Portgordon Flood Study

Moray Council

Options Appraisal Addendum Study

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Portgordon Flood Study

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Jacobs U.K. Limited

160 Dundee Street
Edinburgh
EH11 1DQ
United Kingdom
T +44 (0)131 659 1500
F +44 (0)131 228 6177
www.jacobs.com

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1	27/02/2019	First Issue of Addendum Study	J Scott	A Kirk	J Scott
2	09/05/2019	Second Issue of Addendum Study – Update to formatting	J Scott	A Gibb	J Scott
3	23/05/2019	Third Issue following client comments	J Scott	A Gibb	J Scott

Contents

Executive Summary

Stewart Street in Portgordon suffers from waves overtopping the existing sea defence structure. The resultant flooding to the adjacent properties is exacerbated by the water becoming trapped behind a small setback wall along the seaward edge of the pavement. Jacobs undertook an Options Appraisal and Business Case Study in 2018 to identify and develop potential solutions to address the coastal flooding problem. That study did not establish an economically viable option when considering a 200-year return period along with 100 years of sea level rise due to climate change.

As a result, Jacobs were commissioned by Moray Council to carry out an Addendum Study (reported here), which augments the previous Options Appraisal and Business Case Study by investigating smaller scale solutions in an effort to obtain an economically viable solution. This Addendum Study considers return periods of 10, 50 and 100 years and develops solutions to protect against flooding for each of these events, all of which are smaller in scale than those for the 200-year return period. This Addendum Study considers only a concrete stepped revetment arrangement, as per Moray Council's preference, for the 50 and 100-year return periods, and a small concrete wave return wall added to the existing defences for the 10-year return period. The solutions established in this Addendum Study achieve a lower BCR than those from the previous Options Appraisal and Business Case study and, as such, does not establish a viable solution to be developed further.

This study also considers a drainage only solution, featuring baffles in the existing setback wall at 50m centres. This establishes an economically viable solution, producing a BCR of 4.4, which helps alleviate the current problem of water building up behind the setback wall during an overtopping event. This solution produces a positive BCR as it is a relatively cheap option to implement and reduces flood water levels during overtopping events. However, the solution does not prevent flooding for any of the return periods assessed. Flood maps for each return period are presented in this study. This study recommends that any solution taken forward considers improved drainage through the setback wall.

1. Introduction

1.1 Project Background

The village of Portgordon, on the Moray Coast, is periodically subjected to extreme waves combined with high water levels, resulting in overtopping of the existing coastal defences. The overtopping causes temporary flooding of adjacent roads and properties, principally along Stewart Street.

Jacobs undertook an Options Appraisal and Business Case Report[1] in 2018, hereafter the Options Appraisal Report, which identified potential solutions to address the coastal flooding problem for a design scenario of a 200-year return period wave climate with 100 years of climate change considered. However, the proposed solutions failed to establish an economically viable solution, with the scale of the solutions also being noted as a concern amongst the residents of Portgordon during a Public Consultation. This is documented in the Options Appraisal Report.

Following on from the Options Appraisal Report, Jacobs were commissioned to undertake an additional sensitivity exercise in the form of this Addendum Study. This study investigates solutions that may be implemented to protect against lower return period events, in an effort to identify an economically viable solution that can be developed to protect the properties and residents at Portgordon.

The Options Appraisal Report established the preferred solution as Option 2, a rock armour berm, which achieved the best BCR value of all options considered. However, it was the preference of Moray Council to explore concrete only solutions, moving away from rock armour solutions. This was to likely allow for low maintenance requirements in future and to prevent exacerbating an existing issue for residents where there is a build-up of seaweed that causes an unpleasant odour along the seafront. As such, this Addendum Study explores variations on a concrete stepped revetment arrangement only. The stepped revetment solution is similar in concept to Option 4 from the Options Appraisal Report but with concrete steps to beach level, instead of utilising rock armour seaward of the existing wave return wall.

The return periods considered as part of this study are 10, 50 and 100 years with 100 years of climate change. These were selected as the baseline flood maps had already been established at the Options Appraisal stage, and this would align with the input models established by ABPmer. It was proposed by Jacobs that 50 years of climate change should also be explored. However, the quote received from ABPmer for this additional work was considered too costly by Moray Council at this stage. The higher cost was because it would have involved creating a new input for the extremes analysis, whereas the 100 years of climate change had already been established for the Options Appraisal Report.

An additional drainage only solution, featuring baffles in the existing setback wall at 50m centres, is also investigated as part of this study. This solution is something that can be implemented in the short term to alleviate the extent of flooding during an overtopping event. Additional openings in the setback wall to allow better drainage of overtopped water back to sea was considered important to many residents during the Public Consultation, as documented in the Options Appraisal Report.

The scope of this Addendum Study established 'Hold points', where the outcomes of each stage of the project could be reviewed before progressing. The stages where these reviews were to occur were as follows:

- Completion of ABPmer overtopping assessment;
- Completion of Baseline Damage Assessment & Cost Estimate;
- Completion of Drainage Analysis; and
- Completion of all analysis (including BCR), prior to Report write up.

[1] Portgordon Flood Study Options Appraisal and Business Case Report, January 2018, V1, Jacobs UK Ltd.

Use of hold points is a useful feature of projects with an undefined outcome as it can avoid unnecessary expenditure on processes that were not going to provide any benefit to the identified solution.

Each solution was again appraised over a 100-year period, in line with the typical design life of such structures. Each process of this investigation takes the form as that detailed extensively in the Options Appraisal Report, which should be used as a reference for this Addendum Study. This includes description of the economic assessment, drainage analysis, modelling analysis and cost estimates.

2. Additional Sensitivity Study

2.1 Introduction

The preferred option identified from the Options Appraisal Report[1] was Option 2, a rock armour berm solution. However, it is Moray Council's preference to limit the scope of this addendum study to concrete only solutions due to maintenance concerns and the potential build-up of seaweed that can be associated with a rock armour solution. The preferred arrangement for this additional study is based on the original stepped revetment Option 4 but with the seaward rock armour replaced with a stepped concrete revetment down onto the beach. The BCR established for Option 4 during the Options Appraisal Report was 0.88, including 60% optimism bias.

Table 2-1: BCR of the 200-year return period Option 4 from the Options Appraisal Report[1]

Return Period	Baseline Damages (£k)	Estimated Cost (£k)	Estimated Cost with 60% Optimism Bias (£k)	Damages (£)	BCR
200	17,393	12,280	19,648	0	0.88

2.1.1 Development of Stepped Revetment Solutions

ABPmer were procured to carry out the overtopping assessments of the proposed solutions for the lower return periods of 10, 50 and 100 years. ABPmer provided a price to investigate altering the climate change within the model from 100 years to 50 years. However, as they would not be able to utilise the model already established this would have been a far more costly exercise and so the decision was taken by Moray Council to exclude this from the scope.

An initial iterative high-level sensitivity assessment was carried out for each return period in order to establish an effective arrangement for the structure. The refined arrangements were then run through an extremes analysis, which included the appropriate return period and 100 years of climate change data.

In the Options Appraisal Report[1]. Option 4 had an overtopping rate of 7.57 l/s/m at the setback wall, which was the poorest performing of the five options that incurred no damages. The outcome of the drainage analysis during the Options Appraisal Report demonstrated that no flooding would occur for this overtopping flow rate with baffles installed at 50m centres. As such, the aim of the arrangements put forward within this addendum study is to achieve a similar overtopping rate with the new stepped revetment solutions to give confidence that drainage analysis would most likely show that the solution could eliminate damage to the properties.

The overtopping analysis was carried out in line with the method described in the Options Appraisal Report[1]. The latest report from ABPmer is included in Appendix B.

2.1.2 Baseline Damages and Cost Estimates

The baseline damages were assessed for the 10, 50 and 100-year return periods in the same manner as those calculated for the 200-year return period damages, described in Options Appraisal Report[1]. Damages are assessed over the 100-year design life of the structures. The established damages for which all CAPEX and OPEX costs of each option are assessed are as follows:

- 100-year £10,110,000
- 50-year £8,038,000
- 10-year £5,387,000

CAPEX and OPEX costs are calculated as described in detail in the Options Appraisal Report[1].

2.2 100-year Return Period Solution

ABPmer's analysis, see Appendix B, established the 100-year return period solution as having a slope of 1:3, a wave return wall crest level of +6.0 mODN and a 3m long landing at +3.8 mODN seaward of the wave return wall. An indicative cross section of the proposed layout is shown in Figure 2-1.

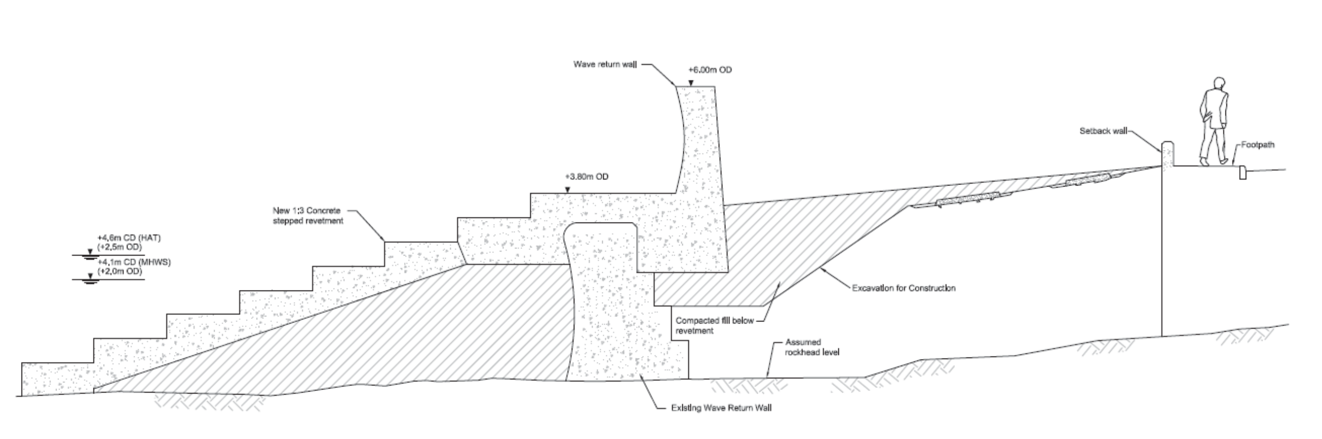


Figure 2-1: Indicative cross section of 100-year return period solution

The arrangement performed well in the extreme overtopping analysis, carried out by ABPmer. As shown in Table 2-2, the overtopping rates at the setback wall are limited to a maximum of 10.9 l/s/m at Defence Section 3, and only 8.5 l/s/m at Defence Section 1. Although the overtopping rate is marginally higher than the targeted 7.57 l/s/m it can be reasonably assumed that the drainage could be arranged such that damages were kept to £0.

Table 2-2: Overtopping rates at setback wall for the 100-year return period solution

	Defence Section 1	Defence Section 2	Defence Section 3
Mean Overtopping Rate (l/s/m)	8.5	9.8	10.9

The combined CAPEX and OPEX costs established an estimated cost of £10.5 million, prior to including the 60% optimism bias. This figure is above the value of baseline damages. Therefore, an economically viable solution remains unlikely for this solution as things stand. The outcome of the economic analysis, carried out as described in the Options Appraisal Report[1], is presented in Table 2-3.

Table 2-3: BCR of the 100-year return period solution

Return Period	Baseline Damages (£k)	Estimated Cost (£k)	Estimated Cost with 60% Optimism Bias (£k)	Damages (£)	BCR
100	10,110	10,500	16,800	0	0.60

With a BCR of only 0.6, this solution achieves a lesser BCR than Options 1, 2 and 4 from the Options Appraisal Report and is equal to the values established for Options 3 and 5. Table 2-4 shows the sensitivity of the BCR with reduced optimism bias.

Table 2-4: BCR Sensitivity for the 100-year return period solution

Optimism Bias	Cost with Optimism Bias (£k)	BCR
0%	10,500	0.96

Optimism Bias	Cost with Optimism Bias (£k)	BCR
40%	14,700	0.69
60%	16,800	0.60

2.3 50-year Return Period Solution

ABPmer’s analysis established the 50-year return period solution as being similar in scale to the 100-year solution. The solution has a slope of 1:3, a wave return wall crest level of +6.0 mODN and a 2.5m long landing at +3.8 mODN to the seaward side of the wave return wall. An indicative cross section of the proposed layout is shown in Figure 2-2.

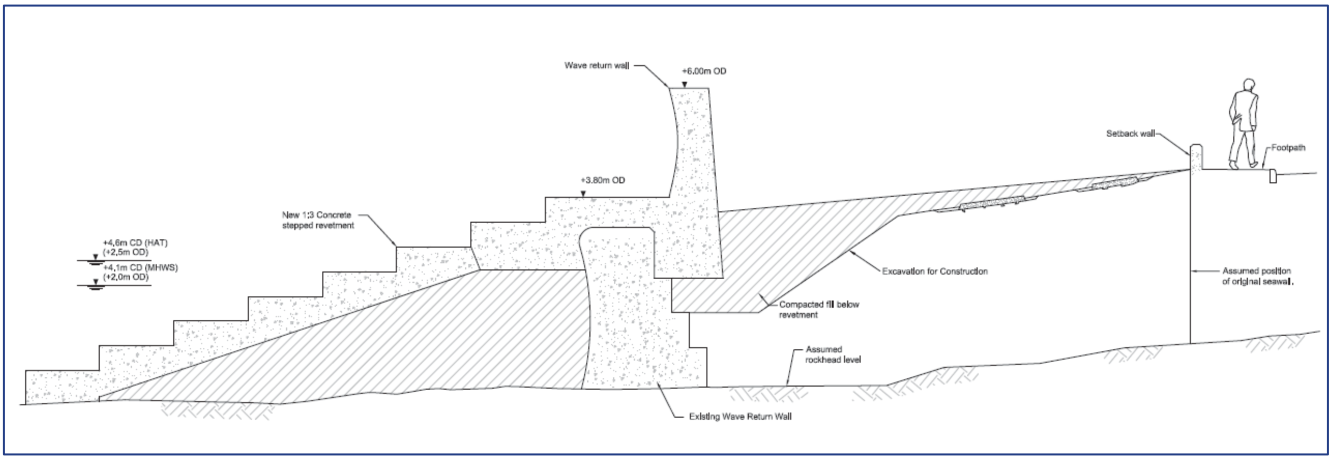


Figure 2-2: Indicative cross Section of 50-year return period solution

The required arrangement was not significantly different from the 100-year solution, with only a shorter landing being the difference between the two. However, the solution performed a little better than the 100-year solution in the extreme overtopping analysis, carried out by ABPmer. As shown in Table 2-5, the overtopping rates at the setback wall are limited to a maximum of 7.9 l/s/m at Defence Section 3, and only 6.1 l/s/m at Defence Section 1. This would suggest that the baffles at 50m centres would likely eliminate damages incurred as they are very similar to the values from Option 4 in the Options Appraisal Report.

Table 2-5: Overtopping rates at setback wall for the 50-year return period solution

	Defence Section 1	Defence Section 2	Defence Section 3
Mean Overtopping Rate (l/s/m)	6.1	6.9	7.9

The combined CAPEX and OPEX costs established an estimated cost of £9.9 million, prior to including the 60% optimism bias. This figure is again above the value of baseline damages. Therefore, an economically viable solution is not possible for this solution as things stand. The outcome of the economic analysis is presented below, in Table 2-6. This was carried out as described in the Options Appraisal Report[1].

Table 2-6: BCR of the 50-year return period solution

Return Period	Baseline Damages (£k)	Estimated Cost (£k)	Estimated Cost with 60% Optimism Bias (£k)	Damages (£)	BCR
50	8,038	9,900	15,840	0	0.51

With a BCR of only 0.51, this solution achieves a lesser BCR than all options from the Options Appraisal Report. Below shows the sensitivity of the BCR with reduced optimism bias, assuming that no damages are incurred.

Table 2-7: BCR Sensitivity for the 50-year return period solution

Optimism Bias	Cost with Optimism Bias (£k)	BCR
0%	9,900	0.81
40%	13,860	0.58
60%	15,840	0.51

2.4 10-year Return Period Solution

A different approach was taken for the development of the 10-year return period solution, due to the fact the 100 and 50-year options had not produced an economically viable solution. For this return period it was decided, following a discussion between Jacobs, ABPmer and Moray Council, that the solution would be arranged so that the estimated CAPEX and OPEX costs would be around the same as the baseline damages. This structure would then be subjected to the extremes analysis by ABPmer for a 10-year return period with climate change. The overtopping rates were then established to examine whether an economically viable solution could be achieved.

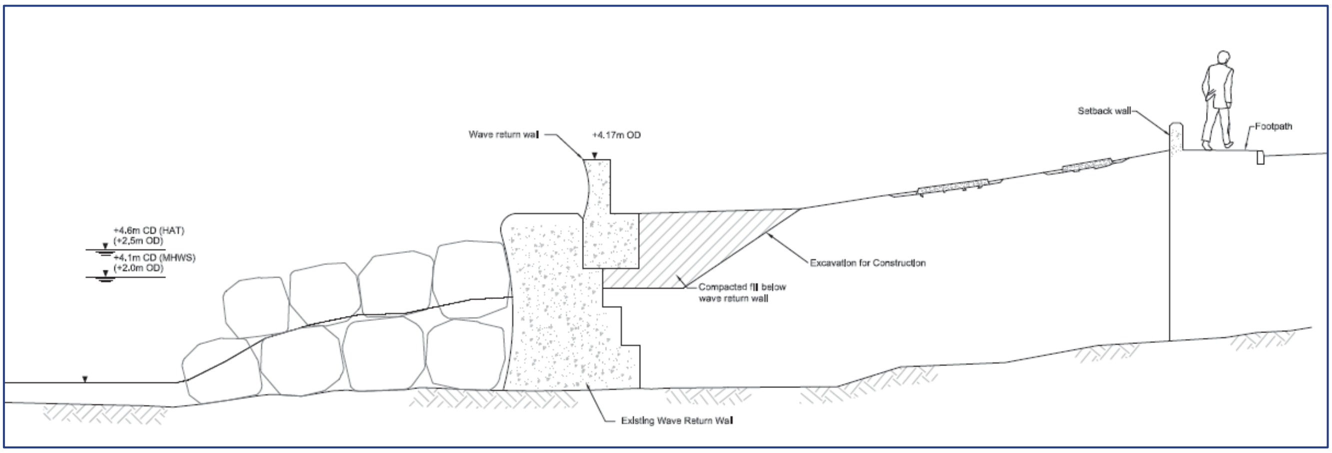


Figure 2-3: Indicative cross section of 10-year return period solution

The outcome of this exercise produced a modest wave return wall, shown in Figure 2-3, which has a crest level of +4.17 mODN and utilises the existing rock armour and wave return wall to keep installation costs to a minimum. However, the arrangement performed much poorer that the 50 and 100-year solutions in terms of overtopping at the setback wall. As shown in Table 2-8, the overtopping rates at the setback wall are 20.6 l/s/m at Defence Section 1 and 24.2 l/s/m at Defence Section 3. These rates are similar to those established for Option 3 in the Options Appraisal Report. Although Option 3 reduced the damages incurred, it did not prevent damages entirely which this solution would require in order to achieve a viable business case.

Table 2-8: Overtopping rates at setback wall for the 50-year return period solution

	Defence Section 1	Defence Section 2	Defence Section 3
Mean Overtopping Rate (l/s/m)	20.6	23.6	24.2

The cost estimate for this option established a cost of £3.4million, £5.4 million with a 60% optimism bias. Due to the likelihood that this solution would not prevent property damage then the arrangement of the solution was not developed further, nor was a drainage analysis carried out. This is in line with the 'Hold Points' agreed in the scope at the outset of this study.

2.5 Summary

For the lower return period solutions, all achieved a lesser BCR than Option 4 form the Options Appraisal Report[1]. This is likely due to a combination of altering the solution to be made entirely of concrete with an associated increase in CAPEX costs and the reduction in damages for the lower return period.

3. Drainage Only Solution

Following on from the unsuccessful sensitivity study, it was decided, in consultation with Moray Council, that a drainage only solution should be investigated in an effort to improve the current situation at a lesser cost than the defence solutions previously considered. The drainage only solution focussed on the installation of baffles at 50m centres along the setback wall to allow water to drain back to the sea.

An issue with the existing defences at Portgordon is that the setback wall retains overtopped flood water during a significant overtopping event and there is not sufficient drainage capability to allow flood water to drain through the wall, back to the sea. Installing additional baffles to the setback wall allows for a reduction in flood levels during an overtopping event and should allow water to drain back to the sea faster following the event.

The combined CAPEX and OPEX cost of this solution is £47,500, which rises to £76,000 with the addition of the 60% optimism bias. The solution will not prevent flooding for any of the calculated return periods with climate change. However, it will likely reduce the extent and total damages incurred during flood events for a relatively low cost. Due to this, drainage modelling was carried out in order to establish the flooding extent of the drainage only solution to inform the calculation of damages to compare against the baseline. The layout of the input for the model is shown in Figure 3-1.

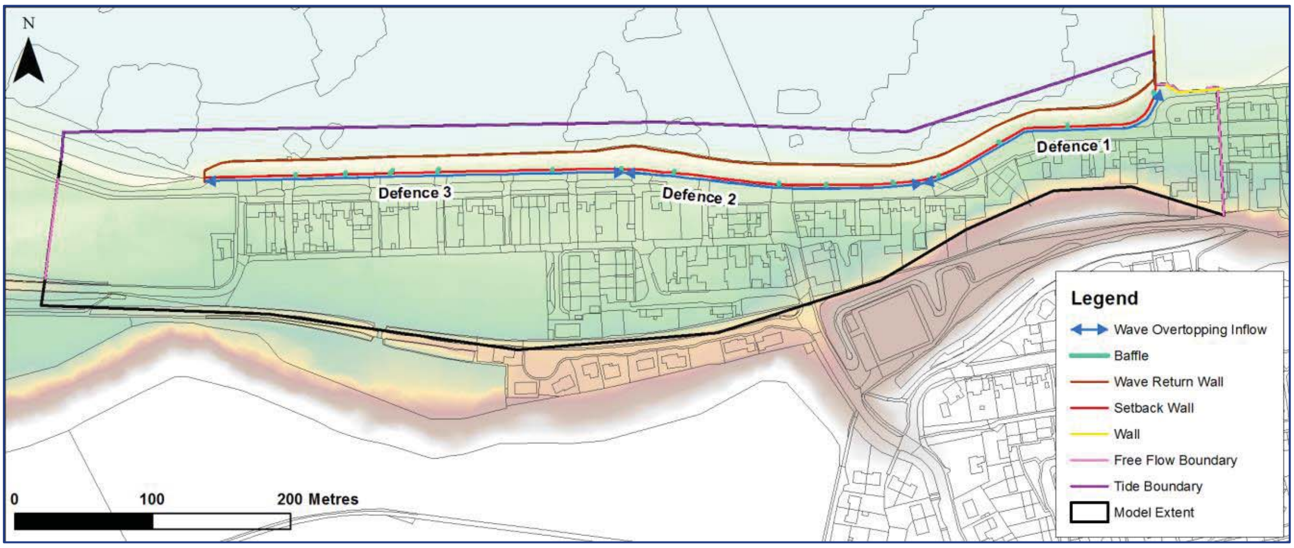


Figure 3-1: Layout of the drainage model input for drainage only solution

The drainage analysis was carried out in line with the approach and processes described in the Portgordon Options Appraisal Report[1]. The outputs of the drainage modelling are shown in Figure 3-2 to Figure 3-5. Each return period includes 100 years of climate change, in line with previous analysis.

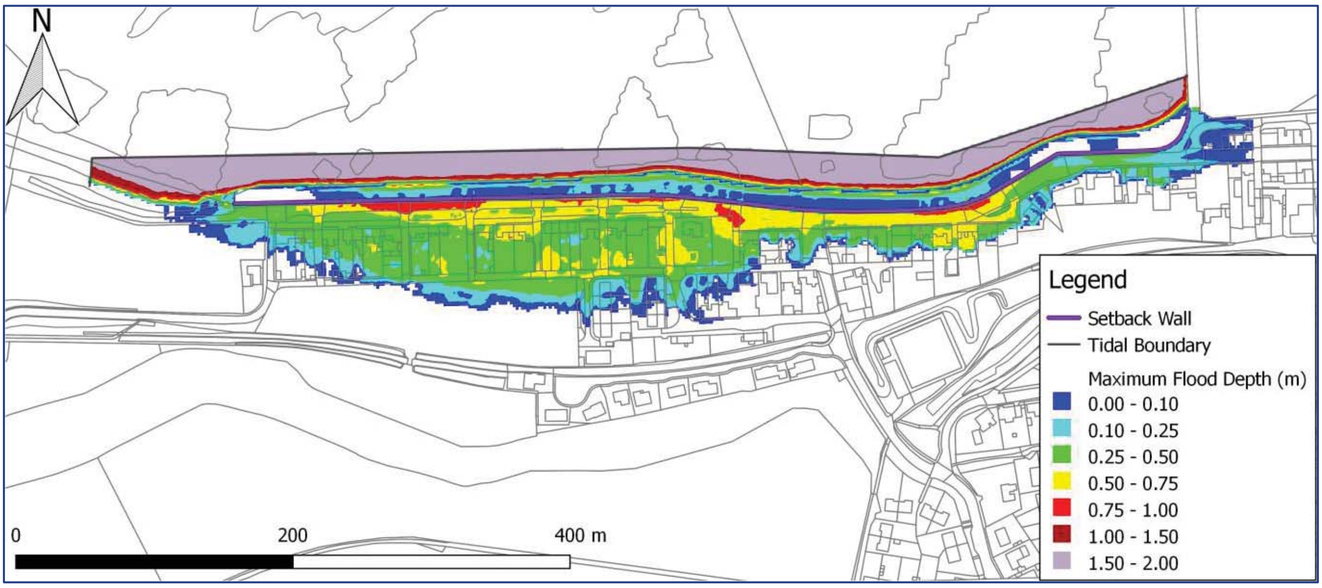


Figure 3-2: Drainage model output for drainage only solution (10-year return period)

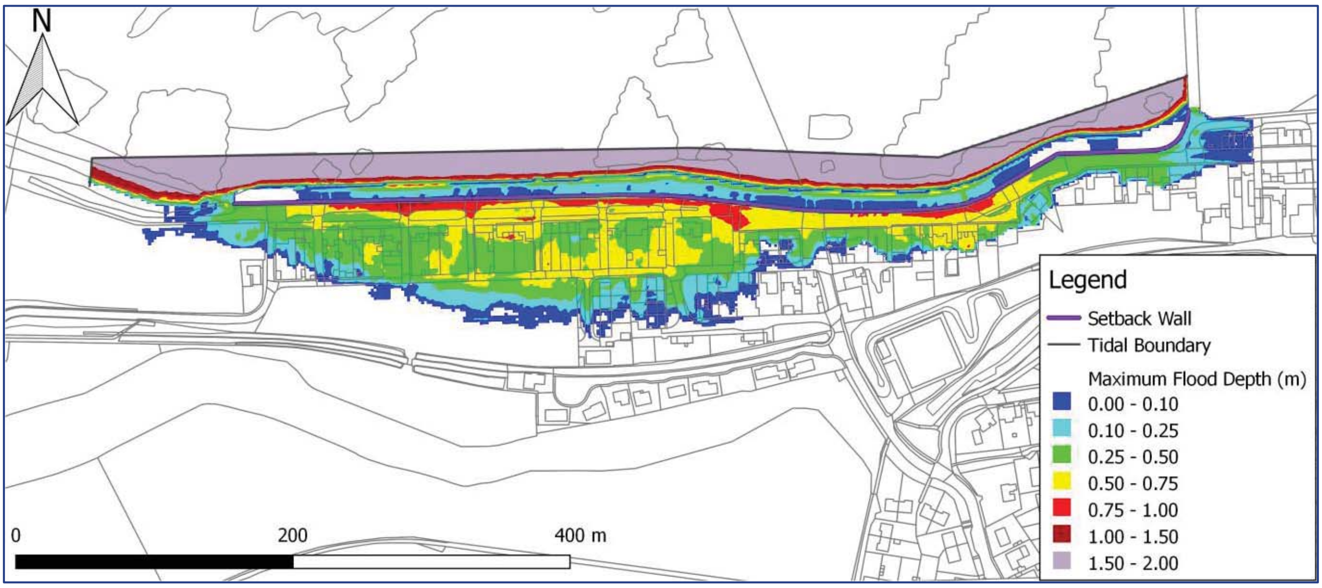


Figure 3-3: Drainage model output for drainage only solution (50-year return period)

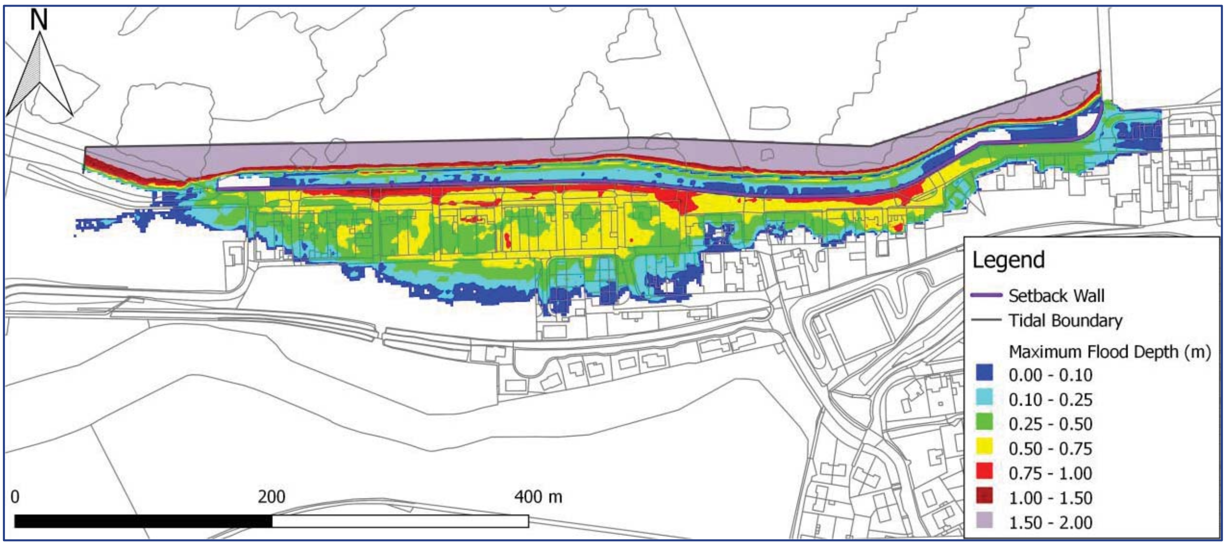


Figure 3-4: Drainage model output for drainage only solution (100-year return period)

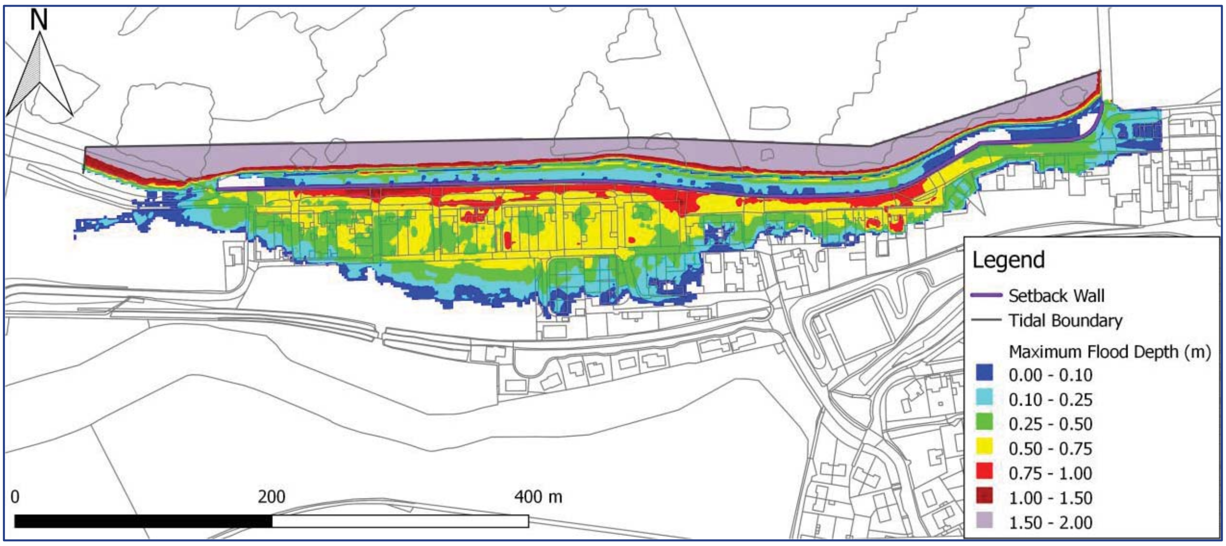


Figure 3-5: Drainage model output for drainage only solution (200-year return period)

The outputs of the drainage analysis were then used to develop an updated damage estimate as described in the Options Appraisal Report[1], and as per the calculation in Appendix A. Table 3-1 shows the total number of properties affected by flooding, and the average maximum flood depth, for each of the return periods for both the Do-Nothing Option and the Drainage Only Solution.

Table 3-1: Comparison between do-nothing and drainage only solution

	10-year Return Period		50-year Return Period		100-year Return Period		200-year Return Period	
	No. of Properties	Avg Flood Depth (m)	No. of Properties	Avg Flood Depth (m)	No. of Properties	Avg Flood Depth (m)	No. of Properties	Avg Flood Depth (m)
Do-Nothing Option	58	0.187	65	0.231	65	0.250	66	0.272
Drainage Only	57	0.172	62	0.209	63	0.228	64	0.246

The drainage only solution provides a limited benefit to the properties of Portgordon, with only a minor reduction in affected properties and to the flood depths the properties are subjected to.

The updated present value damages are established as £10,101k, which has a £334k benefit over the baseline Do-Nothing Option. Therefore, the drainage only solution produces a benefit cost ratio of 4.4, making it an economically viable option, despite the limited benefit provided in terms of reducing the properties at risk. The significant benefit cost ratio is largely due to the relatively low cost associated with the drainage only solution.

An additional benefit of the drainage only solution is a reduction in time that flood water is retained behind the setback wall following an overtopping event. It is estimated that for a 200-year return period, using the modelling data produced for the analysis in both the Options Appraisal Report[1] and this Addendum Study, that the reduction will be between 30 and 45 minutes. For the baseline 200-year return period Do-Nothing Option, the overtopping event is predicted to last 5 hours, with an additional hour to allow water to drain, giving a total submersion duration of 6-hours. This would be reduced to a 5.5-hour duration with the baffles at 50m in place, halving the time it takes for water to drain away following a 200-year return period overtopping event.

3.1 Summary

The drainage only solution provides an economically viable solution that can be taken forward and be implemented. It is recommended that this is progressed as it would alleviate flooding caused by retained water behind the setback wall, which currently maintains the level of flooding and prolongs the time during which properties are flooded.

4. Conclusions and Recommendations

This study assessed defence solutions developed herein for lower return period events, featuring a combination of stepped revetments and wave return walls. The return periods considered were 10, 50 and 100 years with the addition of 100 years of climate change, in line with the Options Appraisal Report[1]. This assessment produced no economically viable solution and all three arrangements performed poorer than Option 4 from the Options Appraisal Report. It is therefore not recommended to pursue these solutions further, as they currently stand.

This study also considered a drainage only solution, which implements baffles at 50m centres in the setback wall to allow trapped flood water to flow back to the sea. This solution produced an economically viable option with a BCR of 4.4. It is recommended that any solution taken forward considers improved drainage through the setback wall.

5. Discussions and Limitations

It was established in the Options Appraisal Report[1] that 60 properties are at risk of flooding and the defence is required to be over 700m long in order to provide the appropriate level of protection. Due to this length being required for all defence solutions, regardless of the return period under consideration, proved to be challenging to obtain a balance between the cost of a solution and the level of protection it provides.

It is recognised that there are a number of significant uncertainties relating to the cost estimates produced. Should there be an appetite to explore any of the solutions further, an experienced contractor(s) with prior knowledge of installing coastal defence structures could be approached to carry out additional cost estimate(s). Although there is no guarantee, the resulting cost estimate may be lower than those reported herein. Greater cost certainty may also justify a reduction in optimism bias, potentially leading to a more viable business case.

This study did not consider a lower level of climate change from the original 100 years. ABPmer priced for establishing an input model that looked at 50 years of climate change, in addition to the 100 years already established, which would have added considerable cost to this study and, as such, was not explored on the request of Moray Council. In particular, studying the 10 and 50-year return period events, using 100 years of climate change is unlikely to be the most effective approach in developing flood protection structures. This could go some way to explain why the BCRs decreased for the lower return periods. However, this cannot be concluded without further investigation.

The preferred solution from the Options Appraisal Report, the rock armour berm, was not explored further in this Addendum Study. Moray Council requested that a concrete stepped revetment solution be developed as it would allow for a low maintenance solution that would be less likely to attract the build-up of seaweed. A full concrete stepped revetment was not established at the Options Appraisal Report for comparison and, therefore, it may be that this solution is simply inappropriate for Portgordon when the effectiveness of such an arrangement is compared with the cost. The reintroduction of a rock armour berm solution for lower return periods and climate change may offer a more economically viable solution. This, again, is speculative without further investigation.

Appendix A. BCA Calculation for Drainage Only Solution

BCR 4.4 with 60% optimism bias.

Project Summary Sheet

Client/Authority			Prepared (date)	15/10/2018		
Morayy Council			Printed	30/10/2018	30/10/2018	30/10/2018
Project name			Prepared by	B Kershaw		
Portgordon Baffles			Checked by	C Whiteside		
Project reference			Checked date			
Base date for estimates (year 0)	Jan-2022					
Scaling factor (e.g. £m, £k, £)	£k	(used for all costs, losses and benefits)				
Year	0	30	75			
Discount Rate	3.5%	3.00%	2.50%			
Optimism bias adjustment factor	60%					
Costs and benefits of options						

	Costs and benefits £k						
Option number	**Do Nothing**		**Option 1**				
Option name	Do-nothing		Baffles				
AEP or SoP (where relevant)							
COSTS:							
PV capital costs	0		39				
PV operation and maintenance costs	0		9				
PV other	0		0				
Optimism bias adjustment	0		29				
PV negative costs (e.g. sales)	0		0				
PV contributions							
Total PV Costs £k excluding contributions	0		76				
Total PV Costs £k taking contributions into account	0		76				
BENEFITS:							
PV monetised flood damages	3,228		3,208				
PV EcMap Damage	7,207		6,893				
PV Total Damge	10,435		10,101				
PV monetised flood damages avoided			334				
PV monetised erosion damages	0		0				
PV monetised erosion damages avoided (protected)			0				
Total monetised PV damages £k	10,435		10,101				
Total monetised PV benefits £k			334				
PV damages (from scoring and weighting)							
PV damages avoided/benefits (from scoring and weighting)							
PV benefits from ecosystem services							
Total PV damages £k	10,435		10,101				
Total PV benefits £k			334				
DECISION-MAKING CRITERIA:							
excluding contributions							
Based on total PV benefits (in cludes benefits from scoring and weighting and ecosystem services)							
Net Present Value **NPV**			258				
Average benefit/cost ratio **BCR**			4.4				

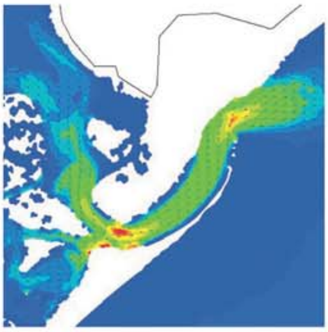
Appendix B. ABPmer Portgordon Sea Defence Options Low Return Period Overtopping Assessment

Jacobs

Portgordon Sea Defence Options

Low return period overtopping assessment

August 2018



Innovative Thinking - Sustainable Solutions

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Portgordon Sea Defence Options

Low return period overtopping assessment

August 2018

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Date	**Version**	**Revision Details**
11/07/2018	1	Issued for client review
10/08/2018	2	Additional scenario tested – issued for client use

Prepared (PM)	Approved (QM)	Authorised (PD)
Alain Le Vieux	David Finch	Heidi Roberts
	pp	

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Notice

ABPmer
Quayside Suite, Medina Chambers, Town Quay, Southampton, Hampshire SO14 2AQ
T: +44 (0) 2380 711844 W: http://www.abpmer.co.uk/

Contents

Appendices

Tables

Figures

1 Introduction

Jacobs is undertaking a study to review options for the sea defences at Portgordon (Figure 1), on behalf of Moray Council. The revetment at Portgordon often suffers from wave overtopping which results in the flooding of the road and properties behind the sea defence. To assist Jacobs, ABPmer has undertaken wave modelling and overtopping analysis to support the development and appraisal of different defence options (ABPmer, 2018).

Source: Map data ©2016 Google. Image © 2016 Terrametrics. Data © SIO, NOAA, U.S. Navy, NGA, GEBCO

Figure 1. Aerial imagery of Portgordon

This report details the overtopping analysis of two different defence variants provided by Jacobs for the frontage. The defence options tested for this report are a continuation from those analysed in ABPmer (2018).

The first version of this document detailed the results for the 50 and 100 year return periods in the 2122 epoch. This second version has been produced to include the 10 year return period assessment for the 2122 epoch.

1.1 Existing defences

Portgordon is defended from coastal flooding by linear defences, which extend around 700 m in length from the western harbour arm. These defences are backed by the main coastal road through Portgordon. The existing defences differ only very slightly along the frontage, primarily in crest height and defence alignment. The study area has been characterised into three defence lengths (Table 1 and Figure 2) based on the differences in crest height, defence facing angle relative to the coastline and variation in wave conditions.

Table 1. Defence lengths

Defence Locations	Length (m)
Defence 1 (Def_1)	194.02
Defence 2 (Def_2)	215.58
Defence 3 (Def_3)	303.61

The full overtopping extreme analysis has been completed for all three defence location lengths and is reported previously in ABPmer (2017).

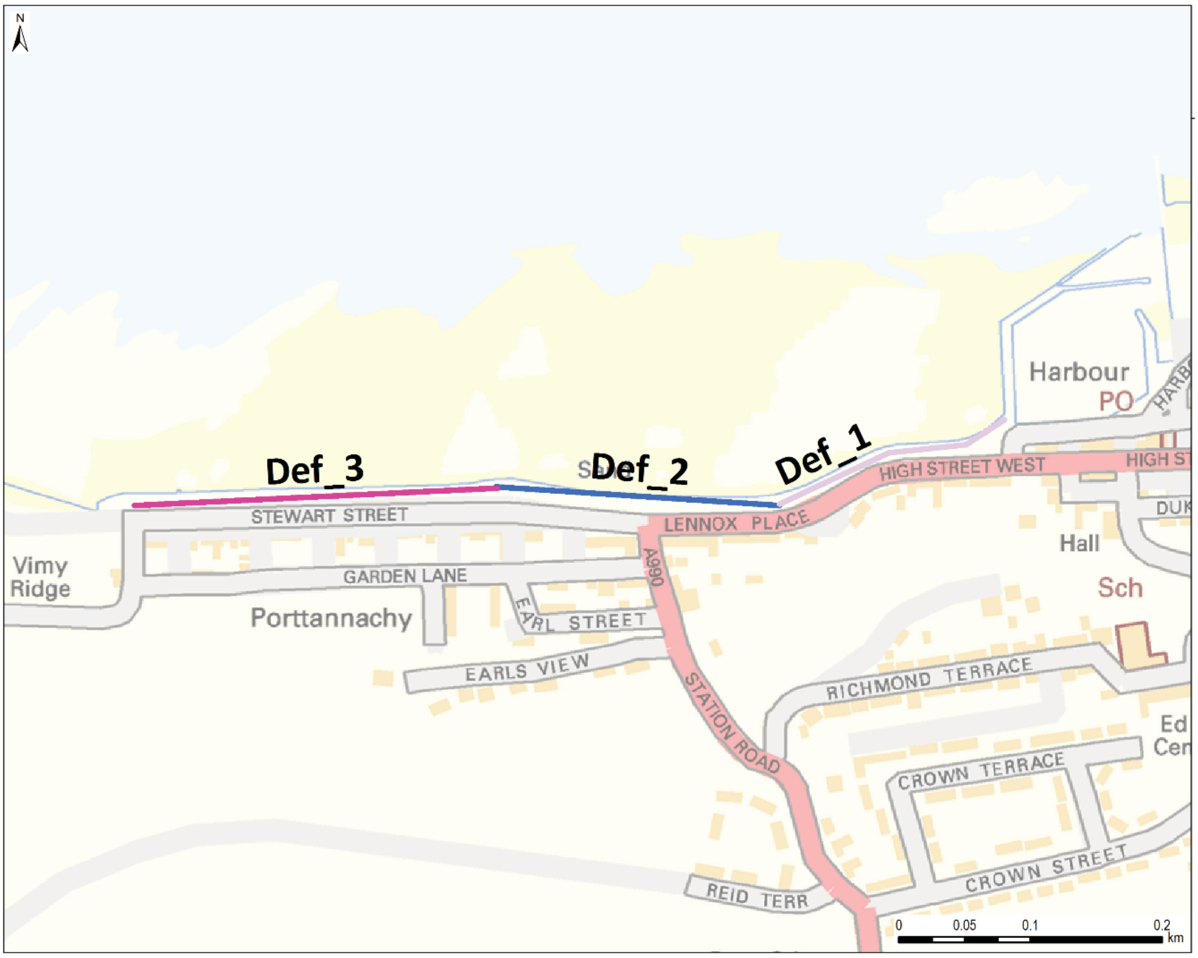


Figure 2. Indicative location of the three defence sections

2 Methodology

The methodology presented below is the same as used previously and documented in ABPmer (2017). This is presented below for continuity.

2.1 Overtopping

Overtopping has been calculated using the Neural Network Tool (NNT) developed under EurOtop (2007) as the most suitable tool for calculating overtopping. However, the NNT does have some limitations and requires engineering judgement when applying the tool and interpreting the overtopping results.

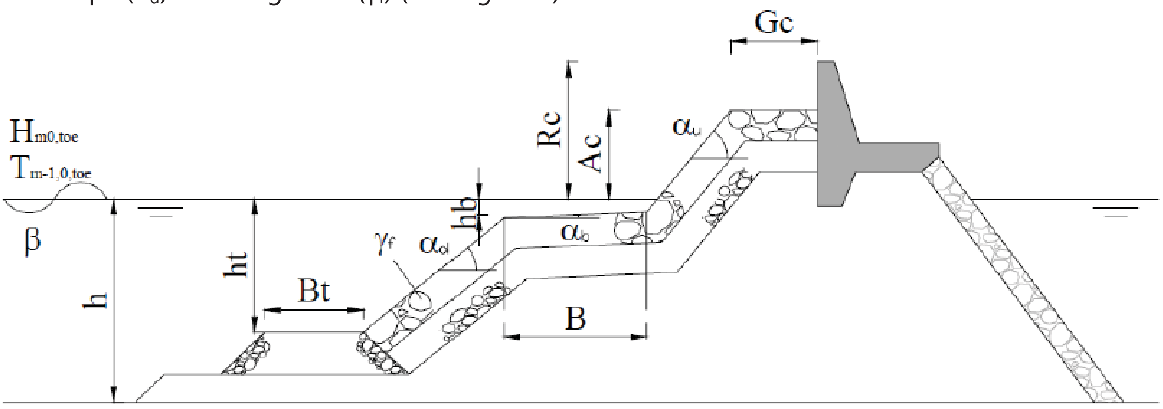
Wave height, periods and directions were extracted from a 37-year record of waves which were transformed to the toe of the structure by the numerical modelling exercise described in ABPmer (2017). These waves were also paired with the coincident water levels, and data derived for the site for the 2122 epoch.

Coincident waves and water levels for the 2122 epoch data sets were then run through the NNT to obtain a continuous timeseries record of overtopping rate for the defence options. The results from these predictions were then subsequently analysed as part of the extremes overtopping assessment (Section 4) to derive overtopping discharges for a range of return periods and specifically the 10, 50 and 100-year return period in the 2122 epoch. The overtopping rates acquired were then used to extrapolate extreme overtopping discharges for a range of return periods.

The significant advantage of the methodology is that overtopping is calculated from over 300,000 historical combinations of waves and water levels, rather than relying on extreme water levels defined offshore (as found in the Environment Agency extreme coastal flood boundary data (2011)). The unique event combinations that resulted in the largest overtopping rates for each defence section are then used to construct a design overtopping hydrograph as per the Environment Agency (2011) methodology.

2.2 Schematisation of defences

Within the NNT defences are schematised using 15 geometric parameters which include; crest height (Rc), armour height (Ac), armour width (Gc), berm elevation (hb), berm width (B), upper slope (α_u), lower slope (α_d) and roughness (γ_f) (See Figure 3).



Source: Coeveld *et al*, 2005: CLASH Database

Figure 3. Schematisation descriptors for a defence profile using Neural Networks overtopping tool

3 Defence Options

The defence options tested for this report are a continuation from those analysed previously in ABPmer (2018). The five previous defence designs comprised of:

- Option 1: Rock armour berm over an upper slope;
- Option 2: High rock armour berm over existing lower seawall;
- Option 3 Rock armour berm extended seaward;
- Option 4: Stepped revetment; and
- Option 5: Vertical wall with wave return.

The focus version 1 of this document was sensitivity and performance testing of the following option:

- Option 6: Stepped revetment with various crest width and set back alignments

In this version, performance testing of the following option has also been carried out:

- Option 7: Rock revetment and stepped revetment with various slopes, crest width and set back alignments.

3.1 Sensitivity Testing

Calculation of the overtopping discharge at a feature (e.g. footpath) setback from the defence crest used EurOtop (2007) manual guidance. Initial tests of crest levels were conducted on the defences prior to full overtopping analysis on the final versions of the defence were undertaken to determine the relative sensitivity of different possible elements of a future design.

The initial "Defence crest height assessment" determined the approximate height of the defence. This insight into the defence performance enabled Jacobs to design two defences that underwent a full overtopping extremes analysis. This was conducted to further investigate the extreme overtopping performance at the required return period scenarios for the chosen designs. The results of the crest level testing are presented in Appendix A for Option 6 only.

A number of variants were also tested for Option 6 to support the selection of the final defence designs by Jacobs. The details of the variant testing are in Appendix B. The tests were all conducted at defence toe Location 3 where the current worst wave overtopping occurs.

3.2 Performance testing

This section provides the performance testing results for each of the variants for Option 6 and Option 7. The variant with the lowest overtopping rate is taken forward for the full overtopping analysis (Section 4).

To establish the best performing variant the 37-year timeseries of incident wave conditions at the toe of the structure were taken from the nearshore wave model results (ABPmer, 2017) at the most western extraction point (Def_3) (Figure 2). This was the section that suffered the highest overtopping rates for the existing defence. This timeseries was then passed through the NNT to develop a 37-year timeseries of mean overtopping rates for each variant. The results were then analysed as part of the extremes overtopping assessment to derive overtopping rates for the 10, 50 and 100-year return periods for that section of the Portgordon defence.

These best performing variant was then used for the whole frontage and time series of wave and water levels extracted from the model at the toe of defence Sections 1 and 2. This method therefore takes account of the variations in wave conditions caused by the bathymetry and orientation of the coast. The highest hindcast 2122 overtopping rate for each Option 6 and 7 variants are presented in Table 2.

Table 2. The hindcast 2122 epoch highest mean overtopping rate for each defence option at defence toe Location 3

Defence Variant	Defence type	Slope	Top Step to WRW Width (m)	WRW Crest Level (mAOD)	Distance to SBW (m)	Overtopping @ Structure (l/s/m)	Overtopping @ SBW (l/s/m)
6.1	Stepped revetment	1:3	2.50	6.0	10.53	81	8
6.2	Stepped revetment	1:3	2.50	5.8	10.55	107	10
6.3	Stepped revetment	1:3	2.75	5.6	10.30	139	13
6.4	Stepped revetment	1:3	3.00	5.5	10.05	157	16
6.5	Stepped revetment	1:3	2.50	6.2	10.55	62	6
6.6	Stepped revetment	1:3	2.75	6.1	10.30	71	7
6.7	Stepped revetment	1:3	3.00	6.0	10.05	80	8
7.1	Rock revetment	1:2	1.25	4.17*	10.83	726	67
7.2	Stepped revetment	1:2.5	1.25	4.17*	10.83	563	52
7.3	Rock revetment	1:2	1.25	4.48*	9.58	670	70
7.4	Rock revetment	1:2	2.25	4.84	9.83	398	41
*Indicates that the crest is a vertical wall in this schematisation							

From the "Peak hindcast overtopping" sensitivity test three variants were chosen by Jacobs. These are:

- Variant 6.1 (Section 3.2.1) to be used to establish the 1:50-year return period overtopping;
- Variant 6.7 (Section 3.2.2) to establish the 1:100-year return period overtopping rates; and
- Variant 7.4 (Section 3.2.3) to establish the 1:10-year return period overtopping rates.

Variants 6.1 and 6.7 are both stepped revetment structures and detailed below in Sections 3.2.1 and 3.2.2. Variant 7.4 is a rock revetment structure designed to provide overtopping for a 10-year return period. The variants are carried forward to the extremes overtopping analysis for each defence section as described in Section 4.

3.2.1 Variant 6.1 - Stepped revetment with wave return wall

This defence configuration was used to calculate to 50-year return period overtopping rates. Variant 6.1 is a stepped revetment structure of the type shown in Figure 4. The entire slope of the structure will be 1:3 (vertical: horizontal) up to a 2.5 m wide crest width, with a 2.2 m high (6.0 mODN) wave return wall (WRW). The overtopping rate is calculated at the footpath 10.53 m from the crest using the EurOtop (2007) guidance.

The defence elements levels and model combinations for the NNT are shown in Figure 4.

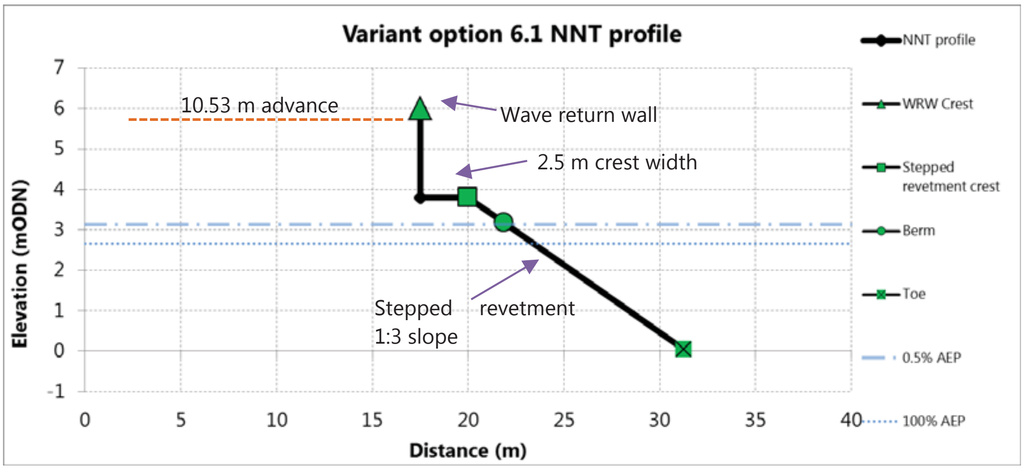


Figure 4. NNT schematisation for Variant Option 6.1

3.2.2 Variant 6.7 - Stepped revetment with wave return wall

Variant 6.7 is a stepped revetment structure of the type shown in Figure 4. The entire slope of the structure is 1:3 (vertical: horizontal) up to a 3.0 m wide crest width, which the 2.2 m high (6.0 mODN) WRW. The overtopping rate is calculated at the footpath 10.05 m from the crest using the EurOtop (2007) guidance.

The defence elements levels and model combinations for the NNT are shown in Figure 5.

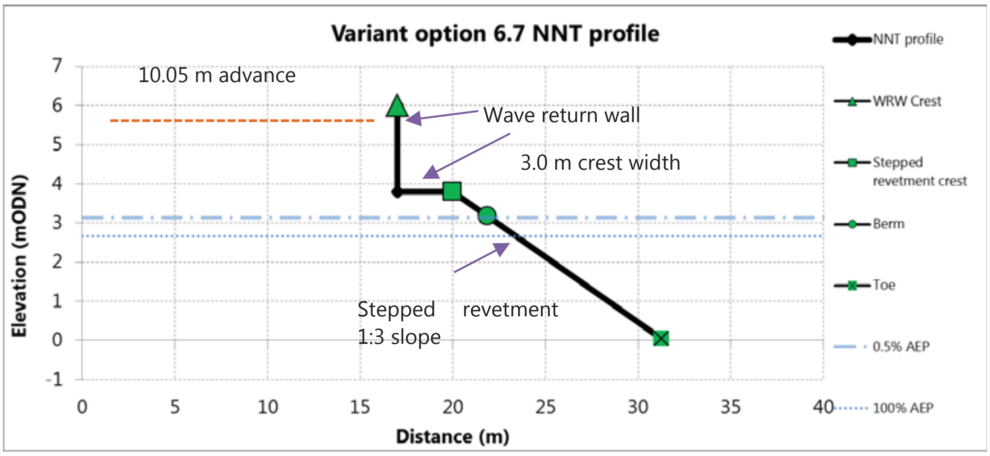


Figure 5. NNT schematisation for Variant Option 6.7

3.2.3 Variant 7.4 – Smaller rock revetment with wave return wall

Variant 7.4 is a rock revetment structure of the type shown in Figure 6. The rock revetment has a slope of 1:2 (vertical: horizontal) with a 2.25 m wide crest width. The wave return wall is at the back of the revetment and 1.67 m high (4.84 mODN). The overtopping rate is calculated at the footpath 9.83 m from the wave return wall using the EurOtop (2007) guidance.

The defence elements levels and model combinations for the NNT are shown in Figure 6.

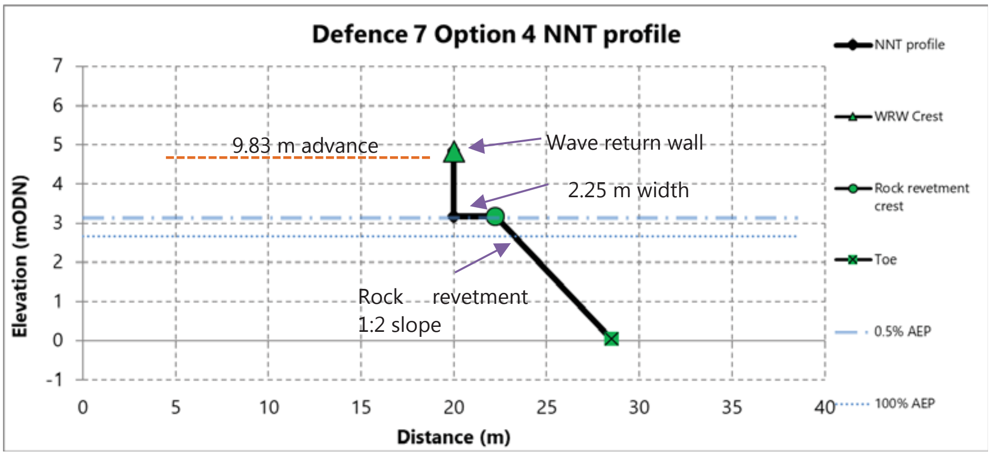


Figure 6. NNT schematisation for Variant Option 7.4

4 Extremes Overtopping Analysis

To derive overtopping rates for different return periods, the 37-year record of overtopping for 2122 epoch were run through a Generalised Pareto Distribution (GPD) extremes package. The overtopping events from the hindcast timeseries above a threshold are selected and are plotted against return period. The Pareto distribution of the overtopping and return periods were then fitted using the software package in2extremes (see Gilleland & Katz, 2016) to the overtopping events. In this process, the shape and scale parameters of the fitted data are determined. The Pareto fit to the data is visually assessed, and if necessary the threshold is reselected and the extrapolation refitted to the data to improve the fit quality. This is a subjective process guided by the behaviour of the scale and shape parameters at various thresholds, and by the experience of the practitioner. Further details on threshold selection can be found in Coles (2001). The final shape and scale parameters are used to extrapolate the theoretical fit to the data to determine extreme conditions for various return periods.

The overtopping resultant fits are provided in Appendix C for each Variant 6.1, 6.7 and 7.4.

5 Extreme Overtopping Hydrographs

5.1 Design tide hydrographs

To estimate overtopping volumes during a storm event, idealised design tide hydrographs have been generated for each return period event, for each defence section for the 2122 epoch. To generate these design tide hydrographs the Environment Agency preferred method (Environment Agency, 2011) was adopted. This method was developed with the support of the Scottish Environment Protection Agency.

To achieve this, a design tide hydrograph was constructed using a distance weighted mean high-water spring (MHWS) base astronomical tide extracted from Total Tide software for Buckie and Lossiemouth. This base astronomical tide was combined with a scaled Moray Firth design surge shape profile (Environment Agency, 2011) such that the water level at the peak of the overtopping event from the hindcast period is equivalent to the required water level for the overtopping event (Figure 7).

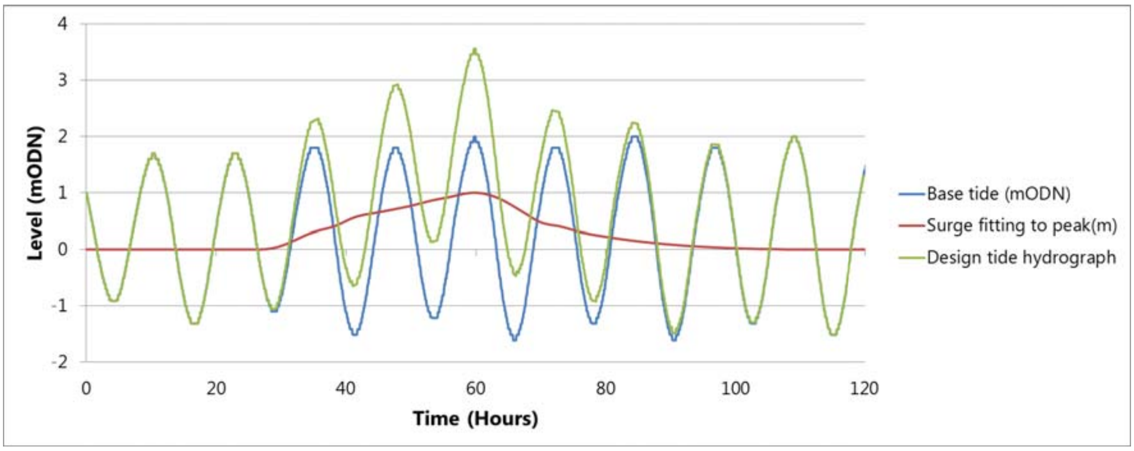


Figure 7. Indicative design tide hydrograph

5.2 Design overtopping hydrographs

To create design overtopping hydrographs the design tidal hydrograph was run through the NNT as described below. This provided a unique overtopping profile shape for each defence section.

In this assessment, a uniform wave condition (wave height, period and direction) was used over the design tidal hydrograph. This wave event equated to the worst overtopping condition obtained at the defence section in the hindcast 37-year overtopping record. The wave conditions for this event are then run through the NNT over the design tidal hydrograph (Section 5.1), providing a 25-hour overtopping hydrograph for each defence section.

In this assessment, the overtopping hydrograph is then scaled to the calculated return period (see Section 4) providing a wave overtopping design hydrograph for the 1:10, 1:50 and 1:100-year return periods. This is a derivation of the method set out in Environment Agency (2011), but we believe is in line with the forthcoming Environment Agency 'State of the Nation' approach.

The method therefore focuses upon defining the *result* of the extreme event (i.e. the actual overtopping of a defence) rather than defining the event itself. We believe that this approach more closely reflects latest industry advances in flood risk assessment. The overtopping hydrographs for each return period were provided in digital format to be used in inundation model inputs.

6 Results

This report details the overtopping analysis of different variants for the following coastal defence option for the 1:10, 1:50 and 1:100-year return periods in the 2122 epoch:

- Option 6: Stepped revetment with various crest width and set back alignments; and
- Option 7: Rock revetment with various crest width and set back alignments, and stepped revetment with steeper slope option.

Eleven variants of the coastal defence option were performance tested and the following were taken forward for extremes and overtopping analysis.

- A stepped revetment with a 2.5 m wide crest, wave return wall with a crest at 6 mODN that is set forward by 10.8 m from the walk way (Variant 6.1);
- A stepped revetment with a 3 m wide crest, wave return wall with a crest at 6 mODN that is set forward by 10.05 m from the walk way (Variant 6.7); and
- A rock revetment with a 2.25 m wide crest, wave return wall with a crest at 4.84 mODN that is set forward by 9.83 m from the walk way (Variant 7.4).

Table 3 provides the 1:10, 1:50 and 1:100-year return period mean overtopping rates at the footpath. overtopping hydrographs are provided separately as excel files.

Table 3. 1:10-year return period OT (Variant 7.4), 1:50-year return period OT (Variant 6.1) and 1: 100-year return period (Variant 6.7((2122 epoch)

Defence Section	1:10 Mean Overtopping Rate (l/s/m) (Variant 7.1)	1: 50 Mean Overtopping Rate (l/s/m) (Variant 6.1)	1:100 Mean Overtopping Rate (l/s/m) (Variant 6.7)
Defence Section (location) 1	20.6	6.1	8.5
Defence Section (location) 2	23.6	6.9	9.8
Defence Section (location) 3	24.2	7.9	10.9

7 References

ABPmer., 2017. Portgordon Wave and Overtopping Modelling. ABPmer, Report No. R.2801.

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8 Abbreviations/Acronyms

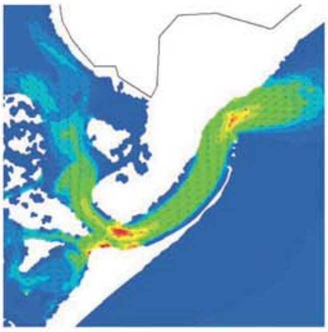
Ac	Armour Height
AOD	Above Ordnance Datum
B	Berm Width
CLASH	Crest Level Assessment Coastal Structures
EurOtop	European Overtopping Manual
Gc	Armour Width
GPD	Generalised Pareto Distribution
hb	Berm Elevation
MHWS	Mean High-Water Spring
NNT	Neural Network Tool
ODN	Ordnance Datum Newlyn
OT	Overtopping
Rc	Crest Height
SBW	Set-Back Wall
WRW	Wave Return Wall
αd	Lower Slope
αu	Upper Slope
γf	Roughness

Cardinal points/directions are used unless otherwise stated.

SI units are used unless otherwise stated.

Appendices




Innovative Thinking - Sustainable Solutions

A Initial Sensitivity Testing

The methodology adopted is as per the original study as reported in ABPmer, 2017 (R.2801). ABPmer has used the existing model setup and ten events from the timeseries data previously generated to undertake the present assessment. It is noted that there is no requirement for joint probability assessment at this time and OT has been calculated based on events from the long-term hindcast datasets of wave and water levels.

Due to the inherent uncertainties associated with the EurOtop methodology, the results should be used as indicative information on the potential effects of particular defence features on overtopping rates.

The overtopping sensitivity tests for Option 6 based upon ten events from the 2122 hindcast dataset of wave and water levels. These 10 events were those that resulted in the worst overtopping for the existing "Do Minimum" defence configuration (ABPmer, 2017 R.2801). Undertaking the present tests using these 10 events allows for different combinations of waves and water levels to be examined rather than testing against a single hydrodynamic condition.

A.1 Option 6 - Stepped revetment initial sensitivity testing

The following defence option was provided by Jacobs:

- Option 6 – Stepped revetment with a wave return wall (Figure A1).

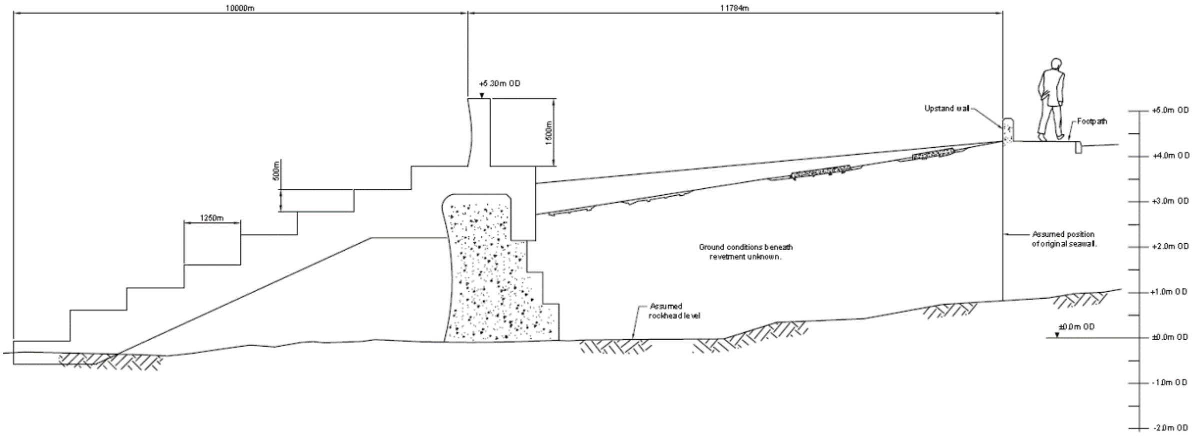


Figure A1. Option 6 stepped revetment

Based on Figure A1 the defence was schematised into the NNT as shown in Figure A2 with various different levels applied to the Wave Return Wall (WRW) crest level. Further details on the schematisation are noted below:

- Stepped revetment (slope 1 in 2.5) from toe at -0.2 mODN to 3.8 mODN, with roughness 0.8;
- WRW initially of 1.5 m in height (crest level 5.30 mODN), increased at 0.2 m increments (roughness 1.0); and
- Variable overall roughness for entire structure based on relative height of WRW to stepped revetment.

The overtopping was then determined at the footpath (set- back 11.8 m from the WRW), using the set-back equation as per EurOtop (2007) guidance.

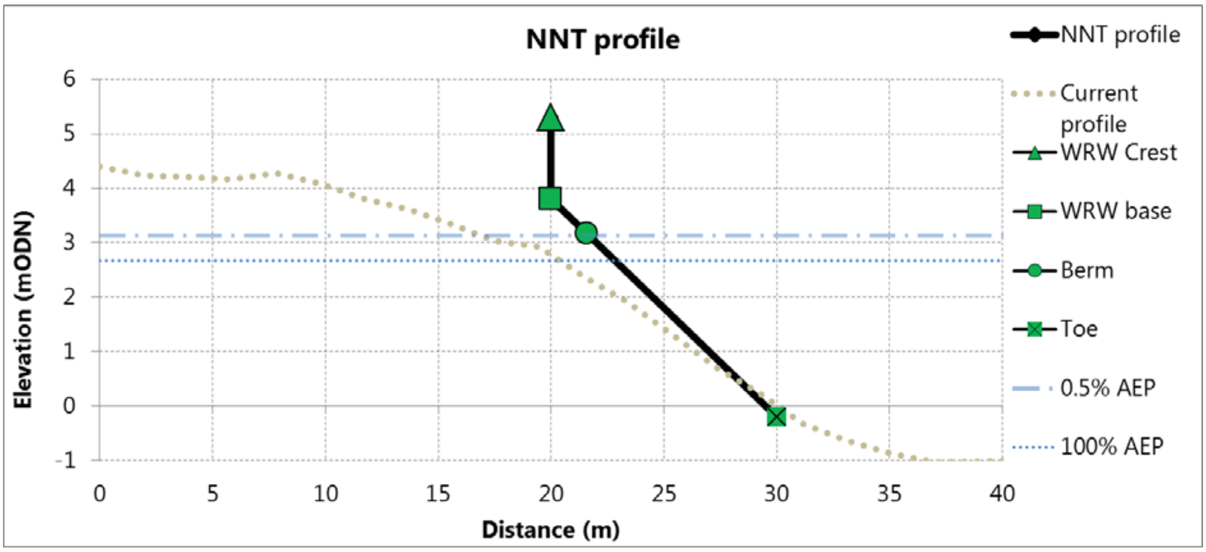


Figure A2. Option 6 NNT profile

Notes:

- Neural Networks is unable to test the specific effects of the stair configurations. The results are based on the change in overall slope and 'roughness' characteristics, therefore the results are likely to be conservative; and
- This analysis was conducted to assess the sensitivity of the overtopping rate to a single variable (feature) of the defence schematisation, the WRW crest level. Other variables have not been considered at this stage.

A.2 Results

In the initial study, the greatest overtopping rate predicted at the footpath, from these 10 events, was 206 l/s/m in the existing "Do Minimum" scenario for 2122 (ABPmer 2017, R.2801).

The greatest overtopping results for Option 6, from these same 10 events, are provided as Table A1, for the range of WRW crest levels examined. These rates are presented at the WRW and footpath, which is set-back 11.8 m from the WRW.

The results at the footpath are also presented in Figure A3.

Table A1. Defence Option 6 crest level sensitivity test

Crest Level (mODN)	Mean Overtopping Rate at WRW (l/s/m)	Mean Overtopping Rate (l/s/m) at Footpath (Set-Back 11.8 m)
5.3	137.4	11.6
5.5	118.5	10.0
5.7	101.0	8.6
5.9	85.1	7.2
6.1	70.9	6.0
6.3	58.7	5.0
6.5	48.1	4.1
6.7	39.2	3.3
6.9	31.6	2.7
7.1	25.4	2.2
7.3	20.3	1.7

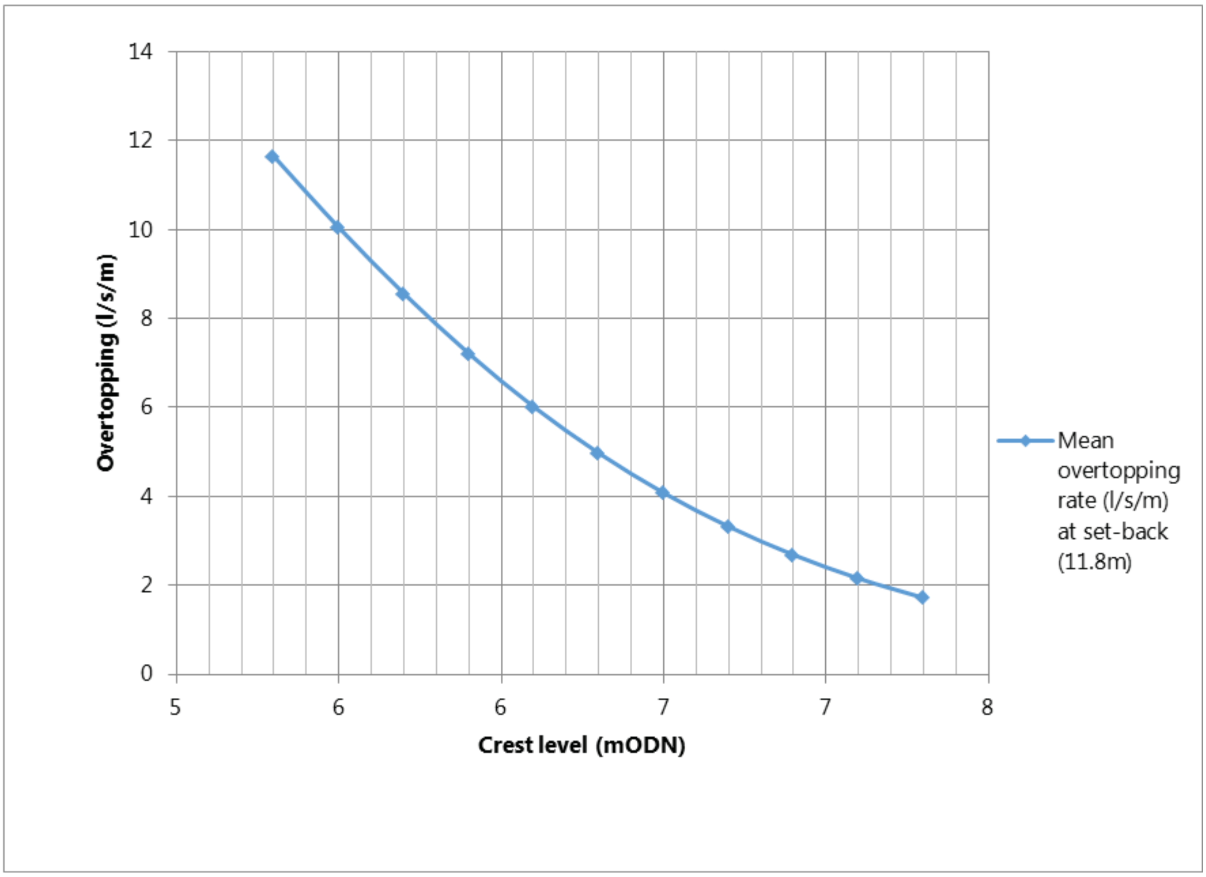


Figure A3. **Option 6 crest level assessment**

B Overtopping Extremes sensitivity testing

Initial sensitivity tests on two defences was done to understand the extreme overtopping values for return periods for the 2122 epoch. The details of the defences are listed below;

Defence 6 Variant 1:

- 1.5 m high wave return wall at crest of 5.3 mODN;
- Set-forward foot-path by 11.8 m (where OT is calculated); and
- Stepped revetment with a roughness 0.8 and a slope of 1:2.5 (vertical: horizontal).

Defence 6 Variant 2:

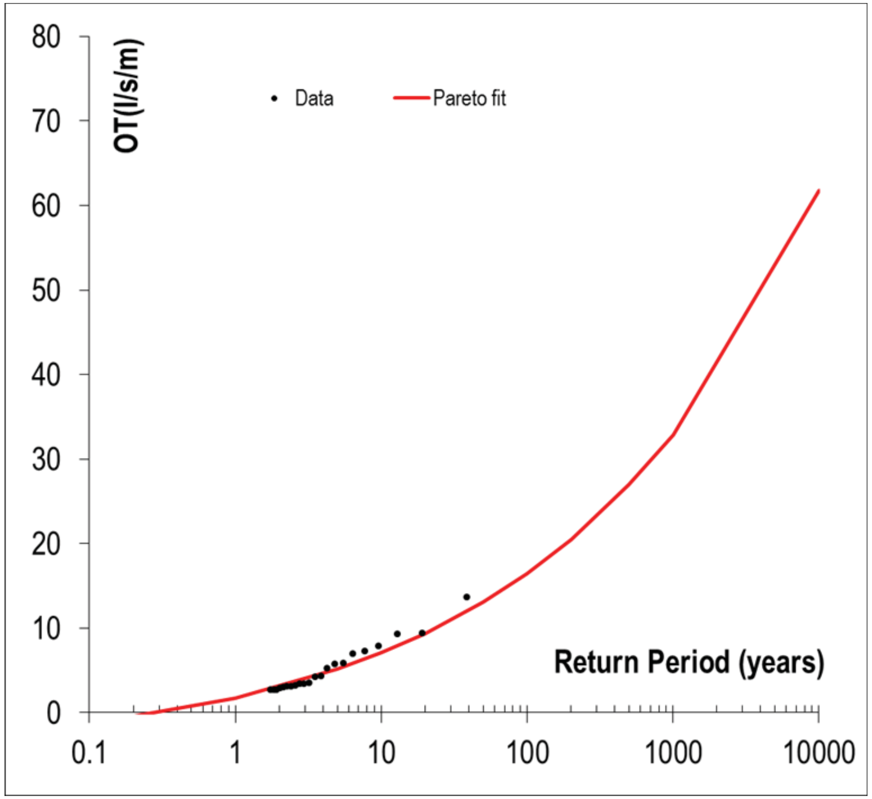
- 1.5 m high wave return wall at crest of 5.8 mODN,
- Set-back to revetment 11.8 m (where OT is calculated); and
- Stepped revetment represented with a roughness of 0.8 and a slope of 1:2.5 (vertical: horizontal).

The return period overtopping rates for the 50 and 100-year in the 2122 epoch are presented in Table B1 with the resultant fits in Figure B1.

Table B1. Extreme overtopping values for Defence 6 Variant 1 and 2 at Location 3

Return Period	Overtopping for Defence 6 (l/s/m) Variant 1	Overtopping for Defence 6 (l/s/m) Variant 2
50	18.2	13.1
100	22.4	16.5

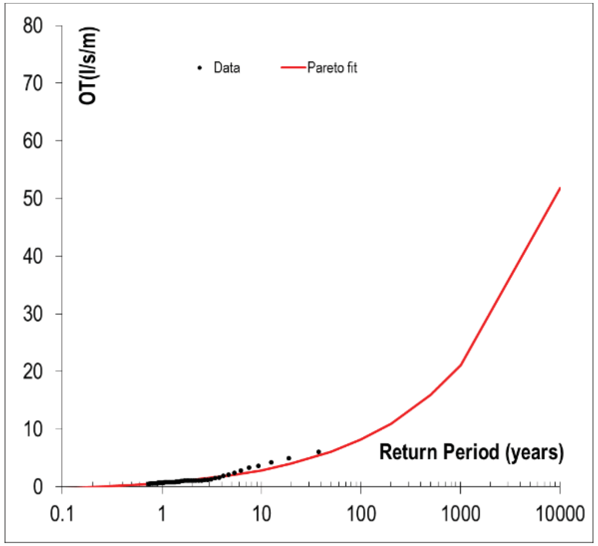
Defence 6 Variant 1



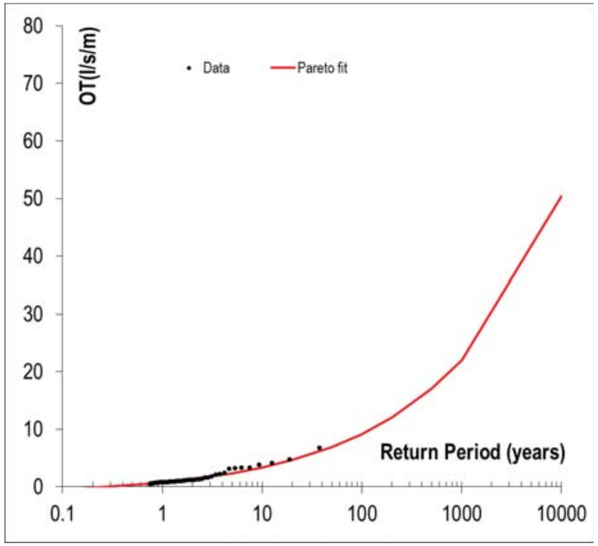
Defence 6 Variant 2

Figure B1. Defence 6 variant 1 and 2 design overtopping extreme figures for 2122 Epoch Location 3 conditions

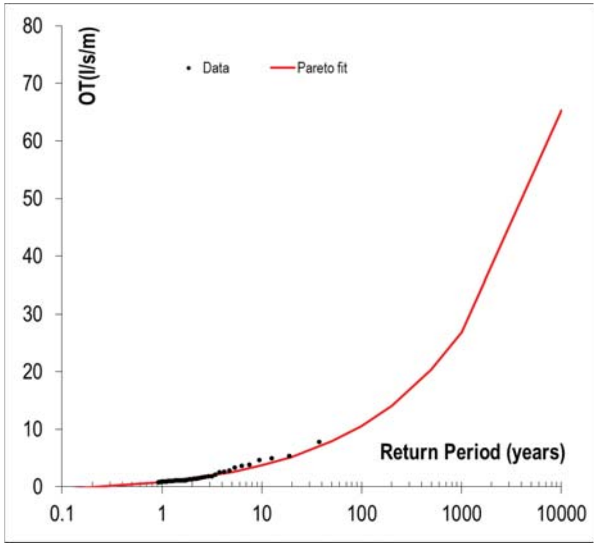
C Extreme Overtopping Results



Defence variant 6.1 Location 1

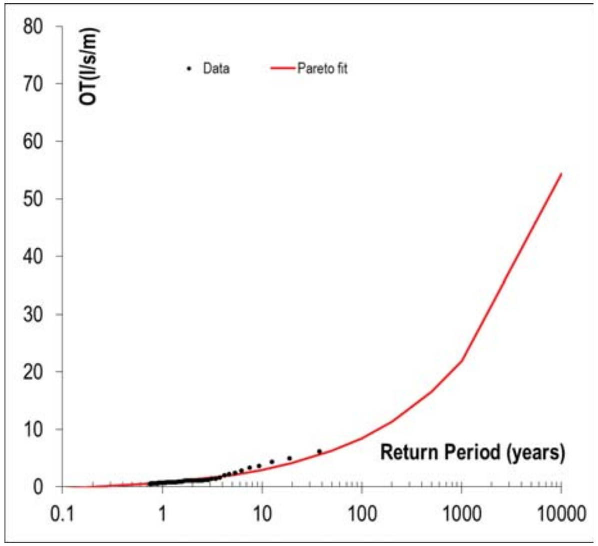


Defence variant 6.1 Location 2

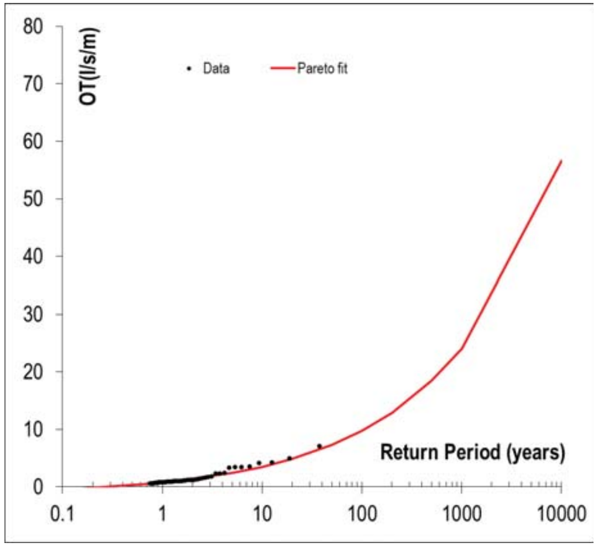


Defence variant 6.1 Location 3

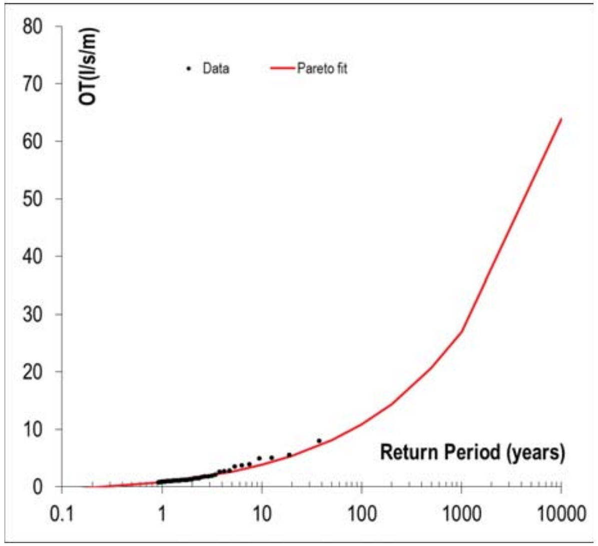
Figure C1. Defence variant 6.1 overtopping results for 2122 epoch



Defence variant 6.7 Location 1

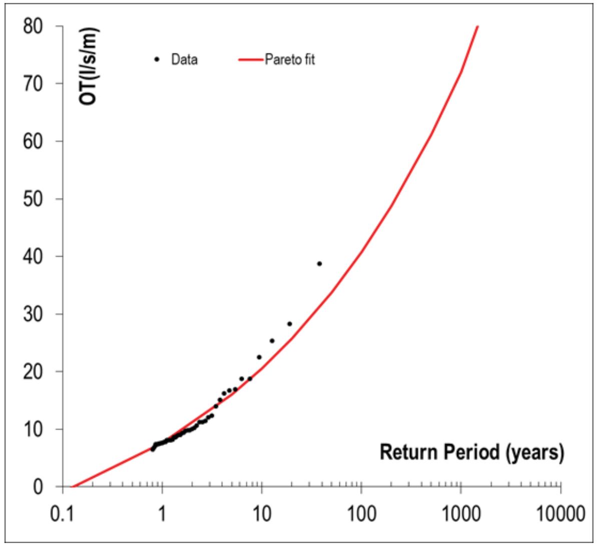


Defence variant 6.7 Location 2

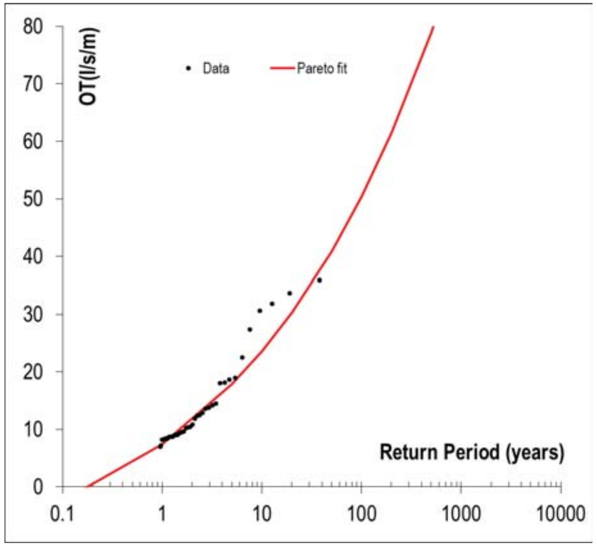


Defence variant 6.7 Location 3

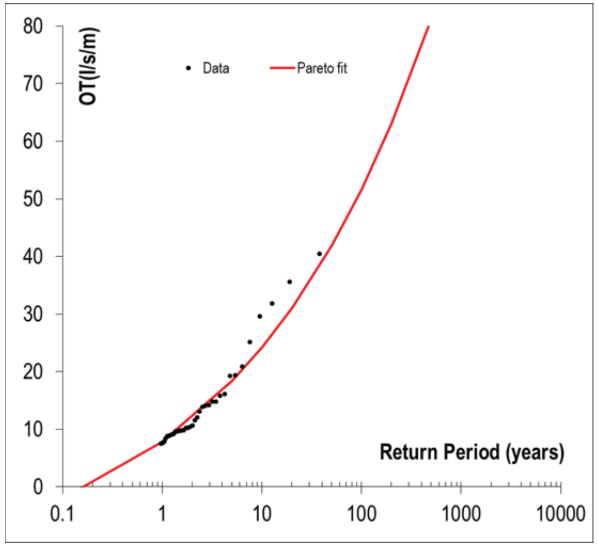
Figure C2. Defence variant 6.7 overtopping results for 2122 epoch



Defence variant 7.4 Location 1



Defence variant 7.4 Location 2



Defence variant 7.4 Location 3

Figure C3. Defence variant 7.4 overtopping results for 2122 epoch

Contact Us

ABPmer

Quayside Suite,
Medina Chambers
Town Quay, Southampton
SO14 2AQ

T +44 (0) 23 8071 1840
F +44 (0) 23 8071 1841
E enquiries@abpmer.co.uk

www.abpmer.co.uk