1	0	3	18	0	17	0	0	0	0	0	0	0	69
01/03/2019	0	33	1	0	0	18	0	6	0	0	0	0	0	0	0	58
02/03/2019	0	33	0	0	0	12	0	6	0	0	0	0	0	0	0	51
03/03/2019	0	28	13	0	0	10	0	12	19	0	0	0	0	0	0	82
04/03/2019	0	21	0	0	2	4	0	26	0	0	0	0	0	0	0	53
05/03/2019	0	18	0	0	0	0	0	27	0	0	0	0	0	0	0	45
11/03/2019	0	48	1	0	1	0	3	11	0	0	0	0	0	0	0	64
12/03/2019	0	38	0	0	4	26	7	8	0	0	0	2	14	0	0	99
13/03/2019	0	26	0	0	2	2	0	14	0	0	0	0	0	18	0	62
16/03/2019	0	14	0	0	0	18	0	8	0	0	0	0	13	0	0	53
17/03/2019	0	31	1	0	1	4	0	17	0	0	0	0	0	0	0	54
25/03/2019	0	42	0	0	0	0	0	17	0	4	0	0	0	0	0	63
26/03/2019	0	24	0	0	3	0	0	24	0	2	0	0	0	0	0	53
27/03/2019	0	32	0	0	0	15	0	9	0	0	3	0	6	0	0	65
28/03/2019	0	11	0	0	1	7	0	12	0	0	11	4	0	0	0	46
29/03/2019	0	39	1	0	0	15	0	13	0	0	0	0	0	0	0	68
30/03/2019	0	42	0	0	0	2	0	6	1	0	0	0	0	0	0	51
31/03/2019	0	41	0	0	3	0	0	20	0	0	0	0	0	0	0	64
04/04/2019	0	41	11	0	0	0	0	11	0	0	0	0	0	0	0	63
05/04/2019	0	27	1	0	6	2	0	21	0	0	0	2	0	0	0	59
15/04/2019	0	49	0	0	0	0	0	30	0	0	0	8	0	0	0	87
16/04/2019	0	29	5	0	5	0	0	27	0	0	0	31	6	0	0	103
17/04/2019	0	43	2	0	4	0	0	21	0	0	0	0	0	0	0	70
18/04/2019	0	9	2	0	3	0	0	34	13	0	0	0	0	0	0	61
20/04/2019	0	9	0	0	0	14	0	9	2	0	0	2	0	0	0	36
22/04/2019	0	4	0	0	1	8	0	9	0	0	11	4	8	0	0	45
23/04/2019	0	3	0	0	0	6	0	17	0	0	3	19	10	0	0	58
24/04/2019	0	18	0	2	0	11	0	46	0	0	0	6	0	0	0	83
25/04/2019	0	20	1	0	3	6	0	44	0	0	0	15	0	0	0	89
26/04/2019	0	6	0	0	4	4	0	17	0	0	0	31	0	0	0	62
29/04/2019	0	8	0	4	0	5	0	11	0	0	0	2	5	0	0	35