ALEXANDRA PARADE SEA WALL REPAIR

Environmental Appraisal

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Alexandra Parade Sea Wall Repair
02
19 September 2019

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1. INTRODUCTION

1.1 Background

1.1.1.1 Peterhead Harbour located in north-east Scotland is one of the UK's most versatile ports, providing deep-water berthing facilities for a range of industries including oil and gas, renewables, fishing and leisure.

1.1.1.2 The Alexandra Parade seawall and revetment is located on the northern boundary of Peterhead Harbour adjacent to North harbour (Figure 1.1). The seawall and revetment acts as a sea defence to the fish processing facility and harbour related businesses that are vital to the operation of the harbour located behind the revetment.

1.1.1.3 During a storm event in 2012, significant overtopping of the existing seawall occurred (waves inundating areas behind the seawall), causing a failure of the seawall structure, and causing the complete destruction of the Mapco fish processing factory located to the east of the proposed works. As a result, improvements to the existing seawall and revetment were undertaken, which included raising the seawall crest height and placing large 60 T precast concrete sections along the revetment crest. However, during construction of the new fish processing facility in 2017-2018, further significant overtopping events occurred during the winter months, which identified that the previous improvement works undertaken were not sufficient to reduce the risk from overtopping, and that the volume of overtopping occurring at the seawall was unacceptable.

1.1.1.4 Further works (herein referred to as the 'Proposal') are therefore proposed for along the entire length of the revetment. The Proposal includes strengthening of the full length of the Alexandra Parade revetment, a total length of circa 330 m, over two phases of construction. The Proposal will involve re-profiling of the existing revetment, formation of a toe trench and placement of various sizes of rock armour and pre-cast concrete units within the toe trench to create the toe mound, on the existing embankment and along the crest extending to the existing seawall.

1.1.1.5 RPS has been commissioned by Peterhead Port Authority (PPA) to support in the submission of the Marine Licence application to Marine Scotland Licensing Operations Team (MS-LOT) as the works associated with the Proposal below Mean High Water Springs (MHWS) are licensable under the Marine (Scotland) Act 2010. This environmental appraisal document has been developed to support the Marine Licence application in order to carry out the Proposal.

1.2 The Applicant

1.2.1.1 Peterhead Port Authority
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Figure 1-1: Location of the Proposal.

1.3 Consultation

1.3.1.1 In 2018 PPA initially sought confirmation that the Proposal was exempt from marine licensing; a request which was declined by MS-LOT. MS-LOT further provided a view that the Proposal should be screened for whether it meets with the requirements of an Environmental Impact Assessment (EIA) under the Marine Works (Environmental Impact Assessment) (Scotland) Regulations 2017 (the EIA Regs).

1.3.1.2 In May 2019, PPA issued a Consenting Approach document to MS-LOT which included a request for an EIA Screening Opinion from MS-LOT under Regulation 10(1) of the 2017 EIA Regulations. The Consenting Approach document also included the proposed scope of this environmental appraisal document for agreement with stakeholders. On 1st July RPS met with MS-LOT to discuss the Consenting Approach document. The meeting looked at the initial responses from consultees to the Consenting Approach document, the requirements in relation to the Moray Firth SAC, and the required level of underwater noise assessment which had been raised by Scottish Natural Power (SNH). Potential changes to the wave climate raised by Marine Scotland Science was also discussed.

1.3.1.3 Consultation with the Scottish Environment Protection Agency (SEPA) and Aberdeenshire Council was also undertaken, due to the nature of the Proposal works to re-profile the revetment. The rock revetment was installed as a coastal defence measure and as such any works to the revetment may result in the potential for a water breach. Given this potential, and with consideration of SEPA's lead role in the implementation of the European Union (EU) Floods Directive and specifically the Flood Risk Management (Scotland) Act 2009, a response to the consenting approach document was received 14th and 26th of June from Aberdeenshire Council and SEPA respectively. The responses highlighted the need for a desk-based Flood Risk Assessment (FRA) to be undertaken. This assessment was undertaken in 2018 and the results have been summarised in Section 3.2: Physical Processes.

1.3.1.4 Applicants for Marine Licences for certain prescribed classes of activities are required to carry out pre-application consultation (PAC) under The Marine Licensing (Pre-application Consultation) (Scotland) Regulations 2013 (the "PAC Regulations"). On 24th June 2019 a pre-application public application event was held. There was minimal attendance recorded during the events and no comments were received (RPS, 2019).

1.3.1.5 A formal Screening Opinion was received from MS-LOT 22nd August 2019. Comments made by MS-LOT and stakeholders consulted with, Aberdeenshire Council, SNH, SEPA and Historic Environment Scotland (HES), have been included within Table 1.1. Following consultation, the Opinion of the Scottish Ministers was that the Proposal did not require an EIA.

Table 1.1: Stakeholder consultation.

Date	Consultee and type of correspondence	Theme	Issues raised	Response to issue raised and/or where considered in this chapter
21/04/2019	Northern Lighthouse Board – Formal Letter	No Objection	No objections to the Proposal and will reply formally in response to the Marine Licence application.	N/A
24/06/2019	Historic Environment Scotland – Formal Letter	Screening Opinion Consultation	Considered it unlikely that the Proposal would result in a significant impact on features within their remit. Content that this is unlikely to result in significant effects on marine archaeology and that the proposed protocol for archaeological discovery (PAD) will provide suitable mitigation for the historic environment.	Impacts are considered in Section 5: Assessment of Effects and the proposed PAD has been in included with Section 4: Embedded Mitigation Measures
14/06/2019	Aberdeenshire Council – Formal Letter	Screening Opinion Consultation	The Council considered the area, design and materials to be used in the Proposal as not having significant environmental impacts, however, concerns were raised about the carbon footprint of materials coming in from abroad. The Council recognised the potential impacts on coastal processes, water quality, benthic habitats, noise emission receptors and that the works may impact on wave climate and potential flood risk but acknowledged that impacts on receptors considered unlikely to be significant. The Council required the applicant to provide evidence that any works would not increase the risk of flooding. The Council recognised that cumulative impacts are expected to be mitigated through standard mitigation practices. The Council noted that no significant issues are expected to arise due to the location of the Proposal in relation to protected sites. The Council considered the works to have limited locational impact on the onshore areas. Material to be reclaimed from the seabed were not considered significant from a terrestrial perspective.	Further information on the project description can be found in Section 2: Project Description. In 2018, RPS undertook modelling to determine the wave climate and overtopping discharge, this has been incorporated into Section 3.2: Physical Processes and is presented in Appendix B. An Environmental Management Plan (EMP) has been proposed in Section 4: Embedded Mitigation Measures.
19/06/2019	Marine Scotland Science Oceanography Group - Email	Screening Opinion Consultation	Concerns raised over the potential for flood risk and whether structural changes to the sea wall will impact wave climate.	In 2018, RPS undertook modelling to determine the wave climate and overtopping discharge, this has been incorporated into Section 3.2: Physical Processes. Additionally, further information on impacts scoped in Section 5: Assessment of Effects and scoped out Appendix A: Scoping Exercise.

Date	Consultee and type of correspondence	Theme	Issues raised	Response to issue raised and/or where considered in this chapter
26/06/2019	SEPA – Formal Letter	Screening Opinion Consultation	Any waste material, including dredge spoil, deposited above the low water mark is subject to a Waste Management Licence, regulated by SEPA, unless it is issued under Part 4 of the Marine (Scotland) Act 2010. Should the spoil be used for land reclamation within the intertidal, then these works are regulated by Marine Scotland. Additionally, SEPA recommended that the applicant demonstrate how the works contribute to sustainable development. Consideration should be given to the nearest Bathing water, which is Peterhead (Lido) (UKS7616042) which currently has Excellent status. SEPA recognised that the works may result in pollution and offered guidance. Mitigation should be put in place to prevent any incidences. SEPA identified that the Proposal must meet the River Basin Management Planning objectives. SEPA recommended that an Invasive Non-Native Species (INNS) Plan should be put in place to prevent the introduction of INNS. SEPA provided information on coastal flood levels for the area. SEPA identified that the works will need to comply with Controlled Activates Regulations (CAR), and any crushing or screening of material will require a licence.	Any waste material is expected to be reused where possible as rock infill. Additionally, an Environmental Management Plan (EMP) has been proposed in Section 4: Embedded Mitigation Measures. The Peterhead (Lido) is located 1.7 km of the Proposal. Further information on project timelines can be found in Section 2.5: Timescales and Duration. Consideration of the water quality and effect of the Proposal on coastal processes can be found in Section 5.2: Physical Processes. An INNS Plan is proposed in Section 4: Embedded Mitigation Measures. In 2018, RPS undertook modelling to determine the wave climate and overtopping discharge and has been utilised to address flood risk. This has been incorporated into Section 3.2: Physical Processes and is presented in Appendix B. CAR has been included within Section 4: Embedded Mitigation Measures.
05/06/2019	Scottish Natural Heritage – Formal Letter	Screening Opinion	SNH identified the Proposal as having the potential to have a likely significant effect on the bottlenose dolphin feature of the Moray Firth Special Area of Conservation (SAC) due to the noise created by the Proposal. However, SNH did not consider the Proposal to have a likely significant effect on the bird features of the Buchan Ness to Collieston Coast Special Protection Area (SPA).	Further information on impacts are considered in Section 5.5: Marine Mammals and within Section 7: HRA Screening.
22/08/2019	Marine Scotland – Formal Letter	Screening Opinion	Following consultation with SEPA, SNH, Aberdeenshire Council, Historic Environment Scotland (HES), Scottish Ministers are of the opinion that the Proposals are not an EIA project under 2017 Marine Works Regulations and, therefore, an EIA is not required to be carried out in respect of the Proposals.	Comments made by SEPA, Aberdeenshire Council, SNH and HES have been addressed within this table.

2. PROJECT DESCRIPTION

2.1 Revetment Design and Footprint

2.1.1.1 The Proposal includes strengthening of the full length of the Alexandra Parade revetment, a total length of circa 330 m, over two phases of construction.

2.1.1.2 The Proposal includes re-profiling of the existing revetment, formation of a toe trench and placement of various sizes of rock armour and pre-cast concrete units within the toe trench to create the toe mound, on the existing embankment and along the crest, extending to the existing seawall (Figure 2.1).

2.1.1.3 The construction footprint of the Proposal will be located within the existing rock revetment footprint covering an area of approximately 5,170 m^2 for phase 1 of the Proposal, and an area of approximately 5,700 m^2 in phase 2.

2.1.1.4 The footprint area of the Proposal extending beyond the footprint of the existing revetment is approximately 710 m^2 for Phase 1 and 1,975 m^2 for Phase 2 (Figure 2.2) with the total area being 2,685 m^2 of which 2,648 m^2 of this area is below MHWS.

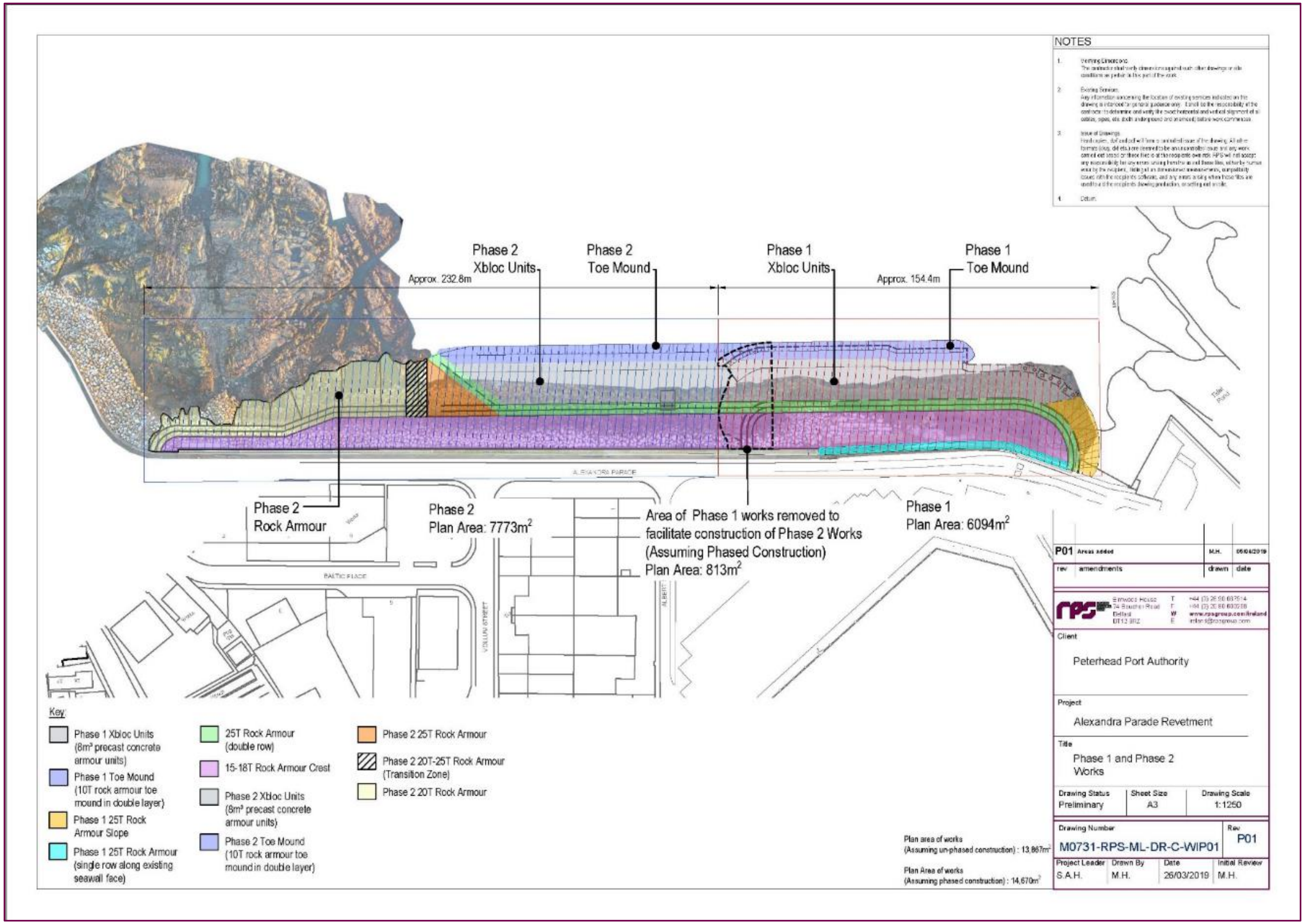

Figure 2-1: Proposed layout of revetment and location of rock armour sections, concrete units.

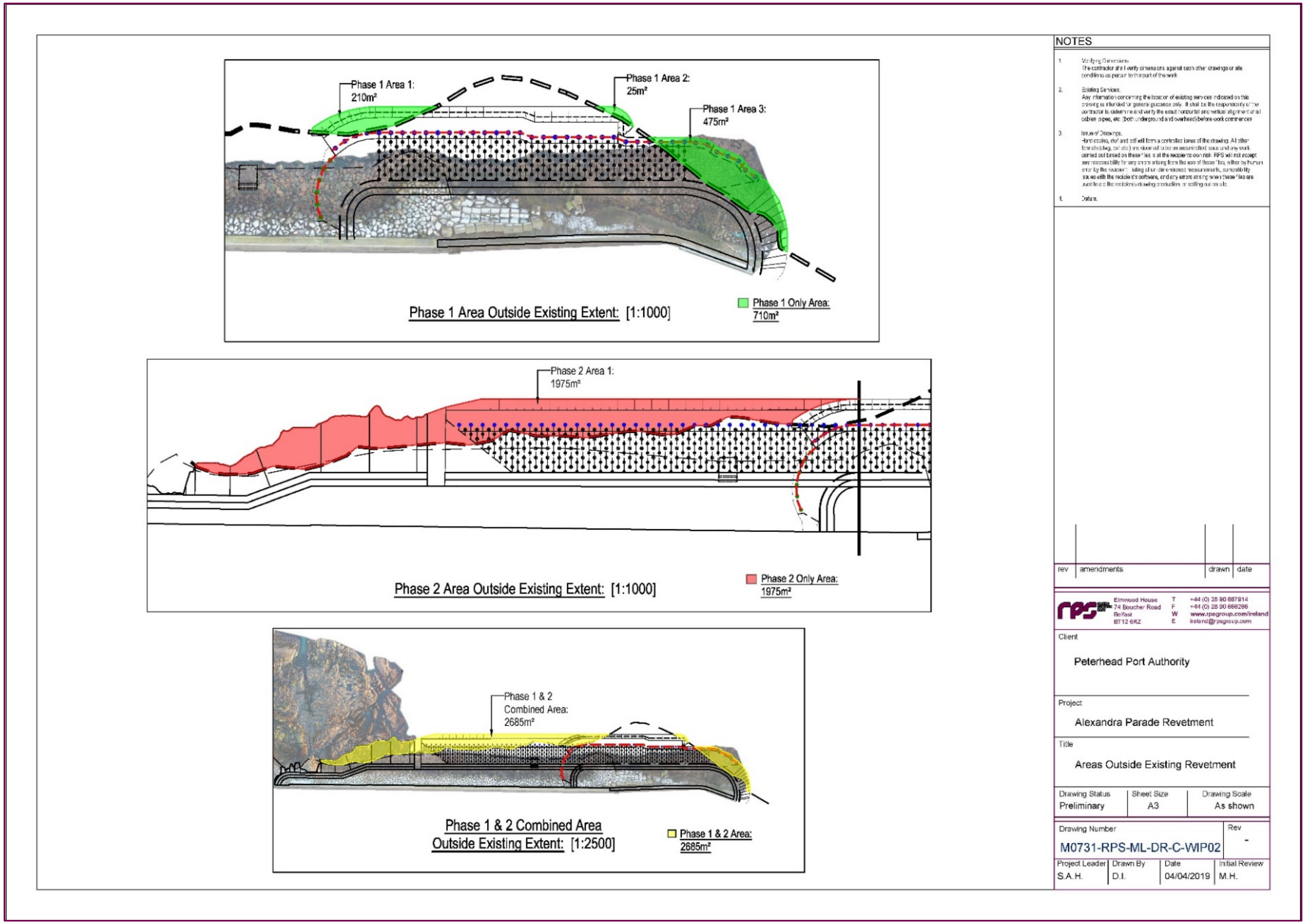

Figure 2-2: Extent of construction footprint outside the existing revetment boundary.

2.2 Materials

2.2.1.1 The types of construction material that will be used as part of the proposed works include 8 m^3 precast concrete armour units, 1-3 T rockfill, 10 T rock armour, 15 T-20 T and 25 T rock armour.

2.2.1.2 Table 2.1 provides details of the type, volume, source of the material and mode of transport that will be adopted to transport the material to site. The proposed volumes include all works above and below MHWS for Phase 1 and Phase 2 of the Proposal and total volume material required below MHWS.

Table 2.1: Details on the construction materials that will be used for the Proposal.

Type	Phase 1 Volume (m^3)	Phase 2 Volume (m^3)	Total Volume Below MHWS (m^3)	Source	Mode of transport
25 T rock armour	3,111	913	3,726	Norway	Barge and landed at at North Breakwater in Peterhead Harbour and brought to works area by internal port roads
20 T rock armour	N/A	3,912	2,398	Norway	Barge and landed at at North Breakwater in Peterhead Harbour and brought to works area by internal port roads
15 T-18 T rock armour	3,711	2,845	1,306	Norway	Barge and landed at North Breakwater in Peterhead Harbour and brought to works area by internal port roads
10 T rock armour	2,647	3,201	5,848	Norway	Barge and landed at North Breakwater in Peterhead Harbour and brought to works area by internal port roads
1-3 T rockfill	9,788	13,207	2,090	Local quarries	Lorry
8 m^3 pre-cast concrete Armour Units (Xbloc)	17,960	16,168	625 nr units (5,000 m^3)	Option 1: Cast onsite within Peterhead Harbour on Smith Quay Embankment	Moulds will likely be brought to site by road in Lorries, concrete will be brought to site by road in concrete lorries
				Option 2: Cast offsite at a suitable facility (such as Nigg Bay)	Precast units will be brought to site either by road or by sea

2.2.1.3 The total volumes provided are based on the Proposal being undertaken over two phases as this will represent the worst case in terms of material volume. This is because it will be necessary to “re-work” the north western (NW) end of Phase 1 to incorporate Phase 2 works. The reworking includes:

- The 25 T rock armour placed on the slope at the NW end of Phase 1 being removed to accommodate the Xbloc units in Phase 2.
- The crest detail at the NW end of Phase 1being reworked (curved end of Phase 1 removed and replaced with straight crest section for Phase 2 extension).
- The 1-3 T revetment infill and crest armour at curved NW end of Phase 1 amended to accommodate the straight section of crest in Phase 2.
- The toe detail at the curved NW end of Phase 1 amended to accommodate the straight extension of toe trench for Phase 2.

2.3 Construction Method

2.3.1.1 Phase 1 and Phase 2 will be undertaken separately. Each phase will comprise of the following activities.

2.3.2 Re-profiling and toe trench development

2.3.2.1 Re-profiling of the existing rock armour revetment will be undertaken by removing existing concrete elements and rock armour in the revetment through the use of a crane or excavator.

2.3.2.2 Remaining sections of the concrete pitched revetment will then be broken up to improve porosity using a rock breaker mounted onto an excavator.

2.3.2.3 Re-profiling of the existing bedrock and remaining revetment toe will then be undertaken to facilitate revetment construction and localised toe trench formation/placement of Xbloc units. The toe trench will be formed using a rock breaker or rock wheel mounted on an excavator. A total of circa 2,210 m^3 of material will be removed to facilitate the toe trench in Phase 1, and circa 2,060 m^3 will be removed to form the toe trench in Phase 2.

2.3.3 Rock Embankment Construction

2.3.3.1 A rock embankment overlaying and encapsulating the existing revetment using 1-3 T rockfill will be constructed. The rockfill will be transported to the Proposal area using a loading shovel or dump truck and placed using an excavator.

2.3.4 Toe Mound Construction

2.3.4.1 8 m^3 pre-cast concrete armour base units (Xbloc) will then be placed in the newly developed toe trench by using an excavator and slings (fitted with a positioning system).

2.3.4.2 A double layer of 10 T rock armour will then be placed on top of the Xbloc base units using an excavator with slings and a positioning system.

2.3.5 Revetment Construction

2.3.5.1 Xbloc units will be placed on the rock embankment slope, extending from the toe structure to the crest of the revetment, using an excavator with slings and a positioning system.

2.3.5.2 25 T rock armour will then be placed on the crest of the revetment, along the back edge of the top row of Xbloc units. The material will then be placed using an excavator with slings, lifting eyebolts and a positioning system.

2.3.5.3 15-18 T rock armour will be placed along the crest of the revetment, to provide a crest width of 20 m from the top of the revetment slope to the existing seawall and placed by an excavator with slings and a positioning system.

2.3.5.4 In Phase 1, 25 T rock armour will be placed at the eastern and western ends of the improved revetment structure, where the armour will be bedded into the existing revetment armour where appropriate.

2.3.5.5 In Phase 2, the Xbloc slope will transition into a 20 T rock armour slope, which will overlay the 1-3 T rockfill, and will tie into the existing revetment at the western extremity of the existing revetment.

2.4 Plant and Equipment

2.4.1.1 Plate 1 to Plate 8 provide typical examples of the plant and equipment that will be used during the proposed works.

Plate 1: Barge for delivery of rock armour from Norway quarry.

Plate 2: HGV lorries for delivery of locally sourced rock armour.

Plate 3: Excavator unloading from dump truck.

Plate 4: A crane for lifting units/armour into place or clearing existing revetment.

Plate 5: Loading shovel/telehandler.

Plate 6: Moxy dump truck.

Plate 7: Concrete wagon.

Plate 8: Moulds for Xbloc units and vibrating concrete pokers for casting units.

2.5 Timescales and Duration

2.5.1.1 The Proposal is scheduled over two phases. Each phase is expected to be completed over a period of 6 months.

2.5.1.2 Preparation, breaking up of the existing revetment and toe trench formation will take approximately 6 weeks, casting of concrete base units will be completed over a period of approximately 7 weeks while placement of rock armour and concrete armour will take approximately 16 weeks for each phase.

2.5.1.3 A timeline for each phase is provided below in Figure 2.3.

PHASE 1- 155m Revetment Construction	PHASE 1: Anticipated works starting onsite April 2020																							
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Localised removal of section of existing sea wall	■																							
Clearance of Existing Revetment (removal of existing precast elements)		■	■																					
Breaking up of existing pitched revetment & re-profiling of existing revetment toe		■	■	■																				
Toe trench formation			■	■	■	■																		
Placement of 1-3T rock fill to form rock embankment				■	■	■	■	■	■	■	■	■	■	■										
Casting of $8m^3$ Precast Concrete Base Units		■	■	■	■	■	■	■																
Placement of $8m^3$ Precast Concrete Base Units in toe trench						■	■	■	■															
Placement of $8m^3$ Precast Concrete Armour Units on slope										■	■	■	■	■	■	■								
Placement of 10T armour for toe mound												■	■	■	■	■	■							
Placement of 15T-25T crest armour															■	■	■	■	■	■	■			
Placement of 25T rock armour at Eastern and Western ends of revetment structure																					■	■		
Reconstruction of section of sea wall																							■	■

PHASE 2- 233m Revetment Extension	PHASE 2: Earliest expected commencement 2022 (During spring/summer months)																							
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Localised removal of section of existing sea wall	■																							
Removal of 25T rock armour at western end of Phase 1 extents	■	■																						
Toe trench formation		■	■																					
Placement of 1-3T rock fill and 3-6T rock armour to form rock embankment			■	■	■	■	■	■	■	■	■	■	■	■	■	■								
Casting of $8m^3$ Precast Units		■	■	■	■	■	■	■																
Placement of $8m^3$ Precast Concrete Base Units in toe trench						■	■	■	■															
Placement of $8m^3$ Precast Concrete Armour Units on slope									■	■	■	■	■	■	■	■	■							
Placement of 10T armour for toe mound										■	■	■	■											
Placement of 25T transition zone between precast units and rock armour											■	■												
Placement of 20T armour on slope along western half of phase 2 revetment extent													■	■	■									
Placement of 15T-25T crest armour														■	■	■	■	■	■	■	■	■	■	
Reconstruction of section of sea wall																							■	■

Figure 2-3: Proposed schedule for completion of the Proposal.

3. EXISTING ENVIRONMENT

3.1 Study Area

3.1.1.1 The study area used for this Environmental Appraisal to guide the review of existing baseline information is the North East Scottish Marine Region (The Scottish Government, 2015) (Figure 3-1), or localised within this as an appropriate for the receptor. A broader study area has been described/referenced for marine mammals, where the appropriate SCANS blocks have been utilised (see Figure 3-5).

3.2 Designated Sites

3.2.1.1 All designated sites with qualifying interest features that could be potentially impacted by the Proposal were identified using the following approach:

- Step 1: All designated sites of international, national and local importance were identified using the MAGIC interactive map[1], the Joint Nature Conservation Committee's (JNCC's) website and the European Site European Nature Information System (EUNIS) database;
- Step 2: Information was compiled on the relevant qualifying feature for each of these sites by examining JNCC and EUNIS databases; and
- Step 3: Using the above information and expert judgement, sites were included in the assessment if:
  - A designated site directly overlaps with Proposal;
  - Sites and associated features were located within the potential Zone of Impact (ZoI) for impacts associated with Proposal, based on expert judgement;
  - Qualifying features of a designated site were either recorded as present during historic surveys within Proposal area, or identified during the desktop study as having the potential to occur within Proposal area; and
  - Where a national site falls outside of an international site, but is located within identified study areas, the national site has been taken forward for further assessment for a particular feature.

3.2.1.2 The Proposal is not located within an EU designated site. A list of identified international and national designated sites, distance from project and qualifying features that have the potential to be impacted by the project are provided in Table 3.1.

[1] http://magic.defra.gov.uk/

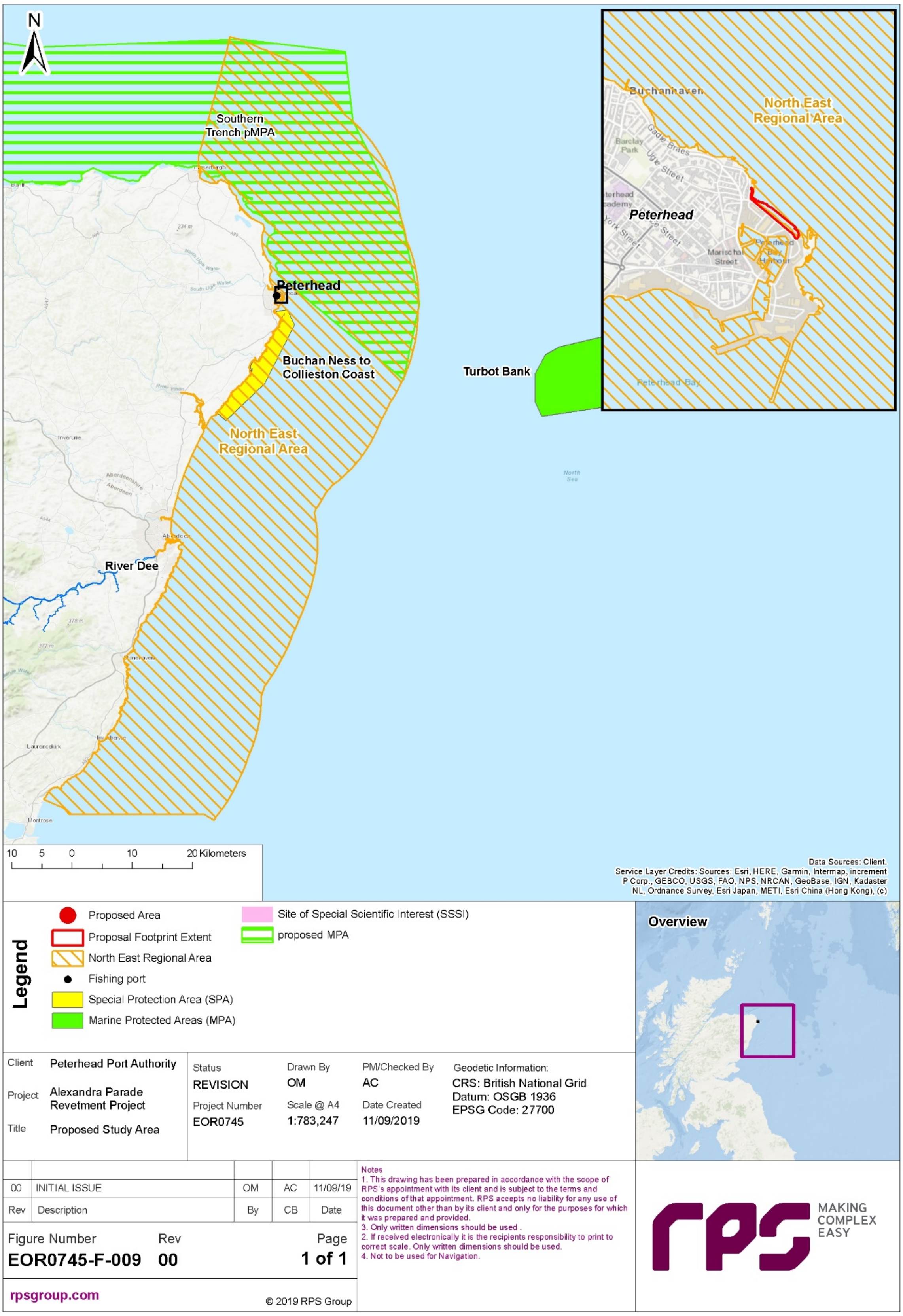

Figure 3-1 Location of the Proposal in context of the North East Scottish Marine Region.

3.2.1.3 The nearest designated site under the EU Habitats Directive is the Buchan Ness to Collieston Coast Special Protected Area (SPA) located 2.4 km to the south of the Proposal which is designated for seabird species and assemblages. Other designated sites include the River Dee Special Area of Conservation (SAC) (45 km south of the Proposal), River Spey SAC (80 km west of the Proposal), Moray Firth SAC (95 km to the west of the Proposal), River South Esk SAC (100 km south of the Proposal), River Tay SAC feeding into the Firth of Tay and Eden Estuary SAC (127 km to the south of the Proposal), Dornoch Firth and Morrick More SAC (128 km west of the Proposal), Isle of May SAC (155 km south of the Proposal), Berwickshire and North Northumberland Coast SAC (175 km to the south of the Proposal) and River Teith SAC (202 km south of the Proposal).

3.2.1.4 The nearest Marine Protected Area (MPA) is the Turbot Bank MPA, located approximately 43 km to the east of the proposed works and is designated for the protection of sandeels. The proposed Southern Trench MPA is located approximately 10 km east of the Proposal and features deep shelf waters (to a depth of ~200 m) and hydrographic fronts, burrowed mud habitat, minke whale *Balaenoptera acutorostrata* and white-beaked dolphin *Lagenorhynchus albirostris*.

3.2.1.5 The nearest Special Site of Scientific Interest (SSSI) is the Bullers of Buchan Coast SSSI located 6 km south of the Proposal area. This SSSI has been designated for its mixed geomorphology and supralittoral rock (coast), range of rocky coastal forms that have developed in igneous rock, including numerous geos, caves, arches, stacks, shore platforms, skerries and isolated islands, including the 60 m deep, enclosed sea inlet of The Pot.

Table 3.1: MPA's and designated sites that may be impacted by the Proposal.

Protected Area	Distance and Direction from Project	Relevant Qualifying Features
Buchan Ness to Collieston Coast Special Protected Area (SPA)	2.4 km south	Seabird species and assemblages
Bullers of Buchan Coast SSSI	6 km south	Mixed geomorphology and supralittoral rock (coast); and Rocky coastal forms.
Southern Trench proposed MPA	10 km east	Deep shelf waters; Hydrodynamic regime and productivity; Burrowed mud habitat; Minke whale (*Balaenoptera acutorostrata*); and White-beaked dolphin (*Lagenorhynchus albirostris*).
Turbot Bank MPA	43 km east	Sandeels (*Ammodytes americanus*)
River Dee SAC	45 km south west	Atlantic salmon (*Salmo salar*) Freshwater pearl mussel (*Margaritifera margaritifera*)
River Spey SAC	80 km west	Freshwater pearl mussel (*Margaritifera margaritifera*) Atlantic salmon (*Salmo salar*) Sea lamprey (*Petromyzon marinus*)
Moray Firth SAC	95 km west	Bottlenose dolphin (*Tursiops truncatus*)
River South Esk SAC	100 km south	Freshwater pearl mussel (*Margaritifera margaritifera*) Atlantic salmon (*Salmo salar*)
River Tay SAC	157 km south west	Atlantic salmon (*Salmo salar*) Sea lamprey (*Petromyzon marinus*)

Protected Area	Distance and Direction from Project	Relevant Qualifying Features
		River lamprey (*Lampetra fluviatilis*)
Firth of Tay and Eden Estuary SAC	127 km south	Harbour seal (*Phoca vitulina*)
Dornoch Firth and Morrich More SAC	128 km west	Harbour seal (*Phoca vitulina*)
Isle of May SAC	155 km south	Grey seal (*Halichoerus grypus*)
Berwickshire and North Northumberland Coast SAC	175 km south	Grey seal (*Halichoerus grypus*)
River Teith SAC	202 km south	Sea lamprey (*Petromyzon marinus*) River lamprey (*Lampetra fluviatilis*)

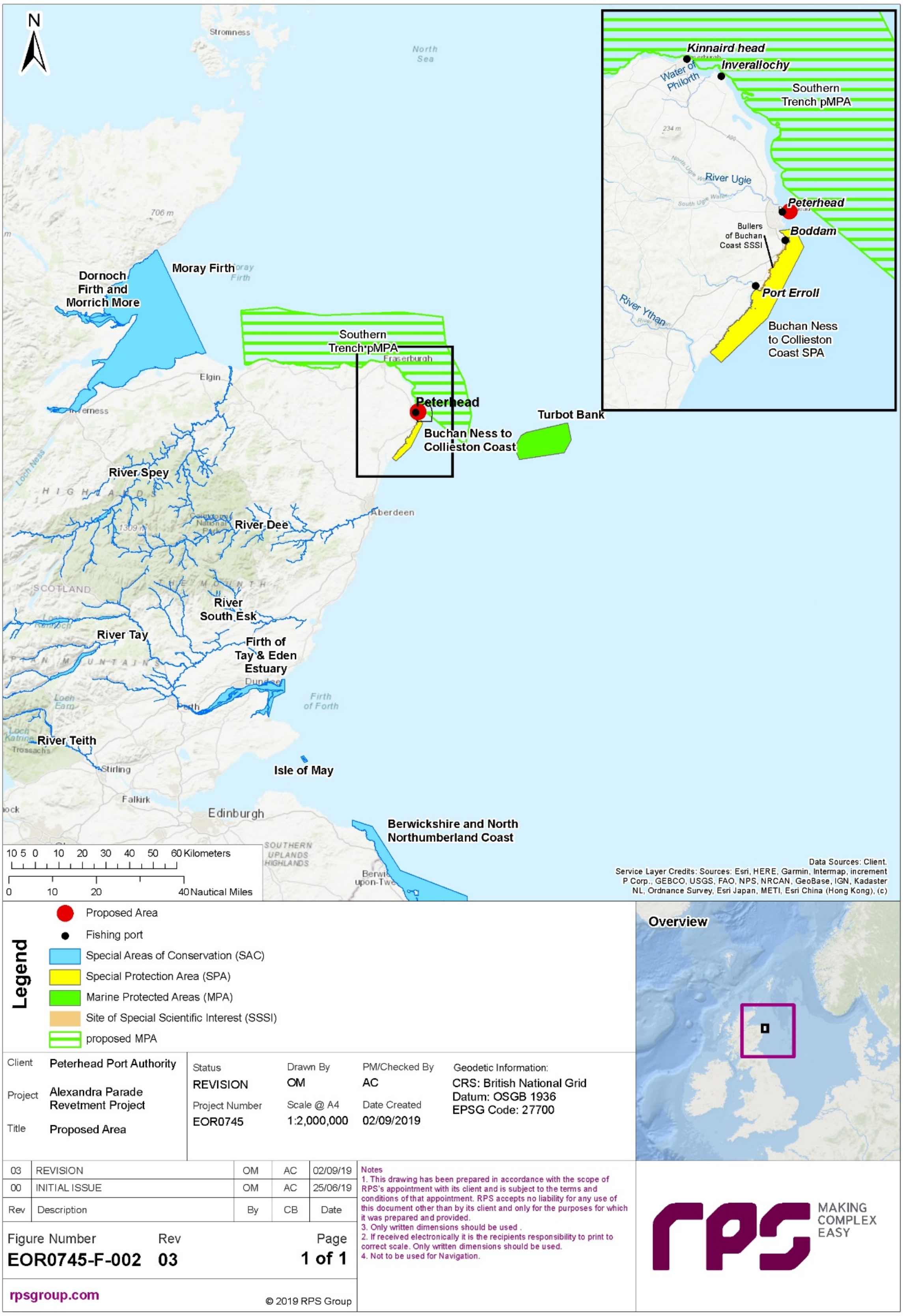

Figure 3-2: Designated sites.

3.3 Physical Processes

3.3.1 Bathymetry

3.3.1.1 Water depths within the Proposal area typically range from 0 m to 4.5 m, becoming deeper (≥10 m) approximately 250 m north east of the Proposal, with depth increasing to circa 125 m approximately 50 km offshore (Figure 3.2 and Figure 3.3).

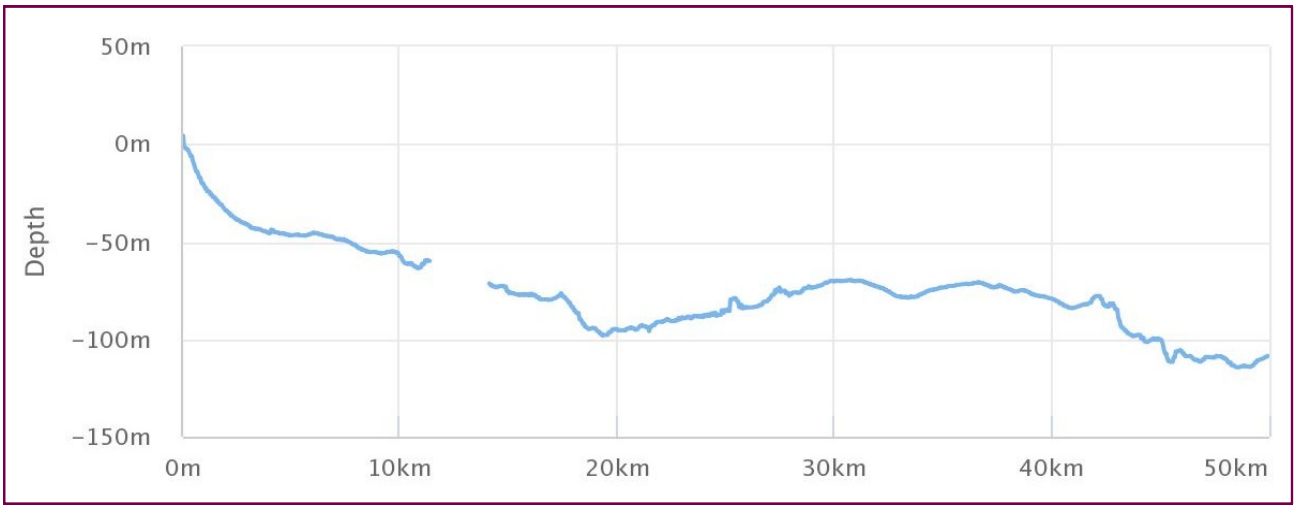

Figure 3-3: Cross section depth profile from Peterhead out 50 km (EMODnet).

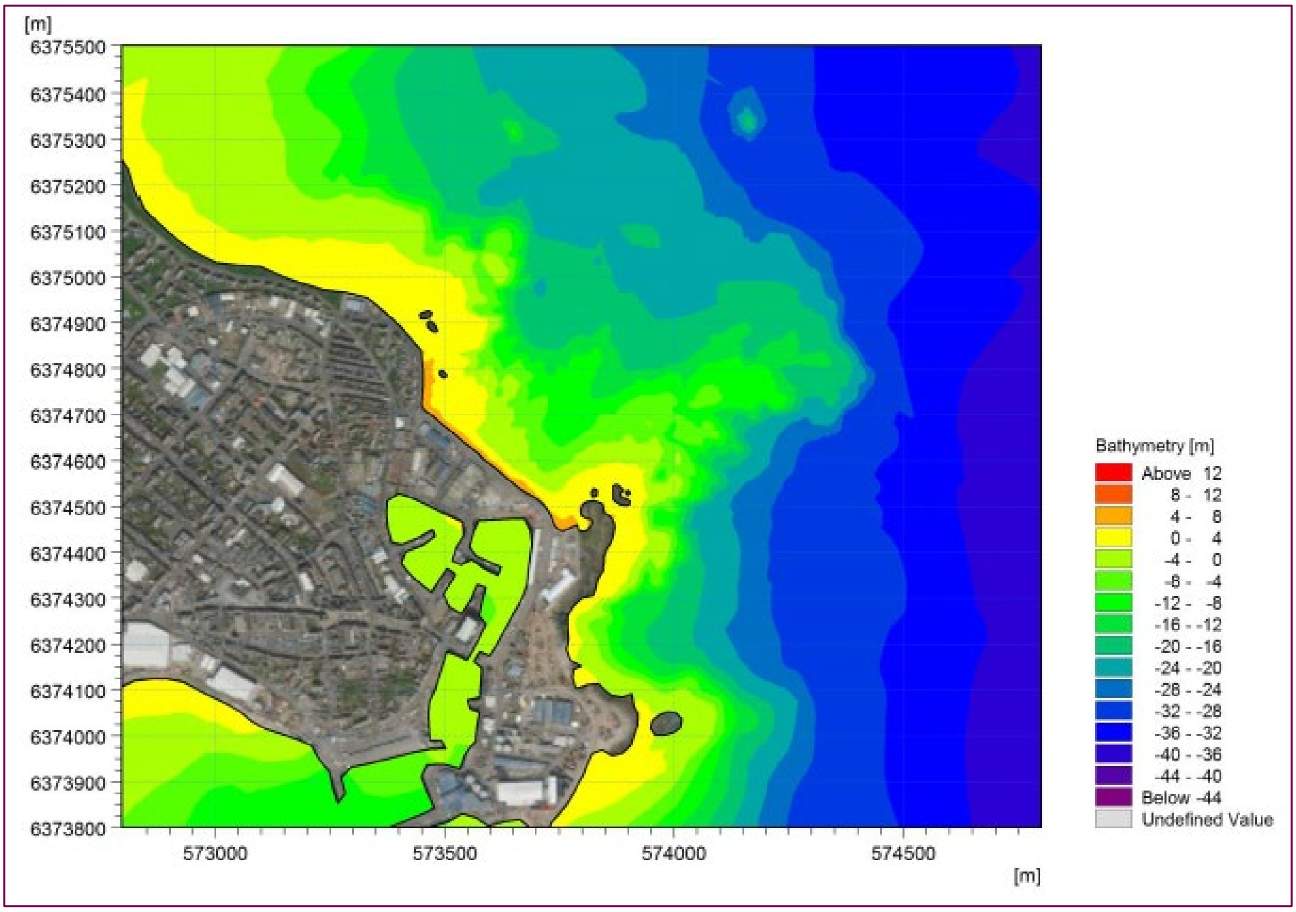

Figure 3-4: Bathymetry in the surrounding Alexandra Parade (RPS, 2018).

3.3.2 Wave Climate

3.3.2.1 In UK waters, the wave climate is strongly seasonal; mean wave heights peak around January, but extreme waves (>15 m at a wave period of 11 seconds) are also likely from October to March (Statoil, 2014). Long term (+50 years) modelling of wave data undertaken by the Hywind project, located circa 23 km east of the project, indicates that the wave climate in the Peterhead area is dominated by waves from the north and south-west, although locally generated wind waves are present from all directions (Statoil, 2014). The modelling indicates that the sea state is dominated by a wave period between 4 to 8 seconds with the majority of significant wave heights of less than 4 m (Statoil, 2014).

3.3.2.2 Further to this, RPS undertook a physical assessment of the Proposal area to establish the inshore wave and water level storm conditions (RPS, 2018; see Appendix B). The study found extreme wave conditions, with a return period of 100 years, were estimated to have a significant wave height of circa 9.9 m. Extreme water levels were recorded at a 4.99 m for a return period of 100 years. Additionally, future climate conditions may exacerbate the overtopping at Peterhead, as sea level rise is expected to increase by 0.278 m by 2040. The study also found that the highest waves are likely to come from the east.

3.3.2.3 The Proposal site is located on the northern face of the Peterhead peninsula and is likely to receive full exposure to the wave climate.

3.3.3 Tidal Currents

3.3.3.1 Tides in the North Sea are predominantly semi-diurnal. The flood and ebb tides in the Aberdeenshire region are strongly rectilinear, with the ebb tide flowing north and flood tide flowing south, parallel to the coastline (Hywind, 2015).

3.3.3.2 At Peterhead, the tidal current reaches a maximum speed of approximately 1.3 m/s during spring tides (UKHO, 2013). Further offshore, at the Hywind Offshore Windfarm (circa 23 km east of the Proposal), mean current speeds were recorded at 0.40 m/s and maximum current speeds of 1.42 m/s at a depth of 25 m (Statoil, 2014). As depth increased (25 m – 90 m), mean and maximum current speeds decreased by 20% (Statoil, 2014).

3.3.3.3 Tidal ranges, at Peterhead, have been recorded at 3.8 m for springs and 3.1 m for neaps (UKHO, 2013).

3.3.4 Sediment Transport

3.3.4.1 Sediment transport (mostly shelly carbonate material) occurs in a southerly direction parallel to the Aberdeenshire coastline and along the coastal margins (BOWL, 2012). Most sediment transport likely occurs in pulses associated with (relatively frequent) storm events, although a very weak background transport rate may be associated with stronger tidal currents and rectilinear waveforms (Hywind, 2015).

3.3.5 Water Quality

3.3.5.1 The River Ugie flows into the North Sea approximately 1.8 km north west of the Proposal location and lies within the Ugie Estuary to Buchan Ness (Peterhead) River Basin Management Plan (RBMP) water body. This RBMP unit is classified as being a heavily modified water body, and currently holds the status of "good ecological potential" and water quality status of "good" (SEPA, 2009). The waterbody is receiving pressure from diffuse source pollution from water transport, morphological alterations from water transport and point source pollution from sewage disposal (SEPA, 2009). Each of these pressures have improvement objectives pinned to them which hope to see them achieve "Good" status by 2021. The RBMP waters bodies to the north and south are both of 'High' status.

3.3.5.2 The nearest designated bathing water (Peterhead (Lido)) is approximately 1.7 km south of the Proposal, located in Peterhead Bay within Peterhead Bay Marina. Peterhead (Lido) has been classified as 'Excellent' (MCSUK, 2019) and is not at risk of excessive production of cyanobacteria, macroalgae or phytoplankton. The bathing season for the bathing waters are from the 1st June through to the 15th September (SEPA, undated).

3.3.5.3 Suspended sediment sampling undertaken as part of the Hywind Export cable route, indicates a Total Suspended Solids (TSS) of 0.05 g (dried weight) at a depth of 20 m, sampling site located 1 km east of the Proposal (Statoil, 2013).

3.3.6 Geology and Sediment

3.3.6.1 The Proposal is found in an area where basement bedrock underlying the much younger Quaternary deposits comprise a sequence of indurated sedimentary (clay, sand and gravel) and igneous rock (granite) sequences dating between Palaeocene and Devonian age (BGS, 2019). The depth to the bedrock interface is irregular, with deep areas lying southeast and northeast of Peterhead.

3.3.6.2 Directly within the Proposal footprint, along the top of the foreshore lies the concrete seawall, with rock armour extending down to Mean Low Water Spring (MLWS). Beyond MLWS, the predominant substrate is exposed rock with sporadic sediments. Coarse and fine sediments have been identified and are most likely present interstitially. No beaches exist within the vicinity of the Proposal area, except for small accumulations of coarse gravel/cobbles between bedrock channels (Xodus, 2013).

3.4 Benthic Ecology

3.4.1 Subtidal

3.4.1.1 Biotopes present within the subtidal section of the Proposal area are likely to be associated with the substrate types identified in Section 3.2.6. A Phase 1 survey of the shallow subtidal area (0-20 m) adjacent to the Proposal as part of the Hywind project classified the biotopes as "*Laminaria hyperborea* with dense foliose red seaweed on exposed infralittoral rock" (IR.HIR.KFaR.LhypR) which is classified as Annex I bedrock reef and "Faunal and algal crusts on exposed to moderately wave-exposed circalittoral rock" (CR.MCR.EcCr.FaAlCr). The patches of sand amongst the bedrock, were classified as "Infralittoral fine sand" (SS.SSa.IFiSa) and "Infralittoral mobile clean sand with sparse fauna" (SS.SSa.IFiSa.IMoSa) with very sparse numbers of infauna species and abundance (Statoil, 2013).

3.4.2 Intertidal

3.4.2.1 The intertidal zone as surveyed by the Hywind project within the Proposal footprint comprises four main biotopes displaying distinct zonation from lower to upper shore. Four identified biotopes are consistent between those identified on the existing revetment, rock armour and adjacent bedrock areas. This indicates that following placement of rock material, typical species associated within the surrounding bedrock reef areas have colonised the placed rock armour material of the revetment. Kelp biotopes in the form of *Laminaria digitata* on moderately exposed sublittoral fringe bedrock (IR.MIR.KR.Ldig/ ldig) dominate the lower intertidal zone with *Fucus serratus* and red seaweeds on moderately exposed lower eulittoral rock (LR.MLR.BF.Fser.R) dominating the middle to lower intertidal zone, followed by mussels and barnacles classified as *Semibalanus balanoides*, *Fucus vesiculosus* and red seaweeds on exposed to moderately exposed eulittoral rock (LR.HLR.MusB.Sem.FvesR), and yellow and grey lichens on supralittoral rock (LR.FLR.Lic) in the upper zone (Xodus, 2013).

3.4.2.2 Additionally, coralline algae rockpools (LR.FLR.Rkp.Cor.Cor) were found circa 200 m north west of the Proposal area. Rockpool biotopes are considered specialised biotopes of particular nature conservation interest because they are often species-rich and therefore increase the biodiversity of the shore (Wyn *et al*., 2000). Rockpools are described as biotopes for additional consideration in the Site of Special Scientific Interest (SSSI) Guidelines (JNCC, 1996). However, no rockpool biotopes were identified as part of the Phase 1 survey within the Proposal area (Xodus, 2013).

3.5 Fish and Shellfish

3.5.1 Regional Fish and Shellfish Assemblage

3.5.1.1 The regional fish assemblage of the area includes demersal, pelagic, migratory and elasmobranchs fish species. Demersal species include sandeel *Ammodytidae*, whiting *Merlangius merlangus*, lemon sole *Microstomus kitt,* ling *Molva molva*, plaice *Pleuronectes platessa*, with pelagic species including herring *Clupea harengus*, sprat *Sprattus sprattus* and saithe *Pollachius virens* likely to be found in the vicinity of the Proposal area. Migratory species such as Atlantic salmon *Salmo salar*, sea trout *Salmo trutta*, sea lamprey *Petromyzon marinus*, river lamprey *Lampetra fluviatilis* and European eel *Anguilla anguilla* have been found to migrate to and from Scottish rivers near to the Proposal and thereby may migrate through the study area to rivers during certain periods of the year. In addition, elasmobranchs (sharks and rays) have been found distributed throughout the east coast of Scotland, with the largest, the basking shark *Cetorhinus maximus*, associated with seasonal feeding grounds.

3.5.2 Migratory Fish

3.5.2.1 Three species of anadromous fish, the Atlantic salmon, sea trout, sea lamprey and river lamprey, and the catadromous fish species European eel have the potential to be found within the study area.

3.5.2.2 Salmonids (Atlantic salmon and sea trout) have a relatively similar life histories whereby eggs are spawned by the adults in freshwater. After hatching the juvenile life stage typically lasts between one to four years before migrating to the sea. Following migration to the sea, salmonids are known as post-smolts until the spring of the following year and after one winter as grilse. Adult salmonids spend the majority of their lives at sea, growing rapidly and only returning to fresh water environments to spawn from November to December (extending from October to late February) (SNH, 2017). Due to a highly acute sense of smell, Salmonids, upon reaching maturity, migrate back to their natal river, this behaviour is observed more in Atlantic salmon than in sea trout (Dipper, 2001; Lockwood, 2005). The length of time a salmonid spends in the sea varies from one to five years (Marine Scotland, 2011).

3.5.2.3 Atlantic salmon are widely distributed throughout Scotland and are recognised as Annex II (EU Habitats Directive), British Action Plan (BAP) species, Scottish Priority Marine Feature (PMF) (juvenile) and as an OSPAR species. They are currently both nationally and internationally important species. In recognition of the importance of Scottish salmon populations, 17 rivers have been designated as SACs for the Atlantic salmon, with the nearest being the River Dee, 40 km south. Sea trout are afforded less protection and is only listed as a UK BAP priority species.

3.5.2.4 Salmonids spawning grounds are found within the River Ugie (1.8 km north), Water of Philorth (21 km north west) and in the River Ythan (25 km south) (Figure 3.5). The routes by which they depart and return to rivers on the north east coast of Scotland are to and from the north (Malcolm *et al.,* 2010).

3.5.2.5 The European eel was last recorded, in the immediate vicinity of the Peterhead area, in 1995 (NBN Atlas, 2019). No sea and river lampreys have been identified within the Peterhead area (NBN Atlas, 2019). The sea lamprey was last recorded in the River Dee in 2010 (NBN Atlas, 2019). The river lamprey was last recorded in the River Tay in 2001 (NBN Atlas, 2019).

3.5.3 Elasmobranchs

3.5.3.1 Elasmobranchs are a cartilaginous fish group that comprises sharks, rays and skates. Shark species expected to be present in the area and listed as a priority marine feature include basking sharks *Cetorhinus maximus*, spiny dogfish *Squalus acanthias*, blue shark *Prionace glauca*, porbeagle shark *Lamna nasus,* spurdog *Squalus acanthias* and tope shark *Galeorhinus galeus* (Coull *et al.*, 1998; Ellis *et al.*, 2012; Baxter *et al.*, 2011). The main species of skate and ray present are spotted ray *Raja montagui*, sandy ray *Leucoraja circularis* common skate *Dipturus intermedia, Dipterus flossata* and *Dipterus batis* (priority marine feature) (Ellis *et al.,* 2012; Baxter *et al.*, 2011).

3.5.3.2 They have been recorded from around the whole Scottish coast, with sightings peaking in the summer months especially at a number of hot spots on the west coast (Baxter *et al.*, 2011). The basking shark has been identified in close proximity to the Proposal area, circa 2.5 km north east. However, this sighting was recorded in 2012. Other sighting records have determined that basking shark tend to cluster around Kinnaird Head (23 km north of Peterhead; n=13), with the last recorded sighting in 2013 (SNH, 2015). More recent surveys carried out to inform the Hywind project observed no basking sharks within the area (NRP, 2015)

3.5.4 Shellfish Assemblage

3.5.4.1 Shellfish are aquatic demersal shelled molluscs. Using commercial landing data as a proxy for species present in proximity to the Proposal and within the wider area, species most caught include the brown crab *Cancer pagarus*, European lobster *Homarus gammarus*, great Atlantic scallop *Pecten maximus*, velvet crab *Necora puber* and squid *Loligo* spp. Other species caught in the area include octopus *Octopodidae*, green crab *Carcinus maenas*, whelks *Buccinum undatum* and cuttlefish *Sepiidae* and *Sepiolidae* (see also Section 3.6).

3.5.4.2 There are no classified shellfish harvesting waters or shellfish water protected areas within 100 km of the Proposal. However, the River Dee, River Spey and the River South Esk SACs, 45km, 80 km west and 100 km south of the Proposal respectively, have primarily been designated as SACs due to the presence of the freshwater pearl mussel *Margaritifera margaritifera*. The freshwater pearl mussel, whilst not present in the marine environment, is dependent on the Atlantic salmon smolting population. Should the Atlantic salmon population be adversely affected by the Proposal, this may have an indirect effect on freshwater pearl mussel populations.

3.5.5 Local Fish and Shellfish assemblage

3.5.5.1 Within the vicinity of the Proposal, where the substrate has been classified as a mix of infralittoral and circalittoral rock with patches of infralittoral fine sand (Section 3.3.1); species such as lobsters (Nephropidae), crabs (Decapoda) and some demersal fish species (gobies *Pomatoschistus spp.*, wrasse *Ctenolabrus rupestris* and *Labrus bergylta*) and butterfish *Pholis gunnellus* are likely to occur in addition to those identified in Section 3.4.1 (Stamp and Tyler-Walter, 2015; Stamp and Tyler-Walter, 2016; Tillin, 2016).

3.5.6 Spawning and/or nursery grounds

3.5.6.1 Species with known spawning periods and nursery habitats identified within the study area have been summarised in Table 3.2.

Table 3.2: Key species with spawning times and spawning and nursery grounds that overlap with the Proposal area (Coull *et al.*, 1998 and Ellis *et al.*, 2012).

Common Name	Species	Spawning grounds	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Nursery grounds
Cod	*Gadus morhua*														
Common skate	*Dipturus intermedia*	Spawning grounds are not well established	Unknown												
European hake	*Merluccius merluccius*														
Herring	*Clupea harengus*[2,8]														High Intensity
Lemon Sole	*Microstomus kitt*														
Ling	*Molva molva*[2,3]														
Plaice	*Pleuronectes platessa*[2,8]														
Saithe	*Pollachius virens*[3]														
Sandeel	*Ammodytidae*[2,3]														High Intensity
Spotted ray	*Raja montagui*[4]	Insufficient data, generally overlap with nursery grounds													
Sprat	*Sprattus sprattus*														
Spurdog	*Squalus sp.* [2,4,6]	Spawning grounds are not well established													
Tope shark	*Galeorhinus galeus*[2,6]	Spawning grounds are not well established													
Whiting	*Merlangius merlangus*[2]														High Intensity

1. Annex II of the EU Habitats Directive
2. BAP Species
3. Priority Marine Feature
4. OSPAR
5. CMS Appendix II
6. IUCN Red List
7. Bern Convention Appendix III
8. EU Management Plans

	Spawning period		Peak spawning		Grounds overlap with Proposal

3.6 Marine Mammals

3.6.1 Cetaceans

3.6.1.1 The northeast of Scotland is comparatively diverse in cetacean species with eight out of 26 cetacean species recorded in the UK regularly recorded in the region (Evans *et al*., 2011). Cetacean species known to regularly occur within the area, identified through SCANS-III surveys (Figure 3.4) include:

- bottlenose dolphin *Tursiops truncatus*;
- harbour porpoise *Phocoena phocoena*;
- minke whale *Balaenoptera acutorostrata*; and
- white-beaked dolphin *Lagenorhynchus albirostris*.

3.6.1.2 The wider Moray Firth area is considered to be an important area for cetaceans (whales, dolphins and porpoise) with the harbour porpoise, bottlenose dolphin, minke whale and white-beaked dolphin occurring regularly within the wider area. However, large cetaceans such as killer and minke whales, are unlikely to be found within the ZoI of the Proposal due to the coastal and shallow nature of the site. Smaller cetaceans, such as porpoise and dolphins, may be present within the ZoI as they forage for prey species such as salmon and trout (Section 3.4) found within the Proposal area.

3.6.1.3 Harbour porpoise and bottlenose dolphin are listed under Annex II of the EC Habitats and Species Directive as species whose conservation requires the designation of SACs and are protected species under the Wildlife and Countryside Act 1981, the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) and the Convention on the Conservation of European Wildlife and Natural Habitats (The Bern Convention).

3.6.1.4 The only area in UK waters designated for bottlenose dolphin occurs in the Moray Firth SAC. This is the only resident population of bottlenose dolphin in the North Sea. The Moray Firth SAC lies approximately 95 km from the Proposal area; however, bottlenose dolphin are known to travel along the coast between the Moray Firth area and the Firth of Forth and Tay area and therefore have the potential to be within the ZoI of the Proposal.

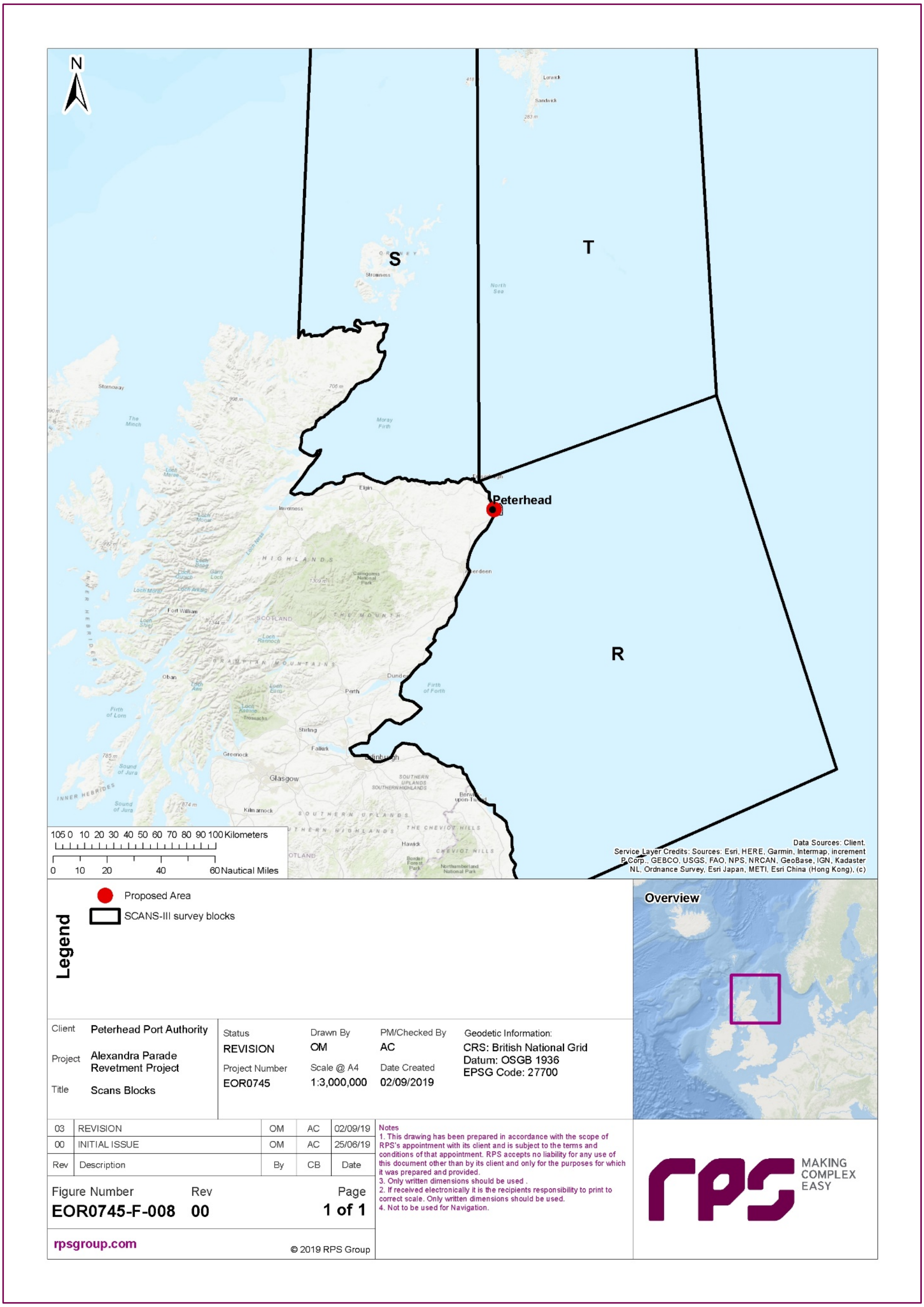

Figure 3-5: Scans III Block areas (SCANS III, 2017).

Bottlenose Dolphin

3.6.1.5 Bottlenose dolphin are distributed throughout UK waters, primarily close to shore (Reid *et al*., 2003). In the north east of Scotland, bottlenose dolphin are observed frequently in inshore waters where they utilise river estuaries, sandbanks, headlands and areas of strong tidal current for foraging (Wilson *et al.,* 1997, Ingram and Rogan, 2002).

3.6.1.6 Bottlenose dolphin is a primary reason for the Moray Firth SAC designation, located circa 95 km west of the Proposal. The Moray Firth SAC supports the only known resident population of bottlenose dolphin in the North Sea with a maximum population estimate of approximately 250 individuals (Moray Firth, 2015). Bottlenose dolphin are present year-round in the Moray Firth, although peak sightings occur between July and October and again in March and April. The bottlenose dolphin within the Moray Firth SAC are considered to be part of the east of Scotland population, and individuals regularly commute between the coastal waters of the southern Moray Firth and down the east coast as far as the St Abbs, Berwickshire (Brookes, 2017). The abundance estimate for this Coastal East Coast (CES) management unit (MU) population of bottlenose dolphin, based on photo-identification work during 2016 and passive acoustic monitoring between 2011 and 2016, is 189 individuals (95% Confidence Interval (CI): 155 – 216) (Cheney *et al.,* 2018),

3.6.1.7 SCANS-III data for Blocks R, S, and T, in proximity to the Proposal were investigated to determine the likely density of bottlenose dolphin in the study area (Hammond *et al.,* 2017; Figure 3.4)[2]. SCANS-III data returned an abundance estimate of 1,924 individual and 0.03 animals per km^2 for Block R, within which the Proposal was situated. There were only 0.004 animals estimated per km^2 in Block S (covering the western half of the outer Moray Firth and the inner Moray Firth) and no bottlenose dolphin were recorded in Block T and therefore the density estimate for this block is given as zero. No observations of bottlenose dolphin were recorded during the visual survey for the Hywind project (Hywind, 2015) which is located 23 km to the east of the Proposal.

3.6.1.8 Bottlenose dolphin are considered more likely to occur in coastal areas where the water depth is less than 25 m. Areas of particular importance include Chanonry Point, Spey Bay, and Sutors (Hastie *et al.,* 2004; Thompson, 2012). Cheney *et al.,* (2013, 2018) observed that identifiable dolphins moved between these areas thereby demonstrating connectivity between areas on the east coast of Scotland. Cheney *et al*., 2018 found the east coast bottlenose dolphin population to be increasing, though it remains small and potentially vulnerable (Cheney *et al.,* 2018). The use of the SAC is considered to be stable despite inter-annual variability and a slight decrease in the proportion of the east coast population utilising the SAC, probably as a result of an overall population increase (Cheney *et al.,* 2018).

3.6.1.9 There is some evidence of seasonal summer peaks in occurrence in bottlenose dolphin numbers along the east coast of Scotland (Wilson *et al.,* 1997; Thompson *et al.,* 2011, Cheney *et al.,* 2018). Hastie *et al.* (2004) and Robinson *et al.,* (2007) suggest that any seasonality observed is likely to be due to seasonal changes in prey availability. The main prey species of bottlenose dolphin are cod *Gadus morhua*, saithe and whiting (Santos *et al.,* 2001) with salmon and haddock *Melanogrammus aeglefinus* also occasionally taken.

[2] For the purposes of the SCANS-III surveys, the UK was divided up into 'blocks', the 'blocks' also aid in the dissemination of the data. 'Block R' is located off the east coast of Peterhead and encompasses an area of 64,464 m^2. Further information can be found in Hammond *et al.,* 2017.

Harbour Porpoise

3.6.1.10 The Harbour porpoise is ubiquitous throughout the temperate and subarctic waters to the North Pacific and North Atlantic oceans and is the most abundant cetacean in north west European waters (Evans *et al*., 2003). The porpoise is the most widely distributed cetacean species in UK waters, with the highest densities occurring in the North Sea (Evans *et al.,* 2003). The North Sea population is estimated to comprise of circa 227,298 individuals (JNCC, 2015).

3.6.1.11 SCANS-III surveys estimate that the highest density of harbour porpoise lies within SCANS-III Block R to the south of the outer Moray Firth region at 0.599 animals per km^2 (Figure 3.4). SCANS Block T has a density estimate of 0.402 animals per km^2 and SCANS Block S has a density estimate of 0.152 animals per km^2. SCANS Blocks R, S and T lie within the North Sea (NS) Management Unit (MU) for harbour porpoise. The average density estimate of harbour porpoise for the SCANS-III areas surveyed in the North Sea MU was 0.52 animals per skm^2 (Hammond *et al.,* 2017).

3.6.1.12 SCANS-III abundance estimate across the North Sea MU is 345,373 animals. SCANS Blocks R, S and T lie within the NS MU with associated abundance estimates for each block as 38,646, 6,147 and 26,309 individuals respectively (Figure 3.4) (Hammond *et al.,* 2017). Observational surveys undertaken for the Hywind project, located 23 km east of the Proposal, covering an area of 170.5 km^2, identified 229 individuals and were recorded as the most frequently sighted animal (Hywind, 2015). This equates to an encounter rate of 1.765 animals per hour and 0.091 animals per km^2 (Hywind, 2015). No hot spots of animals were recorded within the survey area and most individuals were observed to be slow moving. Whilst information on seasonal movements of harbour porpoise is limited (JNCC, 2010; Reid *et al*., 2003), the observation survey for Hywind found numbers of individuals peaked between July and September (Hywind, 2015).

White-beaked Dolphin

3.6.1.13 White-beaked dolphin are the most commonly sighted dolphin species off the east coast of Scotland (Evans *et al*., 2003). Typically, in the northern North Sea, white-beaked dolphins occur offshore in summer between May and October (particularly between July and September). The species breeds mainly between May and August although some breeding may also occur in September and October (Evans and Smeenk, 2008). White-beaked dolphin are considered as a single population of approximately 15,895 individuals (JNCC, 2015).

3.6.1.14 The Proposal lies within the Celtic and Greater North Seas (CGNS) Management Unit (MU).

3.6.1.15 The average density estimate for white-beaked dolphin for all North Sea SCANS-III blocks surveyed was 0.030 animals per km^2 (Hammond *et al.,* 2017). SCANS-III data returned an abundance estimate of 15,694 individual and a density estimate of 0.243 animals per km^2 for Block R, an abundance estimate of 868 animals and a density estimate of 0.021 animals per km^2 for Block S, and an abundance estimate of 2,417 animals and a density estimate of 0.037 animals per km^2 for Block T (Hammond *et al.,* 2017; Figure 3.4). Surveys carried out as part of Hywind project, located 23 km east of the Proposal, observed a total of 39 animals, equating to an encounter rate of 0.301 animals per hour and 0.016 animals per km^2 (Hywind, 2015). No hot spots of activity were identified, and individuals were generally slow moving. Sighting peaked between June and October (Hywind, 2015).

3.6.2 Pinnipeds

3.6.2.1 Two species of seal, harbour (or common) seal *Phoca vitulina* and grey seal *Halichoerus grypus* are both resident in Scottish waters. Both species use coastal sites for breeding/pupping and hauling out, and feed in inshore and offshore waters.

3.6.2.2 Both harbour and grey seal are listed on Annex II of the EC Habitats Directive and are therefore species that require the designation of SACs. There are 24 SACs which feature one or both species of seal as qualifying interest features within the UK. Within proximity to the Proposal there are four sites with grey or harbour seal as a notified interest features; Firth of Forth and Eden Estuary SAC, Dornoch Firth and Morrich More SAC, Isle of May SAC and Berwickshire and North Northumberland Coast SAC (Table 3.1).

3.6.2.3 Seals are protected under the Conservation of Seals Act 1970 and Marine (Scotland) Act 2010. The Marine (Scotland) Act 2010 protects seals from disturbance at designated haul-out sites. Marine Scotland has designated 194 coastal sites around Scotland as designated seal haul-out sites.

Grey Seal

3.6.2.4 Grey seal are generalist feeders and are known to take a wide range of prey items including whiting, cod, haddock, ling *Molva molva* and various species of flatfish. Breeding tends to occur between October and December and seals generally return to their natal breeding beach. Grey seal in the wider Moray Firth area haul out on intertidal sandbanks however they breed on beaches and caves above the high-water mark. The largest number of breeding beaches in the wider Moray Firth area are around Dornoch Firth, Brora and up to Duncansby Head (Duck and Thompson, 2009).

3.6.2.5 The nearest breeding haul out site for the grey seal are located 130 km north west from the Proposal within the Moray Firth. While grey seal are known to travel up to 2,100 km on foraging trips, most foraging trips remain within 145 km from haul-out sites (SCOS, 2018). Pupping occurs between August and December and moulting between December and April, where seals will spend more time ashore (SCOS, 2018). There is a seal haul out site located at the mouth of the River Ythan, located 25 km south west of Peterhead, however this has not been designated as a breeding site. The grey seal population was estimated to be 54,750, using pups born as a proxy for population, in 2017 in Scotland (SCOS, 2018).

3.6.2.6 The total UK population size for grey seal (> 1 year of age) was calculated for 2015 as 139,800 (approximate 95% CI 116,500-167,100), and projected forwards by a year to provide an estimated total UK population size of grey seal (> 1 year of age) in 2016 of 141,000 (approximate 95%CI 117,500-168,500) (SCOS, 2017). SCOS, 2017 provides an estimated grey seal population for the Moray Firth of 1,252 animals.

3.6.2.7 The observational surveys undertaken for the Hywind project recorded 38 individuals, equating to an encounter rate of 0.293 animals per hour and 0.091 animals per km^2 (Hywind, 2015). The Marine Scotland NMPi map indicates a similarly low abundance of grey seal off Peterhead, with the at-sea density of grey seals 0.12 – 0.59 animals per km^2 (Jones *et al.,* 2013).

Harbour Seal

3.6.2.8 Harbour seal are widely distributed around the west and north of Scotland's coastline, though there are also increasingly important haul-outs along the English east coast where numbers are stable following a recovery in numbers subsequent to the declines due to outbreaks of the phocine distemper virus in 1988 and 2002 (SCOS, 2017).

3.6.2.9 Over 5% of the world's population of harbour seal resides in the UK, with approximately 85% of the UK population residing in Scotland (SCOS, 2010; DECC, 2011). Major declines have been recorded in harbour seal numbers in colonies in Scotland, including a 76% decline in Orkney since 2001, 30% decline in Shetland between 2000 and 2009, and 92% decline in the Firth of Tay between 2002 and 2013 (SCOS, 2017). In the Moray Firth, however, whilst there was a 50% decline up to 2005, it was then stable for four years, and then showed an increase by 40% in 2010. It has since shown fluctuations without a major trend (SCOS, 2017).

3.6.2.10 Harbour seal generally give birth on scattered bays around the coast between June and July, however in the Moray Firth, pupping occurs on intertidal sandbanks. Seal also haul out for moulting during August and the Dornoch Firth is a main moulting site, with some additional moulting sites along the north and south coasts (loch Fleet, and Ardersier, Culbin and Findhorn respectively).

3.6.2.11 The closest harbour seal breeding haul out site is located 130 km north west from the Proposal within the Moray Firth. Harbour seal foraging distance are much smaller than that of grey seal, typically 40-50 km from their haul out sites (SCOS, 2017). There is a seal haul out site located at the mouth of the River Ythan, located 25 km south west of Peterhead, however, this has not been designated as a breeding site by Marine Scotland. The harbour seal population was estimated to be 26,600 individuals in 2017 in Scotland (SCOS, 2018).

3.6.2.12 During the Hywind project observation survey, only four individuals were observed, equating to an encounter rate of 0.031 per hour and 0.002 animals per km. The Marine Scotland NMPi map indicates a similarly low abundance, off Peterhead, with the at-sea density of harbour seal 0.003 – 0.004 animals per km^2 (Jones *et al.,* 2013).

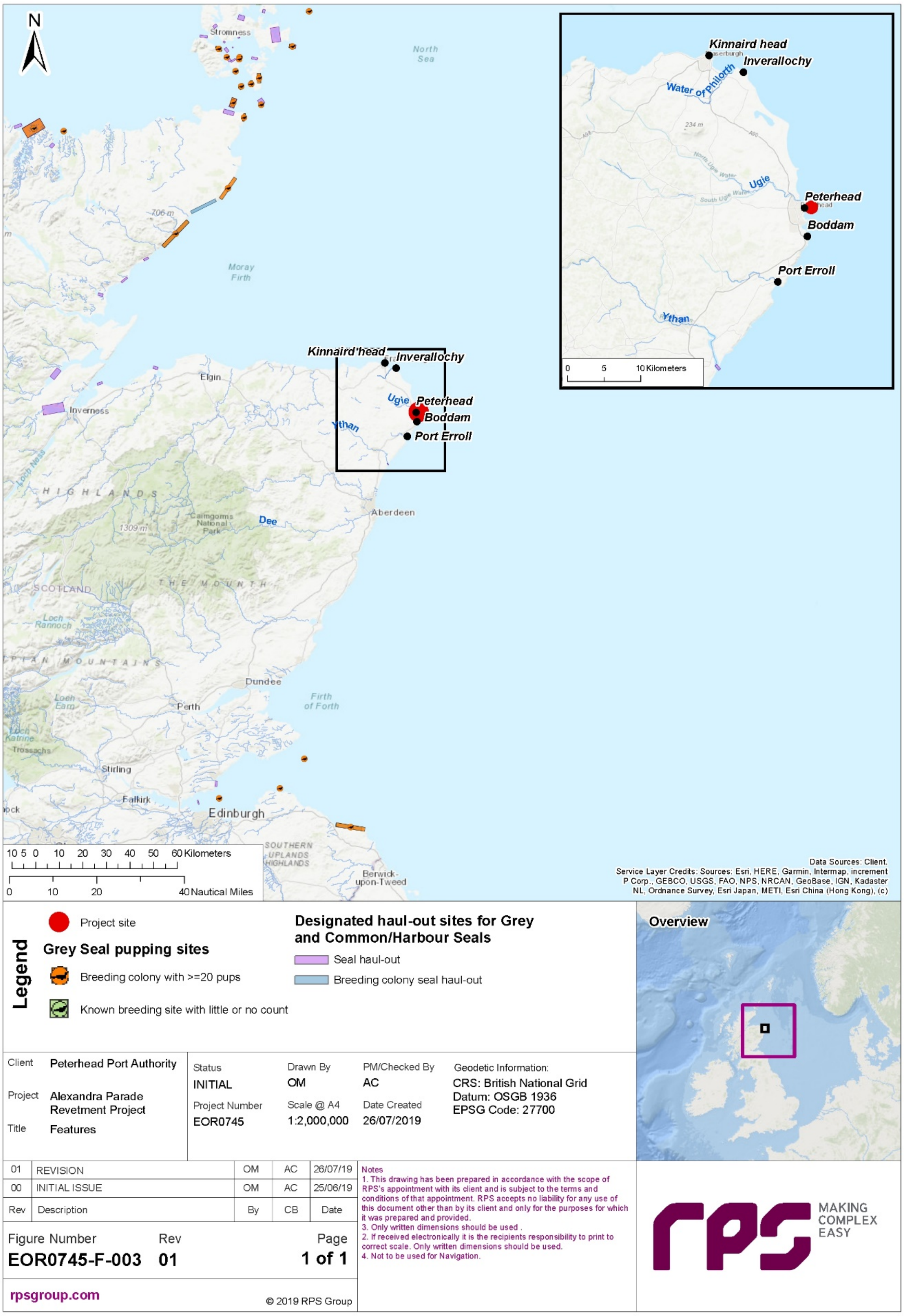

Figure 3-6: Seal haul out locations (Scottish Government, 2017).

3.7 Commercial Fisheries

3.7.1.1 The Proposal is located within International Council for the Exploration of the Sea (ICES) rectangle 44E8 (30 X 30 nautical miles), with fishing effort in this ICES rectangle dominated by demersal dredges (301 effort days[3]) and trawls (632 effort days), and pelagic seine nets (49 effort days) (ICES, 2018). Hooks and lines, traps, surrounding nets and harvesting machines also occur in this rectangle (ICES, 2018). Fishing effort data suggests that ICES rectangle 44E8 area is not of particular importance for passive and pelagic commercial fishing (ICES, 2018). However, demersal gear is comparably high to other ICES rectangles as evidenced by the dominant shellfish catch (Figure 3.6). The main fishing ports along this part of the coast are Peterhead, Aberdeen, Montrose and Inverness, with some vessels also landing fish at Boddam, Port Erroll and Inverallochy (Figure 3.5).

3.7.1.2 Shellfish species constitutes the majority of catch (value and quantity) within ICES rectangle 44E8, with scallop *Pecten maximus* as the main target species and other commercial species landed including brown crab, Norway lobster *Nephrops norvegicus*, lobster and velvet crab. Demersal species targeted in the area include haddock, anglerfish Lophiidae and whiting (Figure 3.6).

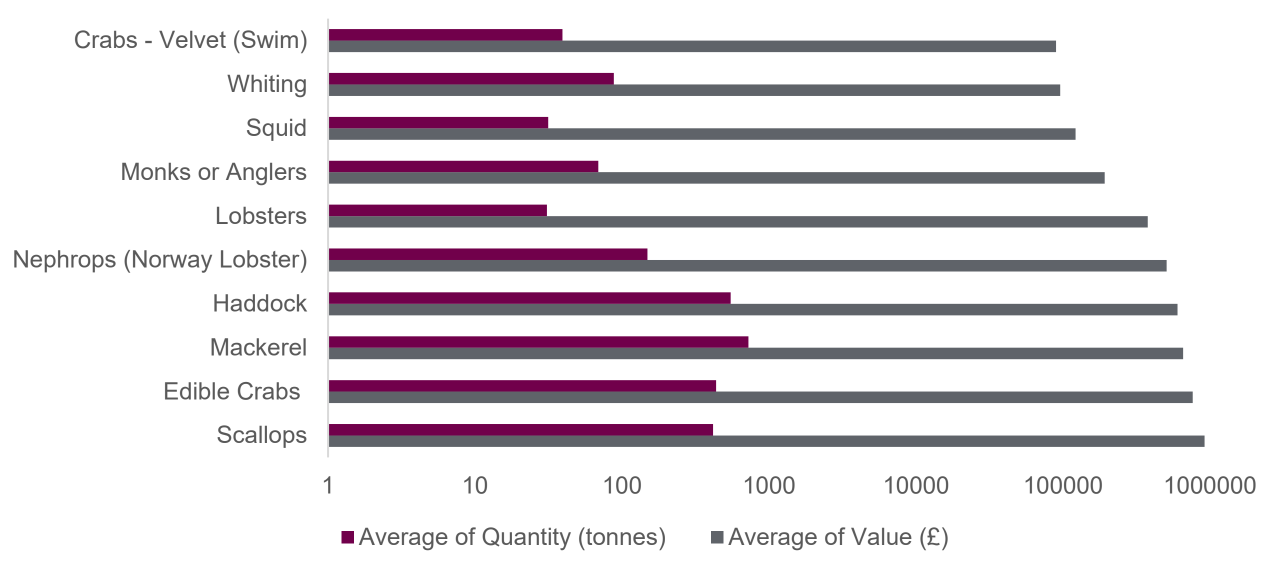

Figure 3-7: Average quantity and value of the top ten fish and shellfish landed between 2014 – 2018 (ICES, 2018).

3.7.1.3 The Proposal is also located within the jurisdiction of the Ugie District Salmon Fisheries Board; the River Ugie meets the sea just to the north of the proposed works, with salmon and sea trout caught between Boddam to Inverallochy, by traditional bag net, net and coble fisheries (UDFB, Undated).

[3] Average number of effort days over four years (2014 – 2018; ICES, 2018).

3.8 Shipping and Navigation

3.8.1.1 The Port of Peterhead and the Boddam harbour are located approximately 0.8 km and 3.7 km south of the Proposal respectively. The Port of Peterhead is the largest fishing port in Europe and acts as an important base for servicing commercial, energy and fishing traffic. In contrast to the Port of Peterhead, Boddam Harbour has considerably lower traffic levels associated with it, with the vessels associated with this harbour primarily characterised by fishing vessels and pleasure craft. The inshore shipping route, immediately outside Boddam Harbour is used by small and medium sized vessels transiting between UK coastal ports.

3.8.1.2 Section 3.3.1 et seq. identifies a variable site depth between 0 m to 4.5 m with outcrops of bedrock. Vessels are likely to avoid these areas due to the potential threat of shipwreck.

3.9 Marine Archaeology

3.9.1.1 Following a review of Historic Scotland webmap, no marine archaeological sites, wrecks or historic marine protected areas were found within the Proposal area or within 1 km of the area (Historic Scotland, Undated). However, there is a conservation area (Peterhead Roanheads) located on land 0.04 km north west of the Proposal.

3.9.1.2 Furthermore, consultation with Historic Environment Scotland considers the Proposal unlikely to have any significant impact on archaeological features within their remit (Table 1.1).

4. EMBEDDED MITIGATION MEASURES

4.1.1.1 A number of embedded mitigation measures are proposed to be incorporated into the design and construction method to manage the risk on the environment. These include:

1. Disturbance of seabed outside existing revetment footprint has been minimised in the construction design where possible.
2. Prior to construction an Environmental Management Plan (EMP) will be produced by the appointed Contractor and submitted to MS-LOT for approval.
3. The Contractor will adopt PPA's existing Marine Pollution Management Plan (MPMP).
4. The Contractor will undertake an Invasive Non-Native Species (INNS) risk assessment on award of contract.
5. Notice to Mariners will be issued prior to the commencement of works.
6. A Protocol for Archaeological Discoveries (PAD) will be implemented should a historical artefact be identified prior to or during execution of the works.

5. ASSESSMENT OF EFFECTS

5.1 Approach

5.1.1.1 The following sections provide an assessment of the potential environmental impacts of the licensable activities on receptors within the following environmental topics: Physical Processes, Benthic Ecology; Fish and Shellfish and Marine Mammals. Topics scoped out of the assessment are presented and discussed in Appendix A.

5.1.1.2 An assessment has been undertaken of the licensable activities for each of the identified receptor groups described above based on the impact scenarios identified in the Consenting Approach document (RPS, 2019) during the project. Impacts scoped out of the assessment are presented and discussed in Appendix A.

5.1.1.3 Each assessment concludes whether the licensable activities are likely to result in a negligible, minor, moderate or major effect on the receptor. Consideration of the potential for Likely Significant Effect (LSE) on European sites is presented in Section 7.

5.2 Physical Processes

5.2.1 Presence of the proposed project has the potential to cause changes to coastal processes

5.2.1.1 The proposed works will be predominantly conducted within the existing revetment footprint. An area of 2685 m^2 will extend outside the footprint. In addition, the revetment profile will change from an existing gradient of 1:1.25 – 1:1.3. to 1:1.5 with a total of 55,047 m^3 of rock and concrete added to the existing revetment slope (RPS, 2018).

5.2.1.2 While an increase of rock and concrete will be added to the structure, it is not expected that currents will change, as the proposed design will ensure that the structure is porous allowing water to flow through the structure rather that flow across the structure. The wave climate within the area will also not be impacted other than reducing the number of overtopping events that are currently observed. Wave conditions will remain the same except the Proposal will reduce the energy of waves as they impact the revetment. The impact from the presence of the Proposal on coastal processes is therefore considered to be negligible.

5.2.2 Preparation of the toe trench has the potential to cause an increase in suspended sediment concentrations in the water column

5.2.2.1 A total of 4,270 m^3 of consolidated material will be removed from the seabed to develop the toe trench for the placement of 28,712 m^3 of Xbloc units. The substrates associated with the toe trench have been characterised as bedrock intermixed with sand sediments. Substrates will be removed using a combination of hydraulic hammer to break the rock prior to removal by a backhoe excavator. During dredging activities, sediments have the potential to be mobilised, which can in turn cause an increase in total suspended sediments and deposition of sediments outside the dredge footprint. Given the material will be predominantly rock and small volume of coarse sediments, suspended sediment concentrations will remain low, as low volumes of fine sediment will be disturbed. Therefore, any sediments mobilised as part of the toe trench development will fall out of suspension rapidly following disturbance. The potential impact from an increase in suspended sediment concentrations is therefore considered to be negligible.

5.2.3 Placement of rock has the potential to cause an increase in suspended sediment concentrations in the water column

5.2.3.1 Quarry sourced rock armour will likely have a small volume of fine soil particles on the rock armour surfaces that are generated during extraction from the quarry site. As they are placed within the revetment footprint, they will be washed by marine water causing the particles to be released into the water column. It is therefore possible that the released soil particles will cause an increase in suspended sediment concentrations within the receiving water column. Total suspended sediment concentrations will however likely reduce to background concentrations, given the low volumes of fine sediments predicted on the surface and the exposed nature of the coastline, which will dilute concentrations rapidly following release. The placement of rock causing an increase in total suspended sediment concentrations is therefore considered to be negligible.

5.3 Benthic Ecology

5.3.1 Project footprint leading to removal of benthic habitats

5.3.1.1 The footprint area of the Proposal that will extend beyond the existing revetment footprint area below MHWS has been calculated to be 2,648 m^2. A total of 1,153 m^2 will be removed from the intertidal and 1,495 m^2 from the subtidal.

5.3.1.2 Based on existing information provided in Section 3.4.1, subtidal benthic habitats that will be permanently removed as a consequence of the project include:

- *Laminaria hyperborea* with dense foliose red seaweed on exposed infralittoral rock;
- Faunal and algal crusts on exposed to moderately wave-exposed circalittoral rock; and
- Patches of Infralittoral fine sand Infralittoral mobile clean sand with sparse fauna amongst the bedrock

5.3.1.3 Based on existing information provided in Section 3.4.2 intertidal benthic habitats that will be permanently removed as a consequence of the project include:

- Kelp biotopes in the form of *Laminaria digitata* on moderately exposed sublittoral fringe bedrock;
- *Fucus serratus* and red seaweeds on moderately exposed lower eulittoral rock;
- *Fucus vesiculosus* and red seaweeds on exposed to moderately exposed eulittoral rock; and
- Mussels and barnacles exposed to moderately exposed eulittoral rock classified by *Semibalanus balanoides.*

5.3.1.4 While a variety of different biotopes will be removed by the project these types of habitat are considered to be common throughout the region and the removal of 2,648 m^2 of habitat is considered comparatively small.

5.3.1.5 In addition, it is likely the proposed rock armour placed within the intertidal and subtidal areas will be colonised by similar characterising biotope species that will initially be removed by the Proposal as shown by the biotopes identified on the existing revetment structure (Statoil, 2015).

5.3.1.6 The impact of the Proposal from permanent removal of benthic habitats has therefore been assessed as negligible.

5.3.2 Introduction of Invasive Non-Native Species (INNS) on benthic ecology

5.3.2.1 Vessels can act as a vector for INNS by allowing the colonisation of benthic species from other geographical areas either as marine fouling on the vessel hull or following entrainment into the vessel through seawater intakes (for ballast water).

5.3.2.2 A low number of vessel movements are expected as a consequence of the Proposal. Locally quarried rock armour material will be transferred to site by lorry or locally sourced barges. Some larger rock armour will however be sourced from a licensed quarry in Norway and transferred by a single barge load. The material will be sourced in a non-marine area and will be transferred in dry conditions which will ensure non-native marine species will not be transferred. In addition, an INNS risk assessment will be undertaken by the Contractor on award of contract. If it is identified there is a risk of INNS, then suitable additional mitigation will be implemented.

5.3.2.3 The impact from introduction of INNS from the Proposal on benthic ecology is therefore considered to be negligible.

5.4 Fish and Shellfish

5.4.1 Toe trench development activities may result in noise emissions leading to disturbance to fish

Rock Breaking

5.4.1.1 Underwater noise can potentially have a negative impact on fish species ranging from physical injury/mortality to behavioural effects. Rock breaking will be undertaken to allow bedrock to be removed from the seabed in order to develop the toe trench. For the purposes of this assessment rock breaking has been assumed as an impulsive sound, similar in nature to small-scale impact piling, albeit directly into the seabed as opposed to transmitted through a pile.

5.4.1.2 Recent peer reviewed guidelines have been published by the Acoustical Society of America (ASA) and provide directions and recommendations for setting criteria (including injury and behavioural criteria) for fish. For the purposes of this assessment, these Sound Exposure Guidelines for Fishes and Sea Turtles (Popper *et al.,* 2014) were considered to be most relevant for impacts of underwater noise on fish species, with Table 5.1 outlining the criteria for injury and behavioural effects due to impulsive noise sources. With respect injury effects, these could be those injuries that lead to immediate or delayed death (i.e. mortality and potential mortal injury) at very high noise levels, or recoverable injuries (e.g. hair cell damage, minor hematomas) which are not likely to result in mortality. Behavioural effects may include a wide variety of responses including startle responses (also known as C-turn responses), strong avoidance behaviour, changes in swimming or schooling behaviour or changes of position in the water. Depending on the strength of the response and the duration of the impact, there is potential for some of these responses to lead to significant effects at an individual level (e.g. reduced fitness, increased susceptibility to predation) or at a population level (e.g. avoidance or delayed migration to key spawning grounds), although these may also result in short term, intermittent changes in behaviour that have no wider effect, particularly once acclimatisation to the noise source is taken into account.

Table 5.1: Criteria for onset of injury to fish due to impulsive noise source (Popper *et al.,* 2014).

Type of Fish	Parameter	Mortality and potential mortal injury	Recoverable injury	Relative risk of behavioural effects
Group 1 Fish: no swim bladder (particle motion detection)	SEL, dB re 1 µPa²s	>219	>216	(*Near*) High (*Intermediate*) Moderate (*Far*) Low
	Peak, dB re 1 µPa	>213	>213	
Group 2 Fish: swim bladder is not involved in hearing (particle motion detection)	SEL, dB re 1 µPa²s	210	203	(*Near*) High (*Intermediate*) Moderate (*Far*) Low
	Peak, dB re 1 µPa	>207	>207	
Group 3 Fish: swim bladder is involved in hearing (primarily pressure detection)	SEL, dB re 1 µPa²s	207	203	(*Near*) Moderate (*Intermediate*) Low (*Far*) Low
	Peak, dB re 1 µPa	>207	>207	
Eggs and larvae	SEL, dB re 1 µPa²s	>210	(*Near*) Moderate (*Intermediate*) Low (*Far*) Low	(*Near*) High (*Intermediate*) High (*Far*) Moderate

The risk of behavioural effects is categorised in relative terms as “high”, “moderate” or “low” at three distances from the source: “near” (i.e. in the tens of metres), “intermediate” (i.e. in the hundreds of metres) or “far” (i.e. in the thousands of metres). Sound Exposure Level (SEL), decibel (dB), Pascal (Pa)

5.4.1.3 There is limited information on the noise levels and signature associated with rock breaking activities using a hydraulic hammer. However, a review of publicly available information has found that for typical rock breaking equipment, a maximum blow energy of approximately 70 kJ is generally estimated.

5.4.1.4 Underwater noise modelling using RAMSGeo software of rock breaking activities undertaken for the Wylfa Newydd Power Station Project found that a hammer with a diameter of 50 cm, with a blow energy of 70 kJ and a strike rate of 43 strikes/minute resulted in a peak source sound pressure level of 208.6 dB re 1 µPa (Peak) @ 1 m, which was found to propagate above a sound pressure level of 140 dB re 1 µPa for a distance up to 21 km from the source (along the north west transect). As the north west transect bathymetry profile data used for the Wylfa Newydd Power Station Project (Figure 5.1) is similar to the bathymetric profile observed within the Proposal ZoI (Figure 5.2) the modelling outputs from the Wylfa Newydd Power Station Project have been used as a proxy for determining the extent of noise impacts for this Proposal from rock breaking (and dredging activities) on fish species.

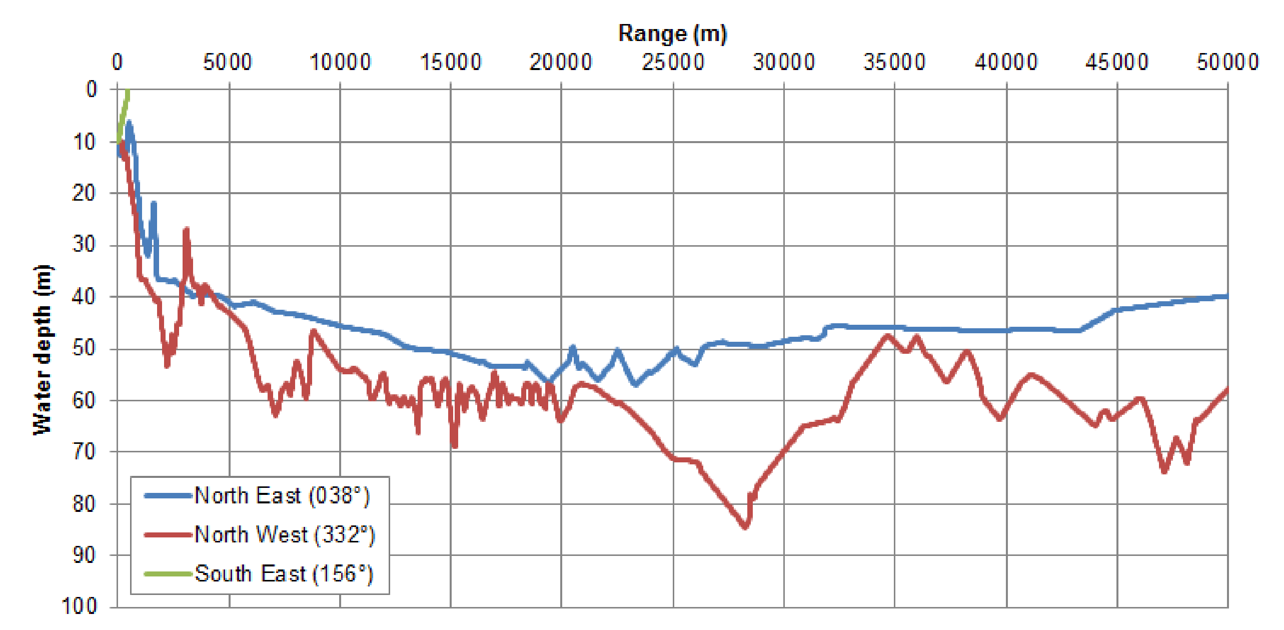

Figure 5-1: Bathymetric profile for the ZoI used in the modelling of rock breaking and dredging activities for Wylfa Newydd Power Station.

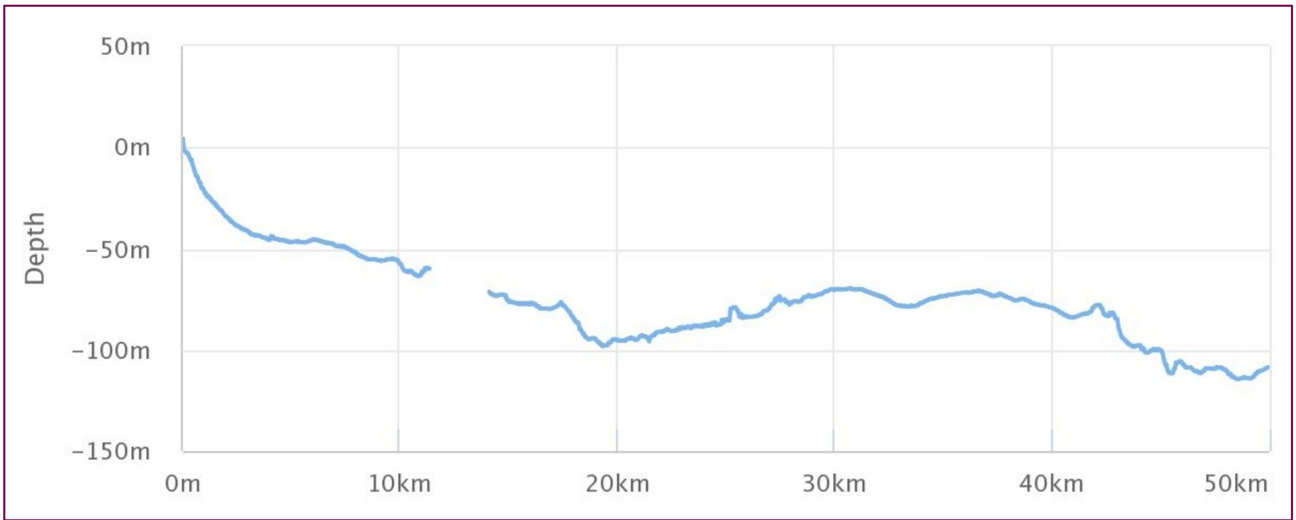

Figure 5-2: Bathymetric profile of the seabed within the ZoI of the Proposal with increasing distance offshore.

5.4.1.5 Based on the criteria outlined in paragraph 5.4.1.2 and Table 5.1, mortality is predicted within 1 m and recoverable injury within 10 m for fish groups 1, 2 and 3. Behavioural response threshold criteria is presented by Popper *et al*. (2014) qualitatively, including a wide variety of responses as set out in paragraph 5.4.1.2. The Popper et al. (2014) guidelines suggest a high risk of such effects expected within 10's of metres and moderate risk within 100's of metres from the source for group 2 fish, of which most of the species identified in the study area belong. To determine the behavioural response in fish quantitatively, the Washington State Department of Transport's Biological Assessment Preparation for Transport Projects - Advanced Training Manual (WSDOT, 2011) suggests an un-weighted sound pressure level of 150 dB re 1 μPa (root mean squared (rms)) as the criterion, based on work by Hastings (2002). Based on the modelling undertaken for the Wylfa Newydd Power Station Project, behavioural responses in fish could occur up to 4.6 km from the source during rock breaking activities, using the criteria in WSDOT (2011).

5.4.1.6 Proposed rock breaking activities will therefore likely result in a behavioural response from fish species within the wider area of the Proposal. No mortality or recoverable injury is predicted given that fish will likely move away from the source before encountering noise levels that could cause injury (<10 m). Given that rock breaking activities will be temporary, short term and intermittent, any effects are considered to be negligible.

Excavation and Rock Placement

5.4.1.7 Toe trench development once rock breaking has been completed to remove bedrock will be conducted using an onshore based excavator to remove rock from the seabed. This type of underwater noise is considered to be non-impulsive and sound pressure levels for this type of dredging has previous been measured at 163 dB re 1 μPa (rms), and 212 dB re 1 $\mu Pa^2 s$ SEL (24h) which is a cumulative measure of sound over a period of 24 hours. Injury and behavioural threshold criteria for non-impulsive noise sources (e.g. excavation activity assumed to be analogous to dredging) has been developed by Popper *et al.* (2014) and are summarised in Table 5.2.

Table 5.2: Criteria for onset of injury and behavioural response to fish due to non-impulsive sound (Popper *et al.*, 2014).

Type of fish	Mortality and potential mortal injury	Recoverable injury	Relative risk of behavioural effects
Group 1 Fish: no swim bladder (particle motion detection)	N) Low (I) Low (F) Low	N) Low (I) Low (F) Low	(*Near*) Moderate (*Intermediate*) Moderate (*Far*) Low
Group 2 Fish: swim bladder is not involved in hearing (particle motion detection)	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(*Near*) Moderate (*Intermediate*) Moderate (*Far*) Low
Groups 3 and 4 Fish: swim bladder involved in hearing (pressure and particle motion detection)	(N) Low (I) Low (F) Low	170 dB rms for 48h	(*Near*) High (*Intermediate*) Moderate (*Far*) Low
Eggs and larvae	(N) Low (I) Low (F) Low	(N) Low (I) Low (F) Low	(*Near*) Moderate (*Intermediate*) Moderate (*Far*) Low

5.4.1.8 Based on threshold criteria adopted above, no injury to fish groups is predicted for toe trench formation activities. Behaviour response which could include a wide variety of responses including startle responses (also known as C-turn responses), strong avoidance behaviour, changes in swimming or schooling behaviour or changes of position in the water column is generally predicted as moderate within 10's of metres and within 100's of metres from the source for all fish species groups.

5.4.1.9 Toe trench development will therefore not result in injury to fish species, and will cause very localised behavioural effects, which will be of short duration (4 weeks) and therefore the potential effect has been assessed as negligible.

5.4.2 Introduction for Invasive Non-Native Species (INNS) on fish and shellfish

5.4.2.1 Vessels can act as a vector for INNS by allowing the colonisation of fish and shellfish species from other geographical areas either as marine fouling on the vessel hull or following entrainment into the vessel through seawater intakes (for ballast water).

5.4.2.2 A low number of vessel movements are expected as a consequence of the Proposal. Locally quarried rock armour material will be transferred to site by lorry or locally sourced barges. Some larger rock armour will however be sourced from a licensed quarry in Norway and transferred by a single barge load. The material will be sourced in a non-marine area and will be transferred in dry conditions which will ensure non-native marine species will not be transferred. In addition, an INNS risk assessment will be undertaken by the Contractor on award of contract. If it is identified there is a risk of INNS, then suitable additional mitigation will be implemented.

5.4.2.3 No significant impact is therefore predicted in terms of introduction of INNS from the Proposal.

5.5 Marine Mammals

5.5.1 Toe trench development activities may result in noise emissions leading to disturbance to marine mammals

5.5.1.1 Marine mammals are sensitive to increased levels of underwater noise in the marine environment, and high levels of underwater sound has the potential to adversely affect marine mammals through mortality/physical injury and/or behaviour impacts. There is the potential for sound emissions from construction activities associated with the Proposal to affect marine mammals – namely rock-breaking, trenching and rock-placement. Development activities will occur at the Proposal site (Figure 1.1) over two 24-week phases. The timescales for different activities within each phase is shown in Figure 2-3. Activities will take place during working hours only (i.e. no 24-hour operations). However, the duration of activities may extend beyond working hours subject to agreement with PPA and compliance with noise regulations.

5.5.1.2 The NOAA National Marine Fisheries Service (NMFS) 'Technical Guidance for Assessing the Effects of Anthropogenic Noise on Marine Mammal Hearing' (NMFS, 2016) provides the latest guidelines on hearing ranges for marine mammals (based on modifications to the hearing groups proposed in Southall *et al*. (2007)).

5.5.1.3 The precautionary frequency-weighting functions for each group, based on known/estimated auditory sensitivity at different frequencies are given as:

a) high frequency (HF) cetaceans (275 Hz to 160 kHz);

b) mid-frequency (MF) cetaceans (150 Hz – 160 kHz);

c) low frequency (LF) cetaceans (7 Hz – 35 kHz); and

d) pinnipeds in water (PW) (50 Hz – 86 kHz).

5.5.1.4 Killer whale and minke whale are considered unlikely to occur within the ZoI of the Proposal due the coastal/intertidal nature of the works and are therefore not considered further in this assessment. Of the species that may occur within the ZoI of the Proposal, bottlenose dolphin and white-beaked dolphin fall within the MF group, harbour porpoise within the HF group, and harbour and grey seals in the PW group.

5.5.1.5 The thresholds for auditory injury for impulsive sounds are presented in Table 5.3 as defined in the NMFS (2016) Technical Guidance (hereafter referred to as the NOAA thresholds). Auditory injury can occur as a permanent threshold shift (PTS) from which there is no recovery or a temporary threshold shift (TTS) which is reversible follow cessation of the noise.

5.5.1.6 The metric considered in this assessment of subsea noise is zero-to-peak sound pressure level (SPL_{zp}) and because it refers only to the change in pressure, this metric is not weighted by the species hearing group. A single exposure at or above this pressure-based metric is considered to have the potential to cause PTS or TTS, regardless of the exposure duration (Southall *et al.,* 2007). As the proposed works are short in duration and impulsive in nature, it is considered highly unlikely that cumulative exposure to sound will occur, therefore SEL has not be presented.

5.5.1.7 Individuals' potential behavioural responses to a noise source are likely to be highly variable and dependent on a variety of factors (e.g. past experience, individual hearing sensitivity, activity patterns, motivational and behavioural state at the time of exposure, age, sex etc.) as well as environmental factors (e.g. prey availability, presence of predators, proximity to shoreline etc.). Unlike thresholds presented above for auditory injury (PTS and TTS), there is currently no established guidance on the appropriate thresholds for behavioural response to underwater noise. A conservative approach therefore uses the NMFS (2005) Level B harassment threshold of 160 dB re 1 μPa (rms) for impulsive sound (Table 5.3). Level B Harassment is defined as *"having the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioural patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering but which does not have the potential to injure a marine mammal or marine mammal stock in the wild"*. This assessment also considers the threshold for mild disturbance of 140 dB re 1 μPa (rms) as determined by the High Energy Seismic Survey (HESS) workshop on the effects of seismic sound on marine mammals (HESS, 1997). This value is similar to the lowest threshold for disturbance of low-frequency cetaceans noted in Southall *et al*. (2007). It is, however, considered unlikely that a threshold for the onset of mild disturbance effects could be defined as significant disturbance.

Table 5.3: Thresholds for PTS, TTS and behaviour for impulsive sounds. Noise metrics for PTS and TTS (NMFS, 2016) are presented as unweighted peak pressure levels for SPL (dB re 1μPa) Noise metrics for behaviour (NMFS, 2005) are presented as root mean squared (RMS) sound pressure level (dB re 1μPa).

Threshold	Harbour porpoise (HF cetacean)	Bottlenose dolphin and white-beaked dolphin (MF cetacean)	Harbour seal and grey seal (PW)
	SPL	SPL	SLP
PTS onset	202	230	218
TTS Onset	196	224	212
Strong Behavioural change		160	
Mild Behavioural change		140	

5.5.1.8 Toe trench development activities that have the potential to cause an increase in underwater noise include rock breaking, trenching and rock placement. To determine the extent of potential injury and disturbance to marine mammals from toe trench development activities, a semi-quantitative assessment of the noise sources associated with these activities was undertaken (as agreed with SNH, pers. comm.) with reference to the marine mammal sensitivities and injury thresholds described above. Consequently, a review of other projects that had included these activities in their noise assessment was conducted to inform the impact assessment.

Rock Breaking

5.5.1.9 Rock-breaking involves rapid hammering of the bedrock and therefore represents an impulsive noise source. In this way, the noise is similar in nature to small-scale piling, although noise is transmitted directly into the seabed instead of through a pile. The Wylfa Newydd Power Station Project described in Section 5.4.1.3 undertook noise-modelling for rock-breaking with a source level of 208.6 dB re. 1µPa (peak). A RAMSGeo noise modelling assessment was carried out by Subacoustech to determine the predicted noise levels moving away from the source. The resulting noise plot (range (m) vs peak SPL) has been used to inform the assessment of rock-breaking activities to be undertaken at the Proposal.

5.5.1.10 Based on the Wylfa Newydd Power Station Project noise modelling report, and applying the criteria set out in Table 5.3 for onset of PTS (202 dB re 1uPa)) in harbour porpoise (as the most sensitive marine mammal species to underwater noise), it is predicted that onset of PTS as a result of rock-breaking could occur at less than 2 m from the noise source. The source level for rock breaking is less than the peak SPL PTS threshold for MF cetaceans and PW (Table 5.3) and therefore there is considered to be no risk of PTS to bottlenose dolphin, white-beaked dolphin, grey seal and harbour seal from rock breaking.

5.5.1.11 Applying the criteria set out in Table 5.3 for onset of TTS (196 dB re 1uPa) in harbour porpoise (as the most sensitive marine mammal species to underwater noise), it is predicted that the onset of TTS as a result of rock-breaking could occur at less than 8 m from the noise source. The source level for rock breaking is less than the peak SPL TTS threshold for MF cetaceans and PW (Table 5.3) and therefore there is considered to be no risk of TTS to bottlenose dolphin, white-beaked dolphin, grey seal and harbour seal from rock breaking.

5.5.1.12 Applying the criteria set out in Table 5.3 for onset of strong or mild behaviour responses (160 and 140 rms respectively), a strong behavioural response for all marine mammals to rock-breaking is likely to occur close to the source, based on the noise modelling assessment for Wylfa Newydd Power Station. The range at which a mild behavioural response could occur was predicted to be out to just 30 m. Therefore, given that rock breaking activities will be temporary, short term and intermittent any effects are considered to be negligible.

Excavation and Rock Placement

5.5.1.13 Excavation to create the toe trench will be carried out by a rock breaker or rock wheel mounted on an excavator.

5.5.1.14 As rock-breaking has been determined to have very low potential for impact on marine mammals that may occur within the ZoI of the Proposal, it is considered highly unlikely that excavation or rock placement will result in injury or disturbance to marine mammals.

5.5.1.15 Culloch *et al.*, 2016 found that there have been few studies explicitly researching impacts of rock dredging, trenching or rock dumping (placement) activities on marine mammals. They concluded that noise from these activities is most likely to be broadband (non-impulsive) with most energy below 1 kHz (Reine *et al.,* 2014) and therefore unlikely to result in auditory injury (Kastelein *et al.,* 2002) in marine mammal receptors.

5.5.1.16 There may however be the potential for masking of communication in marine mammals to occur, in particular if there are impacts on prey species (Todd *et al*, 2015). Culloch *et al.*, (2016) went on to find that there may be some small-scale/temporary changes in harbour porpoise activity during construction-related activity, suggesting mild behavioural responses in the most sensitive marine mammal species. Toe trench development will result in very localised behavioural effects, will be of short duration (4 weeks over two phases) and therefore the potential effect on marine mammals has been assessed as negligible.

6. CUMULATIVE EFFECTS

6.1 Screening of Projects

6.1.1.1 This section considers the potential for cumulative effects arising from the Proposal alongside other known activities. The cumulative effects assessment uses the outcome of the assessment of effects in Section 5 to determine whether cumulative effects are likely and if so whether together they have the potential to increase the effects outlined for each receptor group in Section 5.

6.1.1.2 A review of activities which may potentially act cumulatively with the Proposal was undertaken for this Environmental Appraisal. Five projects were identified as having the potential for cumulative impacts, Moray East and Moray West offshore wind farms (Moray Offshore Windfarm (East) Ltd, 2017 and Moray Offshore Wind Farm (West) Ltd, 2018), Aberdeen harbour extension (Fugro and Waterman Infrastructure and Environment Ltd, 2015), Port of Cromarty Firth Invergordon Service Base Phase 4 Development (Affric, 2018) and the Eastern High Voltage Direct Current (HVDC) link (NGET and SHETL, 2012).

6.1.1.3 Of these projects the main overlap temporally will be the Moray East offshore windfarm (85 km north west) which began piling in June 2019 and will continue through to June 2020. This project has therefore been taken forward into the assessment.

6.1.1.4 The following projects have been scoped out of the cumulative assessment based on a lack of temporal and spatial overlap and in particular for the main noise generating activity:

- Moray West (93 km north west) is not scheduled to begin construction until 2022 with piling not commencing until the 2nd quarter of 2022 (Moray Offshore Windfarm (West) Ltd, 2018). Therefore, there is no temporal overlap between the Proposal and the Moray West offshore wind farm.
- The work at Aberdeen harbour (44 km south) has been ongoing for some time and is scheduled to be completed by the 2nd quarter of 2020 (Fugro and Waterman Infrastructure and Environment Ltd, 2015). Therefore, there is no temporal overlap between the Proposal and Aberdeen harbour.
- The Cromarty Firth Port (143 km west) construction activity was scheduled to start in November 2018 and to be completed in 2020 with piling activity occurring in the 3rd quarter of 2019 (Affric, 2018).
- The Eastern HVDC link has been postponed to beyond 2021 and is currently considered dormant.

6.1.1.5 The above projects do not overlap spatially with the Proposal and therefore, the main effects that require consideration are those that overlap temporally and affect species that migrate up and down the east coast of Scotland. As a result, the key effect to be considered within the assessment is subsea noise. Due to the distance between the Moray East offshore wind farm and the Proposal all other alone effects have been scoped out of the assessment. An assessment of the potential cumulative effects from subsea noise is presented below.

6.2 Fish and Shellfish

6.2.1.1 The assessment of the effects for the Proposal alone with respect to subsea noise on fish and shellfish have demonstrated that the risk of injury or behavioural effects from rock breaking and excavation activities to develop the toe trench is likely to be minimal. Effects are predicted to be very localised for all key species within the study area and therefore the impacts are considered to be negligible. Based on this and the ranges of impact considered for the Moray East offshore wind farm (Moray Offshore Renewables Ltd, 2016) which suggests a maximum impact range for fish species of 3.5 km (herring) there is not considered to be any potential for spatially overlapping cumulative impacts to occur when construction is occurring simultaneously i.e. for a fish receptor to be impact by noise from both activities at the same time. In addition, given the distance between the Moray East offshore wind farm and the negligible effect predicted for the construction of the toe trench, it is unlikely that fish and shellfish will experience cumulative effects if they are exposed to noise at the Moray East offshore wind farm and then move down the coast and are again exposed to noise from the Proposal's rock breaking and excavation activities. Based on this, there is not considered to be any potential for cumulative impacts with other plans or projects in the area, including the Moray East offshore wind farm.

6.3 Marine Mammals

6.3.1.1 The assessment of the effects for the Proposal alone with respect to subsea noise on marine mammals have demonstrated that the risk of injury or behavioural effects on marine mammals from the activities is likely to be very small. Effects are predicted to be very localised for all key species within the study area and therefore the impacts are considered to be negligible. Based on this and the ranges of impact considered for the Moray East offshore wind farm (Moray Offshore Renewables Ltd, 2016) which suggests a maximum impact range for marine mammals of 21 km (harbour porpoise) there is not considered to be any potential for spatially overlapping cumulative impacts to occur when construction is occurring simultaneously i.e. for a marine mammal receptor to be impacted by noise from both activities at the same time. In addition, given the distance between the Moray East offshore wind farm and the negligible effect predicted for the construction of the toe trench, it is unlikely that marine mammals will experience cumulative effects if they are exposed to noise at the Moray East offshore wind farm and then move down the coast are again exposed to noise from the Proposal's rock breaking and excavation activities. Therefore, it is considered there will not be any cumulative effects with other plans or projects in the area, including the Moray East offshore wind farm.

7. HRA SCREENING

7.1.1.1 The location of the Proposal in relation to the European designated sites which include SAC's and SPA's identified in Section 3.1 is shown in Figure 3.1. The need to consider the potential for Likely Significant Effect (LSE) on these sites from the Proposal is discussed below.

7.2 River Dee SAC

7.2.1.1 The Atlantic salmon feature of the River Dee SAC is assessed as "Favourable, maintained" and freshwater pearl mussel is assessed as "Unfavourable no change" (SNH, 2019a).

7.2.1.2 The River Dee SAC lies 45 km south west of the Proposal. Whilst there may be some potential for Atlantic salmon to be in the area and potentially be affected by underwater noise during rock breaking and excavation of the toe trench, the effects are all considered to be localised and reversible (i.e. once the activity has ceased normal behaviour will resume and fish will return to the area where disturbance occurred) and negligible. Therefore, the potential for the activities to result in negative effects on Atlantic salmon as features of the River Dee SAC is considered to be negligible.

7.2.1.3 Freshwater pearl mussel are sessile organisms found in the upper reaches of the River Dee. They are unlikely to be directly affected by the Proposal but may be indirectly affected by impacts on migratory Atlantic salmon (and sea trout) populations (hosts for the parasitic larval stage of the freshwater pearl mussel). However, given effects on these species are considered to be negligible it is likely that any effects on freshwater pearl mussels will also be negligible.

7.2.1.4 Therefore, there is no LSE nor population level effects on qualifying features arising from any of the impacts identified in this assessment either alone or in-combination with any other projects or aspects of the Proposal.

7.3 River Spey SAC

7.3.1.1 The Atlantic salmon in the River Spey SAC is assessed as "Unfavourable, recovering" while the sea lamprey is assessed as "Favourable, maintained" (SNH, 2019b).

7.3.1.2 The river Spey SAC is located 80 km to the west of the proposal footprint. Whilst there may be some potential for the migratory fish citation species (Atlantic salmon and sea lamprey) to be in the area and to potentially be affected by underwater noise due to rock breaking and excavation of the toe trench, the effects are all considered to be localised, reversible and negligible. In addition, the distance from the c Proposal combined with evidence to suggest that migrating Atlantic salmon smolts move rapidly out to sea rather than staying close to the coastline (Newton *et al*., 2017), suggests salmon migrating past the works are unlikely to be in the area for long, or in great numbers. Less is known of the marine distribution of adult sea lamprey other than they can be found in both coastal areas and further offshore (Maitland, 2003). However, there are not any records of large numbers of sea lamprey in the area and it is unlikely that significant effects to sea lamprey populations from the works will occur as adults move out to sea or return to the Spey in order to spawn.

7.3.1.3 The potential for the activities to result in negative effects on the features of the River Spey SAC is considered to be negligible. Therefore, there is no LSE nor population level effects on qualifying features arising from any of the impacts identified in this assessment either alone or in-combination with any other projects or aspects of the Proposal.

7.4 Moray Firth SAC

7.4.1.1 The most recent status assessment of the bottlenose dolphin population of the Moray Firth SAC is “stable or increasing” (Cheney *et al*. 2018). Bottlenose dolphin from the SAC may be present in the vicinity of the works as they transit between the Moray Firth and the more southerly parts of their range. Therefore, they may be affected by subsea noise generated by rock breaking and excavation activities to develop the toe trench. However, the effects are assessed as being localised, short term and reversible (i.e. once the activity has ceased, normal behaviour will have resumed and animals will return to the area where disturbance occurred) and the potential for the activities to result in negative effects on the bottlenose dolphin population as a feature of the Moray Firth SAC is considered to be negligible. Therefore, there is no LSE nor population level effects on qualifying features arising from any of the impacts identified in this assessment, either alone or in-combination with any other projects or aspects of the Proposal.

7.5 River South Esk SAC

7.5.1.1 The Atlantic salmon feature of the River South Esk SAC is assessed as “Unfavourable, recovering” and freshwater pearl mussel is assessed as “Unfavourable no change” (SNH, 2019c).

7.5.1.2 The River South Esk lies 100 km south of the Proposal. Whilst there may be some potential for Atlantic salmon to be in the area and potentially to be affected by underwater noise from toe trench construction activities (rock breaking, excavation), the effects are all considered to be localised, reversible and negligible. In addition, the distance from t Proposal combined with evidence to suggest that migrating Atlantic salmon smolts move rapidly out to sea rather than staying close to the coastline (Newton *et al.,* 2017), also suggests salmon migrating past the works are unlikely to be in the area for long or in great numbers. Therefore, the potential for the activities to result in negative effects on Atlantic Salmon as features of the River South Esk SAC is considered to be negligible.

7.5.1.3 Freshwater pearl mussel are sessile organisms found in the upper reaches of the River South Esk. They are unlikely to be directly affected by the Proposal but may be indirectly affected by impacts on migratory Atlantic salmon (and sea trout) populations (hosts for the parasitic larval stage of the freshwater pearl mussel). However, given effects on these species are considered to be negligible it is likely that any effects on freshwater pearl mussels will also be negligible.

7.5.1.4 Therefore, there is no LSE nor population level effects on qualifying features arising from any of the impacts identified in this assessment either alone or in-combination with any other projects or aspects of the Proposal.

7.6 River Tay SAC

7.6.1.1 The Atlantic salmon, river lamprey and sea lamprey features of the River Tay SAC are all assessed as “Favourable, maintained” (SNH, 2019d).

7.6.1.2 The River Tay SAC is located 157 km to the south west of the Proposal. Whilst there may be some potential for the migratory fish citation species (Atlantic salmon, river and sea lamprey) to be in the area and potentially affected by underwater noise from development of the toe trench (rock breaking, excavation) within the vicinity of the Proposal, the effects are all considered to be localised, reversible and negligible. In addition, the distance from t Proposal area, combined with evidence to suggest that migrating Atlantic salmon smolts move rapidly out to sea rather than staying close to the coastline (Newton *et al*., 2017) also suggests salmon migrating past the Proposal are unlikely to be in the area for long or in great numbers. Adult river lamprey mainly stay within estuarine areas (Maitland, 2003) and are therefore unlikely to migrate up the coast towards Peterhead and are unlikely to be affected by the works during their sea going phase. Less is known of the marine distribution of adult sea lamprey other than they can be found in both coastal areas and further offshore (Maitland, 2003). However, the river Tay is some distance from the Proposal and there are not any records of large numbers of sea lamprey in the area. It is unlikely that significant effects to sea lamprey populations from the works will occur.

7.6.1.3 The potential for the activities to result in negative effects on the features of the River Tay SAC is considered to be negligible. Therefore, there is no LSE nor population level effects on qualifying features arising from any of the impacts identified in this assessment either alone or in-combination with any other projects or aspects of the Proposal.

7.7 Firth of Tay and Eden Estuary SAC

7.7.1.1 Despite historically supporting large numbers of harbour seal, the Firth of Tay and Eden Estuary SAC has undergone dramatic declines in harbour seal numbers. As a qualifying feature of the site, the harbour seal is in ‘Unfavourable’ conservation status and is declining (SNH, 2018a). Population modelling has concluded that the population is likely to become extinct (Hanson *et al*. 2015).

7.7.1.2 Harbour seal from the SAC may occur in the vicinity of the Proposal and therefore may be affected by subsea noise. However, the number of harbour seal potentially affected is extremely low and the effects are assessed as being localised, short term and reversible (i.e. once the activity has ceased normal behaviour will resume and animals will return to the area where disturbance occurred). The potential for the activities to result in negative effects on harbour seal as features of the Firth of Tay and Eden Estuary SAC is considered to be negligible. Therefore, there is no LSE nor population level effects on qualifying features arising from any of the impacts identified in this assessment either alone or in-combination with any other projects or aspects of the Proposal.

7.8 Dornoch Firth and Morrick More SAC

7.8.1.1 The harbour seal feature of the Dornoch Firth and Morrick More SAC is assessed as “Unfavourable, declining” (SNH, 2019e).

7.8.1.2 The Dornoch Firth and Morrick More SAC is located circa 128 km to the west of the proposal footprint. Harbour seal is unlikely to be present within the ZoI from the Proposal. As outlined in paragraph 3.6.2.11, harbour seal has a foraging distance of up to 50 km from their haul-out sites (Thompson *et al.,* 1996) and so the SAC population is unlikely to have connectivity with the Proposal.

7.8.1.3 Thus, there is a low likelihood for harbour seal associated with the SAC occurring within the Proposal ZoI. The assessments presented in Section 5.5.1 concluded that effects arising from the Proposal on harbour seal would be negligible. Therefore, there is no LSE nor population level effects on qualifying features arising from any of the impacts identified in this assessment either alone or in-combination with any other projects or aspects of the Proposal.

7.9 Isle of May SAC

7.9.1.1 The SAC supports the largest grey seal breeding colony on the east coast of Scotland and the fourth largest in the UK. The pup production estimate at the Isle of May increased from 936 in 1989 to 2,133 in 2000, after which it has remained relatively stable with annual pup production estimates between ~1,900 and ~2,300. Pup production was estimated at 2,272 in 2014 (SCOS 2016). As a qualifying feature of the site grey seal has maintained 'Favourable' conservation status (SNH, 2018b).

7.9.1.2 The Isle of May is designated as a breeding site and the project activities will not affect animals present at the SAC during the breeding season. Grey seal which breed on the Isle of May are likely to spend the rest of the year foraging in other regions of the UK (Russell *et al*. 2013). However, the Isle of May SAC is located 155 km to the south of the Proposal. While grey seals are known to travel up to 2,100 km on foraging trips, most foraging trips remain within 145 km from haul-out sites (SCOS, 2017). Therefore, the SAC population is unlikely to have connectivity with the Proposal during the works. Furthermore, low numbers of grey seal have been recorded within the vicinity of the Proposal. Therefore, there is no LSE nor population level effects on qualifying features arising from any of the impacts identified in this assessment either alone or in-combination with any other projects or aspects of the Proposal.

7.10 Berwickshire and North Northumberland Coast SAC

7.10.1.1 The Berwickshire and North Northumberland Coast SAC is located 175 km to the south of the Proposal. However, the Berwickshire and North Northumberland SAC is located 175 km to the south of the Proposal. Grey seal which may be present within the vicinity of the project during the works but have only been recorded in low numbers. While grey seal are known to travel up to 2,100 km on foraging trips, most foraging trips remain within 145 km from haul-out sites (SCOS, 2017). Therefore, the SAC population is unlikely to have connectivity with the Proposal during the works. Therefore, there is no LSE nor population level effects on qualifying features arising from any of the impacts identified in this assessment either alone or in-combination with any other projects or aspects of the Proposal.

7.11 River Teith SAC

7.11.1.1 The Atlantic salmon feature of the River Teith SAC is assessed as "Unfavourable, recovering", river lamprey as "Favourable, maintained" and sea lamprey is assessed as "Unfavourable, declining" (SNH, 2019f).

7.11.1.2 The River Teith SAC lies 202 km to the south of the Proposal. Whilst there may be some potential for the migratory fish citation species (Atlantic salmon, river and sea lamprey) to be in the area and potentially affected by underwater noise, the effects are all considered to be localised, reversible and negligible. In addition, the distance from the location of the Proposal, combined with evidence to suggest that migrating Atlantic salmon smolts move rapidly out to sea rather than staying close to the coastline (Newton *et al.,* 2017) also suggests salmon migrating past the works are unlikely to be in the area for long or in great numbers. Adult river lamprey mainly stay within estuarine areas (Maitland, 2003) and are therefore unlikely to migrate up the coast towards Carnoustie and are unlikely to be affected by the works during their sea going phase. Less is known of the marine distribution of adult sea lamprey other than they can be found in both coastal areas and further offshore (Maitland, 2003). However, the River Teith is some distance from the Proposal and there are no records of large numbers of sea lamprey in the area. It is therefore unlikely that significant effects to sea lamprey populations from the works will occur.

7.11.1.3 The potential for the activities to result in negative effects on the features of the River Teith SAC is considered to be negligible. Therefore, there is no LSE nor population level effects on qualifying features arising from any of the impacts identified in this assessment either alone or in-combination with any other projects or aspects of the Proposal.

8. SUMMARY OF EFFECTS

A description, summary and assessment of the impact scenarios presented in this Environmental Appraisal is provided in Table 8.1.

Table 8.1: Description, summary and assessment of impact scenarios.

Description of impact scenario	Summary of impact scenario	Assessment of impact scenarios
Physical Processes		
Presence of the proposed project has the potential to cause changes to coastal processes	Increase in rock and concrete at the revetment may potentially alter wave climate and conditions. However, the design of the revetment is unlikely to affect the current wave regime, except to prevent overtopping of waves.	Negligible
Preparation of the toe trench has the potential to cause an increase in suspended sediment concentrations in the water column	A total of 4,270 m^3 is to be removed by hydraulic hammer and blackhoe excavator to create the toe trench, this material has the potential to increase sediment present in the water column. However, sediments mobilised are likely to fall out of suspension quickly. Additionally, sediments volumes are considered small.	Negligible
Placement of rock has the potential to cause an increase in suspended sediment concentrations in the water column	Rock used to create the new revetment, will have soil and dust on the surface. This may, once installed within the revetment footprint, release into the water column, increasing suspended sediments. However, it is likely that the volumes of sediment released are minimal.	Negligible
Benthic Ecology		
Proposal footprint leading to removal of benthic habitats	Excavation of material is likely to remove associated benthic communities with it. However, biotopes present are considered common and it is likely that following excavation and placement of rock armour that the rock armour will be quickly recolonised.	Negligible
Introduction for Invasive Non-Native Species (INNS) on benthic ecology	INNS may be introduced or spread from site due to the presence of marine vectors, such as vessels. However, low number of vessel movements are likely. Additionally, an INNS risk assessment will be undertaken as part of embedded mitigation to assess the risk of introduction or spread of INNS.	Negligible
Fish and Shellfish		
Toe trench development activities may result in noise emissions leading to disturbance to fish	Noise emitted from the rock breaking and excavation works may have adverse effects on the fish and shellfish populations. Rock breaking is expected to have a short-term behavioural response i.e. c-turn response. No mortality or recoverable injury is anticipated. Localised behaviour responses are expected from excavation works.	Negligible
Introduction for Invasive Non-Native Species (INNS) on fish and shellfish	Vessels may introduce INNS to site, however, low number of vessel movements are expected, and an INNS risk assessment will be undertaken prior to the commencement of works.	Negligible
Marine Mammals		
Toe trench development activities may result in noise emissions leading to disturbance to marine mammals	Marine mammals are sensitive to increase levels of noise such as rock breaking, excavation and rock placement. However, it is considered highly unlikely that excavation or rock placement will result in injury but may result in a mild behavioural disturbance to marine mammals in close proximity to the works.	Negligible

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Appendix A

Scoping Exercise

Receptor groups scoped out from further assessment

Table A1 below provides a summary of the receptor topics that have been scoped out including a brief justification. Impacts that have been scoped out from further assessment for each receptor topic and a justification have also been provided below.

Table A1: Summary of receptor topics scoped for further assessment.

Receptor Topic	Justification
Marine Ornithology	No impact receptor pathway identified. No significant marine bird populations identified within project footprint.
Commercial Fisheries	Proposed works will not interfere with commercial fishing activities due to all works being undertaken from onshore locations. A notification to mariners will also be issued prior to commencement of works.
Shipping and Navigation	No impact receptor pathway identified. All proposed works will be undertaken within intertidal area with placement of rock in shallow subtidal areas. A notification to mariners will be issued prior to commencement of works.
Marine Archaeology	No artefacts identified within construction footprint. Embedded mitigation to be implemented should an artefact be identified during the Proposal (e.g. PAD).
Landscape, Seascape and Visual Impact Assessment	The Proposal will be undertaken primarily within the existing revetment footprint and therefore will not change the seascape and character of the location.
Other Sea Users	No impact pathway for other sea users to be affected by the proposed works. A notification to mariners will be issued prior to commencement of works.
Socio-economic and Tourism	The Proposal will be short term and identical to the current land use. Potential beneficial impact as there is a reduced risk of damage from overtopping to fish market that provides suitable infrastructure for selling of fish and shellfish.

Impacts scoped out from further assessment

Physical Processes

Impacts to physical environment that have been scoped out from further assessment include:

- **The Proposal structure may lead to a change in the wave climate within the area.**

The proposed works will reduce the impact of waves overtopping the existing sea wall by absorbing the wave energy on contact with the revetment. However, the Proposal will not change the height or frequency of waves prior to contact with the revetment. This impact has therefore been scoped out from further assessment.

Benthic Ecology

Impacts to benthic ecology that have been scoped out from further assessment include:

- **Preparation of the toe trench and placement of rock may cause an increase in suspended sediment concentrations and associated sediment deposition.**

Increases in suspended sediment concentrations has the potential to cause light attenuation at the seabed which can restrict the ability of species to photosynthesise. Smothering of benthic species from sediment deposition can also occur as sediments fall out of suspension following disturbance. However, these potential impacts have been scoped out from further assessment as the material that will be removed to develop the toe trench will be of a very small volume and will be removed over a short period. The material to be excavated to form the toe trench will also be likely rock or mixed coarse sediments which will fall out of suspension rapidly over short distances following suspension.

- **Placement of rock may cause a temporary increases in SSC and associated sediment deposition.**

Increases in SSC has the potential to cause light attenuation at the seabed which can restrict the ability of species to photosynthesise. In addition, as mobilised sediments fall out of suspension and undergo deposition on the seabed impacts on benthic species from smothering maybe possible. This potential impact has been scoped out from further assessment based on the volume of fine sediment residue attached to the rock used for the Proposal which will be very small and following interaction with the sea will dilute rapidly through wave action and tidal currents resulting in elevated suspended sediments for a short period of time within a localised area.

- **Development of the toe trench may cause seabed disturbances leading to the release of sediment contaminants and consequent toxic effects on benthic species.**

The material to be removed from the toe trench will likely consist of coarse sediments and rock which do not have an affinity to bond with contaminates unlike clay and silt sediments. Given the volume of material to be removed and low levels of contaminants likely contained within the material, impacts on benthic ecology from release of contaminants has been scoped out from further assessment.

- **Placement of rock may result in the release of sediment contaminants leading to toxic effects on benthic species.**

No contaminants are predicted to be contained within the small volume of fine sediment residue attached to rock which will be imported from licensed quarries that have environmental measures in place to manage chemicals and fuels onsite. The rock material itself will not absorb contaminants due to the materials geological properties and is therefore considered inert. The potential impact on benthic ecology from release of contaminants from placement of rock has therefore been scoped out from further assessment.

- **Project activities may result in accidental release of pollutants leading to toxic effects on benthic species.**

The potential for accidental release of pollutants affecting benthic ecology receptors has been scoped out of further assessment on the basis of the designed-in mitigation measures which include pollution prevention and control measures which will reduce the likelihood of impact to a negligible level.

Fish

Impacts to fish that have been scoped out from further assessment include:

- **Development of the toe trench may cause seabed disturbances leading to the release of sediment contaminants and consequently toxic effects on fish.**

The material to be removed from the toe trench will likely consist of coarse sediments and rock which do not have an affinity to bond with contaminates unlike clay and silt sediments. Given the volume of material to be removed and low levels of contaminants likely contained within the material, the potential impact on fish from release of contaminants has been scoped out from further assessment.

- **Placement of rock may result in the release of sediment contaminants leading to toxic effects on fish.**

No contaminants are predicted to be contained within the small volume of fine sediment residue attached to rock will be imported from licensed quarries that have environmental measures in place to manage chemicals and fuels onsite. The rock material itself will not absorb contaminants due to the materials geological properties and is therefore considered inert. The potential for impact on fish from release of contaminants has therefore been scoped out from further assessment.

- **Project activities may result in accidental release of pollutants leading to toxic effects on fish.**

The potential for accidental release of pollutants affecting benthic ecology receptors has been scoped out of further assessment on the basis the designed-in mitigation measures which include pollution prevention and control measures reduce the likelihood of impact to a negligible level.

Marine Mammals

Impacts to marine mammals that have been scoped out from further assessment include:

- **Vessel traffic associated with the Proposal may result in collision risk.**

No vessels are proposed to be used to construct the revetment. All works will be undertaken from the shore. However, a single barge will be used for the transport of rock armour from Norway to site. The barge associated with transport of rock will sail at speeds <10 knots; low enough not to cause a collision risk to marine mammals (Laist *et al.,* 2001). Therefore, the potential for collision to marine mammals from vessel movements has been scoped out from further assessment.

Appendix B

RPS 2018 Wave Climate and Overtopping Discharge Study

Wave Overtopping at Alexandra Parade, Peterhead

Wave Climate and Overtopping Discharge Study

Document Control Sheet

Client:	Peterhead Port Authority
Project Title:	Wave Overtopping at Alexandra Parade, Peterhead
Document Title:	Wave Climate and Overtopping Discharge Study
Document No:	IBE1433/01

Text Pages:	34	Appendices:	6

Rev.	Status	Date	Author(s)		Reviewed By		Approved By	
01	Final	26/09/2018	RMcK		AKB		AKB	

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1 INTRODUCTION

Substantial redevelopment work has been undertaken at Peterhead harbour. This redevelopment includes the construction of a new Fish Market building which is located at Alexandra Parade. At its closest point the new building is only about 16 metres behind the existing seawall. There is a history of overtopping at Alexandra Parade seawall with two vehicles damaged during the winter of 2017/2018.

The Harbour Authority became concerned about the risk of damage to the fish market from overtopping waves and appointed RPS to undertake an assessment of the risk to the building from storm wave overtopping and if necessary bring forward recommendations for works to adequately protect the fish market building from damage and/or flooding resulting from wave overtopping at Alexandra Parade..

RPS undertook the study which included the following;

I. Undertake physical examination of the seawall at Alexandra Parade.
II. Establish the inshore wave and water level storm conditions at the seawall.
III. Undertake an analysis of storm wave overtopping of the seawall and assess the risk of damage to the fish market building.
IV. Examine options for the protection of the fish market and Alexandra parade from excessive wave overtopping.
V. Establish the mean and peak wave overtopping rates for various return period storm events for any proposed improvement works to Alexandra Parade using computational and physical modelling as required.
VI. Using the results of the analysis and modelling to provide design details for a scheme to protect the fish market and Alexandra Parade from excessive wave overtopping.

2 SEAWALL ALEXANDRA PARADE, PETERHEAD

Peterhead is located on the easternmost point in mainland Scotland, just North of Aberdeen. The port of Peterhead is one of the UK's most versatile ports serving many industries. A map of Scotland showing the location of Peterhead can be seen in Figure 2-1. A map of Peterhead and the port can be seen in Figure 2-2. The seawall at Alexandra Parade is circled and it can be seen in Figure 2-3.

Figure 2-1 Map of Scotland with the location of Peterhead marked

Figure 2-2 Map of Peterhead with the location of the seawall at Alexandra Parade circled

Figure 2-3 Map of the seawall at Alexandra Parade

As part of a redevelopment project, a new enlarged Fish Market building has been built behind the seawall as shown Figure 2-4. The main purpose of this study was to assess the risk to this building due to wave overtopping along the seawall and identify measures required to protect the building if necessary. The existing structure along the seawall can be subdivided into two categories based on the type of revetment it contains, as labelled in Figure 2-4.

Figure 2-4 Aerial photograph of the seawall and revetment along Alexandra Parade with the new Fish Market building behind it, taken during the redevelopment project

The pitched revetment section spans the initial 80m (approximately) of the seawall when starting at the south-eastern end. It consists of pitched stone which has been largely concreted over. It is slightly curved in profile ranging from 1:1.25 – 1:3. The seawall behind this section sits as 11mCD. Large precast concrete blocks from former coastal structures around the harbour have been positioned on a portion of the pitched revetment to encourage wave energy dissipation, as shown in Figure 2-5. Unfortunately these blocks demonstrate a lack of stability due to considerable movement. A drawing of a typical cross section along the pitched revetment is shown in Section 5.1.

Figure 2-5 Photographs of large precast concrete units placed on the pitched revetment to encourage wave energy dissipation. (L) At the top of the revetment in front of the seawall. (R) At the bottom of the revetment before the toe.

The rock armour revetment spans the remainder of the seawall. The seawall behind this section was thought to sit at 12.2mCD from a previous drone survey by Boskalis however new survey data collected during this project indicates it is actually at 11.5mCD which has been confirmed with Arch Henderson record drawings. It consists of a berm in front of the seawall followed by a slope to the toe, shown in Figure 2-6. The slope is slightly curved due to wave damage with a gradient of 1:1.25 in the upper section and 1:3 in the lower section. A typical profile can be seen in Section 5.1. The majority of the rocks are approximately 6-8T (with a significant amount being less than that) which is undersized for the wave conditions.

Figure 2-6 Photograph of the rock armour revetment taken from the end of the pitched revetment section

3 WATER LEVEL, WAVE AND WIND DATA

3.1 EXTREME SEA LEVELS

The Environmental Agency (EA) and Scottish Environment Protection Agency (SEPA) provide up-to-date and evidence based guidance on extreme sea levels around Great Britain. Data at a location near Peterhead was extracted for this study as summarised in Table 3-1.

Table 3-1 Summary of extreme sea levels at Peterhead to both Ordnance (OD) and Chart Datum (CD)

Return Period	Extreme Water Level (m)	
	OD	***CD***
Highest Astronomical Tide (HAT)	2.2	4.4
0.1	2.13	4.33
0.2	2.23	4.43
0.5	2.3	4.5
1	2.36	4.56
2	2.44	4.64
5	2.52	4.72
10	2.59	4.79
20	2.65	4.85
50	2.74	4.94
100	2.79	4.99
200	2.85	5.05
1000	2.98	5.18

3.2 FUTURE CLIMATE CHANGE

Another major factor that will influence overtopping along Alexandra Parade is the future sea level rise due to climate change. To account for this, reference has been made to the UKCP09 Marine and Coastal Projections to derive future projections for sea level rise assuming relatively high greenhouse gas emissions. The relative sea level rise can be seen in Table 3-2. SEPA recommend using the 95th percentile value for high emissions. It is worth noting that the International Panel on Climate Change (IPCC) are due to issue reviewed sea level rise statistics in November 2018.

Table 3-2 UKCP09 Relative sea level rise at Peterhead based on high emissions (Latitude/Longitude 57.35085/-1.7703)

Year	Relative Sea Level Rise (m)		
	5th Percentile	50th Percentile	95th Percentile
2040	0.05	0.164	0.278
2060	0.078	0.253	0.427
2080	0.11	0.354	0.599
2100	0.146	0.469	0.792

3.3 EXTREME WAVE AND WIND DATA

A dataset of wave and wind conditions was obtained from the Met Office WAVEWATCH III wave model hindcast data. The dataset covers 10/10/1980 – 31/05/2016 at 3 hour intervals for a location east of Peterhead (57.5°North, 1.5°West) shown in Figure 3-1.

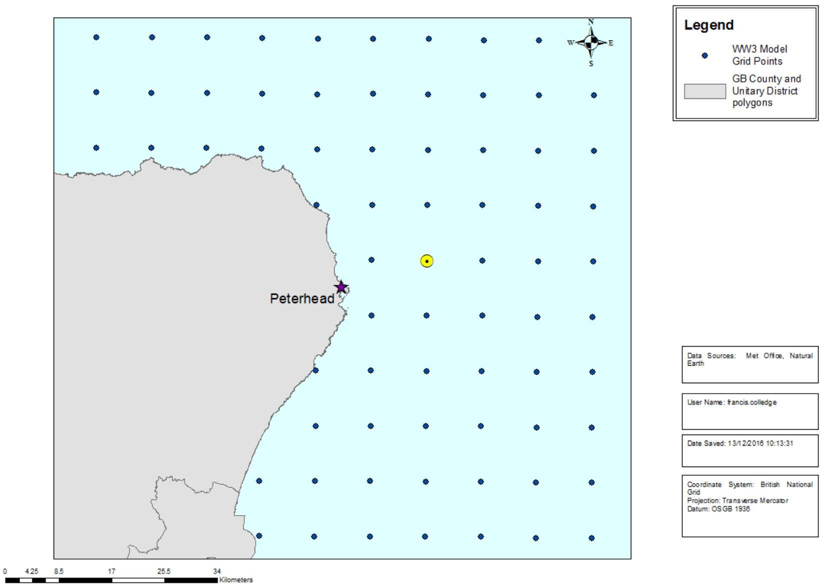


Figure 3-1 Location of data extraction relative to Peterhead

3.3.1 Extreme Value Analysis (EVA)

An EVA of the Met Office data was undertaken using the MIKE Zero EVA Editor toolbox. Due to the exposure of the seawall at Alexandra Parade to northerly and easterly waves, the dataset was divided into 30° sectors while ensuring sufficient data points were in each sector to provide a robust statistical analysis.

The EVA was conducted by fitting a theoretical probability distribution to the 3-hourly Met Office dataset. A partial duration series, also known as a peak over threshold model was used to select the largest events that occurred within each sector of the dataset. In most cases a Weibull probability distribution provided a satisfactory fit to the dataset. Nonetheless a sensitivity study was conducted which applied a Truncated Gumbell and Generalised Pareto probability distribution however these did not significantly improve the fit provided by the Weibull distribution. In all cases a Maximum Likelihood estimation method was applied. All data was fitted using a Monte Carlo simulation technique. This approach was used to determine a series of significant wave heights at a range of return periods for each sector. An example of an EVA analysis for the sector 75°-105° is shown in Figure 3-2.

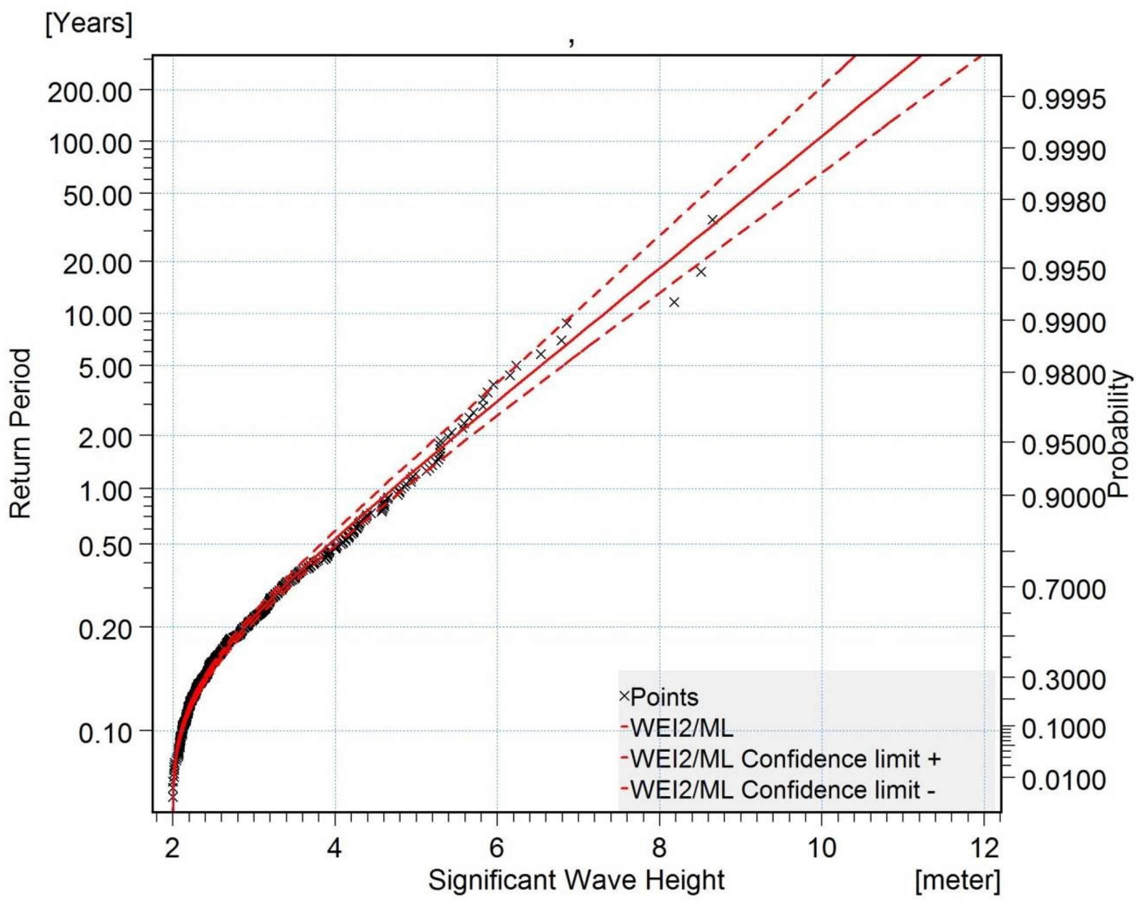


Figure 3-2 Extreme Value Analysis of offshore significant wave heights between 75° and 105° (East)

It can be seen in Figure 3-2 that a return period of 100 years will have a significant wave height of c. 9.9m. An EVA was conducted on both significant wave heights and wind velocities and the results for various return periods across the relevant sectors are presented in Table 3-3 and Table 3-4 respectively.

Table 3-3 Extreme significant wave heights at various return periods and directions

Return Period (years)	Significant Wave Height (m)			
	345° - 15° ***North***	**15° - 45°** ***NNE***	**45° - 75°** ***NEE***	**75° - 105°** ***East***
1	5.245	4.444	3.374	4.707
5	6.712	5.992	4.765	6.534
10	7.319	6.658	5.378	7.316
20	7.909	7.327	5.997	8.096
50	8.677	8.211	6.821	9.134
100	9.247	8.881	7.449	9.919
200	9.811	9.551	8.080	10.701

Table 3-4 Extreme wind velocities at various return periods and directions

Return Period (years)	Wind Velocity (ms^{-1})			
	345° - 15° ***North***	**15° - 45°** ***NNE***	**45° - 75°** ***NEE***	**75° - 105°** ***East***
1	16.851	14.308	13.811	14.520
5	20.085	17.511	16.905	17.240
10	21.385	18.745	17.980	18.257
20	22.649	19.928	19.015	19.217
50	24.268	21.427	20.282	20.423
100	25.467	22.523	21.195	21.295
200	26.642	23.592	22.078	22.141

3.4 JOINT PROBABILITY

As the wave heights at Alexandra Parade are strongly influenced by the water level during a storm event, a joint probability analysis (JPA) was conducted. This analysis took into account offshore wave height and sea level as well as wind velocities and sea level for different sectors.

The JPA was conducted under the guidance of the Department for Environment, Food and Rural Affairs (DEFRA) and EA using report FD2308 *'Joint Probability: Dependence Mapping and Best Practice'.* This document also supplied the required correlation factors between the significant wave height velocities and sea levels. The correlation factors at Peterhead for directions 330°-45° and 45°-180° was taken to be 0.22 and 0.12 respectively. In the absence of more specific data it was assumed that these same correlation factors could be applied between wind velocity and sea levels in the same direction.

The results of the JPA water levels and significant wave height for wave directions between North and East are shown in the Appendix. An example of the JPA output for wave directions between 15° and 45° are presented in Table 3-5. The associated joint exceedance curve is shown in Figure 3-3.

Table 3-5 Results of the joint probability analysis of extreme sea level and significant wave height for wave directions 15° to 45° (NNE)

Extreme Sea Level (mCD) ***[FIRST VARIABLE]***	**Significant Wave Height (m)** ***[SECOND VARIABLE]***							
	Joint Exceedance Return Period (years)							
	1	5	10	20	50	100	200	1000
4.12	2.47	4.35	5.06	5.90	6.97	7.74	8.50	10.27
4.20	1.85	3.64	4.43	5.16	6.26	7.06	7.83	9.59
4.28	1.03	2.67	3.50	4.31	5.28	6.12	6.92	8.70
4.34	0.41	2.03	2.76	3.59	4.61	5.38	6.21	8.03
4.42	N/A	1.41	2.11	2.85	3.94	4.68	5.47	7.35
4.50	N/A	0.59	1.29	1.99	2.98	3.80	4.57	6.42
4.56	N/A	N/A	0.67	1.37	2.30	3.07	3.89	5.70
4.64	N/A	N/A	0.05	0.75	1.68	2.38	3.16	4.95
4.72	N/A	N/A	N/A	N/A	0.86	1.56	2.26	4.11
4.79	N/A	N/A	N/A	N/A	0.23	0.94	1.64	3.38
4.85	N/A	N/A	N/A	N/A	N/A	0.31	1.01	2.65
4.94	N/A	N/A	N/A	N/A	N/A	N/A	0.19	1.82
4.99	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.20
5.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.58
5.18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00

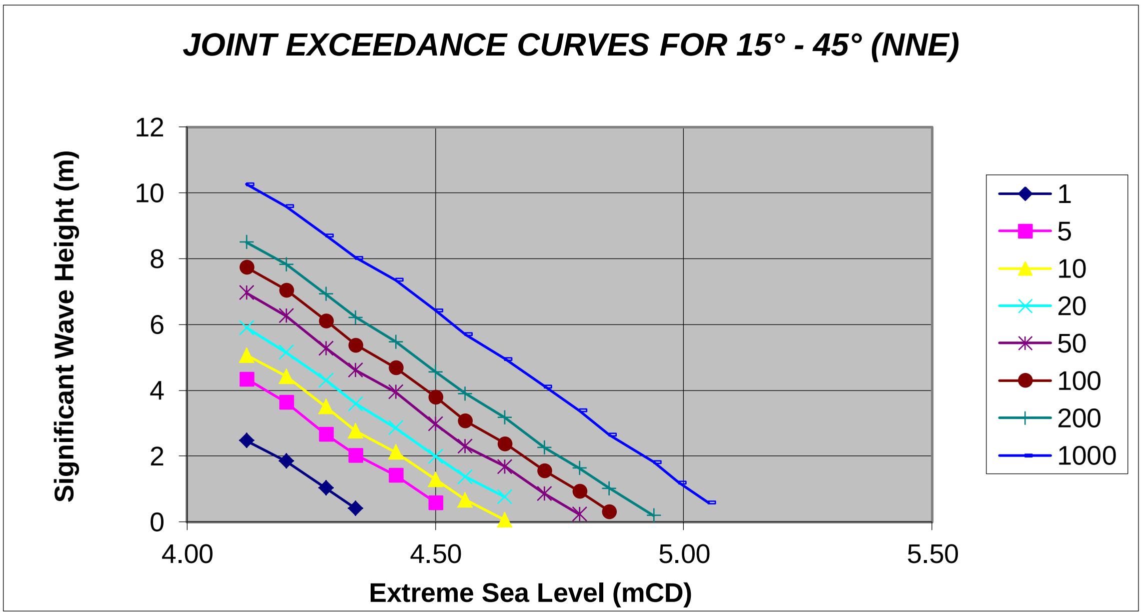


Figure 3-3 Joint exceedance curves for the extreme sea levels and significant wave height for wave directions 15° to 45° (NNE)

For the same directional sector, the results associated with the wind velocities are presented in Table 3-6 and the associated joint exceedance curves are shown in Figure 3-4.

Table 3-6 Results of the joint probability analysis of extreme sea level and wind velocities for wind directions 15° to 45° (NNE)

Extreme Sea Level (mCD) *[FIRST VARIABLE]*	Wind Velocity (ms^{-1}) *[SECOND VARIABLE]*							
	Joint Exceedance Return Period (years)							
	2	5	10	20	50	100	200	1000
4.12	12.70	14.67	16.05	17.34	19.29	20.63	21.91	24.73
4.20	11.42	13.34	14.83	16.19	18.00	19.44	20.77	23.66
4.28	10.04	11.62	13.08	14.59	16.39	17.74	19.21	22.23
4.34	9.01	10.55	11.78	13.25	15.20	16.53	17.91	21.11
4.42	7.97	9.52	10.69	11.95	13.91	15.35	16.68	19.96
4.50	6.59	8.14	9.31	10.48	12.17	13.64	15.11	18.31
4.56	5.55	7.10	8.27	9.45	10.99	12.33	13.82	17.02
4.64	4.52	6.06	7.24	8.41	9.96	11.13	12.50	15.87
4.72	N/A	4.69	5.86	7.03	8.58	9.75	10.92	14.21
4.79	N/A	N/A	4.82	5.99	7.54	8.71	9.89	12.88
4.85	N/A	N/A	N/A	4.96	6.50	7.68	8.85	11.58
4.94	N/A	N/A	N/A	N/A	5.13	6.30	7.47	10.19
4.99	N/A	N/A	N/A	N/A	N/A	5.26	6.43	9.15
5.05	N/A	N/A	N/A	N/A	N/A	N/A	5.40	8.12
5.18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00

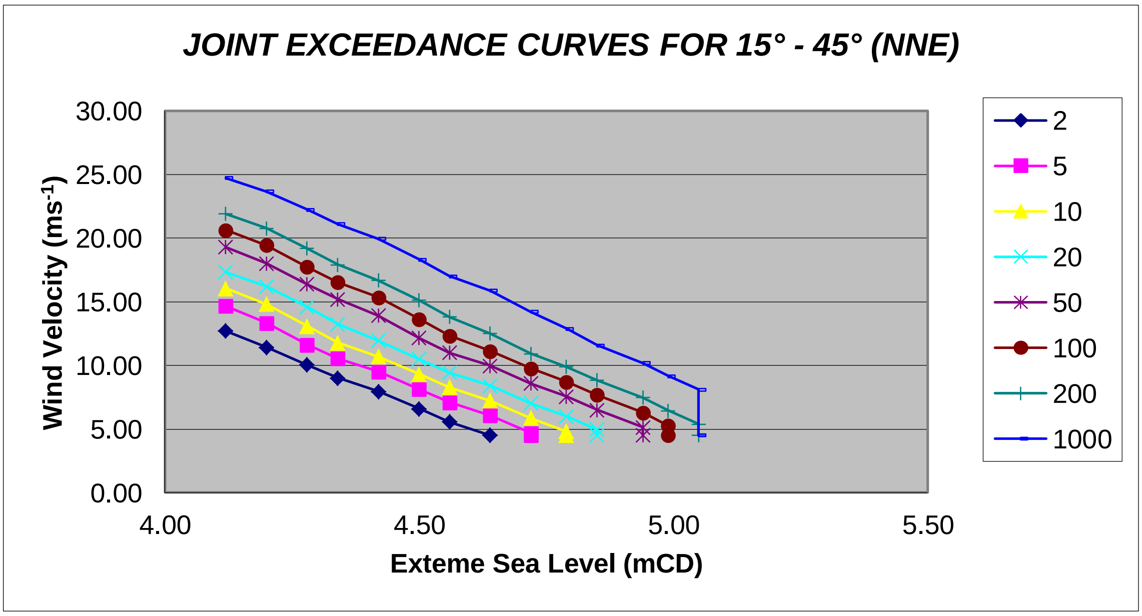


Figure 3-4 Joint exceedance curves for extreme sea levels and wind velocities for wind directions 15° to 45° (NNE)

The joint exceedance curves for the other directions deemed to be of importance can be found in the Appendix.

4 WAVE TRANSFORMATION MODELLING

The wave transformation modelling was undertaken using the Mike21 Spectral Wave (SW) wave model, the details of which are given in the Appendix. The model was used to transform the offshore data to the site of the Alexandra Parade seawall.

4.1 MODEL BATHYMETRY

4.1.1 Existing Bathymetry Data

As RPS has previously studied this area in relation to Peterhead topographic data was available for use in this computational model. This data could be split into two categories;

1. **Data Networks** (including MIKE C-MAP, EMODnet and MEDIN) provided course resolution, offshore data
2. **Survey data** provided fine resolution, nearshore data. In this cases two previous surveys had been conducted;
    - **Boskalis** conducted a drone survey along Alexandra Parade for the area above low water in 2017
    - **Aspect Land & Hydrographic Surveys** conducted a hydrographic survey in Peterhead Bay in 2014, however this did not include the area to the seaward of the seawall at Alexandra Parade.

4.1.2 Clydeside Hydrographic Survey

As the area seaward of the seawall was only covered by relatively sparse Admiralty chart data, Clydeside Surveys Limited were employed to conduct a more thorough multi-beam hydrographic survey of the area to seaward of the existing seawall. This work involved a drone survey for the dry portion of the lower part of the seawall and a hydrographic survey for the wet portion. Although attempts were made to ensure sufficient crossover of the two survey areas, due to a number of factors including a low tidal range, wave breaking on the structure and weather conditions this was not possible. Thus artificial bathymetry data was created by a combination of interpolation and aerial photographs to represent the toe of the structure.

4.1.3 Aspect Hydrographic Survey

In order to cross check the artificial bathymetry data at the toe of the structure, Aspect Land & Hydrographic Surveys were employed to repeat the survey conducted by Clydeside with an extended boundary. The results of the Aspect survey showed good agreement at the toe of the structure thus validating the artificial bathymetry data. The results also highlighted a fundamental error in the previous Boskalis survey in relation to the height of the seawall behind the rock armour revetment section which was validated by Arch Henderson record drawings. The profiles for the pitched revetment and the rock armour revetment can be seen in the Appendix.

The extent of the numerical model is shown in Figure 4-1 with the area around the approaches to Alexandra Parade shown in more detail in Figure 4-2.

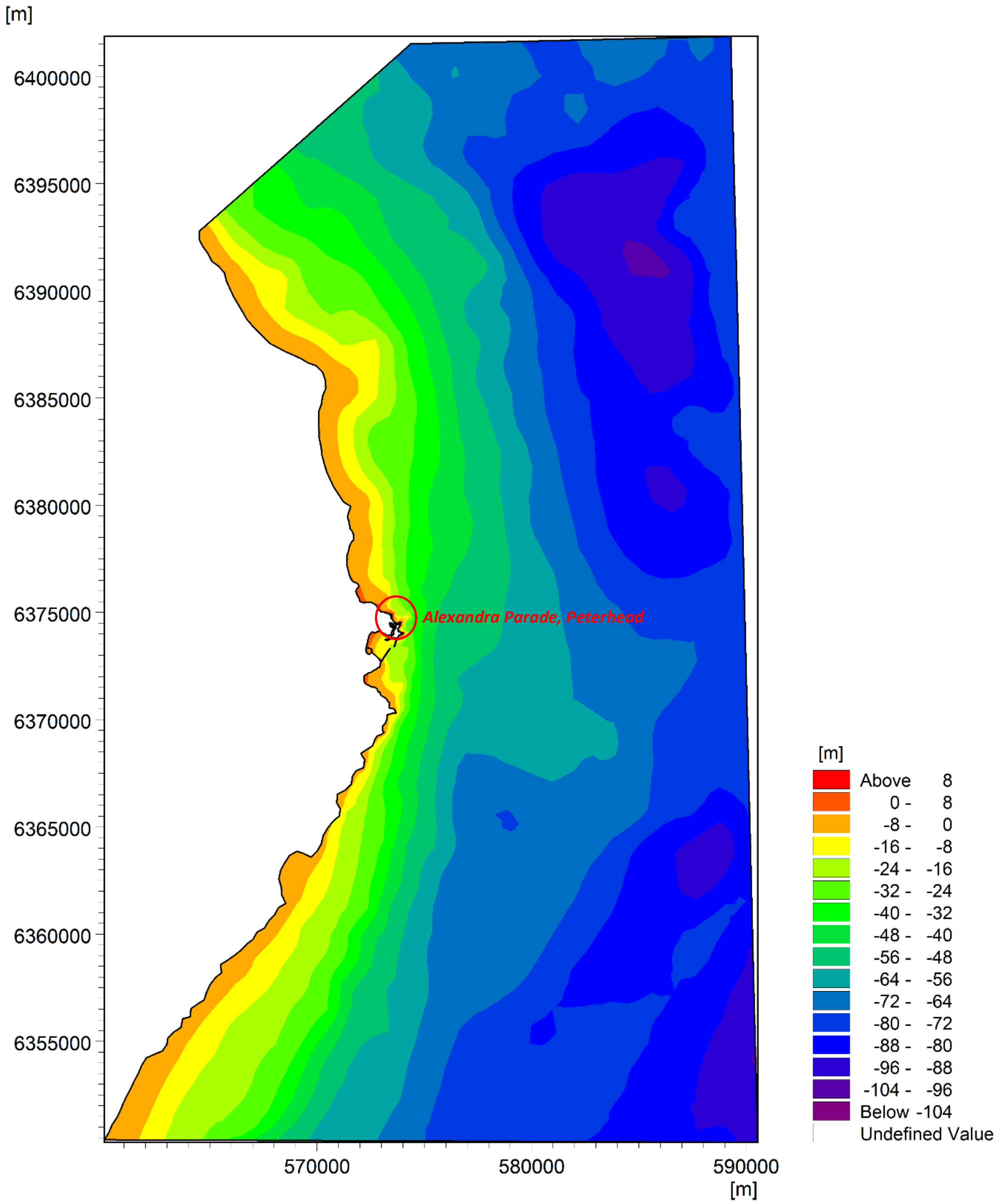


Figure 4-1 Extent and bathymetry of the model used to transform the offshore wave data to the inshore area at Alexandra Parade

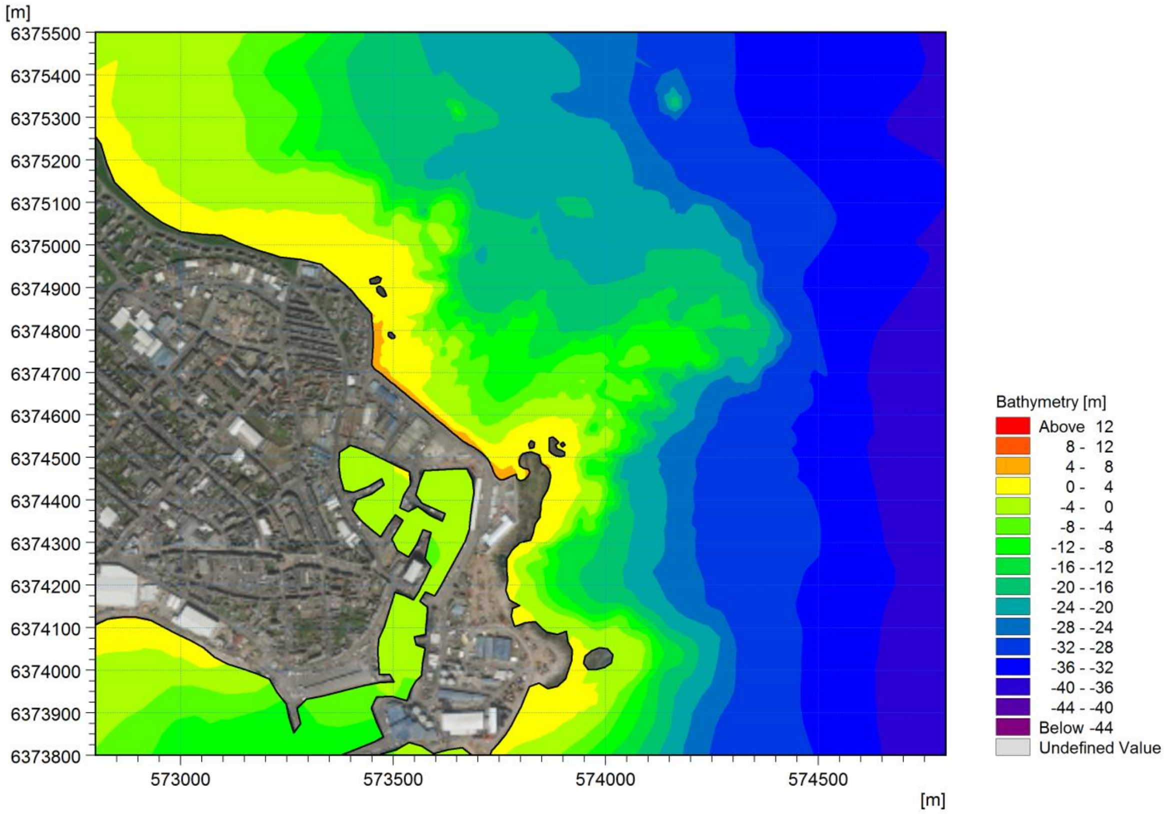


Figure 4-2 Bathymetry in the area surrounding Alexandra Parade

Details of the model mesh can be found in the Appendix.

4.2 INSHORE WAVE CLIMATE

SW wave model simulations for wave directions from North through to East were undertaken for a range of extreme sea levels, significant wave heights and wind velocities for 1 in 2 to 1 in 200 year joint probability events. The results of these simulations were used to examine the wave climate along the Alexandra Parade seawall so that an assessment could be made of the greatest overtopping risk.

4.2.1 Wave and Wind Setup

As the magnitude of waves that can approach and break onto the seawall at Alexandra Parade are strongly influenced by water depth in the area, it is important to consider the local increase in water level during storm conditions caused by wave and wind setup. To conduct this assessment, the combined extreme water levels and wave/wind conditions for Peterhead were applied to the RPS in-house coupled hydrodynamic and spectral wave model.

A range of scenarios for different 1 in 200 Joint Probability return period conditions from an easterly direction are presented in Table 4-1. It can be seen that under certain conditions, the local water level can be increased by as much as 0.7m therefore having a significant impact on factors which could increase overtopping.

Table 4-1 Wave and Wind setup in the area surrounding Alexandra Parade during 1 in 200 Joint Probability conditions from an easterly direction

Joint Probability Scenario	Water Level (m CD)		Wave and Wind Setup (m)
	Coupled Wave and Tide	Tide Only	
Lowest Significant Wave Height & Highest Water Level	4.9	4.9	0
Intermediate	4.88	4.5	0.38
Highest Significant Wave Height & Lowest Water Level	4.8	4.1	0.7

A single wave and wind setup value of 0.4m was applied across all joint probability scenarios from all directions. This was selected as this scenario is most likely to cause overtopping along Alexandra Parade. It is worth noting that this wave and wind setup applies only to the computational modelling. When it comes to the physical modelling it is assumed that the wave setup will occur naturally

4.2.2 Sea Level Rise

As discussed in 3.2 Future Climate Change, the other major factor that will affect overtopping along Alexandra Parade is the future sea level rise due to climate change. According to UKCP09 Marine and Coastal Projections the sea level a Peterhead will rise by approximately 0.8m by 2100 (Table 3-2).

4.3 RESULTS

Figure 4-3 show the 1 in 200 year wave climate in the area surrounding the sea wall at 30° (NNE), taking into account wave and wind setup as well as sea level rise. The wave climate for the other directions deemed to be of importance can be found in the Appendix. Figure 4-4 - Figure 4-5 show the envelope of the largest maximum wave height, significant wave height and wave period for the 1 in 200 year wave climate for all directions of interest. A breakdown of the significant wave height and the maximum wave height for directional sectors can be found in the Appendix.

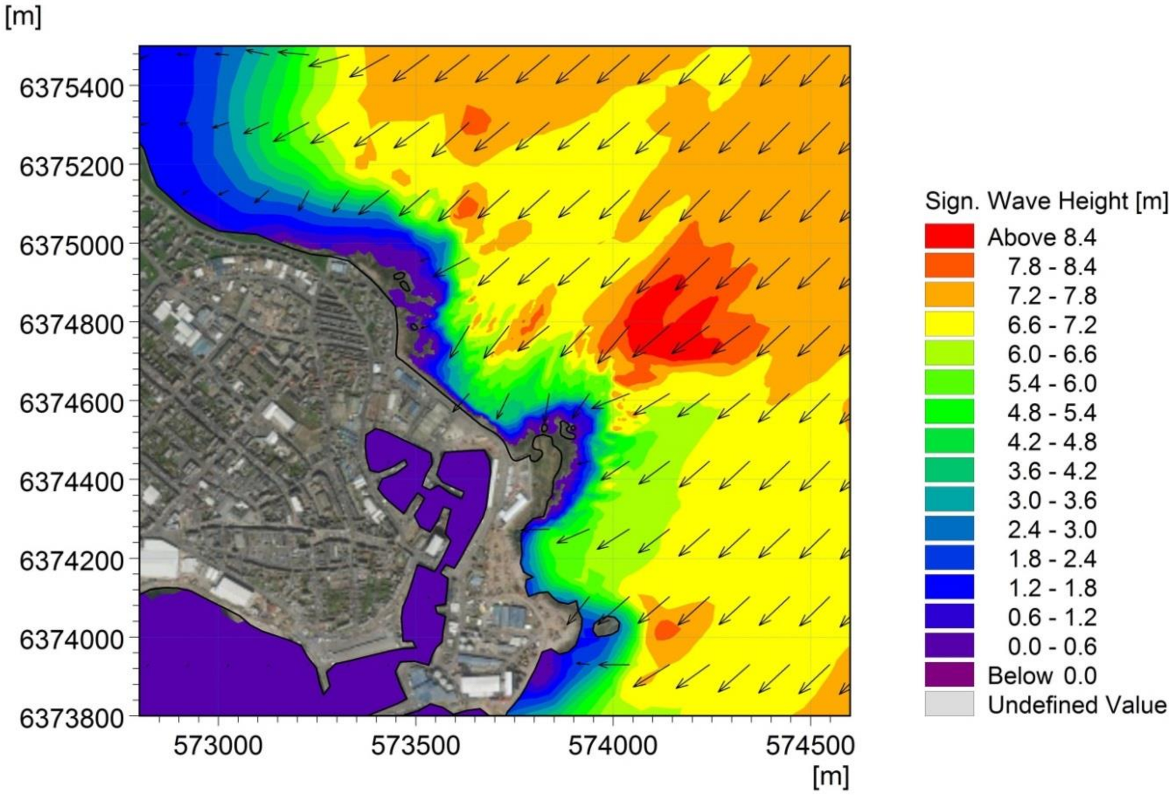


Figure 4-3 Significant wave heights in the area surrounding Alexandra Parade during a I in 200 joint probability event at 30° (NNE)

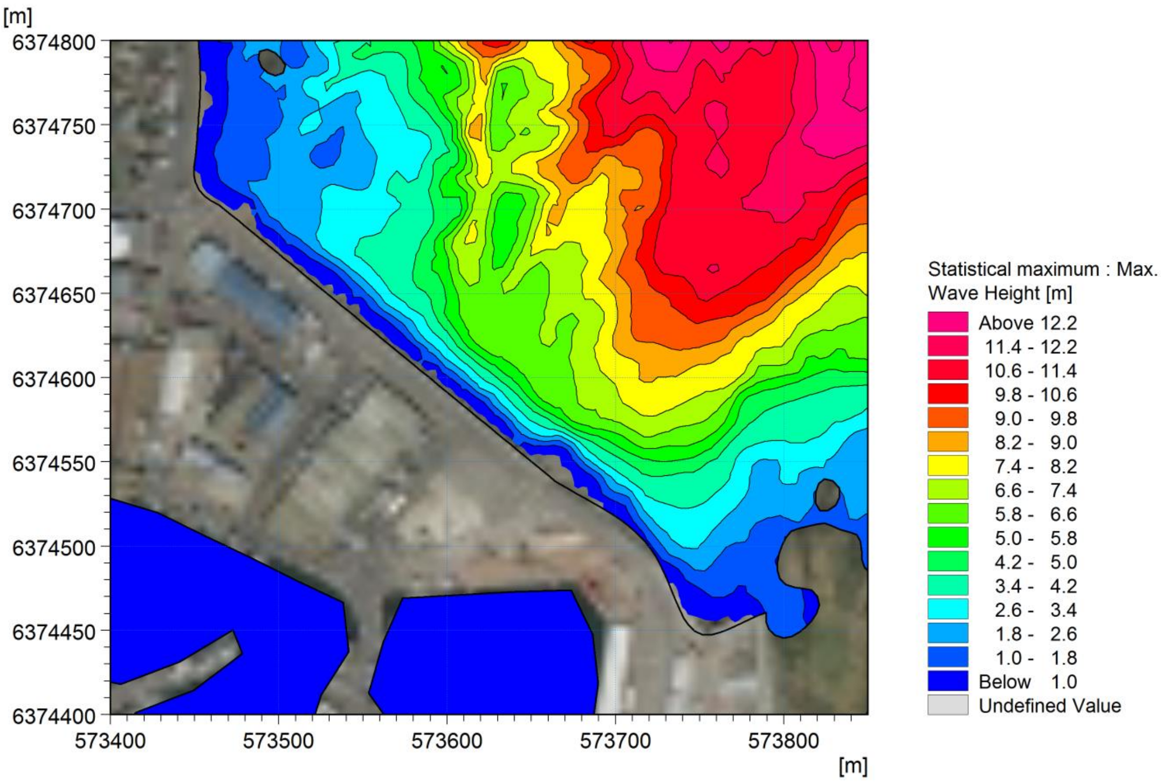


Figure 4-4 Envelope of the largest maximum wave height in the area surrounding Alexandra Parade during a 1 in 200 joint probability event for all incident wave directions

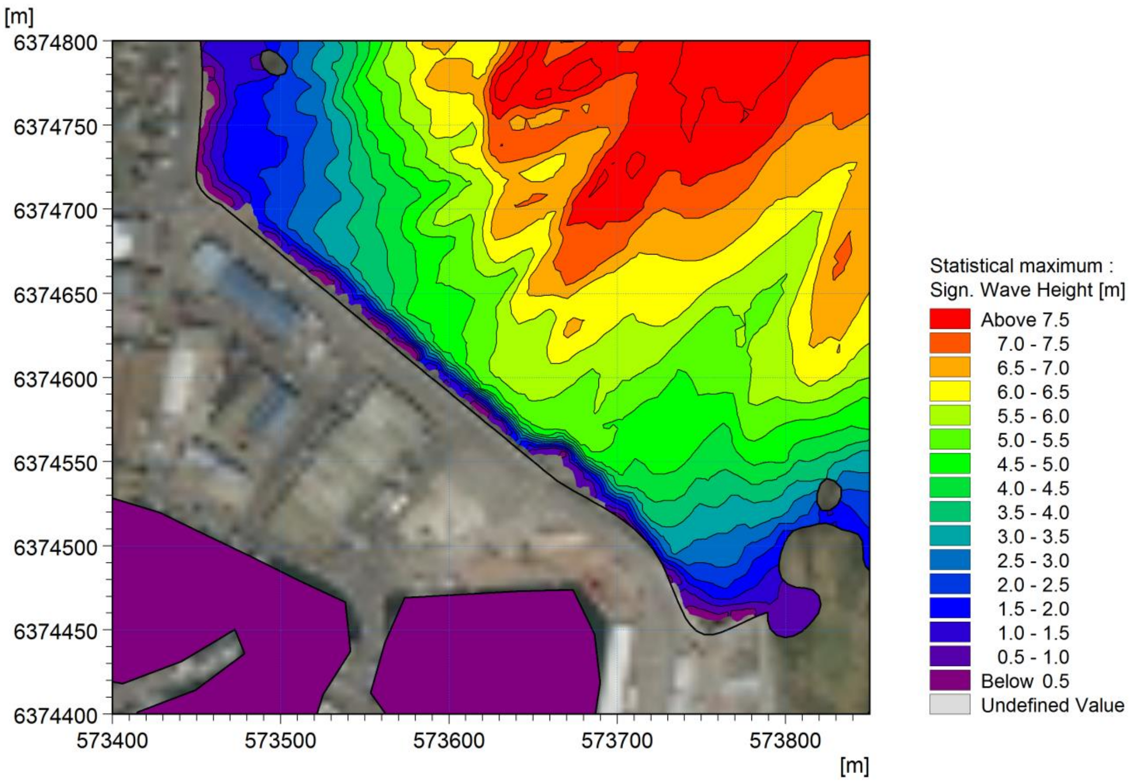


Figure 4-6 Envelope of the largest significant wave height in the area surrounding Alexandra Parade during a 1 in 200 joint probability event for all incident wave directions

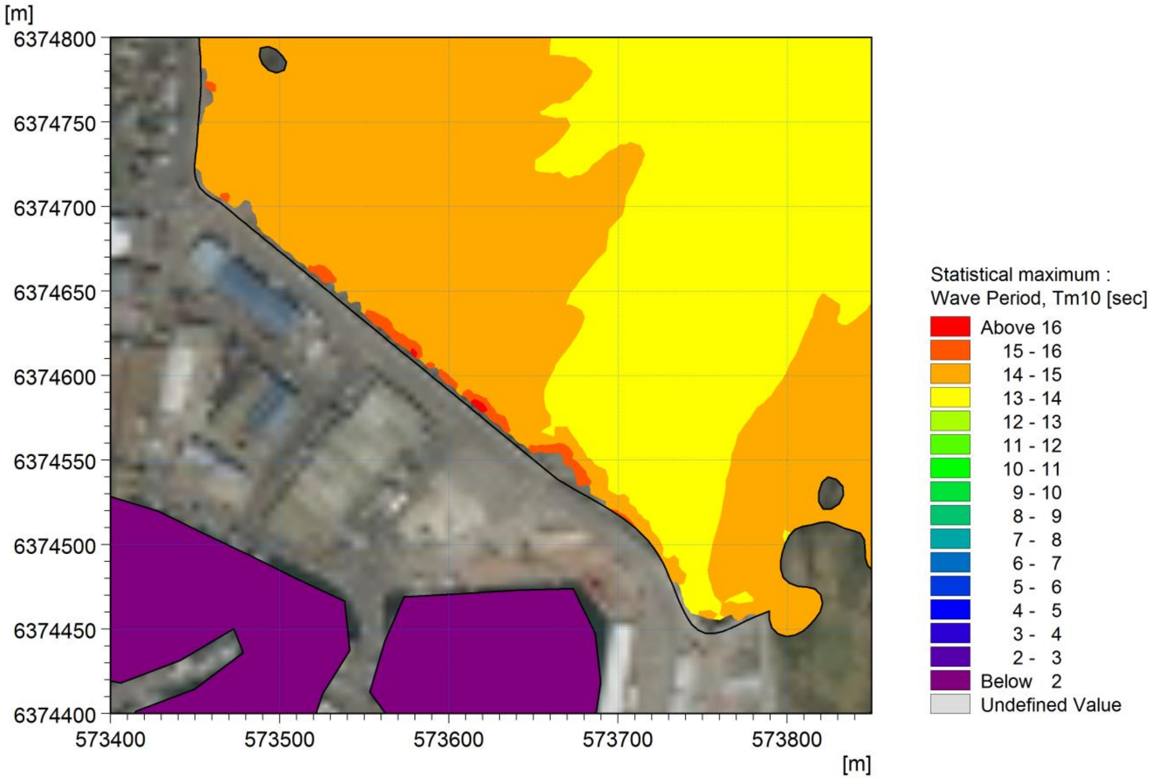


Figure 4-5 Envelope of the largest wave period in the area surrounding Alexandra Parade during a 1 in 200 joint probability event for all incident wave directions

5 OVERTOPPING OF EXISITNG REVETMENTS

RPS have assessed the overtopping for a variety of storm return period events for various parts of the existing seawall using two analytical techniques described in the latest EurOtop manual (2016)

5.1 SCHEMATICS OF EXISTING STRUCTURE PROFILES

RPS assessed topographical data along the structure using a combination of survey data collected by Boskalis (2017) and Clydeside Surveys Limited (January 2018) in order to characterise the cross sections. Although there are variations along the length of the seawall, in general the sections could be categorised into two cross sections;

Pitched Revetment The crest of the seawall ranges between 9.50-11.00m CD. A pitched revetment structure on the seaward side slopes at 1:1.25-3. Along this feature large free standing precast concrete units have been positioned to reduce overtopping (Figure 5-1). These raise the free board level of the coastal defence in this region by c.1.0m resulting in an effective crest level of c.12-12.5m CD. There is uncertainty in this effective crest height due to the gaps between the units. A schematic cross section is shown in the Test Completion Report in the Appendix. Initial assessment indicated that these blocks will be unstable during large storm events.

Rock Armour Revetment The crest of the seawall was consistently shown at c.12.20m CD by previous survey data collected by Boskalis. A rock armour revetment on the seaward side has a notable berm at the base of the seawall followed by a slope. An assessment of the cross sections along with consultation with Wallace Stone drawings (c. 1980) indicate that the slope was originally c.1:3 however due to progressive failure the revetment has partially slipped resulting in a composite slope of c.1:1.25 in the upper section and 1:3 in the lower section. A schematic cross section can be seen in the Test Completion Report in the Appendix.

Figure 5-1 Large free standing concrete blocks along the pitched revetment (photo taken from the crest of the seawall looking easterly)

5.2 HYDRAULIC DATA FOR OVERTOPPING CALCULATIONS

The inshore wave heights and periods were derived using the computational model described in Section 4. RPS assessed storm conditions with return periods of 10, 50 and 200 years coming from the most arduous direction of NNE (15°-45°). Data was extracted from the models accounting for wave and wind setup and sea level rise. Two points (relating to the pitched revetment and the rock armour revetment) in close proximity to the toe of the existing structure were used. The coordinates for the pitched revetment and the rock armour revetment were (573 723, 6 374 610) and (573 679, 6 374 645) respectively. A summary of these inshore conditions can be seen in Table 5-1.

Table 5-1 Inshore wave and water level conditions applied in the overtopping calculations

Return Period (years)	Water Level (m CD)	Pitched Revetment		Rock Armour Revetment	
		Significant Wave Height (m)	Peak Wave Period (s)	Significant Wave Height (m)	Peak Wave Period (s)
10	5.12	3.27	11.50	3.54	11.52
50	5.12	4.36	13.69	4.80	13.74
200	5.12	5.60	14.80	6.28	14.76

The water level which related to the worst case scenario in terms of overtopping was selected. This water level was then adjusted to account for wave and wind setup and sea level rise. The water level quoted in Table 5-1 was 4.12mCD with an additional 0.4m for wave and wind setup and 0.6m for sea level rise predicted for 2080.

5.3 ANALYTICAL OVERTOPPING PREDICTIONS

5.3.1 Methodology

The EurOtop manual (2016) is designed to aid the calculation of wave overtopping of sea defences and related structures. The manual recommends approaches for calculating overtopping discharges, overtopping wave volumes and the proportion of waves overtopping a structure. The manual explains in detail two methods which can be implemented;

1. **Empirical method** This simplifies the physics of the process in equations to relate overtopping discharge to key wave and structure parameters. The form and coefficients of the equations are adjusted to reproduce results from physical models and field measurements of wave overtopping.
2. **Artificial Neural Network** This compares the current parameters to a large extended database that contains more than 13000 tests on wave overtopping.

For the purposes of this assessment, RPS have utilised the Empirical method and ANN tool to analytically predict overtopping discharge rates at the seawall using the wave conditions found at the toe of the structure similar to those in Table 5-1. It is worth noting that the exact location of the toe was unknown thus sensible assumptions had to be made leading to minor variations in this data.

5.3.2 Empirical Method Overtopping

The inshore wave conditions partnered with the geometry of the schematics allowed analytical predictions of mean overtopping discharge to be made, as detailed in Table 5-2. It should be noted that the equations implemented came from the EurOtop manual (2016). The design approach equations were used whereby the average discharge is increased by about one standard deviation.

Table 5-2 Design wave mean overtopping discharges at 15°-45° (NNE) using the empirical method

Return Period (years)	Pitched Revetment (l/s/m)	Rock Armour Revetment (l/s/m)
10	292.23	5.58
50	901.59	73.56
200	1691.71	331.62

The empirical method is limited to mean overtopping discharge and provides no information regarding the peak overtopping. It is this peak overtopping that could pose the biggest threat to the fish market and thus is an essential parameter.

5.3.3 ANN Method Overtopping

The inshore wave conditions partnered with the geometry of the schematics was compared to an extended database of previous tests. The predicted mean overtopping discharge can be seen in Table 5-3 for the 50th and 95th percentile.

Table 5-3 Design wave mean overtopping discharges at 15°-45° (NNE) using the ANN method

Return Period (years)	Pitched Revetment (l/s/m)		Rock Armour Revetment (l/s/m)	
	50th percentile	95th percentile	50th percentile	95th percentile
20	94	328	19.6	205
200	380	1410	480	4970

It is worth noting that the rock armour revetment values are for a 12.2mCD seawall level.

It is clear from Table 5-2 and Table 5-3 that there is a wide divergence in the predicted mean overtopping rates using computational techniques. This, partnered with the absence of information on the peak overtopping discharge for both the empirical method and the ANN method, highlights the necessity of physical modelling.

6 PRELIMINARY REVETMENT DESIGN FOR PHYSICAL MODELLING

6.1 DESIGN OPTIONS

The computational analysis has confirmed that that the overtopping rates for the existing revetments are far too high for safe access along Alexandra Parade and that there is substantial risk that the larger waves in the storm wave climate will result in overtopping water hitting the new fish market building with severe damage to the building and its equipment. The volume of overtopping water is also too high for the proposed land drainage system to discharge with the attendant risk of flooding in the new fish market complex.

The significant wave heights at the toe of the revetments during storm from the north to east sector vary from about 3.5m during a 1 in 1 year return period storm to about 6.3m during a 1 in 200 year return period event. Calculations indicated that either the sea wall along Alexandra Parade would have to be raised by a very substantial amount or that the revetment structure needed to be moved seaward to increase the distance between the wave impact area and the Fish Market, or a combination of both. Given that there are already issues with the stability of the existing blocks on the pitched stone revetment and with the rock armour along the majority of the seaward face of the Alexandra parade, the most suitable way to upgrade the revetment to prevent excessive overtopping was to build a new wave absorbing structure along the seaward side of the Alexandra Parade Seawall which would effectively move the wave impact zone away from the face of the wall and provide a large volume of porous material to help to absorb the wave energy.

6.2 PROPOSED NEW REVETMENT STRUCTURE

The proposed new structure would consist of a rock embankment with an 18 metre wide crest and a relatively steep (1:1.5) seaward face built against the existing seawalls. In the case of the existing pitched stone revetment section, the blocks currently sitting on the pitched stone revetment slope would be removed and used for coastal protection works on another part of the harbour. The existing pitched stone on the pitched revetment would be broken up to provide a good key between the old and new construction and to improve the porosity of the new structure. The storm wave climate is so severe that it is not possible to get rock armour of sufficient size that it would be stable on the seaward face of the new embankment. Thus the seaward face of the embankment would be protected with interlocking concrete armour units such as Xbloc or Accropode II. Initial calculations indicated that 5-6m^3 Xbloc units would be required for stability. The crest of the new embankment would be protected with 15 to 18 Tonne rocks which would be increased to 24 Tonne adjacent to the crest of the concrete armour units.

For the rock armour revetment sections of the Alexandra Parade, the existing rock armour is too small to withstand the existing storm wave climate and the existing armour slope is failing leading to undermining of sections of the existing wall. The new embankment structure can be built directly on the remains of the existing rock armour with the crest level built up to a level of about +10mCD. The form of construction would be the same as that described above and typical sections of the proposed new revetment structure are shown in Figure 6-1 and Figure 6-2.

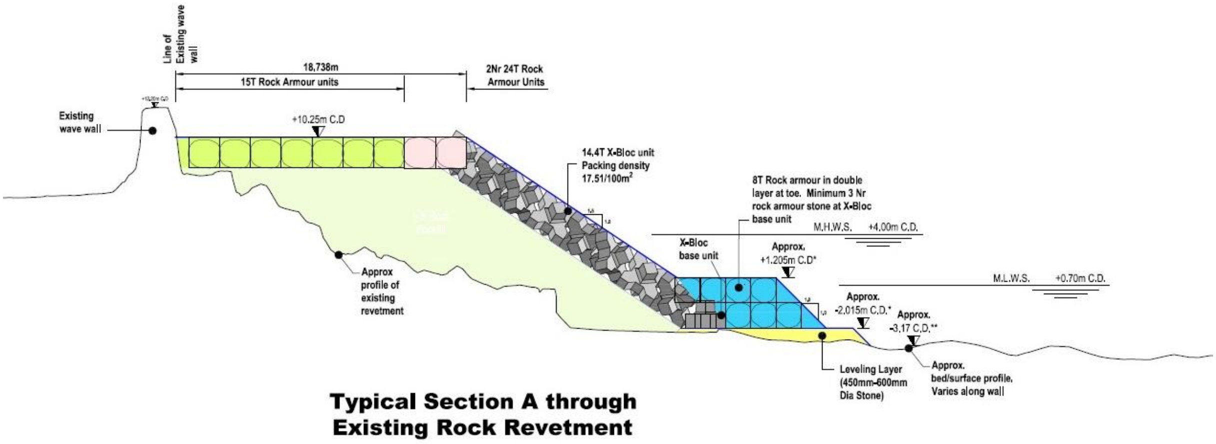


Figure 6-1 Typical section though the proposed embankment along the existing rock revetment at Alexandra Parade seawall

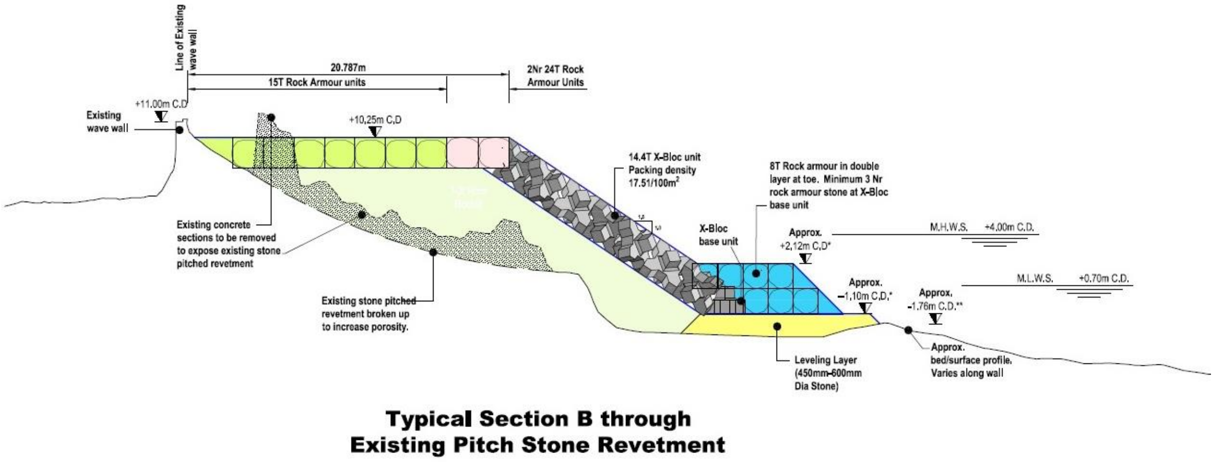


Figure 6-2 Typical section through the proposed embankment along the existing pitched revetment at Alexandra Parade seawall

The first stage of the proposed new revetment would extend along the length of wall require to protect the new fish market complex. The initial extent of the proposed embankment revetment structure is shown in Figure 6-3.

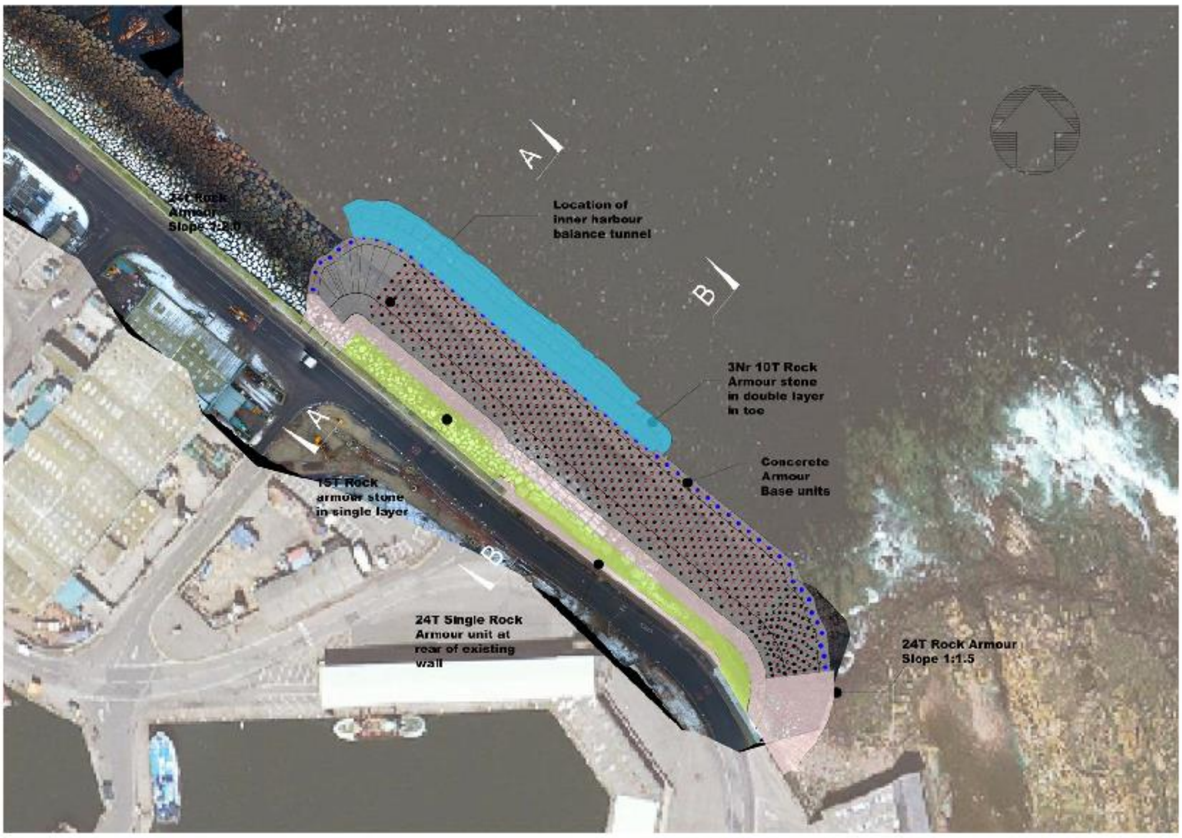


Figure 6-3 Extent of 1st stage of proposed revetment embankment structure at Alexandra Parade seawall

Following the first series of tests, a second design was also proposed which saw modifications to the original proposal. These included an increased crest level of 11.74mCD and an increased seawall level behind the pitched revetment of 11.4mCD.

6.3 ESTIMATED OVERTOPPING

There is a large range in the calculated mean overtopping rates depending upon which formulation is used for the calculations, however the analysis using comparable formulae indicated that the new structure could reduce mean overtopping rates by a factor of 100.

The computational methods are really only applicable to mean overtopping rates which are sufficient for flood analysis but are not suitable for the estimating the effect of peak overtopping from the largest wave in the storm wave spectra which could severely damage the fish market building. The decision was therefore taken to undertake physical model studies of the overtopping (both mean and peak) for the existing and proposed structures.

7 PHYSICAL MODELLING

Queen's University Belfast was commissioned by RPS to conduct physical modelling experiments of Alexandra Parade, Peterhead in the Belfast narrow wave basin (Figure 7-1). A Test Completion Report can be found in the Appendix.

Figure 7-1 Queen's University Belfast narrow wave basin

7.1 SCALE AND BATHYMETRY

Owing to the physical limitations of the wave basin in terms of geometry and wave producing capabilities, it was decided to conduct these tests at 50th scale. To reduce the impact of the side walls of the wave basin during testing, only the centre 2.5m of the basin was utilised allowing 1m either side of the testing area as shown in Figure 7-2and Figure 7-3.

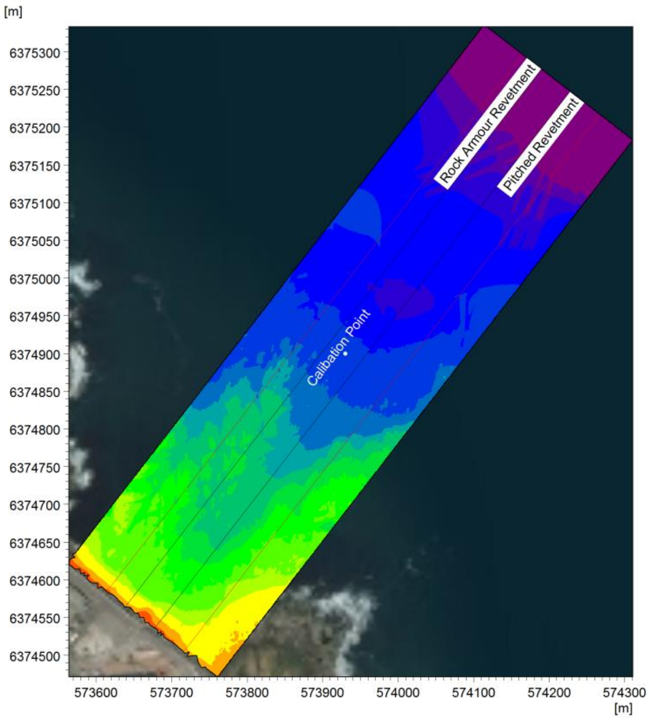


Figure 7-2 Contour plot of the area covered by the wave basin with the testing area and wave calibration point marked

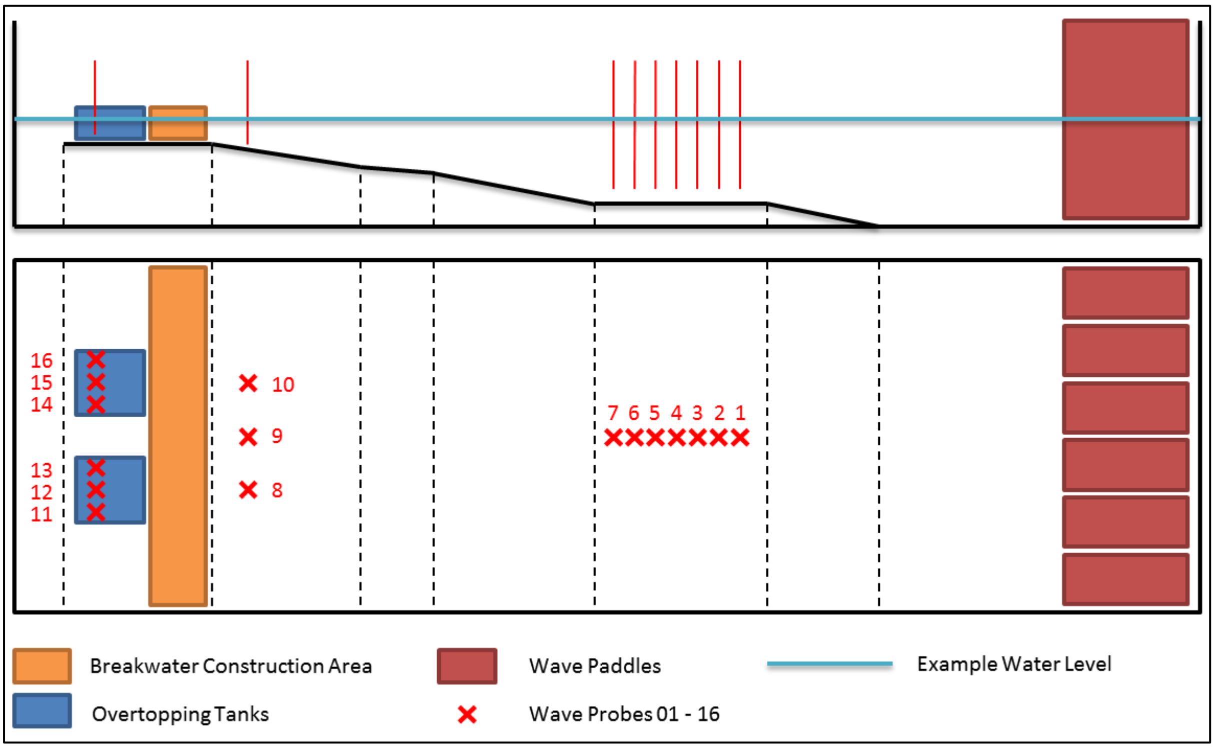


Figure 7-3 Schematic diagram of the physical model in the wave basin (not to scale) taken from the QUB Test Completion Report

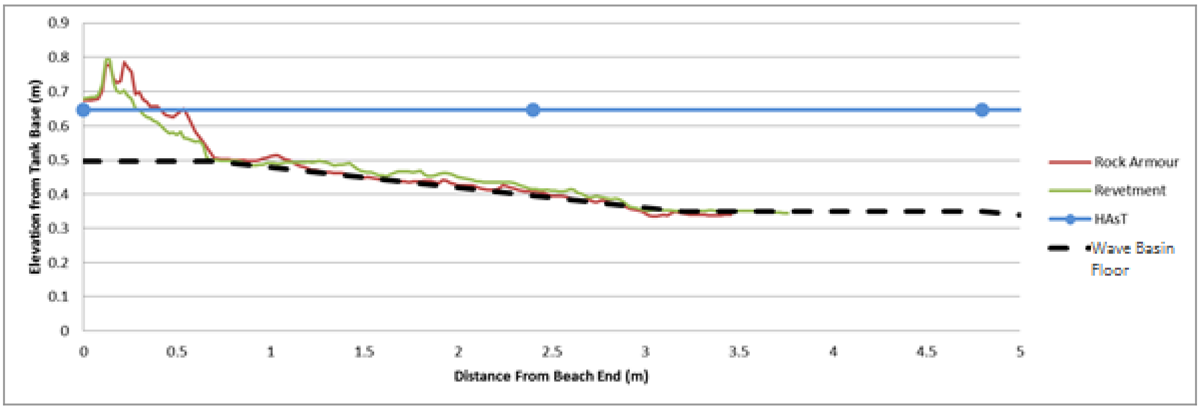


Figure 7-4 Cross section of the Belfast narrow wave basin during the Peterhead overtopping testing campaign taken from the QUB Test Completion Report

The tank floor was slightly modified for this testing campaign to match the bathymetry for this particular study as can be seen in Figure 7-4.

7.2 WAVES

Significant wave height (H_{mo}) and peak wave period (T_p) data was extracted from the Spectral Wave model described in Section 4 at the calibration point with coordinates of (573 930, 6 374 900). This data was extracted for a 1 in 2, 10, 50 and 200 year joint probability storm event. The full scale and model (50th) scale data can be seen in Table 7-1.

Table 7-1 Wave parameters from the calibration point at both full scale and 50th scale

Return period [years]	Full Scale		50th Scale	
	H_{mo} [m]	T_p [s]	H_{mo} [m]	T_p [s]
1 in 2	2.9	10.52	0.06	1.49
1 in 10	4	12.76	0.08	1.80
1 in 50	5	14.31	0.10	2.02
1 in 200	5.8	15.64	0.12	2.21

This allowed JONSWAP spectra to be created and calibrated at the same relative point in the wave tank. The waves were calibrated at a water level of 4.92mCD which correlated to the water level predicted to be the most critical for overtopping (4.12mCD) plus wind setup (as wind and wave setup is 0.4m it can be assumed that wind setup is half, 0.2m) and sea level rise predicted for 2080 (0.6m). The waves were calibrated to be within 2% of the target. A sample wave trace can be seen in Figure 7-5. A high wave height to water depth ratio was found with the extreme waves at the toe of the structure resulting in wave breaking.

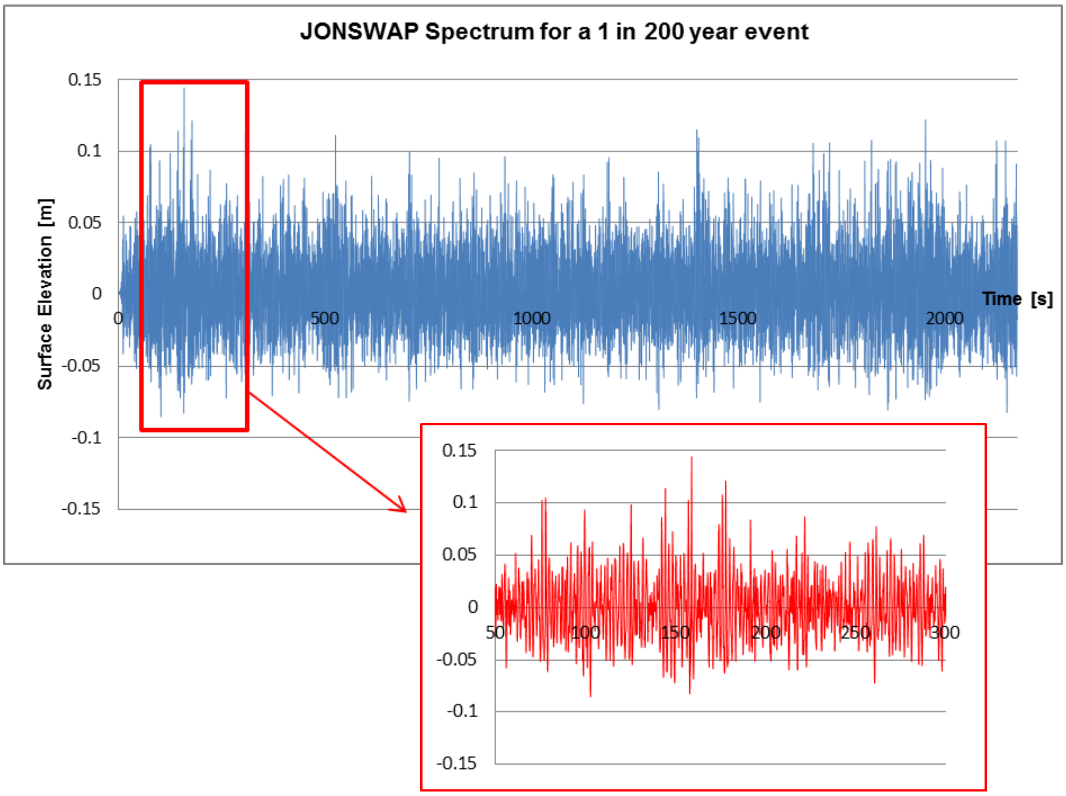


Figure 7-5 The wave trace at the calibration point for the 1 in 200 year storm event at 50th scale

7.3 MODEL SETUPS

There were initially three model setups;

- The existing structure which included the pitched revetment and the rock armour revetment as detailed in Section 5.1 and photographed in Figure 7-6.
- The proposed revetment design as detailed in Section 6 and photographed in Figure 7-7.

Following the results of these two setups, a third was designed;

- The proposed revetment design as detailed in Section 6 with an increased crest level and seawall level behind the pitched revetment section as photographed in Figure 7-8.

The pitched revetment in the existing structure consisted of a piece of plywood with a geotextile mesh layer to increase friction. In the proposed structure, holes were drilled into the surface of the plywood to increase porosity.

Figure 7-6 The existing structure model setup with the pitched revetment on the left and the rock armour revetment on the right

Figure 7-7 The proposed revetment design

Figure 7-8 The proposed revetment design with the crest and seawall levels increased

7.3.1 Model Test Results - Overtopping

The results for these three model setups can be seen in Figure 7-9 (mean overtopping discharge) and Figure 7-10 (peak overtopping discharge).

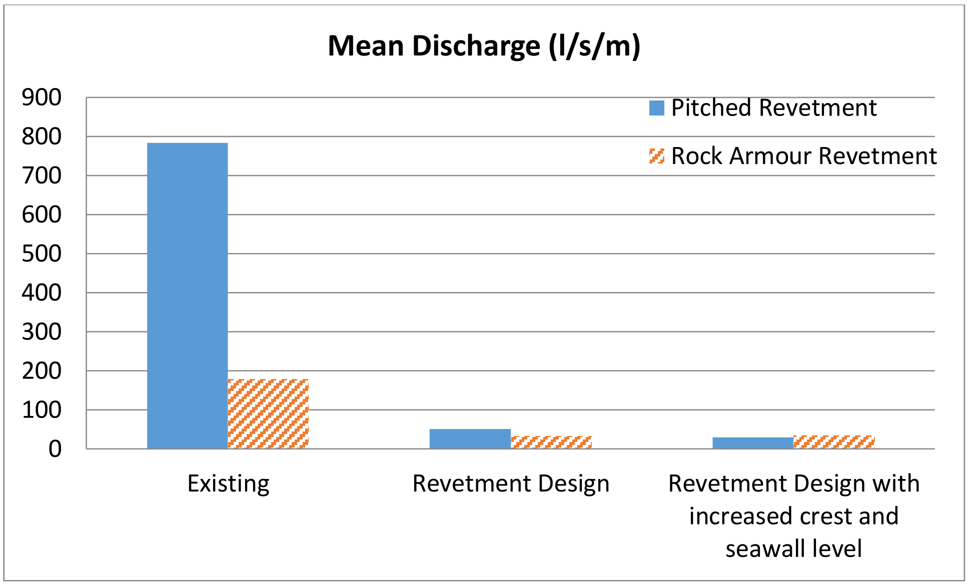


Figure 7-9 Graph of the mean discharge rates at full scale for the model setups

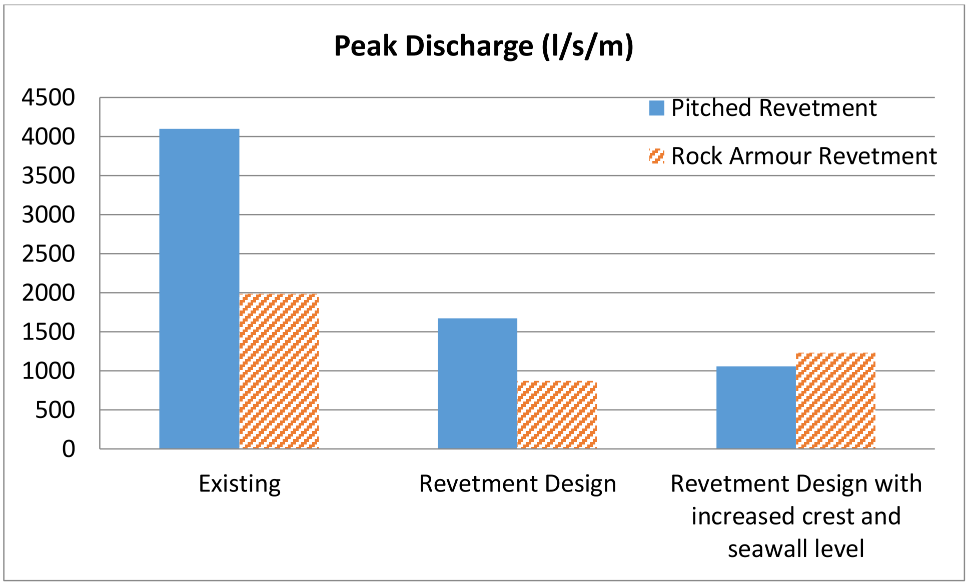


Figure 7-10 Graph of the peak discharge rates at full scale for the model setups

7.3.2 Model Test Results – Armour Stability

During tests with the proposed structure some of the Xbloc units were rocking. In addition one of the 15T rocks on the pitched revetment side was transported from the crest of the structure over the seawall. There was also significant washout of the smaller sized toe stones. The proposed design following these tests is detailed in Figure 7-11.

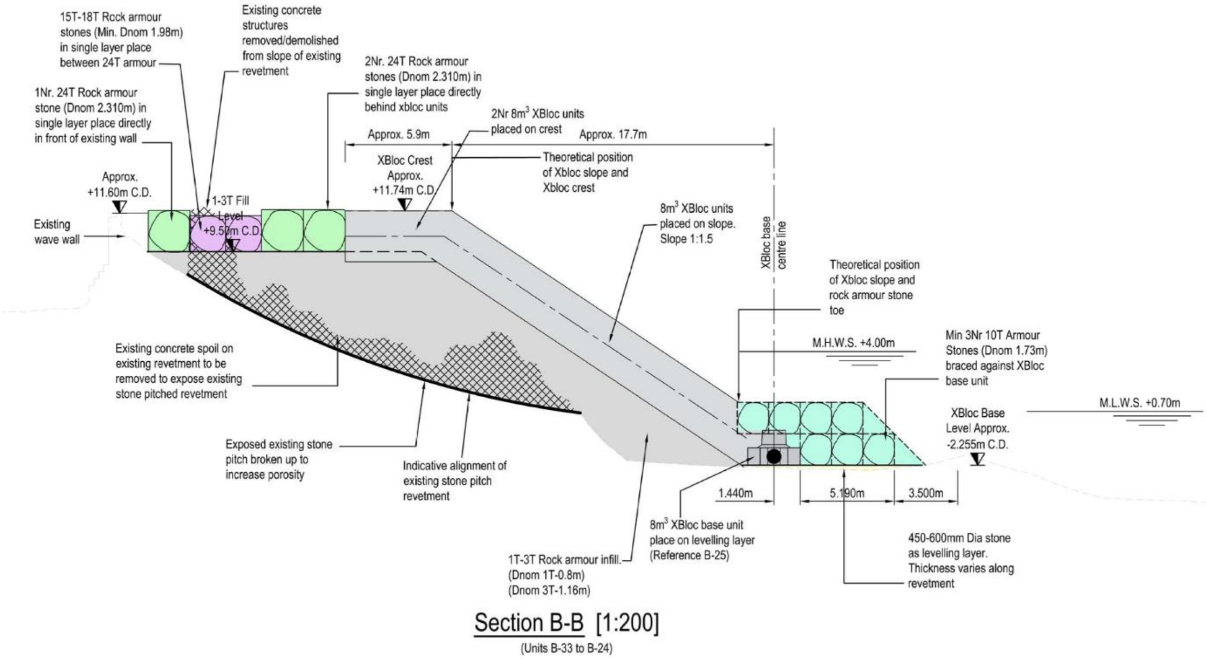


Figure 7-11 A schematic of the proposed revetment design

7.4 REVISED MODEL SETUP

Following the tests described in Section 7.3, another survey was conducted by Aspect Land & Hydrographic Surveys to determine the location of the toe. Although the predicted location of the toe was deemed accurate it became apparent that an error had occurred in a previous survey by Boskalis and the level of the seawall behind the rock armour revetment was misquoted at 12.2mCD. It was found to be 11.5mCD and this was confirmed by Arch Henderson record drawings. In addition, the proposed scheme was too costly and thus a revised proposal was required. This revised revetment design would be sufficient for overtopping conditions that exist currently whilst leaving scope for essential upgrades in the future in relation to sea level rise. Therefore taking these factors into consideration RPS decided to repeat the tests with a revised proposal. The revised proposed revetment design included;

- Reduction to the level of the seawall behind the rock armour revetment to 11.5mCD
- Reduction of the water level from the predicted level in 2100 to the predicted level for 2018
- Increase the Xbloc size from 5m^3 to 8m^3 to increase the stability of the structure and prevent rocking
- Increase the weight of the toe stones to 10T

It is worth noting that the computational model described in Section 4 was re-run with the 2018 water level. The wave parameters at the calibration point remained unchanged and therefore the waves used for the 2100 water level could be reused.

7.4.1 Revised Model Test Results – Overtopping

This revised proposed revetment design was tested at two water levels; 2018 and 2080. The results can be seen in Figure 7-12 (mean overtopping discharge) and Figure 7-13 (peak overtopping discharge).

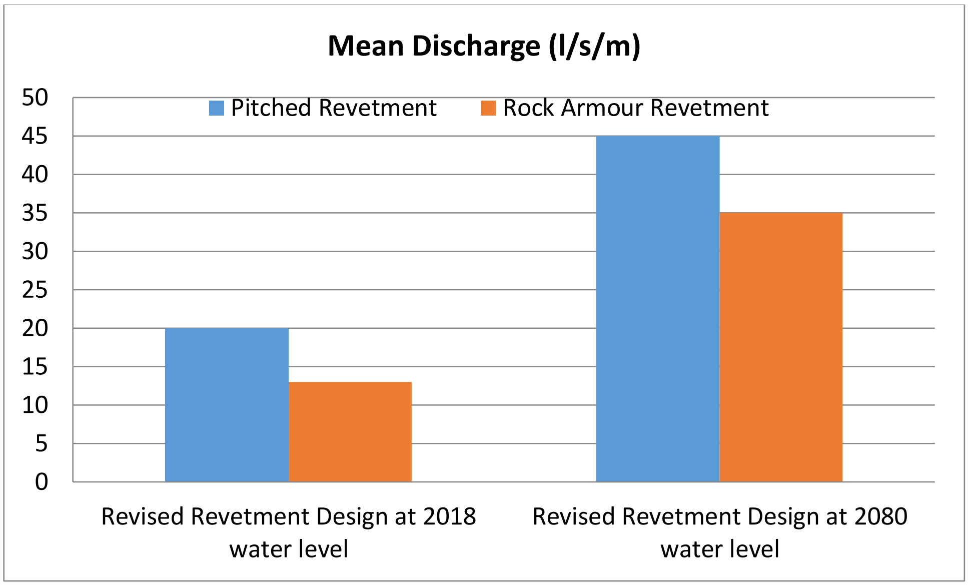


Figure 7-12 Graph of the mean discharge rates at full scale for the revised model setup

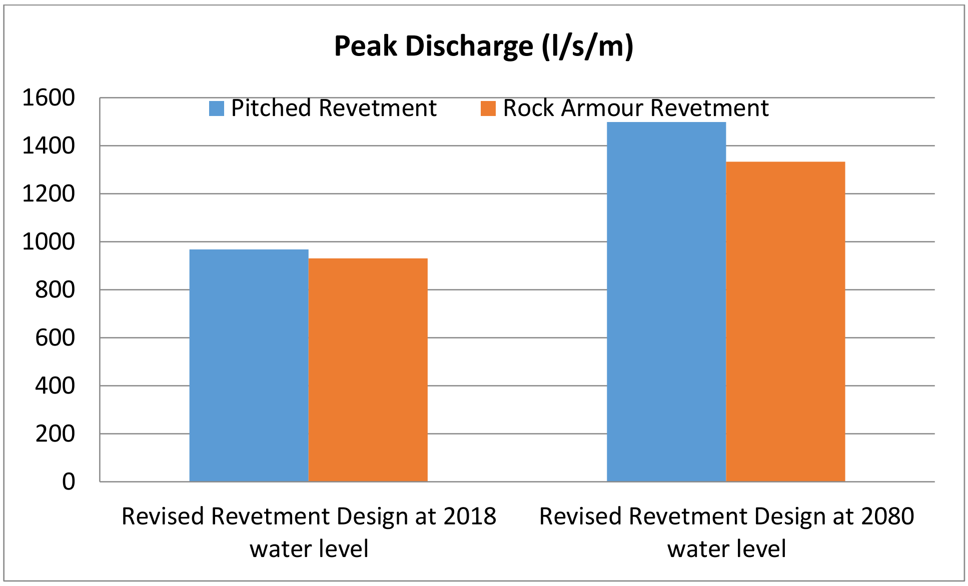


Figure 7-13 Graph of the peak discharge rates at full scale for the revised model setup

7.4.2 Revised Model Test Results – Armour Stability

During the tests of the revised model setup there was no movement in the X blocs or the rock armour.

7.5 SUMMARY OF RESULTS

Details on the data acquisition and analysis can be found in the Test Completion Report in the Appendix.

The results for the five model setups detailed in Section 7.3 can be seen in Table 7-2. The labels denoted with an asterisk represent those setups in which the seawall level was 12.2mCD (full scale). Those without an asterisk represent those with the seawall at its true level of 11.5mCD (full scale).

Table 7-2 Overtopping discharge rates from the physical modelling at full scale

	Mean discharge (l/s/m)	Peak discharge (l/s/m)
Pitched Revetment		
Existing	783	4097
Revetment Design	50	1670
Revetment Design with increased crest and seawall level	29	1058
Revised Revetment Design at 2018 water level	20	967
Revised Revetment Design at 2080 water level	45	1497
Rock Armour Revetment		
Existing*	178	1979
Revetment Design*	33	870
Revetment Design with increased crest and seawall level*	35	1230
Revised Revetment Design at 2018 water level	13	929
Revised Revetment Design at 2080 water level	35	1333

The results for all the model setups tested can be seen in Figure 7-14 and Figure 7-15. The bars with a diagonal stripe fill represent those setups in which the seawall level was at 12.2mCD. The bars with a solid fill represent those setups those with the seawall at its true value of 11.5mCD.

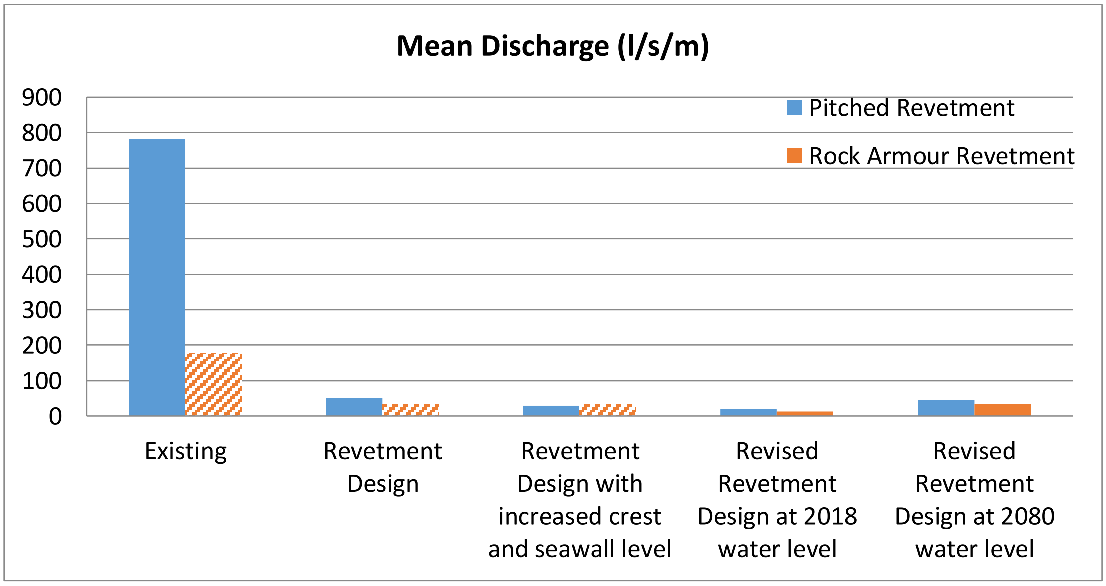


Figure 7-14 Graph of the mean discharge rates at full scale for all model setups

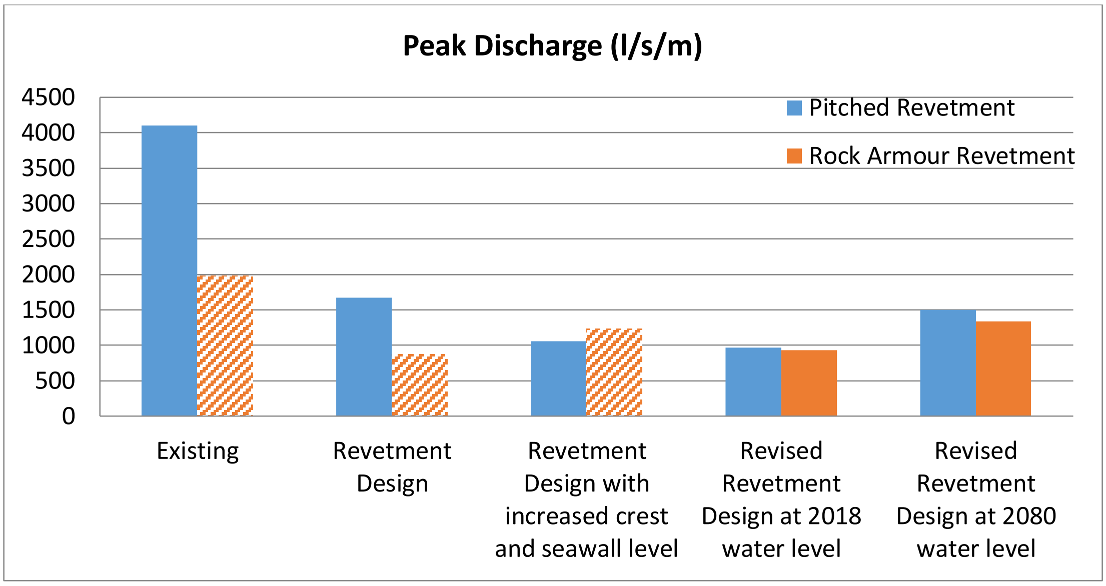
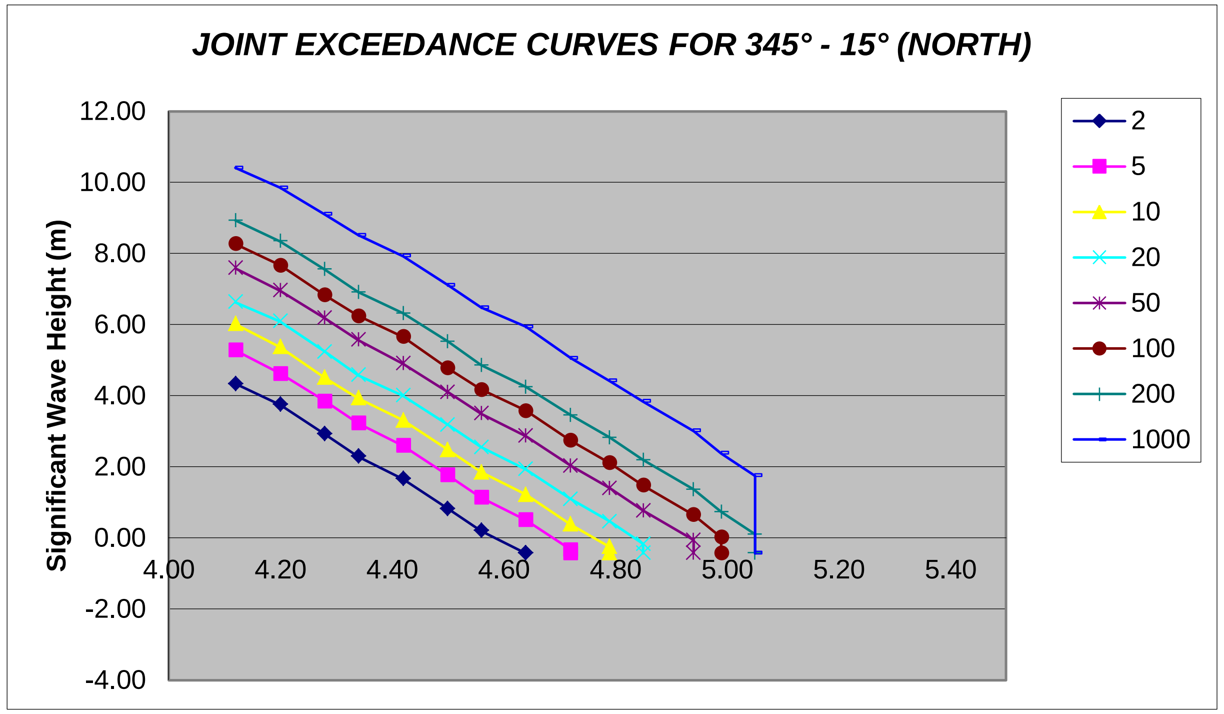


Figure 7-15 Graph of the peak discharge rates at full scale for all model setups

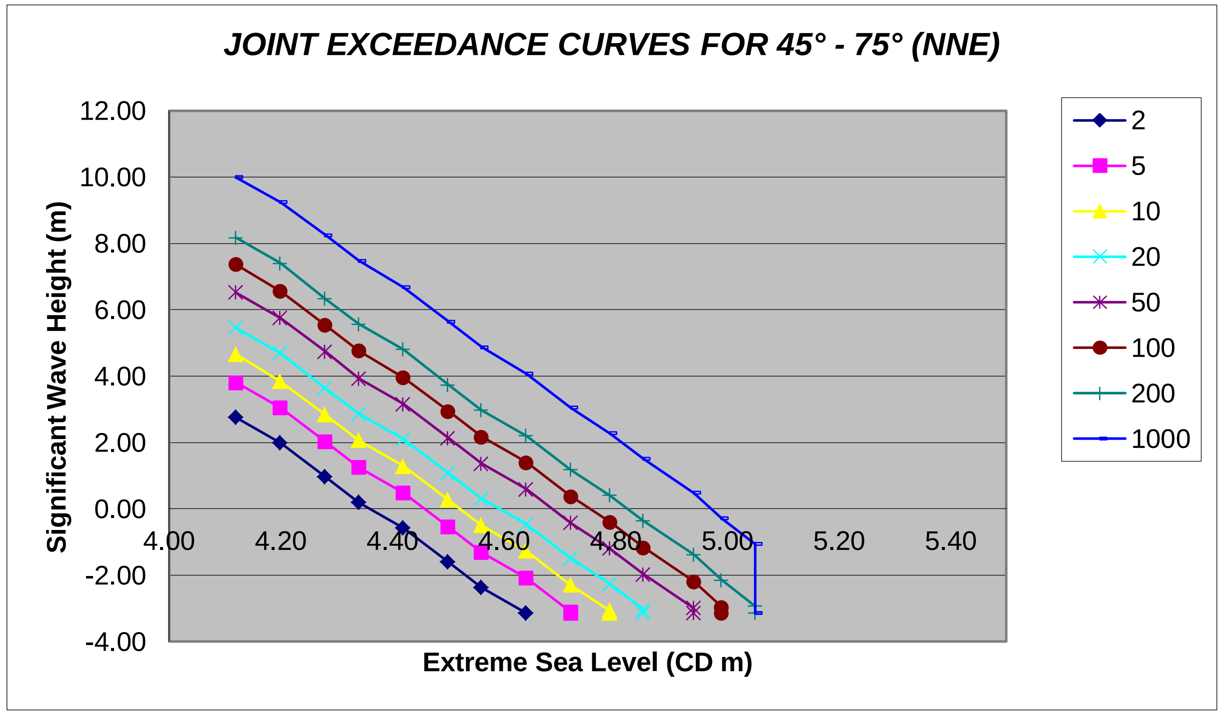
It is evident from these results that the revised revetment design at 2018 water levels provides the same level of protection against overtopping as the original revetment design with increased crest and seawall level.

APPENDIX

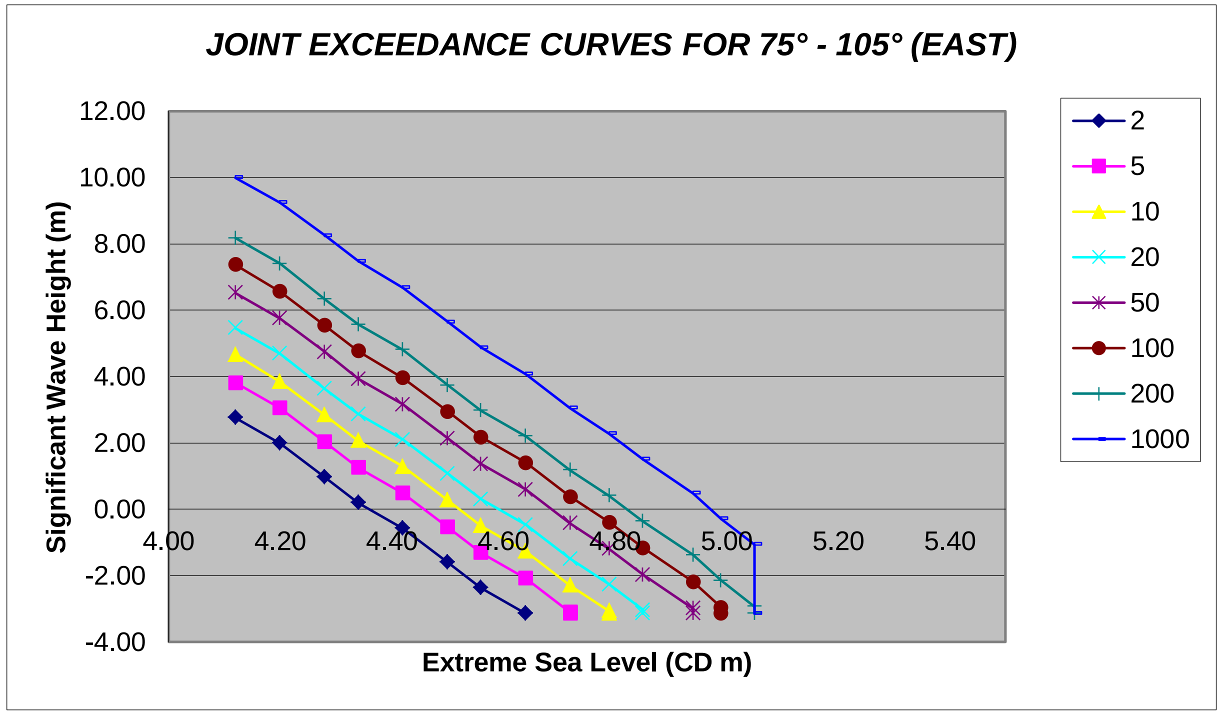
JOINT EXCEEDANCE CURVES FOR THE SIGNIFICANT WAVE HEIGHT AND THE WIND VELOCITY



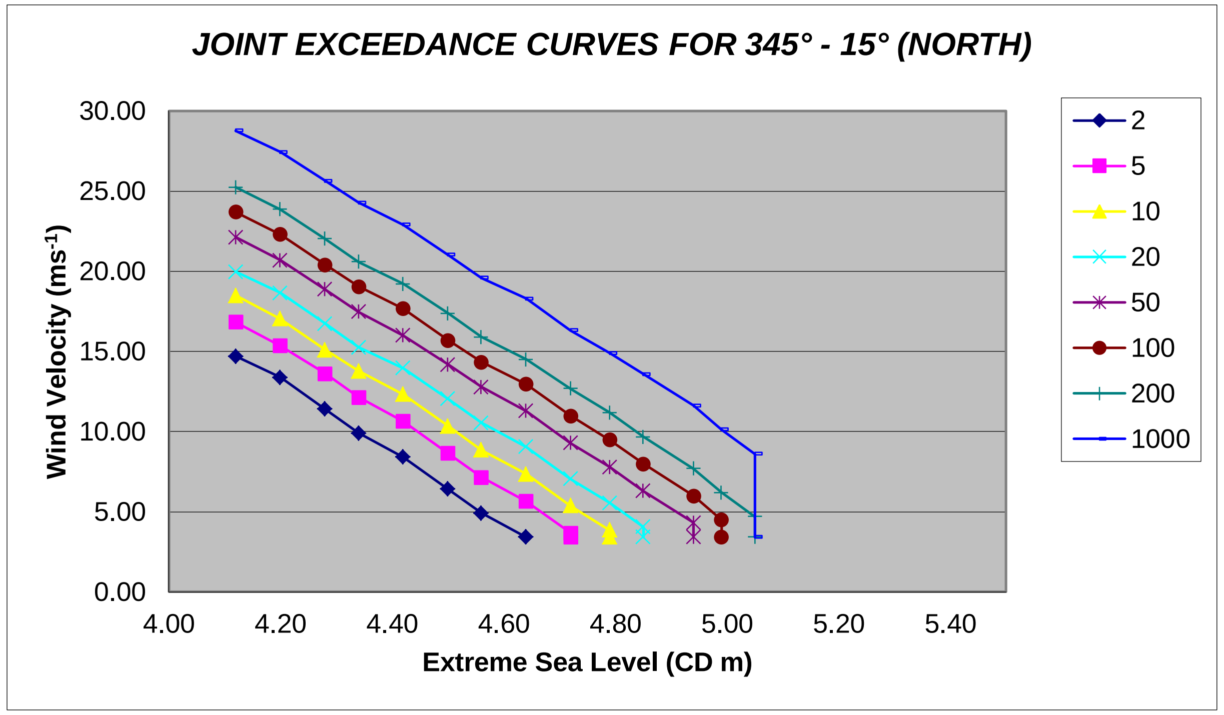
Joint exceedance curves for the significant wave height and extreme sea level between 345° and 15° (North)



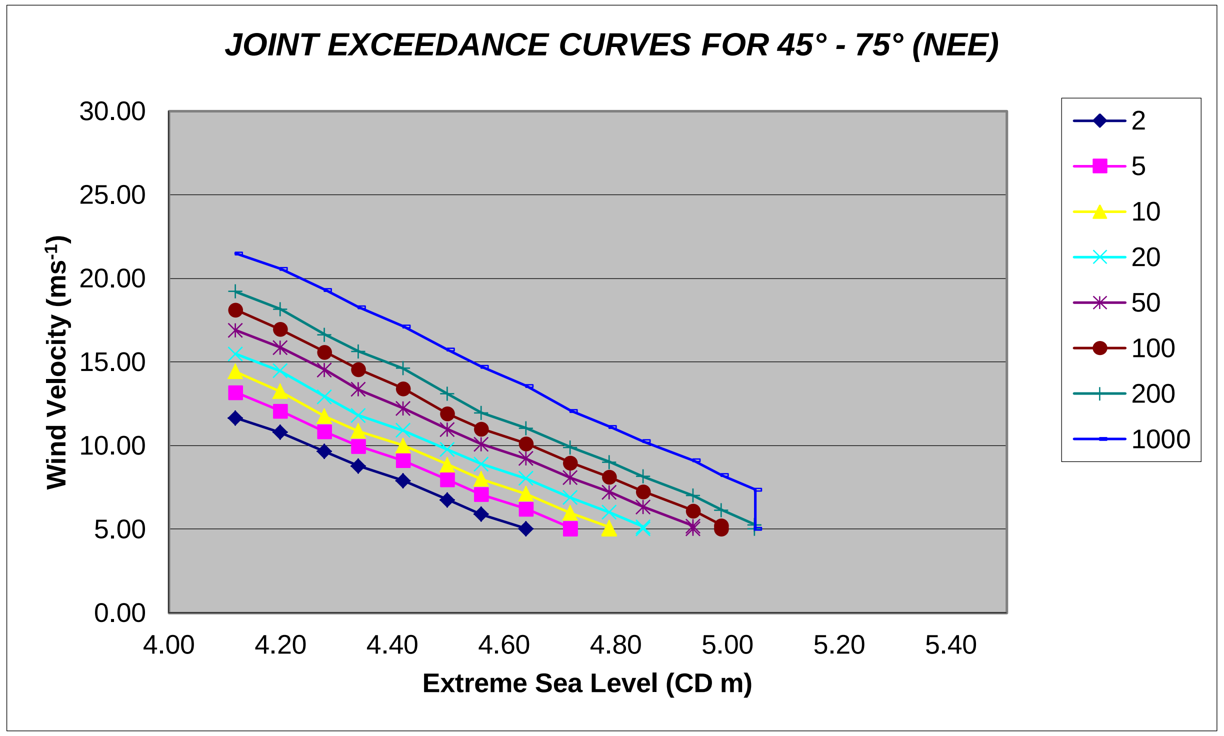
Joint exceedance curves for the significant wave height and extreme sea level between 45 ° and 75° (NEE)



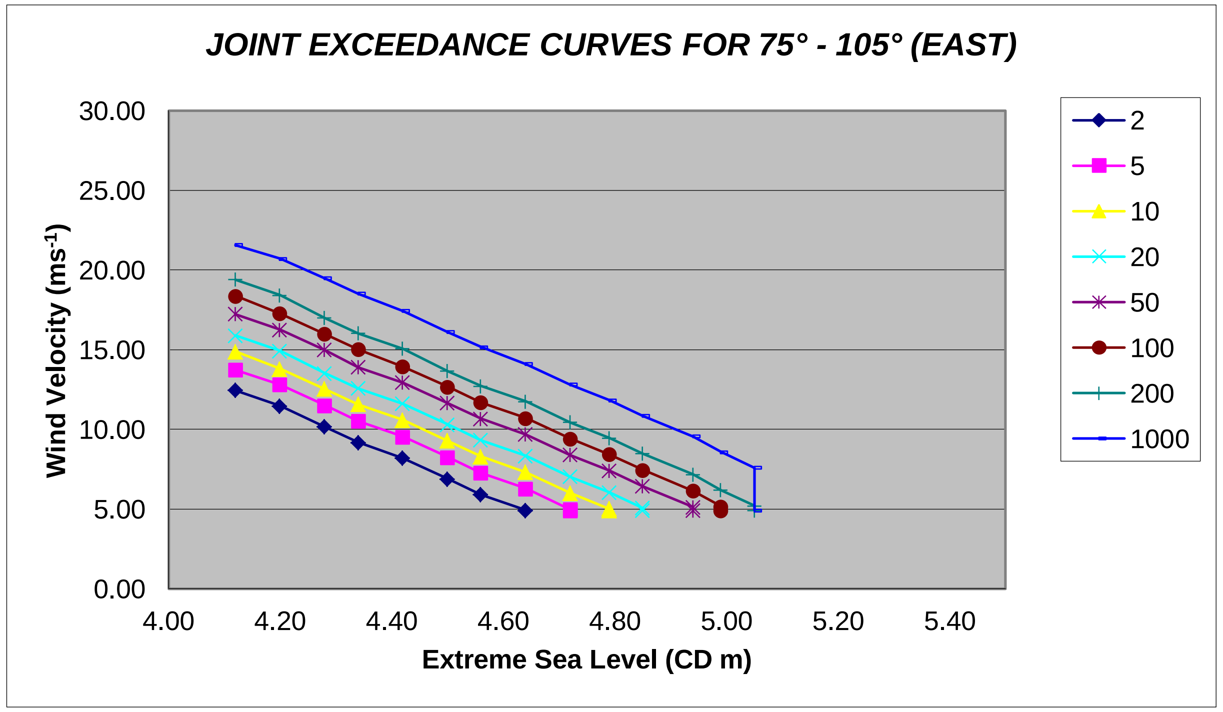
Joint exceedance curves for the significant wave height and extreme sea level between 75° and 105° (East)



Joint exceedance curves for the wind velocity and extreme sea level between 345° and 15° (North)

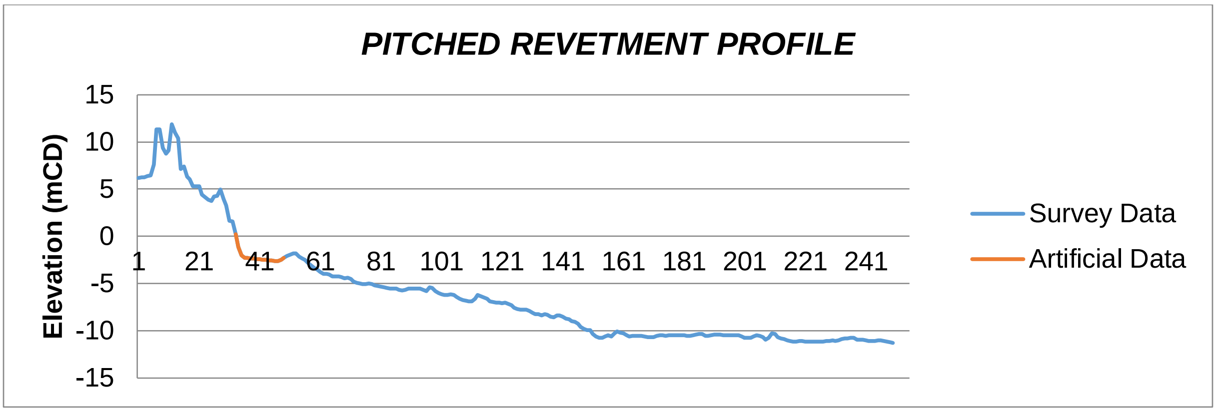


Joint exceedance curves for the wind velocity and extreme sea level between 45° and 75° (NEE)

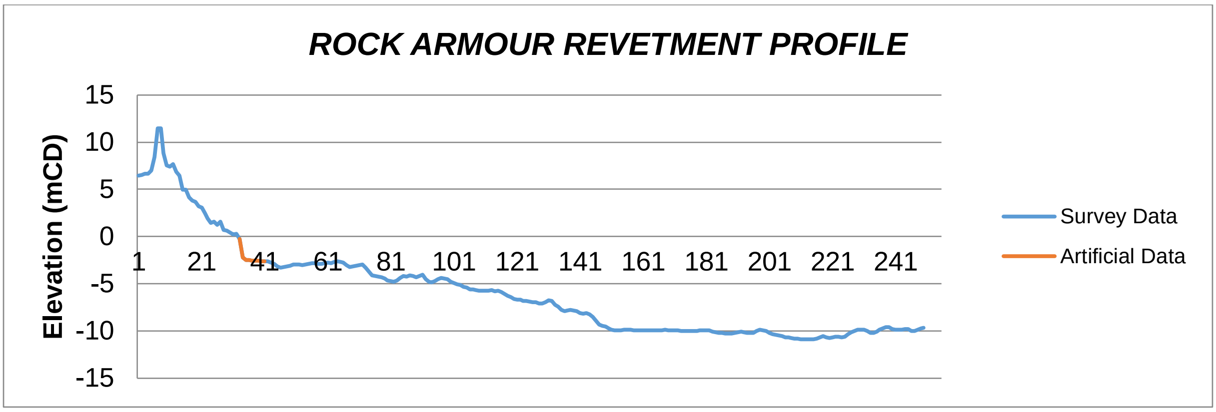


Joint exceedance curves for the wind velocity and extreme sea level between 75° and 105° (East)

PITCHED REVETMENT AND ROCK ARMOUR REVETMENT PROFILES



Elevation along the pitched revetment

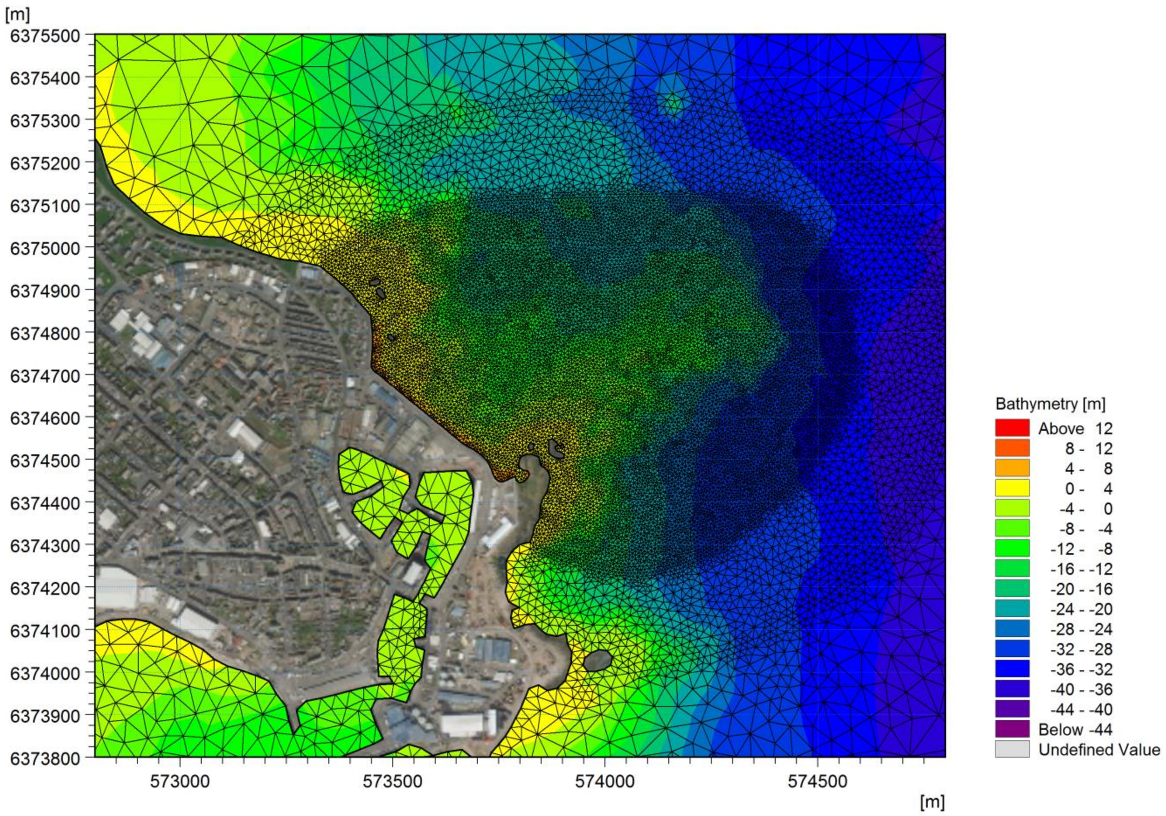


Elevation along the rock armour revetment

MIKE SW MODEL MESH

Extreme sea levels and wave conditions were simulated at Peterhead using a refined version of RPS East Coast of Scotland model with some minor modifications inshore. The model was developed using flexible mesh technology to allow for a very fine resolution to be implemented in the area around Alexandra Parade while a coarser spacing could be employed in remote areas located further offshore.

The fine mesh around the area of interest is shown below. The grid spacing in the model varied from a fine 7-8m spacing in the area surrounding Alexandra Parade to a coarser 1000m in the outer part of the model.



Bathymetry and model mesh in the area surrounding Alexandra Parade

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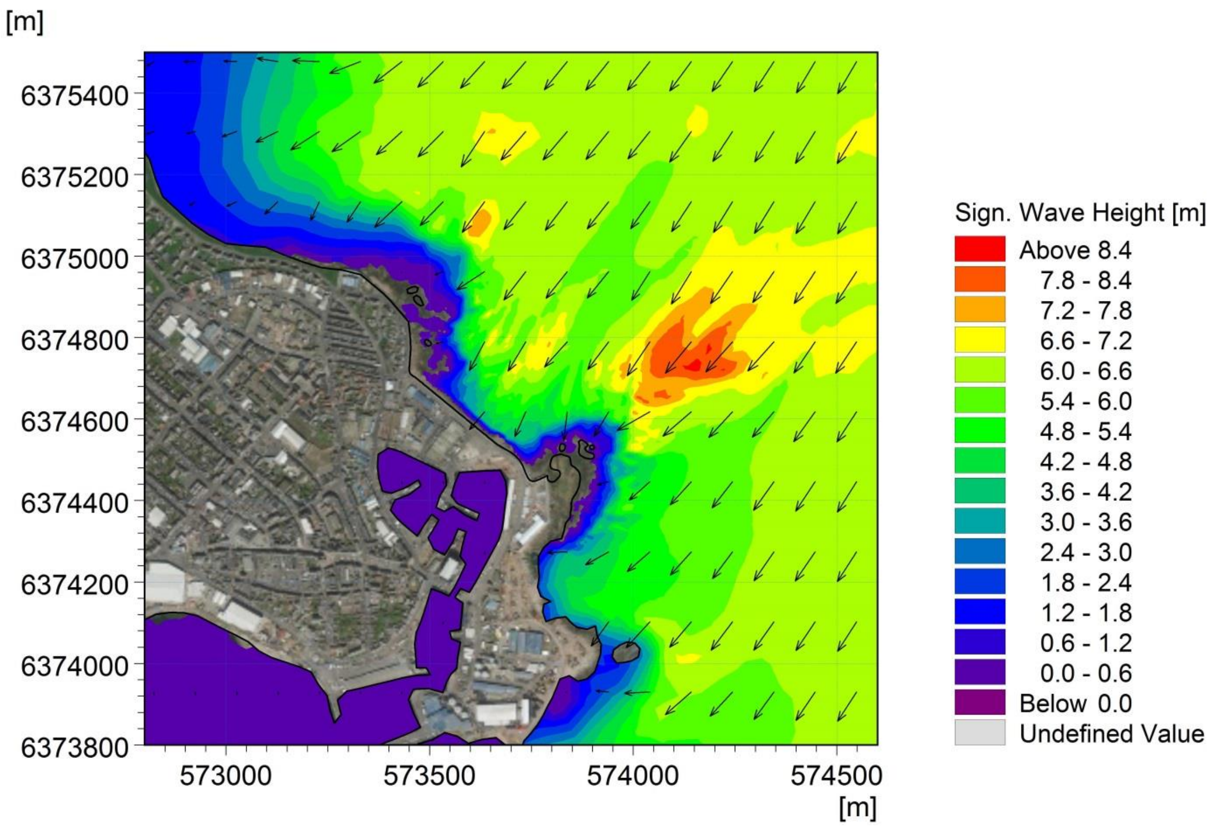
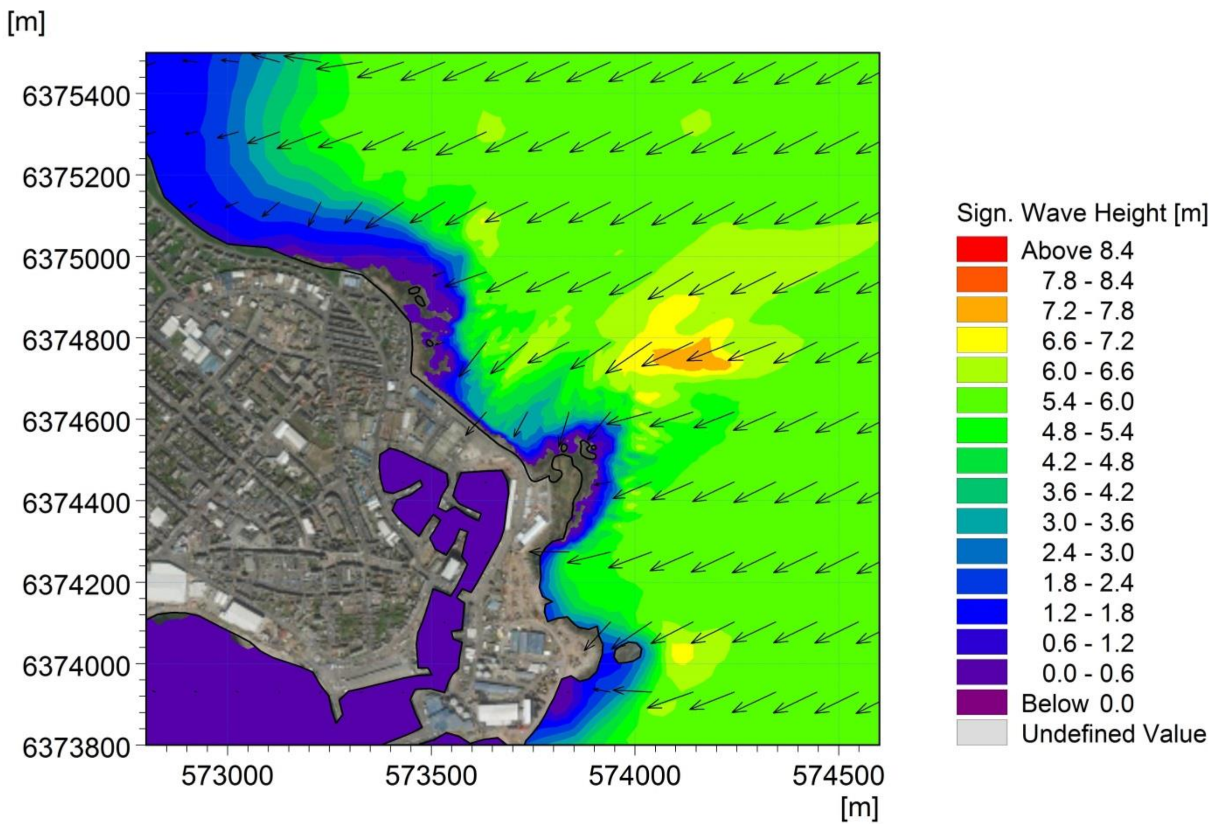
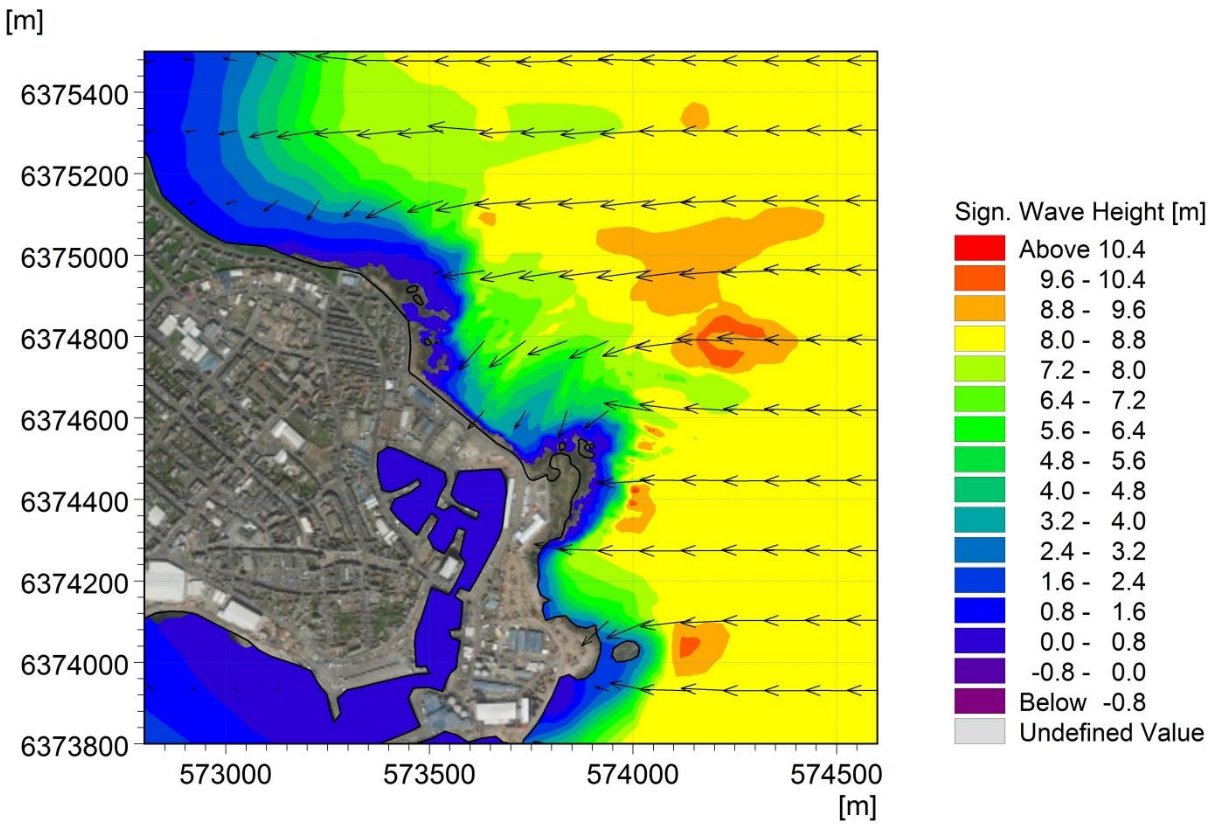
SIGNIFICANT WAVE HEIGHTS IN THE AREA SURROUNDING ALEXANDRA PARADE



Significant wave heights in the area surrounding Alexandra Parade during a I in 200 joint probability event at 345° - 15° (North)

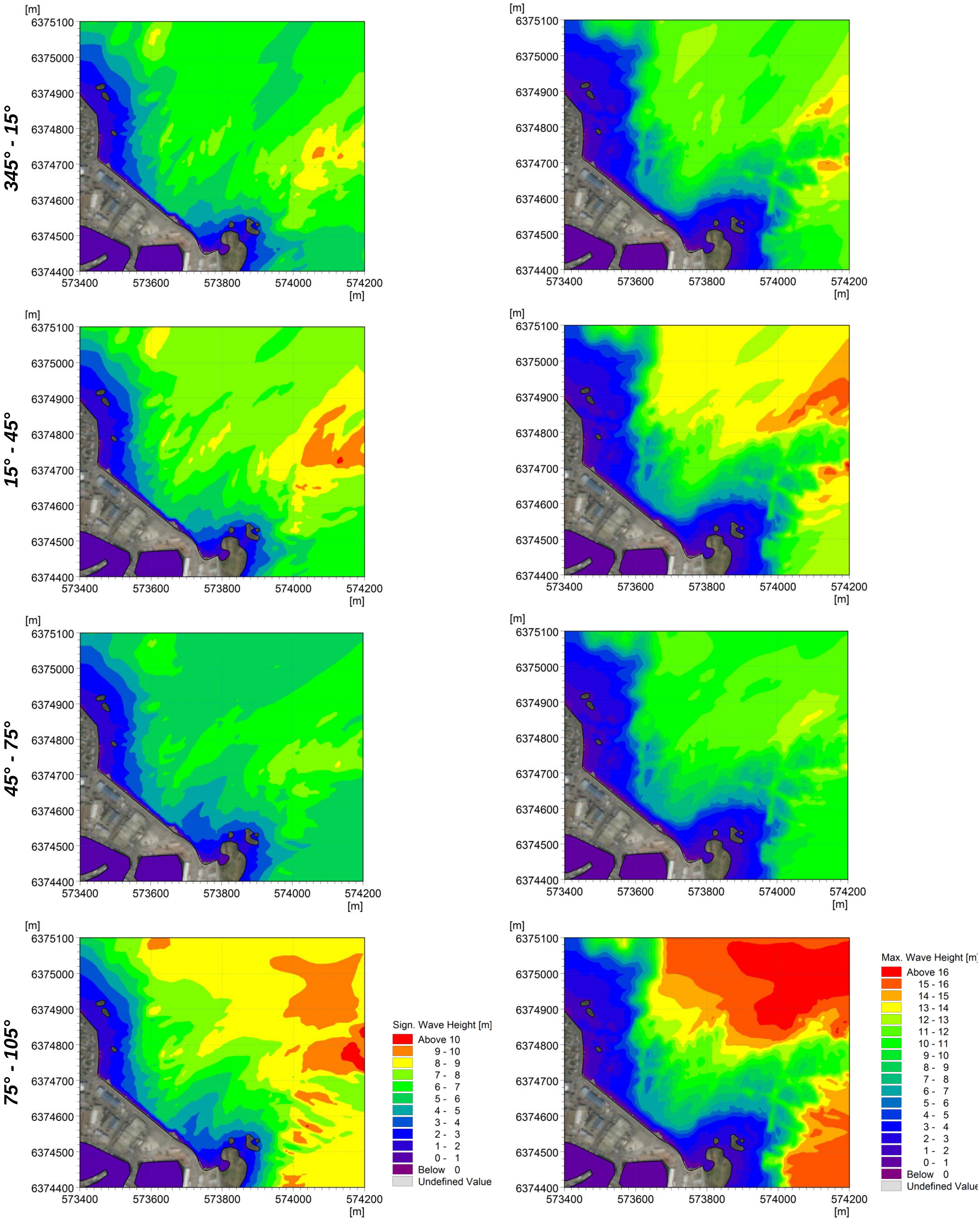


Significant wave heights in the area surrounding Alexandra Parade during a I in 200 joint probability event at 45° - 75° (NEE)



Significant wave heights in the area surrounding Alexandra Parade during a I in 200 joint probability event at 75° - 105° (East)

VARIATION IN SIGNIFICANT AND MAXIMUM WAVE HEIGHT ALONG ALEXANDRA PARADE



The variation in the significant wave height (left) and the maximum wave height (right) over a range of directions for a 1 in 200 year wave around Alexandra Parade

QUB TEST COMPLETION REPORT – PETERHEAD BREAKWATER

(See overleaf)

Peterhead Breakwater – 50th Scale Overtopping Tests

QUB - Test Completion Report

Strictly Private & Confidential

Revision History:					
Rev.	**Date**	**Purpose of Issue**	**Prepared By**	**Checked By**	**Approved By**
01A	04/07/2018	Draft for review	Paul Lamont-Kane	Trevor Whittaker	
01B	09/07/2018	Draft for review	Paul Lamont-Kane	Trevor Whittaker	
01C	09/07/2018	Release	Paul Lamont-Kane	Trevor Whittaker	Trevor Whittaker
01D	07/08/2018	Update	Paul Lamont-Kane	Trevor Whittaker	Trevor Whittaker
01E	08/08/2018	Update	Paul Lamont-Kane	Rachael McKee	

1 Introduction

As part of an infrastructure improvement project for Peterhead, Aberdeenshire, RPS Group Plc (RPS) are undertaking a redesign of the existing Alexandra Parade breakwater (see Figure 1.1) which suffers from significant overtopping during storm events.

Figure 1.1: Satellite Image of the Alexandra Parade Breakwater, Peterhead (Image Credit: Google Maps)

In its current state the breakwater has two distinct profiles along its length. On the north-west edge the breakwater consists of a rock-armour construction. The south-east end consists of a concrete pitched revetment with standalone concrete units (see Figure 1.2 below). The profiles for each of the two sections of the existing breakwater were provided by RPS.

Figure 1.2: Existing Breakwater Profile Locations

The existing breakwater is to be replaced by a new rock-armour breakwater faced on the front with a single layer of Xbloc armour units. Two different design scenarios have been tested, the difference being an increased breakwater crest height on the revetment slope end of the breakwater for the second design. Section profiles for each of the two proposed design scenarios were again provided by RPS. Throughout this report, the first design is referred to as Design 1. The second design iteration (with the increased crest height above the revetment slope section) is referred to as Design 2.

Queen's University Belfast (QUB) was commissioned by RPS to design and conduct a small scale experimental investigation of the overtopping experienced by the existing breakwater and the two potential design options. Key design and test conditions specified by RPS were as follows:

- Experiments to be conducted at 50^{th} scale
- Wave tank bathymetry to be modified to resemble that of Peterhead site
- Test in seven irregular sea states representing a range of storm events. Details are given in Section 2.3, Table 2.1.
- Test in > 1,000 wave cycles for overtopping tests
- Measure the wave climate both nearshore and at the toe of structure
- Measure the mean and instantaneous overtopping volumes

2 Methodology

2.1 Wave Basin Configuration

The narrow wave basin in QUB measures 18m by 4.5m and can operate with water depths up to 800mm. The basin is equipped with six sector-carrier, force-feedback wave paddles supplied by Edinburgh Designs Ltd. An absorbent beach sits opposite the wave-maker and consists of coarse geotextile matting laid on top of a 1 in 6 revetment slope. Under typical conditions the beach is used to absorb the incident wave energy, thus minimising reflections from the back wall of the basin. The paddle control software allows a broad range of wave fields to be generated including irregular, long crested waves which were used in these tests. The paddles benefit from a force-feedback mechanism which allows them to remove unwanted reflections returned from models or other obstacles in the tank. Waves are calibrated prior to testing to ensure incident sea states are per specification at particular points of interest within the wave basin. The basin also has a 'false-floor' set in place on top of the tank base to provide bathymetric profiles as required.

2.1.1 Wave Basin Bathymetry Modification

In order to approximate the bed profile leading up to the breakwater the tank floor slabs were adjusted and reset manually to provide a continuous 1 in17 slope for 120m (full scale) beyond the toe of the breakwater followed by a 1 in 55 slope for an additional 60m (full scale). A comparison of the profiles, the pre-existing wave tank floor and the modified tank floor plotted in excel is presented in Figure 2.1. Note the figure only presents the first 5m of the wave basin (at model scale) and also shows the water level at 4.92m above chart datum.

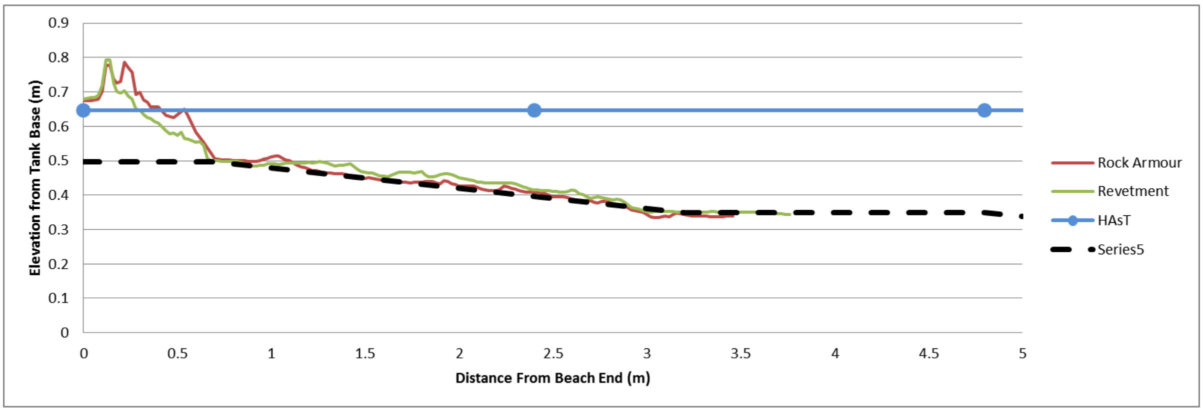


Figure 2.1: Requested Peterhead Profiles, Pre-Existing and Modified Tank Bathymetric Profiles

2.2 Test Setup

Figure 2.2 shows the wave basin setup during testing. Red areas in Figure 2.2 represent the wave paddles. Hence wave propagation is from right to left in this perspective. The orange area denotes the location where the breakwater models were constructed for testing. Blue areas denote the overtopping tanks used to estimate volumes of water overtopping breakwater models. Red X's and vertical lines represent wave probes used during testing.

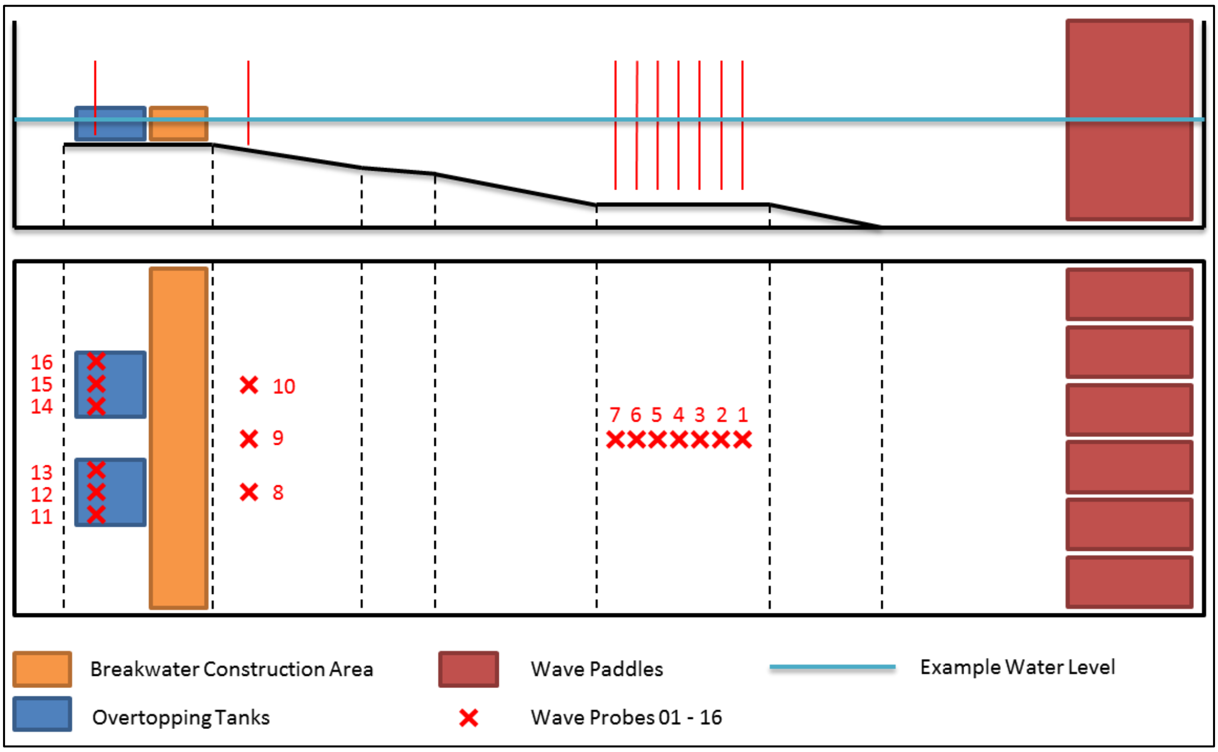


Figure 2.2: Outline of the Wave Basing Setup During Testing

Seven Wave Probes (WPs) were placed at the nearshore location. Seas were calibrated at WP5. Three wave probes were placed to seaward of the toe of the breakwater. Each overtopping tank had 3 wave probes set within it to measure the instantaneous water levels.

2.3 Sea State Calibration

In total, seven sea states were calibrated for use with the overtopping tests. Only four of these, deemed the most critical in terms of overtopping volume, were used during testing. The seas employed were calibrated 'nearshore' in an equivalent water depth of 24m. The wave characteristics of these seas at the nearshore reference location are given in Table 2.1 below.

Table 2.1: Target Sea State Characteristics (Full Scale)

Return Period (yr)	Water Level (mACD)	H_s (m)	T_p (s)
1 in 200	4.92	5.8	15.64
1 in 2	4.92	2.9	10.52
1 in 10	4.92	4	12.76
1 in 50	4.92	5	14.31

Sea states were calibrated with the pre-existing wave basin bathymetry and to within ±5% of the requested characteristics. Seas were generated with a repeat time of 2,048 seconds corresponding to a full scale time of over 4 hours and around 1,200 waves for each sea state. During each calibration run/test data was collected for 2,176 seconds with the intention of removing the first 128s in post-processing. This approach gives the wave basin a short time to reach a steady state and grant the collection of a fully repeating time-series during testing.

2.4 Physical Model – Existing Breakwater

Prior to testing of the proposed breakwater design, the existing breakwater was first tested to provide a benchmark for comparison. In collaboration with RPS, a 50th scale model of the existing breakwater was designed and constructed within the QUB wave basin. Due to the width limitation of the wave basin it was not possible to construct the entire 600m length of the breakwater. Consequently, a representative section was selected from the centre of the breakwater and constructed. This allowed testing of both the North-Westerly failing Rock-Armour section and the South-Easterly revetment section simultaneously. The model was designed and constructed based on site data provided by RPS. A photograph of the completed existing breakwater construction is shown in Figure 2.3. In this image, the North-Westerly failing rock-armour section is closest, with the South-Easterly revetment slope section in the background. Note the varied crest wall height on either side as per the profiles given.

For the revetment section of the existing breakwater (background in Figure 2.3) was constructed using marine-plywood. The revetment was overlain with a single sheet of geotextile meshing to increase the surface roughness of the revetment. The Rock-Armour section of the existing breakwater (foreground in Figure 2.3) was formed from sorted[1] 8T stone set atop an inner core of 1-3T stone. Either side of the two main breakwater elements was filled with large stone to reduce edge effects of the model during testing.

[1] Note – stone used in existing breakwater construction was sorted prior to use. To ensure stone was representative of rock armour elements stone was sorted by weight and size. To be considered acceptable for use, stone had to be within ±25% of target mass and exhibit a minimum to maximum edge length ratio of 2.5.

Figure 2.3: Photograph of the 50th Scale Existing Breakwater Model

Section profiles for the Revetment and Rock-Armour sections of the existing breakwater are presented in Figure 2.4 and Figure 2.5 respectively.

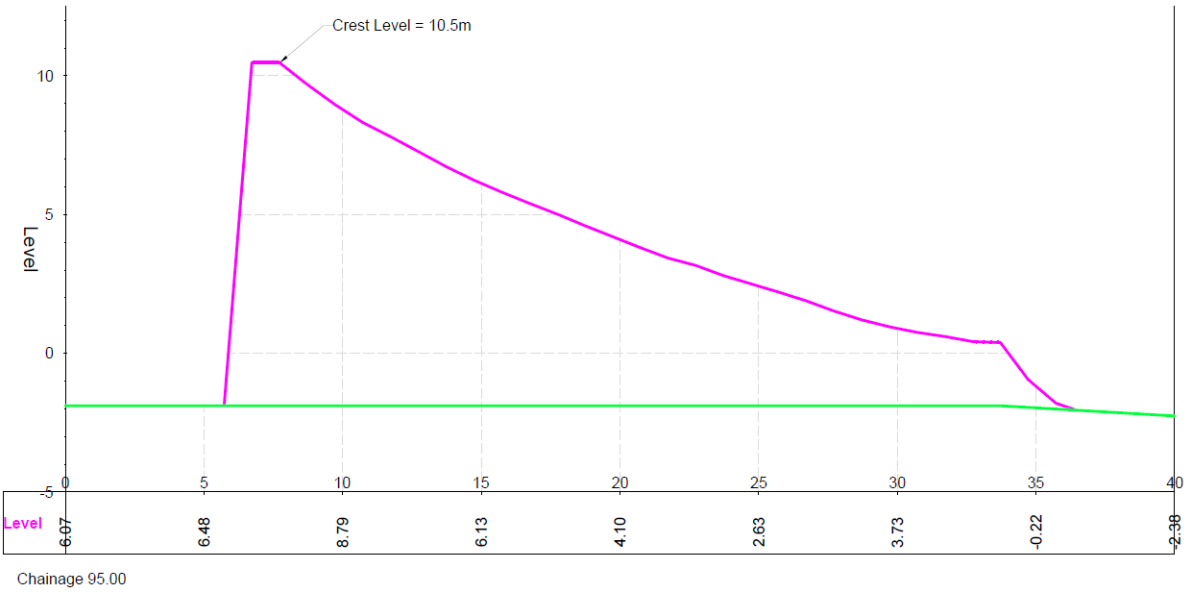


Figure 2.4: Section profile for the South-Easterly revetment section of the existing breakwater

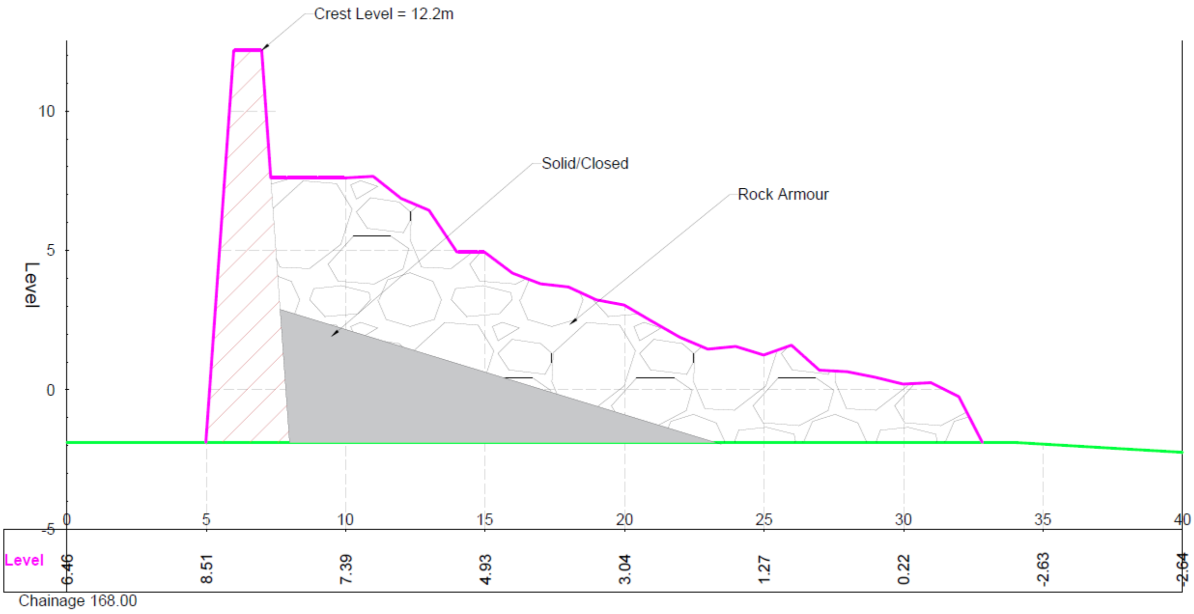


Figure 2.5: Section profile for the North-Westerly failing Rock-Armour section of the existing breakwater

2.5 Physical Model – Design 1

Upon completion of testing with the existing breakwater model, the first of 2 proposed breakwater designs (Design 1) was constructed. The Design 1 breakwater was constructed with a core of 1-3T stone, a toe of 8T rock armour, a front face of 5m^3 Xbloc units placed 1 unit deep and a crest platform of 24T and 15T rock armour as per physical drawings supplied by RPS. The edges of the breakwater were profiled into the large rock to minimise edge effects. A photograph of the Design 1 model setup is shown below in Figure 2.6. A section detail of the breakwater is presented in Figure 2.7. Note the crest wall against which the breakwater is constructed varies on each side to mimic the varied crest wall heigh across the Peterhead site.

Figure 2.6: Photograph of the 50th Scale Design 1 Breakwater

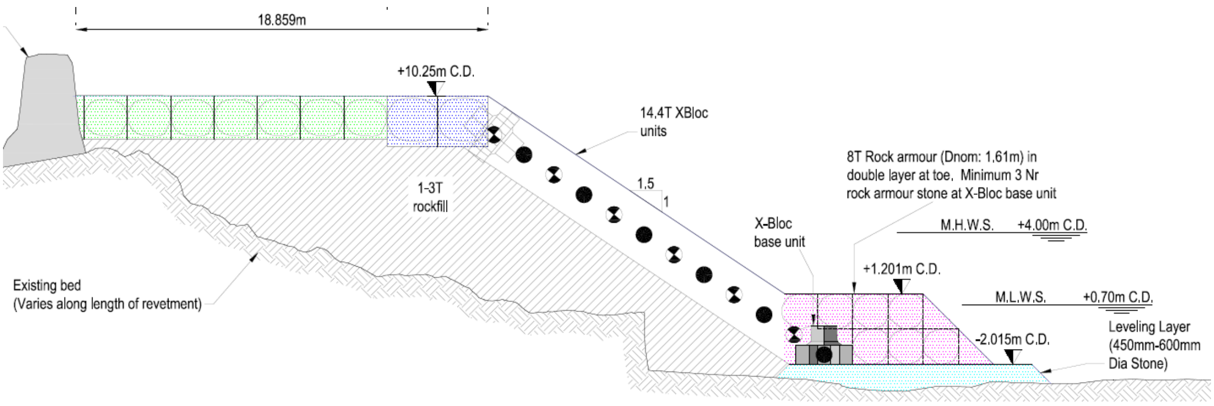


Figure 2.7: Section profile of the Design 1 proposed breakwater

2.6 Physical Model – Design 2

The Design 2 breakwater was constructed as a slight modification of the Design 1 breakwater with the following modifications:

- Crest wall height on the Revetment side increased from 10.5m to 11.4m
- Breakwater Rock Armour Crest height on revetment side increased from 10.25m to 11.75m

2.7 Overtopping Tanks

Two overtopping tanks were constructed to measure the volume of fluid overtopping the breakwater; one tank was constructed for the revetment side and one for the rock armour side. Each overtopping tank was filled with geotextile mesh to reduce sloshing during overtopping events. Two V-notch weirs were cut into the back face of each tank to permit a controlled discharge during testing. Three wave probes were set within each overtopping tank to record the instantaneous water level within the tanks. Prior to use the overtopping tanks were calibrated to determine both the volume of water retained at a given water level and the discharge through the V notches at given water levels. Details on the calibration methods can be found in *Appendix B – Overtopping Tank Calibration Methodology*.

3 Results

Full scale mean and peak overtopping volumes for the various sea states are given in the following sub-sections. Results have been scaled according to Froude Scaling laws which for units of L/s/m yields a scaling factor of $\lambda^{3/2}$. Note that model scale results are presented in Appendix D – Model Scale Results.

Aside from overtopping measurement, significant rocking of the 5m^3 Xbloc units was noted during testing in the 1 in 10, 1 in 50 and 1 in 200 year sea states with one unit becoming completely dislodged during testing of the 1 in 200 year sea state. Also a rock was moved during the 1 in 200 year sea state from the berm to the top of the seawall.

3.1 Mean Overtopping Volumes – Full Scale

Results for mean overtopping volumes at full scale for the Revetment and Rock-Armour sections of breakwater are presented in Table 3.1 and Table 3.2 respectively. Values are presented graphically in Figure 3.1 for ease of reader inspection.

Table 3.1: Revetment Side Mean Overtopping Volumes in L/s/m at Full Scale

Breakwater	Revetment Section - Mean Overtopping (L/s/m @ full scale)			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	783	64	337	598
Design 1	50	3	5	14
Design 2	29		5	10

Table 3.2: Rock-Armour Side Mean Overtopping Volumes in L/s/m at Full Scale

Breakwater	Rock Section - Mean Overtopping (L/s/m @ full scale)			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	178	5	40	89
Design 1	33	4	5	9
Design 2	35		4	12

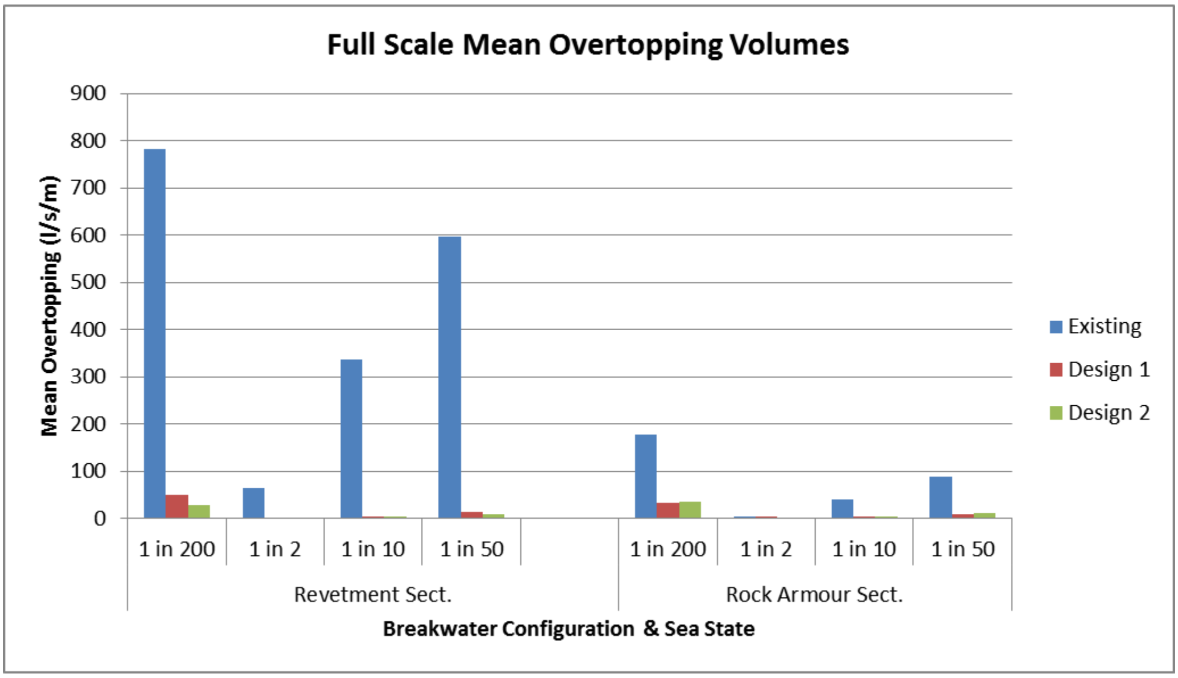


Figure 3.1: Mean Overtopping Volumes at Full Scale

Clearly both the 1st and 2nd designs both significantly reduce the volume of overtopping experienced. The percentage reductions achieved by Design 1 and Design 2 in the various sea states tested are presented in Table 3.3 and Table 3.4.

Table 3.3: Percentage Reduction in Mean Overtopping Volumes (Revetment Section)

Breakwater	Revetment Section - Mean Overtopping Reduction %

	1 in 200	1 in 2	1 in 10	1 in 50
Existing	-	-	-	-
Design 1	93.6%	95.3%	98.5%	97.7%
Design 2	96.3%		98.5%	98.3%

Table 3.4: Percentage Reduction in Mean Overtopping Volumes (Rock-Armour Section)

	Rock-Armour Section - Mean Overtopping Reduction %			
Breakwater	**1 in 200**	**1 in 2**	**1 in 10**	**1 in 50**
Existing	-	-	-	-
Design 1	81.5%	20.0%	87.5%	89.9%
Design 2	80.3%		90.0%	86.5%

3.2 Peak Overtopping Volumes – Full Scale

Results for peak overtopping volumes at full scale for the Revetment and Rock-Armour sections of breakwater are presented in Table 3.5 and Table 3.6 respectively. Values are presented graphically in Figure 3.2 for ease of reader inspection.

Table 3.5: Revetment Side Peak Overtopping Volumes in L/s/m at Full Scale

	Revetment Section - Peak Overtopping (L/s/m @ full scale)			
Breakwater	**1 in 200**	**1 in 2**	**1 in 10**	**1 in 50**
Existing	4,097	1,103	2,438	3,546
Design 1	1,670	14	122	520
Design 2	1,058		67	278

Table 3.6: Rock-Armour Side Peak Overtopping Volumes in L/s/m at Full Scale

	Rock Section - Peak Overtopping (L/s/m @ full scale)			
Breakwater	**1 in 200**	**1 in 2**	**1 in 10**	**1 in 50**
Existing	1,979	174	750	1,125
Design 1	870	17	67	332
Design 2	1,230		79	392

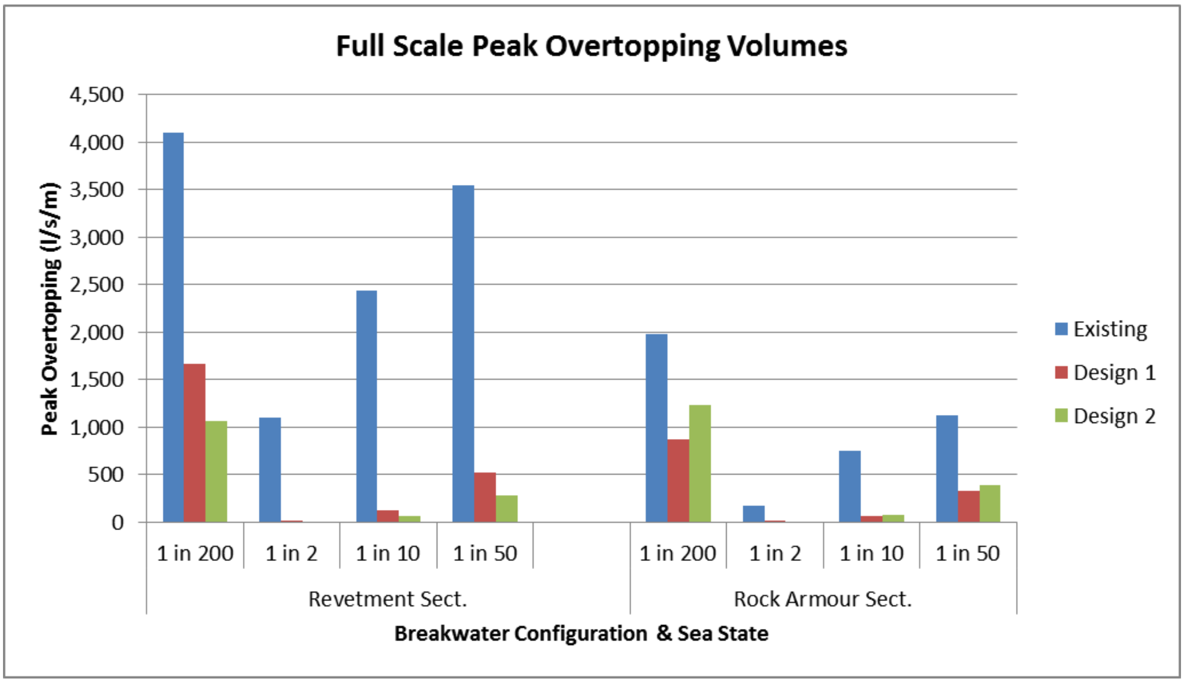


Figure 3.2: Peak Overtopping Volumes at Full Scale

Both Design 1 and 2 successfully reduce the peak volume of overtopping experienced however the relative reduction relative reduction achieved is less significant than for the mean overtopping volumes. The percentage reductions percentage reductions achieved are presented in Table 3.7 and

Table 3.8.

Table 3.7: Percentage Reduction in Peak Overtopping Volumes (Revetment Section)

Breakwater	Revetment Section - Peak Overtopping Reduction %			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	-	-	-	-
Design 1	59.2%	98.7%	95.0%	85.3%
Design 2	74.2%		97.3%	92.2%

Table 3.8: Percentage Reduction in Peak Overtopping Volumes (Rock-Armour Section)

Breakwater	Rock-Armour Section - Peak Overtopping Reduction %			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	-	-	-	-
Design 1	56.0%	90.2%	91.1%	70.5%
Design 2	37.8%		89.5%	65.2%

4 Additional Tests for Revised Breakwater

Upon completion of the initial tests previously described, further tests were carried out on a revised breakwater design. Modifications to the previous design were as follows:

- The size of the X-Bloc armour units set on the front face of the breakwater was increased to $8m^3$

- The size of the rock-armour units set at the toe of the breakwater was increased
- The sea wall crest height behind the Failed Rock Armour section was reduced by 0.7m to 11.5m

One set of tests was conducted with the revised breakwater at a water level of 4.12m above chart datum. Two additional sets of tests were also conducted at a water level of 4.92m above chart datum; the first with the breakwater configured as described above and the second with the height of the crest wall on the Revetment side of the structure being increased by 0.9m full scale.

4.1 Mean Overtopping Volumes – Full Scale

Results for mean overtopping volumes at full scale for the Revetment and Rock-Armour sections of breakwater are presented in Table 4.1 and Table 4.2 respectively. Values are presented graphically in Figure 4.1 for ease of reader inspection. Note that results obtained during physical testing of the 'Existing' breakwater are also included for comparative purposes.

Table 4.1: Revetment Side Mean Overtopping Volumes in L/s/m at Full Scale

	Revetment Section - Mean Overtopping (L/s/m @ full scale)			
Breakwater	**1 in 200**	**1 in 2**	**1 in 10**	**1 in 50**
Existing	783	64	337	598
Water level 4.12mCD	45			11
Water Level 4.92mCD	20	*	2	6
Water Level 4.92mCD with increased crest wall	28			7

Table 4.2: Rock-Armour Side Mean Overtopping Volumes in L/s/m at Full Scale

	Rock Section - Mean Overtopping (L/s/m @ full scale)			
Breakwater	**1 in 200**	**1 in 2**	**1 in 10**	**1 in 50**
Existing	178	5	40	89
Water level 4.12mCD	35			8
Water Level 4.92mCD	13	*	1	2
Water Level 4.92mCD with increased crest wall	34			8

Note that values indicated by * denote that overtopping volumes were too small to measure with significant certainty.

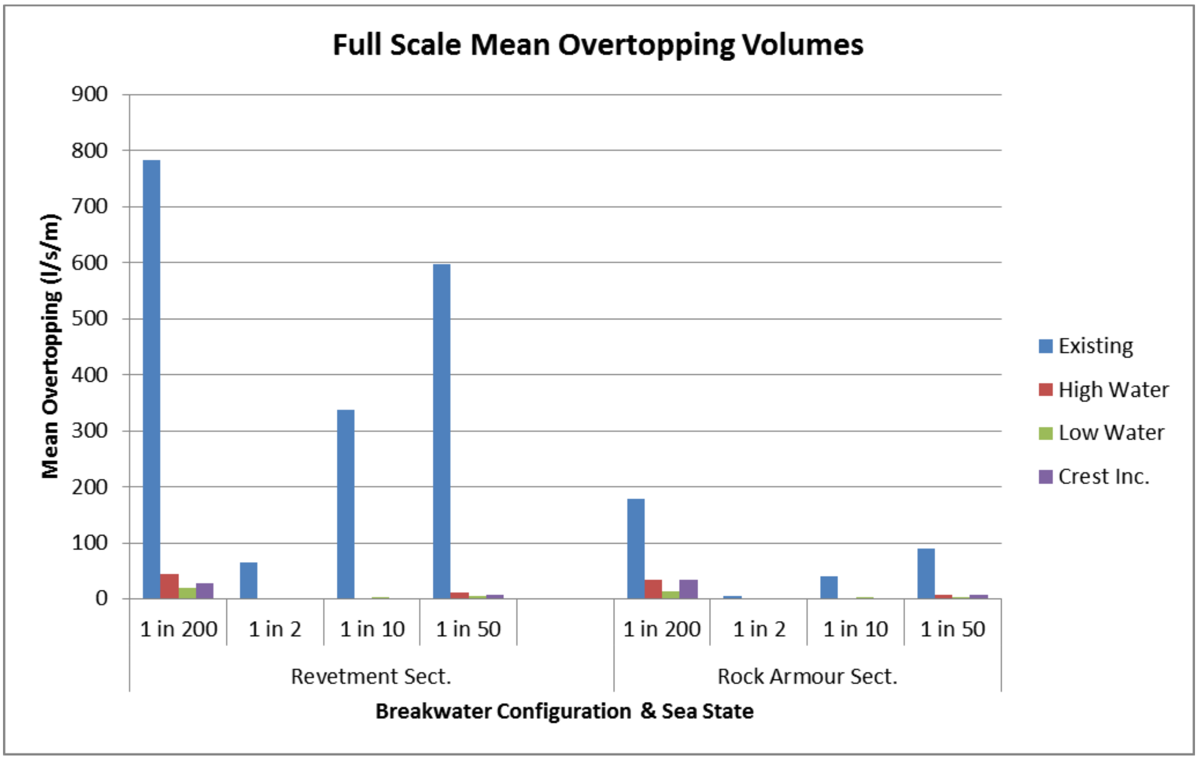


Figure 4.1: Mean Overtopping Volumes at Full Scale

The percentage reductions achieved in the various sea states tested are presented in Table 4.3 and Table 4.4.

Table 4.3: Percentage Reduction in Mean Overtopping Volumes (Revetment Section)

Breakwater	Revetment Section - Mean Overtopping Reduction %			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	-	-	-	-
Water level 4.12mCD	94.3%			98.2%
Water Level 4.92mCD	97.4%	**	99.4%	99.0%
Water Level 4.92mCD with increased crest wall	96.4%			98.8%

Table 4.4: Percentage Reduction in Mean Overtopping Volumes (Rock-Armour Section)

Breakwater	Rock-Armour Section - Mean Overtopping Reduction %			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	-	-	-	-
Water level 4.12mCD	80.3%			91.0%
Water Level	92.7%	**	97.5%	97.8%

4.92mCD				
Water Level 4.92mCD with increased crest wall	80.9%			91.0%

Note ** indicates small mean overtopping volumes and hence, almost complete reduction in mean overtopping volumes.

4.2 Peak Overtopping Volumes – Full Scale

Results for peak overtopping volumes at full scale for the Revetment and Rock-Armour sections of breakwater are presented in Table 4.5 and Table 4.6 respectively. Values are presented graphically in Figure 4.2 for ease of reader inspection.

Table 4.5: Revetment Side Peak Overtopping Volumes in L/s/m at Full Scale

Breakwater	Revetment Section - Peak Overtopping (L/s/m @ full scale)			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	4,097	1,103	2,438	3,546
Water level 4.12mCD	1,497			454
Water Level 4.92mCD	967	*	66	168
Water Level 4.92mCD with increased crest wall	1,176			315

Table 4.6: Rock-Armour Side Peak Overtopping Volumes in L/s/m at Full Scale

Breakwater	Rock Section - Peak Overtopping (L/s/m @ full scale)			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	1,979	174	750	1,125
Water level 4.12mCD	1,361			416
Water Level 4.92mCD	929	*	48	165
Water Level 4.92mCD with increased crest wall	1,333			396

Note that values indicated by * denote that overtopping volumes were too small to measure with significant certainty.

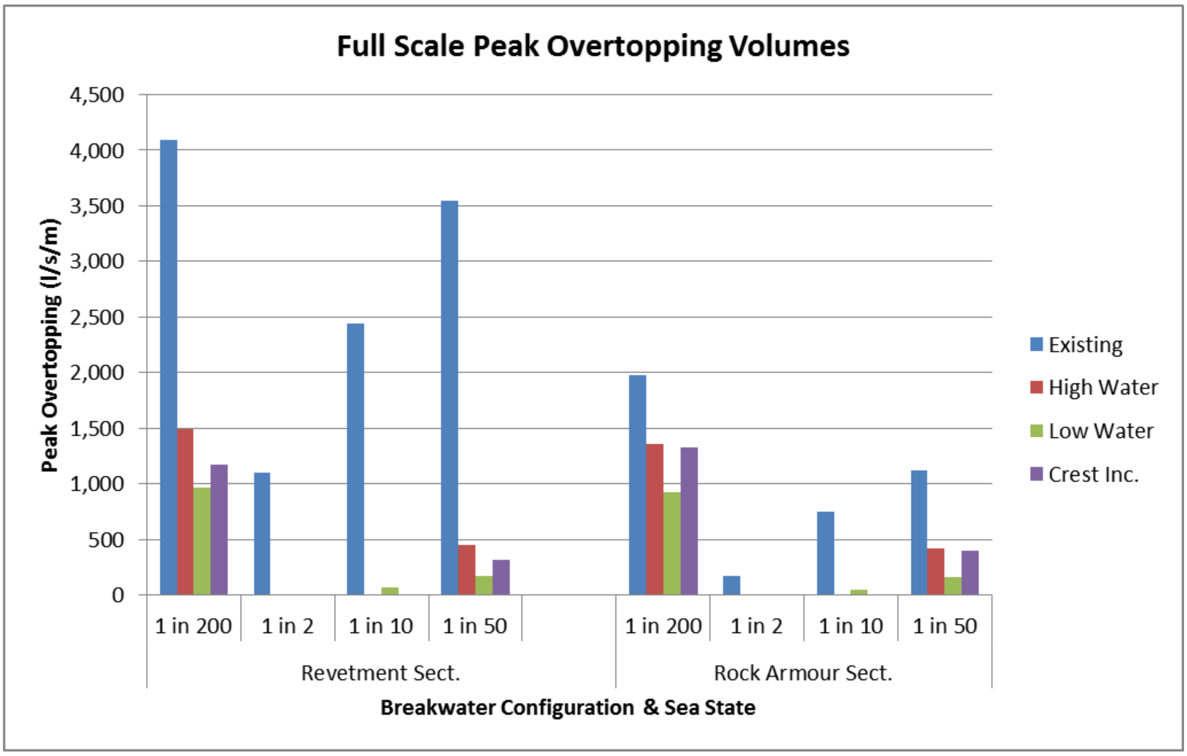


Figure 4.2: Peak Overtopping Volumes at Full Scale

The percentage reductions achieved are presented in Table 4.7 and Table 4.8.

Table 4.7: Percentage Reduction in Peak Overtopping Volumes (Revetment Section)

Breakwater	Revetment Section - Peak Overtopping Reduction %			
	1 in 200	**1 in 2**	**1 in 10**	**1 in 50**
Existing	-	-	-	-
Water level 4.12mCD	63.5%			87.2%
Water Level 4.92mCD	76.4%	**	97.3%	95.3%
Water Level 4.92mCD with increased crest wall	71.3%			91.1%

Table 4.8: Percentage Reduction in Peak Overtopping Volumes (Rock-Armour Section)

Breakwater	Rock-Armour Section - Peak Overtopping Reduction %			
	1 in 200	**1 in 2**	**1 in 10**	**1 in 50**
Existing	-	-	-	-
Water level 4.12mCD	31.2%			63.0%
Water Level 4.92mCD	53.1%	**	93.6%	85.3%
Water Level 4.92mCD with increased crest wall	32.6%			64.8%

Note ** indicates small peak overtopping volumes and hence, almost complete reduction in peak overtopping volumes.

5 Appendix A: Sensitivity Check

During test setup and re-zeroing of the Overtopping Tanks it was noted that variations in water level within the tanks at the zero level taken could be approximately +/- 2mm as a result of the influence of surface tension withholding water at the base of the V-notch. To determine the potential error in results obtained due to imperfect re-zeroing of wave probes set within the Overtopping Tanks a sensitivity study was conducted on a subset of tests completed. To conduct the sensitivity study, an additional 2mm and 4mm of water level was manually added to the free surface elevation data traces for the Overtopping Tanks, thus modelling the system as if it had been re-zeroed 2mm, and 4mm too low respectively. This manual adjustment has the effect of permitting user inspection of the results had the water levels been increased relative to those expected to assess the potential variation in overtopping experienced due to the higher rates of discharge experienced at these higher water levels. Results for the study are shown below. Clearly the influence of even a very significant deviation in the true water level relative to that expected has a small effect on results obtained and as such, there is surety in the significance of the values reported.

	Revetment Section - Mean Overtopping (L/s/m @ full scale)			
Breakwater	**1 in 200**	**1 in 2**	**1 in 10**	**1 in 50**
High Water	45			11
+2mm	49			13
+4mm	53			15

	Rock Section - Mean Overtopping (L/s/m @ full scale)			
Breakwater	**1 in 200**	**1 in 2**	**1 in 10**	**1 in 50**
High Water	35			8
+2mm	37			9
+4mm	39			12

	Revetment Section - Peak Overtopping (L/s/m @ full scale)			
Breakwater	**1 in 200**	**1 in 2**	**1 in 10**	**1 in 50**
High Water	1,497			454
+2mm	1,499			454
+4mm	1,502			454

	Rock Section - Peak Overtopping (L/s/m @ full scale)			
Breakwater	**1 in 200**	**1 in 2**	**1 in 10**	**1 in 50**
High Water	1,361			416
+2mm	1,365			416
+4mm	1,368			416

6 Appendix B – Overtopping Tank Calibration Methodology

6.1 Overtopping Tanks – Water Level: Volume Calibration

In order to determine the instantaneous volume of water retained at a given water level, known quantities of water were incrementally added to each overtopping tank as tested and with the V-notch weirs covered. The incremental fill levels were 11.46L (+0/-0.2L). This data was used to establish an empirical relationship between the instantaneous water surface elevation in each overtopping tank and the volume of fluid contained. Results for the calibration are presented in Figure 6.1. In both cases it has been assumed that a linear relationship fits the data with sufficient accuracy.

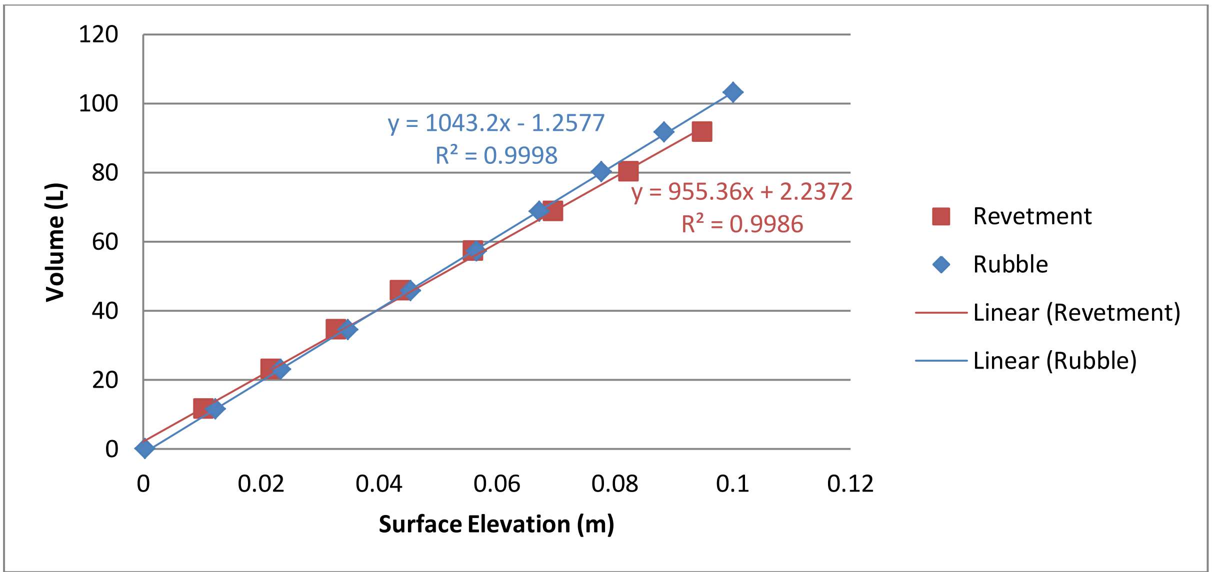


Figure 6.1: Overtopping Tank Water Level : Volume Calibration Functions

6.2 Overtopping Tanks – Water Level: Discharge Calibrations

In order to ensure the overtopping tanks did not over spill the walls, two V-notch weirs were cut into the back face of each tank allowing overtopped water to drain back into the wave basin. These V-notches were used in a variety of configurations for different tests depending on the overtopping volumes. Consequently 6 different calibrations were completed, 1 for each permutation of overtopping tank setup employed. The calibration method is outlined below.

In order to determine the total volume of overtopping it is necessary to know the amount of discharge through the V-notch weirs during testing. In order to estimate this discharge, a series of controlled discharge experiments were completed. Each experiment involved blocking the V-notch weirs, filling the overtopping tank using a pump and then swiftly opening the V-notch weirs. The water level over time was recorded as the fluid discharged through the weirs and the water level in the tanks dropped. As the volume at a given water level was already known the volume discharged could be determined. These details were then plotted and a polynomial curve fitted to the data which could be used to calibrate discharge upon collection of surface elevation data during overtopping tests. An example calibration function generated is presented in Figure 6.2. Here, results generated by the polynomial curve results are shown at discrete intervals in red.

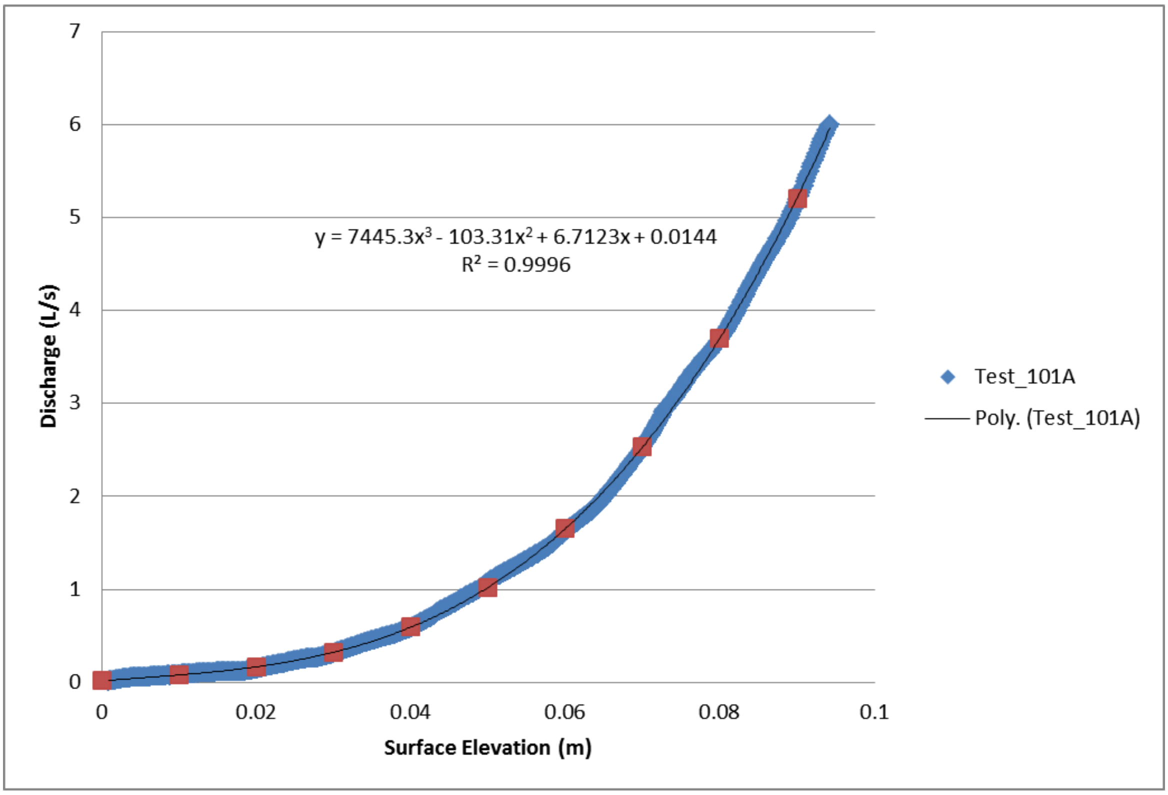


Figure 6.2: Example Water Level : Discharge Calibration Function

7 Appendix C – Data Analysis Procedures

Using the instantaneous Overtopping Tank (OT) free surface elevation data recorded during testing it is possible to estimate the volume of overtopping using the Volumetric and Discharge calibration functions described in Section 6.1 and Section 6.2 respectively. The outline procedure adopted is presented in Figure 7.1. Note that throughout the data analysis process additional post-processing operations such as filtering were applied to the data to mitigate the effects of electrical noise and sloshing of the overtopping tanks. At all times manual quality control was applied to ensure these processes did not adversely impact the results produced. This is exampled in the following sections. Note all units in this section are given at model scale.

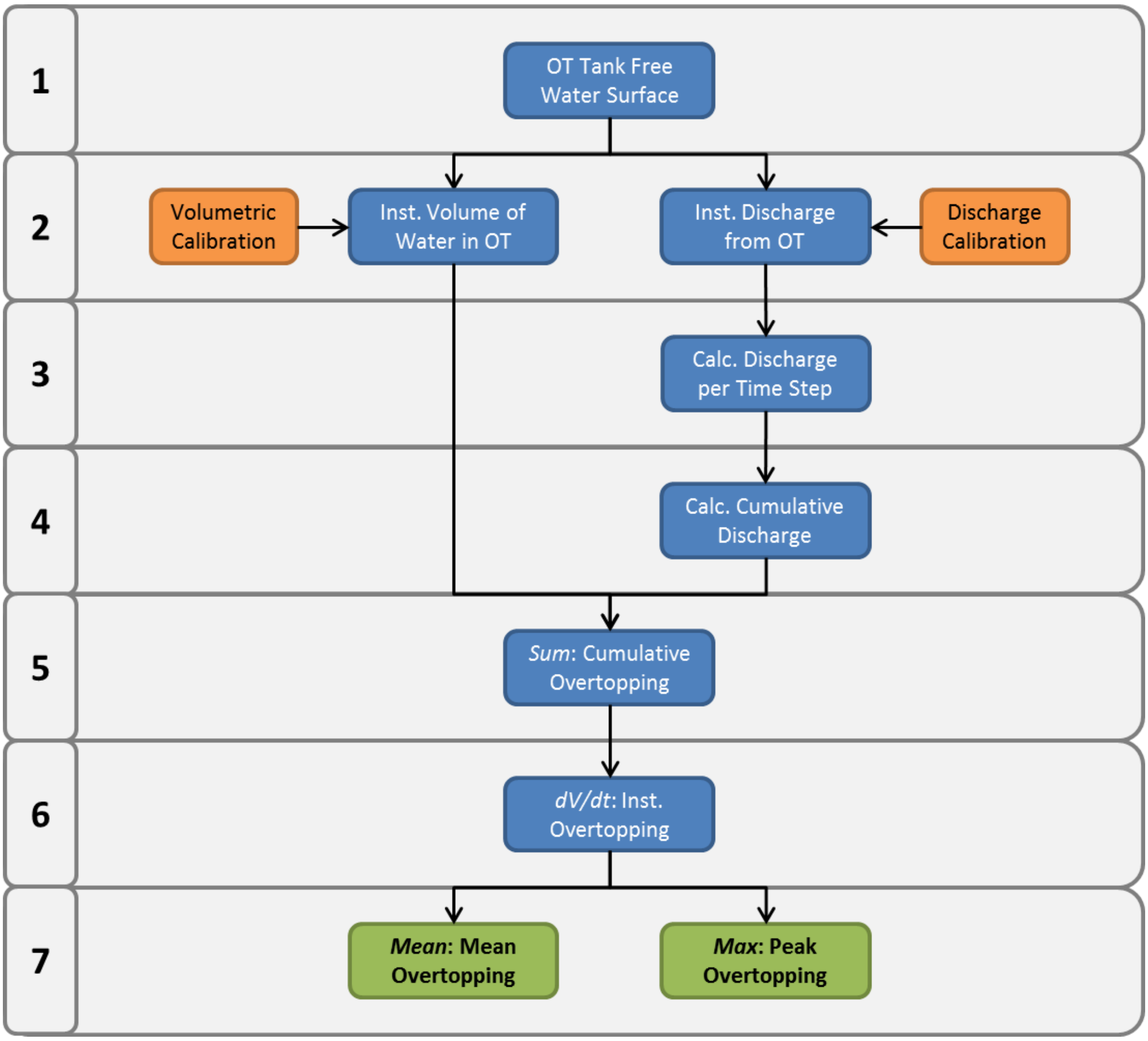


Figure 7.1: Outline Methodology for Estimation of Overtopping Volumes

7.1 Step 1: Data Collection

Free surface elevation data was collected in each Overtopping Tank at 3 discrete locations as indicated in Figure 2.2. Data was sampled at 128Hz for 2,176 seconds. During post-processing it was noted that despite the geotextile mesh set within the overtopping tanks a small sloshing still occurred within the tanks following overtopping events. The frequency of the sloshing oscillation was noted to be approximately 0.5Hz. The amplitude of sloshing at the probes was typically much less than 10-15mm however this would be sufficient to vastly misrepresent peak overtopping results due to the differential operations later required for their estimation. A low pass filter with a cut-off frequency of 0.25Hz was therefore applied to the data in order to mitigate the influence of electrical noise and the observed sloshing on subsequent analyses. Figure 7.2 and Figure 7.3 show the influence of the filtering on overtopping tank wave probes traces. It can be seen that the key characteristics of the dataset are primarily retained whilst the artificial readings resulting from sloshing are heavily attenuated.

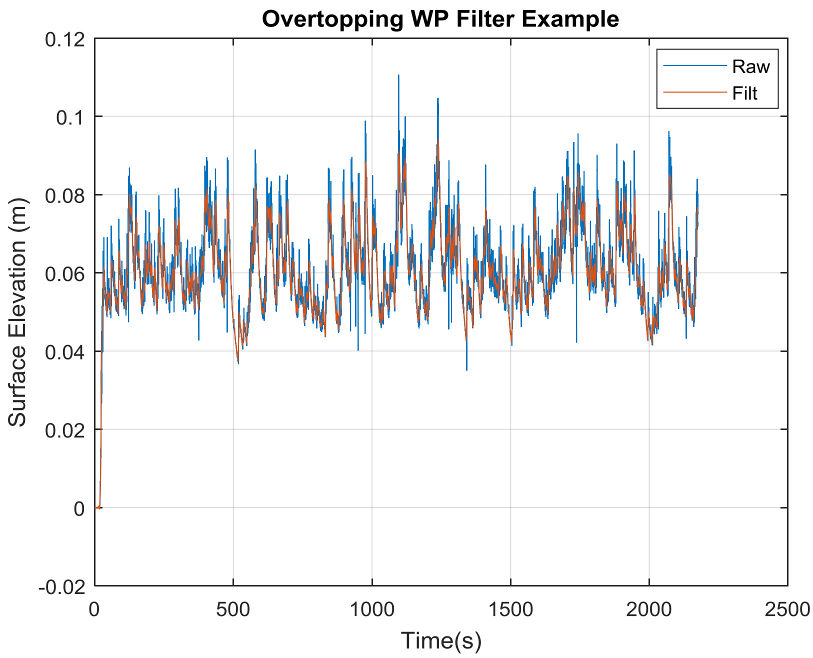


Figure 7.2: Example Filtering of Overtopping Wave Probe Time-Trace (model scale)

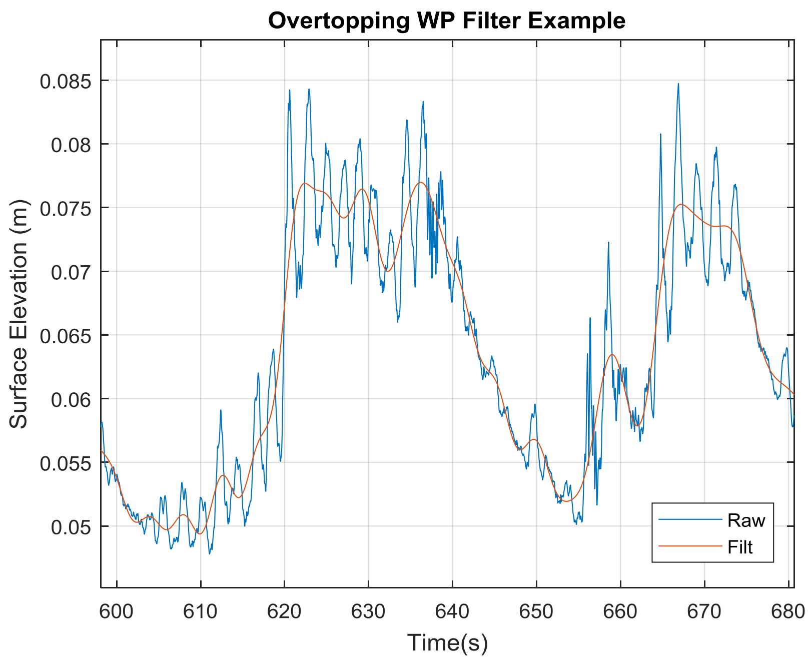


Figure 7.3: Closer Inspection of Filtering Influence on Overtopping Wave Probe Trace (model scale)

Filtered results from each of the three wave probes were averaged to give mean instantaneous surface elevations in each overtopping tank. An example of the averaging is presented in Figure 7.4.

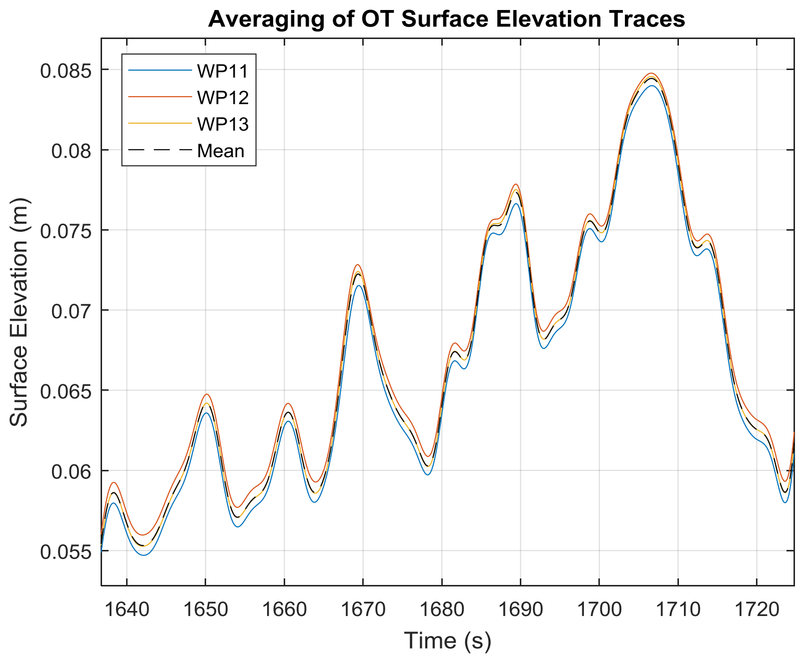


Figure 7.4: Example Averaging of OT Surface Elevation Traces (model scale)

7.2 Step 2: Overtopping Tank Calibration

The instantaneous volume of water retained within, and the instantaneous discharge from, each overtopping tank were calculated using the filtered and averaged instantaneous free surface elevation data (see Section 7.1) and the Volumetric and Discharge Calibration Functions (see Sections 6.1 and 6.2 respectively). In some cases, the lower ends of Discharge Calibration Functions were tapered due to slight imperfections of fit in the generated polynomials. Upon subsequent inspection, despite the improvement very little influence on results was observed due to the scarcity of time when the tanks were at such low water levels. Examples of Overtopping Tank Volume and Discharge with time can be seen in Figure 7.5 and Figure 7.6.

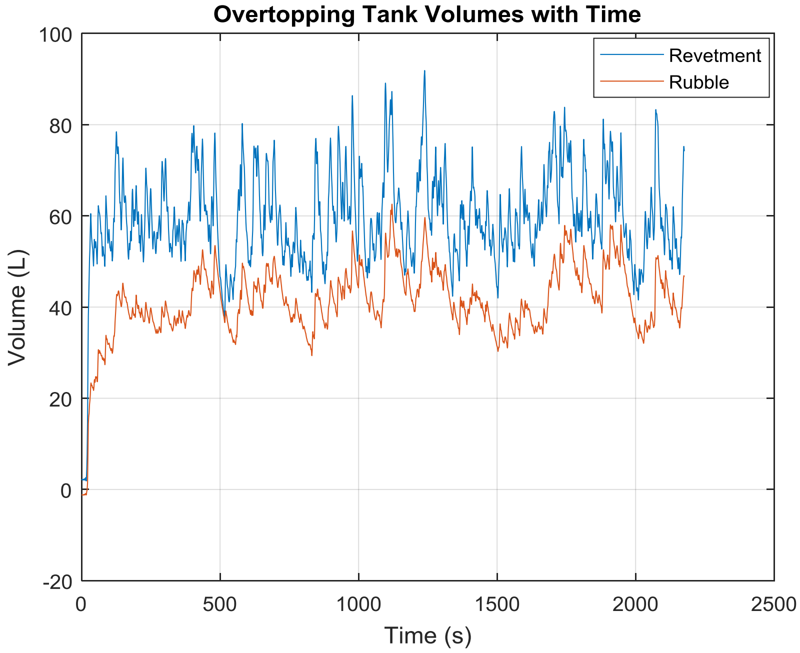


Figure 7.5: Example Instantaneous Volume Retained by Overtopping Tanks (model scale)

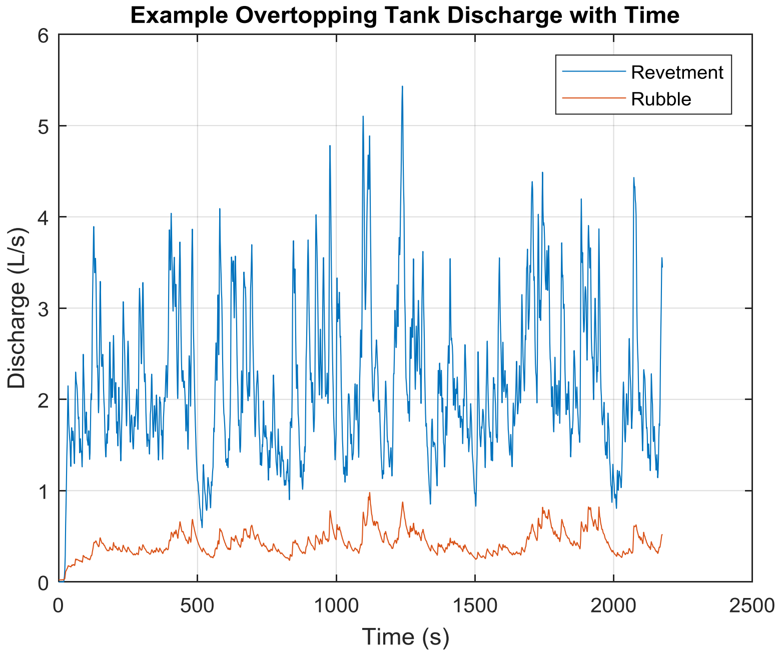


Figure 7.6: Example Overtopping Tank Discharge Figures (model scale)

7.3 Step 3 & 4: Calculation of Discharge per Time-Step & Cumulative Discharge

The total volume of fluid which has overtopped the crest of the breakwater at a given time is determined through summation of the instantaneous volume of water retained at that point and the cumulative volume of fluid which has been discharged to that point in time. The instantaneous volume of fluid is already known (see section 7.2). Cumulative discharge was d, the instantaneous discharge in volume/second was first used to calculate the volume/time-step (Figure 7.7) after which a cumulative sum could be obtained (Figure 7.8).

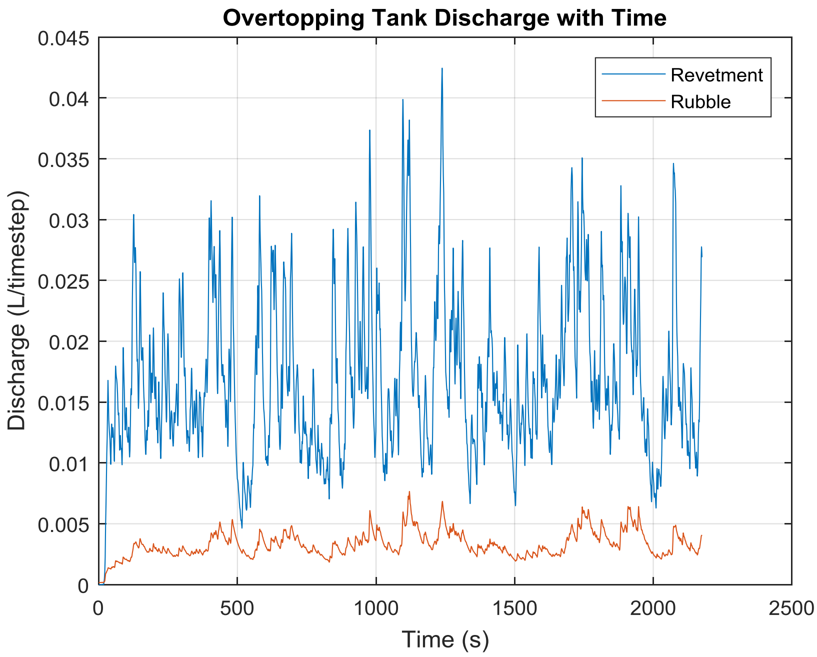


Figure 7.7: Instantaneous Overtopping Tank Discharge Per Time-Step (model scale)

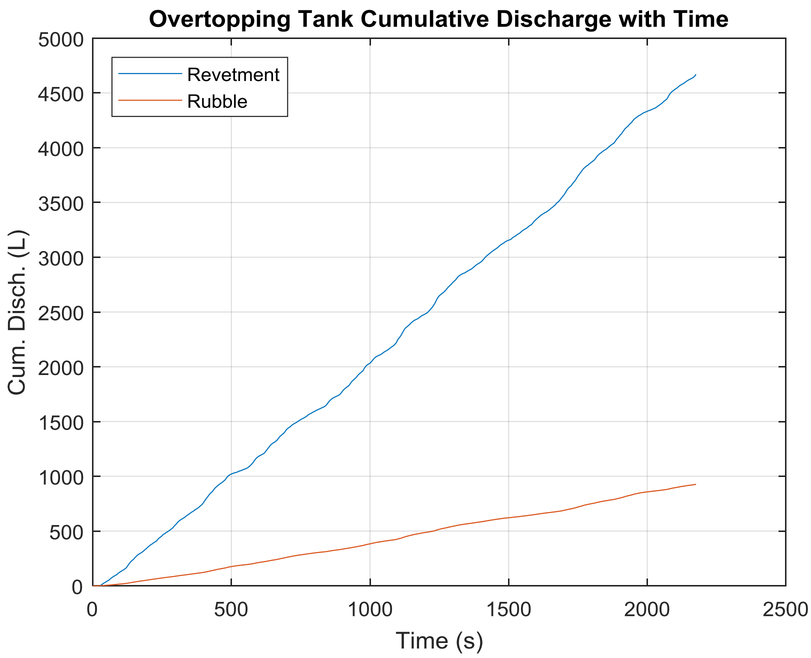


Figure 7.8: Cumulative Overtopping Tank Discharge with Time (model scale)

7.4 Step 5: Calculation of Cumulative Overtopping

The cumulative overtopping is found from the sum of the instantaneous volume and the cumulative discharge. In essence, this calculation provides the volume of overtopped fluid assuming no discharge had taken place. After summation, a smoothing function is applied to the data to ensure minimal influence of any remaining noise on the trace which would significantly impact local gradients for Step 6. The influence of the smoothing is very small however to ensure minimal impact on results. An example cumulative overtopping trace and the effect of smoothing is shown in Figure 7.9 and Figure 7.10 respectively.

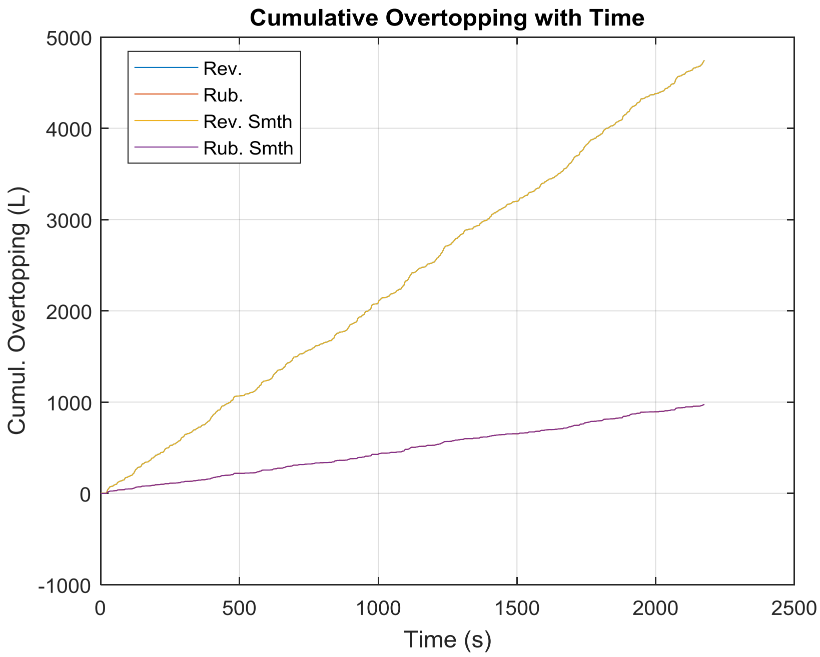


Figure 7.9: Cumulative Overtopping Volume with Time (model scale)

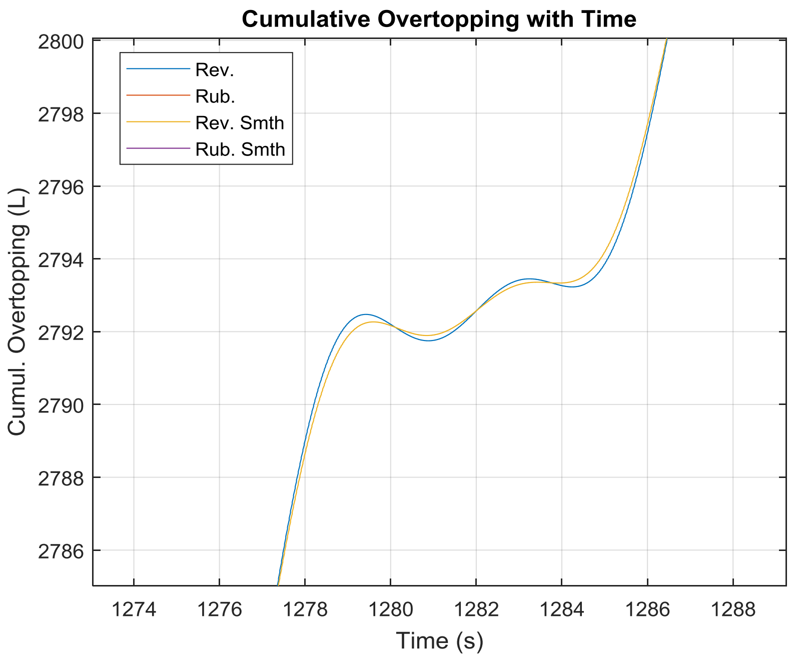


Figure 7.10: Example of the Influence of Smoothing on Overtopping Volumes (model scale)

7.5 Step 6: Calculation of Instantaneous Overtopping

Instantaneous overtopping is simply calculated as the time derivative of the cumulative overtopping volume. Some small remaining negative values exist due to imperfect removal of sloshing artefacts however further filtering and smoothing was not applied. Instead these artefacts were set to zero during post-processing. An example of instantaneous overtopping volumes is presented in Figure 7.11. A zoomed-in view of a shorter window is presented in Figure 7.12.

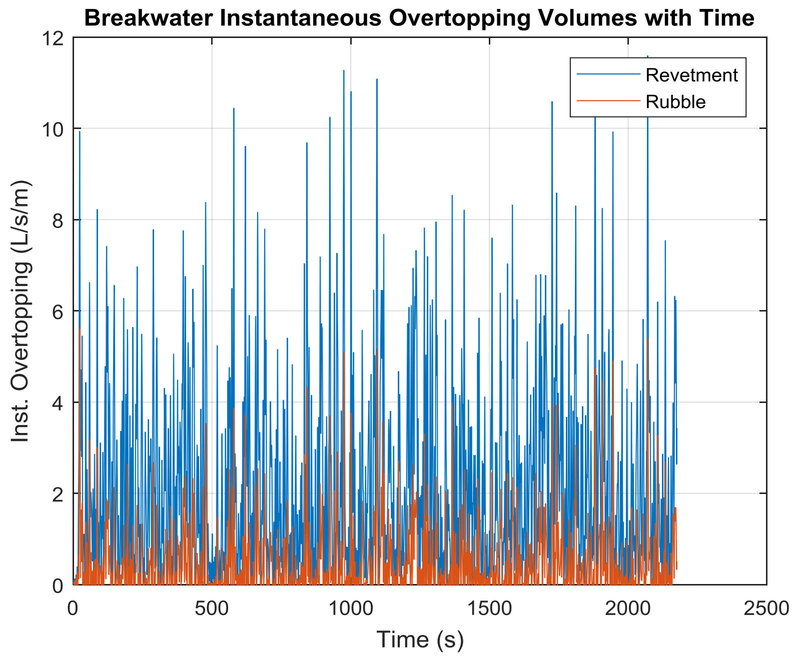


Figure 7.11: Example Instantaneous Overtopping Volumes (model scale)

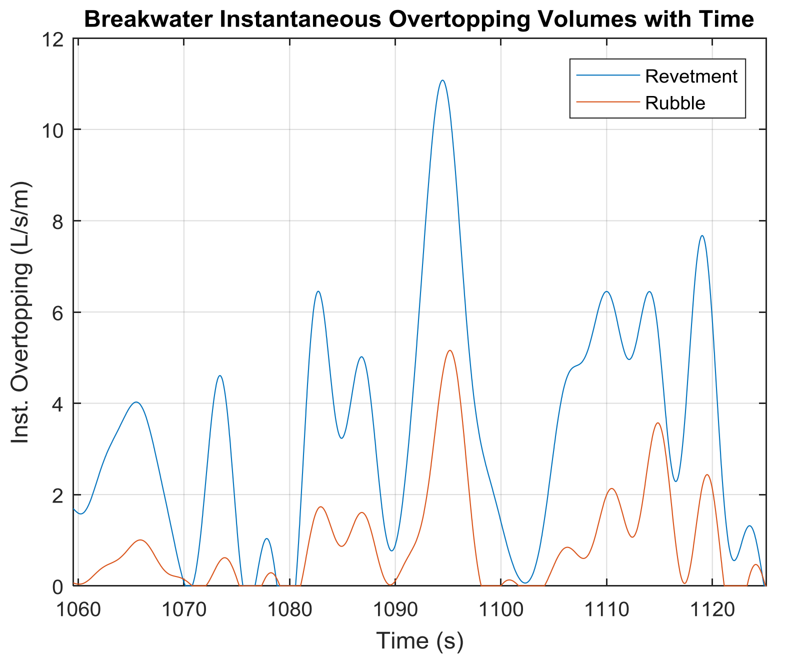


Figure 7.12: Close-up of Example Instantaneous Overtopping Volumes (model scale)

7.6 Step 7: Estimation of Mean & Peak Overtopping Volumes

To estimate mean overtopping, instantaneous overtopping values were averaged over the duration of the test. Peak overtopping values were taken as the maximum instantaneous value recorded.

8 Appendix D – Model Scale Results

8.1 Mean Overtopping Volumes – Model Scale

Model scale results for the mean overtopping volume experienced by each breakwater configuration, on both the Revetment and Rock-Armour side, in the various sea states are presented in Table 8.1 and Table 8.2.

Table 8.1: Revetment Side Mean Overtopping Volumes in L/s/m at Model Scale

Breakwater	Revetment Section - Mean Overtopping (L/s/m @ model scale)			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	2.215	0.181	0.953	1.691
Design 1	0.141	0.008	0.014	0.040
Design 2	0.082		0.014	0.028

Table 8.2: Rock-Armour Side Mean Overtopping Volumes in L/s/m at Model Scale

Breakwater	Rock-Armour Section - Mean Overtopping (L/s/m @ model scale)			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	0.503	0.014	0.113	0.252
Design 1	0.093	0.011	0.014	0.025
Design 2	0.099	0.000	0.011	0.034

The percentage reductions achieved by the Mk1 and Mk2 redesigns in the various sea states are presented in Table 8.3 and Table 8.4.

Table 8.3: Percentage Reduction in Mean Overtopping Volumes (Revetment Section)

Breakwater	Revetment Section - Mean Overtopping Reduction %			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	-	-	-	-
Design 1	93.6%	95.3%	98.5%	97.7%
Design 2	96.3%		98.5%	98.3%

Table 8.4: Percentage Reduction in Mean Overtopping Volumes (Rock-Armour Section)

Breakwater	Rock-Armour Section - Mean Overtopping Reduction %			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	-	-	-	-
Design 1	81.5%	20.0%	87.5%	89.9%
Design 2	80.3%		90.0%	86.5%

8.2 Peak Overtopping Volumes – Model Scale

Model scale results for the peak overtopping volume experienced by each breakwater configuration, on both the Revetment and Rubble-Mound side, in the various sea states are presented in Table 8.5 and Table 8.6.

Table 8.5: Revetment Side Peak Overtopping Volumes in L/s/m at Model Scale

Breakwater	Revetment Section - Peak Overtopping (L/s/m @ model scale)			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	11.588	3.120	6.896	10.030
Design 1	4.723	0.040	0.345	1.471
Design 2	2.992		0.190	0.786

Table 8.6: Rock-Armour Side Peak Overtopping Volumes in L/s/m at Model Scale

Breakwater	Rock-Armour Section - Peak Overtopping (L/s/m @ model scale)			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	5.597	0.492	2.121	3.182
Design 1	2.461	0.048	0.190	0.939
Design 2	3.479	0.000	0.223	1.109

The percentage reductions achieved by the Mk1 and Mk2 redesigns in the various sea states are presented in Table 8.7 and Table 8.8.

Table 8.7: Percentage Reduction in Peak Overtopping Volumes (Revetment Section)

Breakwater	Revetment Section - Peak Overtopping Reduction %			
	Sea State 3	Sea State 5	Sea State 6	Sea State 7
Existing	-	-	-	-
Design 1	59.2%	98.7%	95.0%	85.3%
Design 2	74.2%		97.3%	92.2%

Table 8.8: Percentage Reduction in Peak Overtopping Volumes (Rock-Armour Section)

Breakwater	Rock-Armour Section - Peak Overtopping Reduction %			
	1 in 200	1 in 2	1 in 10	1 in 50
Existing	-	-	-	-
Design 1	56.0%	90.2%	91.1%	70.5%
Design 2	37.8%		89.5%	65.2%

9 Appendix E – Post Test Breakwater Profiling

After testing was complete the Rock-Armour side breakwater was profiled using a drop-pin profiler. Elevations of the breakwater were taken along its depth at 3 discrete locations – one towards the left of the section (towards the middle of the overall breakwater), one towards the middle of the section and one towards the right hand side of the section. The recorded elevations are presented in figure in terms of their distance below the elevation of the crest wall height for that section. Tabular data is also presented below.

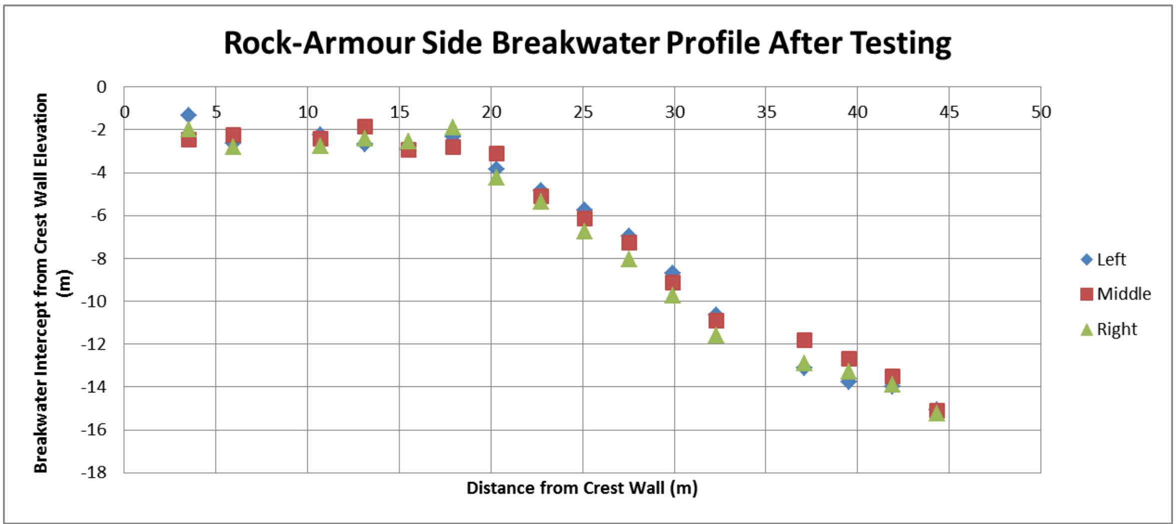


Figure 9.1: Elevation Data for Rock-Armour Section of Breakwater after Testing

Reading	x	Left	Middle	Right
0	0	0	0	0
1	3.525	-1.35	-2.45	-2
2	5.925	-2.65	-2.25	-2.8
3	10.725	-2.25	-2.4	-2.75
4	13.125	-2.7	-1.85	-2.4
5	15.525	-2.95	-2.95	-2.55
6	17.925	-2.35	-2.8	-1.9
7	20.325	-3.85	-3.1	-4.25
8	22.725	-4.85	-5.1	-5.35
9	25.125	-5.75	-6.15	-6.75
10	27.525	-6.95	-7.25	-8.05
11	29.925	-8.7	-9.15	-9.75
12	32.325	-10.65	-10.9	-11.6
13	37.125	-13.1	-11.8	-12.9
14	39.525	-13.75	-12.7	-13.3
15	41.925	-14	-13.5	-13.9
16	44.325	-15.05	-15.1	-15.25