Wave Overtopping Modelling Study
Pennington Point, Sidmouth

East Devon District Council

Final Report

22 November 2002

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1 INTRODUCTION AND BACKGROUND

This report is part of a wider study being undertaken to investigate proposals for coastal protection works at Pennington Point and the Salcombe Hill frontage at Sidmouth.

Pennington Point and Salcombe Hill lie immediately to the east of the River Sid in Sidmouth, Devon. Whilst the main Sidmouth frontage, between the western bank of the River Sid and the Chit Rocks, has been provided with coast protection since the 1830's, the coastlines either side have continued to erode such that the present Sidmouth seawall is some 15 to 20 metres forward of the natural line of the coast.

The Sidmouth frontage has historically suffered periodic beach depletion. The most recent serious occurrence followed the storms of 1989/90. A three phase scheme comprising two offshore breakwaters, three rock groynes and beach renourishment has recently been completed to maintain protection to the main town frontage. The adjacent unprotected frontages also suffer from the same problem of periodic beach drawdown under south westerly storm conditions.

Protection is currently being sought by East Devon District Council (EDDC) for Pennington Point and the Salcombe Hill frontage. The land behind the frontage is mainly residential. Approximately 300m east of Pennington Point the land becomes agricultural. At Pennington Point a footbridge known as Alma Bridge spans the River Sid. The Alma Bridge is used by pedestrians on the South West Coast Path and by tourists and residents to get to and from Sidmouth. The loss of the beach fronting Pennington Point and Salcombe Hill has led to an increase in erosion of the cliff face which has had the following consequences:

1. The western wall of the River Sid and the buttresses of the Alma Bridge are becoming more exposed to direct wave action. The eastern buttress of the Alma Bridge is now in danger of being outflanked.

2. The erosion has led to a loss of a section of the South West Coast Path that continued from the Alma Bridge along Salcombe Hill; the path has now been diverted along Cliff Road. Properties at the top of Salcombe Hill, on the southern side of Cliff Road, are at risk from erosion.

A coastal study for the frontage aimed at identifying potential coast protection options was undertaken in March 2001. The study identified four initial options for consideration, one of which (Option IV) would provide protection to the entire frontage - Option IV consisted of constructing a rock revetment extending the length of the Salcombe Hill frontage. Selecting Option IV as the preferred option, EDDC commissioned further work assessing possible alternatives within Option IV. Following four further appraised options, a rock revetment, of some 210 metres in length, has been proposed as the preferred option to provide protection to Pennington Point and the Salcombe Hill frontage on the basis of economic and technical selection criteria (see Section 3.3 of the Environmental Statement).

2 AIMS

In the absence of any beach material, Pennington Point and the Salcombe Hill frontage are currently eroding at an accelerated rate to that previously witnessed at Sidmouth. Whilst a rock revetment could be constructed to provide total protection to the frontage and therefore stop erosion of the cliffs, English Nature have specified that due to the international designations which protect this site, a scheme will only be considered if it does not completely stop erosion. In order to comply with English Nature, it is proposed that a revetment be constructed with a crest level that would allow some overtopping - ideally the revetment should simulate the same conditions at the cliff toe that would prevail with a full beach fronting the cliffs.

This study aimed to meet the following objectives in order to satisfy the conditions of English Nature:

- To determine the wave action that prevailed at the base of Salcombe Hill cliffs prior to the storm events of 1989/1990 using the AMAZON Wavewatch modelling program. Erosion rates prior to this event, which depleted most of the beach fronting the cliffs, were less than 0.3 metres per year.

- To determine the optimum height and distance from the cliff face of a rock revetment structure designed to simulate the wave action at the base of Salcombe Hill prior to the 1989/1990 storm event using the AMAZON Wavewatch modelling program.

3 OVERTOPPING MODELLING

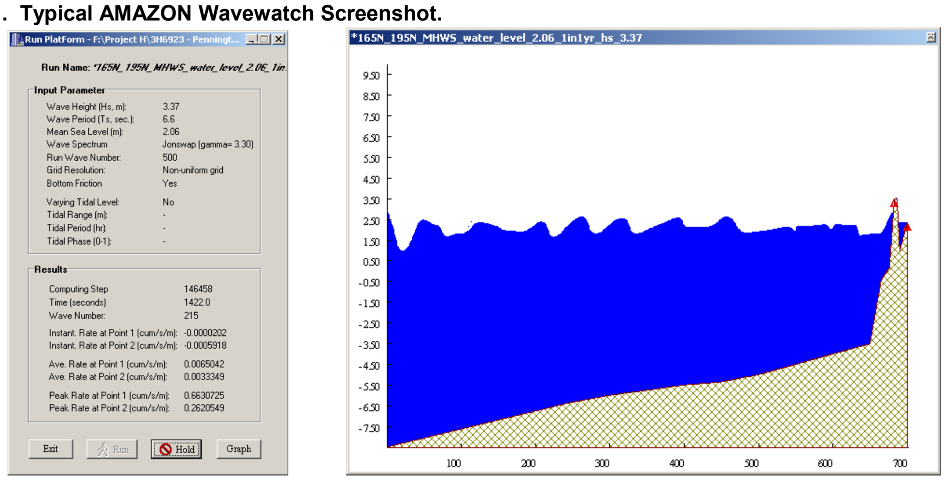
The modelling of overtopping events was undertaken using the AMAZON Wavewatch modelling program.

3.1 AMAZON Wavewatch

AMAZON Wavewatch, developed by Posford Haskoning and Manchester Metropolitan University, is a high resolution 2-D finite model used to generate forecasts of the peak and mean overtopping rates and volumes. The model solves the shallow water equations of wave propagation and run-up providing time series changes in water levels and depth averaged velocities using random waves as a boundary condition. AMAZON is applicable to any beach or revetment profile, including vertical walls, and is particularly useful for predicting wave overtopping and run-up at complex structures due to it accurately modelling wave breaking.

AMAZON can model wave propagation over complex and rapidly changing bathymetry in shallow water. It takes account of wave diffraction, refraction, reflection, wave breaking and other shallow water effects.

Figure 1. Typical AMAZON Wavewatch Screenshot.



3.2 Parameter Selection

The overtopping model requires the input of bathymetry (or cross-section profile for 1-D calculation) and incident wave conditions. Typical parameter input for each model is listed below.

- Beach/sea defence profile
- Significant wave height and period
- Water level

3.3 Overtopping Rates

The overtopping rates determined with the numerical modelling are recorded as a mean and a peak discharge rate (cum/s/m). The mean discharge rate represents the average overtopping rate during the analysed period whilst the peak discharge rate represents the highest instantaneous overtopping rate determined during the analysed period.

4 MODEL DATA

4.1 Beach/Foreshore Levels

The foreshore was modelled under three scenarios:

- Pre 1989/90 storms condition;
- Present day condition;
- Present day condition with rock revetment structure.

4.1.1 Pre 1989/90 beach levels

From aerial photographs taken during 1987 (see Attachment A), at a time when a healthy beach fronted Salcombe Hill, beach levels were interpreted at the base of the cliff and at the high water tide mark (see Table 4.1). The beach displays a healthy profile with a berm fronting the cliffs for a distance of approximately 6.5 metres. A typical slope of 1 in 7 was assumed for the shingle.

The best estimates of the beach levels from the photographs relied upon correlation with known levels on the Sidmouth frontage. This method of estimation is open to some interpretation and a sensitivity of +/- 0.5 metres has been included and modelled for the 'best estimate' profile.

4.1.2 Post 1989/90 beach levels

Beach levels over the period since 1989/90 have generally been lower, although unlike the main Sidmouth frontage no formal monitoring of the Salcombe Hill frontage has been undertaken. However, aerial photographs taken at various times (Posford Duvivier, 2001) show the condition in 1993, 1995, 2000 and 2001. A beach level survey was undertaken in February 2002 to assist in the design of the proposed scheme and the profile from this survey has been used for modelling the overtopping of the various structures.

4.2 Structures Modelled

The landward toe of the revetment structure was placed at three distances from the cliff face: 0m, 10m and 15m. The height of the structure was varied at each distance with crests of +3.5m, +4.0m, +4.5m and +5.0m ODN.

In order to assess the sensitivity of beach levels to overtopping with the structures in place, the model was also run with foreshore profiles representing a denuded beach with bare rock exposed, much as was evident in the 1995 and 2000 aerial photographs.

Comparison with the beach levels taken in February and the underlying rock levels (also investigated at the time by trial pit) show the beach coverage was limited to the upper 25 metres of the foreshore (see Table 4.1).

4.3 Offshore Levels

The offshore bathymetry was modelled using data obtained from a combination of Admiralty Charts and data previously used for the Mobile Bed Physical Model Study undertaken by HR Wallingford, 1993 (see Table 4.1). The physical modelling assisted in the determination of the optimum position of the offshore breakwaters which have since been constructed at Sidmouth.

Table 4.1. 1987 and present day beach profiles used in the model.

Distance from Cliff Face (m)	Foreshore and Offshore Levels (mODN)		
	1987 Profile	Present Day Profile	
		With Beach	Denuded Beach
0	+3.50	+2.35	+1.90
6.63	+3.50	-	-
10	-	+1.67	+0.97
24	+1.00	-	-
25	-	-0.42	-0.42
50	-3.50	-3.50	-3.50
100	-4.00	-4.00	-4.00
150	-4.50	-4.50	-4.50
200	-5.00	-5.00	-5.00
250	-5.35	-5.35	-5.35
300	-5.50	-5.50	-5.50
350	-5.75	-5.75	-5.75
400	-6.00	-6.00	-6.00
450	-6.35	-6.35	-6.35
700	-8.50	-8.50	-8.50

4.4 Wave Conditions

Waves are one of the most significant factors shaping any coastline. Information on waves is therefore a vital input into any coastal process study. An understanding of the wave climate assists with the prediction of wave overtopping.

Wave heights (Hs) and periods (Ts) representing waves from a SSE to SSW direction - the predominant wave propagation directions for this coastline - (165°- 195°N), with return periods of 1 in 1 year and 1 in 50 year were used in the model (see Table 4.2). The wave heights and periods used in this model were those previously determined for the Mobile Bed Physical Model and provide results based on one frequent and one extreme condition. A series of 500 waves were run for each model.

Table 4.2. Wave conditions used in the model.

Return Period (years)	Wave Height, Hs (m)	Wave Period, Ts (sec)
1 in 1 year	3.37	6.6
1 in 50 year	5.11	8.1

4.5 Water Levels

Water levels were determined from the Admiralty Tide Tables and the most recent work in determining extreme levels around this coastline (Posford Haskoning, 2002).

The model was run under MHWS and MHWN mean sea levels and the 1 in 1 year and 1 in 50 year return period water levels to give results based on frequent and extreme water level conditions (Table 4.3).

Table 4.3. Water levels used in the model.

Return Period (years)	Water Level (mODN)
MHWS	2.06
MHWN	0.86
1 in 1 year	2.66
1 in 50 year	3.36

5 RESULTS

A large volume of data has been produced for twelve differing revetment height/distance from cliff face configurations. Each profile has been numerically modelled under eight different water level and wave return period configurations as shown in the following table:

Table 5.1. Water level and wave return period configurations used in the model.

1	MHWS water level (2.06m) and the 1 in 1 year wave height and period (3.37m, 6.6secs)
2	MHWS water level (2.06m) and the 1 in 50 year wave height and period (5.11m, 8.1secs)
3	MHWN water level (0.86m) and the 1 in 1 year wave height and period (3.37m, 6.6secs)
4	MHWN water level (0.86m) and the 1 in 50 year wave height and period (5.11m, 8.1secs)
5	1 in 1 year water level (2.66m) and the 1 in 1 year wave height and period (3.37m, 6.6secs)
6	1 in 1 year water level (2.66m) and the 1 in 50 year wave height and period (5.11m, 8.1secs)
7	1 in 50 year water level (3.36m) and the 1 in 1 year wave height and period (3.37m, 6.6secs)
8	1 in 50 year water level (3.36m) and the 1 in 50 year wave height and period (5.11m, 8.1secs)

In order to provide representative comparisons of the performance of the various structures and beach profiles the analysis focussed on one frequent and one extreme condition as follows:

1. MHWS water level (2.06m) and the 1 in 1 year wave height and period (3.37m, 6.6secs)

2. 1 in 50 year water level (3.36m) and the 1 in 1 year wave height and period (3.37m, 6.6secs)

A complete dataset of the results are included in Attachment B.

5.1 Overtopping rates for revetment constructed at the base of cliffs

Table 5.2. Mean overtopping rates for 1987 and present day.

	1987 Profile			Present Day Profile				
					Revetment Crest Level (ODN)			
		+0.5m	-0.5m		3.5m	4.0m	4.5m	5.0m
MHWS water level/1 in 1 yr Hs (cum/s/m)	0.008	0.000	0.034	0.153	0.005	0.001	0.000	0.000
1 in 50 yr water level/1 in 1 yr Hs (cum/s/m)	0.260	0.002	0.692	1.787	0.254	0.091	0.030	0.008

Table 5.3. Peak overtopping rates for 1987 and present day.

	1987 Profile			Present Day Profile				
					Revetment Crest Level (ODN)			
		+0.5m	-0.5m		3.5m	4.0m	4.5m	5.0m
MHWS water level/1 in 1 yr Hs (cum/s/m)	0.371	0.222	0.735	2.160	0.364	0.122	0.027	0.000
1 in 50 yr water level/1 in 1 yr Hs (cum/s/m)	2.244	1.140	3.463	5.458	2.163	1.242	0.713	0.359

Figure 1. Graphical representation of the mean and peak overtopping rates.

5.2 Overtopping rates for revetment constructed 10 metres from the base of cliffs

Table 5.4. Mean overtopping rates for 1987 and present day.

	1987 Profile			Present Day Profile				
					Revetment Crest Level (ODN)			
		+0.5m	-0.5m		3.5m	4.0m	4.5m	5.0m
MHWS water level/1 in 1 yr Hs (cum/s/m)	0.008	0.000	0.034	0.153	0.004	0.000	0.000	0.000
1 in 50 yr water level/1 in 1 yr Hs (cum/s/m)	0.260	0.002	0.692	1.787	0.270	0.116	0.039	0.010

Table 5.5. Peak overtopping rates for 1987 and present day.

	1987 Profile			Present Day Profile				
					Revetment Crest Level (ODN)			
		+0.5m	-0.5m		3.5m	4.0m	4.5m	5.0m
MHWS water level/1 in 1 yr Hs (cum/s/m)	0.371	0.222	0.735	2.160	0.260	0.069	0.000	0.000
1 in 50 yr water level/1 in 1 yr Hs (cum/s/m)	2.244	1.140	3.463	5.458	2.181	1.425	0.644	0.338

Figure 2. Graphical representation of the mean and peak overtopping rates.

5.3 Overtopping rates for revetment constructed 15 metres from the base of cliffs

Table 5.6. Mean overtopping rates for 1987 and present day.

	1987 Profile			Present Day Profile				
					Revetment Crest Level (ODN)			
		+0.5m	-0.5m		3.5m	4.0m	4.5m	5.0m
MHWS water level/1 in 1 yr Hs (cum/s/m)	0.008	0.000	0.034	0.153	0.004	0.000	0.000	0.000
1 in 50 yr water level/1 in 1 yr Hs (cum/s/m)	0.260	0.002	0.692	1.787	0.276	0.108	0.038	0.010

Table 5.7. Peak overtopping rates for 1987 and present day.

	1987 Profile			Present Day Profile				
					Revetment Crest Level (ODN)			
		+0.5m	-0.5m		3.5m	4.0m	4.5m	5.0m
MHWS water level/1 in 1 yr Hs (cum/s/m)	0.371	0.222	0.735	2.160	0.194	0.019	0.000	0.000
1 in 50 yr water level/1 in 1 yr Hs (cum/s/m)	2.244	1.140	3.463	5.458	1.814	1.205	0.168	0.351

Figure 3. Graphical representation of the mean and peak overtopping rates.

6 DISCUSSION

The pre 1989/90 storm foreshore was interpreted from aerial photographs taken of the Salcombe Hill frontage in 1987. This was a period when the beach conditions are considered to have provided sufficient protection to the frontage. All interpreted data should be treated with some caution and as such a sensitivity of +/-0.5 metres was additionally modelled and included in the analysis. The 1987 profile of the foreshore is, however, considered to be a good representation of beach levels present prior to the storm events of 1989/90.

The model uses varying bed friction values along the profile. The rock revetment structure was given a relatively high friction value to simulate the change in material from sand/shingle to coarse rock/boulders. The program does not account for the dissipation of hydrodynamic forces within the rubble mound structure, and as such although the results are likely to be representative of the likely overtopping, considerations such as the type and grading of the armour will have an effect on reducing overtopping values (both peak and average).

From the graphs above (Figures 1 to 3), it can be seen that the 1987 profile and the +/-0.5m 1987 profile follow the pattern expected. That is, by lowering the 1987 profile the overtopping rate experienced at the cliff face increases and by increasing the height of the 1987 profile the overtopping rate decreases. This pattern provides an initial validation to the model.

The graphs show that all the revetments would reduce the overtopping rate at the cliff toe when compared against the results of the present day profile with no revetment in place. A structure within the height range modelled would satisfy the condition of reducing erosion of the cliff face without stopping it completely.

The results all display the anticipated trend of decreasing overtopping rates at the cliff toe as the height of the revetment structure is increased. This trend provides further validation to the model. When compared against each other, the graphs show that the distance of the revetment from the cliff face has not made a significant difference to the overtopping rates exhibited at the cliff toe. The effectiveness of the revetment in simulating the conditions that prevailed prior to the 1989/90 storm events is therefore based predominantly on the height of the revetment structure.

The results show that a revetment constructed with a crest level of 3.5 metres ODN produces similar overtopping rates to those rates yielded from the 1987 profile. The revetments constructed above 3.5 metres ODN reduce the overtopping rate experienced at the cliff toe when compared against the 1987 profile.

If the +0.5 metre sensitivity of the 1987 profile is compared against the revetment profiles, the best comparison is gained against the revetments constructed with a crest level of 4.0 metres ODN. A revetment constructed with a crest level of 3.5 metres ODN in this instance will lead to higher levels of overtopping than those experienced under the 1987 +0.5 metre condition whilst a revetment constructed with a crest level above 4.0 metres ODN will reduce the overtopping rate experienced at the cliff toe.

Under the 1987 –0.5 metre sensitivity profile, all of the revetments considered would provide greater protection to the cliff toe than that experienced under the 1987 -0.5 metre condition.

It is important to note that the projected future increase in the rate of sea level rise to 6 millimetres per year will, in time, result in increased overtopping and erosion of any coast protection structure.

As discussed above, the distance of the revetment from the cliff face has made little difference to overtopping rates across the range of heights modelled; the revetment with a crest level of 3.5 metres ODN constructed at the cliff face, for example, produces similar overtopping rates to a revetment of the same crest level constructed at 10m and 15m from the cliff face. Considerations of the position of the structure with respect to the cliff face are therefore dependent on other issues (such as health and safety). Positioning the structure with respect to the cliff face will be based on previous work and experience; construction and public safety issues; and construction costs.

Previous work carried out by Posford Haskoning at Seaton, which lies approximately 16km to the east of Sidmouth, involved the design and construction of a revetment to provide full protection to the Seaton frontage in 1999. The cliffs at Seaton are of similar geological composition to those at Sidmouth – Mercia Mudstones Sandstones. A revetment, designed to stop erosion, was constructed at the cliff face with a crest level of 4.8 metres ODN. The crest level is higher than historical levels of the beach and therefore compensates for the protection provided to the cliffs by the beach following beach drawdown events. Three years on from its construction, the revetment at Seaton is proving to be successful in providing complete protection to the frontage following storm and beach depletion events.

The instability of the cliffs at Pennington Point and Salcombe Hill could present a danger to construction staff if the revetment is constructed too close to the cliff face. As overtopping rates differ little by varying the distance of the revetment from the cliff face, it would prove safer to construct the revetment some distance from the cliff face. However, as the distance of the structure increases so will the costs of construction due to the crest levels remaining constant whilst the foreshore levels lower – the increase in volume of the structure will require more rock. Ultimately, positioning the revetment has to be based on a balance between construction safety and construction costs.

7 CONCLUSIONS AND RECOMMENDATIONS

Any scheme adopted to provide protection to Pennington Point and the Salcombe Hill frontage should be able to withstand storm conditions of relatively frequent occurrence. In the course of the optimisation and development of a revetment to provide protection to the frontage, 15 variations have been modelled against a model of the 1987 beach profile under one frequent and one extreme event.

It is concluded that:

- A revetment with a crest level of 3.5 metres ODN constructed within the range of 0 to 15 metres from the cliff face would simulate the conditions that prevailed under the interpreted 1987 beach conditions.

- Due to the relative instability of the cliff face, a revetment constructed at the cliff face could present a danger to construction staff.

- Construction costs increase as the distance of the revetment from the cliff face increases, due to associated increases in the volume of rock required.

- Photographs of Pennington Point and the Salcombe Hill frontage over the years have shown the western limit of the frontage is more susceptible to beach depletion, wave attack and cliff falls.

From the above conclusions it is recommended that:

- A revetment of varying height be constructed along the frontage. A crest of 4.0 metres ODN at the western end (Pennington Point), where the frontage is more susceptible to cliff falls, tapering to 3.5 metres ODN over the remaining frontage.

- The revetment be constructed between 5 to 15 metres from the cliff face in response to construction safety and construction cost issues.

8 REFERENCES

1. HR Wallingford. 1993. Mobile Bed Physical Model Study.

2. Posford Duvivier. 2001. Sidmouth – Pennington Point Coastal Study.

3. Posford Haskoning. 2002. Regional Extreme Tide Levels, South West Region – Report for the Environment Agency.

Attachment A

Photographs

Photograph A1. 1987 photograph used to determine pre 1989/90 storm beach levels.

Photograph A2. 1995 photograph showing denuded beach fronting Pennington Point and Salcombe Hill.

Attachment B.

Summary of AMAZON results

Table B1. Revetment constructed at cliff face.

	Revetment Crest Level (ODN)			
	3.5m	4.0m	4.5m	5.0m
MHWS water level/1 in 1 yr Hs, average rate (cum/s/m)	0.0049	0.0008	0.0001	0.0000
MHWS water level/1 in 1 yr Hs, peak rate (cum/s/m)	0.3642	0.1224	0.0264	0.0000
1 in 50 yr water level/1 in 1 yr Hs, average rate (cum/s/m)	0.2541	0.0905	0.0296	0.0077
1 in 50 yr water level/1 in 1 yr Hs, peak rate (cum/s/m)	2.1637	1.2415	0.7132	0.3588

Table B2. Revetment constructed 10m from cliff face.

	Revetment Crest Level (ODN)			
	3.5m	4.0m	4.5m	5.0m
MHWS water level/1 in 1 yr Hs, average rate (cum/s/m)	0.0044	0.0002	0.0000	0.0000
MHWS water level/1 in 1 yr Hs, peak rate (cum/s/m)	0.2597	0.0691	0.0000	0.0000
MHWN water level/1 in 1 yr Hs, average rate (cum/s/m)	0.0017	0.0270	0.0099	0.0037
MHWN water level/1 in 1 yr Hs, peak rate (cum/s/m)	0.0735	2.3266	1.6592	1.2973
MHWS water level/1 in 50 yr Hs, average rate (cum/s/m)	0.0510	0.0000	0.0000	0.0000
MHWS water level/1 in 50 yr Hs, peak rate (cum/s/m)	2.9791	0.0000	0.0000	0.0000
MHWN water level/1 in 50 yr Hs, average rate (cum/s/m)	0.0027	0.0011	0.0001	0.0000
MHWN water level/1 in 50 yr Hs, peak rate (cum/s/m)	0.9506	0.6362	0.1575	0.0220
1 in 1 yr water level/1 in 1 yr Hs, average rate (cum/s/m)	0.0487	0.0158	0.0022	0.0001
1 in 1 yr water level/1 in 1 yr Hs, peak rate (cum/s/m)	0.7762	0.4368	0.1822	0.0661
1 in 1 yr water level/1 in 50 yr Hs, average rate (cum/s/m)	0.1679	0.0930	0.0397	0.0149
1 in 1 yr water level/1 in 50 yr Hs, peak rate (cum/s/m)	4.2342	3.5192	2.6661	2.1286
1 in 50 yr water level/1 in 1 yr Hs, average rate (cum/s/m)	0.2699	0.1157	0.0393	0.0101
1 in 50 yr water level/1 in 1 yr Hs, peak rate (cum/s/m)	2.1818	1.4254	0.6442	0.3381
1 in 50 yr water level/1 in 50 yr Hs, average rate (cum/s/m)	0.5419	0.3006	0.1494	0.0698
1 in 50 yr water level/1 in 50 yr Hs, peak rate (cum/s/m)	6.3276	5.4224	436655	3.9083

Table B3. Revetment constructed 15m from cliff face.

	Revetment Crest Level (ODN)			
	3.5m	4.0m	4.5m	5.0m
MHWS water level/1 in 1 yr Hs, average rate (cum/s/m)	0.0044	0.0000	0.0000	0.0000
MHWS water level/1 in 1 yr Hs, peak rate (cum/s/m)	0.1938	0.0187	0.0000	0.0000
1 in 50 yr water level/1 in 1 yr Hs, average rate (cum/s/m)	0.2755	0.1080	0.0380	0.0104
1 in 50 yr water level/1 in 1 yr Hs, peak rate (cum/s/m)	1.8143	1.2050	0.6182	0.3513