Ventnor Options Appraisal

Technical Report

Revision 5

8th October 2019

Isle of Wight Council

Ventnor Options Appraisal

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Executive Summary

The towns of Ventnor and Bonchurch are located in the Undercliff on the south coast of the Isle of Wight, on a complex pre-existing deep landslide system that is subject to land instability caused by coastal erosion and excess groundwater levels. The frontage is protected by various coastal defences which have a positive benefit on the stability of the Undercliff; however, many are nearing the end of their design life and require repair or replacement to ensure an acceptable standard of coastal protection is provided over the next 100 years. Without coastal defences, the Undercliff landslide system will become more active than present with accelerated rates of toe erosion causing widespread ground movement, landslide reactivation and asset damage in Ventnor and Bonchurch. Given the status quo, and even with improved coastal defences in future, the incipient ground movement damage to infrastructure, property, and services experienced historically is still likely to occur and increase, without deep drainage intervention, due to the effects of climate change, extreme winter rainfall and excess groundwater levels.

As part of appraisals required for gaining government funding for replacement coastal defences, Jacobs (previously CH2M) was commissioned by Isle of Wight Council to provide an initial appraisal and scheme identification for Ventnor and Bonchurch. This technical report forms part of the overarching assessment to identify how the 'Hold the Line' policies for the Ventnor and Bonchurch frontage can be implemented, by evaluating a range of options, seeking best value for money in schemes that are technically robust, environmentally acceptable, economically justified and in full accordance with the latest FCERM Appraisal Guidance.

The report comprises a quantitative risk assessment (QRA) of ground movement, landslide hazard and consequence scenarios, and a cost benefit analysis (CBA) of maintaining and replacing the coastal defences at Ventnor and Bonchurch. The QRA and CBA are used to provide an auditable decision-making tool for the management and prioritised investment in coastal defences and deep drainage measures to prevent coastal erosion and land instability that will ensure the long-term viability of the frontage for the community and also for safe access, recreation and tourism. To achieve this, the QRA and CBA compare the risk profiles and economic benefits of three possible future management cases:

- The 'do nothing' option, effectively involves allowing the frontage and Undercliff to evolve naturally. It results in a significant increase in risk once the residual life of the existing coastal and cliff stabilisation measures is exceeded.
- The 'do minimum' option involves limited intervention and can be an appropriate and effective risk mitigation strategy to temporarily reduce but not remove the possible consequences of harmful events.
- The 'improve' options, involving various coastal protection schemes and deep cliff drainage measures to prevent or reduce the likelihood of damaging events.

Development of the QRA and CBA in this study has involved detailed analysis of the following cliff behaviour and consequence parameters:

- the full extent of the cliffs, landslides, systems and processes
- the types of contemporary ground movement
- the frequency of landslide events
- the causes of landslides, including coastal erosion, antecedent rainfall and groundwater
- the predicted impacts of climate change including sea level rise and increasing winter rainfall
- the impact of ground movement in built up areas
- the extent, condition and economic value of the assets at risk
- the vulnerability of different buildings to cliff instability and ground movement
- the cost and impact on risk reduction of all feasible future coastal defence and cliff stability management/engineering options.

To deal with the unique circumstances of the Undercliff at Ventnor and Bonchurch, it has been necessary to develop a bespoke QRA to model the various hazard scenarios and their consequences. Qualifying benefits under national Outcome Measures 3 relate to the reduction in direct damages to residential properties caused by eroding coastlines. At Ventnor and Bonchurch coastal erosion has far wider reaching consequences than would normally be expected of simple eroding cliffs because the Undercliff landslide complex extends up to 500m landward of the shoreline and encompasses the majority of the built-up area. Coastal erosion at the toe of the slope will trigger and unlock ground movement further upslope in the landslide complex.

As such, the QRA developed for this study doesn't consider the linear coastal erosion recession model typically used in OM3, rather the annual damages caused by cliff instability and erosion throughout the entire part of the Undercliff occupied by the town, from the shoreline to the Undercliff headscarp. The QRA uses a probabilistic approach to modelling landslide hazards and the benefits of controlling coastal erosion and groundwater. The assessment acknowledges the fundamental link between cliff instability and erosion by the sea that is required to be considered for grant in aid under the Coast Protection Act 1949. This approach is wholly consistent with the EA guidance (FCERM-AG, 2010) and other complex coastal cliff stabilisation schemes, such as Lyme Regis Phases II & III, East Cliff Phase IV, Fairlight Cove and Scarborough Spa.

To address the EA guidance that 'to secure asset design life, existing or proposed coast protection works may require complementary drainage or slope stabilisation to prevent landslides endangering their integrity', the benefits of deep drainage to provide additional risk reduction has also been assessed.

Investment in coastal defences and landslide stabilisation needs to be offset by the resultant reduction in losses that will otherwise occur. As such, the CBA compares the total expected cost of the range of management and engineering options against the total expected benefits (or reduction in losses over the study period afforded by the various options), to see whether the benefits outweigh the costs, and by how much. The CBA results demonstrate that the existing aging coastal and cliff stabilisation schemes and practices (do minimum) adopted at Ventnor and Bonchurch have moderately reduced economic risk across the study site. The risks could be reduced significantly further, however, by improving the global stability of the area. The results demonstrate that effective coastal cliff and landslide management at Ventnor and Bonchurch requires solutions that prevent coastal erosion and excess groundwater levels.

At a strategic level over 100 years there are economically viable schemes comprising deep drainage and various new and upgraded coastal defences for defined landslide reactivation units (LRUs) with high total asset values and/ or at least one of the coastal defences being in very poor condition (Ventnor Park, Central Ventnor, Wheelers Bay and Castle Cove). Schemes at Bonchurch West and Bonchurch East, comprising drainage and coastal defence schemes targeted at failing assets are potentially viable but will likely require further notable partnership funding to proceed. There is unlikely to be a viable scheme at 'The Landslip' area in the east, although the consequences of landslide recession breaching the A3055 road will have significant local and political implications in the future.

The next phase of the overarching assessment of coastal defence management at Ventnor and Bonchurch is the Future Schemes report which will move the generic 100-year assessment presented here into identifying future schemes and their spending profiles, to inform the national programme requirements for future funding cycles. To develop the most robust cost model for a programme that will meet partnership funding requirements in the Future Schemes Report, the Improve options providing the best benefit cost ratio for each LRU, are developed through the Partnership Funding calculator to identify economically viable future schemes.

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Acronyms and Abbreviations

AONB	Area of Outstanding Natural Beauty
AWB	Artificial Water Bodies
BCR	Benefit Cost Ratio
BGS	British Geological Survey
CBA	Cost Benefit Analysis
DEM	Digital Elevation Model
EA	Environment Agency
FCERM	Flood and Coastal Erosion Risk Management
FCERM-AG	Flood and Coastal Erosion Risk Management Appraisal Guidance
FDGiA	Flood Defence Grant in Aid
GI	Ground Investigation
GiA	Grant in Aid
H&S	Health and Safety
HMWB	Heavily Modified Water Bodies
IBCR	Incremental Benefit Cost Ratio
IOW	Isle of Wight
IWC	Isle of Wight Council
LNR	Local Nature Reserve
LRU	Landslide Reactivation Unit
MCM	Multi-coloured Manual
PF	Partnership Funding
PV	Present Value
QRA	Quantitative Risk Assessment
RBMP	River Basin Management Plan
SAC	Special Area of Conservation
SPA	Special Protection Areas
SMP	Shoreline Management Plan
SSSI	Site of Special Scientific Interest
WFD	Water Framework Directive

1. Introduction

1.1 Overview

The town of Ventnor and Bonchurch Village are situated in the Undercliff, an extensive coastal cliff and landslide complex with significant urban development where approximately 7,000 people live. The site covers a 4 km section of the eastern Undercliff, comprising the steepest and most developed part of the landslide complex (Figure 1). Coastal defences at the toe of the undercliff help prevent landslide reactivation that would otherwise occur if erosion was not controlled. Beyond the limits of the coastal defences active toe erosion, cliff recession and landsliding are evident.

Despite the toe protection afforded by the coastal defences, the Undercliff at Ventnor and Bonchurch is subject to slope instability including progressive deep-seated ground movement and occasional landslides due to the effects of rainfall and groundwater. As a result of urban occupation and land use, the cumulative impact and associated cost to the coastal defence assets, roads, property, businesses and services has been substantial.

The Isle of Wight Council (IWC) has taken a major role in addressing coastal erosion and cliff instability. Important elements of their strategy include various coastal defences and slope stabilisation measures, site investigation, monitoring and ad hoc repairs to property and infrastructure. However, because many of the coastal defence structures are ageing and over the next century, climate change and relative sea level rise are expected to result in an increase in coastal erosion and cliff instability, a more efficient and coordinated plan of coastal management is required to mitigate the increasing risk.

This technical report provides an assessment of coastal management options for Ventnor and Bonchurch. It comprises a quantitative risk assessment (QRA) of landslide hazard and consequence scenarios, and a cost benefit analysis (CBA) of maintaining and replacing the coastal defences at Ventnor and Bonchurch. It forms a key element of the overarching assessment aimed at identifying technically robust and economically viable coastal protection and cliff management options to reduce coastal instability risk at Ventnor and Bonchurch.

In summary, the overarching assessment comprises the following elements:

1. **Structures assessment**: provides the baseline condition and residual life of the existing coastal defences.
2. **Technical report**: provides the baseline condition of land instability in the Undercliff, quantitative risk assessment and cost benefit analysis of mitigation options.
3. **Future schemes report**: provides option selection and forward proposals/spending profile for priority schemes with a robust case for seeking grant in aid (GiA) funding during future funding cycles
4. **Non-technical summary**: provides a non-technical summary of the above.

The work has been carried out during between 2017-2019 in full accordance with all relevant and latest national flood and coastal erosion risk management guidance.

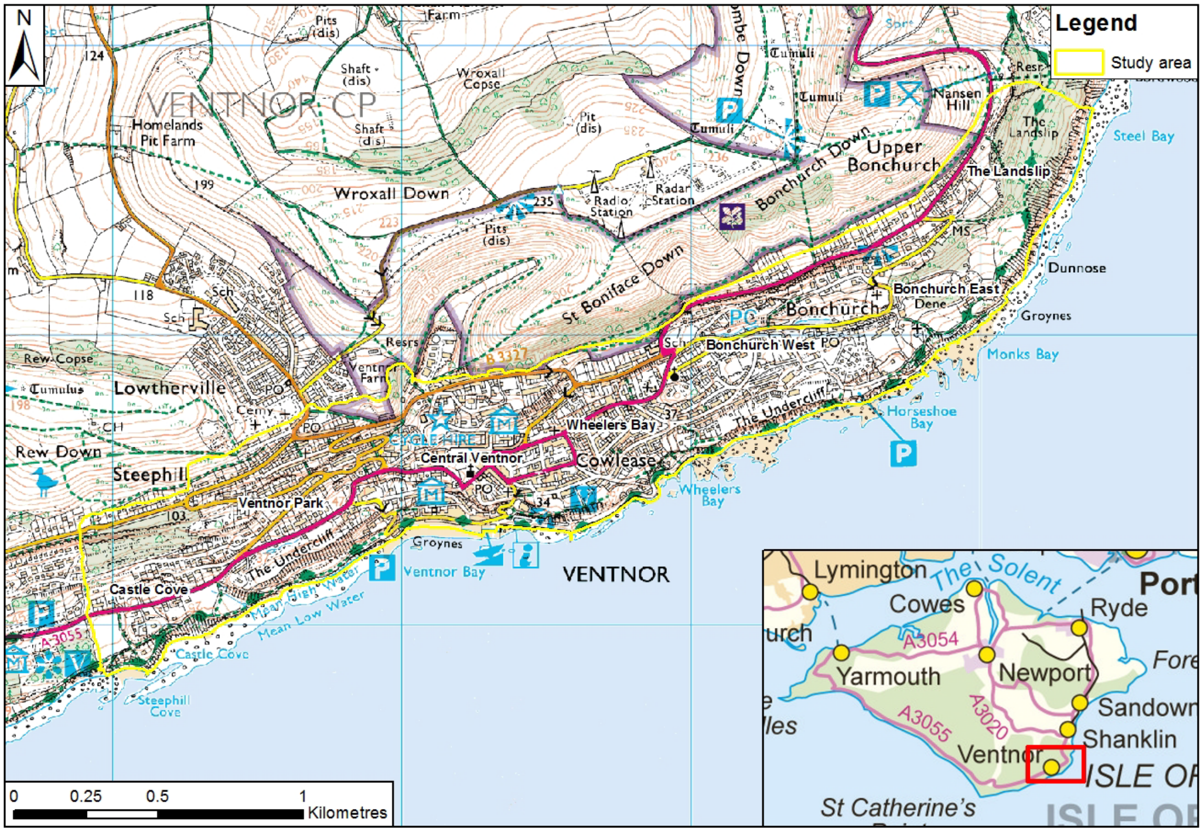

Figure 1. Site location map. Credit: OS © Crown copyright (2017).

1.2 Background

The study area is the 4 km frontage between Steephill Cove, Ventnor and Monk's Bay, Bonchurch. This area has a variety of existing coastal defences and cliff stabilisation schemes to reduce the risk of coastal erosion and cliff instability; the IWC is the asset maintainer. The coastal defences were constructed up to 30 years ago and require a coordinated plan for their maintenance and replacement, including sections requiring urgent repair (such as the deteriorating steel sheet piling along Ventnor Eastern Esplanade and west of Wheeler's Bay). Maintaining and improving the coastal defences will be key to preventing toe erosion, cliff instability and landslide reactivation on the Undercliff, and consequential damages and losses to services, infrastructure and property.

This technical report forms part of the overarching assessment to identify how the 'Hold the Line' policies for the Ventnor and Bonchurch frontage can be implemented, by evaluating a range of options, seeking best value for money in schemes that are technically robust, environmentally acceptable, economically justified and in full accordance with the latest FCERM Appraisal Guidance. The QRA and CBA detailed herein identify the assets and communities at risk from coastal erosion, cliff instability and erosion, and the schemes and management options which provide the most robust case for seeking GiA funding.

The particular circumstances at Ventnor and Bonchurch being exposed to the risk of coastal asset failures and their consequences due to erosion and landslides which are predicted to increase due to the effects of climate change - mean that this study has made special consideration of how coastal erosion and land instability impacts the long-term performance of existing and future coastal defences and cliff protection measures.

1.3 Study objectives

The objectives for this technical report have been delivered in accordance with Section 3 of the Technical Specification and Scope specified by IWC, and include:

- Define the characteristics and annual probabilities of credible cliff instability and landslide hazard scenarios over the next 100 years (hazard model).
- Define the consequences of each scenario in terms of the Present Value (0-99 years) economic risk (consequence model).
- Demonstrate the economic viability of different cliff management and stabilisation options (cost benefit analysis).
- Consider a programme of future coastal engineering schemes and management which achieve the best cost/benefit ratio (results of this element will be provided in the Future Schemes report)

1.4 Scope of work

The scope of work for this technical report has been delivered in accordance with requirements a, b, c, d, e, f, I and j set out in Section 3 of the Technical Specification and Scope produced by IWC. In summary, the scope comprises the following key tasks:

- **Information sources**: A review of existing ground investigations and key information sources.
- **Ground monitoring review**: An update and assessment of the *in-situ* monitoring data for the period 2002 to present.
- **Environmental review:** A review of environmental risks that need to be considered as part of the study.
- **Ground model review:** Interpretation of cliff instability and landslide mechanisms to split the frontage into Landslide Reactivation Units (LRUs) and to define failure scenarios.
- **QRA**: Quantitative risk analysis comprising Hazard and Consequence Models
- **Options Assessment**: Identification of the possible coastal and cliff management options.
- **CBA**: Cost benefit analysis to demonstrate the economic viability of various cliff management and stabilisation options.

1.5 Approach

A QRA and CBA are used to provide an auditable decision-making tool for the management and prioritised investment in risk reduction measures to prevent coastal erosion and instability of the cliffs that will ensure the long-term viability of the frontage for safe access, recreation and tourism.

The QRA is split into 2 elements, the hazard model which defines the credible landslide hazards, and the consequence model which determines the losses arising from each hazard. CBA is then used to assess the benefits of investment in the various risk reduction options.

1.5.1 Hazard model

Based on the state of knowledge, credible cliff instability and landslide hazard scenarios are developed in Section 4.2. Each scenario is underpinned by the data, observations and analysis documented by previous work. The scenarios range from low magnitude high frequency events (e.g. slope creep) to high magnitude low frequency events (e.g. first-time deep-seated landslides).

Expressed in terms of an annual probability, the scenarios represent realistic projections of what might happen based upon historical precedent of ground movement, coastal defence performance, ongoing in situ monitoring data, and current cliff behaviour conditions. Uncertainty over the frequency and magnitude of ground movement characteristics for these scenarios is accounted for through the definition of '*reference events*'. These pre-defined events provide benchmark conditions for estimating scenario probability and the development of consequence models.

1.5.2 Consequence model

In Section 4.3 the consequence model determines the annual value of losses arising from the hazard scenarios by multiplying the potential impacts of each scenario by the value of the assets affected. The assets at risk from the landslide hazard scenarios include private property, commercial property, roads, utilities, public amenity, traffic disruption, tourism and emergency service response.

1.5.3 Cost benefit analysis

A CBA is used to assess the benefits of investment in risk reduction options over the expected lifetime of a scheme. Options include planning and development control, monitoring and early warning, and engineering coastal defences and land stabilisation measures such as deep drainage. Costs will include all those incurred during the investigation, planning and design, construction and operation of future schemes.

This study compares risk profiles of three future management cases:

- The 'do nothing' option, effectively involves walking away and allowing the frontage and cliffs to evolve naturally. It results in a significant increase in risk once the residual life of the existing coastal and slope stabilisation measures are exceeded. Whilst this may be unrealistic throughout much of the frontage at Ventnor and Bonchurch it provides a baseline against which other management options, including current practice, can be assessed.
- The 'do minimum' option involves limited intervention and can be an appropriate and effective risk mitigation strategy to reduce but not remove the possible consequences of harmful events (e.g. minor maintenance of existing coastal and cliff stabilisation measures, ad-hoc repairs to paths and highways).
- The 'improve' options, involving coastal protection schemes and cliff stabilisation measures to prevent or reduce the likelihood of damaging events, are appropriate where the risks are found to be high and engineering schemes are justified. Under this option, risk reduction is achieved through engineering, such as new sea walls and deep drainage and/or by extending the residual life of current defences.

1.6 Information sources

This section details the main sources of technical information used to undertake the options study.

Key to this assessment are the following projects commissioned by IWC and carried out by CH2M and others:

- **Ventnor Undercliff, Isle of Wight Coastal Instability Risk: Interpretative Report and Quantitative Risk Analysis, Halcrow Group Ltd 2006**. This report provides a quantitative risk assessment of the Ventnor Park landslide system based on a reinterpretation of the landslide ground model enabled via two major ground investigations and *in situ* slope monitoring in 2002 and 2005. This report covers the central part of the new study area. The understanding of the mechanisms, causes and long-term behaviour of the Undercliff landslide complex and economic consequences established in this report are used here as the framework to extend and develop a fully quantitative cost benefit appraisal of future landslide reactivation scenarios across the study area of this new study between Castle Cove and the Landslip.
- **Ventnor to Niton A3055 Route Options Study Appraisal Report, Halcrow Group Ltd 2010**. This study addressed the problems of ground instability and risk to the Undercliff Drive between St Lawrence and Niton, and identified options for mitigation and relocation of the strategic road network including whole life costing and extensive local consultation.
- **Undercliff Drive Expert Review and Position Statement, CH2M 2017.** This study provides an up-to-date expert review on the state of knowledge on the Undercliff ground models and hydrogeology from existing technical reports and published literature.
- **Isle of Wight Shoreline Management Plan 2 (IWC, Royal Haskoning, EA 2010).** The SMP provides a large-scale assessment of the risks associated with coastal evolution and presents a

policy framework to address these risks to people and the developed, historic and natural environment in a sustainable manner

Also central to the Ventnor options assessment are the following peer-reviewed journal papers and good practice guides on the Ventnor Undercliff:

- R Moore, EM Lee and AR Clark (1995). The Undercliff of the Isle of Wight: a Review of Ground Behaviour, ISBN 1 873295 70 7. Cross Publishing, Newport, Isle of Wight, 1995.
- EM Lee and R Moore (1991). Coastal Landslip Potential Assessment: Isle of Wight Undercliff, Ventnor. DoE Research Contract PECD 7/1/272.
- J Carey, R Moore and D Petley (2014). Patterns of movement in the Ventnor landslide complex, Isle of Wight, southern England. Journal on Landslides, 12(6), 1107-1118.
- R Moore, JM Carey & RG McInnes (2010). Landslide behaviour and climate change: predictable consequences for the Ventnor Undercliff, Isle of Wight. Quarterly Journal of Engineering Geology and Hydrogeology, Vol. 43, pp447-460.
- J Barlow, R Moore and D Gheorghiu (2016). Reconstructing the recent failure chronology of a pre-existing multistage landslide complex using cosmogenic isotope concentrations: St Catherine's Point, UK. Geomorphology 268; 288–295.

The following guidance and peer-reviewed journal papers completed by CH2M under commission to the Environment Agency are integral to developing guidance on the funding of cliff protection works for the option assessment in Sections 5 and 6:

- Halcrow Group Ltd (2010) Assessment of coastal erosion and landsliding for the funding of coastal risk management projects: guidance notes. Report published by the Environment Agency.
- R Moore & RG McInnes (2011) Cliff instability and erosion management in Great Britain: a good practice guide. Published by Halcrow Group Ltd.
- R Moore and G Davis (2015) Cliff instability and erosion management in England and Wales. Journal of Coastal Conservation, 19(6), 771-784.

The options assessment has also made reference to other authorities and communities facing similar complex coastal defence and cliff instability issues:

- R Moore, M Stannard, G Davis & N Browning (2016) Stabilising Lyme Regis – a strategic approach. Proceedings of the Institution of Civil Engineers.

Guidance on adaptation to property loss and innovative approaches to planning policy and stakeholder engagement, including partnership funding of coastal protection schemes, has been drawn from:

- R Siddle, S Rowe and R Moore (2016). Adaptation to Property Loss due to Coastal Cliff Instability and Erosion: Case study into the Knipe Point Cliff Retreat Pathfinder Project. A Baptiste (ed) Coastal Management: proceedings of the international conference, Amsterdam, 8-9 September 2015. ICE Publishing.
- R Moore, RG McInnes (2012). Landslides and climate change – innovative approaches to planning policy and stakeholder engagement in England. Proc. of the 11th International and 2nd North American Symposium on Landslides and Engineered Slopes, Banff, Canada, Vol. 1; 395-400.
- A Frampton, A Parsons, J Pickles, and J Kippax (2015). A New Coastal Change Adaptation Planning Guide for England. ICE Coastal Management Conference, Amsterdam, The Netherlands, 7-9 September 2015.

2. Undercliff setting

This section collates the factual data and understanding that underpins development of the Hazard Model in Section 4.2.

2.1 Site location

The study area is located at Ventnor and Bonchurch on the south coast of the Isle of Wight. The 4 km frontage is situated in the Undercliff, an extensive coastal cliff complex with significant urban development. Where developed the frontage is protected from coastal erosion by a variety ageing coastal defences including seawalls, rock revetments and steel sheet piling. The terraces of the landslide complex above the frontage area are generally fully developed, including large numbers of residential properties, Ventnor town center, and numerous roads and other assets. The 3D section through Ventnor Park in Figure 2 is typical of much of the site. It shows the landslide complex is split into upper and lower tiers (this is developed further in Section 3) and how these are divided into a number of landslide terraces based on the series of rotational landslide blocks. The area has a 'Hold The Line' policy set in the Shoreline Management Plan (2011).

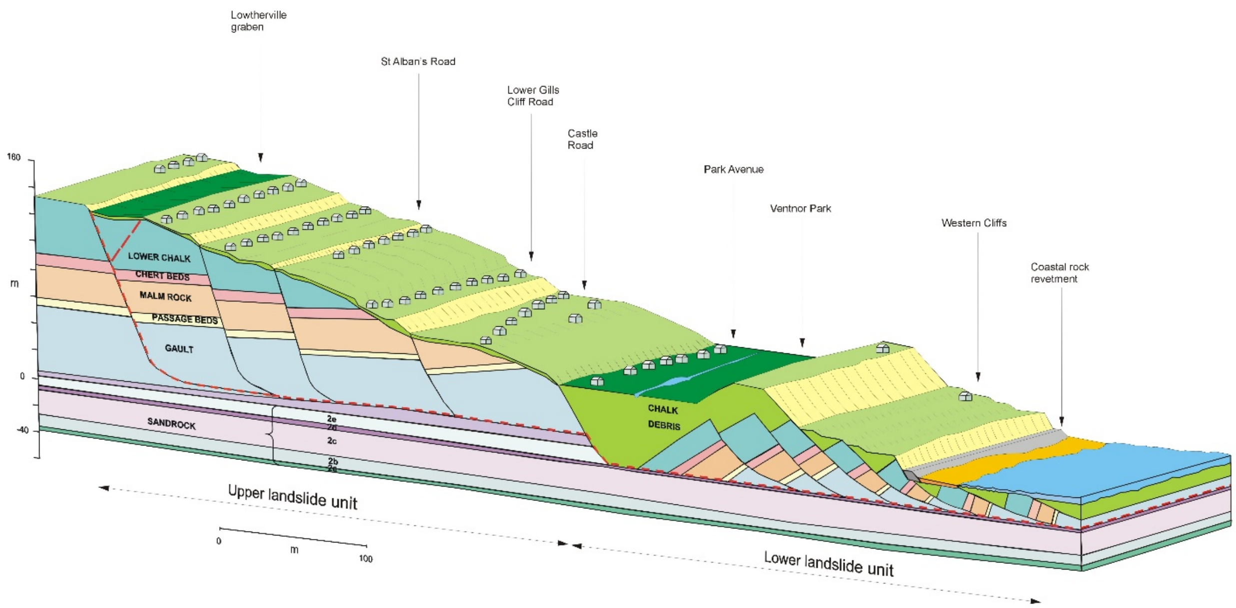

Figure 2. 3D section illustrating the landslide mechanisms at Ventnor Park, and the property located upon the various landslide blocks (Source: Moore et al. 2010).

2.2 Geology

The Undercliff is situated on the southern limb of the Southern Downs and comprises a sequence of interbedded sedimentary rocks that dip seaward by about 1.5° – 2° (White 1921, BGS 2017). The sedimentary rocks were laid down in the Cretaceous period, approximately 80 to 120 million years ago. Parts of the Lower Chalk and Upper Greensand Formations are exposed in the rear scarp of the Undercliff. These are underlain by the Gault Formation (known locally as the 'blue slipper') and the Lower Greensand Formation. Detailed accounts of the geology of the Isle of Wight and Undercliff are provided by White (1921) and Hutchinson and Bromhead (2002). The St Lawrence – Ventnor syncline (after Hutchinson 1965) is an important feature that controls strata outcrop at the shoreline, the hydrogeology regime, and the mechanism and depth of landslides along the Undercliff. This is considered further in Section 3.

Table 1 provides description of the key geological (stratigraphic) units proved by ground investigations in the Undercliff, particularly those funded by IWC in more recent times at Bonchurch (2002), Ventnor (2002 and 2005) and Undercliff Drive (2001-2004). The Gault and the Sandrock 2d shear surfaces on which the upper and lower tier of the Undercliff landslide complex is formed respectively are highlighted. Terminology follows current BGS nomenclature, with former names included where relevant. All borehole locations and logs have been assembled in a geospatial database, in ArcGIS format, for the purposes of correlating key strata between boreholes and for developing the ground models in Section 3.

This geological sequence has been severely disrupted along much of the Undercliff as a result of both deep seated and shallow mass movements, with some strata being lost completely as a result of major landslides and other strata being displaced, contorted and overturned by large block movements.

Some of the borehole logs in the area are freely available on open access from the British Geological Survey (BGS), whilst others are on restricted access from the BGS or are only available in unpublished reports. The information from the borehole logs has been brought together to produce the ground models described in Section 3.3.

2.3 Hydrogeology

The hydrogeology of the Undercliff is directly linked to the occurrence of ground instability and landsliding. The Undercliff is connected with the Southern Downs which collects water from precipitation. Because the watershed lies very close to the southern edge of the Downs, most surface and near-surface water drains northwards away from the Undercliff via the Whitwell and Wroxall valleys into the Eastern Yar and to a lesser extent the Medina. The shallow southerly dip carries the more deeply infiltrating groundwater towards the Undercliff where it feeds into the rear of the landslides via well-developed springs within the Passage Beds.

Hutchinson and Bromhead (2002) identify two main aquifers comprising the Chalk and Upper Greensand, and the Lower Greensand, which are separated by the Gault aquitard. The upper aquifer is unconfined and perched on the relatively impermeable Gault, whilst the lower aquifer is confined beneath the Gault. The degree of influence exerted by the lower aquifer on the landslides has not been established, but could be significant where artesian groundwater pressures are present.

Knowledge and understanding of the hydrogeology of the Undercliff landslides has been greatly improved in recent decades from the results of ground investigations at Bonchurch and Ventnor (Halcrow Group Ltd 2002, 2006; Moore et al. 2010) and the Undercliff Drive (High-Point Rendel 2004, Bracegirdle et al. 2007). The link between Undercliff hydrogeology, rainfall, groundwater and instability is considered further in the Undercliff ground behaviour models in Section 3.

Table 1. Lithostratigraphy of the Undercliff (revised after Palmer et al. 2007, Halcrow Group Ltd. 2009 and BGS lexicon).

Group	Formation	Unit	Typical thickness (m)	Typical description	Relative vertical permeability
Chalk	West Melbury Marly Chalk (formerly Lower Chalk	6b Chalk Marl	>5.5	Grey clayey Chalk	Low to moderate
		6a Glauconitic Marl	2-5	Light grey to dark green clayey sand and sandstone	Low to moderate
Selborne	Upper Greensand	5c Chert Beds	6-10	Alternating bands of chert and weak sandstone	High
		5b Malm Rock	20-24	Grey clayey sandstone with strong nodules. Upper part of the Marl Rock is harder and known as the Freestone Bed	High
		5a Passage Beds	2-12	Dark grey silty and sandy cemented beds	Moderate
	Gault	**4 Undivided**	**44-45**	**Dark blue plastic clay. Lower and upper thirds are siltier. The base of the Gault is known to be the zone of weakness in which the shear surface of the upper tier of the Undercliff landslide complex is formed.**	**Very low**

Group	Formation	Unit	Typical thickness (m)	Typical description	Relative vertical permeability
Lower Greensand	Monks Bay Sandstone (formerly Carstone)	3	4-10	Brown grit with many small pebbles and clayey interbeds	High
	Sandrock	2f	0-6	Grey sand with wood, pebbles and concretions	Moderate to high
		2e	6-10	Yellow and grey cross-bedded cemented sand	Moderate
		2d	**3-6**	**Laminated silty clay. Sandrock 2d is known to be the zone of weakness in which the shear surface of the lower tier of the Undercliff landslide complex is formed.**	**Very low**
		2c	11-20	White and yellow cemented sands	Moderate to high
		2b	5-18	Mainly clay, laminated in places	Very low
		2a	6-10	White cross-bedded cemented sands	High
	Ferruginous Sands	1c	0-11	Dark grey and black silty clay	Very low
		1b	7-70	Ferruginous cemented sands	High
		1a	27	Green, yellow and brown cemented sands	

2.4 Geomorphology

Historical erosion at the toe of the Undercliff landslide complex has created the current oversteep profile of the slope at Ventnor and Bonchurch, making it prone to instability and failure. The geomorphology of the Undercliff reflects a history of instability and landsliding. It was mapped over the period 1990-1996 as part of the Department of the Environment's initial pilot study of central Ventnor and the council's extension of this work to include the entire Undercliff (see Appendix 1 for geomorphological map). Although the mapping was produced over 25 years ago, the maps remain a true account of the Undercliff's geomorphology due to the relatively slow rates of ground displacements and because the landslides which have occurred do not fundamentally alter the ground model.

The principal geomorphological features of interest in the study area comprise:

- the Chalk Downs, landward of the Undercliff, which are mostly unaffected by landslides;
- a high near-vertical rear escarpment formed of exposed Chalk and Upper Greensand which delimits the landward extent of the Undercliff;
- an upper-tier landslide zone of multiple-rotational and translational blocks of Upper Greensand and Chalk seated in the Gault, giving rise to large linear benches and steep scarp slopes, and
- a lower-tier landslide zone of translational block slides and mudslides resulting in block degradation, retrogressive mudslides and associated run-out onto the shoreline.

2.5 Causes of land instability and climate forcing

2.5.1 Groundwater and increased winter rainfall

As well as coastal erosion over-steepening and removing passive support to the slope, groundwater pressures in the Undercliff have a direct and profound effect on its stability by both imposing a destabilising force on a landslide mass and by reducing the frictional component of strength along the landslide shear surface. The result of this plus the current protection from erosion and unloading afforded by the coastal defences mean, whilst the defences are in place, rainfall is the most significant trigger of instability and landslides in the Undercliff (note that the frequency and scale of ground instability and landslides would increase significantly if toe protection was removed).

Appendix 2 details how an understanding rainfall thresholds associated with historical instability and landsliding and climate change predictions can be used to estimate current and future rainfall triggered landslide probabilities for this study. A summary is provided below:

The different forms and rates of historical ground movement and landslides recorded can be linked to antecedent rainfall conditions. Moore et al. (2010) were able to demonstrate a strong correlation between maximum 4-month Winter Effective Rainfall and reported landslide events (See Figure 3). For example, periods of localised creep and settlement up to 100 mm per year, such as experienced in Ventnor during the winter of 2001-01, are linked to antecedent rainfall conditions expected on a 1 in 10-year basis. Similarly, periods of widespread creep and settlement up to 1 m per year, such as experienced in Ventnor over the winter of 1960-61 that caused extensive damage and property loss, are linked to antecedent rainfall conditions expected on a 1 in 100-year basis.

Based on the latest climate change predictions which point to significant increases in winter rainfall frequency, intensity and amount, it is likely that the probability will increase so that hitherto marginally stable areas of the Undercliff may become unstable, and, in areas previously affected by ground movement or landslides, the frequency and rate of ground movement and landslides is expected to increase (Moore et al. 2007 & 2010).

The initial (2018) annual probabilities of threshold winter rainfall values determined for the landslide hazard scenarios developed in Section 4.2 are based on the relationship between historical landslide events and the 4-month antecedent rainfall data for the Undercliff (after Halcrow Group Ltd. 2006).

Figure 4 defines the return period for antecedent rainfall conditions of a given amount. As an example of how the annual probability of a winter rainfall threshold increases, it shows that under a medium emissions scenario a 1 in 32-year event in 2017 will became a 1 in 10-year event by 2080. This represents a cumulative 2% annual increase in return period which has been applied to the probability of winter rainfall thresholds over the study period (see Section 4.2.3).

Over the 100-year study period a 2% annual increase in probability leads to a 7.2 times increase in the likelihood of exceeding the winter rainfall threshold so that, for example, an event with an annual probability of 0.1 becomes 0.72.

2.5.2 **Coastal erosion and sea level rise**

Undefended segments of the Undercliff frontage, which on average experience 0.4m/yr of coastal erosion (Isle of Wight Council, 2016) due to wave action, provide a good indication of how the Ventnor and Bonchurch coastline would respond should the coastal defences fail. On top of the obvious loss of land and assets in the area eroded, the removal of the slope toe increases the overall slope angle from base to crest of the Undercliff and removes passive toe support and weighting, encouraging instability and landslides throughout the slope. The development of a subsiding graben at the head of the Ventnor Park landslide system is a good example of the landward extent and influence of cliff instability and erosion.

The projected increase in relative mean sea level for the Environment Agency 2011 guidance change factor (UKCP 09 medium 95% tile, excluding the surge component) for the Isle of Wight is for approximately 75cm of sea level rise by 2115 (Isle of Wight Council, 2016). The Study has considered the potential impact of current sea level and future sea level rise on the future stability of the Ventnor Undercliff landside complex, and also notes the range of alternative scenarios outlined in the guidance including higher sea level rise totals also possible. Based on predicted sea level rise and enhanced wave energy due to increased storminess and water depths presented in the UK Climate Projections Briefing Report (Jenkins *et al*. 2009), the rate of erosion is predicted to increase. Originally estimated in SMP2 (Isle of Wight Council, 2010) and more recently updated with improved climate change and coastal response predictions in the West Wight Coastal Strategy undertaken in 2015 (Isle of Wight Council, 2016), the 20, 50 and 100-year erosion estimates under the 'No Active Intervention' scenario, which assumes the defences are allowed to fail, were investigated and mapped. The assessment shows the importance of maintaining the coastal defences. It estimates the current unprotected erosion rate will more than double to 0.91m/yr over the next 100 years. Many of the current coastal defences have minimal residual life remaining. Were defences to be lost, up to 80 m of coastal erosion could occur, resulting in the removal/destruction of assets in this zone.

It is highlighted that from the present day, the failure of any current seawalls/defences, at the present sea level, would result in erosion and wave attack undermining the toe of the landslide complex from day 1. Furthermore, the level of erosion and loss of passive toe support outlined above would cause reactivation and potentially severe landslide damage to assets throughout the Undercliff, up to and potentially beyond the present landward limit of the current landslide system.

A good example of the slope response to toe erosion following coastal defence failure is at Monk's Bay where the seawall collapsed following severe storms in 1990/91. A combination of coastal erosion and a very wet winter led to a rapid cliff failure and retrogression extending some 250 m back from the shoreline with the opening of tension cracks, putting at risk historic listed buildings, properties, highways and other infrastructure.

2.6 Landslide event history

Historical records collected over the past 200 years indicate that Ventnor has episodically been affected by ground movement and landslide events. These have occurred at locations along the whole frontage and have caused damage to property and services. The ground instability has generally been classified as slow moving 'creep' along pre-existing shear surfaces with periods of accelerated ground movement and/or landslide events which have led to significant damage along the road network and properties (Halcrow Group Ltd 2010, Bracegirdle et al. 2007, McInnes et al. 2007, High-Point Rendel 2001 and 2004, Moore et al. 1995, Lee and Moore 1991, Hutchinson 1987).

A summary of recent past landslide events and the associated damage is provided in Table 2. The frequency, magnitude and distribution of the areas affected by historical ground movement and landslides and their link to antecedent rainfall is analysed in Section 2.5.2. This has been used to help inform the hazard model reference event scenarios and their probabilities in Section 4.2).

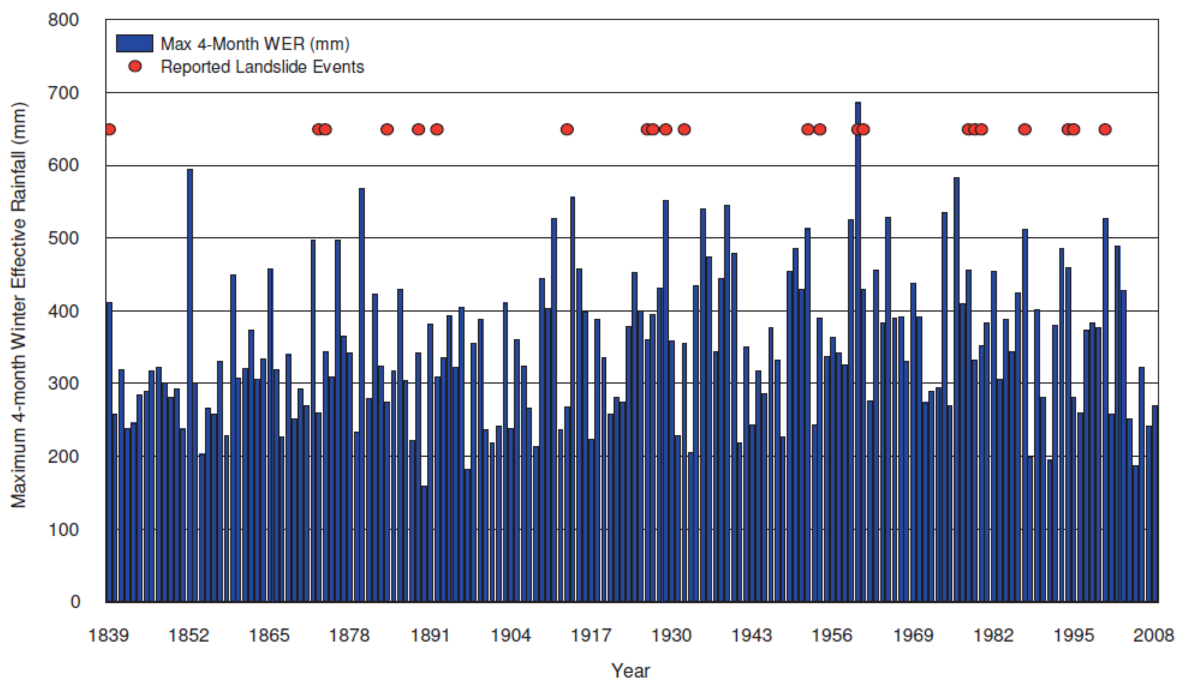

Figure 3. Maximum 4-month Winter Effective Rainfall and reported landslide events (Moore et al. 2010).

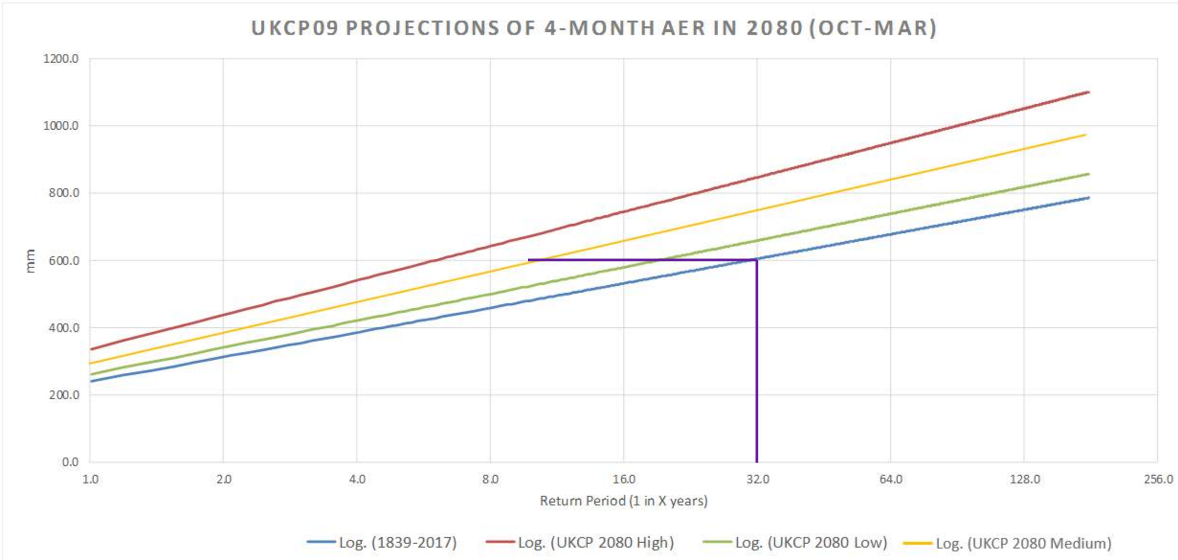

Figure 4. Return period for antecedent rainfall conditions of a given magnitude under current conditions and the various UKCP emissions scenarios. Under the medium emissions scenario a 1:32 year event becomes a 1:10 year event by 2080. This equates to a cumulative annual increase of 2%.

Table 2. Examples of recent landslide events and associated damage in the Ventnor Undercliff landslide complex. Note that this list only coverers recent events and is not comprehensive (the complete inventory of events reviewed in this assessment dates back 200 years after Lee and Moore 1991).

2015-2016, ongoing	**Wheelers Bay to Eastern Esplanade, Ventnor:** New damage is occurring to the old seawall due to ground movement in this area, with the ageing defences of increasingly deteriorated sheet piling at the toe of the developed coastal slopes and terraces of the town.
2016 -ongoing	**Lowtherville Graben:** The Graben is a feature approximately 450 metres long at the top (rear scarp) of the landslide complex, with the most developed parts of Ventnor town located on the sequence of landslide terraces directly below. Over recent decades progressive ground movement of this block has occurred (subsiding between two faults), affecting the main road and infrastructure crossing the graben into Ventnor. This has required ongoing repairs and reprofiling of the road and key utility pipelines. Properties have been lost in the area and some parts turned into public open space, and further remaining properties are affected by ongoing ground movement. This area of Upper Greensand parallel to the coast is sinking and extending at a rate of approximately 20mm a year.
2013	**Bonchurch:** A landslide occurred in the unprotected coastal slopes at Bonchurch, at the eastern edge of the defences, severing the coastal footpaths and encroaching nearer to the properties in Bonchurch village upslope.
2000	**Wheelers Bay, Ventnor:** A study by the former Department of Environment (1988-91) had highlighted the maintenance and improvement of coastal defences as a key strategic task in reducing the impact of landsliding on the local community. An illustration of this is when ground movements within the slope behind Wheelers Bay at the toe of the landslide complex showed there was significant risk to the existing old seawall and property and infrastructure upslope, resulting in a new coastal protection and slope stabilisation scheme built in 2000.
1993-1994	**Castle Cove, Ventnor:**

	Failure of the coastal slope in 1993-94 with risk to properties behind.
1990-1991	**Bonchurch:** At Monk's Bay the Victorian seawall collapsed following severe storms in 1990/91. A combination of coastal erosion and a very wet winter led to a rapid retrogressive failure extending some 250m back from the coastal slope with the opening of tension cracks, and risk to historic listed buildings, properties, highways and other infrastructure.
1990	**Western cliffs, Ventnor:** Storm Damage in 1990 resulted in aggressive marine erosion of the Western Cliffs in Ventnor (which are made up of loosely consolidated chalk debris deposited at the end of the last Ice Age), with significant risk of reactivation of the ancient landslide complex behind.
1960-61	**Ventnor Bay:** Significant ground movements occurred in the coastal slopes in the centre of Ventnor town, around Ventnor Bay. Landsliding resulted in significant road and property damage, with loss at the western end of the Esplanade and at Bath Road. Bath Road (which links the clifftop of the first terrace of the town to the seafront) dropped by a foot resulting in the road being regraded to its current steep 25% gradient.

2.7 Environmental review

A desk study has been undertaken to assess the environmental risks and constraints that need to be considered as part of the Ventnor Options Study. The review divides the considerations into the various environmental designations (protected sites) and Water Framework Directive constraints.

There are a number of environmental designations and interests within the Ventnor to Bonchurch study area. These are summarised below. A number of environmental designations concern sites or interests adjacent or peripheral to the coastal defence aspects of this study area and are not considered relevant; however, they are included in Appendix C for reference and completeness of this review.

Isle of Wight Downs Special Area of Conservation (SAC) provides European protection status for the vegetated sea cliffs of the Atlantic and Baltic coasts including the sea cliffs of the Isle of Wight; qualifying species are Early gentian, Gentianella anglica.

The South Wight Maritime SAC provides European protection status for the southern shore of the Isle of Wight, and includes a number of subtidal reefs that extend into the intertidal zone. This site is recognised for its variety of reef types and associated communities, including chalk, limestone and sandstone reefs. Reef habitats within the site include areas of large boulders off the coast around Ventnor. The bedrock is extensively bored by bivalves. Their presence, together with the holes they create, give shelter to other species, which adds further to habitat diversity. Intertidal pools support a diverse marine life, including a number of rare or unusual seaweeds, such as the shepherd's purse seaweed Gracilaria bursa-pastoris. A number of other species reach their eastern limit of distribution along the English Channel at the Isle of Wight.

South Wight Maritime SAC also recognises the contrasting Cretaceous hard cliffs, semi-stable soft cliffs and mobile soft cliffs. The most exposed chalk cliff tops support important assemblages of nationally rare lichens, including Fulgensia fulgens. The vegetation communities are a mixture of acidic and mesotrophic grasslands with some scrub and a greater element of maritime species, such as thrift Armeria maritima, than is usual on soft cliffs. This section supports the Glanville fritillary butterfly Melitaea cinxia in its main English stronghold. A small, separate section of the site on clays has a range of successional stages, including woodland, influenced by landslips.

Compton Chine to Steephill Cove Site of Special Scientific Interest (SSSI) is notified for its vegetated maritime cliffs and slopes, species-rich unimproved chalk grassland, nationally rare plant species, an assemblage of nationally scarce plants, an outstanding assemblage of nationally rare and scarce invertebrates, exposed and moderately exposed rocky shores (littoral rock) and nationally important coastal geomorphology.

The Bonchurch landslip SSSI provides protection for the ash Fraxinus excelsior woodland on Gault clay landslips immediately below the Upper Greensand escarpment. The landslips descend steeply eastward to soft, eroding cliffs. The lower slopes of the landslips support a complex mosaic of species-rich acidic and calcareous plant communities on unstable clays and sands. The close juxtaposition and mixing of disparate plants is of considerable ecological interest. Geomorphologically, the site is of great interest for its complex of mass-movement features, including the Undercliff itself and the coastal landslips and mud flows beneath it.

Water Framework Directive water bodies of relevance include the Southern Downs Lower Greensand and Chalk ground water body. Linked protected areas include the Habitats Directive (linked to SAC), Bathing Waters Directive, Urban Waste Water Treatment Directive, Birds Directive and Nitrates Directive.

The Ventnor and Bonchurch study site has a rich maritime history and evidence of human occupation from 4000bc. Many of the 119 grade II listed buildings, the Grade II registered park, several items on the local list and many of the 169 monument records indicated on the south coast of the Isle of Wight fall within the sites coastal frontage. Offshore there are 71 recorded shipwreck sites and 3 air wrecks classed as Military Remains Protected Places. Bonchurch, Ventnor and St. Lawrence are also designated Conservation areas. At Flowers Brook advance archaeological investigations as part of the construction of a pumping station revealed evidence for Saxon and Medieval occupation.

The full environmental review is detailed in Appendix 3. In summary, the following points need to be taken forward for any options considered for future schemes:

- A WFD preliminary assessment will need to be undertaken for preferred coastal and slope management options. These will need to be put forward to a WFD specialist in order to assess the potential impacts and benefits.
- Consultation with Natural England will need to be undertaken with regards to the Bonchurch Landslips SSSIs.
- A screening assessment under Habitats Regulations is likely required due to the Isle of Wight Downs and South Wight Maritime Special Areas of Conservation (SACs). This also needs discussing with Natural England.
- The South Wight Maritime SAC designation extends along the study area, although usually the designation boundary extends seawards from the low watermark so is located approximately 30+ m offshore. Future works along the coastline would still need to seek minimal damage in the intertidal area due to the connection to designated habitats. It should also be noted that for a 170m section near Wheeler’s Bay, the SAC boundary is located directly up against the present defence line, and requires careful consideration in future schemes.
- Two sections of the coastline are designated as Conservation Areas, and also requires careful consideration in future scheme proposals. These are 200m west of Monk’s Bay, and 1.4 km from the western edge of Wheeler’s Bay to the Flowers Brook outfall. Scheme design will require careful consideration in these areas.
- The Solent & Dorset Coast pSPA is downdrift of any proposed scheme such that the impacts on Tern habitat of changes to sediment and nutrient pathways and the potential to create contamination will need to be considered.
- The Bembridge and Sandown Bay rMCZ is downdrift of any proposed scheme such that the impacts on habitats of changes to sediment and nutrient pathways and the potential to create contamination will need to be considered.

3. Undercliff ground behaviour models

3.1 Landslide reactivation units

The geomorphology maps (discussed in Section 2.4 and provided in Appendix 1) underpin understanding of the various landslide systems that form the Undercliff, together with patterns of groundwater and surface water drainage. Within the area of interest, the geomorphology has been used to map seven landslide reactivation units (LRUs), which define zones of similar ground behaviour and land instability risk, taking account of the distinctive morphology and landslide system boundaries, event history and contemporary behaviour (Figure 5). The LRUs are further subdivided into landslide reactivation sub-units A, B and C, which represent the sequential reactivation zones of the landslide system; such reactivation is caused by coastal erosion and toe unloading, progressing upslope and displacing the interlocking landslide blocks to the landward system boundary, typically ~500 m inland and 125 m above sea level. This will be explored further in Section 4.2.4.

When combined with the available sub-surface boreholes and in situ slope monitoring data, the geomorphology provides a detailed geospatial framework for determining the 3D landslide geometry, geological controls, failure mechanisms, causes, processes and sensitivity to change. The integration of these data to derive landslide ground behaviour models is developed in Section 3.3.

The LRUs shown in Figure 5 provide the spatial framework for the quantitative risk assessment in Section 4. The seven LRUs named in Figure 5 are used throughout the report. Figure 6 shows the LRUs with Ordnance Survey basemapping so that the LRU boundaries can been seen in relation to key features, road and buildings.

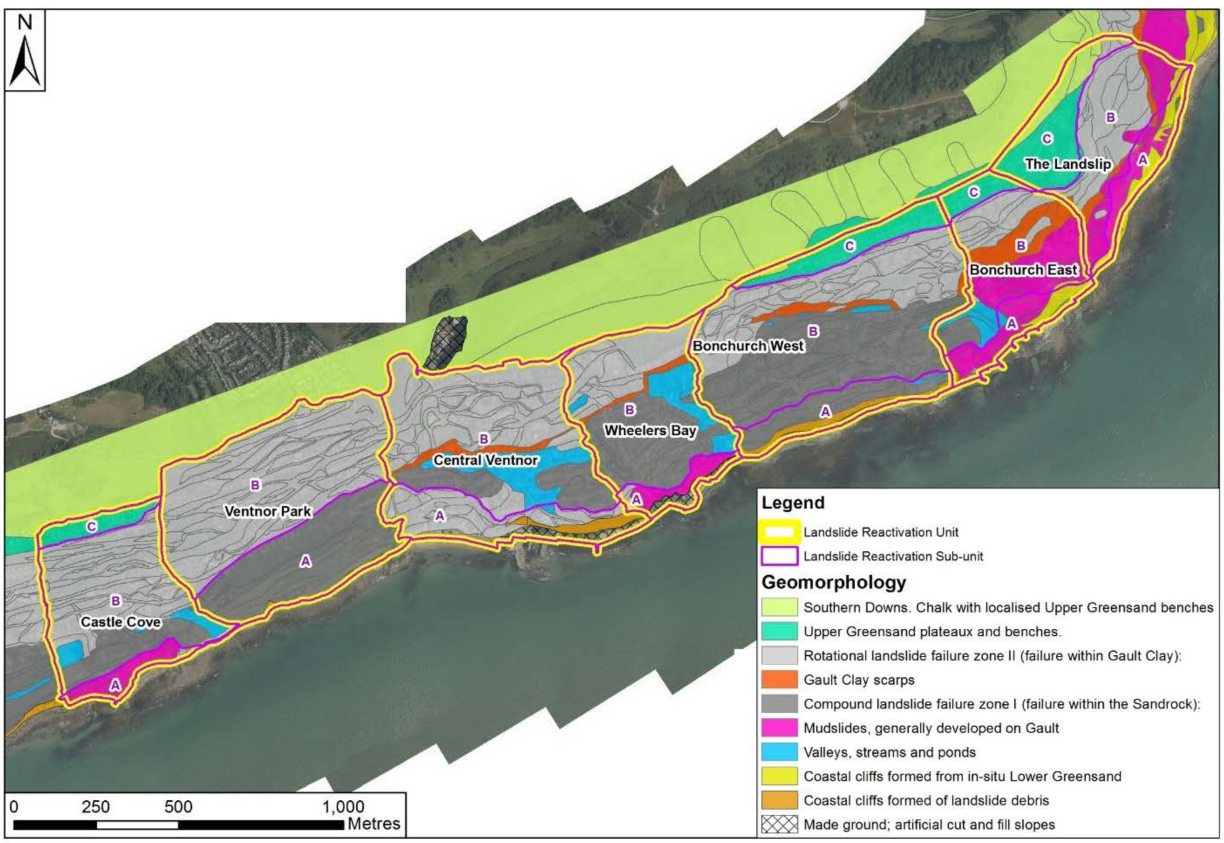

Figure 5. Geomorphology and landslide reactivation units

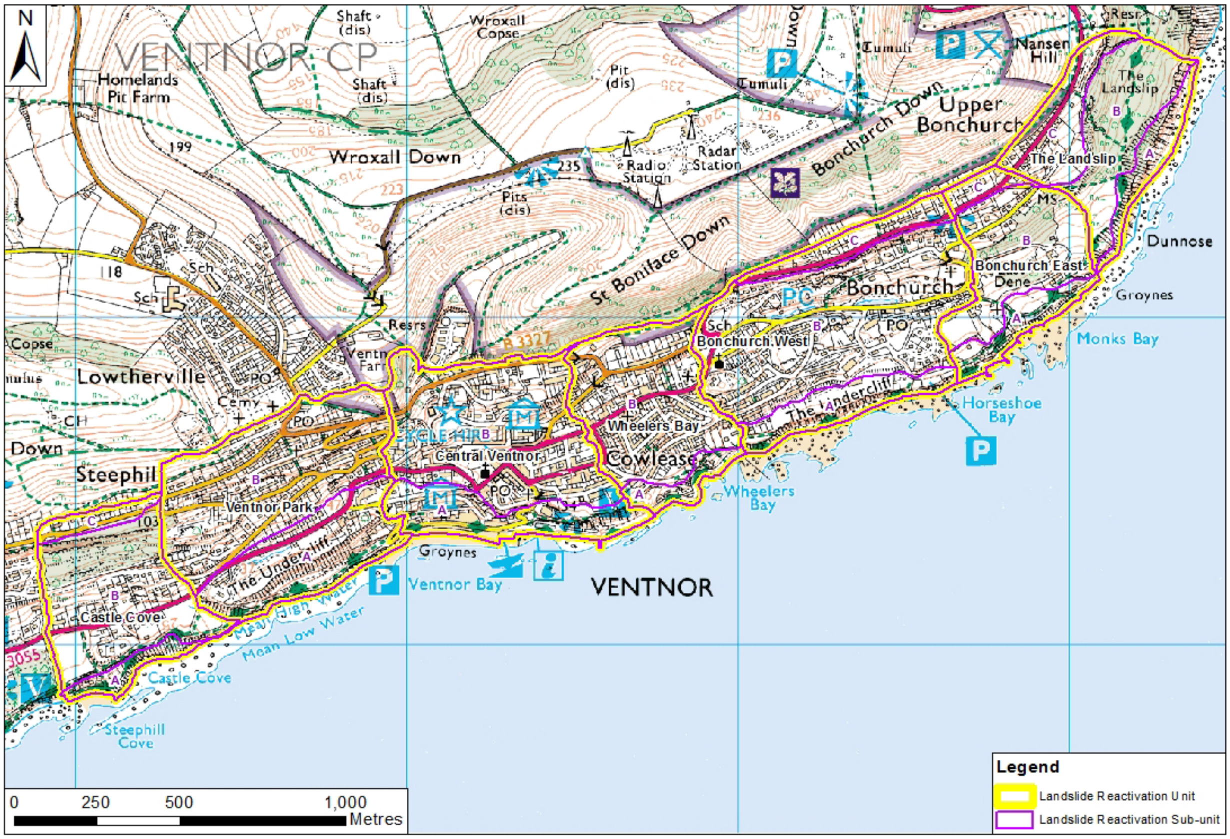

Figure 6. Landslide reactivation units with OS basemapping. Contains OS © Crown copyright (2017).

3.2 Monitoring review

The development of ground models and land instability hazard scenarios and probabilities at Ventnor and Bonchurch has been supported by a review of the monitoring data collected in the area over the period 2002 to present. The review comprises the following components:

- ***In-situ* monitoring**: A review of the *in-situ* monitoring was carried out by Prof. Roger Moore on 21st April 2017 and includes data from inclinometers, extensometers, piezometers, settlement cells, tiltmeters, crackmeters and a weather station at Ventnor Park.
- **GPS network**: A review of horizontal and vertical ground movement of permanent ground markers distributed across the Ventnor Park LRU and measured by dGPS between 2003-2017.
- **Terrestrial Laser scans** (TLS): A review of ground movement measured by sequential TLS surveys at the Lowtherville Graben and Wheelers Bay. Elevation change between TLS surveys was measured by comparing and subtracting digital elevation models from different epochs.

Analysis of these data have been fundamental to establishing relationships between rainfall patterns, groundwater response, ground movement, coastal erosion and landslide reactivation.

The detailed findings and recommendations are provided in Appendix 4. Key observations are summarized below.

1. Areas historically susceptible to ground movement including Devil's Chimney, Bath Road, Castle Court and the Lowtherville Graben show seasonal winter ground movement in the form of progressive creep which relates to antecedent rainfall conditions. In places, the creep is indicative of pre-failure movement which is potentially the precursor to a landslide.

2. The dGPS network data and TLS data for the Ventnor Park LRU show that the lower tier of the landslide system moved seaward by up to 1 m between 2003-2017. In response to this movement the depression between opposing blocks at the Lowtherville Graben at the head of the system deepened by up to 0.5 m between 2003-2017. The settlement is caused by the progressive loss of support and landslide block rotation downslope, which in turn is caused by the mass movement of the lower tier landslide units seaward. The TLS data also show that the graben is extending to the east.
3. The TLS data captured at Wheelers Bay show that in exposed locations the seawall and promenade are settling. The data suggest that this could be due to the loss of support previously provided by rock armour which has shifted seaward in places. In locations which do not have rock armour, settlement of the seawall and promenade is likely due to the lack of protection. The Wheelers Bay TLS data demonstrate the deterioration of the current coastal defences due to wave loading, coastal erosion and local cliff instability.
4. Where data are available the distribution and magnitude of ground movement recorded is consistent with the ground models indicated by the geomorphology and GI data and which have been used in this study.
5. There are large areas not covered by in situ or dGPS monitoring that should be addressed to advance the ground model to the standards required to support the coastal defence and landslide stabilisation mitigations put forward in Section 5.

3.3 Ground models

Landslide ground behaviour models have been developed for each LRU to inform the hazard model scenarios used for quantitative risk assessment. Ground models for the seven LRUs are developed using a 3D geological model which interprets the available GI data and ground models presented in earlier reports and papers. Appendix 5 details the approach and methods used whilst this section provides a summary.

The 3D ground model presented in Figure 7 shows that St Lawrence - Ventnor Syncline plays a significant role in the outcrop of key strata known to be prone to failure. The effect of the syncline is to lower the elevation of these strata in the central part of the Undercliff whilst raise the elevation of strata on the rising limbs to east and west. Due to this, the lower tier deep shear surface in Sandrock 2d is well below present-day sea level (up to 40 m at Wheelers Bay) in all but the Landslip LRU. Coastal defences in LRUs with shear surfaces below sea level do not directly act to reduce the movement along the pre-existing basal shear surfaces of the Undercliff, and will be subject to seaward displacement. However, the coastal defences do act to prevent toe erosion of the coastal cliffs of the lower tier formed in landslide debris. The primary failure mechanisms in these LRUs is translational or compound landsliding in the Sandrock on the lower tier, and rotational landsliding in the Gault Clay on the upper tier.

In the east of the area at the Landslip where the basal shear surface in Sandrock 2d crops out at or above sea level, coastal defences would improve stability by directly preventing erosion and displacement at this contact. The primary failure mechanism in this unit is rotational landsliding and mudslides in Gault Clay, triggered by rainfall and, because the cliffs are unprotected, rapid erosion and unloading of the system by coastal processes, causing movement along the basal shear surfaces.

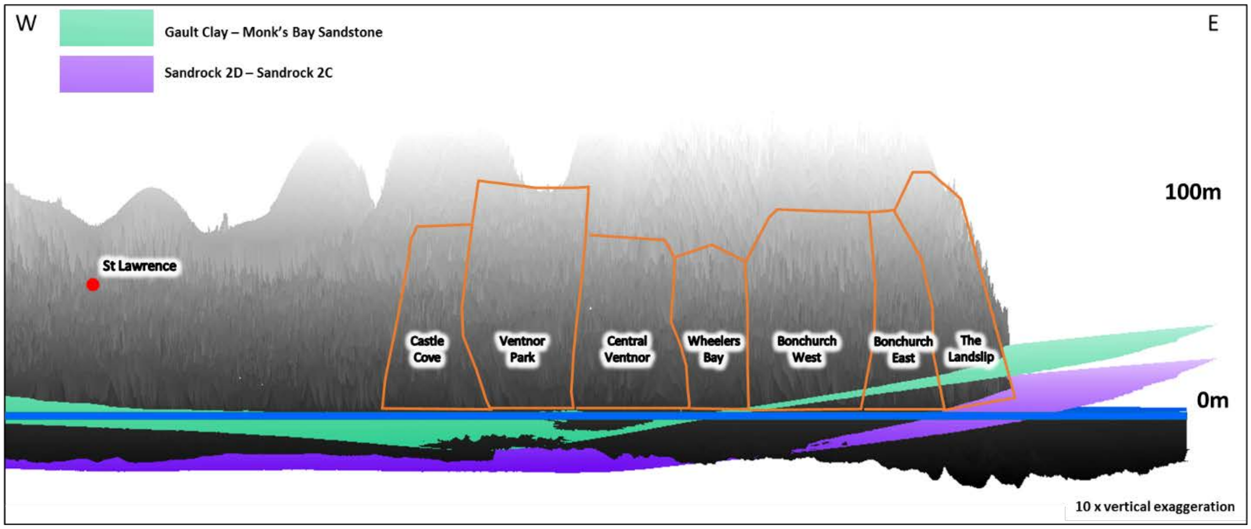

Figure 7. Longitudinal section of projected strata outcrop across area of interest and LRUs. Key strata are shown as inclined planes and viewed landward from the sea.

Individual ground behaviour models for each LRU are provided in Appendix 5.

A cross-section of Central Ventnor is presented below in Figure 8 as an example ground model. As is typical of the frontage, except the Landslip LRU, the model for Central Ventnor shows a two-tier landslide system, whereby the upper tier is developed on the basal shear surface near the base of the Gault Clay. Movement along the shear surface has resulted in rotational failure and formation of a steep backscarp in the Chalk landward of the system. The lower tier landslide system consists of compound failures within clay layers in the Sandrock, with ridges formed of Upper Greensand blocks and infilled depressions. Rotational failure of landslide debris also occurs along the coastal slopes. Whilst the current coastal defences are in place and due to the depth of the landslide complex, failures for all LRUs except the Landslip are primarily driven by rainfall causing movement along the basal shear surfaces. The marginal stability of the LRUs will decrease significantly if the coastal defences deteriorate and not replaced or upgraded, increasing the likelihood and scale of toe erosion and land instability.

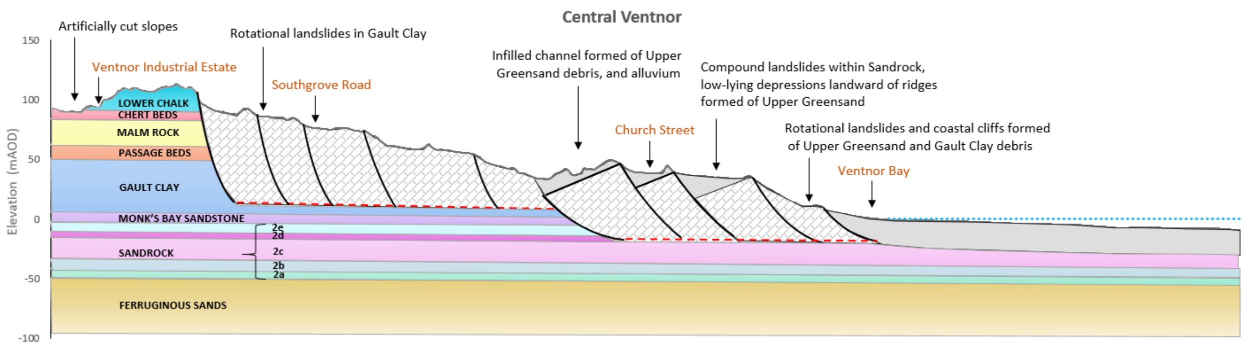

Figure 8. Central Ventnor ground behaviour model cross-section. The strata and slip surfaces have a slight seaward dip.

4. Quantitative risk assessment

The Quantitative Risk Assessment (QRA) and Cost-Benefit Analysis (CBA) in Section 6 of this report provide an auditable decision-making tool for the management of and prioritised investment in risk reduction measures to prevent coastal erosion and control land instability and ground movement that will ensure the long-term viability of the frontage and town for residents, business and for safe access, recreation and tourism.

4.1 Approach

The quantitative risk assessment provides an economic value of the *risk* associated with cliff instability and landsliding under present and future conditions and various coastal defence intervention options at Ventnor and Bonchurch. Risk is expressed as the product of the likelihood of a hazard and its consequences (Royal Society 1992). Cliff instability and erosion at Ventnor pose hazards and risk to the public and assets located on the Undercliff, and in this context, risk is defined as:

Risk = Probability (Landslide event) x Consequences

Quantification of the probability of cliff instability and landslide events is considered by the Hazard Model and estimation of the associated impact and losses by the Consequence Model. Development of these models has involved detailed analysis of the following cliff behaviour and consequence parameters:

- the full extent of the cliffs, landslides, systems and processes
- the types of contemporary ground movement
- the frequency of landslide events
- the causes of landslides, including antecedent rainfall and sea level rise and their temporal variability
- the predicted impacts of climate change including sea level rise and increasing winter rainfall
- the impact of ground movement in built up areas
- the extent, condition and economic value of the assets at risk
- the vulnerability of different buildings to cliff instability and ground movement

The Hazard Model generates an annual probability of occurrence for a given cliff instability and landslide scenario (hazard scenarios), where a probability of 0 means the scenario is not possible and a probability of 1 means the scenario is certain. Annual probability values are presented as decimals where, for example, 0.1 equates to 1 in 10 years.

The Consequence Model estimates the potential economic damages and losses associated with the hazard scenarios.

The flow diagram shown in Figure 9 shows how the hazard and consequence models are brought together to define risk in terms of the potential future value of losses associated with cliff instability and coastal erosion. The diagram also signposts the report sections which detail the input parameters and calculations associated with each element of the model.

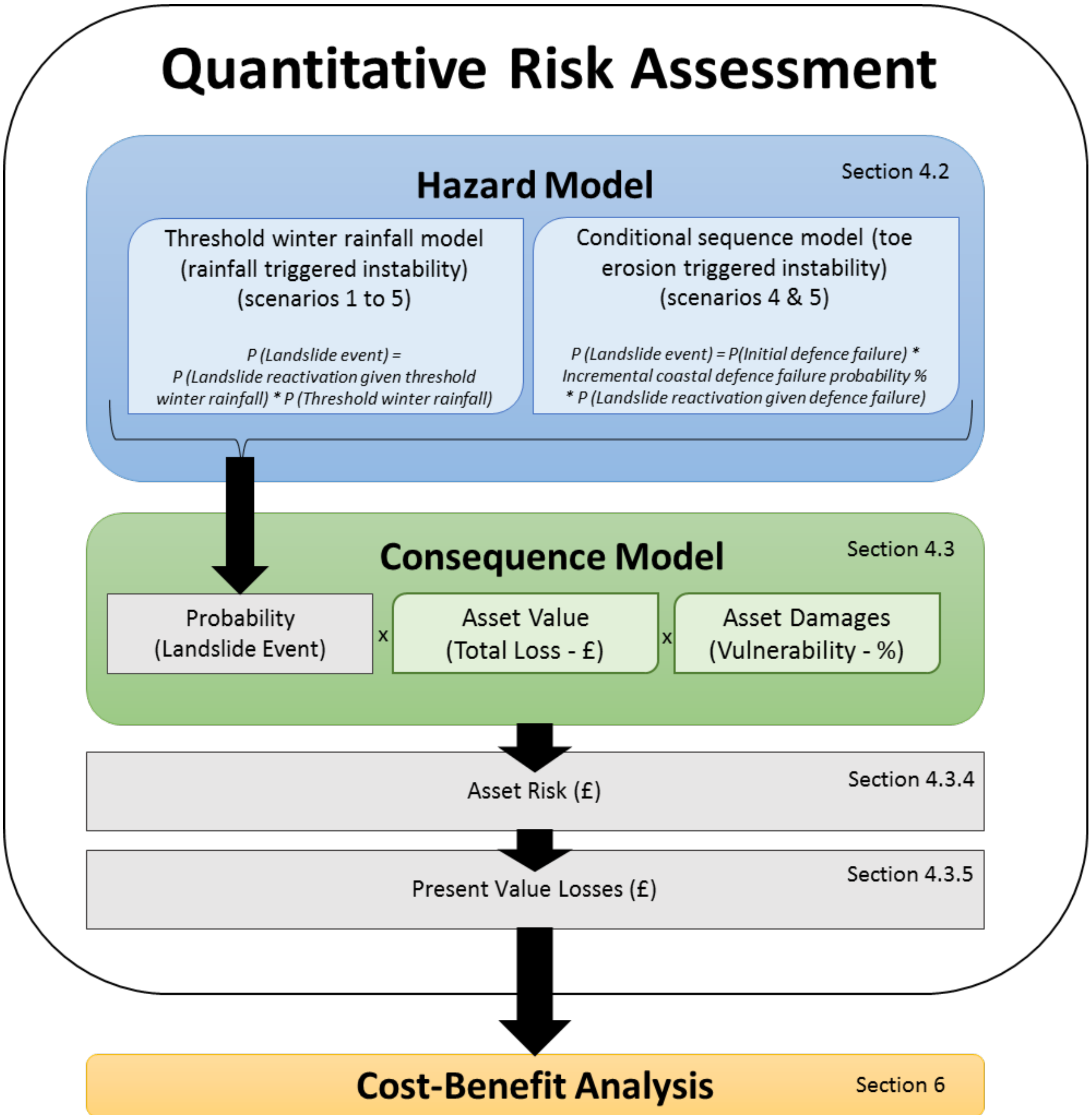

Figure 9. Flow diagram showing how the hazard and consequence models are brought together to define risk in terms of the future value of losses associated with cliff instability and coastal erosion

4.1.1 Divergence from standard Outcome Measures 3 (OM3) Appraisal Guidance

In order to reflect the unique terrain, hazards and consequences on the complex cliff at Ventnor and Bonchurch, it has been necessary to develop a bespoke QRA from first principles. Qualifying benefits under OM3 relate to the reduction in direct damages to residential properties caused by eroding coastlines. At Ventnor and Bonchurch coastal erosion has far wider reaching consequences because it undercuts and destabilises a coastal slope which extends 500 m landward of the shoreline (the Lowtherville Graben at the head of the Ventnor Park LRU is a good example of the landward extent of ground instability caused by toe erosion).

As such, the QRA developed for this study does not consider the linear coastal erosion model used in OM3, rather the annual damages caused by ground instability within the Undercliff, from the shoreline to the Undercliff headscarp. The QRA model adopts a similar approach developed for the 2006 QRA for Ventnor Park (Halcrow, 2006). It considers the wider benefits of controlling rainfall and toe erosion triggered ground instability whilst also acknowledging the fundamental link with the sea that is required for future projects to be considered for grant in aid under the Coast Protection Act 1949.

This approach is wholly consistent with the EA guidance (FCERM-AG, 2010) and compares with other complex coastal landslide remediation schemes such as Lyme Regis Phase II & III, East Cliff Phase IV, Fairlight Cove and Scarborough Spa. The EA guidance notes: to secure asset design life, existing or proposed coast protection works may require complementary drainage or slope stabilisation to prevent landslides endangering their integrity. This acknowledges the fact that unless these works are undertaken, risks may be posed to the coastal defence structures from landsliding occurring behind the defence itself. In addition, at Ventnor and Bonchurch there is precedence for slope stabilisation works being carried out to secure the coastal defence assets e.g. Wheeler's Bay.

Figure 10 shows a hypothetical section of the slope from the east of the site to illustrate the type and distribution of the various land instability hazards encountered at Ventnor and Bonchurch. Starting at the coast (slope toe), typically, there are Gault scarps on which coastal erosion triggers retrogressive mudslides. This in turn can destabilise the slopes above and promote movement between the pre-existing compound and rotational landslide blocks which, depending on severity of the trigger, can experience anything from minor creep to widespread landslide activity and ground disruption, with over 10m surface lateral/vertical displacements. This movement has the knock-on effect of further opening grabens beneath the headscarp and this could eventually cause retrogressive failure of the slope crest, increasing the overall area affected by instability. See section 4.2 for full details of the hazard model.

As any application for coastal defence scheme funding will be made by OM3, the QRA model, although bespoke, has been designed to feed back into qualifying household benefits under OM3.

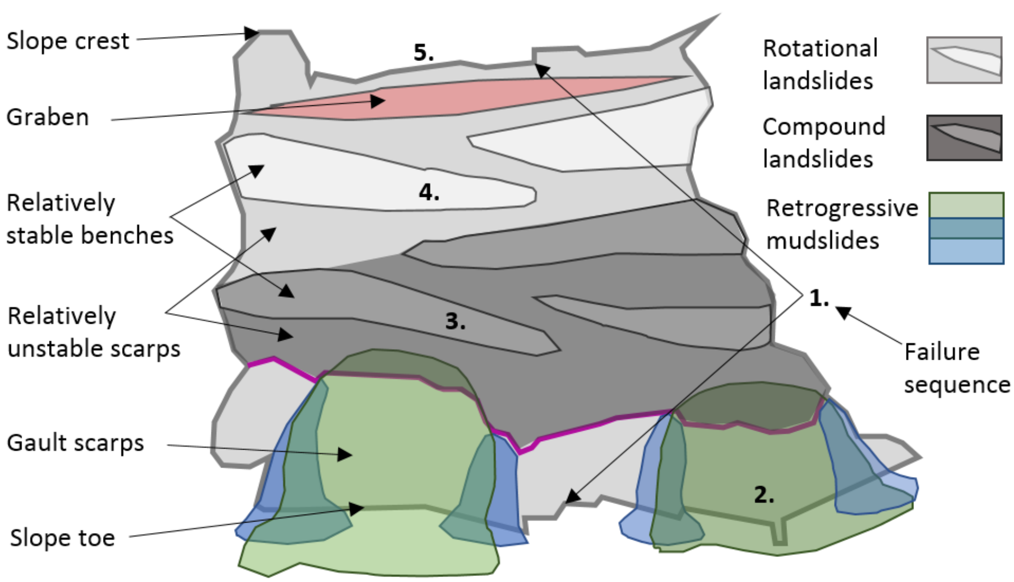

Figure 10. Type and distribution of the various hazards encountered at Ventnor and Bonchurch illustrated on a hypothetical portion of the Undercliff from the east of the site. Failure sequence: 1. Progressive failure of whole system; 2. Toe landslides unloading system; 3. Compound block acceleration and retrogressive failure of system; 4. Rotational block acceleration and retrogressive failure of system; 5. Landward retrogression of the system.

4.2 Hazard model

This section describes the input data which define the probability of instability and landslides in the hazard model.

From the previous work documenting landslide hazards in the Undercliff (Lee & Moore, 2007), the geomorphology, historical records, evolutionary model and contemporary cliff conditions, five cliff instability and landslide hazard scenarios have been developed. The frequency and magnitude of each scenario is accounted for by a reference event that provides the baseline for estimating scenario probability. The likelihood and severity of the scenarios range from those that are occurring today, such as slope creep, to those which require a series of conditioning events, such as sea level rise or the failure of coastal defences.

The hazard scenarios and their probabilities were agreed during an expert risk forum. The experts included the project team, Professor Roger Moore (expert in cliff instability and erosion management in the UK), Geoff Davis, Ross Fitzgerald, Claire Czarnomski (experts in cliff instability and QRA) and Jon Denner (expert in coastal erosion management). The consensus best estimates are based on the expert judgements provided during the risk forum on 27th September 2017 and by an expert panel at the risk forum held by Isle of Wight Council on 20-23rd May 2002 (Halcrow Group Ltd. 2006; Hutchinson & Bromhead 2002); they give a broad indication of the expected event probability and should not be viewed as implying a rigorous quantification of the likelihood of each scenario.

4.2.1 Hazard scenarios

The five credible landslide hazard scenarios are defined in Table 3.

Scenarios 1 to 3 are exclusively driven by exceedance of the rainfall thresholds (see Section 2.5.2) and vary in accordance with the rate of movement and severity of damage from local to widespread spatially. Scenario 4 can be caused by both the exceedance of the relevant rainfall threshold and via coastal defence failure causing reactivation of a pre-existing deep-seated landsliding. Scenario 5 represents the re-establishment of active toe erosion along the whole frontage, resulting in cliff undercutting and reactivation of the natural state and landslide evolutionary model. This scenario has no recent historical precedent at Ventnor or Bonchurch and requires sea level rise and/or sea wall failure to restore the connection between the sea and the Undercliff.

Table 3. Coastal erosion and landslide hazard scenarios

Scenario	Triggering event(s)	Duration	Surface Disruption	Example Event	Current (defended) estimated annual probability
1	Threshold winter rainfall exceeded	Winter Period	Localised creep up to 10 mm/yr., very slow settlement of landslide blocks and development of tension cracks along block boundaries (up to 1 mm wide).	Ventnor, typical year	0.95 (every year)
2	Threshold winter rainfall exceeded	Winter Period	Localised creep up to 100 mm/yr., slow settlement of landslide blocks and development of tension cracks along block boundaries (up to 10 mm wide).	Ventnor 2000-2001	0.1 (1 in 10 years)

Scenario	Triggering event(s)	Duration	Surface Disruption	Example Event	Current (defended) estimated annual probability
3	Threshold winter rainfall exceeded	Winter Period	Widespread creep up to 1 m/yr., settlement of landslide blocks with evidence of localised surface displacement (<1m displacement) and development of tension cracks along block boundaries (up to 50 mm wide).	Ventnor 1960-1961	0.01 (1 in 100 years)
4	Coastal defence failure and loss of geometric support Threshold winter rainfall exceeded	<10 days	Major deep-seated landslide event, involving widespread ground disruption within the slide area, with up to 10m surface lateral/vertical displacements and tension cracks (up to 0.5m wide).	The Landslip 1810, 1818; Rock End 1928; Blackgang 1994-1995 St Catherine's Point (Barlow et al. 2016)	0.001 (1 in 1000 years)
5	Coastal defence failure and loss of geometric support Rapid sea level rise	<10 days	Extensive major landslide activity re-shaping the pre-existing systems and creating significant changes to the landslide geomorphology. Widespread ground disruption, with over 10m surface lateral/vertical displacements and tension cracks (up to 1m wide).	No contemporary analogue	0.0001 (1 in 10,000 years)

The estimated annual probabilities of scenarios 1 to 4 are based on historical precedents on the defended frontage at Ventnor and Bonchurch. The estimate for scenario 5 is based on expert judgement.

Note that the annual probabilities provided in Table 3 would be significantly higher if the frontage was not defended. The rest of the chapter analyses the increased annual hazard probabilities associated with defence failure.

4.2.2 Hazard scenario probability

Hazard scenario probability is the annual probability that land instability will occur in a given year. This is based on the annual probability of the triggering event (e.g. sea wall failure or rainfall threshold exceedance) and the conditional probability of the landslide response, where:

*P (Landslide event) = P (Response|Triggering event) * P (Triggering event)*

Hazard scenario probabilities have been modelled over a 100-year period to cover the lifetime of the proposed management scheme.

The landslide reactivation sub-units are treated individually based on the geomorphology, landslide event history and the ground behaviour model. Both expert judgement and empirical evidence are utilised in the hazard model. These values are documented in Appendix 6.

The approach to modelling the different triggering events are described in detail in the following Sections 4.2.3 and 4.2.4.

4.2.3 Threshold winter rainfall model (scenarios 1 to 5)

The threshold winter rainfall model generates the annual probability that a landslide event occurs due to exceedance of threshold winter rainfall in a given year. This is calculated by multiplying the annual probability of threshold rainfall by the conditional probability of landslide reactivation given exceedance of threshold rainfall, where:

*P (Landslide Event) = P (Response|Triggering Event) * P (Triggering event)*

*P (Landslide Event) = P (Landslide reactivation given threshold winter rainfall) * P (Threshold winter rainfall)*

To account for the effects of climate change a 2% cumulative annual increase in the probability of threshold winter rainfall is applied (see Section 2.5.2). This represents the increase in rainfall intensity for the UKCP09 medium emissions scenario. Table 4 shows how, over the 100-year study period, a 2% annual increase in probability leads to 7.2 times increase in the likelihood of a threshold rainfall event.

Table 4. Year 1 and year 100 annual threshold rainfall probabilities based on the 4-month antecedent rainfall threshold

	Scenario				
	1	2	3	4	5
Year 1 annual probability of threshold rainfall	0.95	0.1	0.02	0.002	0.002
Year 100 probability of threshold rainfall under UKCP09 medium emissions scenario	1	0.72	0.14	0.014	0.014

Expert judgement and historical landslide records have been used to inform the probability of landslide reactivation given occurrence of threshold rainfall for the five hazard scenarios (Table 5). Further details are provided in Appendix 6.

Table 5. Landslide reactivation probabilities given exceedance of winter rainfall (given defences are in place)

Scenario	Sub-Unit	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip
1	**A**	1	1	1	1	1	1	1
	B	1	1	1	1	1	1	1
	C	0				0	0	0
2	**A**	1	1	1	1	0.5	1	1
	B	1	1	1	1	0.5	1	1
	C	0				0	0	0
3	**A**	0.5	0.5	0.5	0.5	0.5	0.5	1
	B	0.5	0.5	0.2	0.2	0.2	0.5	0.5
	C	0				0	0	0
4	**A**	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	B	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	C	0				0	0	0

Scenario	Sub-Unit	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip
5	A	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0
	C	0				0	0	0

4.2.4 Conditional sequence model (toe erosion triggered landslide) (scenarios 4 and 5)

The conditional sequence model generates the probability that a landslide event occurs for the first time in a given year due to failure of the coastal defence. The model incorporates a lag between the failure of the coastal defence and reactivation of the landslide unit in which it impacts. For each LRU, this is sub-unit A, the most seaward sub-unit. Landslide sub-unit B reactivates due to the unloading effect from sub-unit A. Similarly, there is a lag in response between the failure of sub-unit A and landslide reactivation in sub-unit B, which is incorporated in the model. The same follows for sub-unit C which reactivates to the unloading effect from sub-unit B.

To calculate the probability of a landslide event in sub-unit A, there are three input parameters required:

- **Initial coastal defence failure probability**. This represents the coastal asset in the poorest condition and with the greatest likelihood of failing in a given year (i.e. the weakest link along the LRU frontage), see Section 5.3.4 for further detail.
- **Incremental coastal defence failure probability %.** This is applied as an annual percentage increase on the initial probability of the coastal defence failure. This is based on the residual life of the asset in question as it deteriorates over time without active intervention. Section 5.3.3 provides details of how the residual life of the coastal defence assets are estimated.
- **Probability of landslide reactivation** given failure of the coastal defence or downslope sub-unit. The input probability for year 1 is based on expert judgment which accounts for the residual effect of the damaged defence and the characteristics of the land behind the defence (see Table 6) for conditional sequence landslide probabilities). Given that mean high water is typically already at a higher elevation than the ground landward of the coastal defences assets (i.e. the ground that would interact with waves if the defence were removed) the model considers coastal erosion would be triggered immediately following defence failure from year 1 (i.e. future sea level rise is not required in combination with defence failure to trigger erosion).

Table 6. Landslide reactivation probabilities for conditional sequence model scenarios 4-5

Scenario	Sub-Unit	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip
4	A	0.3	0.3	0.4	0.5	0.5	0.5	0.1
	B	0.025	0.025	0.025	0.025	0.025	0.025	0.025
	C	0.025				0.025	0.025	0.025
5	A	0.03	0.03	0.04	0.05	0.05	0.05	0.01
	B	0.025	0.025	0.025	0.025	0.025	0.025	0.025
	C	0.025				0.025	0.025	0.025

The input parameters are combined using the following equation:

*P (Landslide Event) = P(Initial Coastal Defence Failure)*Incremental coastal defence failure probability % * P (Landslide Reactivation)*

4.2.5 Combining threshold rainfall and conditional sequence probabilities

The combined probability of landslide reactivation in a given year due to defence failure or threshold rainfall (or both) is calculated as the addition of the probability of landslide reactivation occurring for the first-time due to defence failure and the annual probability of landslide reactivation due to threshold rainfall, subtracting the product of the probabilities. This assumes the initiating events are independent.

For example, when the probability of landslide reactivation due to defence failure (P(A)) and probability of landslide reactivation due to threshold rainfall (P(B)) are added, the probability of the intersection (and) is added twice, and to compensate for this double inclusion, the intersection must be subtracted so that:

$$P(A \text{ or } B) = P(A) + P(B) - P(A \text{ and } B)$$

Which is: $$P(A \text{ or } B) = P(A) + P(B) - (P(A) \times P(B))$$

This is multiplied by the probability that landslide reactivation has not occurred in the years previous so that the final probability is in relation to the given year.

To illustrate the hazard probabilities on an undefended frontage, Table 7 shows an example comparison of the changes in cumulative hazard probability after 1, 20, 50 and 100 years of the do nothing (walk away and let the defences fail). The probabilities take account of the effect of increased winter rainfall on land instability and coastal defence residual life as detailed in sections 4.2.3 and 4.2.4 respectively.

The results in Table 7 show how the cumulative probability of each hazard scenario having occurred increases with time under the do nothing scenario.

Table 7. Comparison of typical cumulative hazard probability after 1, 20, 50 and 100 years of the do nothing scenario.

Year	Cumulative hazard probability				
	1	2	3	4	5
1	0.9500	0.1000	0.0100	0.0809	0.0080
20	1.0000	1.0000	0.2430	0.6568	0.3841
50	1.0000	1.0000	0.8458	0.6776	0.5681
100	1.0000	1.0000	1.0000	0.7434	0.6200

4.3 Consequence model

The aim of this section is to provide estimates of the potential economic losses arising from the various cliff hazard scenarios at Ventnor and Bonchurch. The consequence model evaluates the probable economic losses and damages arising from ongoing cliff instability and erosion. The analysis takes into account the five scenarios that comprise the hazard model in Section 4.

The coastal cliffs and landslide terraces at Ventnor and Bonchurch are typically heavily developed with buildings and infrastructure. The management of the area over the next 100 years will determine the amount of losses and damage avoided and the benefits and cost of intervention. The cost benefit analysis provides a tool to judge the economic justification for investing in stabilisation and coastal defence measures over the next 100 years.

4.3.1 Approach

The consequence model has been developed by a panel of experts: Professor Roger Moore (expert in cliff instability and management in the UK), Geoff Davis, Ross Fitzgerald, Claire Czarnomski (experts in cliff instability and QRAs) and Jon Denner (expert in coastal erosion management). The first element of the QRA, the hazard model, specifies the areas likely to be affected by ground movement and landslides, and quantifies the probability of occurrence of five hazard scenarios. This element of the QRA, the consequence model, quantifies the losses due to the various hazard scenarios.

The impact of a hazard scenario is controlled by: the ground behaviour, the assets at risk and their vulnerability to damage. Combining these factors enables landslide consequence models to be developed that reflect the potential losses and damage outcomes associated with the hazard scenarios. Hence for a hazard scenario of a given probability and intensity:

Risk = Probability (Event) x Consequence (Total Loss x Vulnerability)

The ‘total loss’ is the estimated asset value within each LRU sub-unit (see Section 4.3.2). The valuation of economic loss follows best practice, including HM Treasury Rules (2013), FCERM-AG (2010) and the Multi-coloured Manual (2005, 2010). The ‘vulnerability’ or asset damages represents the proportion of assets that would be damaged or lost given landslide reactivation of a given hazard scenario (see Section 4.3.3).

As with the hazard model, the LRUs and sub-units provide the spatial framework for the consequence model. The above calculation has been carried out for each LRU sub-unit and the five hazard scenarios. The hazard model and consequence model are combined for all hazard scenarios to provide potential economic losses arising from the various hazard scenarios (i.e. the risk) in each sub-unit.

4.3.2 Asset values

The asset values within each LRU sub-unit were estimated using: the National Receptor Database which provides a breakdown of residential and non-residential property numbers for the study area; traffic counts and tourism data provided by the Isle of Wight Council; and estimates for utilities, services, transport and emergency services based on the Ventnor 2006 QRA (Halcrow, 2006) and Ordnance Survey data. The value of education and health, public amenity and value of enjoyment have not been included in this assessment due to the unavailability or unsuitability of datasets.

The types of assets at risk from ground movement and landslides and their estimated 2018 values are presented in Table 8. Details of how the various asset values have been calculated or estimated can be found in Appendix 8.

Table 8. Estimated current total Ventnor and Bonchurch asset cash values (2018)

Asset type	Asset value (£) by LRU							
	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip	Total
Residential property	£70,924,624	£116,406,384	£259,890,512	£248,039,141	£70,753,208	£11,359,460	£8,925,290	£786,298,619
Residential property no. (in total)	101	417	931	721	436	70	55	2731
Non-residential property	£38,622,320	£37,685,520	£134,272,112	£77,748,746	£27,587,260	£9,412,124	£3,570,116	£328,898,198

Asset type	Asset value (£) by LRU							
	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip	Total
Non-residential property no.	55	135	481	226	170	58	22	1147
Tourism	£770,925	£1,431,718	£17,180,617	£4,735,683	£3,193,833	£1,101,322	£330,396	£28,744,493
Transport (highways & footpaths)	£3,948,146	£10,439,786	£8,433,730	£4,529,066	£9,945,283	£3,502,490	£1,179,559	£41,978,060
Traffic disruption	£929,059	£2,532,583	£1,574,918	£1,344,442	£1,190,791	£960,316	£883,490	£9,415,599
Utilities & services	£13,145,633	£18,491,028	£47,299,515	£39,094,546	£11,800,856	£2,492,590	£1,499,449	£133,823,618
Emergency response	£6,134,629	£8,629,147	£22,073,107	£18,244,122	£5,507,066	£1,163,209	£699,743	£62,451,022
Total asset value (£)	£134,475,336	£195,616,165	£490,724,511	£393,735,746	£129,978,298	£29,991,511	£17,088,043	£1,391,609,609

4.3.3 Asset damage

Within the study area, asset damage tends to occur between major landslide blocks, and the degree of hazard can vary dramatically within a few metres of the surface exposure of inter-block shear surfaces. Damage to one property may be severe whilst nearby a property may have negligible damage. As described, the degree of property damage also varies between landslide units and sub-units, reflecting their varying susceptibility and behavioural response to deep seated displacement.

Table 9 shows the level of damage caused by each of the hazard scenarios. The rationale for the values is as follows:

- An average residential property value has been applied to the total number of residential and non-residential property assets within each landslide reactivation sub-unit. Non-residential property values were not available;
- The repairs/write-off values are based on a percentage of the approximate average residential property price for Ventnor and Bonchurch;
- The high frequency low magnitude hazard scenarios (1 and 2) predominantly cause damage at the lower end of the scale in the negligible and slight categories and the value of repairs are low at 0.1 to 1% of the asset value;
- In the low frequency high magnitude hazard scenarios (4 and 5) a greater proportion of each asset is damaged so the dominant damage categories are severe and serious and the value of repairs or write-off are high at 50 to 100% of the asset value;
- For each scenario the model assumes even spatial probability of damage across each unit.

The total losses in a sub-unit in the event of a landslide reactivation (the consequences) are calculated for all five hazard scenarios by multiplying total asset value by percentage asset damage for the given scenario:

Consequence = Total losses (asset value) x Vulnerability (percentage asset damage)

If necessary, the resultant losses are capped at the total market value of all affected assets e.g. assets can only be written-off once. This provides a realistic estimate of risk in terms of the economic valuation of the losses and damages which could be incurred over the next 100 years.

Table 9. Asset damage (cash cost) matrix showing the % of asset damage by each hazard scenario

Damage category	% of asset value loss	Value of repairs/write-off Per asset	% damage to assets under scenario				
			1	2	3	4	5
Negligible	0.10%	£250.00	95%	40%	10%	0%	0%
Slight	1.00%	£2,500.00	5%	50%	15%	0%	0%
Moderate	10.00%	£25,000.00	0%	10%	50%	0%	0%
Serious	25.00%	£62,500.00	0%	0%	15%	10%	0%
Severe	50.00%	£125,000.00	0%	0%	10%	50%	5%
Write-off	100.00%	£250,000.00	0%	0%	0%	40%	95%

4.3.4 Asset risk

The risk in a sub-unit for a given hazard scenario is the probability of a landslide reactivation multiplied by the total losses in a sub-unit in the event of a landslide reactivation:

Risk = Probability (Event) x Consequence

This calculation combines the hazard model results with the consequence model results.

The risk within a sub-unit is the combined risk of all five hazard scenarios for a given year. To avoid double counting of total losses from the different landslide reactivation scenarios, the risk is calculated by plotting the landslide damage curve. This plots the probability of failure for a given year on one axis and the total losses (consequences) on the other axis, for all five scenarios. The area beneath the curve represents the total risk for the sub-unit. This has been calculated in a simple equation:

(Consequence x Probability (Event)) + ((Consequence-Consequence) x Probability (Event)) + ((Consequence-Consequence) x Probability (Event)) …

Where green is scenario 1, red is scenario 2, and purple is scenario 3, and so forth. The calculated risk in a given year for all hazard scenarios in each LRU sub-unit provides the input for calculation of present value losses which feed into the cost-benefit analysis.

4.3.5 Present value losses

Present value losses are the economic value of predicted future losses expressed in terms of the present day, and are calculated as:

PV Losses = Risk x Discount Factor

As asset loss is worth more today than it would be worth tomorrow, discounting is required to determine the present value of losses incurred in the future. The discount factor is a factor dependent upon discount rates set by HM Treasury used to reduce the value of predicted future losses to their value in terms of the present day. These are calculated for each year over a 100-year period for each landslide reactivation sub-unit.

The results are summarised in Table 10 which shows the present value (PV) losses for each LRU under the ‘do-nothing scenario’. Losses total over £450 M over the 100-year period. In the table the losses have been compared to the total present-day cash value of assets in each LRU to demonstrate that there hasn’t been double counting of damages. The PV losses provide the baseline against which the mitigation options are compared in the cost benefit analysis in Section 6.

The PV losses results show that under the ‘do-nothing’ scenario the greatest losses are in Central Ventnor, Wheelers Bay and Ventnor Park due to the number of assets and that losses are low at the Landslip LRU because it contains the fewest assets.

Table 10. Total present value (PV) damages from year 0 - 99 for each LRU under the do-nothing scenario and total asset cash values

LRU	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip	Total
Total PV Losses (Do Nothing	£34,959,027	£76,391,515	£172,483,747	£132,905,507	£25,414,667	£11,048,343	£1,564,651	£454,767,456
Total Asset values	£134,475,336	£195,616,165	£490,724,511	£393,735,746	£129,978,298	£29,991,511	£17,088,043	£1,391,609,609

To determine the most advantageous (in terms of risk reduction) year in which to build risk mitigation measures the peak in *annual* PV losses has been identified. There are two forces at play in determining where the *annual* PV losses peak:

1. The annual probability of an asset being damaged (and the cost of this damage), which depending on the relative influence of the various hazards at the that location, peaks at some point between year 5 and year 20 (i.e. typically a hazard is less probable in the first few years due to, for example, defences being in place and in later years because it is more likely to have already occurred).
2. Discounting: superimposed on the trend in point 1, relative asset losses reduce each year because asset loss is worth more today than it would be worth tomorrow.

Figure 11 shows the typical trend in annual PV losses and, as a result of the factors above, that they peak early in the study period.

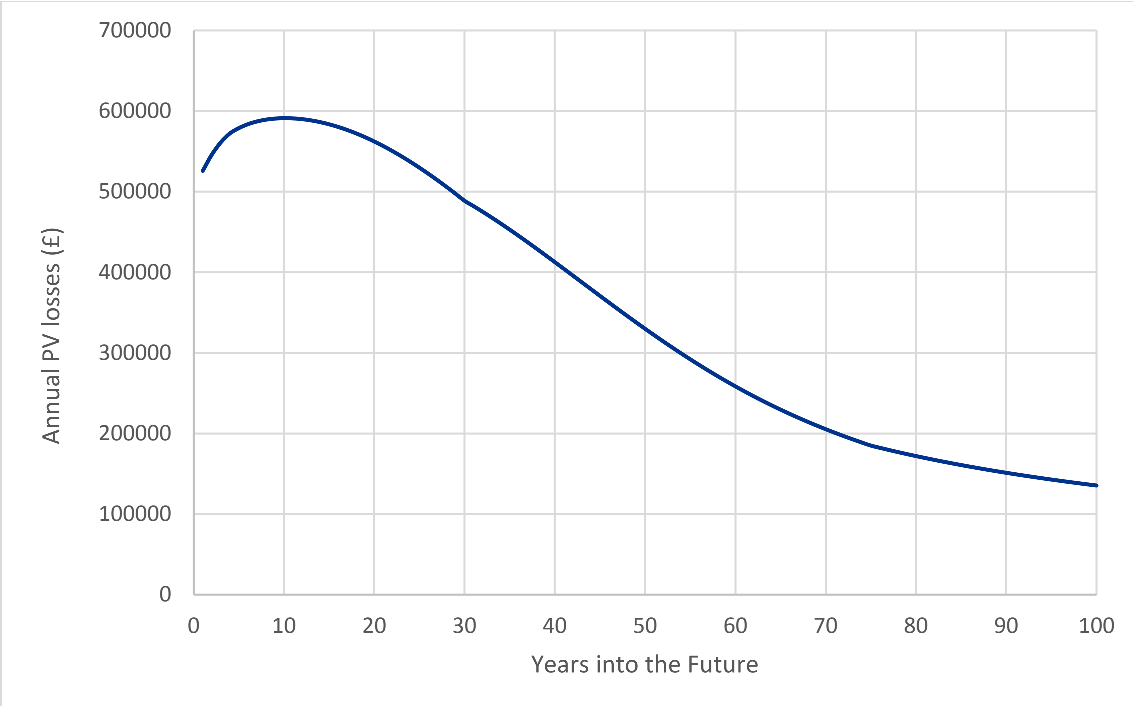

Figure 11. Graph showing a typical trend in changing annual PV losses over the 100-year study period

5. Mitigation options

5.1 Approach

The following section outlines the range of cliff and coastal management options considered to achieve the 'Hold the Line' SMP policies for the frontage at Ventnor and Bonchurch. To identify which options to take forward to the Future Schemes stage, the costs (life of management/ scheme cost) and benefits (reduction in present value damage) ratio of each is then assessed in Section 6.

Although not included in the consequence model as a potential economic loss arising from the various complex cliff hazard scenarios it is important to acknowledge that instability and landsliding has caused significant historical damage to the coastal defence assets at Ventnor and Bonchurch. This is because that, while coastal defences prevent a significant proportion of risk related to loss of passive toe support, the extent, depth and behaviour of the landslides at Ventnor and Bonchurch (see Section 3) mean a significant proportion of the landslide risk is generated by rainfall and groundwater so that assets which prevent toe erosion alone will not prevent future ground movement and land instability. Effective landslide remediation requires solutions that deal with both toe erosion and rainfall-groundwater triggers of ground movement.

As such this section puts forward future management options under two categories:

- Slope stability deep drainage measures to control the rate of deep-seated landslide displacement and protect the coastal defence and other assets from failure,
- Coastal defences to prevent cliff toe erosion and loss of passive support.

5.2 Slope stability: Deep drainage

Due to the Undercliff landslide system extending some distance offshore, with basal shear surfaces both behind and up to 40 m below the coastal defences and because toe erosion is currently prevented by coastal protection, a significant proportion of the landslide risk at Ventnor and Bonchurch is driven by rainfall and groundwater. As such, to safeguard the design life of the coastal defences and secure their effectiveness in upholding the frontage SMP policy of Hold the Line, existing or proposed coast protection measures require complementary works to protect them from damage caused by deep-seated displacement of the Undercliff. EA guidance recommends that such works comprise drainage or slope stabilisation (Halcrow, 2010b) with similar combined coastal defence/ drainage solutions successfully employed to solve major coastal instability and recession problems at Castehaven, Lyme Regis Phase IV and Fairlight Cove.

The Lyme Regis Phase IV Landslip Remediation Scheme, appraised, designed and constructed between 2010 and 2015 has several analogies with the proposed project at Ventnor:

- Subsurface and surface drainage with the aim to decrease the groundwater pressures to acceptable levels for cliff stability.
- An engineering cost of £20 million between 2010-2015 which is comparable to the proposed schemes at Ventnor in today's money.
- Securing the long-term future of a town against coastal erosion and landsliding in one of the most unstable geological settings in the UK.
- Innovative design of scheme based on a deep understanding of the geomorphology, geology and natural processes, with enhanced environmental and amenity benefits.
- Reconciles technical requirements to counter coastal erosion and instability with major environmental constraints pertaining to geology, geomorphology and wildlife.
- Creating and capitalising on significant opportunities and benefits in dealing with an initially intractable situation through strategic planning and programming.
- Successfully balancing the technical requirements of the project, the needs of the local community and environmental issues.
- Remaining on programme and within budget, whilst working safely through one of the worst winters on record (2013-2014) in the UK, both in terms of prolonged heavy rainfall and sea state.
- Widespread critical acclaim, both locally and nationally.

The Fairlight Cove Landslip Remediation Scheme, appraised, designed and constructed between 2007 and 2015 has analogies in well depth and spacing:

- A series of 55 No pumping wells at 6m spacing and up to 30m deep. The role of the pumping wells has been to decrease the groundwater pressures to acceptable levels for the cliff stability.
- Re-profiling of the land slipped mass and installation of a network of surface drains. The re-profiling assisted in eliminating ponding conditions and encourage vegetation growth.
- A rock berm 240m long constructed along the toe of the landslip at the shoreline. The role of the berm has been to dissipate the wave action and decrease significantly the effects of sea erosion to the cliff material.

A large component of the stability and progressive movement of the lower-tier deep-seated landslide blocks is controlled by groundwater pressures developed on basal shear surfaces in the Lower Greensand Sandrock (e.g. bed 2d) varying from sea level at the east of the frontage to up to 40 metres below sea level at Central Ventnor. Deep drainage to relieve ground water pressure could be highly effective at reducing ground displacement and improving global stability of the Undercliff. Relief of artesian groundwater pressures on the basal shear surface could achieve significant improvement in the stability of the lower-tier landslide blocks, which in turn would arrest retrogressive movement and failure of the upper-tier landslide blocks above the Gault Formation. In time the system would lock-up or self-stabilise as a result of the immobile lower tier exerting passive support to the upper tier.

Due to the extensive scale and depth of the Undercliff landslide complex, access constraints, and engineering limitations associated with alternative slope stabilisation measures such as slope regrading and deep piling, the preferred and only feasible slope stabilisation scheme to protect coastal defence assets from instability at Ventnor and Bonchurch is deep drainage.

5.2.1 Well drainage - general considerations

Well drains refer to the installation of deep wells which are typically vertical boreholes provided with a permeable liner at the level at which de-watering is required (in this case the Sandrock 2c). This supports the sides of the hole, whilst allowing water to enter the well. The wells reduce groundwater pressure on a landslide shear surface by removing water from the system through a variety of methods. Each well will have a zone of influence around it where groundwater is drawn down around the well in a cone of depression, the radius and characteristics of which will depend upon the permeability of the surrounding material and the nature and distribution of discontinuities such as joints. Wells are designed to drawdown water pressures by a specific amount to ensure an adequate factor of safety and improvement of landslide stability. The aim of this would be ensuring that winter groundwater levels are kept at or below normal summer groundwater levels, so that the triggering of landslide movements which typically occur during the winter or early spring does not take place.

Due to the inherent variability in ground conditions, and mass permeability in particular, within landslide systems, the effectiveness of each well can only be predicted in general terms on the basis of ground investigation and pumping tests, and actual performance needs to be confirmed through the monitoring of groundwater pressures around the well in a series of separate observation wells. As each well has a limited radius of influence and in order for them to be effective as a stabilisation measure, wells need to be installed in groups, often closely spaced and in lines with each well being less than 10 m away from its neighbours.

5.2.2 Pumped wells

In pumped wells groundwater lowering is achieved with pumps that remove water to the surface from each well. Electro-pneumatic pumps are generally favoured as they have simple parts which are easily maintained. These pumps operate using compressed air from a compressor house that flows through an airline to the pump when required. Pumped wells have been used successfully at an Undercliff site 5 km west of the Study Area at Castlehaven, where drawdowns of 5 to 10 m below surface level have been achieved at the position of the wells, to about 20 m below ground level. Pumped wells are a potentially feasible option for a landslide drainage system for the Undercliff, allowing considerable reduction of ground water pressures at depth, and having a proven track record nearby at Castlehaven.

5.2.3 Siphon drainage

Siphon drains work on the same principle as pumped wells except that the water is removed not by pumps but by gravity along siphon pipes which are kept primed by an automatic system located at the downstream outlet of each siphon pipe. Siphon drains have also been used at Castlehaven, in conjunction with other stabilisation measures. The system requires an accessible and stable location for siphon outlets at a level lower than the intended design groundwater level. The system is limited to what drawdowns can be achieved compared with a pumped system (with the practical limit of drawdown of a siphon drain being around 8 m). The required drawdown of groundwater within the Undercliff is likely to be relatively large in order to provide an adequate factor of safety and improvement in land stability, and there is also the potential difficulty of providing sites for siphon outlets at low level in the Undercliff. Hence it is considered that siphon drainage has significant disadvantages compared to pumped wells and is not likely to form the principal part of a drainage scheme.

5.2.4 Relief wells

Relief wells are used in locations where artesian water pressure drives landslide movements. Wells are drilled into a confined aquifer through the overlying aquiclude and groundwater is allowed to rise to the surface under artesian head thereby reducing the pressure on the landslide shear surface and increasing stability, requiring neither pumps nor siphons. This is a potentially effective technique in those areas where artesian heads are known to exist, needing less equipment and maintenance than either siphon drains or pumped wells. However, while there is likely to be significant artesian pressure in the Sandrock 2c, the existence of sufficient heads have not yet been demonstrated thoughout the area of interest in the Undercliff.

5.2.5 Drainage cost

Although containing significant uncertainty, an indicative cost of a drainage scheme for Ventnor and Bonchurch can be estimated based on the drainage works at Castlehaven in 2004. The scheme cost approximately £2 million for a mixture of 150 pumped wells and syphon drains across a 550 m stretch of frontage. This cost included capital investment for the works themselves, works supervision, a scoping study, ground investigation and drainage trials, all of which would be required at Ventnor and Bonchurch.

By applying a 3% annual multiplier for inflation it is possible to provide an estimated drainage scheme cost at 2018 prices of £2.4 million for each of the smaller LRU's (e.g. Castle Cove) and £3.5 million for each of the larger LRUs (e.g. Ventnor Park) at Ventnor and Bonchurch. See Table 11 for a full list of estimated drainage costs by LRU.

The costs of the drainage schemes have been added to the cost of the coastal defence schemes, developed in Section 5.3, to provide a total scheme cost for each LRU. The drainage costs apply only to improve options A, B and C (explained further below). Drainage doesn't form part of the Do Minimum option.

Table 11. Estimated cost of deep drainage by LRU

LRU	Estimated cash costs (not discounted) for deep drainage cost (£k)
Castle Cove	2,362
Ventnor Park	3,542
Central Ventnor	3,542
Wheelers Bay	2,362
Bonchurch West	3,542
Bonchurch East	2,362
The Landslip	738

The cost of maintaining the drainage wells is included in the costs for coastal maintenance in Section 5.3.2. Drainage maintenance cost isn't reported separately here or in Section 5.3.2 because there is significant cost uncertainty relating to the type of drainage deployed, the local ground conditions and how quickly ground movement can be arrested. As such, any figures quoted could later be misleading. The cost associated with the maintenance of drainage is significantly less than coastal maintenance such as beach recharge/recycling, structural repairs and the import of rock. By ensuring there is a healthy budget for a robust regime of coastal maintenance, provision has been made for maintaining the drainage wells.

5.2.6 Timing of drainage interventions

Drainage interventions for each of the LRUs have been modelled at year 5. This is because the annual present value damages for rainfall triggered ground instability (scenarios 1-4) peaks very early in the study period (typically before year 10) and because the lifespan of the present and any future coastal protection assets is, in part, reliant on achieving slope stability. 5 years also accounts for the time required for the ground investigation, drainage tests and other appraisals necessary for detailed design of a scheme and for construction.

5.2.7 Post drainage landslide probabilities

The hazard models for rainfall triggered landslides (scenarios 1-4) presented the failure probability and the annual increase in this failure probability due to climate change for the 'do-nothing' option. By investing in deep drainage, the risk of failure is substantially reduced. An order of magnitude reduction in failure probability for the post drainage Undercliff systems has been applied based on experience and expert judgement (Ventnor Options Study Workshop, Sept 2017). Table 12 provides the pre- and post-deep drainage landslide reactivation probabilities.

Table 12. Pre and Post drainage scheme Landslide reactivation probabilities given exceedance of winter rainfall.

Scenario	Sub-Unit	Castle Cove		Ventnor Park		Central Ventnor		Wheelers Bay		Bonchurch West		Bonchurch East		The Landslip	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	A	1	0.1	1	0.1	1	0.1	1	0.1	1	0.1	1	0.1	1	0.1
	B	1	0.1	1	0.1	1	0.1	1	0.1	1	0.1	1	0.1	1	0.1
	C	0	0							0	0	0	0	0	0
2	A	1	0.1	1	0.1	1	0.1	1	0.1	0.5	0.05	1	0.1	1	0.1
	B	1	0.1	1	0.1	1	0.1	1	0.1	0.5	0.05	1	0.1	1	0.1
	C	0	0							0	0	0	0	0	0
3	A	0.5	0.05	0.5	0.05	0.5	0.05	0.5	0.05	0.5	0.05	0.5	0.05	1	0.1
	B	0.5	0.05	0.5	0.05	0.2	0.02	0.2	0.02	0.2	0.02	0.5	0.05	0.5	0.05
	C	0	0							0	0	0	0	0	0
4	A	1E-03	1E-04	1E-03	1E-04	1E-03	1E-04	1E-03	1E-04	1E-03	1E-04	1E-03	1E-04	1E-03	1E-04
	B	1E-03	1E-04	1E-03	1E-04	1E-03	1E-04	1E-03	1E-04	1E-03	1E-04	1E-03	1E-04	1E-03	1E-04
	C	0	0							0	0	0	0	0	0

Scenario	Sub-Unit	Castle Cove		Ventnor Park		Central Ventnor		Wheelers Bay		Bonchurch West		Bonchurch East		The Landslip	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	C	0	0							0	0	0	0	0	0

5.3 Coastal defences

This section presents the preferred management options identified for each of the shoreline coastal Defence Units. The various Defence Units (frontages) covering the study frontage are defined within the SMP and the Defence Appraisal Assessment (see Appendix 10) and are defined by individual defence IDs e.g. IW30 / 001. Each shoreline Defence Unit incorporates various engineering assets for that frontage, including the shoreline structures (seawalls, revetments), beach control structures (groynes), offshore structures (breakwaters) and set-back defence elements (set back flood walls/gabions etc) associated with providing the standard of protection for the given frontage.

5.3.1 Coastal defence options

The Defence Appraisal (Appendix 10) is used to identify the engineering assets within each Defence Unit that are below standard or vulnerable to various failure modes. This high-level, strategic options appraisal identifies various management and engineering options to maintain and improve the engineering assets to prevent erosion of the shoreline and the risk of landslide reactivation.

The management options that have been considered and developed for each Defence Unit are as follows:

- The **Do Nothing** (No Active Intervention) option is used as a baseline against which all other options are appraised.
- The **Do Minimum** management option has no capital works associated with it. Such options would not improve the standard of protection to a consistent or acceptable standard (where needed), but may serve to maintain a given standard, but the risk of failure will increase over time. This option reflects the level of maintenance that is typically currently undertaken along each frontage, based on data supplied by the IWC for recent years
- Multiple **Improve** options have been identified. These represent management options to improve the standard of protection:
    - **Improve option A** considers the initial replacement of all failing engineering assets (structures), plus drainage. All engineering assets are then subject to an active and aggressive maintenance regime, but such measures would take place largely on a reactive basis, typically as emergency capital works. This may involve placing rock at the toe of a structure before it becomes critically exposed, or more active local beach recycling. This asset management option seeks to maximise the residual life of the asset.
    - **Improve options B and C** seek to uniformly improve the protection to a 0.005% (1 in 200 year) standard of protection for the Defence Unit, replacing assets as required under a full capital works and maintenance programme, plus drainage. Engineering judgement has been used for this strategic level assessment to identify the engineering measures required and the most viable option to progress. Options B and C represent two such representative engineering options (concepts) to consider for the strategic economic case (for some assets only one option, Option B, has been identified). Option C considers an

early intervention compared to Option B. A full options appraisal stage would be required should an economically viable scheme be identified within the strategic programme of priority works for a given frontage.

The options above are described in detail in Appendix 8 and 9 for each Defence Unit within each Landslide Reactivation Unit.

A suite of local measures has been selected on a Defence Unit basis to deliver the Improve options, seeking the most cost-effective, practical and suitable measures for each Defence Unit (frontage). This has been undertaken on a strategic basis only to define a strategic programme of works for the overall study area. A full scheme-level options appraisal would be required at Outline Business Case stage. This would include reconsidering and reconfirming the long list of options, the identification of a short list of options (where various standards of protection could be considered alongside a range of engineering solutions) and the identification of the preferred option through the outline design process. The short-listing process would use results from survey (geotechnical site investigation, topographic survey, environmental surveys etc), coastal processes assessment and analysis.

The choice of measures outlined in Appendix 8, however, is deemed appropriate considering the unique local circumstances of this coastal landslide complex, and experience at this site and elsewhere in the UK, with reasoning documented in Appendix 8.

Measures selected include the replacement or repair/ strengthening/ enhancement of the following;

- Revetments
- Seawalls
- Groynes
- Breakwaters
- Rock armour
- Beaches

5.3.2 Coastal defence costs

Appendix 8 and 9 detail the costs of the various schemes and maintenance options (as described in the previous section) along with the proposed intervention timing for each Defence Unit over the 100-year appraisal period. Table 13 provides a summary of unit cost rates for maintenance and replacement of coastal defences.

Table 13. Unit cost rates for maintenance and replacement of coastal defences.

Element	Rate	Unit	Notes
Large rock revetment	13	£k/m	Based on CH2M costs and priced works at Deal inclusive of a 30% mark ups for prelims/profit etc. Assumes large-sized rock with fair access
Medium rock revetment	8.2	£k/m	Based on CH2M costs and priced works at West Bay and Deal inclusive of a 30% mark ups for prelims/profit etc. Assumes large-sized rock, but relatively small cross section with fair access
Medium rock revetment	7.9	£k/m	Based on CH2M costs and priced works at West Bay inclusive of a 30% mark ups for prelims/profit etc. Assumes mid-sized rock with fair access
Rock in front of seawall	3.4	£k/m	CH2M price based on a typical 100m length of toe rock in front of existing structure with fair access. Inclusive of a 30% mark ups for prelims/profit etc.

Element	Rate	Unit	Notes
Shallow rock breakwater or large rock groyne into deep water	1,300	£k each	Based on CH2M costs and priced works at West Bay inclusive of a 30% mark ups for prelims/profit etc. Assumes mid-sized rock with fair access
Shingle recharge	14	£/m^3	Based on CH2M costs and priced works at Deal inclusive of a 30% mark ups for prelims/profit etc. Assumes large quantity of material available locally.
Shingle recycling	9	£/m3	Based on CH2M costs and priced works at Pett inclusive of a 30% mark ups for prelims/profit etc. Assumes good access and short haul route
Rock groyne repair	390	£k each	Based on CH2M costs and priced works at West Bay inclusive of a 30% mark ups for prelims/profit etc. Significant rebuild of rock structure with minimal import of new material.
2-weeks of rock structure maintenance	43	£k each	Based on CH2M costs and priced works at Stolford inclusive of a 30% mark ups for prelims/profit etc. For a 2-week maintenance programme (excludes any rock)
2-weeks of rock structure maintenance (incl. rock import)	100	£k each	Based on CH2M costs and priced works at Stolford inclusive of a 30% mark ups for prelims/profit etc. For a 2-week maintenance programme (includes 600m3 of new rock (using West Bay rates)
1-week rock structure maintenance	26.5	£k each	Based on CH2M costs and priced works at Stolford inclusive of a 30% mark ups for prelims/profit etc. For a 1-week maintenance programme (excludes any rock)
2-weeks of rock structure maintenance (incl. rock import)	55	£k each	Based on CH2M costs and priced works at Stolford inclusive of a 30% mark ups for prelims/profit etc. For a 1-week maintenance programme (includes 600m3 of new rock (using West Bay rates)

There are no costs associated with the Do Nothing scenario. It is assumed that costs for closing footpaths and signage (managing H&S) would be covered by existing council budgets.

The cost estimates for the Do Minimum option are considered as annual costs, which links typical annual expenditures on these frontages.

The cost estimates for the Improve options are based on contractor priced or outturn construction prices for similar, recent UK coastal engineering schemes, including West Bay in Dorset, Deal in Kent, Pett in East Sussex and Stolford in Somerset. Typically, these contractor costed schemes have been broken down to provide a typical cost per metre length of frontage for the types of interventions proposed for Ventnor. The cost estimates for the more active maintenance components such as beach recycling and rock placement at the toe of structures have been assessed by assuming a quantity of material (for beach recycling) or a length of frontage covered (for toe rock), and taking unit costs from similar recent priced schemes. These unit rates have been scaled where appropriate to reflect differences in expected scale of intervention. These costs include for contractor’s preliminaries and profit (typically totaling 30%).

As an example of this costing process, a comparable scheme in the south of the UK has been used to assess typical revetment costs. This particular scheme used rock of a similar grading to what would be expected to be required for Ventnor and the typical profile was of a comparable scale. The outturn construction cost of that revetment was approximately £2m for a 200m length. This translates to a cost per metre run of £10k. This has been uplifted by 30% to give an overall cost per metre run of £13k. For Ventnor, typically an upper seawall would be required, which has been reflected by an additional cost per metre run. These rates have been applied to the overall frontage length to give an overall indicative cost.

The cost associated with the maintenance of drainage is significantly less than coastal maintenance such as beach recharge/recycling, structural repairs and the import of rock. By ensuring there is a healthy budget for a robust regime of coastal maintenance, provision has been made for maintaining the drainage. The cost of drainage maintenance isn’t reported separately here or in Section 5.2.5 because there is significant cost uncertainty relating to the type of drainage deployed, the local ground conditions and how quickly ground movement can be arrested. As such, any figures quoted could later be misleading.

All costs are subject to a 60% optimism bias uplift during the later economic analysis stage (the typical rate for strategic level assessments such as this). Hence, no risk has been included in the intervention costs.

Table 14 provides a summary of the 100-year costs for the options for each landslide unit. The table shows the costs for the coastal works and drainage works (see Section 5.2.5) are split into capital costs for improvement schemes and maintenance costs. It should be noted that these aggregated costs are cash costs and have not been economically discounted as per the tables accompanying the economic appraisal.

Table 14. Estimated cost of coastal interventions, coastal and drainage maintenance, drainage and total combined costs by LRU.

Landslide Reactivation Unit	Expenditure Type	Estimated cash costs (not discounted) of options (£) over 100 years				
		Do Nothing	Do Minimum	Improve A	Improve B	Improve C
Castle Cove	Drainage	-	-	£2,362,000	£2,362,000	£2,362,000
	Coastal	-	-	-	£3,067,000	£3,067,000
	Maintenance	-	£800,000	£1,334,000	£957,000	£814,000
	Total	**-**	**£800,000**	**£3,696,000**	**£6,386,000**	**£6,243,000**
Ventnor Park	Drainage		-	£3,542,000	£3,542,000	£3,542,000
	Coastal	-	-	-	£3,517,000	£3,517,000
	Maintenance	-	£600,000	£1,113,000	£625,000	£530,000
	Total	**-**	**£600,000**	**£4,655,000**	**£7,684,000**	**£7,589,000**
Central Ventnor	Drainage		-	£3,542,000	£3,542,000	£3,542,000
	Coastal	-	-	£3,801,000	£8,041,000	£8,041,000
	Maintenance	-	£1,400,000	£2,100,000	£1,511,000	£1,511,000
	Total	**-**	**£1,400,000**	**£9,443,000**	**£13,094,000**	**£13,094,000**
Wheelers Bay	Drainage		-	£2,362,000	£2,362,000	£2,362,000
	Coastal	-	-	£3,202,000	£7,658,000	£7,713,000
	Maintenance	-	£1,100,000	£799,000	£627,000	£599,000
	Total	**-**	**£1,100,000**	**£6,363,000**	**£10,646,000**	**£10,674,000**
Bonchurch West	Drainage		-	£3,542,000	£3,542,000	£3,542,000
	Coastal	-	-	-	£14,250,000	£14,250,000
	Maintenance	-	£400,000	£900,000	£609,000	£492,000
	Total	**-**	**£400,000**	**£4,442,000**	**£18,401,000**	**£18,284,000**
Bonchurch East	Drainage		-	£2,362,000	£2,362,000	£2,362,000
	Coastal	-	-	-	£6,310,000	£7,019,000
	Maintenance	-	£1,000,000	£2,179,000	£1,123,000	£960,000
	Total	**-**	**£1,000,000**	**£4,541,000**	**£9,795,000**	**£10,340,000**
The Landslip	Drainage		-	£738,000	£738,000	£738,000
	Coastal	-	-	-	£4,685,000	£4,685,000
	Maintenance	-	£50,000	£270,000	£150,000	£250,000
	Total	**-**	**£50,000**	**£1,008,000**	**£5,572,000**	**£5,672,000**

*Values have been rounded to the nearest thousand. Values do not include optimism bias or appraisal and design costs.

5.3.3 Timing of coastal defence interventions

The intervention timing is based on the point at which the defence is expected to degrade to such a point that the risk of failure becomes unacceptable. This is linked to the initial failure probability and the annual increases in this failure probability. This reflects the residual life of each asset, but rather than simply stating when the defence is anticipated to fail and then seek to rebuild it just before it fails, it uses a probabilistic approach to failure, which more accurately reflects increasing risk as it degrades, which can then be linked into the QRA.

5.3.4 Failure probability of coastal defence Units

The Defence Appraisal assessment (Appendix 10) presented the failure probability and the annual increase in this failure probability for the Do Nothing option. By investing in maintenance of these structures the standard of protection or overall risk of failure does not typically change, but the maintenance investment will typically reduce the rate at which the defence degrades. This is expressed as a reduction in the annual increase in failure probability.

As structures are replaced, or significantly upgraded through a capital scheme, this will improve the standard of protection and reduce the failure probability to the design standard. Given the strategic nature of this commission, it has been assumed that all new/rebuilt defences as part of a capital investment will be designed to a 0.005 or 1 in 200-year standard of protection. Such a standard is typical of new coastal schemes, but alternative standards would be considered at options appraisal stage (Outline Business Case).

5.3.5 Link between coastal defence unit and landslide reactivation unit

The identified landslide reactivation units (LRUs) do not link directly to single Defence Units. The links between the two are summarised in Table 15. There can be a number of engineering assets (structures) within each Defence Unit.

Table 15. Links between LRUs and Defence Units

LRU	Defence Units comprising the Landslide Reactivation Unit							
Bonchurch East	IW30/001	IW30/002	IW30/003	IW31/001	IW31/002 (part)			
Bonchurch West	IW31/002 (part)							
Wheelers Bay	IW32/001	IW32/002	IW32/003	IW33/001				
Central Ventnor	IW33/002	IW34/001	IW34/002	IW34/003	IW34/004	IW35/001		
Ventnor Park	IW35/002	IW35/003	IW35/004	IW35/005				
Castle Cove	IW36/001	IW36/002	IW36/003	IW36/004	IW36/005	IW36/006	IW36/007	IW36/008
The Landslip	No coastal defences in landslide unit							

In some cases, multiple Defence Units (and defences) protect a single LRU. In the case of 'The Landslip' LRU there are no existing coastal defences. There are also overlaps where the LRU boundaries do not exactly align with the ends of the Defence Units. Where this overlap is minor, the Defence Unit has been aligned with the LRU where the majority of the main defence asset (structure) is located. There is one case (Defence ID IW31/002), where a single defence spans significant lengths of two landslide units. In this case the defence has been split within the QRA and economic assessment, with costs in each unit linked with the defence length.

The QRA and the economic assessment considers each landslide unit (LRU) in isolation. The costs and failure probabilities for each landslide unit needs to reflect the group of Defence Units assets at its toe.

Where there are shared benefits (within a LRU) for a group of Defence Units, it is not economically possible to value the benefit for a single Defence Unit (or engineering asset). The exception is where there is a single defence structure, or part of a defence, within a LRU, such as Bonchurch West, where the full benefit (damage avoided) from landslide reactivation due to a breach of the coastal defence can be fully aligned to one asset only.

The QRA and economic assessment for LRUs with multiple Defence Units needs to represent the group of coastal defence assets (structures) working together to provide the economic benefit. In terms of costs for the economic assessment, the costs of the various contributing coastal defences simply need to be aggregated for each LRU. For the failure probabilities as inputs into the QRA, the case of the defence unit (or asset) weakest link is adopted.

5.3.6 Failure probability of landslide units

Assessing the combined probability of failure of multiple coastal defences, each with an individual failure probability for a Defence Unit (and annual increase in that probability), leading to the reactivation of a landslide unit would be a very complex calculation. In addition, this would lead to the risk of overlapping benefits, which would not be an acceptable economic basis for claiming FDGiA. Hence, a 'weakest link' approach has been adopted to identify the failure probability for the group of Defence Units (or engineering assets).

For the Do Nothing and the Do Minimum options, the failure probability and annual increase in this probability is consistent over time. The Defence Unit with the highest probability of failure is identified for each LRU and the corresponding failure probability and annual increase in failure probability is adopted for the appraisal period (100-years for the economic appraisal).

The tables in Appendix 8 provide the full details of the various coastal defence options for each LRU. The details include the description of the option, the intervention timing, the cost and the post management/ scheme failure probabilities.

In each table the probabilities in **green** have been identified as the weakest link within each landslide unit for the **Do Nothing** option. This weakest link is used for the QRA analysis. Similarly, the **purple** text highlights the **Do Minimum** weakest link within that landslide unit.

For the Improve options (Improve A, B & C), these have a programme of capital coastal defence works being implemented at various points over the appraisal period. Hence, the weakest link at any given time is adopted, identified by **red** text for the **Improve** option. This weakest link for the Improve option can vary over time, as capital schemes are implemented at various points over the economic appraisal. As a defence is improved, the next weakest link is adopted for the failure probability (which will have been deteriorating over this time as per the increase in failure probability identified for that defence).

5.3.7 Post coastal scheme failure probabilities

Each of the proposed coastal defence options reduce the risk of the instability and landslide reactivation occurring by varying degrees. The factor of improvement (reduction in annual hazard probability) is based on experience and expert judgement (Ventnor Options Study Workshop, Sept 2017). The following factors were taken into consideration:

- The nature and condition of the existing defence structure or management
- The nature of the proposed improvement/upgrade
- The nature and geometry of the frontage

Appendix 9 provides an LRU by LRU breakdown of the post coastal defence scheme failure probabilities.

In addition, the probability of landslide response given a defence failure depends on the nature and geometry of the frontage and the type of defences (i.e. some continue to afford some protection even in a failed state e.g. rock revetments). As failing concrete structures are replaced/strengthened with rock structures (as in the Improve Options), the frontage resilience increases. This increased resilience is most dramatic where concrete structures are replaced by rock structures, as in many of the Improve B and Improve C options. Where assets are strengthened only, as in many of the Improve A options (perhaps rock toe protection), the resilience is improved, but to a lesser degree than when the full structure is replaced.

Table 16 summarises the link between coastal defence failure and the reactivation of a landslide within each Landslide Reactivation Unit (LRU). This varies

Table 16. Pre and post scheme landslide reactivation probabilities given the failure of one of the structures within the LRU

LRU	Reactivation Scenario	Probability that a landslide is reactivated given the failure of one of the structures within the LRU					Notes
		Do Nothing	Do Min	Improve A	Improve B	Improve C	
Bonchurch East	**4**	0.5	0.5	0.2	0.1	0.1	Relatively high chance of activating a landslide following the failure of a defence. Many of the defences have a high retained height and as there are many concrete structures, these typically fail quicker and more catastrophically (in comparison to say rock structures).
	5	0.05	0.05	0.02	0.01	0.01	
Bonchurch West	**4**	0.5	0.5	0.2	0.1	0.1	Relatively high chance of activating a landslide following the failure of a defence. Many of the defences have a high retained height and as there are many concrete structures, these typically fail quicker and more catastrophically (in comparison to say rock structures).
	5	0.05	0.05	0.02	0.01	0.01	
Wheelers Bay	**4**	0.5	0.5	0.1	0.1	0.1	Relatively high chance of activating a landslide following the failure of a defence. Many of the defences have a high retained height and as there are many concrete structures, these typically fail quicker and more catastrophically (in comparison to say rock structures).
	5	0.05	0.05	0.01	0.01	0.01	
Central Ventnor	**4**	0.4	0.4	0.1	0.1	0.1	Reduced chance to that to the eastern frontages of activating a landslide following a defence failure.

LRU	Reactivation Scenario	Probability that a landslide is reactivated given the failure of one of the structures within the LRU					Notes
		Do Nothing	Do Min	Improve A	Improve B	Improve C	
	5	0.04	0.04	0.01	0.01	0.01	This is due to the relatively moderate retained height with either the beach or harbour in front of the majority of the frontage and typically a road directly behind.
Ventnor Park	**4**	0.3	0.3	0.2	0.05	0.05	Typical there are low retained heights across structures. Erosion of toe would likely initially result in local landslide only as steep cliff.
	5	0.03	0.03	0.02	0.005	0.005	
Castle Cove	**4**	0.3	0.3	0.2	0.05	0.05	Even in failed state, significant bulk of rock material and beaches will continue to manage risk of landslide reactivation
	5	0.03	0.03	0.02	0.005	0.005	
The Landslip	**4**	0.1	0.1	0.1	0.05	0.05	No protection in a DN or Do Min option. However, significant landslips are not regularly occurring, but risk will increase over time
	5	0.01	0.01	0.01	0.005	0.005	

6. Cost benefit analysis

This section assesses the economic viability of the various coastal erosion and landslide mitigation options for each LRU put forward in Section 5. The cost benefit of each option has been tested in full accordance with all relevant requirements and latest national and latest FCERM and HM Treasury Guidance using the Environment Agency's "Supporting Spreadsheet to the Economic Appraisal for a Flood or Coastal Erosion Risk Management Project" (based on older Defra Project Appraisal Guidance (PAG) spreadsheet, corrected and updated to reflect the new FCERM-AG). The full life cycle cost of each option has been compared to the reduction in PV damages benefit with careful consideration given to the effect on the cost benefit of alternative approaches, costings and implementation timings.

This CBA has been developed to assist IWC understand the distribution of risk across Ventnor and Bonchurch and support decisions on future investment in risk reduction measures through implementation of an Undercliff coastal management strategy.

6.1 CBA method and calculations

Cost benefit analysis involves comparing the total expected cost of the range of management and engineering options against the total expected benefits (or reduction in losses over the study period afforded by the various options), to see whether the benefits outweigh the costs, and by how much. Any investment in coastal defences and landslide stabilisation needs to be offset by a resulting reduction in the losses that will otherwise occur. A clear way of showing the relationship between investment and reduction in losses is the ratio of benefits to costs.

In the first part of this analysis, the results are expressed as a single number known as the benefit cost ratio (BCR). If this number is less than 1, the cost of the scheme outweighs the benefits; if the number is greater than 1 it shows the beneficial return of investment i.e. a BCR of 2 means for every £1 spent on engineering £2 of benefit is realised.

To aid identification of preferred options where multiple economically viable schemes are obtainable, the second part of this analysis expresses results as an incremental benefit cost ratio IBCR. This enables options which provide the greatest amount of protection but not necessarily the highest BCR to be selected as future schemes. The procedure works by considering progressively higher-protection options. At each stage, a higher-protection option is accepted in preference to a lower-protection option if the incremental benefit–cost ratio is greater than some critical value (1 for the move from the do-nothing option to the option with the highest benefit–cost ratio, 'robustly greater than 1' for further improvements below the indicative range).

The benefit of a scheme is the reduction in risk, expressed in monetary terms, compared to the 'no active intervention' case. The costs include all the costs incurred during the investigation, planning and design, construction and implementation of the scheme. Both benefits and costs are considered initially over the appraisal period of 100 years and related to Present Value by discounting in accordance with HM Treasury guidance. At the next stage of this assessment the Future Schemes Report will assess and provide forward proposals and a spending profile for strategic level priority schemes with a robust case for grant in aid GiA funding during the next funding cycle. The range of risk management options assessed are detailed in Section 5.

It should be noted that the resolution of data used herein only supports rough estimates of BCR which are suitable for identifying potentially economically viable schemes. Schemes that are ultimately taken forward will require bespoke, detailed CBA and Partnership Funding (PF) calculations based on detailed design and firm prices to gauge funding eligibility at the Full Business Case (FBC) stage.

6.2 CBA results

The CBA results (presented in Table 17) demonstrate that the existing coastal and cliff stabilisation schemes and practices (do minimum) adopted at Ventnor and Bonchurch have moderately reduced economic risk across the study site. However, the risks could be reduced significantly further by improving the overall stability of the Undercliff through deep drainage and improved coastal protection measures. In summary:

- The Improve B option (deep drainage and new and upgraded coastal defences) is the preferred option at Castle Cove, Ventnor Park and Central Ventnor and Wheelers Bay where the greatest value of assets are protected and/ or at least one of the coastal defences is in very poor condition.
- The Improve A option (drainage and coastal schemes targeted at failing assets and maintenance elsewhere) is the preferred option at Bonchurch West and Bonchurch East where more moderate assets values are protected.
- At a strategic level over 100 years there are economically viable schemes at Castle Cove, Ventnor Park, Central Ventnor and Wheelers Bay.
- At a strategic level over 100 years there are potentially economically viable schemes at Bonchurch West and Bonchurch East.
- There is unlikely to be an economically viable scheme at The Landslip due to the relatively low asset values protected. However, it is noted that the A3055 coastal road forms part of the Island's strategic road network linking the Undercliff with Shanklin and is at risk of breaching from landslide reactivation and recession adjacent to the Devil's Chimney.

Table 17. Benefit Cost Ratio (BCR) and Incremental Benefit Cost Ratio (IBCR) for each LRU (preferred options in bold)

Landslide Reactivation Unit	Economic Parameter	Benefit Cost ratio (BCR) and Incremental Benefit Cost Ratio (IBCR) for each LRU option			
		Do Minimum	**Improve A** (drainage, targeted new coastal defences and maintenance)	**Improve B** (drainage and new and improved coastal defences)	**Improve C** (drainage and early intervention new and improved coastal defences)
Castle Cove	BCR	3.8	5.7	**5.3**	4.7
	IBCR		5.8	**3.4**	0.4
Ventnor Park	BCR	6.3	7.7	**8.2**	7.8
	IBCR		7.7	**11.0**	0.0
Central Ventnor	BCR	1.1	9.4	**9.8**	N/A
	IBCR		9.8	**14.8**	N/A
Wheelers Bay	BCR	1.0	8.7	**7.7**	7.5
	IBCR		9.0	**4.5**	4.1
Bonchurch West	BCR	8.9	**2.8**	2.0	1.5
	IBCR		**2.6**	0.3	0.0
Bonchurch East	BCR	0.8	**1.5**	1.1	0.9
	IBCR		**1.6**	0.3	0.3
The Landslip	BCR	0.0	0.3	0.2	0.1
	IBCR		0.4	0.1	0.0

The economic assumptions describing the selection of the preferred options (in bold above) are summarised below for the various Landslide Reactivation Units:

- The highest BCRs for **Ventnor Park** and **Central Ventnor** are for the Improve B options (BCRs of 8.2 and 9.8 respectively). The 0 IBCR for Improve C option for Ventnor Park does not justify moving up to this more expensive option. There is no Improve C option for Central Ventnor (in the economic tables it is the same as Improve B). *Preferred Option*: **Improve B**
- The highest BCR for **Castle Cove** is for the Improve A option (BCR of 5.7). The 3.4 IBCR for the Improve B option for Castle Cove is greater than 3.0, making it economically justified under Defra decision rules for the increased expenditure of the Improve B option, which improves the overall standard of protection. The Improve C option has a IBCR below 1, which does not justify the higher cost Option C. *Preferred Option*: **Improve B**
- The highest BCR for **Wheelers Bay** is the Improve A option (BCR of 8.7). The 7.7 BCR for the Improve B option is greater than 3.0 making it economically justified under Defra decision rules for the increased expenditure of the Improve B option, which improves the overall standard of protection. An IBCR greater than 5.0 is required to justify a higher cost scheme with a lower probability of failure, therefore Improve C is not justified. *Preferred Option:* **Improve B**
- The highest BCR for **Bonchurch West** and **Bonchurch East** is the Improve A option (BCRs of 2.8 and 1.5 respectively). The IBCRs for the Improve B options are below 1.0 (0.3), hence the higher maintained standard of protection provided by Improve B is not justified economically. *Preferred Option:* **Improve A**
- Both the BCRs and the IBCRs for **The Landslip** are below 1.0, hence no scheme is justified for this location. The Do Nothing option remains the preferred option (as currently is the case in this unit as there are no existing coastal defences in place). *Preferred Option:* **Do Nothing**

The preferred options for each LRU are listed individually, but each LRU is also influenced by its neighbours, so it is essential to consider management actions across the study area in a coordinated way. Table 18 details the type and year of each of the preferred stability and coastal defence interventions. The capital scheme interventions are shown in bold text, the maintenance intervention in standard text.

Table 18. Type and year of each of the preferred stability and coastal defence interventions.

LRU	Preferred option	Summary of coastal defence works	Coastal schemes and management strategy by asset	Slope stabilisation strategy
Castle Cove	Improve B	Monitor, undertake repairs to seawall/rock structures and plan capital works prior to coastal structure failure. Placement of additional toe rock when seawall toe vulnerable. Localised beach recharge.	IW36/001 - Monitor, patch/local repairs, repair rock if movement (assumed every 20yrs) and rebuild/strengthen revetment, seawall and gabions (Yr 60). IW36/ 002 - Monitor and repair rock if movement (assumed every 20yrs) and rebuild/strengthen groyne (Yr 60). IW36/003 - Monitor, patch/local repairs, repair rock if movement (assumed every 20yrs), rebuild/strengthen wall and rock structure and recharge with beach material (Yr 60). IW36/004 - Monitor, with repairs to concrete seawall and reposition and/or top up rock if movement (assumed every 20yrs), rebuild/strengthen wall and rock and recharge with beach material (yr 60). IW36/005 - Monitor and repair rock if movement (assumed every 20yrs) and rebuild/strengthen groyne and wall (Yr 60). IW36/006 & 007 - Monitor, with local repairs to seawalls as required and reposition and/or top up toe rock if movement/required (assumed every 20yrs) and rebuild wall with rock at toe (Yr 60). IW36/008 - Monitor, with local repairs to seawalls as required and reposition and/or top up toe rock if movement/required (assumed every 20yrs) and rebuild wall and revetment at end of serviceable life (Yr 60).	Pumped well drainage in the body of the landslide in year 8 when PV damages peak for rainfall triggered instability. As well as protecting property this scheme will prolong the lifespan of present and future coastal protection assets which is, in part, reliant on achieving slope stability.

LRU	Preferred option	Summary of coastal defence works	Coastal schemes and management strategy by asset	Slope stabilisation strategy
Ventnor Park	Improve B	Monitor, undertake repairs to seawall/rock structures and plan capital works prior to coastal structure failure. Placement of additional toe rock when seawall toe vulnerable. Localised wall drainage improvements.	IW35/002 - Monitor with minor repairs, place additional rock in front of sections of wall that become vulnerable and rock repairs every 20yrs and then strengthening to structures at end of serviceable life (assumed yr60). **IW35/003 - Rebuild encasement with drainage and increased rock revetment levels as priority capital scheme.** IW35/004 - Monitor with repairs to seawall rendering, additional rock added to the revetment as required, assume every 20yrs and rebuild seawall with increased rock revetment level (assumed yr60). IW35/005 - Monitor, re-position and/or top up rock if movement every 20yrs and rebuild/strengthen groynes and increased rock revetment levels in yr60.	Pumped and relief well drainage interventions at or close to the slope toe from year 8 when PV damages peak for rainfall triggered instability*. As well as protecting property this scheme will prolong the lifespan of present and future coastal protection assets which is, in part, reliant on achieving slope stability.
Central Ventnor	Improve B	Priority capital works for new revetment/seawall. Monitor, undertake repairs to seawall/rock structures and plan capital works prior to coastal structure failure. Localised beach recycling.	**IW33/002 - Replace structure with new rock revetment with concrete upper seawall as priority capital scheme** and pro-actively maintain. IW34/001, 002 & 003 - Monitor with minor repairs and rock repairs every 20yrs and significant repairs/strengthening to structures at end of serviceable life (assumed yr60). IW34/004 & IW35/001 - Monitor with minor repairs, reactive beach recycling on average every 10yrs, concrete repairs every 20yrs and strengthening to structures at end of serviceable life (assumed yr60).	
Wheelers Bay	Improve B	Priority capital works for new revetment/seawall. Monitor, undertake repairs to seawall/rock structures and plan capital works prior to coastal structure failure. Placement of additional toe rock when seawall toe vulnerable.	**IW32/001 - Replace structure with new rock revetment with concrete upper seawall as priority capital scheme** and pro-actively maintain. IW32/002 & 003 - Monitor, patch seawall repairs and rock repairs every 20yrs. **IW33/001 - Landslide drainage to reduce susceptibility to landslides and replace toe with new sheet piles and rock revetment to add toe support as priority capital scheme.**	
Bonchurch West	Improve A	Monitor, undertake repairs and bring in additional toe rock as required.	IW31/002- Monitor, patch repairs and extend and replace toe rock as required (assumed every 10-years). Rock will increasingly become more important in providing standard of protection as volumes increase over time.	
Bonchurch East	Improve A	Monitor, undertake repairs and bring in additional toe rock as required. Localised beach recycling.	IW30/001: Monitor, patch repairs, top up with additional rock (1-week of rock works every 10yrs for toe rock and 1-week rock works on groyne every 20-yrs). IW30/002 & 003 - Monitor, patch repairs to seawall, shingle recycling and shingle recharge/rock repairs every 20yrs. IW31/001 & 002- Monitor, patch repairs and extend and replace toe rock as required (assumed every 10-years)	
The Landslip	N/A	There are currently no economically viable schemes		

7. Conclusions

7.1 Conclusions

This study has shown that coastal instability and landslides at Ventnor and Bonchurch are driven by toe erosion, rainfall and groundwater. Without the ageing coastal defences in place, the system would change behaviour and toe erosion will cause widespread landslide reactivation under the town and this has the potential to cause significant asset damage. Even with the coastal defences preventing toe erosion, significant historical damage to coastal defence assets as well as property, services and infrastructure has been caused by instability due to the impact of rainfall on groundwater pressures. The QRA and CBA clearly show that effective coastal management and landslide remediation at Ventnor and Bonchurch requires solutions that deal with both toe erosion and rainfall-groundwater triggers of ground instability.

As such, it is recommended that future management options and schemes must combine deep drainage with coastal defences to provide the most beneficial and cost-efficient strategy to implement the SMP 'Hold The Line' policy at Ventnor and Bonchurch. Failure to take this approach could result in wasteful use of funding if, for example, a new coastal defence asset was built, and this was damaged by ground movement or a landslide because rainfall triggered instability hadn't been dealt with.

7.2 Options to take forward

There are economically viable schemes comprising deep drainage and new and upgraded coastal defences (Improve B) in the landslide reactivation units (LRUs) with high total asset values (Ventnor Park, Central Ventnor, Wheelers Bay and Castle Cove). Schemes at Bonchurch West and Bonchurch East comprising drainage and coastal schemes targeted at failing assets (Improve A) are potentially viable but will likely require significant partnership funding to proceed. There is unlikely to be a viable scheme at 'The Landslip' in the east of the area where 'No Active Intervention' will continue, although the consequences of breaching the A3055, due to landsliding retreating upslope in due course, will have significant local and political impact.

The next phase of the overarching assessment of coastal defence management at Ventnor and Bonchurch is the Future Schemes report which will move the generic 100-year assessment presented here into identifying future schemes and their spending profile, to inform the national programme requirements for future funding cycles. To develop the most robust cost model for a programme that will meet partnership funding requirements in the Future Schemes Report, the Improve options providing the best benefit cost ratio for each LRU, are developed through the Partnership Funding calculator to identify economically viable future schemes.

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Workshops:

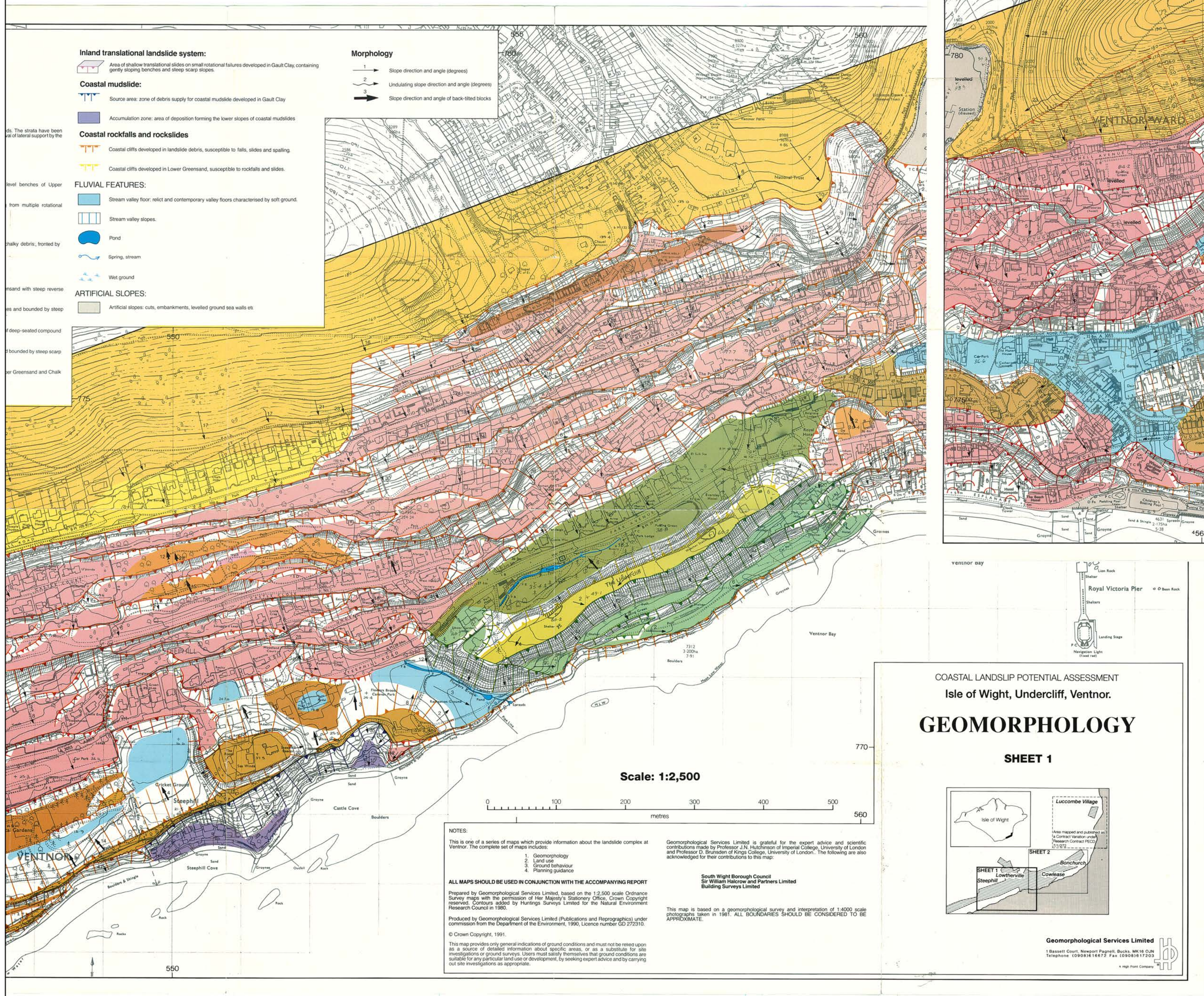
Ventnor Options Study Workshop held on 27 September 2017 at CH2M, Elms House, London.
Attendees: Moore R, Davis G, Denner J, Fitzgerald R, Czarnomski C.

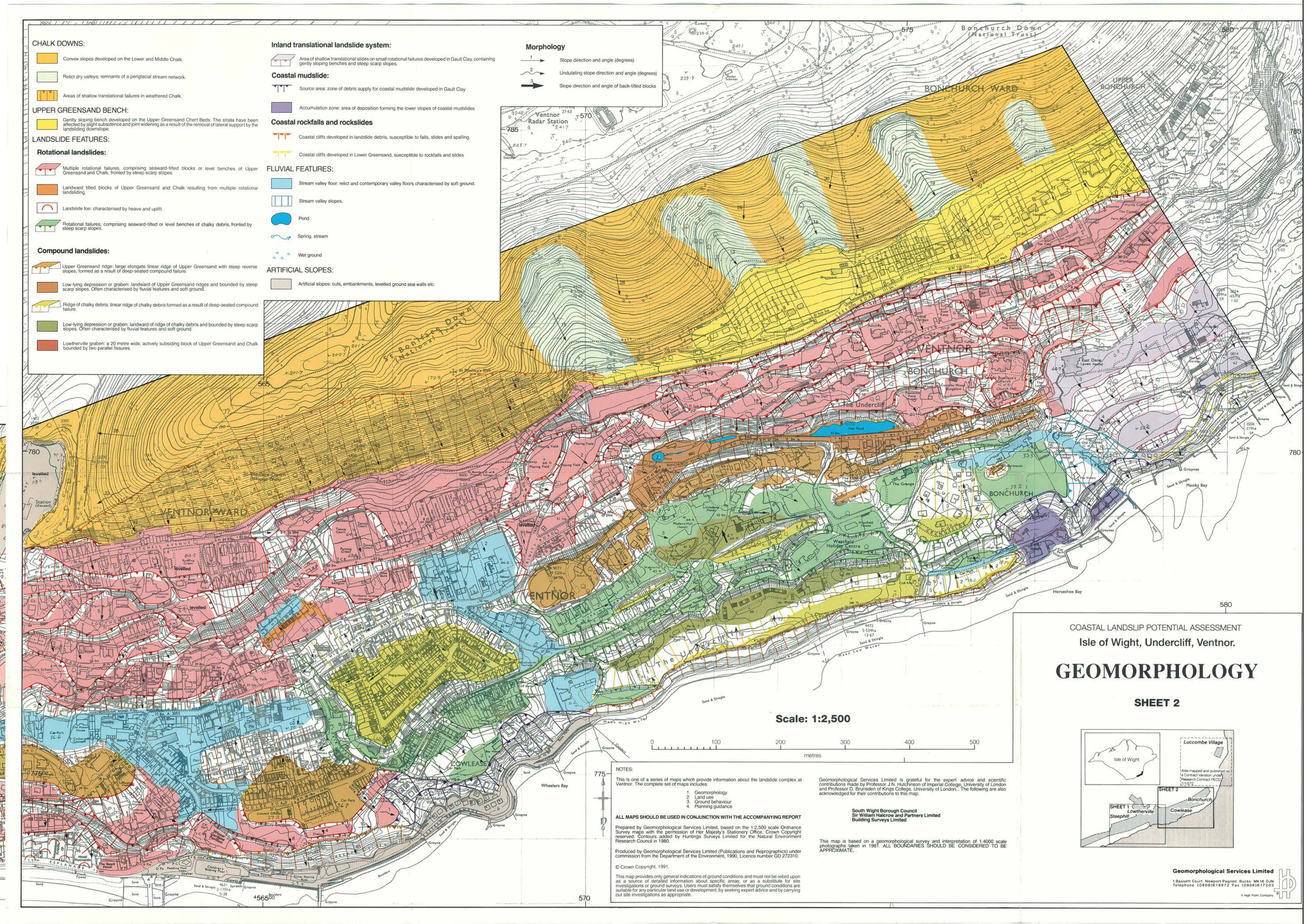
Appendix 1. Undercliff geomorphological map

The geomorphology of the Isle of Wight Undercliff reflects a history of ground instability and landsliding. It was mapped over the period 1990-1996 as part of the Department of the Environment's initial pilot study of central Ventnor, followed by the Isle of Wight Council's phased extension of this work to include the entire Undercliff over the following years.

Although the mapping shown here for the study area was produced over 25 years ago, the suitability and effectiveness of the mapping has been considered as part of the current study, and the maps remain a true account of the Undercliff's geomorphology due to the relatively slow rates of ground displacements and because the landslides which have occurred do not fundamentally alter the ground model.

This appendix provides the Geomorphological map of the study area. Ground Behavior and Planning Guidance maps are also available.


Inland translational landslide system:
Area of shallow translational slides on small rotational failures developed in Gault Clay, containing gently sloping benches and steep scarp slopes.
Coastal mudslide:
Source area: zone of debris supply for coastal mudslide developed in Gault Clay
Accumulation zone: area of deposition forming the lower slopes of coastal mudslides
Coastal rockfalls and rockslides
Coastal cliffs developed in landslide debris, susceptible to falls, slides and spalling.
Coastal cliffs developed in Lower Greensand, susceptible to rockfalls and slides.
FLUVIAL FEATURES:
Stream valley floor: relict and contemporary valley floors characterised by soft ground.
Stream valley slopes.
Pond
Spring, stream
Wet ground
ARTIFICIAL SLOPES:
Artificial slopes: cuts, embankments, levelled ground sea walls etc.
Morphology
Slope direction and angle (degrees)
Undulating slope direction and angle (degrees)
Slope direction and angle of back-tilted blocks
VENTNOR
Royal Victoria Pier
Ventnor Bay
Castle Cove
Steephill Cove
COASTAL LANDSLIP POTENTIAL ASSESSMENT
Isle of Wight, Undercliff, Ventnor.
GEOMORPHOLOGY
SHEET 1
Scale: 1:2,500
0 100 200 300 400 500
metres
Geomorphological Services Limited


CHALK DOWNS:
Convex slopes developed on the Lower and Middle Chalk.
Relict dry valleys; remnants of a periglacial stream network.
Areas of shallow translational failures in weathered Chalk.
UPPER GREENSAND BENCH:
Gently sloping bench developed on the Upper Greensand Chert Beds. The strata have been affected by slight subsidence and joint widening as a result of the removal of lateral support by the landsliding downslope.
LANDSLIDE FEATURES:
Rotational landslides:
Multiple rotational failures, comprising seaward-tilted blocks or level benches of Upper Greensand and Chalk, fronted by steep scarp slopes.
Landward tilted blocks of Upper Greensand and Chalk resulting from multiple rotational landsliding.
Landslide toe: characterised by heave and uplift.
Rotational failures, comprising seaward-tilted or level benches of chalky debris, fronted by steep scarp slopes.
Compound landslides:
Upper Greensand ridge: large elongate linear ridge of Upper Greensand with steep reverse slopes, formed as a result of deep-seated compound failure.
Low-lying depression or graben: landward of Upper Greensand ridges and bounded by steep scarp slopes. Often characterised by fluvial features and soft ground.
Ridge of chalky debris: linear ridge of chalky debris formed as a result of deep-seated compound failure.
Low-lying depression or graben: landward of ridge of chalky debris and bounded by steep scarp slopes. Often characterised by fluvial features and soft ground.
Lowtherville graben: a 20 metre wide, actively subsiding block of Upper Greensand and Chalk bounded by two parallel fissures.
Inland translational landslide system:
Area of shallow translational slides on small rotational failures developed in Gault Clay, containing gently sloping benches and steep scarp slopes.
Coastal mudslide:
Source area: zone of debris supply for coastal mudslide developed in Gault Clay
Accumulation zone: area of deposition forming the lower slopes of coastal mudslides
Coastal rockfalls and rockslides
Coastal cliffs developed in landslide debris, susceptible to falls, slides and spalling.
Coastal cliffs developed in Lower Greensand, susceptible to rockfalls and slides
FLUVIAL FEATURES:
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Stream valley slopes.
Pond
Spring, stream
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Artificial slopes: cuts, embankments, levelled ground sea walls etc.
Morphology
Slope direction and angle (degrees)
Undulating slope direction and angle (degrees)
Slope direction and angle of back-tilted blocks
Ventnor Radar Station
St Boniface Down (National Trust)
Bonchurch Down (National Trust)
BONCHURCH WARD
VENTNOR WARD
VENTNOR
BONCHURCH
COWLEASE
COASTAL LANDSLIP POTENTIAL ASSESSMENT
Isle of Wight, Undercliff, Ventnor.
GEOMORPHOLOGY
SHEET 2
Scale: 1:2,500
0 100 200 300 400 500
metres
NOTES:
This is one of a series of maps which provide information about the landslide complex at Ventnor. The complete set of maps includes:
1. Geomorphology
2. Land use
3. Ground behaviour
4. Planning guidance
ALL MAPS SHOULD BE USED IN CONJUNCTION WITH THE ACCOMPANYING REPORT
Prepared by Geomorphological Services Limited, based on the 1:2,500 scale Ordnance Survey maps with the permission of Her Majesty's Stationery Office, Crown Copyright reserved. Contours added by Huntings Surveys Limited for the Natural Environment Research Council in 1980.
Produced by Geomorphological Services Limited (Publications and Reprographics) under commission from the Department of the Environment, 1990, Licence number GD 272310.
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This map provides only general indications of ground conditions and must not be relied upon as a source of detailed information about specific areas, or as a substitute for site investigations or ground surveys. Users must satisfy themselves that ground conditions are suitable for any particular land use or development, by seeking expert advice and by carrying out site investigations as appropriate.
Geomorphological Services Limited is grateful for the expert advice and scientific contributions made by Professor J.N. Hutchinson of Imperial College, University of London and Professor D. Brunsden of Kings College, University of London... The following are also acknowledged for their contributions to this map:
South Wight Borough Council
Sir William Halcrow and Partners Limited
Building Surveys Limited
This map is based on a geomorphological survey and interpretation of 1:4000 scale photographs taken in 1981. ALL BOUNDARIES SHOULD BE CONSIDERED TO BE APPROXIMATE.
Luccombe Village
Research Contract PECD 7/1/272
SHEET 1
SHEET 2
Steephill
Lowtherville
Cowlease
Bonchurch
Geomorphological Services Limited
1 Bassett Court, Newport Pagnell, Bucks. MK16 OJN
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A High Point Company

Appendix 2. Ventnor climate and rainfall

A.2 Climate and Rainfall

The UK south coast and Isle of Wight are close to continental Europe and experience continental weather influences, which bring cold spells in winter and hot, humid weather in summer. The Isle of Wight is some distance from the paths of most Atlantic depressions, with their associated cloud, wind and rain, so the climate is mild, and storms are relatively rare.

The most relevant weather parameters influencing land stability within the Undercliff are rainfall, evapotranspiration and air temperature. These factors determine the potential net contribution of precipitation to groundwater levels that is not lost through surface water run-off.

Historical weather records in the Undercliff date back to 1839 and provide one of the longest datasets on the south coast of England. Weather stations have been established at St Catherine's Point, The Royal National Hospital (now the Botanical Gardens), Ventnor Park and Ventnor Cemetery. The IWC, Met Office and Environment Agency currently maintain and record weather data in the Undercliff.

In terms of air temperature, January is typically the coldest month whilst July is the warmest. There is a close link between solar radiation, air temperature and evapotranspiration. Modern weather stations record evapotranspiration directly whereas in the past this was calculated using the Penman-Montieth formula using temperature data, which give rise to some variance between calculated and measured data. In Figure 1, mean monthly evapotranspiration recorded at Ventnor Park is shown. This is plotted against mean monthly rainfall that is generally well-distributed throughout the year but with an autumn/early winter maximum. The data demonstrate that there is a significant net contribution of rainfall to surface run-off and groundwater during the winter months (September to March), less so during the summer period.

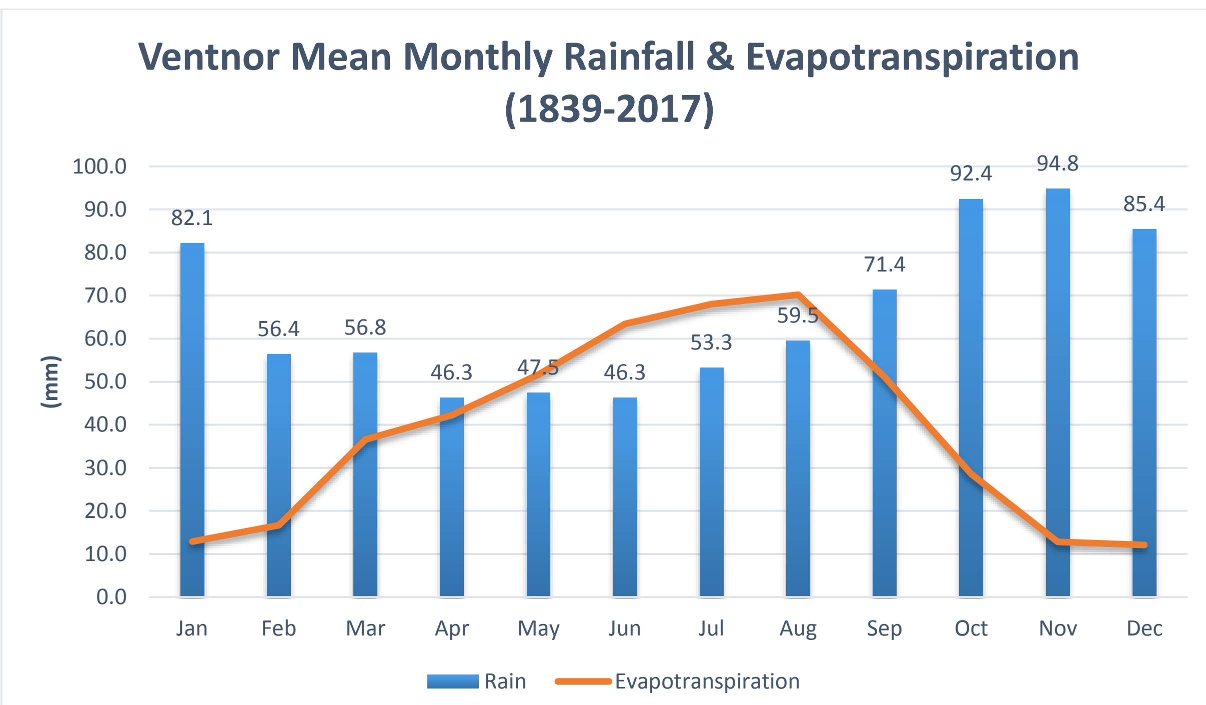

Figure 1. Monthly rainfall and evapotranspiration averages recorded at Ventnor Park weather station.

Antecedent effective rainfall (i.e. cumulative rainfall minus evapotranspiration over a period of weeks or months) provides a measure of the amount of rainfall directly contributing to groundwater levels within slopes. Historical records from Ventnor indicate that effective rainfall has increased by around 25% over the past 178 years (Figure 2), which has been linked to an increase in the frequency of landslides and ground movement in the Undercliff (e.g. Carey et al. 2015; Moore et al. 2010; Bracegirdle 2007; Ibsen and Brunsden 1996).

Latest climate change predictions point to significant increases in winter rainfall frequency, intensity and amount, drier summers and rising sea level which are likely to prove particularly challenging in terms of managing ground instability in the Undercliff. The implications of climate change predictions for the Undercliff are both spatial and temporal; firstly, there are concerns that hitherto marginally stable areas of the Undercliff may become unstable due to reactivation of ground movement and the occurrence of new landslides, secondly, in areas previously affected by ground movement or landslides, the frequency and rate of ground movement and landsliding is expected to increase (Moore et al 2007 & 2010). The maximum 4 month winter effective rainfall (WER) total between September and January in any given year was reported by Moore et. Al (2010) to be statistically the most significant climate parameter related to incidents of ground movement and landsliding in the Undercliff.

Figure 2 presents the maximum 4 month WER and reported landslide events for the period 1839–2017. Analysis of the data reveals that during the 19th century the maximum 4 month WER averaged 324.5 mm with only two winter events exceeding 500 mm. During the 20th century the maximum 4 month WER averaged 369.5 mm with 12 events exceeding 500 mm. Since 2000, the maximum 4 month WER has averaged 365.3 mm and one event has exceeded 500 mm. These historical data show that the amount and frequency of WER has increased over the past 100 years.

The correlation between WER and past events provides the basis of a simple forecasting tool involving a comparison of the maximum 4 month WER leading up to the initiation of landslide and ground movement in the Undercliff (Lee & Moore 1991; Moore et al. 1995). The relationship has been used to account for the spatial distribution of marginally stable and unstable areas in the Undercliff and to provide a probabilistic framework for quantitative risk assessment for Ventnor (Lee et al. 1998; Hosking & Moore 2002; Moore et al. 2007b).

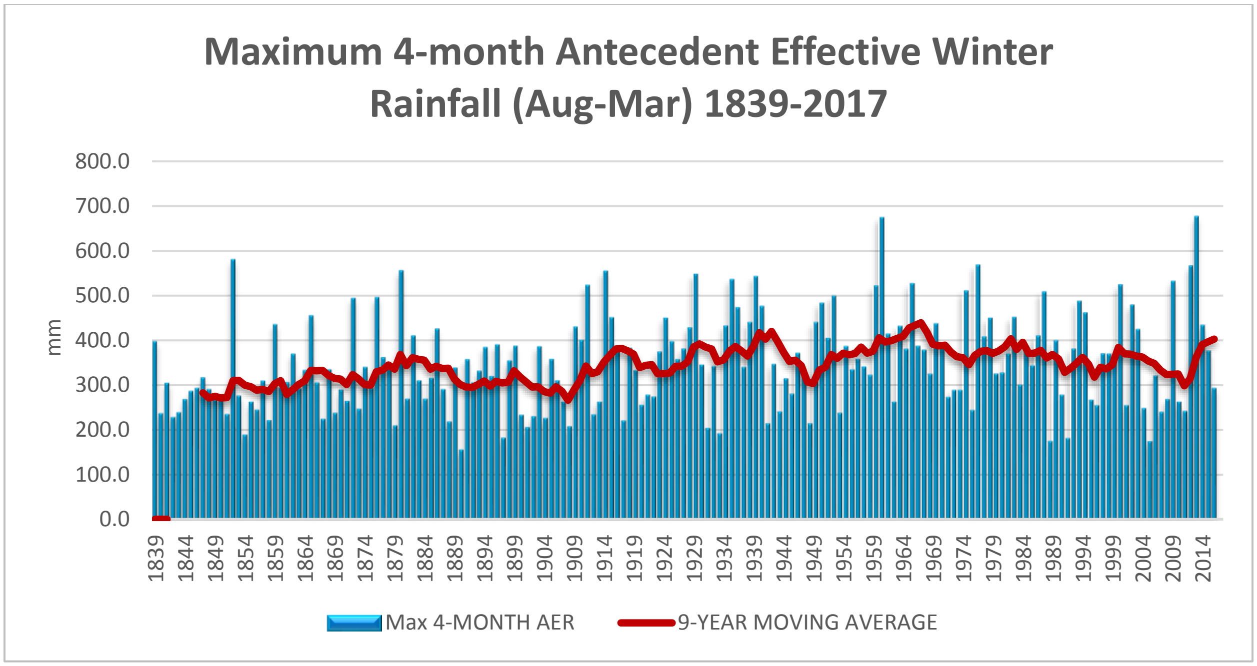

Figure 2. Maximum Annual Effective Winter Rainfall and trend (Source: CH2M records).

The initial (2018) annual probabilities of threshold winter rainfall values determined for the landslide hazard scenarios developed in Section 4.2 of the main report have been based on the relationship between historical landslide events and the 4-month antecedent rainfall data at the Undercliff (Halcrow 2006).

Figure 3 defines the return period for antecedent rainfall conditions of a given amount. Based on the International Panel on Climate Change predictions, the UK Climate Projections science report (UKCP09, 2010) shows that under a medium emissions scenario a 1 in 32-year event in 2017 will become a 1 in 10 year event by 2080. This represents a cumulative 2% annual increase in return period which has been applied to the probability of threshold winter rainfall over the study period (see Section 4.2.3 of the main report).

Over the 100-year study period a 2% annual increase in probability leads to a 7.2 times increase in the likelihood of a threshold rainfall event so that, for example, an event with an annual probability of 0.1 becomes 0.72.

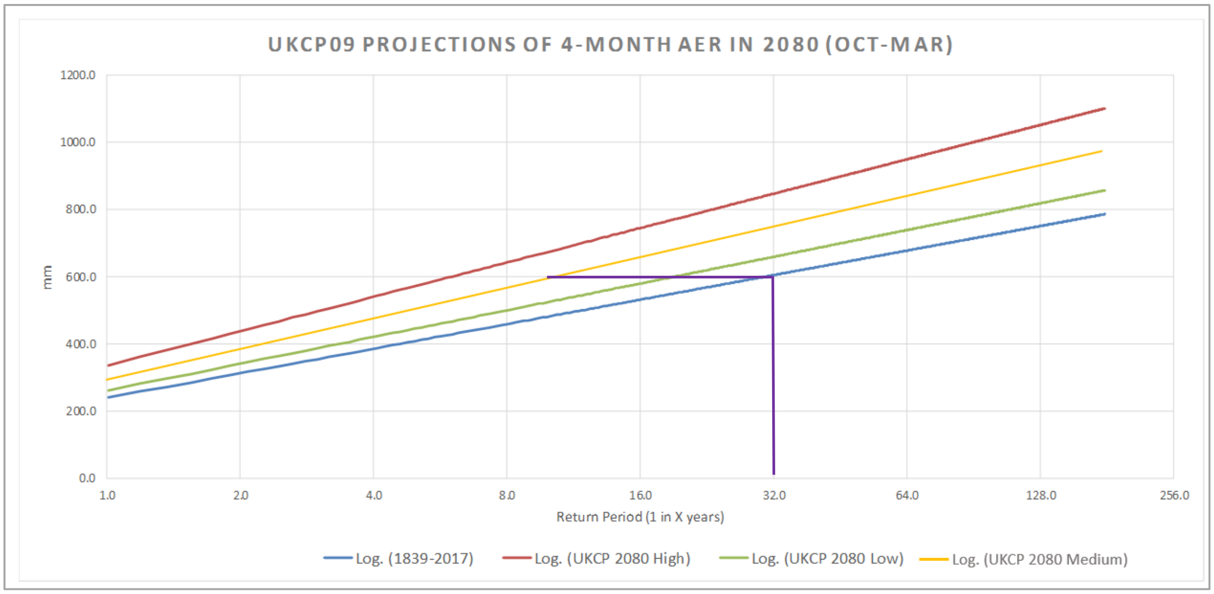

Figure 3. Return period for antecedent rainfall conditions of a given magnitude under current conditions and the various UKCP emissions scenarios. Under the medium emissions scenario a 1:32 year event becomes a 1:10 year event by 2080. This equates to a cumulative annual increase of 2%.

A.2.1 References

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Appendix 3. Environmental review

A.3 Ventnor Options Study Environmental Review

A desk study has been undertaken to assess the environmental risks that need to be considered as part of the Ventnor Options Study. Data have been extracted from the Natural England MAGIC website. A brief environmental review has been undertaken to consider the environmental constraints to any options put forward to protect the Ventnor frontage for this note. They are divided into environmental designations (protected sites) and Water Framework Directive constraints:

A.3.1 Environmental designations

The designations for Ventnor are included in Table 1 and illustrated in Figure 1.

Table 1: Environmental designations

Site	Reasons for designation	Implications for project
Isle of Wight Downs SAC	The site is designated under article 4(4) of the Directive (92/43/EEC) as it hosts the following habitats listed in Annex I: • European dry heaths • Semi-natural dry grasslands and scrubland facies: on calcareous substrates *(Festuco Brometalia).* (Dry grasslands and scrublands on chalk or limestone) • Vegetated sea cliffs of the Atlantic and Baltic coasts; qualifying species are Early gentian, *Gentianella anglica*	European site protection. Need to undertake a screening assessment under Habitats Regulations to determine if an Appropriate Assessment is necessary.
South Wight Maritime SAC	Annex I habitats that are the main reason for designation: 1 170 Reefs The southern shore of the Isle of Wight, off the coast of southern England, includes a number of subtidal reefs that extend into the intertidal zone. This site is selected on account of its variety of reef types and associated communities, including chalk, limestone and sandstone reefs. To the west and south-west some of the most important subtidal British chalk reefs occur, representing over 5% of Europe's coastal chalk exposures, including the extensive tide-swept reef off the Needles and examples at Culver Cliff and Freshwater Bay. These support a diverse range of species in both the subtidal and intertidal. Other reef habitats within the site include areas of large boulders off the coast around Ventnor. There is a large reef of harder limestone off Bembridge and Whitecliff Bay, where the horizontal and vertical faces and crevices provide a range of habitats. The bedrock is extensively bored by bivalves. Their presence, together with the holes they create, give shelter to other species, which adds further to habitat diversity. Intertidal pools support a diverse marine life, including a number of rare or unusual seaweeds, such as the shepherd's purse seaweed *Gracilaria bursa-pastoris*. A number of other species reach their eastern limit of distribution along the English Channel at the Isle of Wight. 1230 Vegetated sea cliffs of the Atlantic and Baltic Coasts South Wight Maritime on the south coast of England represents contrasting Cretaceous hard cliffs, semi-stable	European site protection. Need to undertake a screening assessment under Habitats Regulations to determine if an Appropriate Assessment is necessary. The South Wight Maritime SAC is a key designation for considering future scheme design in the area as it extends along the full length of the study area. The boundary of the SAC is typically 30 metres offshore, extending seawards from the low water mark. Schemes in the intertidal area would still need to seek minimal damage as the habitat impacted by any works would be connected to the designated area. For approximately 170 metres near Wheelers Bay the SAC boundary is closer to the shore, immediately against the current defence line, so schemes in this area have the potential to impact the footprint of the SAC. The rocky reef features along the Ventnor Undercliff shoreline and the soft cliffs downdrift (longshore drift is west to east) will require careful consideration. The zone of influence around any drainage wells

	soft cliffs and mobile soft cliffs. The western and eastern extremities of the site consist of high chalk cliffs with species-rich calcareous grassland vegetation, the former exposed to maritime influence and the latter comparatively sheltered. At the western end, the site adjoins the Isle of Wight Downs, providing an unusual combination of maritime and chalk grassland. The most exposed chalk cliff tops support important assemblages of nationally rare lichens, including *Fulgensia fulgens*. The longest section is composed of slumping acidic sandstones and neutral clays with an exposed south-westerly aspect. The vegetation communities are a mixture of acidic and mesotrophic grasslands with some scrub and a greater element of maritime species, such as thrift *Armeria maritima*, than is usual on soft cliffs. This section supports the Glanville fritillary butterfly *Melitaea cinxia* in its main English stronghold. A small, separate section of the site on clays has a range of successional stages, including woodland, influenced by landslips. These cliffs are minimally affected by sea defence works, which elsewhere disrupt ecological processes linked to coastal erosion, and together they form one of the longest lengths of naturally-developing soft cliffs on the UK coastline. 8330 Submerged or partially submerged sea caves The southern shore of the Isle of Wight, off the coast of southern England, includes a number of either submerged or partially submerged sea caves. The exposure of the south coast of the island to high wave energy has allowed the erosion of the Cretaceous calcareous hard cliffs to form sea caves. Examples of this habitat can be found from the Needles along the south-west coast of the Island to Watcombe Bay, and also in Culver Cliff on the south-east coast of the Island. This site also contains the only known location of subtidal chalk caves in the UK. The large littoral caves in the chalk cliffs are of ecological importance, with many hosting rare algal species, which are restricted to this type of habitat. The fauna of these sea caves includes a range of mollusc species such as limpets *Patella spp*. and the horseshoe worm *Phoronis hippocrepia.*	proposed will also need careful consideration for the SAC and SSSIs.
Solent & Dorset Coast pSPA (subject to approval)	The Joint Nature Conservation Committee (JNCC) identified the Solent and Dorset coast as important breeding and foraging areas for seabirds, including terns, that warrant protection.	The Solent & Dorset Coast pSPA is a significant distance from the proposed site (4 km to the northwest). However, because downdrift of any proposed scheme, impacts on sediment and nutrient pathways and the potential to create contamination may influence Tern fishing and prey availability.
Bembridge and Sandown Bay rMCZ (subject to approval)	This rMCZ wraps around the east coast of the Isle of Wight and extends seaward towards the Nab shipping channel. It is currently recommended as a rMCZ for exceptionally diverse habitats and species. These include a wide range of coastal, intertidal and marine fauna and flora.	The Bembridge and Sandown Bay rMCZ adjacent to the study site. However, because downdrift of any proposed scheme, impacts on sediment and nutrient pathways and the potential to create contamination may affect the diverse habitats and species

IOW AONB	Considerable scientific and ecological importance and includes exceptional flora-rich chalk grasslands, the north coast's major estuarial habitats and the geologically notable southern cliffs and landslips. AONB is dominated by chalk in the sharp upfold which forms both the island's eastwest backbone and southern expanse of wide green downs. In the south, the complex landscapes bounded by the Tennyson Heritage Coast range from sandy bays to high unstable sandstone and chalk cliffs, cut by wooded 'chines'.	The extent of the ANOB includes the undercliff coastline to the east and west of the study area. Consider further as schemes are developed.
Rew Down SSSI	Rew Down is a steep south-facing chalk slope capped with superficial Pleistocene gravel exhibiting a wide range of soils and supporting a diversity of species-rich plant communities. The occurrence of both strongly acid soils (on the ridge top gravels) and basic soils (on the escarpment face) gives rise to disparate plant communities of considerable ecological interest.	National legislation of SSSI – requirement for protected species to be protected. If scheme is within SSSI zone or near to, then consultation with Natural England required.
Compton Chine – Steephill Cove SSSI	The site is notified for its vegetated maritime cliffs and slopes, species-rich unimproved chalk grassland, nationally rare plant species, an assemblage of nationally scarce plants, an outstanding assemblage of nationally rare and scarce invertebrates, exposed and moderately exposed rocky shores (littoral rock) and nationally important coastal geomorphology. In addition, the cliffs and foreshore between Hanover Point to St Catherine's Point are part of a nationally important geological site for successions of the Wealden Group and the overlying Lower Greensand Group. The Wealden Group is of international importance for the diverse fauna of early Cretaceous dinosaurs that it has yielded, and also contains important elements of the flora present at the time these reptiles were alive.	National legislation of SSSI – requirement for protected species to be protected. If scheme is within SSSI zone or near to, then consultation with Natural England required. Also component of IOW SAC.
Ventnor downs SSSI	Over much of the site the junction between acid gravels and calcareous chalk is marked by a change in scrub type except for a combe adjacent to Luccombe Down. Here the gorse, on strongly acid gravel, gives way to bracken on more neutral soils which in turn changes to neutral and then to chalk grassland. The bracken *Pteridium aquilinum* dominated combe has in association with it a variety of woodland plants such as bluebells, red campion *Silene dioica* and wood sorrel *Oxalis acetosella*. The occurrence of heathland on deep gravel overlying chalk, the naturalised holm oak woodland and the juxtaposition of heath and chalkland vegetation are all unusual biological features in Britain.	National legislation of SSSI – requirement for protected species to be protected. If scheme is within SSSI zone or near to, then consultation with Natural England required. Also a component of SAC.
Bonchurch landslip SSSI	The Site of Special Scientific Interest comprises ash *Fraxinus excelsior* woodland on Gault clay landslips immediately below the Upper Greensand escarpment. The landslips descend steeply eastward to soft, eroding cliffs. The lower slopes of the landslips support a complex mosaic of species-rich acidic and calcareous plant communities on unstable clays and sands. The close juxtaposition and mixing of disparate plants is of considerable ecological interest.	National legislation of SSSI – requirement for protected species to be protected. This SSSI is on the coast immediately to the east of the study site so will require consultation with Natural England

	Geomorphologically, the site is of great interest for its complex of mass-movement features, including the Undercliff itself and the coastal landslips and mud flows beneath it.	
Rew Down LNR	Part of the biological SSSI of Rew down SSSSI. Species rich chalk grassland which is good for plants and butterflies	National legislation of SSSI – requirement for protected species to be protected. If scheme is within SSSI zone or near to, then consultation with Natural England required.
Tennyson heritage coast	Tennyson Down is one of the most significant downland sites in Britain. It forms the western end of the Tennyson Heritage Coast. It is part of the Headon Warren And West High Down SSSI (Site of Special Scientific Interest) and is part of the Isle of Wight's Area of Outstanding Natural Beauty.	National legislation of SSSI – requirement for protected species to be protected. If scheme is within SSSI zone or near to, then consultation with Natural England required.

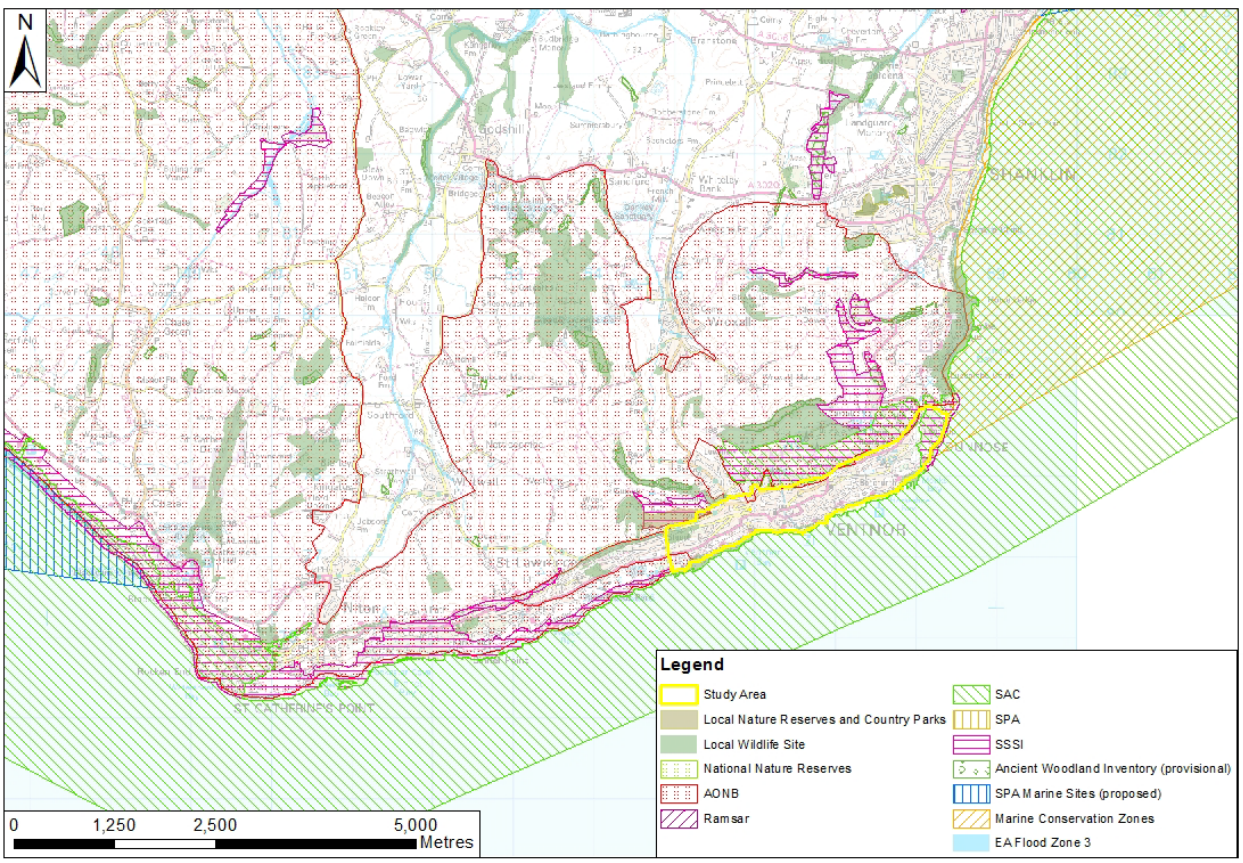

Figure 1: Conservation designations at and around Ventnor

A.3.2 WFD Classification

The WFD[1] requires all natural water bodies to achieve both good chemical status and good ecological status. For each River Basin District, a River Basin Management Plan (RBMP) outlines the actions required to enable natural water bodies to achieve this. Water bodies that are designated in the RBMP as Heavily Modified Water Bodies (HMWB) or Artificial Water Bodies (AWB) may be prevented from reaching good ecological status by the physical modifications for which they are designated or purpose for which they were constructed (e.g. navigation, flood defence, urbanisation). Instead they are required to achieve good ecological potential, through implementation of a series of mitigation measures outlined in the South EastRBMP (and in some cases updated since the publication of the RBMP).

The status of water bodies is classified through the use of various criteria or Quality Elements which use monitoring data and/or expert judgement to deem whether each category is at good, moderate or poor status overall. The ecological component uses biological quality elements (e.g. fish, invertebrates and macrophytes), hydromorphology (hydrological regime and morphology), physico-chemical (pH, temperature, dissolved oxygen) and pollutants to assess the state of the water body. Some water bodies cannot achieve good ecological status because of modifications and structures within the water body and so are classed as heavily modified. Schemes affecting water environment have potential to adversely impact biological conditions either directly or indirectly by changing the supporting hydromorphological, physico-chemical and/or chemical 'quality elements' which may lead to deterioration in water body status or potential. As a consequence, a series of mitigation measures can be used to improve the water body and prevent further deterioration. Water bodies are riverine, lacustrine, estuarine, coastal and groundwater.

Within this note is an outline of the water bodies relevant to the Ventnor frontage. It is not a WFD assessment.

Relevant WFD water bodies

- IOW lower greensand – ground water body
- IOW southern downs chalk – ground water body
- Isle of Wight rivers: eastern Yar lower (heavily modified) and Wroxall stream (not designated as heavily modified or artificial)
- Isle of Wight East transitional coastal (TraC) (heavily modified).

Other

In addition to the statutory/non-statutory designations, other features of note are the bathing waters at Ventnor. The scheme should not cause deterioration to the bathing water standards, increase suspended sediment load to a threshold much higher than local standards, and also not affect water quality as a whole. Contaminants and pollutants need to be avoided close to the sea. A construction environmental management plan would need to be proposed.

[1] Water Framework Directive (Directive 2000/60/EC), implemented in England by the Water Environment (Water Framework Directive) (England and Wales) Regulations (SI 3242/2003).

Linked protected areas which should be considered as part of WFD include Habitats Directive (linked to SAC), Bathing Waters Directive, Urban Waste Water Treatment Directive, Birds Directive and Nitrates Directive.

Historic Environment

The site at Ventnor and Bonchurch has a rich maritime history and evidence of human occupation from 4000bc. Many of the 119 grade II listed buildings, the Grade II registered park, several items on the local list and many of the 169 monument records indicated on the south coast of the Isle of Wight fall within the sites the coastal frontage. Offshore there are 71 recorded shipwreck sites and 3 air wrecks classed as Military Remains Protected Places. Bonchurch, Ventnor and St. Lawrence are also designated Conservation areas. At Flowers Brook advance archaeological investigations as part of the construction of a pumping station revealed evidence for Saxon and Medieval occupation.

A.3.3 Statutory Considerations to Designated Sites – Impacts from Scheme:

Natura 2000 is the name of the European Union-wide network of nature conservation sites established under the EC Habitats and Birds Directives. This network comprises Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). Marine Natura 2000 sites contribute to the ecologically coherent network of marine protected areas.

SACs are designated under the EC Habitats Directive. The Directive applies to the UK and the overseas territory of Gibraltar. SACs are areas which have been identified as best representing the range and variety within the European Union of habitats and (non-bird) species listed on Annexes I and II to the Directive. SACs in terrestrial areas and territorial marine waters out to 12 nautical miles are designated under the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended). Beyond 12 nautical miles they are designated under the Offshore Marine Conservation (Natural Habitats &c.) Regulations 2007 (as amended). SACs will be one of six designations contributing to our ecologically coherent network of marine protected areas. **Any development within an SAC needs a Screening assessment undertaken as part of the Habitats Regulations.**

Originally notified under the National Parks and Access to the Countryside Act 1949, **SSSIs** were re-notified under the Wildlife and Countryside Act 1981. Improved provisions for the protection and management of SSSIs were introduced by the Countryside and Rights of Way Act 2000 (in England and Wales). The SSSI legislation provides statutory protection for the best examples of the UK's flora, fauna, or geological or physiographical features. **These sites are also used to underpin other national and international nature conservation designations such as SACs and SPAs.** If the scheme is within the boundary or adjacent/close proximity to, Natural England need to be consulted. Schemes must consider the potential impact on SSSI land and any special habitats and species of proposed activities and works and apply for a permit to do works (an assent). Schemes need to consider methods that cause as little damage as is reasonably practicable; and also make sure the site can be restored to its former condition, where practicable, if works do cause damage.

In England, Wales and Northern Ireland, the primary purpose of the **AONB** designation is to conserve natural beauty – which by statute includes wildlife, physiographic features and cultural heritage as well as the more conventional concepts of landscape and scenery. Account is taken of the need to safeguard agriculture, forestry and other rural industries and the economic and social needs of local communities. AONBs have equivalent status to National Parks as far as conservation is concerned. AONBs are designated under the National Parks and Access to the Countryside Act 1949, amended in the Environment Act 1995. The Countryside and Rights of Way Act 2000 clarifies the procedure and purpose of designating AONBs.

Under the National Parks and Access to the Countryside Act 1949, **LNRs** may be declared by local authorities after consultation with the relevant statutory nature conservation agency. LNRs are declared and managed for nature conservation, and provide opportunities for research and education, or simply enjoying and having contact with nature.

WFD designated water bodies:

The following should be considered:

- Impacts to groundwater body through deterioration of Source Protection zones need to be avoided;
- Impacts to rivers could be negligible as there is no river flowing into Ventnor; the riverine water bodies are upstream of the site;
- Coastal TraCs (transitional coastal water bodies) are most likely to be impacted along the frontage.

A preliminary assessment as part of WFD should consider the following, for example:

- Interruption to hydromorphology and modifications to sediment transport;
- Shoreline morphology;
- Water quality and increased suspended load;
- Ecological linked areas such as the SAC;
- Impacts to macrophytes and invertebrates;
- Shell Fish, Birds, Habitats and Bathing Water Directives; and
- Deterioration in water quality and overall adjacent habitats.

A.3.4 Summary

From this note, the following points need to be taken forward:

A WFD preliminary assessment will need to be undertaken as part of this Ventnor Options Study. The options will need to be put forward to the WFD specialist prior to this exercise being undertaken in order to assess the potential impacts and benefits.

- Consultation with Natural England will need to be undertaken with regards to the SSSIs.
- A screening assessment under Habitats Regulations is likely required due to the Isle of Wight Downs and South Wight Maritime Special Areas of Conservation (SACs). This also needs discussing with Natural England.
- The South Wight Maritime SAC designation extends along the study area, although usually the designation boundary extends seawards from the low watermark so is located approximately 30+ m offshore. Future works along the coastline would still need to seek minimal damage in the intertidal area due to the connection to designated habitats. It should also be noted that for a 170 m section near Wheeler's Bay, the SAC boundary is located directly up against the present defence line, and requires careful consideration in future schemes.
- Two sections of the coastline are designated as Conservation Areas, and also requires careful consideration in future scheme proposals. These are 200 m west of Monk's Bay, and 1.4 m from

the western edge of Wheeler's Bay to the Flowers Brook outfall. Scheme design will require careful consideration in these areas.

- The Solent & Dorset Coast pSPA is downdrift of any proposed scheme such that the impacts on Tern habitat of changes to sediment and nutrient pathways and the potential to create contamination will need to be considered.
- The Bembridge and Sandown Bay rMCZ is downdrift of any proposed scheme such that the impacts on habitats of changes to sediment and nutrient pathways and the potential to create contamination will need to be considered.

A.3.5 References

DEFRA (2017) MAGIC. Found at: www.natureonthemap.naturalengland.org.uk (accessed: 03/2017)

Appendix 4. Ground monitoring review

A.4 Ground monitoring review

The development of ground models and hazard scenarios and probabilities at Ventnor and Bonchurch has been supported by a review of the monitoring data which measure ground movement at Ventnor and Bonchurch for the period 2002 to present. The review comprises the following components:

- ***In-situ* monitoring**: A review of the *in-situ* monitoring was carried out by Prof. Roger Moore on 21st April 2017 and includes data from inclinometers, extensometers, piezometers, settlement cells, tiltmeters, crackmeters and a weather station at Ventnor Park.
- **GPS network**: A review of horizontal and vertical ground movement measured by GPS at the permanent ground markers at Ventnor Park between 2003-2017.
- **Terrestrial Laser scans** (TLS): A review of ground movement measured by sequential TLS surveys at the Lowtherville Graben and the Wheelers Bay frontage was undertaken. Elevation change between TLS surveys was measured by subtracting the digital elevation model created from the earlier TLS from the digital elevation model created from the more recent TLS.

Analysis of these data have been fundamental to establishing relationships between rainfall patterns, groundwater response, ground movement, coastal erosion and landslide reactivation.

A detailed summary of the *in-situ* monitoring review from the *in-situ* instruments is available in Table 1. Figure 1 provides the location of the permanent ground markers used to measure ground movement at Ventnor Park and Figures 2 and 3 shown the horizontal and vertical ground movement measured at each of these markers. Figures 4 and 5 show ground surface elevation change measured by TLS at the Lowtherville Graben between 2013 and 2016 and the Wheelers Bay frontage between 2015 and 2017 respectively.

The key observations from Table 1 and Figures 1-5 are summarized here along with proposed recommendations/actions the Council/Island Roads might consider for improving the *in-situ* monitoring network and value of the data recorded.

Key observations:

1. Ventnor Park - The GPS network data (Figure 1-3) and TLS data (Figure 5) at the Ventnor Park show that the lower tier of the landslide system moved seaward by up to 1 m between 2003-2017. These data also show that in response to this movement the depression between blocks at the Lowtherville Graben in the upper tier of the system has deepened by up to 0.5 m between 2003-2017 as the seaward block rotates and moves downslope to accommodate the space freed by the lower tier movement. The TLS data also show that the Graben is extending to the east. The GPS and TLS data corroborate one another and demonstrate ongoing progressive creep consistent with the ground models indicated by the geomorphology and GI data and which have been used in this study.
2. Wheelers Bay - The TLS data captured at Wheelers Bay (Figure 5) show that in exposed locations such as the headland, and in the east beyond rock protection, the seawall and promenade are settling. At the headland the data also show that this could be due to the loss of support provided by rock armour which has shifted seaward. At other locations, such as beyond the eastern extent of the rock armour, settlement of the seawall and promenade is likely due to the lack of protection. The Wheelers Bay TLS data demonstrate the deterioration of the current

coastal defences to wave forces and the vulnerability of the frontage to coastal erosion and subsequent instability.

3. Devil's Chimney – Crackmeter CM1 indicates little movement happening from 2002 until Jan 2013 when the wire extended 30mm over a period of a few months. The wire extended again by 60mm over the same period in 2014, and 20mm since. The data correlate with the winter months we'd expect movements to occur and also the very wet winters from 2012 to 2014. Although these movements are small they are possibly significant in that they indicate progressive or pre-failure movement of the lower landslide system at this location.
4. Bath Road – Settlement cell records sudden movement in Feb14 and ongoing movement in the winter months since. This corroborates evidence of seaward movement of the lower landslide tier at Ventnor Park as anticipated by the ground model.
5. Lowtherville Graben – significant ongoing ground movement recorded historically and since 2016.
6. Castle Court – Crackmeter shows ground movement response in Feb 2014. The movements are small but nevertheless correlate with the very wet winter of 2014 which saw widespread ground movement (and landslides) in the Undercliff and south coast.

Recommendations:

1. The GPS network have provided good quality and cost-effective data on ground movement at Ventnor Park. It is recommended that this network is extended to verify the extent, magnitude and nature ground movement throughout the study site.
2. Winter Gardens – Piezometers PZ1 and PZ2 require calibration into meaningful units, mH2O, so the data can be used; high priority to provide information on the Central Ventnor ground model
3. Bath Road – Crackmeter is not recording, replace; high priority to provide information on ground movement rates in Central Ventnor and Ventnor Park.
4. Ventnor Park Weather Station – carry out check/calibration/replace AWS rainfall sensors; high priority to allow for ongoing analysis of the relationship between instability and rainfall.
5. Western Cliffs - Retrofit BH4 with automatic piezometers; low priority but would provide valuable data for Ventnor ground model.
6. Park Avenue - Retrofit BH1 with automatic piezometers; high priority to provide information on the Ventnor Park ground model.
7. Castle Road - Retrofit BH3 and BH5 with automatic piezometers; low priority but would provide valuable data for Ventnor ground model.
8. St Albans Road - Retrofit BH2 with automatic piezometers; high priority to provide information on the Ventnor Park ground model.
9. Lowtherville Graben - TB2 not recording, replace; re-calibrate settlement cells; high priority to provide information on the Ventnor Park ground model.

Table 1: summary of inspection of monitoring sites by MC and RM on 21 April 2017

Site Location	In situ Sensors	Data Period & Record	Observations 2002-2010	Observations 2010-2017	Notes & Actions
Bonchurch 3 (Smugglers Haven car park and footpath)	1 no. wire extensometer, 1 no. tiltmeter BH piezometer	auto recording July 2002 to present	CM1 – no significant change, data spikes 2004-08 TM3 – no apparent tilt PZ1 – no meaningful data	CM1 – c.30mm 01/13, 60mm 01/14, 20mm 01/16 TM3 – no apparent tilt PZ1 – no meaningful data	CM1 indicates significant movement ongoing at Devil's Chimney since Jan 2013, keep an eye on this. Recalibrate TM3/PZ1
Bonchurch 2 (70 Leeson Road, private garden)	2 no. wire extensometers, linked in series BH piezometer	Disused due to uncooperative owner	Ext1 - no meaningful data Ext2 - no meaningful data PZ2 – no meaningful data	Ext1 - no meaningful data Ext2 - no meaningful data PZ2 – no meaningful data	De-commission or recalibrate sensors
Bonchurch 1 (Bonchurch Shute verge)	2 no. tiltmeters	Auto recording: July 2002 to present	BNCH_01 - 2mm>12mm BNCH_02 - <2.5mm (no data post May 06)	BNCH_01 – 11mm>5mm BNCH_02 - <6mm	Recalibrate sensors
Ventnor (Winter Gardens car park)	1 settlement cell 2 no. piezometers retrofit to existing BHs	Auto recording: Sep 2007 to present	SC – no meaningful trend 2008-10, 1mH2O cyclic fluctuations PZ1 – cyclic fluctuations, falling head of raw data 01/08, 12/09 PZ2 - cyclic fluctuations, falling head	SC – 0.5m > -0.75mH2O trend, falling head PZ1 - cyclic fluctuations, falling head of raw data PZ2 - cyclic fluctuations, no trend	Sensors recording raw data but require calibration into meaningful units mH2O
Ventnor (Bath Road pavement)	1 no. settlement cell, 1 no. crack meter	Auto recording: Dec 2008 to present	SC - no meaningful trend 2008-10, 1mH2O cyclic fluctuations CM – no records	SC – notable event Feb14 increase in pressure head and upward trend since, 1mH2O cyclic fluctuations CM – 0mm > 10mm 08/12 to 03/14, no further readings	Settlement cell indicates movement in Feb14 and ongoing movement in winter months since CM requires replacement

Ventnor (Western Cliffs ridge crest)	Weather station (AWS) BH4i inclinometer BH4 piezometer cluster	AWS (1992) - auto recording Manual readings only: BH4i (2005 to 2008) – now sheared at depth BH4 (2005)	AWS – archive data BH4i – records for 2005-08 BH4 – no readings	AWS – data every 15 mins from 20 Nov 13 to present, available via website BH4i – no readings BH4 – no readings	AWS shows very low rainfall in 2015 and 2016; 22%-40% compared to regional SW data Retrofit BH4 with automatic piezometers
Ventnor (Park Avenue carriageway)	BH1 piezometer cluster	Manual readings only: BH1 (2002)	BH1 – no readings	BH1 – no readings	Retrofit BH1 with automatic piezometers
Ventnor (12 Castle Road driveway and junction with Gills Cliff Rd)	BH3 and BH5 piezometer clusters	Manual readings only: BH3 (2002) BH5 (2005)	BH3 – no readings BH5 – no readings	BH3 – no readings BH5 – no readings	Retrofit BH3 and BH5 with automatic piezometers
Ventnor (St Albans Rd)	BH2 inclinometer and separate piezometer cluster	Manual readings only: BH2i (2002 to 2008) – now sheared at depth BH2 (2002)	BH2i – records for 2002-08 BH2 – no readings	BH2i – no readings BH2 – no readings	Retrofit BH2 with automatic piezometers
Ventnor (Lowtherville graben)	2 no. settlement cells 2 no. crackmeters 2 no. tiltbeams 8 no. soil extensometers	Auto recording: 1992 crackmeters and settlement cells replaced in 2012/2014 Soil extensometers and tiltbeams installed 2016	Archive data available? SC1 – no data SC2 - no data CM1 – c.60mm 2008-10 CM2 - no meaningful data	SC1 - disused SC2 - cyclic c.0.8mH2O CM1 – c.30mm 2015-17 CM2 - c.20mm 2015-17 TB1 – <2.5mm/m 2016-17 TB2 – no data	Island Roads have replaced and installed additional sensors; evidence of significant ground movement historically and since 2016 TB2 not recording SC re-calibrate

				Ext1_A - <1mm 2016-17 Ext1_B - <1mm 2016-17 Ext1_C – 6mm 2016-17 Ext1_D - <1mm 2016-17 Ext2_A - <1mm 2016-17 Ext2_B – 7.5mm 2016-17 Ext2_C - <2mm 2016-17 Ext2_D - <2mm 2016-17	
Ventnor (Castle Court)	1 no. settlement cell, 1 no. crackmeter	Auto recording: 1992 to present	Archive data available ? SC1 - no trend, error +-1m H2O 2008-10 CM – <1mm 2008-10	SC1 - trend 0-0.5m, cyclic error +-0.5m H2O 2011-17 CM – <1mm 2010-17; 0-4mm upward trend since 02/14	Sensor locations not optimal; significant ongoing movement damage to roads and pavement evident. CM response in 02/14. Island Roads plans to install 4 no. crack meters and settlement cells

Figure 1. Location of the permanent ground markers used to measure ground movement via GPS at Ventnor Park between 2003-2017.

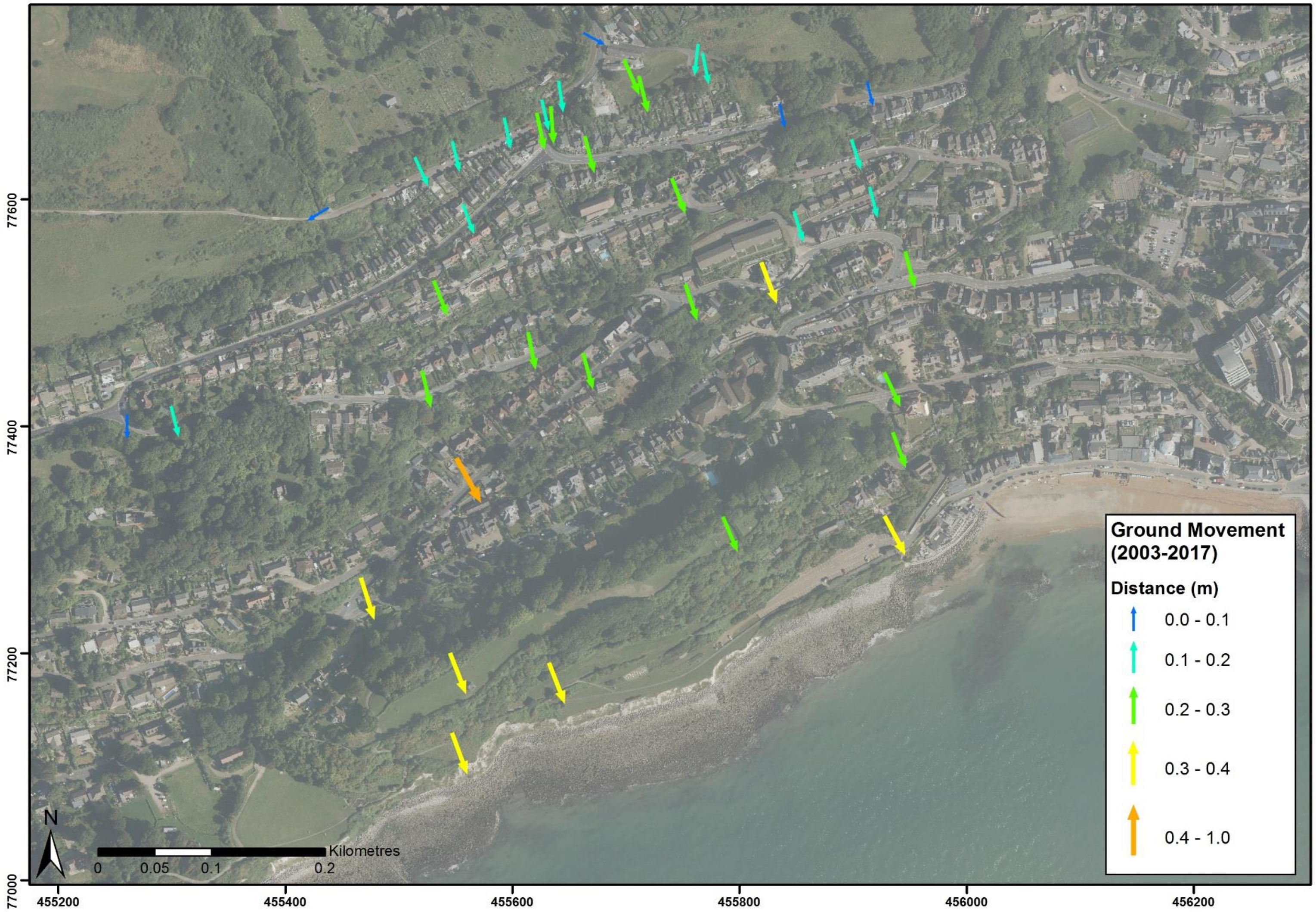

Figure 2. Horizontal ground movement and movement direction at each of the permanent ground markers at Ventnor Park between 2003-2017.

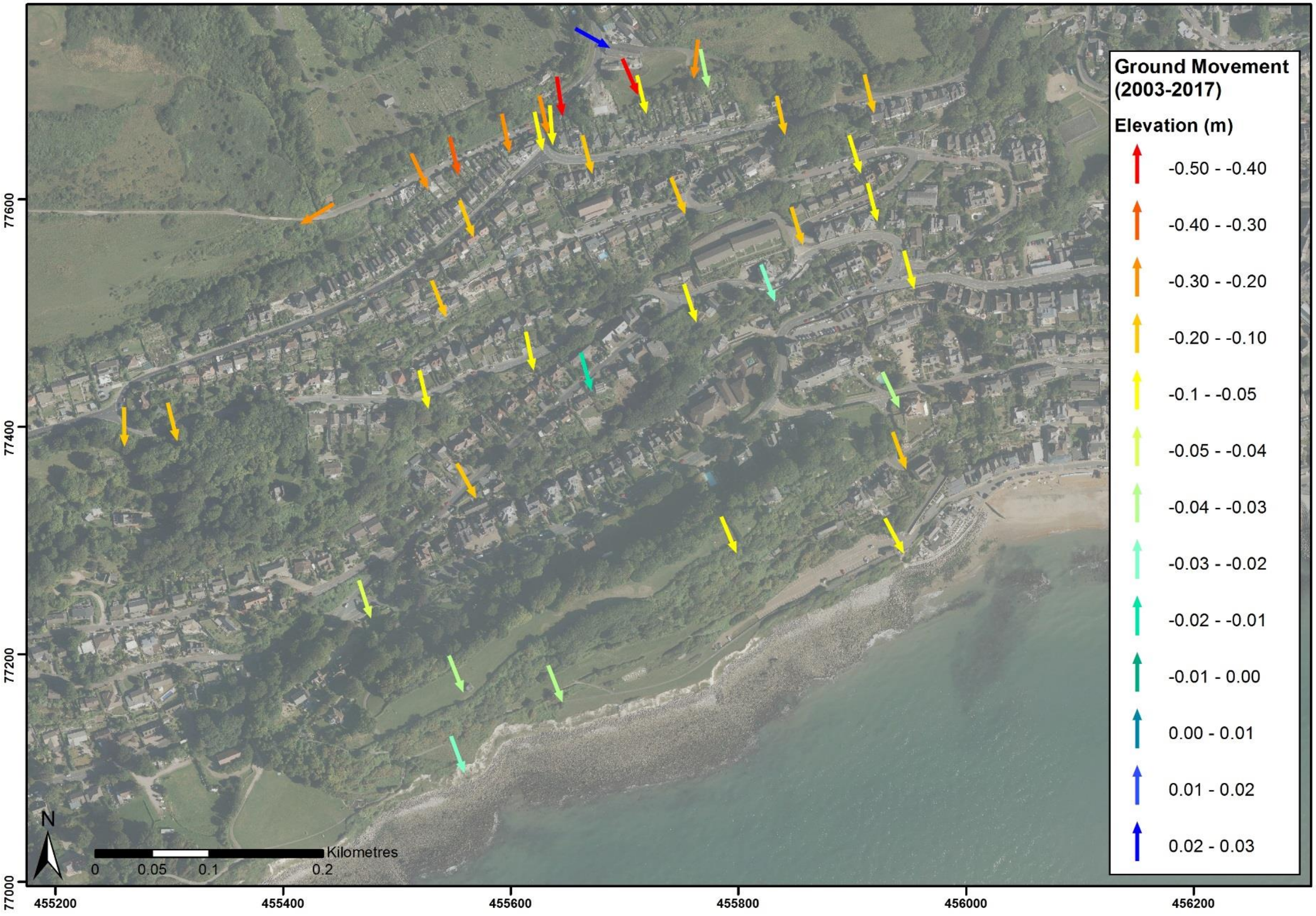

Figure 3. Ground surface elevation change at each of the permanent ground markers at Ventnor Park between 2003-2017.

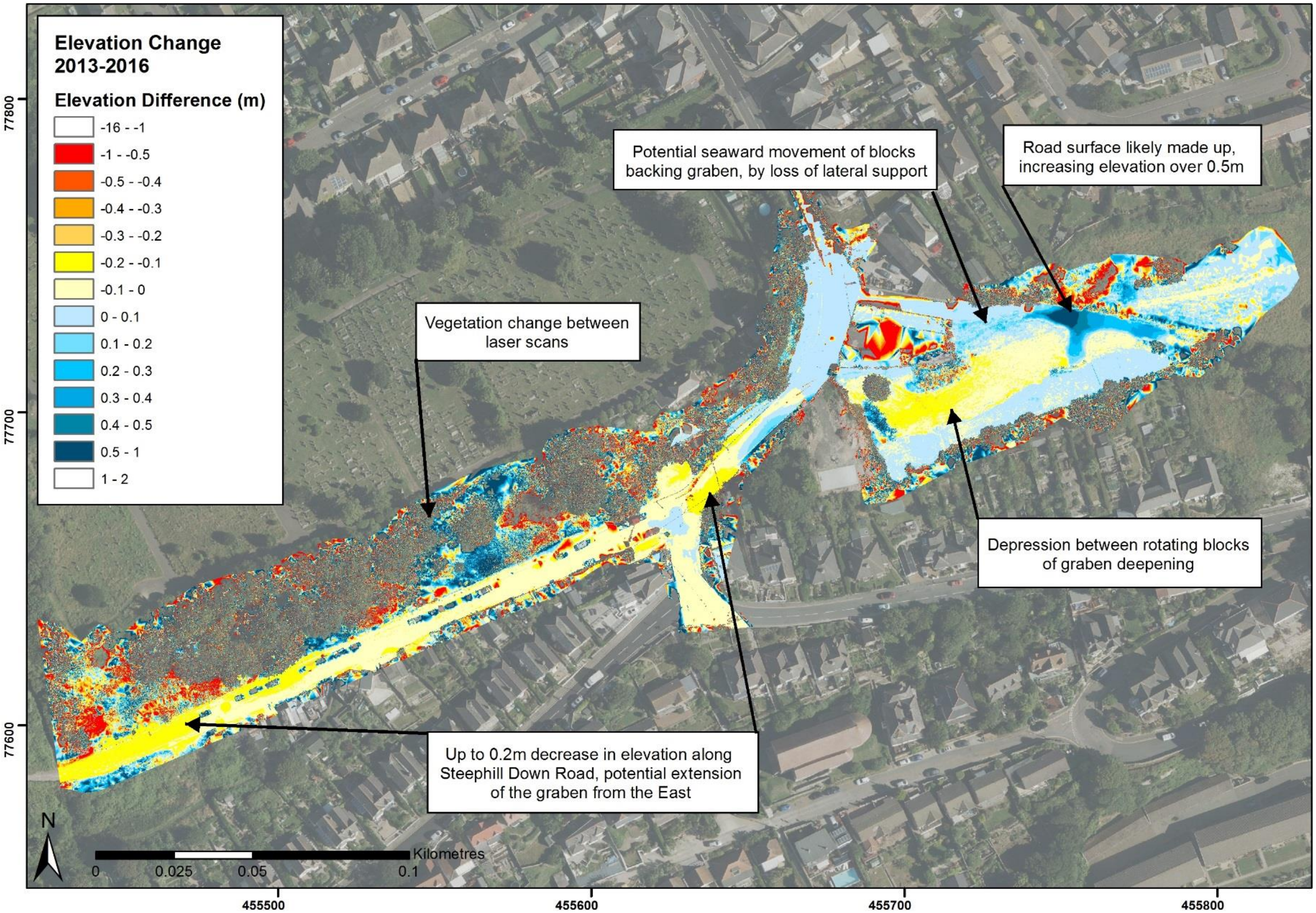

Figure 4. Ground surface elevation change calculated from 2013 and 2016 terrestrial laser scans at the Lowerville Graben.

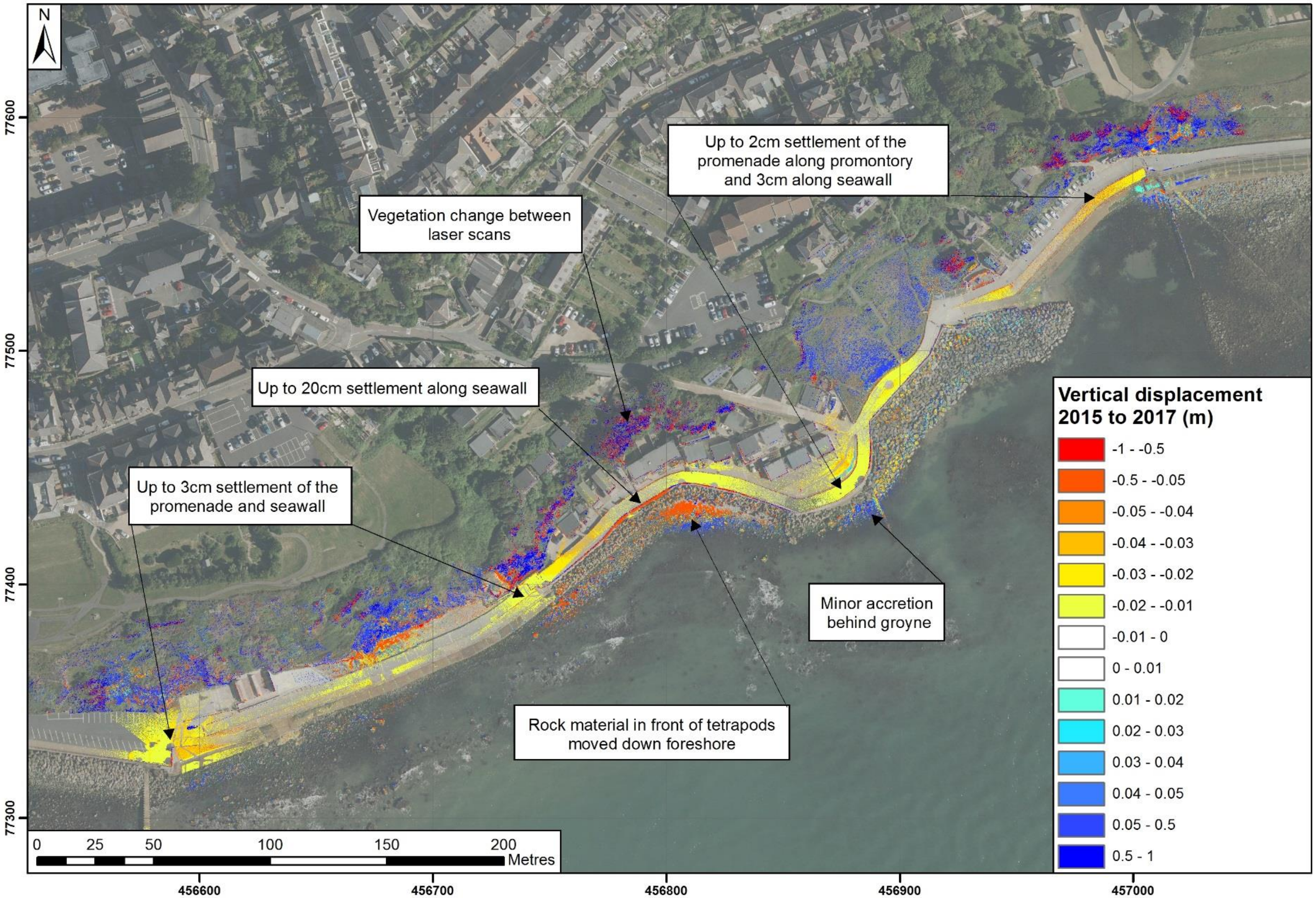

Figure 5. Ground surface elevation change calculated from 2015 and 2017 terrestrial laser scans on the frontage at Wheelers Bay

Appendix 5. Ground models

A.5 Ground models

Landslide ground behaviour models were developed for each Landslide Reactivation Unit (LRU) to inform the hazard model as part of the quantitative risk assessment. The ground models have been produced for the seven LRUs using a 3D geological model and thematic data held in ArcGIS and alongside those previously presented in earlier reports and papers.

A.5.1 Influence of the Ventnor Syncline

The syncline that underlies the Southern Downs of the Isle Wight exerts a fundamental control on the disposition of strata and their outcrop at the shoreline. The syncline was surveyed by Chandler (1984) using outcrops of marker beds along the coast and the inland escarpment. Figure 1, reproduced from Chandler's work courtesy of Prof. Bromhead, plots the elevation of the base of the Freestone bed (Malm Rock) in metres above Ordnance Datum.

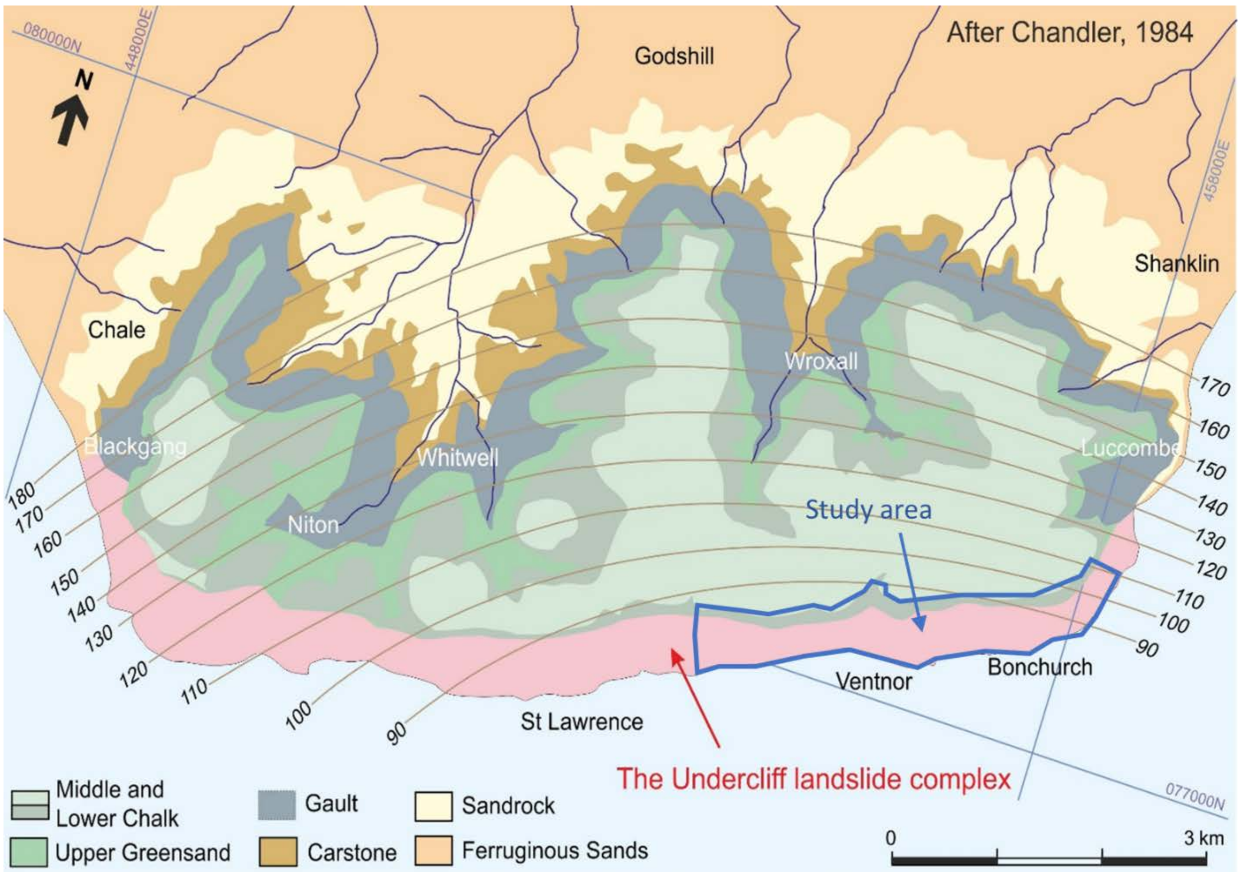

Figure 1. Contours of the Ventnor Syncline (metres OD). Courtesy: Professor E.N. Bromhead.

The effect of the syncline is to lower the elevation of strata in the central part of the Undercliff whilst raise the elevation of strata on the rising limbs to east and west. This has a fundamental influence on the Undercliff landslides, hydrogeology and ground models, specifically the outcrop of key strata prone to failure, the Gault and Sandrock bed 2d, relative to sea level.

Given the significance of the syncline and its influence on the hydrogeology and ground models in the area of interest, new work was undertaken for this report to develop a 3D geological model that incorporates recent ground investigation borehole data in the Undercliff and using ArcGIS/ArcScene visualisation software. While there is scope to improve this new model with more detailed interpretive work, it is considered more detailed and accurate than Chandler's original map as it is constructed from verified sub-surface stratigraphical data in the Undercliff and surrounding area.

A.5.2 3D Geological Model

The geological model is constructed from available boreholes from BGS archives and the IWC within the Undercliff and Southern Downs. Figure 2 provides a location map of boreholes within the area of interest.

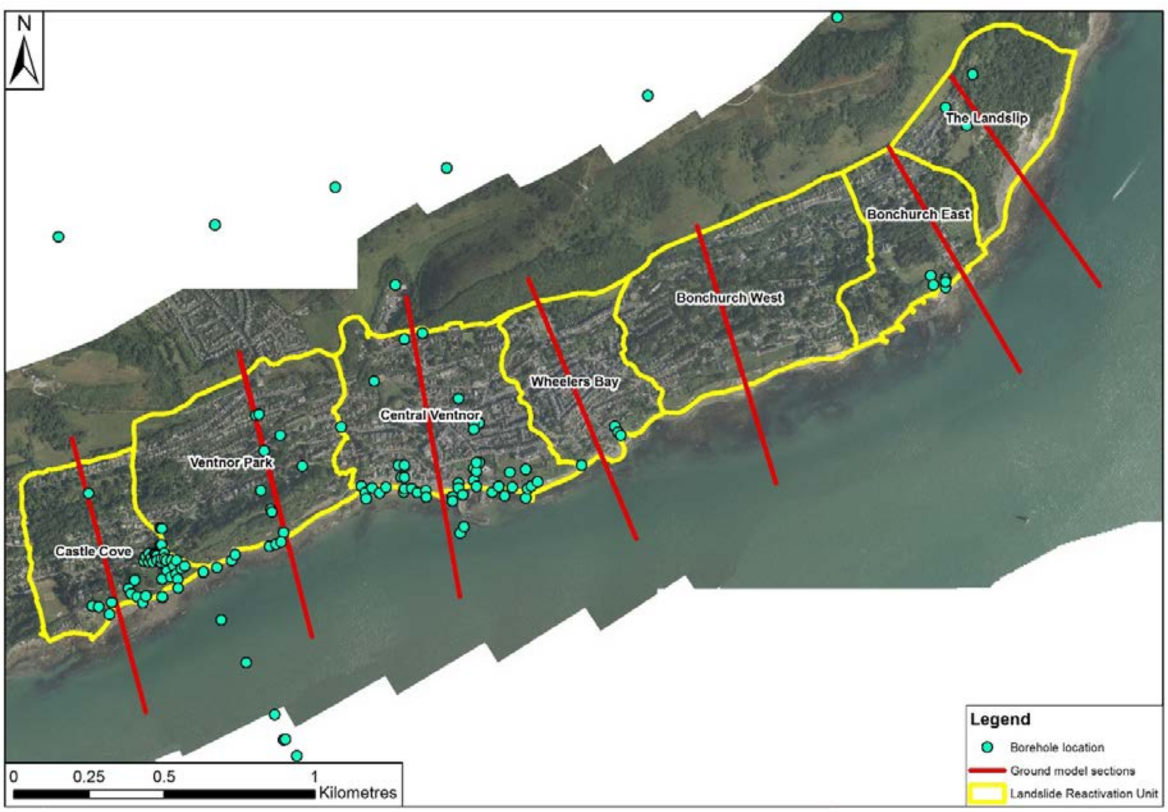

Figure 2. Location of boreholes and ground model sections.

The 3D geological model is developed using the following approach and methods:

Borehole field logs are interpreted using knowledge of the geological sequence to determine the contacts between each of the geological units. The field logs vary in terms of the format and detail in which the rock and soil were recorded. Some field logs interpret the stratigraphic formations based on the descriptions, whilst others do not. In the latter instance, the stratigraphy was interpreted based on the soil and rock descriptions, referring to geological memoirs and the known characteristics of the formations, such as described in the BGS Lexicon of Named Rock Units. Descriptions of disturbed ground and debris were regarded as landslide material and not included within the stratigraphic model.

Using a spreadsheet, the elevations of the geological contacts in each borehole are listed, with the position of the borehole in eastings and northings. In this instance, the top of each geological unit is extracted. In addition, the ground level of each borehole is extracted from the Digital Elevation Model (DEM) in ArcGIS.

The data are then organised into stratigraphic units which provides a format for the creation of surfaces which represent the geological strata. The spreadsheet is imported into ArcGIS, and the data are plotted in three-dimensions. For each stratigraphic unit, a Triangulated Irregular Network (TIN) surface is constructed by triangulating the plotted set of vertices. The TIN surface is a digital structure which models the contacts between strata.

The TIN requires extension of the surfaces beyond the extent of the borehole layout to cover the area of interest. For example, in some areas of the Undercliff there are few deep boreholes, such as in the Bonchurch West landslide reactivation unit (Figure 3-3). The TIN surface is extended using extrapolated modelled points.

A.5.3 Mapping and Visualisation of the Syncline

Based on recent deep borehole investigations at Ventnor (Moore et al. 2007), the critical controlling horizons upon which basal shear surfaces develop are known to be the Gault Formation and Sandrock bed 2d. Prior to these investigations, it was thought that shear surfaces in the Gault occurred at multiple levels down to approximately 15m from the base of the Gault, coinciding with a change in lithology from a plastic clay to a silt-dominated layer. However, at Ventnor, the basal shear surface was found to coincide with the base of the Gault Formation.

Based on the above, the critical strata horizons for visualising the syncline are the base of Gault and base of Sandrock 2d. These are shown in Figure 3.

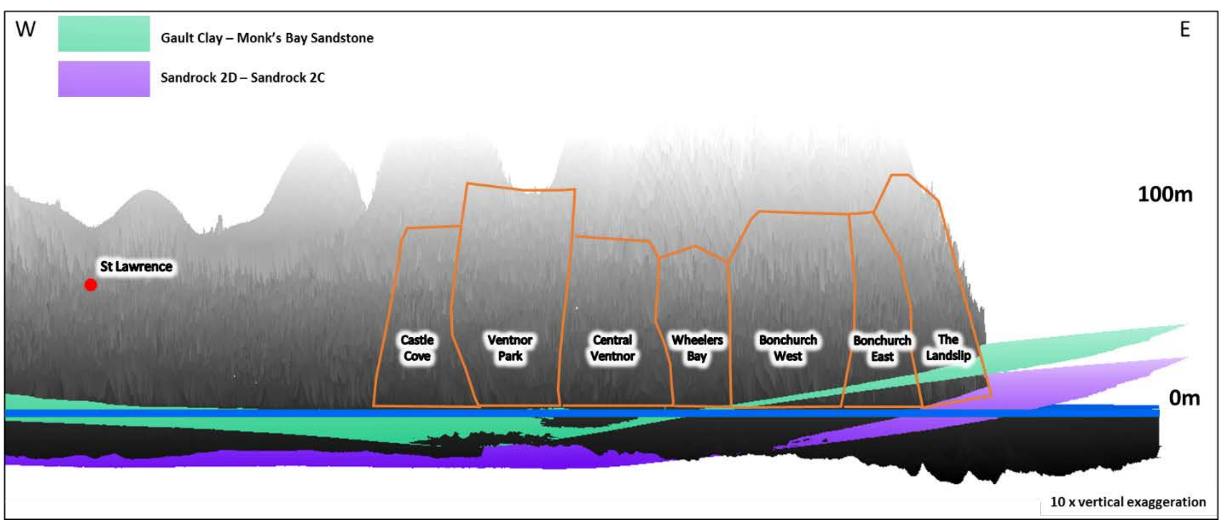

Figure 3. Longitudinal section of projected strata outcrop across area of interest and LRUs.

The model shows the landslide reactivation units are located on the eastern limb of the syncline, where the strata have a general dip to the south-west. Outcrop elevations of the geological units therefore differ along the coastal section. The base of the Gault is above sea level in four units, and Sandrock 2d crops out above sea level in only two units. This difference has the potential to influence the hydrogeology and landslide ground models for each unit.

- Castle Cove – Sandrock 2D and the base of the Gault Clay is below sea level
- Ventnor Park – Sandrock 2D and the base of the Gault Clay is below sea level.
- Central Ventnor – Sandrock 2D and the base of the Gault Clay is below sea level, the axis of the syncline is aligned NE-SW and passes through this unit.
- Wheelers Bay – Sandrock 2D is below sea level, and the base of the Gault Clay is close to sea level ascending above sea level in the eastern extent of the unit.
- Bonchurch West – Sandrock 2D is below sea level and the base of the Gault Clay crops out above sea level.
- Bonchurch East – The base of Sandrock 2D is close to sea level, ascending above sea level in the eastern extent of the unit. The base of the Gault Clay crops out above sea level.
- The Landslip – The base of both Sandrock 2D and the Gault Clay crops out above sea level.

A.5.4 Undercliff Ground Behaviour Models

The ground behaviour models have been produced for seven LRUs using the 3D geological model and thematic data held in ArcGIS alongside those models previously presented in earlier reports and papers. In general, the differences between the LRUs ground behaviour highlight the importance of the stratigraphic position of horizons upon which basal shear surfaces develop in the Gault Clay Formation and Sandrock 2D bed.

In all but the Landslip LRU, the basal shear surfaces continue at a depth of up to 40m below the coastal defences along the frontage, and the landslide system extends offshore. The coastal defences in these sections do not directly act to reduce the movement along the basal shear surfaces that are well below sea level. The defences instead act to reduce erosion of the coastal cliffs formed of landslide debris. The primary failure mechanisms in these units are deep-seated rotational landslides in Gault Clay and compound landslides within the Sandrock, which, whilst defended, are driven by rainfall inducing movement along the basal shear surfaces.

In the Landslip LRU, where the basal shear surfaces crop out above sea level, the coastal defences would if present directly reduce the erosion and unloading at the landslide toe, and consequently stabilise the landslide system. The primary failure mechanisms in these units are rotational landslides in Gault Clay and mudslides, driven by rainfall and unloading of the landslide toe via coastal processes, causing movement along the basal shear surfaces.

The ground behaviour models for each LRU are provided in detail below.

A.5.5 Castle Cove

Figure 4 shows the landslide ground behaviour model generated for Castle Cove using the 3D GIS model. The basal shear surface in the upper landslide system is indicated as being close the base of the Gault, however the actual elevation may vary both laterally along the coast and along the line of the section.

The lower landslide system is interpreted to have moved within Sandrock 2d, and extended offshore. Evidence of historical compound failures can be observed using bathymetry along this section offshore. Failure mechanisms include deep-seated rotational failure in the Gault and compound failures in Sandrock, resulting in coastal slopes/cliffs formed of mainly Upper Greensand blocks and landslide debris, as well as shallow mudslides. Whilst coastal defences are in place and preventing toe erosion landslide failures are primarily driven by rainfall inducing movement along the basal shear surfaces. The shear surface developed in the Sandrock is up to approximately 20m below sea level along this frontage.

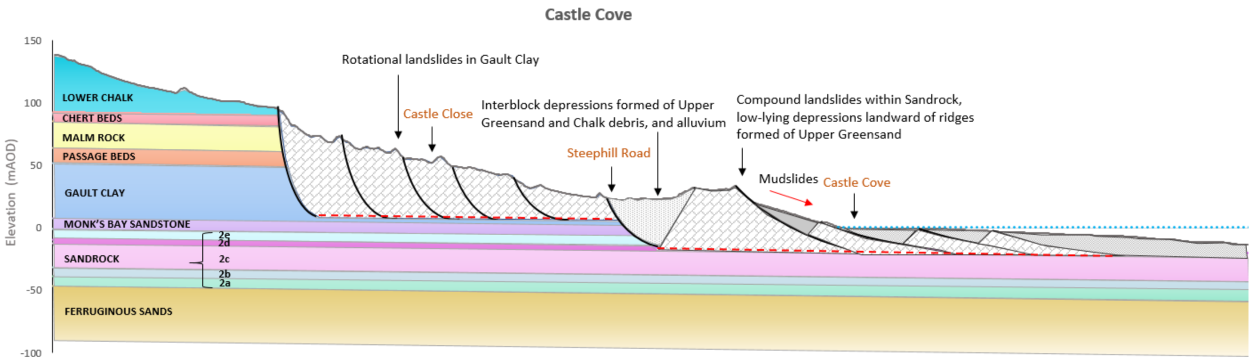

Figure 4. Castle Cove ground behaviour model

A.5.6 Ventnor Park

Figure 5 shows the landslide ground behaviour model generated for Ventnor Park using the 3D GIS model. The upper tier landslide system is developed on the basal shear surface indicated near the base of the Gault Clay Formation. The actual elevation may vary both laterally along the coast and along the line of the section. Movement along the shear surface has resulted in rotational failure and formation of the Lowtherville graben towards the landward edge of the system. Seaward are a combination of inter-block depressions filled with landslide debris and compound failures developed within Sandrock. Blocks of failed Chalk and Upper Greensand form the coastal cliffs, and historical compound failure blocks are evident in the offshore morphology. Whilst coastal defences are in place and preventing toe erosion landslide failures are primarily driven by rainfall inducing movement along the basal shear surfaces. The basal shear surface in the Sandrock lies up to approximately 30m below sea level along this frontage.

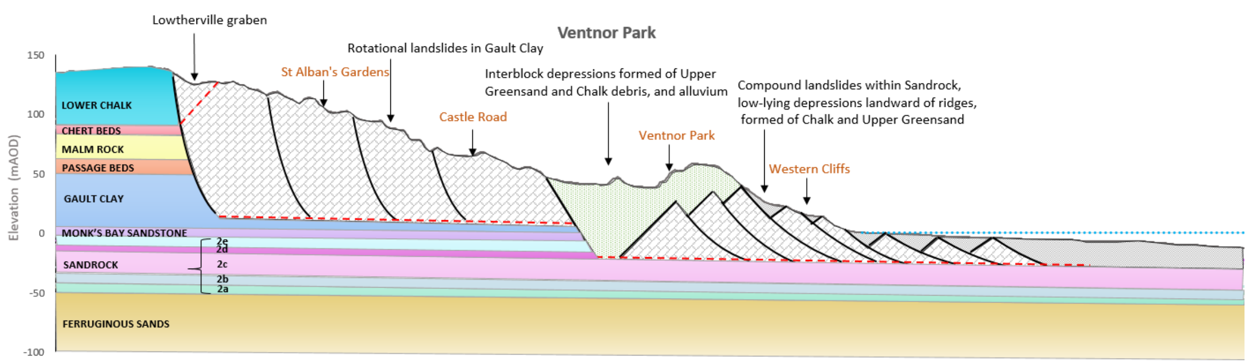

Figure 5. Ventnor Park ground behaviour model

A.5.7 Central Ventnor

Figure 6 shows the landslide ground behaviour model generated for Central Ventnor using the 3D GIS model. The model shows a two-tier landslide system, whereby the upper tier is developed on the basal shear surface indicated near the base of the Gault Clay Formation. The actual elevation may vary both laterally along the coast and along the line of the section. Movement along the shear surface has resulted in rotational failure and formation of a steep backscarp in the Chalk landward of the system. The lower tier landslide system consists of compound failure within Sandrock, with ridges formed of Upper Greensand blocks and infilled depressions. Rotational failure of landslide debris occurs along the coastal slopes. Whilst coastal defences are in place and preventing toe erosion landslide failures are primarily driven by rainfall inducing movement along the basal shear surfaces. The axis of the Ventnor syncline is aligned NE-SW across Central Ventnor, and the basal shear surface in the Sandrock extends deep below sea level by up to approximately 40m. However, historical evidence of compound landslide failures extending offshore is not well defined in the offshore morphology, possibly as a result of dredging undertaken around Ventnor Harbour.

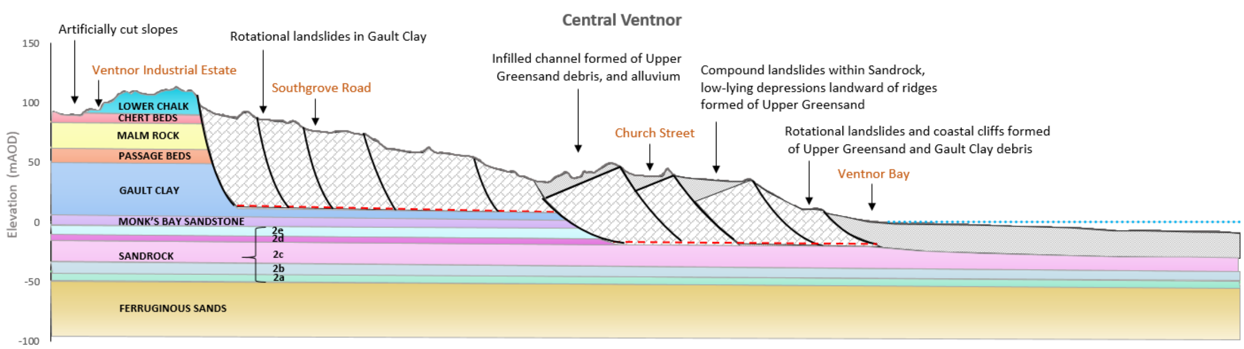

Figure 6. Central Ventnor ground behaviour model

A.5.8 Wheelers Bay

Figure 7 shows the landslide ground behaviour model generated for Wheelers Bay using the 3D GIS model. The landslide unit represents a two-tier system. In the upper tier, the basal shear surfaces are developed in the Gault Clay Formation. These are indicated near the base of the Gault; however, the actual elevation may vary both laterally along the coast and along the line of the section. Movement along the shear surface has resulted in rotational failure and formation of a steep backscarp in the Chalk landward of the system. The lower tier landslide system consists of compound failure within Sandrock, comprising of large blocks of failed Chalk and Upper Greensand, infilled depressions and mudslides on the coastal slopes. Whilst coastal defences are in place and preventing toe erosion Landslide failures are primarily driven by rainfall inducing movement along the basal shear surfaces. The LRU is located on the rising eastern limb of the syncline, therefore the basal shear surface in the Sandrock lies up to approximately 30m below sea level along this frontage. Evidence of compound failures extending offshore are not well defined.

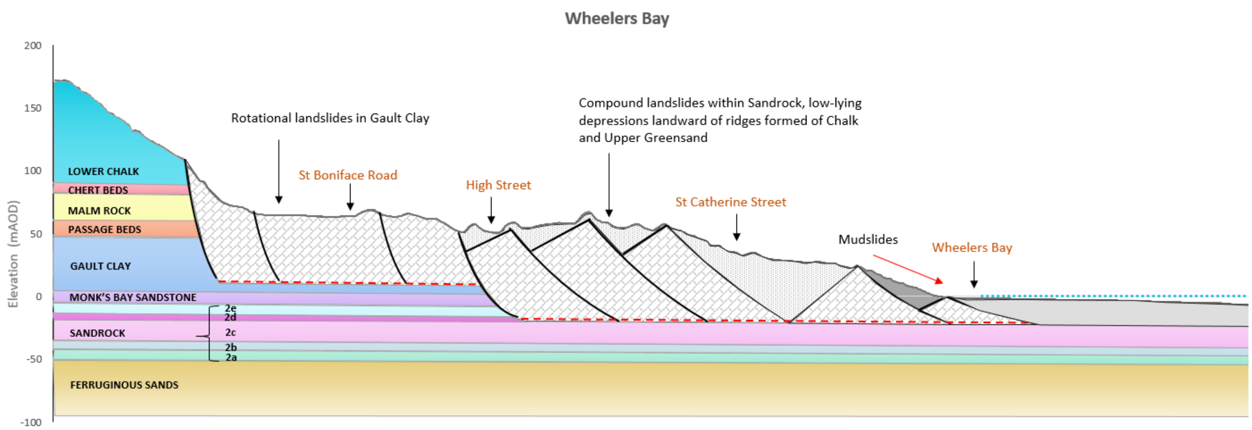

Figure 7. Wheelers Bay ground behaviour model

A.5.9 Bonchurch West

Figure 8 shows the landslide ground behaviour model generated for Bonchurch West using the 3D GIS model. This landslide unit comprises of an upper and lower landslide tier. The basal shear surfaces in the upper tier are developed in the Gault Clay Formation. These are indicated near the base of the Gault; however, the actual elevation may vary both laterally along the coast and along the line of the section. Movement along the shear surface has resulted in rotational failure. Relative to the LRUs westwards, the lower tier compound landslide failure compasses a wider portion of the unit. The compound failure is developed on the basal shear of the Sandrock, which has resulted in translated blocks of Chalk and Upper Greensand and infilled depressions, fronted by coastal cliffs formed of landslide debris. Whilst coastal defences are in place and preventing toe erosion landslide failures are primarily driven by rainfall induced movement along the basal shear surfaces. The basal shear surface is up to 15m below sea level along the frontage. Evidence of compound failures extending offshore are not well defined, possibly due to the level of the seabed relative to the basal shear on the Sandrock horizon, and the degradation of the compound failure blocks due to coastal processes.

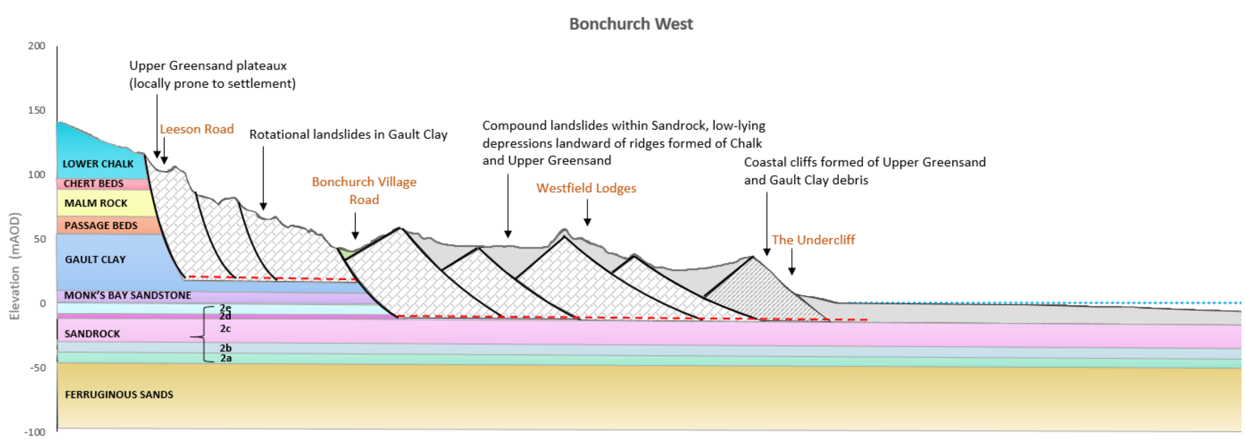

Figure 8. Bonchurch West ground behaviour model

A.5.10 Bonchurch East

Figure 9 shows the landslide ground behaviour model generated for Bonchurch East using the 3D GIS model. Within this landslide unit, the base of the Gault Clay Formation crops out above sea level at approximately 15m to 20m AOD. It is interpreted that a two-tier landslide system exists within the Gault, with rotational failures occurring in the upper tier, and shallow mudslides developed in Gault Clay and landslide debris on the lower tier. The Sandrock 2D horizon is close to sea level, and ascends above sea level in the eastern extent of the unit forming in-situ Lower Greensand coastal cliffs. Landslide failures are driven by a combination of rainfall induced movement along the basal shear surfaces, and the gradual erosion of the cliffs by coastal processes enabling unloading at the toe of the landslide which destabilises the system.

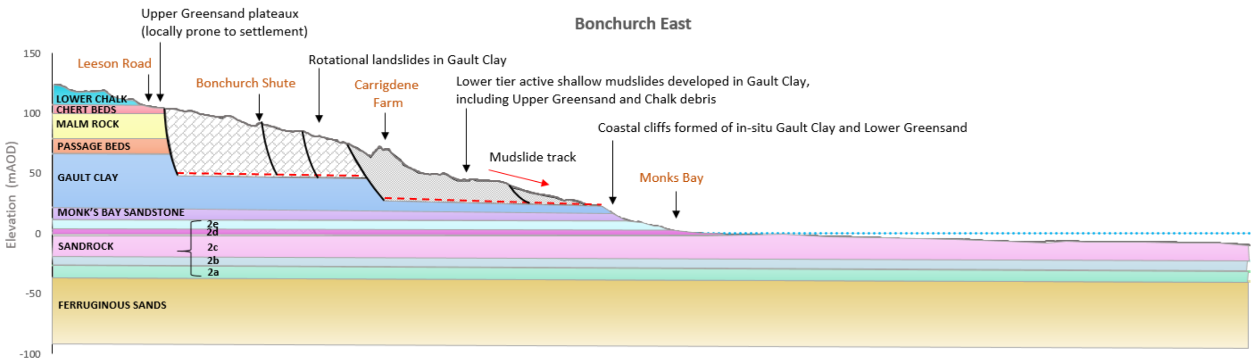

Figure 9. Bonchurch East ground behaviour model

A.5.11 The Landslip

Figure 10 shows the landslide ground behaviour model generated for The Landslip using the 3D GIS model. The stratigraphic positions of the critical horizons are above sea level in this landslide unit. The base of the Gault Clay Formation is over 20m above sea level. Morphological evidence suggests multiple landslide failure tiers have developed within the Gault Clay, with shallow rotational block failures in the upper tier, and active mudslides and degradation of block failures occurring in the lower tiers. The coastal cliffs are formed of in-situ Gault Clay and Lower Greensand which are readily eroded by coastal processes. Erosion of the cliffs results in the unloading and destabilisation of the landslide system, inducing movement along the shear surfaces and mudslides. Rainfall also contributes to the movement along shear surfaces and mudslide development.

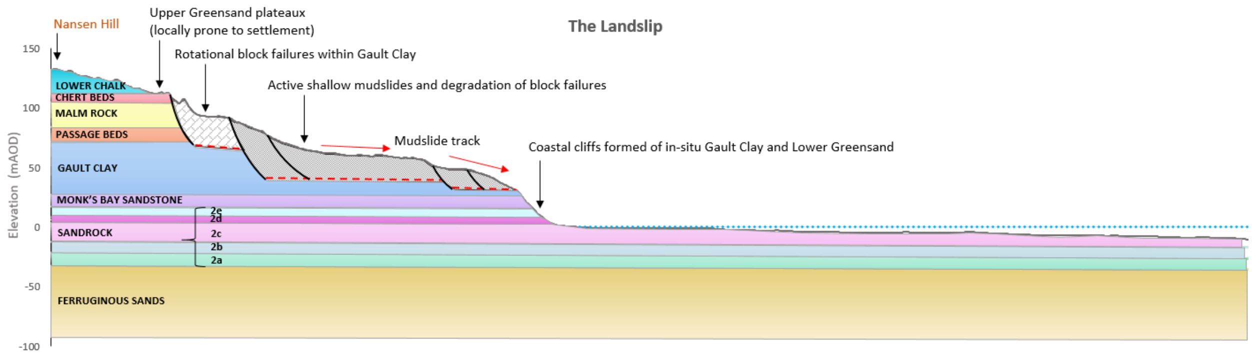

Figure 10. The Landslip ground behaviour model

A.5.12 References

Chandler MP (1984). The Coastal Landslides Forming the Undercliff of the Isle of Wight. Unpublished PhD Thesis, Imperial College, University of London.

Moore R, Carey JM, McInnes RG, Houghton J (2007) Climate change, so what? Implications for ground movement and landslide event frequency in the Ventnor Undercliff, Isle of Wight. In: McInnes R, Jakeways, J, Fairbank H, Mathie E (eds) Landslides and Climate Change; Challenges and Solutions. Taylor and Francis, London.

Appendix 6. Hazard model

A.5 Hazard model

From the previous work documenting landslide hazards in the Undercliff (Lee & Moore, 2007), historical records, evolutionary model and contemporary cliff conditions, five cliff instability and landslide hazard scenarios have been developed. The frequency and magnitude of each scenario is accounted for by a reference event that provides the baseline for estimating scenario probability. The likelihood and severity of the scenarios range from those that are occurring today, such as slope creep, to those which require a series of conditioning events, such as sea level rise and the failure of coastal defences.

The hazard scenarios and their probabilities were agreed during an expert risk forum. The experts included the project team, Professor Roger Moore (expert in cliff instability and management in the UK), Geoff Davis, Ross Fitzgerald, Claire Czarnomski (experts in cliff instability and QRAs) and Jon Denner (expert in coastal erosion management). The consensus best estimates are based on the expert judgements provided during the risk forum on 27th September 2017 and by an expert panel at the risk forum held by Isle of Wight Council on 20-23rd May 2002 (Halcrow Group Ltd. 2006; Hutchinson & Bromhead 2002); they give a broad indication of the expected event probability and should not be viewed as implying a rigorous quantification of the likelihood of each scenario.

A.5.1 Hazard scenarios

The five credible landslide hazard scenarios are defined in Table 1.

Scenarios 1 to 3 are exclusively driven by exceedance of the rainfall thresholds and range in rate of movement and from local to widespread spatially. Scenario 4 can be caused by both the exceedance of the relevant rainfall threshold and via coastal defence failure causing reactivation of a pre-existing deep-seated landsliding. Scenario 5 represents the re-establishment of active toe erosion along the whole frontage, resulting in cliff undercutting and reactivation of the natural state and landslide evolutionary model. This scenario has no recent historical precedent at Ventnor and requires sea level rise and/or sea wall failure to restore the connection between the sea and the cliff.

Table 1. Current coastal erosion and landslide hazard scenarios

Scenario	Triggering event(s)	Duration	Surface Disruption	Example Event	Current (defended) estimated annual probability
1	Threshold winter rainfall exceeded	Winter Period	Localised creep up to 10 mm/yr., very slow settlement of landslide blocks and development of tension cracks along block boundaries (up to 1 mm wide).	Ventnor, typical year	0.95 (every year)
2	Threshold winter rainfall exceeded	Winter Period	Localised creep up to 100 mm/yr., slow settlement of landslide blocks and development of tension cracks along block boundaries (up to 10 mm wide).	Ventnor 2000-01	0.1 (1 in 10 years)
3	Threshold winter rainfall exceeded	Winter Period	Widespread creep up to 1 m/yr., settlement of landslide blocks with evidence of localised surface displacement (<1m displacement) and development of tension cracks along block boundaries (up to 50 mm wide).	Ventnor 1960-61	0.01 (1 in 100 years)

Scenario	Triggering event(s)	Duration	Surface Disruption	Example Event	Current (defended) estimated annual probability
4	Coastal defence failure and loss of geometric support Threshold winter rainfall exceeded	<10 days	Major deep-seated landslide event, involving widespread ground disruption within the slide area, with up to 10m surface lateral/vertical displacements and tension cracks (up to 0.5m wide).	The Landslip 1810, 1818; Rock End 1928; Blackgang 1994-95 St Catherine's Point (Barlow et al. 2016)	0.001 (1 in 1000 years)
5	Coastal defence failure and loss of geometric support Rapid sea level rise	<10 days	Extensive major landslide activity re-shaping the pre-existing systems and creating significant changes to the landslide geomorphology. Widespread ground disruption, with over 10m surface lateral/vertical displacements and tension cracks (up to 1m wide).	No contemporary analogue	0.0001 (1 in 10,000 years)

A.5.2 Hazard scenario probability

Hazard scenario probability is the annual probability that the landslide event will occur in a given year. This is based on the annual probability of the triggering event and the conditional probability of the landslide response, where:

*P (Landslide event) = P (Response|Triggering event) * P (Triggering event)*

For hazard scenarios 1 to 5, the exceedance of threshold winter rainfall has been modelled as a landslide triggering event (Section 1.2.1). For hazard scenarios 4 and 5, the failure of coastal defences has also been modelled as a landslide triggering event (Section 1.2.2). Hazard scenario probabilities have been modelled over a 100-year period to cover the lifetime of the proposed management scheme.

The landslide reactivation sub-units are treated individually based on the geomorphology, landslide event history and the ground behaviour model. Both expert judgement and empirical evidence are utilised and documented.

The approach to modelling the different triggering events are described in detail in the following Sections 1.2.1 to 1.2.3.

A.5.3 Threshold winter rainfall model (scenarios 1 to 5)

The threshold winter rainfall model generates the annual probability that a landslide event occurs due to exceedance of threshold winter rainfall in a given year. This is calculated by multiplying the annual probability of threshold rainfall by the conditional probability of landslide reactivation given exceedance of threshold rainfall, where:

*P (Landslide Event) = P (Response|Triggering Event) * P (Triggering event)*

*P (Landslide Event) = P (Landslide reactivation given threshold winter rainfall) * P (Threshold winter rainfall)*

The annual probability that threshold rainfall occurs in a given year is calculated using the initial annual probability of threshold rainfall and applying the annual percentage increase in probability of threshold rainfall. The initial annual probabilities of threshold winter rainfall values determined for each landslide hazard scenario are based on the relationship between historical landslide events and 4-month antecedent rainfall data at the Undercliff (Appendix 4; Halcrow Group Ltd, 2006). The initial threshold winter rainfall probabilities for each scenario are shown in Table 2.

To account for the effects of climate change a 2% cumulative annual increase in the probability of threshold winter rainfall is applied (see Section 2.6 of the main report and Appendix 2). This represents the increase in rainfall intensity for the UKCP09 medium emissions scenario. Table 2 shows how, over the 100-year study period, a 2% annual increase in probability leads to a 7.2 times increase in the likelihood of a threshold rainfall event.

Table 2 Year 1 and year 100 annual threshold rainfall probabilities based on the 4 month antecedent rainfall threshold

	Scenario				
	1	2	3	4	5
Year 1 annual probability of threshold rainfall	0.95	0.1	0.02	0.002	0.002
Year 100 probability of threshold rainfall under UKCP09 medium emissions scenario	1	0.72	0.14	0.014	0.014

Expert judgement and historical landslide records informed the probability of landslide reactivation given threshold rainfall for the five hazard scenarios, on a sub-unit basis between all LRUs. It has been assumed that the probability of a landslide event for subsequent inland landslide reactivation sub-units is independent of the failure of the seaward sub-unit (in this rainfall model). Details of sub unit probabilities are provided in Table 3. The rationale for these values is described below:

- Scenarios 1 and 2: There is compelling evidence to suggest the exceedance of threshold rainfall in sub-unit A and B in all LRUs will cause a landslide response. Probability values are 1 (i.e. a response is certain), except for Bonchurch West in scenario 2 which lacks monitoring evidence and probability values are 0.5.
- Scenario 3: There is historical evidence over the 200-year record of landslide events to indicate landslide reactivation due to exceedance of threshold rainfall only. Between Central Ventnor and Bonchurch West there is a lack of geomorphological evidence in several sub-units. Probability values are 0.5 where evidence is abundant, and 0.2 where evidence is lacking. Active deterioration at The Landslip indicates probability values of 1 (i.e. a response is certain).
- Scenario 4: It is highly unlikely that landslide reactivation can be triggered due to exceedance of threshold rainfall only. Recent research suggests a 1 in 1000-year landslide event may be triggered given threshold rainfall is exceeded (Barlow et al., 2016). Probability values are therefore 0.5.

- Scenario 5: There is no credible evidence to suggest landslide reactivation due to exceedance of threshold rainfall only. Landslide reactivation is dependent on the loss of geometric support due to unloading at the toe. Probability values are 0 (i.e. a response is not credible).
- Scenarios 1-5: Sub-unit C in all LRUs is located on the Upper Greensand plateaux within the backscarp of the landslide system (Figure 3-1), therefore, landslide response is dependent on the unloading of effects from sub-unit B. Probability values are 0 (i.e. a response is not credible based on rainfall alone).

Table 3. Landslide reactivation probabilities given exceedance of winter rainfall.

Scenario	Sub-Unit	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip
1	A	1	1	1	1	1	1	1
	B	1	1	1	1	1	1	1
	C	0				0	0	0
2	A	1	1	1	1	0.5	1	1
	B	1	1	1	1	0.5	1	1
	C	0				0	0	0
3	A	0.5	0.5	0.5	0.5	0.5	0.5	1
	B	0.5	0.5	0.2	0.2	0.2	0.5	0.5
	C	0				0	0	0
4	A	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	B	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	C	0				0	0	0
5	A	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0
	C	0				0	0	0

A.5.4 Conditional sequence model (toe erosion triggered instability) (scenarios 4 and 5)

The conditional sequence model generates the probability that a landslide event occurs for the first time in a given year due to failure of the coastal defence. The model incorporates a lag between the failure of the coastal defence and reactivation of the landslide unit in which it impacts. For each LRU, this is sub-unit A, the most seaward sub-unit. Landslide sub-unit B reactivates due to the unloading effect from sub-unit A. Similarly, there is a lag in response between the failure of sub-unit A and landslide reactivation in sub-unit B. The same follows for sub-unit C which reactivates to the unloading effect from sub-unit B.

To calculate the probability of a landslide event in sub-unit A, three input parameters required:

- **Initial coastal defence failure probability**. This represents the coastal asset in the poorest condition with the greatest likelihood of failing in a given year (i.e. the 'weakest link' along the LRU frontage). The assessment of the weakest link is based on the residual life and condition of the current defences, which accounts for the effects of sea level rise. This assessment is detailed in Section 5.3.4 of the main report.
- **Incremental coastal defence failure probability %**. This is applied as an annual percentage increase on the initial probability of the coastal defence failure. This is based on sea level rise and the deterioration of the defence over time without active intervention, see Section 5.3.4 of the main report for further detail.

- **Probability of landslide reactivation.** This is the probability of landslide reactivation taking place for the first time in a given year, given that the coastal defence failed in year 1 for the most seaward sub-unit (i.e. sub-unit A). Given that mean high water is typically already at a higher elevation than the ground landward of the coastal defences assets (i.e. the ground that would interact with waves if the defence were removed) the model considers coastal erosion would be triggered immediately following defence failure from year 1 (i.e. future sea level rise is not required in combination with defence failure to trigger erosion). The same applies given failure of sub-units A and B for sub-units B and C respectively (see table 4 for probabilities). This is the cumulative probability of landslide reactivation for the given year minus the cumulative probability of landslide reactivation in the previous year. The input probability for year 1 is based on expert judgment which accounts for the residual effect of the damaged defence and the characteristics of the land behind the defence. Failure of the defences does not necessarily lead to the immediate destabilisation of sub-unit A, and similarly failure of sub-unit A will take some time to undermine and destabilise sub-unit B.

Table 4. Landslide reactivation probabilities for conditional sequence model scenarios 4-5

Scenario	Sub-Unit	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip
4	A	0.3	0.3	0.4	0.5	0.5	0.5	0.1
	B	0.025	0.025	0.025	0.025	0.025	0.025	0.025
	C	0.025				0.025	0.025	0.025
5	A	0.03	0.03	0.04	0.05	0.05	0.05	0.01
	B	0.025	0.025	0.025	0.025	0.025	0.025	0.025
	C	0.025				0.025	0.025	0.025

To calculate the probability of a landslide event due to failure of the coastal defence for a given year in sub-unit A, the joint probability of the initiating event followed by the response is generated within a matrix. Each value in the matrix represents the joint probability of failure of the coastal defence in a given year followed by landslide reactivation in a given year. This considers a possible lag in response between the failure of the defence and landslide reactivation. The probability of failure of coastal defence occurring for the first time is multiplied by the probability of landslide reactivation taking place for the first time given that coastal defence failure occurred in year 1.

The probability of a landslide event occurring for the first time in a given year is the sum of the joint probabilities over a 100-year period for failure of the coastal defences followed by landslide reactivation in a given year (which are mutually exclusive).

Landslide reactivation probabilities generated for sub-unit A feed sequentially into calculations for sub-unit B, and then from sub-unit B to sub-unit C.

In scenarios 4 and 5, more than one initiating event can result in a landslide reactivation. These are not mutually exclusive events, and hence the overall probability of a landslide reactivation is not simply the sum of the probabilities. There is some overlap in probabilities.

A.5.5 Combining threshold rainfall and conditional sequence probabilities

The combined probability of landslide reactivation in a given year due to defence failure or threshold rainfall (or both) is calculated as the addition of the probability of landslide reactivation occurring for the first-time due to defence failure and the annual probability of landslide reactivation due to threshold rainfall, subtracting the product of the probabilities. This assumes the initiating events are independent.

For example, when the probability of landslide reactivation due to defence failure (P(A)) and probability of landslide reactivation due to threshold rainfall (P(B)) are added, the probability of the intersection (and) is added twice, and to compensate for this double inclusion, the intersection must be subtracted so that:

$$P(A \text{ or } B) = P(A) + P(B) - P(A \text{ and } B)$$

Which is:

$$P(A \text{ or } B) = P(A) + P(B) - (P(A) \times P(B))$$

This is multiplied by the probability that landslide reactivation has not occurred in the years previous so that the final probability is in relation to the given year.

A.5.6 References

Barlow J, Moore R and Gheorghiu D (2016). Reconstructing the recent failure chronology of a pre-existing multistage landslide complex using cosmogenic isotope concentrations: St Catherine's Point, UK. Geomorphology 268; 288–295.

Halcrow Group Ltd (2006). Ventnor Undercliff, Isle of Wight, Coastal Instability Risk: Interpretative Report and Quantitative Risk Analysis. Technical Report to the Isle of Wight Council.

Hutchinson JN and Bromhead EN (2002). Keynote Paper: Isle of Wight landslides, In McInnes RG and Jakeways J (eds.) Instability Planning and Management: seeking sustainable solutions to ground movement problems. Proceedings of the International conference organised by the Centre for the Coastal Environment, Isle of Wight Council, and held in Ventnor, Isle of Wight, UK on 20-23rd May 2002. Thomas Telford.

Lee E.M. and Moore R. (2007) Ventnor Undercliff - development of hazard scenarios and quantitative risk assessment. Proceedings of the International Conference on Landslides and Climate Change, Ventnor, Isle of Wight. p323-334.

Workshops:

Ventnor Options Study Workshop held on 27 September 2017 at CH2M, Elms House, London. Attendees: Moore R, Davis G, Denner J, Fitzgerald R, Czarnomski C.

Appendix 7. Consequence model

A.7 Consequence model

The aim of this section is to provide estimates of the potential economic losses arising from the various landslide hazard scenarios at Ventnor and Bonchurch. The consequence model evaluates the probable economic losses and damages arising from ongoing cliff instability and landslides. The analysis takes into account the five hazard scenarios that comprise the hazard model in Section 4 of the main report.

The coastal cliffs and landslide terraces at Ventnor and Bonchurch are typically heavily developed with property, businesses and services infrastructure. The management of the area over the next 100 years will dictate the amount of losses and damage avoided and the benefits and costs of intervention. The benefit cost analysis provides a decision-making tool to judge the economic benefits of investing in cliff stabilisation and coastal defence measures over the next 100 years.

A.7.1 Approach

The consequence model has been developed by a panel of experts: Professor Roger Moore (expert in cliff instability and management in the UK), Geoff Davis, Ross Fitzgerald, Claire Czarnomski (experts in cliff instability and QRAs) and Jon Denner (expert in coastal erosion management). The first element of the QRA, the hazard model, specifies the areas likely to be affected by ground movement and landslides, and quantifies the probability of occurrence of five hazard scenarios. This element of the QRA, the consequence model, quantifies the economic losses caused by the various hazard scenarios. The valuation of economic loss follows best practice, including HM Treasury Rules (2013), FCERM-AG (2010) and the Multi-coloured Manual (2005, 2010, 2013).

A.7.2 Types of Asset Included in the Consequence Model

The assets in the study area were categorised and valued according to economic best practice where data are available. Some assets have been screened out due to lack of data or where data has been determined unsuitable for effective interrogation and analysis (e.g. partial datasets). In some instances where data is unavailable, some asset values have been estimated based on analogous sites which are comparable to the Study Area. The baseline for the economic analysis was January 2018 all economic data have been uplifted to that date. Subsequently, in June 2019 the data was sense-checked. Generally, there had been a very small reduction in assets values since the baseline. For example, residential properties had fallen by 0.24% in the last year which has less of an impact in the QRA than the rounding of asset values. Therefore, the data set remains valid and suitable for this appraisal.

The analysis of the economic consequences was based on several types of asset, which are described below. All costs are provided as cash costs.

A.7.3 Residential and non-residential property assets

The value of both residential and non-residential property in each landslide reactivation sub-unit requires:

- The residential and non-residential asset count within each sub-unit as provided by the National Receptor Database (NRD). The NRD contains residential categories for flats, terraced houses and semi-/detached houses. Non-residential assets include retail property, offices, warehouses, leisure and sports facilities, public buildings, industry and other miscellaneous properties. There are also many larger non-residential properties which occupy areas over 25 km^2.

- The value of individual assets which is defined by the average property value for each area (i.e. Castle Cove, Ventnor, Wheelers Bay and Bonchurch), as provided by Zoopla on 20/03/2018 (Table 1).

The asset count is multiplied by the average property value for the sub-unit to provide the total residential and non-residential property value for each sub-unit at present day values (Table 2). This method provides a conservative approach to calculating asset values as it assumes each property has an average property value, including non-residential assets which in many instances are likely to exceed the average residential property size and value. This approach may be refined with more detailed analysis of non-residential property values should this data become available.

Table 1: Average residential property values, supplied by Zoopla.

Area	Average residential property value (as of 20/03/2018)
Castle Cove	£702,224
Ventnor	£279,152
Wheelers Bay	£344,021
Bonchurch	£162,278

Table 2: National Receptor Database (NRD) total residential and non-residential assets

	Landslide Reactivation Unit						
	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip
Sub-unit	**NRD total asset count (residential and non-residential)**						
A	20	198	175	50	44	43	3
B	110	354	1237	897	526	70	3
C	26				36	15	71
Total	**156**	**552**	**1412**	**947**	**606**	**128**	**77**
	Total asset value (residential and non-residential)						
A	£14,044,480	£55,272,096	£48,851,600	£17,201,050	£7,140,232	£6,977,954	£486,834
B	£77,244,640	£98,819,808	£345,311,024	£308,586,837	£85,358,228	£11,359,460	£486,834
C	£18,257,824				£5,842,008	£2,434,170	£11,521,738
Total	**£109,546,944**	**£154,091,904**	**£394,162,624**	**£325,787,887**	**£98,340,468**	**£20,771,584**	**£12,495,406**

The estimated total value of residential and non-residential property assets within the Study Area at is **£1,115,196,817**. The greatest asset values are found in LRUs at Central Ventnor, Wheelers Bay and Ventnor Park.

The residential and non-residential property assets are apportioned separately to the LRU sub-units in Tables 3 and 4.

Table 3: National Receptor Database (NRD) total residential assets only

	Landslide Reactivation Unit						
	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip
Sub-unit	**NRD total asset count (residential)**						
A	10	130	99	20	29	21	0
B	72	287	832	701	374	41	0
C	19				33	8	55

Total	**101**	**417**	**931**	**721**	**436**	**70**	**55**
	Total asset value (residential)						
A	£7,022,240	£36,289,760	£27,636,048	£6,880,420	£4,706,062	£3,407,838	£0
B	£50,560,128	£80,116,624	£232,254,464	£241,158,721	£60,691,972	£6,653,398	£0
C	£13,342,256				£5,355,174	£1,298,224	£8,925,290
Total	**£70,924,624**	**£116,406,384**	**£259,890,512**	**£248,039,141**	**£70,753,208**	**£11,359,460**	**£8,925,290**

Table 4: National Receptor Database (NRD) total non-residential assets only

	Landslide Reactivation Unit						
	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip
Sub-unit	**NRD total asset count (non-residential)**						
A	10	68	76	30	15	22	3
B	38	67	405	196	152	29	3
C	7				3	7	16
Total	**55**	**135**	**481**	**226**	**170**	**58**	**22**
	Total asset value (non-residential)						
A	£7,022,240	£18,982,336	£21,215,552	£10,320,630	£2,434,170	£3,570,116	£486,834
B	£26,684,512	£18,703,184	£113,056,560	£67,428,116	£24,666,256	£4,706,062	£486,834
C	£4,915,568				£486,834	£1,135,946	£2,596,448
Total	**£38,622,320**	**£37,685,520**	**£134,272,112**	**£77,748,746**	**£27,587,260**	**£9,412,124**	**£3,570,116**

Residential property assets account for an estimated total of **£786,298,619**, whilst non-residential property assets account for an estimated total of **£328,898,198**.

A.7.4 Tourism

The current annual worth of tourism to the economy on the Isle of Wight is estimated to be £550 M. To calculate the contribution of the Study Area towards tourism's annual worth to the island's economy, firstly the NRD was interrogated using the Multi-Coloured Handbook guidelines to provide tourism related asset count for the entire island and for the Study Area. Tourism related asset groups included:

- Retail (including food and drink establishments, shops, markets)
- Leisure (including holiday accommodation, theatres, beach huts)
- Sport (including sports centres, amusements)

To find the proportion of tourism related assets within Ventnor compared to the entire island, the total number of assets within the Study Area are divided by the total number of assets on the island. This proportion is presented as a percentage (Table 5). The contribution to the economy in terms of tourism within the Study Area was estimated to be 5% of the total tourism worth to the economy. This represents £28.7 M annual contribution to the economy.

Table 5: Annual contribution of Study Area to tourism economy on the Isle of Wight

	Tourism related asset count	**Contribution to tourism (%)**	**Contribution to economy (£)**
Isle of Wight	4994	100%	£550,000,000
Study Area	261	5%	**£28,744,493**

The annual worth of tourism for each landslide reactivation sub-unit was calculated by further sub-dividing the tourism related asset counts for each sub-unit and finding the proportions to which each sub-unit contributed to the worth of tourism for the Study Area (Table 6). For example, when totalling all contributions from each sub-unit, this equals £28.7 M. Central Ventnor and Wheelers Bay contribute the greatest to tourism within the Study Area (Table 6).

Table 6: Annual contribution of sub-units in each landslide reactivation unit to tourism economy

	Landslide Reactivation Unit						
	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip
Sub-unit	**Tourism related asset count**						
A	4	10	18	19	5	6	0
B	3	3	138	24	24	3	0
C	0				0	1	3
	Contribution to total (%)						
A	1.53%	3.83%	6.90%	7.28%	1.92%	2.30%	0.00%
B	1.15%	1.15%	52.87%	9.20%	9.20%	1.15%	0.00%
C	0.00%	0.00%	0.00%	0.00%	0.00%	0.38%	1.15%
	Contribution to total (£)						
A	£440,529	£1,101,322	£1,982,379	£2,092,511	£550,661	£660,793	£0
B	£330,396	£330,396	£15,198,238	£2,643,172	£2,643,172	£330,396	£0
C	£0				£0	£110,132	£330,396
Total	**£770,925**	**£1,431,718**	**£17,180,617**	**£4,735,683**	**£3,193,833**	**£1,101,322**	**£330,396**

The estimated total value of tourism assets within the Study Area is **£28,744,493**.

The method used to quantify tourism may favour built-up areas if tourists are drawn to the less developed locations such as those shown below:

- Castle Cove, where there are a number of cottages let out, bathing facilities, tea room and shop.
- Ventnor Park, where the gardens, aviary, bandstand, pond and fish, walks and tea chalet.
- Bonchurch, where there is a pond, tea rooms and access to coastal walks at Horseshoe Bay and Monks Bay.
- The Landslip, where there is and Smugglers tea room

It is possible that benefits could be increased in these LRUs if detailed assessment of tourism is undertaken during OBC stage.

A.7.5 Transport (highways and footpaths)

The value of highways and footpaths were estimated by determining their length within each landslide reactivation sub-unit. This approach utilised GIS vector data provided by the Isle of Wight Council and Ordnance Survey OpenData.

The value of highways and footpaths for the Ventnor Park LRU are published in the 2006 QRA (Halcrow, 2006 – Appendix G, Table G8). This data was uplifted to represent present day values by applying a 3% increase per year (original values were collected in 2005). By dividing the value of highways in Ventnor Park into the total length of highways within Ventnor Park, this provided an estimated value per metre length (Table 7). It is assumed that the value of highways is average across the entire LRU. This was also calculated for footpaths.

Table 7: Estimated value of footpaths and roads

Ventnor Park LRU	Length (m)	Value (£)	Value per metre (£)
Footpaths	3280	£541,585	£165
Roads	8759	£9,898,201	£1,130

To estimate the value of highways and footpaths in all sub-units, their lengths were multiplied by their average value per metre. A summary is provided below for each LRU in Table 8.

Table 8: Asset values for footpaths and roads by LRU

	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip
Length (m)							
Footpaths	3037	3280	2656	1915	2441	1960	2264
Roads	3050	8759	7075	3728	8444	2813	713
Value (£)							
Footpaths	£501,461	£541,585	£438,552	£316,200	£403,051	£323,630	£373,826
Roads	£3,446,685	£9,898,201	£7,995,179	£4,212,866	£9,542,232	£3,178,860	£805,733
LRU total	£3,948,146	£10,439,786	£8,433,730	£4,529,066	£9,945,283	£3,502,490	£1,179,559

The estimated total value of road and footpath assets within the Study Area is **£41,978,060**.

A.7.6 Traffic disruption

Traffic disruption cost estimates were generated for each LRU by modelling the impact of severing the main thoroughfare for traffic to and from the Study Area (Table 9). The B3327 runs north-south from Ventnor to the A3020 near Godshill which carries traffic northward to Newport and the ferry terminals. The B3327 junction is within the headscarp of the Ventnor Park LRU, and landslide reactivation has the potential to result in damage and possible severance of the road. This model represents a worst-case scenario, as the B3327 is a key artery road in the transport network in the Study Area.

The diversion-value method is used to calculate the value of time based solely on the length of the diversion (assuming there is no reduction in traffic speed). It is assumed that vehicles will be diverted onto neighbouring roads and therefore the distance that they will travel will increase. According to the Highways Agency data and Department for Transport estimate of the values associated with travellers' time, a single car delay of one hour on a motorway or trunk road will cost the UK £11.90. The average speed for detouring vehicles has been estimated at 50 km/hr given the nature of the roads.

Increases to distances travelled via diversions were determined for each LRU. For LRUs east of the B3327 junction, all vehicles were diverted eastwards via Leeson Road to Shanklin, and back to the B3327 at Wroxall. For LRUs west of the B3327 junction, all vehicles were diverted westwards via Whitwell Road and back towards the B3327 at Wroxall via the A3020. At Ventnor Park, diversions were split at the junction between Ocean View Road, Gill's Cliff Road and the B3327.

Traffic counts were provided by the Isle of Wight Council showing the eastwards and westwards vehicle counts on Leeson Road, Ocean View Road and Gill's Cliff Road. The total counts for each day were averaged across the week and divided by 24 hours to represent an hourly average traffic count for the given road. For LRUs east of the B3327, traffic counts westbound on Leeson Road were used, however in Ventnor Park westbound traffic on Ocean View Road were used. For LRUs to the west of the B3327, traffic counts eastbound on Gill's Cliff Road were used. These counts represent the traffic volumes that are to be diverted.

The average time delay per hour was calculated by multiplying the added diversion distance by the average speed (50 km/hr). The cost of the delay to all vehicles per hour was calculated as:

*Traffic count (/hr) * Average delay (hr) * Cost of delay per vehicle (£/hr)*

This result is then multiplied by the number of hours the traffic disruption lasts, which is until the road is again fully operational. In this instance, it was assumed the road would be closed for a year until repairs are made.

Table 9: Traffic disruption costs

Landslide Reactivation Unit (LRU)	Diversion direction	Diversion distance (km)	Average Speed (km/hr)	Traffic count per hour	Average Delay Time (hr)	Cost of Delay per Vehicle (£/hr)	Cost of delay to all vehicles per hour (£)	Cost of delay to all vehicles over time * (£)
Castle Cove	West	8.6	50	52	0.172	£11.90	£106.35	£929,059
Ventnor Park	West	9.4	50	52	0.188	£11.90	£116.24	£1,015,483
Ventnor Park	East	8.8	50	83	0.176	£11.90	£173.66	£1,517,100
Central Ventnor	East	8.2	50	92	0.164	£11.90	£180.28	£1,574,918
Wheelers Bay	East	7	50	92	0.140	£11.90	£153.90	£1,344,442
Bonchurch West	East	6.2	50	92	0.124	£11.90	£136.31	£1,190,791
Bonchurch East	East	5	50	92	0.100	£11.90	£109.93	£960,316
The Landslip	East	4.6	50	92	0.092	£11.90	£101.13	£883,490
Total:								**£9,415,599**

* Duration of disruption 8736 hours (i.e. a year)

The estimated total value of traffic disruption costs within the Study Area is **£9,415,599**.

A.7.7 Utilities and Services

Estimating the losses to electricity, gas, telecommunications, water and water treatment assets caused by the direct damaged and disruption to supply requires detailed analysis of datasets, which are currently unavailable.

Direct damages are highly variable depending on the configuration and siting of equipment, and site surveys and further discussions with infrastructure owners would be required to assess these. The cost of disruption to services may be estimated by the number of properties served by the infrastructure and estimated duration of disruption to supply and associated costs to these. Partial datasets were available and were considered unsuitable for effective interrogation. A summary of the utilities data is provided below (Table 10).

Table 10: Utilities and service providers data

Asset	Provider	Data format
Electricity	Southern Electric	Currently unavailable
Gas	SGN	Mapped assets, .jpeg but no values
Water and water treatment	Southern Water	Maps of key assets provided (listed below). Asset values currently unavailable. https://www.southernwater.co.uk/mains-and-sewer-maps
Telecommunications	BT Openreach	Mapped assets, .jpeg but no values

Southern water infrastructure includes assets at Lions Point (Ventnor Harbour Pumping Station), and also assets east of Wheelers Bay, Bonchurch, Eastern Esplanade, Flowers Brook and Steephill Cove.

The replacement value of utilities and services (gas, electricity and water only) due to direct damage from instability for the Ventnor Park LRU is published in the 2006 QRA (Halcrow, 2006 – Appendix G, Table G8). The ratio of the value of each of these assets to the value of properties at Ventnor Park had been calculated and is shown in Table 11, using present day property and asset values. The combined ratio for gas, electricity and water value to property value is 0.12, and this ratio is applied to the property values in all other LRUs to estimate combined utility values. This calculation assumes the comparable property value to utility value ratios apply across the entire Study Area which is unlikely to be true throughout.

Table 11: Utilities and services asset value in Ventnor Park (adapted from Halcrow, 2006)

Ventnor Park LRU	Gas	Electricity	Water	Combined
Present Day Replacement Value (£)	£2,689,393	£3,551,428	£12,735,830	£18,976,651
Property Value (£)	£154,091,904	£154,091,904	£154,091,904	£154,091,904
Ratio	0.02	0.02	0.08	0.12

Estimates for each LRU are presented in Table 12 below. It is important to note that the utilities and services values specific to each LRU other than Ventnor Park should be sought from suppliers and used for schemes to be carried forward.

Table 12: Utilities and services asset values by LRU

LRU	Castle Cove	Ventnor Park	Central Ventnor	Wheelers Bay	Bonchurch West	Bonchurch East	The Landslip
Property Value (£)	£109,546,944	£154,091,904	£394,162,624	£325,787,887	£98,340,468	£20,771,584	£12,495,406
Gas (£)	£2,190,939	£3,081,838	£7,883,252	£6,515,758	£1,966,809	£415,432	£249,908
Electricity (£)	£2,190,939	£3,081,838	£7,883,252	£6,515,758	£1,966,809	£415,432	£249,908
Water	£8,763,756	£12,327,352	£31,533,010	£26,063,031	£7,867,237	£1,661,727	£999,632
Combined	£13,145,633	£18,491,028	£47,299,515	£39,094,546	£11,800,856	£2,492,590	£1,499,449

The estimated total value of utility costs within the Study Area is **£133,823,618**.

A.7.8 Emergency services

The costs incurred by the local authority, police, ambulance, fire service and others during the response and recovery in the event of a landslide has been estimated based on the value of the commercial and residential properties in each LRU.

The Multi-coloured Manual (MCM) Handbook (2010) guidance states that in relation to project appraisals of flood alleviation schemes, between 5.6% to 10.7% of the total property damages reflect the costs of emergency and recovery that are not counted elsewhere in the consequence model. Guidance on landslide hazard and coastal erosion is unavailable, therefore the lower bound of percentage of the total property losses (5.6%) has been applied as a general multiplier to give an estimate for cost of emergency responses of **£62,451,022**. This is not applied to the creep scenarios as creep does necessitate emergency response.

A.7.9 Types of Asset Not Included in the Consequence Model

Several assets listed in the Multi-coloured Manual (MCM) Handbook (2010) have not been included in the consequence model due to the need for further data and detailed analysis of these datasets should they become available. Assets not included in this model are:

- Education and health
- Public amenity and value of enjoyment

A summary of all NRD counts are included in Table 13 below for reference.

Table 13: Summary of NRD counts by pre-defined categories. Miscellaneous items include the following: Car Park, Public Convenience, Cemetery, Bus Station, Electrical-Substation.

Landslide Reactivation Unit	Residential	Retail	Offices	Warehouses	Leisure	Sport	Public buildings	Industry	Miscellaneous	Non-residential Assets (>25 km^2)	Grand total
Castle Cove									0		
A	10	1			3				3	3	20
B	72	1			2				18	17	110
C	19								4	3	26
Castle Cove Total	101	2			5				25	23	156
Ventnor Park									0		
A	130	3	1		7		1	1	39	16	198
B	287	1		1	2		1		45	17	354
Ventnor Park Total	417	4	1	1	9		2	1	84	33	552
Central Ventnor									0		
A	99	9	1		9			1	37	19	175
B	832	130	4		7	1	14	4	174	71	1237
Central Ventnor Total	931	139	5		16	1	14	5	211	90	1412
Wheelers Bay									0		
A	20	2			17				6	5	50
B	701	11			8	5	10	9	112	41	897
Wheelers Bay Total	721	13			25	5	10	9	118	46	947
Bonchurch West									0		
A	29	3				2			7	3	44
B	374	12			12		2	1	77	48	526
C	33						1		2		36
Bonchurch West Total	436	15			12	2	3	1	86	51	606
Bonchurch East											
A	21	4			2				14	2	43
B	41	2		1	1		1		8	16	70
C	8				1				3	3	15
Bonchurch East Total	70	6		1	4		1		25	21	128
The Landslip									0		
A									3		3
B									3		3
C	55	1			2			1	5	7	71
The Landslip Total	55	1			2			1	11	7	77
Grand Total	**2731**	**180**	**6**	**2**	**73**	**8**	**30**	**17**	**560**	**271**	**3878**

A.7.10 References

FCERM-AG 2010. Flood and Coastal Erosion Risk Management Appraisal Guidance. Environment Agency.

Halcrow Group Ltd (2006). Ventnor Undercliff, Isle of Wight, Coastal Instability Risk: Interpretative Report and Quantitative Risk Analysis. Technical Report to the Isle of Wight Council.

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Multi-coloured Manual 2005. The Benefits of Flood and Coastal Risk Management: A Manual of Assessment Techniques. Penning-Roswell, E. Johnson, SC. Tunstall, S. Tapsell, S. Morris, J. Chatterton, J. Green, C. Flood Hazard Research Centre.

Multicoloured Manual Supplementary Note 2010. The Benefits of Flood and Coastal Risk Management: A Handbook of Assessment Techniques. Flood Hazard Research Centre.

Appendix 8. Coastal defence options

Introduction

This appendix presents the management options identified for each of the shoreline coastal defences. Each shoreline Defence Unit also incorporates the shoreline structure (seawalls, revetment etc), beach control structures (groynes), offshore structures (breakwaters) and set-back defence elements (set back flood walls/gabions etc) associated with providing the standard of protection for each Defence Unit.

All capital and maintenance costs provided in this Appendix are cash costs without optimism bias. Section 5.2.3 of the main report provide the cost sources.

Improve Options 1, 2 and 3 included in the tables are not the same as Improve Options A, B and C in the main report and Appendix 9. Improve Options 1, 2 & 3 relate to specific engineering intervention alternatives at a given Defence Unit (which typically comprises several individual engineering assets, or structures). Those engineering options that are considered most suitable to take forward have been identified within the tables.

Options A, B and C in Appendix 9 relate to those shortlisted options (from Option 1, 2 & 3) or combination of options that will comprise a programme of work for the wider LRU. The differences between Options A, B, and C are specified in each table below, for clarity. In some cases, Options B and C are identical for the various Defence Units and in some cases they are identical for the wider LRU programme of works. In some cases, Option C is the same as Option B but with an earlier intervention date. The economic assessment and the Partnership Funding calculator use Options A, B and C, looking strategically at the programme of works for the wider LRU.

In each table below the probabilities in **green** have been identified as the weakest link within each landslide unit for the **Do Nothing** option. This weakest link is used for the QRA analysis. Similarly, the **purple** text highlights the **Do Minimum** weakest link within that landslide unit.

For the Improve options (Improve A, B & C), these have a programme of capital coastal defence works being implemented at various points over the appraisal period. Hence, the weakest link at any given time is adopted, identified by **red** text for the **Improve** option. This weakest link for the Improve option can vary over time, as capital schemes are implemented at various points over the economic appraisal. As a defence is improved, the next weakest link is adopted for the failure probability (which will have been deteriorating over this time as per the increase in failure probability identified for that defence).

Coastal Defence Options

Defence Unit ID	**IW 36 / 001**	*Description*	**Castle Cove**		*Length*	**231m**	*Condition Grade*	**2 (good)**
Landslide Unit: Castle Cove								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath		Yes (as baseline)	N/A	0	0	0.005	2.5
Do Minimum	Monitor, patch repairs, local repair around steps if movement continues		Yes.	Annual	N/A	2	0.005	2.5
Improve 1	As above, repair rock if movement		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Every 20yrs from Yr 40 for rock repairs	N/A	27	0.005	1
Improve 2	Rebuild/strengthen revetment, seawall and gabions		Yes. Improve B. Timing brought forward for Improve C	Rebuild in **Yr 60** or **Yr 40** for Improve C. Every 20yrs from Yr 40 for rock repairs	4.0	914	0.005	0
Improve 3	N/A		No					
Notes	Monitoring and repairs only required for foreseeable future as structures are in good condition.							
Link to geomorphology	The revetment structure is providing a significant contribution as toe weight for the cliffs and also serves to protect the cliff toe from erosion. In the event of failure of the rock structure, this would likely be localised, but could initiate a landslide. However, even in a failed state, these structures would continue to provide toe weight and protection until such point that they break up into small enough components to be removed from the area, or allow the fines from the structure behind to be lost. As such, this would be a slow increase in landslide risk.							

Defence Unit ID	**IW 36 / 002**	*Description*	**Steephill Cove – terminal groyne**		*Length*	**7m**	*Condition Grade*	**1 (very good)**
Landslide Unit: Castle Cove								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	N/A		Yes (as baseline)	N/A	0	0	0.005	2.5
Do Minimum	Monitor		Yes	Annual	N/A	0.5	0.005	2.5
Improve 1	As above, repair rock if movement		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Every 20yrs from Yr 40 for rock repairs	N/A	13	0.005	1
Improve 2	As Improve 1 and rebuild/strengthen groyne		Yes. Improve B. Timing brought forward for Improve C	Rebuild in **Yr 60** or **Yr 40** for Improve C. Every 20yrs from Yr 40 for rock repairs	N/A	390	0.005	0
Improve 3	N/A		No					
Notes	Monitoring and repairs only required for foreseeable future as structures are in good condition.							
Link to geomorphology	The terminal structure is providing an important coast defence function in protecting the shoreline structures either side (Castle Cove and Steephill Cove) through stabilisation of the bays and reducing direct wave attack where the coastal defences meet at this SW corner. The rock structure is also providing some contribution as toe weight for these structures, hence the cliffs. In the event of failure of the rock structure, the likelihood of failure of the adjacent structures would increase.							

Defence Unit ID	**IW 36 / 003**	*Description*	**Steephill Cove – eastern section**		*Length*	**60m**	*Condition Grade*	**2 (good)**
Landslide Unit: Castle Cove								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath		Yes (as baseline)	N/A	0	0	0.005	5
Do Minimum	Monitor, with repairs to concrete seawall.		Yes	Annual	N/A	1	0.005	2.5
Improve 1	As above, re-position and/or top up rock if movement		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Every 20yrs from Yr 40 for rock repairs	N/A	28	0.005	1
Improve 2	As Improve 1, rebuild/strengthen wall and rock structure and recharge with beach material		Yes. Improve B. Timing brought forward for Improve C	Rebuild in **Yr 60** or **Yr 40** for Improve C. Every 20yrs from Yr 40 for rock repairs and beach recharge	7.4	446	0.005	0
Improve 3	N/A		No					
Notes	Monitoring and repairs only required for foreseeable future as structures are in good condition.							
Link to geomorphology	The revetment structure is providing contribution as toe weight for the cliffs and also serves to protect the cliff toe from erosion. In the event of failure of the rock structure, this would likely be localised, but could initiate a landslide. However, even in a failed state, these structures would continue to provide toe weight and protection until such point that they break up into small enough components to be removed from the area, or allow the fines from the structure behind to be lost. As such, this would be a slow increase in landslide risk.							

Defence Unit ID	**IW 36 / 004**	*Description*	**Steephill Cove – central section**		*Length*	**51m**	*Condition Grade*	**1 (very good)**
Landslide Unit: Castle Cove								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath		Yes (as baseline)	N/A	0	0	0.005	5
Do Minimum	Monitor, with repairs to concrete seawall.		Yes	Annual	N/A	1	0.005	2.5
Improve 1	As above, re-position and/or top up rock if movement		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Every 20yrs from Yr 40 for rock repairs	N/A	28	0.005	1
Improve 2	As Improve 1, rebuild/strengthen wall and rock and recharge with beach material		Yes. Improve B. Timing brought forward for Improve C	Rebuild in **Yr 60** or **Yr 40** for Improve C. Every 20yrs from Yr 40 for rock repairs and beach recharge	7.4	379	0.005	0
Improve 3	N/A		No					
Notes	Monitoring and repairs only required for foreseeable future as structures are in good condition.							
Link to geomorphology	The revetment structure is providing contribution as toe weight for the cliffs and also serves to protect the cliff toe from erosion. In the event of failure of the rock structure, this would likely be localised, but could initiate a landslide. However, even in a failed state, these structures would continue to provide toe weight and protection until such point that they break up into small enough components to be removed from the area, or allow the fines from the structure behind to be lost. As such, this would be a slow increase in landslide risk.							

Defence Unit ID	**IW 36 / 005**	*Description*	**Steephill Cove – rock groyne**		*Length*	**23m**	*Condition Grade*	**2 (good)**
Landslide Unit: Castle Cove								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath and evacuation of property		Yes (as baseline)	N/A	0	0	0.01	5
Do Minimum	Monitor		Yes	Annual	N/A	0.5	0.01	2.5
Improve 1	As above, repair rock if movement		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Every 20yrs from Yr 40 for rock repairs/additional rock at toe	N/A	27	0.01	1
Improve 2	As Improve 1 and rebuild/strengthen groyne and wall		Yes. Improve B. Timing brought forward for Improve C	Rebuild in **Yr 60** or **Yr 40** for Improve C. Every 20yrs from Yr 40 for rock repairs/additional rock at toe	N/A	490	0.005	0
Improve 3	N/A		No					
Notes	Monitoring and repairs only required for foreseeable future as structures are in good condition.							
Link to geomorphology	The rock structure is providing a sheltering effect and stabilising beach levels. In combination with the concrete structures is if proving some toe weight for the cliffs and also serves to protect the cliff toe from erosion. In the event of failure of these structure, they would likely continue to provide toe weight/protection. Eventually, as the materials further break up then there would likely be an increased risk of initiating a landslide.							

Defence Unit ID	**IW 36 / 006**	*Description*	**Steephill Cove – western section**		*Length*	**21m**	*Condition Grade*	**2 (good)**
Landslide Unit: Castle Cove								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath and evacuation of property		Yes (as baseline)	N/A	0	0	0.01	5
Do Minimum	Monitor, patch repairs		Yes	Annual	N/A	1	0.01	2.5
Improve 1	As above, adding rock to toe if required		Yes (also used in Improve 2 option prior to capital scheme). Improve A.	Every 20yrs from Yr 20 for rock repairs/additional rock at toe	N/A	14	0.01	1
Improve 2	As Improve 1 and rebuild wall with rock at toe		Yes. Improve B. Timing brought forward for Improve C	Rebuild in **Yr 60** or **Yr 40** for Improve C. Every 20yrs from Yr 20 for rock repairs/additional rock at toe	5.4	114	0.005	0
Improve 3	N/A		No					
Notes	Monitoring and repairs only required for foreseeable future as structures are in good condition.							
Link to geomorphology	The structure is providing contribution as toe weight for the cliffs and also serves to protect the cliff toe from erosion. In the event of failure of the structure, this would likely be localised, but could initiate a landslide.							

Defence Unit ID	**IW 36 / 007**	*Description*	**Steephill Cove – western property wall**		*Length*	**10m**	*Condition Grade*	**2 (good)**
Landslide Unit: Castle Cove								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Evacuation of property		Yes (as baseline)	N/A	0	0	0.01	5
Do Minimum	Monitor, patch repairs		Yes	Annual	N/A	1	0.01	2.5
Improve 1	As above, adding additional rock to toe if required		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Every 20yrs from Yr 20 for rock repairs/additional rock at toe	N/A	8	0.01	1
Improve 2	As Improve 1 and rebuild wall with rock at toe		Yes. Improve B. Timing brought forward for Improve C	Rebuild in **Yr 60** or **Yr 40** for Improve C.. Every 20yrs from Yr 20 for rock repairs/additional rock at toe	5.4	54	0.005	0
Improve 3	N/A		No					
Notes	Monitoring and repairs only required for foreseeable future as structures are in good condition.							
Link to geomorphology	The structure is providing contribution as toe weight for the cliffs and also serves to protect the cliff toe from erosion. In the event of failure of the structure, this would likely be localised, but could initiate property failure, which could in turn initiate a landslide.							

Defence Unit ID	**IW 36 / 008**	*Description*	**Steephill Cove – western cliffs**		*Length*	**81m**	*Condition Grade*	**2 (good)**
Landslide Unit: Castle Cove								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Manage public H&S		Yes (as baseline)	N/A	0	0	0.01	5
Do Minimum	Monitor, patch repairs		Yes	Annual	N/A	1	0.01	2.5
Improve 1	As above, adding additional rock to toe if required		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Every 20yrs from Yr 40 for rock repairs/additional rock at toe	N/A	28	0.01	1
Improve 2	As Improve 1 and rebuild wall and revetment at end of serviceable life		Yes. Improve B. Timing brought forward for Improve C	Rebuild in **Yr 60** or **Yr 40** for Improve C. Every 20yrs from Yr 40 for rock repairs/additional rock at toe	3.4	278	0.005	0
Improve 3	N/A		No					
Notes	Monitoring only required for foreseeable future as structures are in good condition.							
Link to geomorphology	The structure is providing contribution as toe weight for the cliffs and also serves to protect the cliff toe from erosion. In the event of failure of the structure, this would likely be localised and the rock would continue to provide protection. Over time, the defences would further break up, increasing overtopping rates and allow the cliff toe erosion to re-commence, which could in turn initiate a landslide.							

Defence Unit ID	**IW 35 / 002**	*Description*	**Spyglass Inn**	*Length*	**84m**	*Condition Grade*	**2 (good)**
Landslide Unit: Ventnor Park							
Option	**Description of option**	**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of pub on eventual structure failure	Yes (as baseline)	N/A	0	0	0.01	5
Do Minimum	Monitor with minor repairs	Yes	Annual	N/A	2	0.01	2.5
Improve 1	As above, place additional rock in front of sections of wall that become vulnerable	Yes (also used in Improve 2 option prior to capital scheme). Improve A	Additional rock and rock repairs every 20yrs from Yr 20	N/A	28	**0.01**	**1**
Improve 2	Concrete repairs and then strengthening to structures at end of serviceable life	Yes. Improve B. Timing brought forward for Improve C	Rock repairs every 20yrs from Yr 20 and upgrade in **Yr 60.** Bring forward to **Yr 40** for Improve C.	7.9	665	**0.005**	**0**
Improve 3	N/A	No					
Notes	Monitoring and repairs only required for foreseeable future as structures are in good condition.						
Link to geomorphology	The structure is providing a contribution as toe weight for the cliffs with moderate relative retained height. In the event of failure of the seawall the failed structure and the hinterland/pub structure would continue to provide toe support. As the failed structure breaks up further there would be increased overtopping and loss of mass of the structure, toe and hinterland, which would reduce cliff toe weight and eventually expose the base of the cliff. This would present an increased risk of landslide reactivation but this is unlikely to rapidly increase the risk of to a critical point.						

Defence Unit ID	**IW 35 / 003**	*Description*	**Western cliffs – eastern section**	*Length*	**12m**	*Condition Grade*	**4 (poor)**
Landslide Unit: Ventnor Park							
Option	**Description of option**	**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath, car park and pub on structure failure	Yes (as baseline)	N/A	0	0	0.05	5
Do Minimum	Monitor with minor repairs	Yes	Annual	N/A	1	0.05	2.5
Improve 1	As above, with wall drainage added	Yes (also used in Improve 2 option prior to capital scheme). Improve A	Drainage added Yr 3 and repaired every 20yrs from yr 30	N/A	25/13	0.02	1
Improve 2	Rebuild encasement with drainage and increased rock revetment levels	Yes. Improve B and Improve C	Upgrades in **Yr 3** and rebuilt in Yr 60.	11.4	137	0.005	0
Improve 3	N/A	No					
Notes	Monitoring required to assess the drainage issues and identify suitable solutions. Large scale re-building may not be required if the existing structure can be stabilised.						
Link to geomorphology	The structure is providing a small contribution as toe weight for the cliffs with high relative retained height. In the event of failure large scale failure could be expected, which could be rapid. Failure would present a much elevated risk of landslide reactivation.						

Defence Unit ID	**IW 35 / 004**	*Description*	**Western Cliffs – below car park**		*Length*	**104m**	*Condition Grade*	**2 (good)**
Landslide Unit: Ventnor Park								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath, car park and beach access on structure failure		Yes (as baseline)	N/A	0	0	0.01	5
Do Minimum	Monitor with repairs to seawall rendering		Yes	Annual	N/A	2	0.01	2.5
Improve 1	As above, with additional rock added to the revetment as required		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Every 20yrs from Yr 40 for toe rock	N/A	55	0.01	1
Improve 2	Rebuild seawall and increased rock revetment levels		Yes. Improve B. Timing brought forward for Improve C	Rebuild in **Yr 60** – brought forward to **Yr 40** for Improve C.	7.4	774	0.005	0
Improve 3	N/A		No					
Notes	Loss of rendering will allow accelerated degradation of the seawall, but its function is less critical due to the rock revetment, so a full seawall improve option is unlikely to be justified in the short/medium.							
Link to geomorphology	The structure is providing a small contribution as toe weight for the cliffs with high relative retained height. In the event of failure large scale failure could be expected, which could be rapid, but may result in local cliff falls only. Failure would present a much elevated risk of landslide reactivation.							

Defence Unit ID	**IW 35 / 005**	*Description*	**Western Cliffs – central & western section**		*Length*	**615m**	*Condition Grade*	**2 (good)**
Landslide Unit: Ventnor Park								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure/diversion of footpath		Yes (as baseline)	N/A	0	0	0.01	2.5
Do Minimum	Monitor		Yes	Annual	N/A	1	0.01	2.5
Improve 1	As above, re-position and/or top up rock if movement		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Every 20yrs from Yr 60 for additional toe rock and groyne repairs	N/A	82	0.01	1
Improve 2	Rebuild/strengthen groynes and increased rock revetment levels		Yes. Improve B and C	Rebuild in **Yr 60**. Every 20yrs from Yr 60 for additional toe rock and groyne repairs	N/A	1804	0.005	0
Improve 3	N/A		No					
Notes	Monitoring only required for foreseeable future as structures are in good condition.							
Link to geomorphology	The revetment structure is providing a contribution as toe weight for the cliffs but the main function is to protect the cliff toe from erosion. In the event of failure of the rock structure, this would likely be localised, but could initiate a landslide should erosion of a vulnerable section of cliff occur.							

Defence Unit ID	**IW 33 / 002**	*Description*	**Eastern cliffs – western section**	*Length*	**181m**	*Condition Grade*	**5 (very poor)**

Landslide Unit: Central Ventnor							
Option	**Description of option**	**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath	Yes (as baseline)	N/A	0	0	**0.2**	**5**
Do Minimum	Monitor, patch repairs to prevent further material loss and occasional rock placement at toe	Yes	Annual.	N/A	5	**0.2**	**2.5**
Improve 1	Replace structure with new rock revetment with concrete upper seawall	Yes. Improve A, Improve B and Improve C	Capital works in **Yr 3.** From Yr 60, every 20yrs rock repairs for Improve A. Rebuild in Yr 70 for Improve B and Improve C	21	3,801	0.005	0
Improve 2	Rebuild toe and lower apron and protect lower toe with low rock revetment	No					
Improve 3	N/A						
Notes	Retaining slipway access may prove difficult with any repair/strengthen options. Improve 1 option is expected to be the most likely improve option, and it could have various viable sub-options with different toe/ revetment/ seawall configurations. Improve 2 may not be viable due to the following reasons 1) removal of toe could initiate failure of upper revetment, 2) foreshore is protected under SAC, so further loss of foreshore may be resisted, 3) voids may extend under the main structure, 4) concrete testing may show that main structure is seriously compromised and 5) wall movements that have been identified are too excessive and the structure is too compromised. This option may not be viable if there is any failure of the upper structure prior to construction.						
Link to geomorphology	The structure is directly protecting the toe of the lower chalk and upper greensand cliffs. This coastal structure has a high overall retained height, but the structure has a relatively wide footprint (revetment profile). Its overall retained height and loading from the cliff system, puts it at high risk of a fairly rapid failure, which would quickly extend from a localised point. However, the failed concrete structure would continue to provide some toe support and some wave protection due to its revetment profile. As the failed structure breaks up further there would be increased overtopping and loss of fines reducing the cliff toe weight and expose the base of the cliff. This would present an increased risk of landslide reactivation but this may take time to reach a critical point.						
Defence Unit ID	**IW 34 / 001**	*Description*	**Eastern Esplanade**	*Length*	**263m**	*Condition Grade*	**2 (good)**

Landslide Unit: Central Ventnor							
Option	**Description of option**	**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of esplanade and road/parking on eventual structure failure	Yes (as baseline)	N/A	0	0	0.005	2.5
Do Minimum	Monitor with minor repairs	Yes	Annual	N/A	2	0.005	2.5
Improve 1	As above, and rock repairs	Yes (also used in Improve 2 option prior to capital scheme). Improve A	Rock repairs every 20yrs from Yr 40	N/A	43	0.005	1
Improve 2	As above and significant repairs/strengthening to structures at end of serviceable life	Yes. Improve B and Improve C	Rock repairs Yr 40 and upgrade in Yr 60	N/A	1,000	0.005	0
Improve 3	N/A	No					
Notes	Monitoring only required for foreseeable future as structures are in very good condition.						
Link to geomorphology	The structure is directly protecting the toe of the lower chalk and upper greensand cliffs. This coastal structure has a relatively high overall retained height, but the structure has a relatively wide footprint with significant rock fronting the structure in a revetment profile. Its overall retained height and loading from the cliff system, puts it at increased risk of a fairly rapid failure, which would quickly extend from a localised point. However, the cliff is set back behind the car park and the failed concrete structure in combination with the rock revetment units would continue to provide toe support and some wave protection. As the failed structure breaks up further there would be increased overtopping and loss of fines reducing the mass of the car park and the cliff toe weight and eventually expose the base of the cliff. This would present an increased risk of landslide reactivation but this may take time to reach a critical point.						

Defence Unit ID	**IW 34 / 002**	*Description*	**Ventnor Haven - breakwaters**		*Length*	**504m**	*Condition Grade*	**1 (very good)**
Landslide Unit: Central Ventnor								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of harbour on eventual structure failure		Yes (as baseline)	N/A	0	0	0.005	2.5
Do Minimum	Monitor with minor repairs		Yes	Annual	N/A	2	0.005	2.5
Improve 1	As above, and rock repairs		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Rock repairs every 20yrs from Yr 40	N/A	86	0.005	1
Improve 2	Significant repairs/strengthening to structures at end of serviceable life		Yes. Improve B and Improve C	Rock repairs Yr 40 and upgrade in **Yr 60**	N/A	1,200	0.005	0
Improve 3	N/A		No					
Notes	Monitoring and repairs only required for foreseeable future as structures are in very good condition.							
Link to geomorphology	No direct link to cliff geomorphology, but failure of these structures would expose the inner harbour walls, which would then link to the cliff stability							

Defence Unit ID	**IW 34 / 003**	*Description*	**Ventnor Haven – pumping station**	*Length*	**38m**	*Condition Grade*	**1 (very good)**
Landslide Unit: Central Ventnor							
Option	**Description of option**	**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of pumping station on eventual structure failure	Yes (as baseline)	N/A	0	0	0.005	2.5
Do Minimum	Monitor with minor repairs	Yes	Annual	N/A	1	0.005	2.5
Improve 1	As above, and rock repairs	Yes (also used in Improve 2 option prior to capital scheme). Improve A	Rock repairs every 20yrs from Yr 40	N/A	27	0.005	1
Improve 2	Significant repairs/strengthening to structures at end of serviceable life	Yes. Improve B and Improve C	Rock repairs every Yr 40 and upgrade in **Yr 60**	N/A	200	0.005	0
Improve 3	N/A	No					
Notes	Monitoring only required for foreseeable future as structures are in very good condition.						
Link to geomorphology	Due to the bulk of engineered material comprising this area, even following failure of the coastal defences there would be significant protection to the cliffs. Hence, there is considered no direct link to cliff geomorphology.						

Defence Unit ID	**IW 34 / 004**	*Description*	**Ventnor Haven – stepped revetment**		*Length*	**29m**	*Condition Grade*	**1 (very good)**
Landslide Unit: Central Ventnor								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of pumping station and promenade on eventual structure failure		Yes (as baseline)	N/A	0	0	0.005	2.5
Do Minimum	Monitor with minor repairs		Yes	Annual	N/A	1	0.005	2.5
Improve 1	As above, reactive beach recycling and concrete repairs		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Beach recycling every 10 years covered in 35/001. Concrete repairs every 20yrs from Yr 20	N/A	20	0.005	1
Improve 2	Reactive beach recycling, concrete repairs and strengthening to structures at end of serviceable life		Yes. Improve B and Improve C.	Beach recycling every 10 years covered in 35/001. Concrete repairs every 20yrs from Yr 20 and upgrade in Yr 60	N/A	200	0.005	0
Improve 3	N/A		No					
Notes	Monitoring, beach recycling and repairs only required for foreseeable future as structures are in very good condition.							
Link to geomorphology	Due to the bulk of engineered material comprising this area, even following failure of the coastal defences there would be significant protection to the cliffs. Hence, there is considered no direct link to cliff geomorphology.							

Defence Unit ID	**IW 35 / 001**	*Description*	**Ventnor Bay**		*Length*	**302m**	*Condition Grade*	**2 (good)**
Landslide Unit: Central Ventnor								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of esplanade and road/parking on eventual structure failure		Yes (as baseline)	N/A	0	0	0.01	2.5
Do Minimum	Monitor with minor repairs and local beach recycling to manage H&S		Yes	Annual	N/A	3	0.01	2.5
Improve 1	As above, reactive beach recycling and concrete repairs		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Beach recycling every 10 years. Concrete repairs every 20yrs from Yr 20	N/A	46/66	**0.01**	**1**
Improve 2	Reactive beach recycling, concrete repairs and strengthening to structures at end of serviceable life		Yes. Improve B and Improve C	Beach recycling every 10 years. Concrete repairs every 20yrs from Yr 20 and upgrade in **Yr 60**	N/A	500	**0.005**	**0**
Improve 3	N/A		No					
Notes	Monitoring only required for foreseeable future as structures are in very good condition. Rock revetment is not deemed appropriate along the back of this popular accessible public beach area.							
Link to geomorphology	The structure is providing a small contribution as toe weight for the cliffs, but this is marginal as retained heights are not significant and the cliffs are set back from the shoreline. In the event of failure of the seawall the failed structure and the promenade/road would continue to provide toe support. As the failed structure breaks up further there would be increased overtopping and loss of mass of the promenade/road, which would reduce cliff toe weight and eventually expose the base of the cliff. This would present an increased risk of landslide reactivation but it would likely be a slow process to reach a critical point. Significant ground movements occurred in this area in 1960/61.							

Defence Unit ID	**IW 32 / 001**	*Description*	**Wheelers Bay – eastern section**		*Length*	**133m**	*Condition Grade*	**2 (good)**
Landslide Unit: Wheelers Bay								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath and closure of slipway and boat park on failure of revetment		Yes (as baseline)	N/A	0	0	0.2	5
Do Minimum	Monitor, patch repairs to prevent further material loss and rock at toe		Yes	Annual	N/A	5	0.2	2.5
Improve 1	Replace structure with new rock revetment with concrete upper seawall		Yes. Improve A, Improve B and Improve C	Capital works in Yr 3 Every 20yrs rock repairs from Yr 50. Strengthening rock works in Yr 70 for Improve B and Improve C	21	2,793	0.005	0
Improve 2	Rebuild toe and lower apron and protect lower toe with low rock revetment		No					
Improve 3	N/A		No					
Notes	Retaining slipway access may prove difficult with any repair/strengthen options, which could force re-build options. Improve 1 option could have various viable sub-options with different toe/ revetment/ seawall configurations Improve 2 may not be viable due to the following reasons 1) removal of toe could initiate failure of upper revetment, 2) voids may extend under the main structure and 3) concrete testing may show that main structure is seriously compromised. This option may not be viable if there is any failure of the upper structure prior to construction.							
Link to geomorphology	Coastal structure protects toe of lower chalk and upper greensand cliffs. Failure of the structure could occur very quickly and the failure would quickly extend from a localised point. The failed concrete structure would continue to provide some toe support and some wave protection but increased overtopping and loss of fines would continue to reduce the cliff toe weight and expose the base of the cliff. This will relatively quickly increase the risk of landslide reactivation.							

Defence Unit ID	**IW 32 / 002**	*Description*	**Wheelers Bay – western section**		*Length*	**90m**	*Condition Grade*	**1 (very good)**
Landslide Unit: Wheelers Bay								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath on eventual structure failure		Yes (as baseline)	N/A	0	0	0.005	2.5
Do Minimum	Monitor, patch repairs		Yes	Annual	N/A	1	0.005	2.5
Improve 1	As above, and rock repairs		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Rock repairs every 20yrs from Yr 40	N/A	43	0.005	1
Improve 2	Significant repairs/strengthening to structures at end of serviceable life		Yes. Improve B and Improve C	Rock repairs Yr 40 and upgrade in Yr 60	N/A	1000	0.005	0
Improve 3	N/A		No					
Notes	Monitoring and repairs only required for foreseeable future as structures are in very good condition.							
Link to geomorphology	Coastal structure protects toe of lower chalk and upper greensand cliffs. Failure of the structure would likely occur relatively slowly due to the large quantities of rock, so low risk of landslide reactivation.							

Defence Unit ID	**IW 32 / 003**	*Description*	**Wheelers Bay - point**		*Length*	**60m**	*Condition Grade*	**2 (good)**
Landslide Unit: Wheelers Bay								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath on eventual structure failure		Yes (as baseline)	N/A	0	0	0.01	2.5
Do Minimum	Monitor, patch repairs		Yes	Annual	N/A	1	0.01	2.5
Improve 1	As above, and rock repairs		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Rock repairs every 20yrs from Yr 40	N/A	55	**0.01**	**1**
Improve 2	Increase rock protection at the toe to create a full rock revetment and concrete seawall strengthening. Note: Low capital cost for brought forward element for Improve C, so does not impact on benefits period.		Yes. Improve B and Improve C	Rock repairs Yr. 40 and upgrade in **Yr 60 .** Upgrade brought forward to **Yr 20** for Improve C	13	1,280	**0.005**	**0**
Improve 3	N/A		No					
Notes	Increasing the rock levels in front of the structure will improve the overall standard of this defence and help in prolonging the life of the structure in facing climate change. The addition of a rock revetment will limit overtopping and provide additional toe support.							
Link to geomorphology	Coastal structure protects toe of slopes. Being a protrusion, there is more bulk of material than in adjacent frontages. This increased toe weight will minimise the risk of reactivation of landslides.							

Defence Unit ID	**IW 33 / 001**	*Description*	**Eastern cliffs – eastern section**		*Length*	**119m**	*Condition Grade*	**4 (poor)**
Landslide Unit: Wheelers Bay								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath and evacuation of property on failure of the main defence		Yes (as baseline)	N/A	0	0	0.02	2.5
Do Minimum	Monitor (visual and displacement), patch repairs, repair handrail		Yes		N/A	4	0.02	2.5
Improve 1	As above, additional rock toe support		Yes (also used in all other Improve options prior to scheme). Improve A	Add additional toe rock in **Yr 3** and rock repairs every 20yrs from Yr 50	3.4	409/43	**0.02**	**1**
Improve 2	Landslide drainage to reduce susceptibility to landslides and replace toe with new sheet piles and rock revetment to add toe support		Yes. Improve B and Improve C	Full rock revetment/ drainage in **Yr 3** and rock repairs every 20yrs from Yr 70.	13	1,747	0.005	0
Improve 3	Ground anchors or sheet piling landward of the structure in combination with drainage to reduce susceptibility to landslides and additional rock toe support		No					
Notes	Principally a geotechnical solution, but there will be coastal improvements in any options that incorporate additional rock armour (or concrete units) in front of the wall. Ground anchors may not be viable due to the depth of the fault line and the extra stresses this could create. Any option should seek to significantly reduce the risk of further movements. If movement is prevented then the main concrete structure will have significant residual life. Rebuilding the seawall is likely not required with movement to date, but further movement could require this structure to be re-built.							
Link to geomorphology	This coastal structure has a high retained height and is directly protecting the toe of the lower chalk and upper greensand cliffs. Due to its retained height and loading from the cliff system, failure of the structure could occur very quickly and the failure would quickly extend from a localised point. The failed concrete structure would continue to provide some toe support and some wave protection but increased overtopping and loss of fines would rapidly reduce the cliff toe weight and expose the base of the cliff. This will relatively quickly significantly increase the risk of landslide reactivation.							

Defence Unit ID	**IW 31 / 002**	*Description*	**Bonchurch - cliffs**		*Length*	**910m**	*Condition Grade*	**2 (good)**
Landslide Unit: Bonchurch East (160m) and Bonchurch West (750m)								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath on defence failure		Yes (as baseline)	N/A	0	0	0.005	5
Do Minimum	Monitor, patch repairs		Yes	Annual	N/A	2/4	0.005	2.5
Improve 1	As above, but pro-active protection of severely abraded lower apron with rock		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Every 20yrs from Yr 10 for toe rock	n/a	Bonchurch East: 55 Bonchurch West: 100	0.005	1
Improve 2	Full structural repair of abraded sections of defence and prevention of future abrasion through extensive rock toe protection. Full replacement with revetment at end of serviceable life.		Yes. Improve B. Timing brought forward for Improve C	Yr 20 wall repairs. Replacement in **Yr 70** Improve C bringing forward to Yr 50. Every 20yrs from Yr 10 for toe rock.	19	Bonchurch East: 3040 Bonchurch West: 14250	0.005	0
Improve 3	N/A							
Notes	Extending the life of the existing concrete structure is likely to be the most economically viable solution. This will require repair of stressed sections of the apron and measures to prevent a re-occurrence of structure degradation through abrasion. 160m of the total length is assumed to be within Bonchurch East Landslide Activation Unit and 730m is in Bonchurch West.							
Link to geomorphology	Coastal structures have a significant retained height and are serving an important function of protecting the toe of the lower chalk and upper greensand cliffs. Failure of the structure could occur quickly and the failure would quickly extend from a localised point. The failed concrete structure would continue to provide some toe support and some wave protection but increased overtopping would continue to reduce the toe weight and expose the base of the cliff. This will relatively quickly increase the risk of landslide reactivation.							

Defence Unit ID	**IW 30 / 001**	*Description*	**Monks Bay – eastern bays**		*Length*	**154m**	*Condition Grade*	**2 (good)**
Landslide Unit: Bonchurch East								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath and evacuation of property following failure of wall		Yes (as baseline)	N/A	0	0	0.01	2.5
Do Minimum	Monitor, patch repairs		Yes	Annual	N/A	3	0.01	1.5
Improve 1	Monitor, patch repairs, top up with additional rock (1-week of rock works every 20yrs for toe rock or works on groyne)		Yes (also used in all other Improve options prior to capital scheme). Improve A	Every 20yrs from Yr 10 for toe rock or groyne repairs	N/A	55	0.01	1
Improve 2	Revetment with falling toe seaward of existing seawall. Improve 1 until intervention and 1 week rock works every 20yrs on groynes)		Yes. Improve B. Timing brought forward for Improve C	**Yr 40** – Improve C bringing forward to Yr 20. Rock repairs every 20yrs from Yr 10.	8	1,266	**0.005**	**0**
Improve 3	Replacement concrete seawall with rock		No					
Notes	As the frontage is difficult to access with plant (particularly the eastern end) regular shingle re-nourishment of the bays are not considered viable. Hence, foreshore changes (with increased exposure and wave size) will likely best be managed by increased protection to the wall through the placement of additional armour rock. With adequate protection from rock, the seawall will have an increased life.							
Link to geomorphology	Seawall failure would expose cliff to regular high overtopping/wave impact forces and would result in rapid erosion at the toe (due to low beach levels). The seawall provides some toe support. However, failure of the seawall would be localised and even in a failed state there would remain some degree of toe support (in combination with the toe rock). Over time in the DN scenario, more of the wall and rock would be washed away leading to an increased risk of re-activation of larger landslide unit.							

Defence Unit ID	**IW 30 / 002**	*Description*	**Monks Bay – western bays**		*Length*	**142m**	*Condition Grade*	**2 (good)**
Landslide Unit: Bonchurch East								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath following loss of shingle crest		Yes (as baseline)	N/A	0	0	0.05	5
Do Minimum	Monitor and shingle recycling		Yes	Annual	N/A	3	0.05	1
Improve 1	As above, but with occasional shingle recharge and rock repairs		Yes (also used in all other Improve options prior to capital scheme). Improve A	Recharge and rock repairs every 20yrs from Yr 20.	N/A	139	0.02	1
Improve 2	Regular recycling and recharge to improve and maintain beach. Repairs to rock structures every 20 years (1 week of rock works)		No					
Improve 3	Modifications to breakwater (or extending rock structure to the west) to improve stability of shingle bay. Repairs to rock structures every 20 years (1 week of rock works)		Yes. Improve B. Timing brought forward for Improve C	Yr 30 – Improve C brings forward to Yr 10. Rock repairs every 20yrs from Yr 10.	N/A	910	0.005	0
Notes	Closing the gap opening between the breakwater and the rock groyne in IW 30 / 003 will likely be the most sustainable option as this will reduce the impact of the deep offshore seaward channel propagating out from the gap and result in a more stable bay shape. With correctly optimized gap the beach should remain stable but closure of the gap could impact on boat access.							
Link to geomorphology	The beach volume provides shelter to the toe of the hinterland (relatively gentle slopes). The beach may also provide some toe support. A withdrawal of beach maintenance (without any beach control structure optimization) would lead to erosion at the toe of the slope and could trigger landslides, especially as the beach would likely become compromised along most of the western bay as shingle is lost to the northern bay and subsequently lost around the northern groyne.							

Defence Unit ID	**IW 30 / 003**	*Description*	**Monks Bay – western end of bay**	*Length*	**54m**	*Condition Grade*	**3 (fair)**

Landslide Unit: Bonchurch East

Option	**Description of option**	**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath and ramp following wall failure	Yes (as baseline)	N/A	0	0	0.02	2.5
Do Minimum	Monitor, patch repairs, shingle recycling to keep ramp active	Yes – shingle recycling costs covered in IW30 /002.	N/A	N/A	1	0.02	1
Improve 1	As above, but with occasional shingle recharge	Yes – shingle costs covered in IW30 /002 (also used in all other Improve options prior to capital scheme).	N/A	N/A	N/A	0.01	1
Improve 2	Rock at toe of seaward wall extending beyond the ramp combined with regular recycling and recharge to improve and maintain beach	No					
Improve 3	Modifications to rock structure such as lengthening or introduction of seaward roundhead (or extension of the breakwater) to improve stability of shingle bay and shingle recharge	Yes – rock costs covered in IW30 /002.	N/A	N/A	N/A	0.005	0
Notes	Closing the gap opening between the rock groyne and the breakwater in IW 30 / 002 will likely be the most sustainable option as this will reduce the impact of the deep offshore seaward channel propagating out from the gap and result in a more stable bay shape with improve shingle levels at the ramp and in front of the wall. With correctly optimized gap the beach should remain stable but closure of the gap could impact on boat access.						
Link to geomorphology	The beach volume provides provide toe support to the wall and the cliffs/property behind. A withdrawal of beach maintenance (without any beach control structure optimization) could lead to loss of the concrete wall, which in turn could trigger landslides and/or loss of property. However, this would be expected to be a slow process.						

Defence Unit ID	**IW 31 / 001**	*Description*	**Bonchurch – eastern bays**	*Length*	**73m**	*Condition Grade*	**3 (fair)**
Landslide Unit: Bonchurch East							
Option	**Description of option**	**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Closure of footpath/road and evacuation of property following wall failure	Yes (as baseline)	N/A	0	0	0.02	2.5
Do Minimum	Monitor, patch repairs	Yes	Annual	N/A	1	0.02	1
Improve 1	As above, extend and replace toe rock as required	Yes (also used in all other Improve options prior to capital scheme). Improve A	Every 20yrs from Yr 10 for toe rock and groyne repairs		55	0.01	1
Improve 2	Rock revetment covering lower sections of seawall and encase concrete wall	Yes. Improve B. Timing brought forward for Improve C	Yr 30 – Improve C brings forward to Yr 20.	15	1095	0.005	0
Improve 3	Improvement of toe rock (replace and extend), regular recharge and replace wall in Year 30	No					
Notes	The cost of replacement of the seawalls would be significant, hence, the most cost effective solutions are those that extend the life of the existing seawall. There are many combinations of options to achieve this with varying proportions/configurations of rock placement and beach maintenance. Larger scale options such as replacement seawalls, new full height revetment and breakwaters are unlikely to be justifiable (at least initially).						
Link to geomorphology	Coastal structures have a significant retained height and are serving an important function of protecting the development at the base of the upper slopes. Failure of the structure could occur quickly and the failure would quickly extend from a localised point. Loss of the structure would quickly destabilise the road and property and the risk of re-activating landslides will increase quickly. The failed concrete structure would continue to provide some toe support and some wave protection but increased overtopping would continue to reduce the toe weight and expose the base of the cliff.						

Defence Unit ID	**N/A**	*Description*	**The Landslip**		*Length*	**740m**	*Condition Grade*	**N/A**
Landslide Unit: The Landslip								
Option	**Description of option**		**Option carried forward?**	**Intervention timing, year**	**Cost per linear length, £k/m**	**Intervention cost, £k (per event)**	**Initial failure prob., %**	**Incremental failure prob., %/yr**
Do Nothing	Manage public H&S		Yes (as baseline)	N/A	0	0	1	0
Do Minimum	Monitor		Yes	N/A	N/A	0.5	1	0
Improve 1	As above, adding additional rock to toe where erosion is active and critical		Yes (also used in Improve 2 option prior to capital scheme). Improve A	Every 20yrs from Yr 20 additional rock at toe	N/A	55	**0.1**	**1**
Improve 2	As Improve 1 and rock revetment		Yes. Improve B. Timing brought forward for Improve C	**Yr 40**. Improve C brings forward to **Yr 10**. Every 20yrs from Yr 20 for additional rock at toe	6.3	4685	**0.005**	**0**
Improve 3	N/A		No					
Notes	No defences currently in place along this entire frontage. Defences may be required in the future to protect the landslide complex and the road/property.							
Link to geomorphology	A new structure would provide contribution as toe weight for the cliffs and would also serve to protect the cliff toe from erosion. In the event of failure of the structure, this would likely be localised and the rock would continue to provide protection. Over time, the defences would further break up, increasing overtopping rates and allow the cliff toe erosion to re-commence, which could in turn initiate a landslide.							

Appendix 9. Coastal options costing

Summary of Costs

The table below summarises the capital and maintenance costs for the options at each LRU. This summary considers all of the costs within each of the Defence Units. Capital costs cover those costs that relate to capital schemes where the SoP will be improved and would typically be linked to DFGiA or other external funding. Maintenance costs include ongoing costs to maintain the assets, typically funded by the operating authority. Maintenance costs can also include local recycling of beach material (but recharge from an external source would be capital works) and the local placement of toe rock to prevent structure undermining.

Landslide Reactivation Unit	Expenditure Type	Estimated cash costs (not discounted) of options (£) over 100 years				
		Do Nothing	**Do Minimum**	**Improve A**	**Improve B**	**Improve C**
Castle Cove	Coastal	-	-	-	£3,067,000	£3,067,000
	Maintenance	-	£800,000	£1,334,000	£957,000	£814,000
	Total	**-**	**-**	**-**	**£4,024,000**	**£3,881,000**
Ventnor Park	Coastal	-	-	-	£3,517,000	£3,517,000
	Maintenance	-	£600,000	£1,113,000	£625,000	£530,000
	Total	**-**	**£600,000**	**£1,113,000**	**£4,142,000**	**£4,047,000**
Central Ventnor	Coastal	-	-	£3,801,000	£8,041,000	£8,041,000
	Maintenance	-	£1,400,000	£2,100,000	£1,511,000	£1,511,000
	Total	**-**	**£1,400,000**	**£5,901,000**	**£9,552,000**	**£9,552,000**
Wheelers Bay	Coastal	-	-	£3,202,000	£7,658,000	£7,713,000
	Maintenance	-	£1,100,000	£799,000	£627,000	£599,000
	Total	**-**	**£1,100,000**	**£4,001,000**	**£8,285,000**	**£8,312,000**
Bonchurch West	Coastal	-	-	-	£14,250,000	£14,250,000
	Maintenance	-	£400,000	£900,000	£609,000	£492,000
	Total	**-**	**£400,000**	**£900,000**	**£14,859,000**	**£14,742,000**
Bonchurch East	Coastal	-	-	-	£6,310,000	£7,019,000
	Maintenance	-	£1,000,000	£2,179,000	£1,123,000	£960,000
	Total	**-**	**£1,000,000**	**£2,179,000**	**£7,433,000**	**£7,979,000**
The Landslip	Coastal	-	-	-	£4,685,000	£4,685,000
	Maintenance	-	£50,000	£270,000	£150,000	£250,000
	Total	**-**	**£50,000**	**£270,000**	**£4,835,000**	**£4,935,000**

Option Failure Probabilities (weakest link)

At the LRU level, the landslide reactivation probability is linked to the weakest link coastal Defence Unit. The tables below identify the weakest link (highest failure probabilities) of the various Defence Units within a given LRU. The weakest links change over the appriasal period as the failing defences are inproved, passing the weakest link in a Defence Unit to the next worst performing defence. These tables summarise the variation in failure probability over time.
Probability of failure and incrementaiton failure probability are identified for each option (Do Nothing, Do Min and the Improve options) for each LRU. This is translated into the QRA as the weakest links.
The number of weakest link changes can vary between LRUs as this is a function of the timing of improvement works.

Castle Cove

	Defence ID used for probability	Option used for probability	Probability of failure	Incremental failure prob.,
Castle Cove - INPUTS for Do Nothing	IW 36 / 005	Do Nothing	0.01	5.00%
Castle Cove - INPUTS for Do Min	IW 36 / 005	Do Min	0.01	2.50%
Castle Cove - INPUTS for Improve A	IW 36 / 005	Improve A	0.01	1.00%

Castle Cove - INPUTS for Improve B	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	IW 36 / 005	Improve A	0	0.01	1.00%
Capital Schemes at IW 36 / 001 to IW 36 / 008	IW 36 / 005	Improve B	60	0.005	0.00%

Castle Cove - INPUTS for Improve C	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	IW 36 / 005	Improve A	0	0.01	1.00%
Capital Schemes at IW 36 / 001 to IW 36 / 008	IW 36 / 005	Improve B	40	0.005	0.00%

Ventnor Park

	Defence ID used for probability	Option used for probability	Probability of failure	Incremental failure prob.,
Ventnor Park - INPUTS for Do Nothing	IW 32 / 001	Do Nothing	0.05	5.00%
Ventnor Park - INPUTS for Do Min	IW 32 / 001	Do Min	0.05	2.50%
Ventnor Park - INPUTS for Improve A	IW 32 / 001	Improve A	0.02	1.00%

Ventnor Park - INPUTS for Improve B	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	IW 35 / 003	Improve A	0	0.02	1.00%
Capital Scheme at IW 35 / 003	IW 35 / 002	Improve A	20	0.01	1.00%
Capital Scheme at IW 32 / 003	IW 32 / 003	Improve B	60	0.005	0.00%

Ventnor Park - INPUTS for Improve C	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	IW 35 / 003	Improve A	0	0.02	1.00%
Capital Scheme at IW 35 / 003	IW 35 / 002	Improve A	20	0.01	1.00%
Capital Scheme at IW 32 / 003	IW 32 / 003	Improve B	40	0.005	0.00%

Central Ventnor

	Defence ID used for probability	Option used for probability	Probability of failure	Incremental failure prob.,
Central Ventnor - INPUTS for Do Nothing	IW 33 / 002	Do Nothing	0.2	5.00%
Central Ventnor - INPUTS for Do Min	IW 33 / 002	Do Min	0.2	2.50%

Wheelers Bay - INPUTS for Improve A	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	IW 33 / 002	Do Min	0	0.2	2.50%
Capital Scheme at IW 33 / 002	IW 35 / 001	Improve A	3	0.01	1.00%

Central Ventnor - INPUTS for Improve B	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	IW 33 / 002	Improve A	0	0.05	1.00%
Capital Scheme at IW 33 / 002	IW 35 / 001	Improve A	3	0.01	1.00%
Capital Scheme at IW 35 / 001	IW 35 / 001	Improve B	60	0.005	0.00%

Central Ventnor - INPUTS for Improve C	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	IW 33 / 002	Improve A	0	0.05	1.00%
Capital Scheme at IW 33 / 002	IW 35 / 001	Improve A	3	0.01	1.00%
Capital Scheme at IW 35 / 001	IW 35 / 001	Improve B	60	0.005	0.00%

Wheelers Bay

	Defence ID used for probability	Option used for probability	Probability of failure	Incremental failure prob.,
Wheelers Bay - INPUTS for Do Nothing	IW 32 / 001	Do Nothing	0.2	5.00%
Wheelers Bay- INPUTS for Do Min	IW 32 / 001	Do Min	0.2	2.50%

Wheelers Bay - INPUTS for Improve A	Defence ID used f	Option used fo	Year of replacement/	Initial probability	Incremental failure prob., %/yr
Initial probability of failure	IW 32 / 001	Do Min	0	0.2	2.50%
Capital Scheme at IW 32 / 001	IW 33 / 001	Improve A	3	0.02	1.00%

Wheelers Bay - INPUTS for Improve B	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	IW 32 / 001	Improve A	0	0.05	1.00%
Capital Scheme at IW 32 / 001	IW 33 / 001	Improve A	3	0.02	1.00%
Capital Scheme at IW 33 / 001	IW 32 / 003	Improve A	10	0.01	1.00%
Capital Scheme at IW 32 / 003	IW 32 / 003	Improve B	60	0.005	0.00%

Wheelers Bay - INPUTS for Improve C	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	IW 32 / 001	Improve A	0	0.05	1.00%
Capital Scheme at IW 32 / 001 & 33 / 001	IW 32 / 003	Improve A	3	0.01	1.00%
Capital Scheme at IW 32 / 003	IW 32 / 003	Improve B	60	0.005	0.00%

Bonchurch West

	Defence ID used for probability	Option used for probability	Probability of failure	Incremental failure prob.,
Bonchurch West - INPUTS for Do Nothing	IW 31 / 002	Do Nothing	0.005	5.00%
Bonchurch West - INPUTS for Do Min	IW 31 / 002	Do Min	0.005	2.50%
Bonchurch West - INPUTS for Improve A	IW 31 / 002	Improve A	0.005	1.00%

Bonchurch West INPUTS for Improve B	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	IW 31 / 002	Improve A	0	0.005	1.00%
Capital Scheme at IW 31 / 002	IW 31 / 002	Improve B	70	0.005	0.00%

Bonchurch West - INPUTS for Improve C	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	IW 31 / 002	Improve A	0	0.005	1.00%
Capital Scheme at IW 31 / 002	IW 31 / 002	Improve B	50	0.005	0.00%

Bonchurch East

	Defence ID used for probability	Option used for probability	Probability of failure	Incremental failure prob.,
Bonchurch East - INPUTS for Do Nothing	IW 30 / 002	Do Nothing	0.05	5.00%
Bonchurch East - INPUTS for Do Min	IW 30 / 002	Do Min	0.05	1.00%
Bonchurch East - INPUTS for Improve A	IW 30 / 002	Improve A	0.02	1.00%

Bonchurch East - INPUTS for Improve B	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	IW 30 / 002	Improve A	0	0.02	1.00%
Capital Scheme at IW 30 / 002	IW 30 / 001	Improve A	30	0.01	1.00%
Capital Scheme at IW 30 / 001	IW 31 / 002	Improve A	40	0.005	1.00%
Capital Scheme at IW 31 / 002	IW 30 / 001	Improve B	70	0.005	0.00%

Bonchurch East - INPUTS for Improve C	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	IW 30 / 002	Improve A	0	0.02	1.00%
Capital Scheme at IW 30 / 002	IW 30 / 001	Improve A	10	0.01	1.00%
Capital Scheme at IW 30 / 001	IW 31 / 002	Improve A	20	0.005	1.00%
Capital Scheme at IW 31 / 002	IW 30 / 001	Improve B	5	0.005	0.00%

The Landslip

	Defence ID used for probability	Option used for probability	Probability of failure	Incremental failure prob.,
The Landslip - INPUTS for Do Nothing	The Landslip	Do Nothing	1	0.00%
The Landslip - INPUTS for Do Min	The Landslip	Do Min	1	0.00%
The Landslip - INPUTS for Improve A	The Landslip	Improve A	0.5	1.00%

The Landslip - INPUTS for Improve B	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	The Landslip	Improve A	0	0.1	1.00%
Capital Scheme at The Landslip	The Landslip	Improve B	40	0.005	0.00%

The Landslip - INPUTS for Improve C	Defence ID used for probability	Option used for probability	Year of replacement/ improvement	Initial probability of failure	Incremental failure prob., %/yr
Initial probability of failure	The Landslip	Improve A	0	0.1	1.00%
Capital Scheme at The Landslip	The Landslip	Improve B	10	0.005	0.00%

Landslide Reactivation Probabilities

The table below summarises the link between coastal defence failure and the reactivation of a landslide within the Landslide Reactivation Unit (LRU). This varies depending on the geometry of the frontage, the type of defences (do they continue to afford some protection even in a faiued state e.g. rock revetments). As failing concrete structures are replaced/strenghtened with rock structures (as in the Improve Options), the frontage resilience increases. This increased resilience is most dramatic where concrete structures are full replaced by rock structures, as in many of the Improve B and Improve C options. Where assets are strenghtned only, as in many of the Improve A options (perhaps rock toe protection), the resilince is improved, but to a lesser degree than when the full structure is replaced.

		Probabilty that a landslide is reactivated given the failure of one of the structures within the LRU					
LRU	**Reactivation Scenario**	**Do Nothing**	**Do Min**	**Improve A**	**Improve B**	**Improve C**	**Notes**
Castle Cove	**4**	0.3	0.3	0.2	0.05	0.05	
	5	0.03	0.03	0.02	0.005	0.005	Even in failed state, significant bulk of rock material and beaches will continue to manage risk of landslide reactivation
Ventnor Park	**4**	0.3	0.3	0.2	0.05	0.05	Typicall thre are low retained heights acorss structures. Erosion of toe would likely initially result in local landslide only as steep cliff.
	5	0.03	0.03	0.02	0.005	0.005	
Central Ventnor	**4**	0.4	0.4	0.1	0.1	0.1	Reduced chance to that to the eastern frontages of activating a landslide following a defence failure. This is due to the relatively moderate retained height with either the beach or harbour in front of the majority of the frontage and typically a road directly behind.
	5	0.04	0.04	0.01	0.01	0.01	
Wheelers Bay	**4**	0.5	0.5	0.1	0.1	0.1	Relatively high chance of activating a landslide following the failure of a defence. Many of the defences have a high retained height and as there are many concrete structures, these typically fail quicker and more catastrophically (in comparison to say rock structures).
	5	0.05	0.05	0.01	0.01	0.01	
Bonchurch West	**4**	0.5	0.5	0.2	0.1	0.1	Relatively high chance of activating a landslide following the failure of a defence. Many of the defences have a high retained height and as there are many concrete structures, these typically fail quicker and more catastrophically (in comparison to say rock structures).
	5	0.05	0.05	0.02	0.01	0.01	
Bonchurch East	**4**	0.5	0.5	0.2	0.1	0.1	Relatively high chance of activating a landslide following the failure of a defence. Many of the defences have a high retained height and as there are many concrete structures, these typically fail quicker and more catastrophically (in comparison to say rock structures).
	5	0.05	0.05	0.02	0.01	0.01	
The Landslip	**4**	0.1	0.1	0.1	0.05	0.05	No protection in a DN or Do Min option. However, significant landslips are not regularly occurring, but risk will increase over time
	5	0.01	0.01	0.01	0.005	0.005	

Castle Cove - Summary of costs over appraisal period

This table summarises the capital and maintenance costs for each option in each Defence Unit.
The table summarises the costs for this LRU. The table shows the timing of interventions and should be read in conjunction with Appendix 8. All costs presented in £k.

	IW 36 /001				**IW 36 /002**				**IW 36 /003**				**IW 36 /004**				**IW 36 /005**		
	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B
Annual Maintenance Cost - pre capital work	2	2	2	*2*	0.5	0.5	0.5	*0.5*	1	1	1	*1*	1	1	1	*1*	0.5	0.5	0.5
Annual Maintenance Cost - post capital work			2	*2*			0.5	*0.5*			1	*1*			1	*1*			0.5
Yr 3																			
Yr 10																			
Yr 20																			
Yr 30																			
Yr 40		27	27	*914*		13	13	*390*		28	28	*446*		28	28	*379*		27	27
Yr 50																			
Yr 60		27	914			13	390			28	446			28	379			27	490
Yr 70																			
Yr 80		27				13				28				28				27	
Yr 90																			
Total Capital costs (non-discounted)	0	0	914	*914*			390	*390*			446	*446*			379	*379*			490
Total Maintenance costs (non-discounted)	200	279.5	223	*196*	50	90	62	*49*	100	183	126	*98*	100	182.5	126	*98*	50	130	76
Assumed rate per m (£k/m frontage length)		LS	4.0	*4.0*			LS	*LS*			7.4	*7.4*			7.4	*7.4*			LS
Length			231	*231*							60	*60*			51	*51*			
Cost per intervention		27	914	*914*		13	390	*390*		28	446	*446*		28	379	*379*		27	490

* Design and pre-construction survey work to be covered by a 20% mark up on the capital costs, applied in the year preceeding the capital works.

	IW 36 /006				IW 36 /007				IW 36 /008				Package costs			
Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve	Improve C	Do Min	Improve A	Improve	Improve C
0.5	1	1	1	*1*	1	1	1	*1*	1	1	1	*1*	8	8	Varies	Varies
0.5			1	*1*			1	*1*			1	*1*	0	0	Varies	Varies
													0	0	0	0
													0	0	0	0
		14	14	*14*		8	8	*8*					0	22	22	22
													0	0	0	0
490		14	14	*114*		8	8	*54*		28	0	*278*	0	171	143	3066
													0	0	0	0
		14	114			8	54			28	278		0	171	3067	0
													0	0	0	0
		14				8				28			0	171	0	0
													0	0	0	0
490			114	*114*			54	*54*			278	*278*	0	0	3067	3067
49	100	155	126	*112*	100	133	115	*106*	100	182.5	98	*98*	800	1334	949	806
LS			5.4	*5.4*			5.4	*5.4*			3.4	*3.4*				
			21	*21*			10	*10*			81	*81*				
490		14	114	*114*		8	54	*54*		28	278	*278*				

Ventnor Park - Summary of costs over appraisal period

This table summarises the capital and maintenance costs for each option in each Defence Unit. The table summarises the costs for this LRU. The table shows the timing of interventions and should be read in conjunction with Appendix 8. All costs presented in £k.

	IW 35 /002				**IW 35 /003**				**IW 35 /004**				**IW 35 /005**				**Package costs**			
	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C
Annual Maintenance Cost - pre capital work	2	2	2	2	1	1	1	1	2	2	2	2	1	1	1	1	6	6	Varies	Varies
Annual Maintenance Cost - post capital work			1	1			1	1			1	1			1	1	0	0	Varies	Varies
Yr 3						25	137	137									0	25	137	137
Yr 10																	0	0	0	0
Yr 20		28	28	28													0	28	28	28
Yr 30						13											0	13	0	0
Yr 40		28	28	665						55	55	774				1804	0	83	83	3242
Yr 50						13											0	13	0	0
Yr 60		28	665				137	137		55	774			82	1804		0	164	3380	137
Yr 70						13											0	13	0	0
Yr 80		28		28						55				82			0	164	0	28
Yr 90						13											0	13	0	0
Total Capital costs (non-discounted)	0	0	665	665			0	0			774	774			1804	1804	0	0	3242	3242
Total Maintenance costs (non-discounted)	200	310	212	192	100	175	98	98	200	365	212	137	100	263	100	100	600	1113	622	527
Assumed rate per m (£k/m frontage length)		LS	7.9	7.9			11.4	11.4			7.4	7.4								
Length			84	84			12	12			104	104			LS	LS				
Cost per intervention		28	665	665		25	137	137		55	774	774		82	1804	1804				

* Design and pre-construction survey work to be covered by a 20% mark up on the capital costs, applied in the year preceeding the capital works.

Central Ventnor - Summary of costs over appraisal period

This table summarises the capital and maintenance costs for each option in each Defence Unit. The table summarises the costs for this LRU. The table shows the timing of interventions and should be read in conjunction with Appendix 8. All costs presented in £k.

	IW 33 /002				IW 34 /001				IW 34 /002				IW 34 /003				IW34 / 004		
	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B
Annual Maintenance Cost - pre capital work	5	5	5	5	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1
Annual Maintenance Cost - post capital work		1	1	*1*			2	*2*			2	*2*			1	*1*			1
Yr 3		3801	3801	*3801*															
Yr 10																			
Yr 20																		20	20
Yr 30																			
Yr 40						43	43	*43*		86	86	*86*		27	27	*27*		20	20
Yr 50																			
Yr 60		27				43	1000	*1000*		86	1200	*1200*		27	200	*200*		20	220
Yr 70			1140	*1140*															
Yr 80		27				43				86				27				20	
Yr 90																			
Total Capital costs (non-discounted)	0	3801	4941	*4941*			1000	*1000*			1200	*1200*			200	*200*			200
Total Maintenance costs (non-discounted)	500	111	111	*111*	200	329	243	*243*	200	458	286	*286*	100	180	127	*127*	100	180	160
Assumed rate per m (£k/m frontage length)	LS	21	21	*21*															
Length		181	181	*181*															
Cost per intervention	70	3801	3801	*3801*		43	1000			86	1200			27	200				200

* Design and pre-construction survey work to be covered by a 20% mark up on the capital costs, applied in the year preceeding the capital works.

	IW35 / 001				Package costs			
Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C
1	3	3	3	3	14	14	Varies	Varies
1			2	*2*	0	Varies	Varies	Varies
					0	3801	3801	3801
		46	46	*46*	0	46	46	46
20		66	66	*66*	0	86	86	86
		46	46	*46*	0	46	46	46
20		66	66	*66*	0	241	241	241
		46	46	*46*	0	46	46	46
220		66	566	*566*	0	268	3186	3186
		46			0	46	1140	1140
		66			0	268	0	0
		46			0	46	0	0
200			500	*500*	0	3801	8041	8041
160	300	790	633	*633*	1400	2047	1560	1560
		46	500					

<u>Wheelers Bay - Summary of costs over appraisal period</u>

This table summarises the capital and maintenance costs for each option in each Defence Unit. The table summarises the costs for this LRU. The table shows the timing of interventions and should be read in conjunction with Appendix 8.All costs presented in £k.

	IW 32 /001				**IW 32 /002**				**IW 32 /003**				**IW 33 /001**				**Package costs**			
	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C
Annual Maintenance Cost - pre capital work	5	5	5	5	1	1	1	1	1	1	1	1	4	4	4	4	11	11	Varies	Varies
Annual Maintenance Cost - post capital work		1	1	*1*			1	*1*			1	1			1	1	0	Varies	Varies	Varies
Yr 3		2793	2793	*2793*										409	1747	1747	0	3202	4540	4540
Yr 10																	0	0	0	0
Yr 20												780					0	0	0	780
Yr 30																	0	0	0	0
Yr 40						43	43	*43*		55	55	55				0	0	98	98	98
Yr 50		27	27	*27*										43			0	70	27	27
Yr 60						43	1000	*1000*		55	1280	555				43	0	98	2280	1598
Yr 70		27	838	*838*										43	43		0	70	881	838
Yr 80						43				55						43	0	98	0	43
Yr 90														43	43		0	43	43	0
Total Capital costs (non-discounted)	0	2820	3631	*3631*			1000	*1000*			1280	1280			1747	1747	0	2820	7658	7658
Total Maintenance costs (non-discounted)	500	111	111	*111*	100	229	143	*143*	100	265	155	155	400	938	251	194	1100	1543	660	603
Assumed rate per m (£k/m frontage length)	LS	21	21	*21*							13	13		3.4	13	13				
Length		133	133	*133*							60	60		119	119	119				
Cost per intervention	120	2793	2793	*2793*		43	1000			55	780	780		409	1747	1747				

* Design and pre-construction survey work to be covered by a 20% mark up on the capital costs, applied in the year preceeding the capital works.

Bonchurch West - Summary of costs over appraisal period

This table summarises the capital and maintenance costs for each option in each Defence Unit.
The table summarises the costs for this LRU. The table shows the timing of interventions and should be read in conjunction with Appendix 8. All costs presented in £k.

	IW31 / 002				**Package costs**			
	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C
Annual Maintenance Cost - pre capital work	4	4	4	4	4	4	4	4
Annual Maintenance Cost - post capital work			1	1	0	0	3	3
Yr 3					0	0	0	0
Yr 10		100	100	100	0	100	100	100
Yr 20					0	0	0	0
Yr 30		100	100	100	0	100	100	100
Yr 40					0	0	0	0
Yr 50		100	100	14250	0	100	100	14250
Yr 60					0	0	0	0
Yr 70		100	14250		0	100	14250	0
Yr 80					0	0	0	0
Yr 90		100		43	0	100	0	43
Total Capital costs (non-discounted)	0	0	14250	14250	0	0	14250	14250
Total Maintenance costs (non-discounted)	400	900	305	255	400	900	305	255
Assumed rate per m (£k/m frontage length)			19	19				
Length		LS	750	750				
Cost per intervention		100	14250	14250				

* Design and pre-construction survey work to be covered by a 20% mark up on the capital costs, applied in the year preceeding the capital works.

Bonchurch East - Summary of costs over appraisal period

This table summarises the capital and maintenance costs for each option in each Defence Unit. The table summarises the costs for this LRU. The table shows the timing of interventions and should be read in conjunction with Appendix 8. All costs presented in £k.

	IW30 / 001				IW30 / 002				IW30 / 003				IW31 / 001				IW31 / 002				Package costs			
	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C	Do Min	Improve A	Improve B	Improve C
Annual Maintenance Cost - pre capital work	3	2	2	2	3	2	2	2	1	1	1	1	1	1	1	1	2	2	2	2	10	8	Varies	Varies
Annual Maintenance Cost - post capital work			0	0			1	1							1	1			1	1	0	0	Varies	Varies
Yr 3																					0	0	0	0
Yr 10		55	55	55			27	910						55	55	55		55	55	55	0	165	192	1075
Yr 20				1266		139									27	1095					0	139	27	2361
Yr 30		55	55				910							55	1095			55	55	55	0	165	2115	55
Yr 40			1266			139															0	139	1266	0
Yr 50		55						26.5						55				55	55	3040	0	165	55	3067
Yr 60				55		139															0	139	0	55
Yr 70		55					27	26.5						55				55	3040		0	165	3067	27
Yr 80			55	55		139										55					0	139	55	110
Yr 90		55		380			27	26.5						55	55	329		55		0	0	165	82	735
Total Capital costs (non-discounted)	0	0	1266	1645	0	0	910	910	0	0	0	0	0	0	1095	1424	0	0	3040	3040	0	0	6311	7019
Total Maintenance costs (non-discounted)	300	475	243	243	300	754	187	206.5	100	100	100	100	100	375	235	208	200	475	167	157	1000	2179	931	915
Assumed rate per m (£k/m frontage length)			8	8											15	15			19	19				
Length		LS	154	154		LS	LS	LS						LS	73	73		LS	160	160				
Cost per intervention		55	1266	1266		139	910	910						55	1095	1095		55	3040	3040				

* Design and pre-construction survey work to be covered by a 20% mark up on the capital costs, applied in the year preceeding the capital works.

The Landslip - Summary of costs over appraisal period

This table summarises the capital and maintenance costs for each option in each Defence Unit.
The table summarises the costs for this LRU. The table shows the timing of interventions and should be read in conjunction with Appendix 8. All costs presented in £k.

	IW 36 /001				Package costs			
	Do Min	Improve A	Improve	Improve C	Do Min	Improve A	Improve	Improve C
Annual Maintenance Cost - pre capital work	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Annual Maintenance Cost - post capital work			0.5	0.5			0.5	0.5
Yr 3				4685	0	0	0	4685
Yr 10					0	0	0	0
Yr 20		55	100		0	55	100	0
Yr 30					0	0	0	0
Yr 40		55	4685		0	55	4685	0
Yr 50					0	0	0	0
Yr 60		55			0	55	0	0
Yr 70				100	0	0	0	100
Yr 80		55			0	55	0	0
Yr 90				100	0	0	0	100
Total Capital costs (non-discounted)	0	0	4685	4685	0	0	4685	4685
Total Maintenance costs (non-discounted)	50	270	149	249	50	270	149	249
Assumed rate per m (£k/m frontage length)		LS	6.3	6.3				
Length			740	740				
Cost per intervention		55	4685	4685				

* Design and pre-construction survey work to be covered by a 20% mark up on the capital costs, applied in the year preceeding the capital works.

Summary of Units

Summary of coastal defence assets contained within each landslide reactivation unit (LRU). Coastal defence asset spatial data and labels are provided by the Isle of Wight Council. The following maps show the location of the defence assets and LRUs.

Castle Cove	36/001	36/002	36/003	36/004	36/005	36/006	36/007	36/008
Ventnor Park	35/002	35/003	35/004	35/005				
Central Ventnor	33/002	34/001	34/002	34/003	34/004	35/001		
Wheelers Bay	32/001	32/002	32/003	33/001				
Bonchurch West	31/002 (part)							
Bonchurch East	30/001	30/002	30/003	31/001	31/002 (part)			
The Landslip								

N
Central Ventnor
Ventnor Park
Castle Cove
IW 35 / 001
IW 35 / 004
IW 35
IW 36 / 001
IW 36 / 003
IW 36 / 005
IW 36 / 008
Legend
Replacement structure
Concrete groyne
Concrete slipway
Concrete tetrapods
Concrete wall
Gabions
Masonry wall
Mobs and English groyne
Rock armour
Rock armour breakwater
Rock armour groyne
Steel groyne
Steel sheet piling
Timber breastwork
Timber groyne
Undefended
Landslide Reactivation Unit
0
0.05
0.1
0.2
Kilometres

N
Bonchurch West
Wheelers Bay
Central Ventnor
Ventnor Park
IW 31 / 002
IW 32 / 001
IW 32 / 002
IW 33 / 001
IW 33 / 002
IW 34 / 001
IW 34 / 001
IW 34 / 001
IW 34 / 002
IW 34 / 003
IW 34 / 004
IW 35 / 001
IW 35 / 001
IW 35 / 001
IW 35
Legend
Replacement structure
Concrete groyne
Concrete slipway
Concrete tetrapods
Concrete wall
Gabions
Masonry wall
Mobs and English groyne
Rock armour
Rock armour breakwater
Rock armour groyne
Steel groyne
Steel sheet piling
Timber breastwork
Timber groyne
Undefended
Landslide Reactivation Unit
0 0.05 0.1 0.2
Kilometres


N
The Landslip
Bonchurch East
Bonchurch West
IW 30 / 001
IW 30 / 002
IW 31 / 001
IW 31 / 002
Legend
Replacement structure
Concrete groyne
Concrete slipway
Concrete tetrapods
Concrete wall
Gabions
Masonry wall
Mobs and English groyne
Rock armour
Rock armour breakwater
Rock armour groyne
Steel groyne
Steel sheet piling
Timber breastwork
Timber groyne
Undefended
Landslide Reactivation Unit
0
0.05
0.1
0.2
Kilometres

Summary of Maintenance Costs (provided by IoW council)

UNDERCLIFF STRATEGY STUDY
UNDERCLIFF MAINTAINANCE COSTS (2009 - 2016)

Luke Ellison - Coastal Engineer

Purchase Order	Date	Observation ID / Description	REF.	Policy Unit (SMP)	Cost £ (exc. Vat)	Cliff Safety Works Cliff Clearance
3500112747	20.01.12	Relocation of shingle - Monks Bay	V.2-303	IW 30	£3,105.00	
3500158799	14.10.13	Ventnor Coastal Repairs	V.2-450	IW 30	£327.25	
3500160094	05.11.13	V.2-459 Monks bay Storm Works	V.2-459	IW 30	£952.75	
3500167636	26.03.14	V.2-459 Storm materail relocation	V.2-459	IW 30	£1,463.00	
3500202818	11.04.16	V.2-459 Monks Bay Works	V.2-459	IW 30	£4,115.00	
				TOTAL	£9,963.00	
3500038413	18.12.09	Ventnor Coastal Repairs	V.2-228	IW 31	£150.00	
3500048483	16.03.10	2010-11 Ventnor Repairs	V.2-191 / V.2-244	IW 31	£100.00	
3500052419	14.04.10	Ventnor - Bonchurch Groyne Works	V.2-255 / V.2-286	IW 31	£2,495.00	
3500083921	02.02.11	Repairs to Promenade and Steps Ventnor	V.2-315	IW 31	£190.00	
3500086455	01.03.11	Removal of Rock from promenade - Venntor	V.2-317	IW 31	£100.00	100.00
3500094965	07.06.11	Ventnor Catch Fence Repairs	V.2-326	IW 31	£1,190.00	1,190.00
3500094964	07.06.11	Ventnor Repairs	V.2-327	IW 31	£376.66	
3500094964	07.06.11	Ventnor Repairs	V.2-310	IW 31	£376.66	
3500096611	27.06.11	Ventnor Railing Repairs	V.2-136	IW 31	£179.00	
3500128036	09.07.12	Ventnor Coastal Repairs	V.2-339 / V.2-365	IW 31	£738.46	
3500139849	11.12.12	V.2-390 V.2-401 Ventnor Repairs	V.2-390	IW 31	£800.00	
3500145920	27.02.13	V.2-409 Emergency Cliff Clearance Works	V.2-409	IW 31	£1,258.50	1,258.50
3500145917	08.03.13	V.2-420 - V.2-409 Catch Fence Repairs	V.2-420 / V.2-409	IW 31	£285.00	285.00
3500158799	14.10.13	Ventnor Coastal Repairs	V.2-449 / V.2-457 / V.2-458	IW 31	£327.25	
3500163573	20.01.14	V.2-468 - V.2-471 Ventnor Repairs	V.2-468	IW 31	£225.00	
3500165525	20.02.14	V.2-461 Bonchurch slab repair	V.2-461	IW 31	£585.00	
3500166654	07.03.14	Ventnor Repairs	V.2-486	IW 31	£165.00	
3500166654	07.03.14	Ventnor Repairs	V.2-482	IW 31	£1,675.00	1,675.00
3500167365	21.03.14	V.2-481 Ventnor railing repairs	V.2-481	IW 31	£795.89	
3500167364	21.03.14	V.2-474 Cliff fall works - catch fence	V.2-474	IW 31	£1,177.00	1,177.00
3500179036	05.11.14	V.2-519 - V.2-520 Ventnor Repairs	V.2-520	IW 31	£299.54	
3500184383	04.03.15	V.2-503 - V.2-535 - V.2-534 Ventnor	V.2-534	IW 31	£75.00	
3500192428	12.08.15	V.2-514 - V.2-554 Ventnor Repairs	V.2-514 / V.2-554	IW 31	£150.00	
3500198226	21.12.15	Ventnor Coastal Repairs	V.2-565 / V.2-558	IW 31	£168.50	
3500205220	17.06.16	Coastal work in Ventnor	V.2-579	IW 31	£200.00	
				TOTAL	£14,082.46	
3500038413	18.12.09	Ventnor Coastal Repairs	V.2-238	IW 32	£150.00	
3500083921	02.02.11	Repairs to Promenade and Steps Ventnor	V.2-315	IW 32	£100.00	
3500094964	07.06.11	Ventnor Repairs	V.2-327	IW 32	£376.66	
3500094964	07.06.11	Ventnor Repairs	V.2-307	IW 32	£376.66	
3500096611	27.06.11	Ventnor Railing Repairs	V.2-160	IW 32	£179.00	
3500100888	11.08.11	Replacement Flap Valve	V.2-319	IW 32	£598.00	
3500111197	23.12.11	Replacement Flap Valve - Wheelers Bay	V.2-354	IW 32	£610.00	
3500128036	09.07.12	Ventnor Coastal Repairs	V.2-365 / V.2-380 / V.2-382 / V.388	IW 32	£738.46	
3500189076	01.06.15	V.2-545 Replacement post	V.2-545	IW 32	£210.00	
3500198226	21.12.15	Ventnor Coastal Repairs	V.2-565	IW 32	£168.50	
3500205220	17.06.16	Coastal work in Ventnor	V.2-547	IW 32	£400.00	
3500011552	01.06.09	Ventnor - Bonchurch Promenade Repairs	V.2-242 / V.2-246 - V.2-247	IW 33	£1,632.68	
3500038413	18.12.09	Ventnor Coastal Repairs	V.2-268	IW 33	£150.00	
3500048483	16.03.10	2010-11 Ventnor Repairs	V.2-279	IW 33	£200.00	
3500067248	04.08.10	Ventnor - Fort Vic Promenade Repairs	V.2-295	IW 33	£490.00	
3500083921	02.02.11	Repairs to Promenade and Steps Ventnor	V.2-315	IW 33	£100.00	
3500094964	07.06.11	Ventnor Repairs	V.2-327	IW 33	£376.66	
3500094964	07.06.11	Ventnor Repairs	V.2-280	IW 33	£376.66	
3500099126	19.07.11	Removal of dumped moorings	V.2-332	IW 33	£474.00	
3500113698	10.02.12	Eastern Esplanade Joint Repairs	V.2-353	IW 33	£1,750.00	
3500113697	01.02.12	Promenade joint repairs - Wheelers Bay	V.2-353	IW 33	£1,309.49	

3500128036	09.07.12	Ventnor Coastal Repairs	V.2-365 / V.2-384 / V.2-387	IW 33	£738.46	
3500139849	11.12.12	V.2-390 V.2-401 Ventnor Repairs	V.2-401	IW 33	£775.00	
3500148417	10.04.13	V.2-417 Cliff fall removal - Wheelers Bay	V.2-417	IW 33	£1,375.00	1,375.00
3500148946	26.04.13	V.2-430 Wheelers Bay Repairs	V.2-430	IW 33	£1,585.00	
3500150145	14.05.13	V.2-422 V.2-427 V.2-430 Ventnor Repairs	V.2-422 / V.2-427 / V.2-430	IW 33	£1,482.13	
3500150397	20.05.13	V.2-436 Wheelers bay Repair	V.2-436	IW 33	£295.00	
3500158799	14.10.13	Ventnor Coastal Repairs	V.2-447 / V.2-456	IW 33	£327.25	
3500162384	18.12.13	V.2-470 Damaged wave return repair	V.2-470	IW 33	£745.00	
3500163573	20.01.14	V.2-468 - V.2-471 Ventnor Repairs	V.2-471	IW 33	£200.00	
3500166654	07.03.14	Ventnor Repairs	V.2-480	IW 33	£275.00	
3500181698	12.01.15	V.2-527 Ventnor Repairs	V.2-527	IW 33	£185.60	
3500183799	19.02.15	V.2-536 Ventnor Promenade Repairs	V.2-536	IW 33	£990.00	
3500184383	04.03.15	V.2-503 - V.2-535 - V.2-534 Ventnor	V.2-535	IW 33	£75.00	
3500190208	24.06.15	V.2-551 Ventnor Void Repair	V.2-551	IW 33	£1,120.00	
3500190927	09.07.15	V.2-551 ventnor - Concrete	V.2-551	IW 33	£140.00	
3500198226	21.12.15	Ventnor Coastal Repairs	V.2-565	IW 33	£168.50	
3500184017	24.02.15	Coastal Survey Work, Ventnor		IW 33	£750.00	
3500205220	17.06.16	Coastal work in Ventnor	V.2-419	IW 33	£1,767.37	
				TOTAL	£23,761.08	
3500102260	31.08.11	Repairs to Ventnor Haven Railings	V.2-348	IW 34	£124.00	
T. Stillman	01.02.13	V.2-403 Capital Projects - Ventnor Haven Railings	V.2-403	IW 34	£6,450.00	
3500184383	04.03.15	V.2-503 - V.2-535 - V.2-534 Ventnor	V.2-503	IW 34	£82.88	
3500207915	31.08.16	V.2-594 - V.2-595 Ventnor Railings	V.2-594	IW 34	£30.00	
T. Stillman	01.12.16	V.2-594 - V.2-595 Ventnor Railings	V.2-594	IW 34	£3,500.00	
				TOTAL	£10,186.88	
3500018178	27.07.09	Urgent repairs to Ventnor Railings	-	IW 35	£665.00	
3500048483	16.03.10	2010-11 Ventnor Repairs	V.2-278	IW 35	£120.00	
3500130922	17.08.12	Repairs to damaged railing - Ventnor	V.2-389 / V.2-393	IW 35	£112.00	
3500133130	19.09.12	Coastal Repairs - Ventnor - Ryde - Bem	V.2-389	IW 35	£145.59	
T. Stillman	01.12.12	V.2-289 Spyglass Railings	V.2-289	IW 35	£6,836.00	
3500147776	09.04.13	V.2-426 Re-pointing Ventnor Esplanade	V.2-426	IW 35	£750.00	
3500148833	25.04.13	V.2-289 Ventnor Esplanade Railing Repair	V.2-289	IW 35	£241.80	
3500149086	29.04.13	V.2-425 Removal of material - Ventnor	V.2-425	IW 35	£539.58	
3500197309	30.11.15	V.2-567 - N.14-150 Railing Repairs	V.2-567	IW 35	£76.50	
3500203573	03.05.16	S.5-082 - V.2-581 Step Repairs	V.2-581	IW 35	£104.25	
3500207915	31.08.16	V.2-594 - V.2-595 Ventnor Railings	V.2-295	IW 35	£90.00	
T. Stillman	01.12.16	V.2-594 - V.2-595 Ventnor Railings	V.2-595	IW 35	£154.00	
				TOTAL	£9,834.72	
3500038413	18.12.09	Ventnor Coastal Repairs	V.2-268	IW 36	£150.00	
3500038413	18.12.09	Ventnor Coastal Repairs	V.2-240	IW 36	£80.00	
3500044113	10.02.10	Castle Cove Vegetation Clearance Works	V.2-252	IW 36	£651.90	
3500067248	04.08.10	Ventnor - Fort Vic Promenade Repairs	V.2-295	IW 36	£490.00	
3500093914	24.05.11	Castle Cove Coastal Works	V.2-141 / V.2-196 / V.2-305	IW 36	£595.00	
3500111198	13.12.11	Castale Cove Railing Reapirs	V.2-359 / V.2-360	IW 36	£200.00	
3500116260	05.03.12	Steephill Cove step encasement	V.2-306	IW 36	£2,350.00	
3500128036	09.07.12	Ventnor Coastal Repairs	V.2-368 / V.2-377	IW 36	£738.46	
3500133131	18.09.12	Shanklin - Lake - Ventnor Coastal Works	V.2-394	IW 36	£88.26	
T. Stillman	01.01.13	V.2-369 Steephill Cove Railing	V.2-328	IW 36	£6,927.00	
T. Stillman	01.01.13	V.2-328 Condition of Castle Cove Railing	V.2-328	IW 36	£3,187.00	
3500158799	14.10.13	Ventnor Coastal Repairs	V.2-397 / V.2-438	IW 36	£327.25	
3500167271	20.03.14	V.2-484 Reapir damaged railing	V.2-484	IW 36	£110.00	
3500169266	25.04.14	V.2-478 / V.2-485 / V.2-487 Steephill	V.2-478 / V.2-485 / V.2-487	IW 36	£1,600.00	
3500179036	05.11.14	V.2-519 - V.2-520 Ventnor Repairs	V.2-519	IW 36	£300.00	
3500189314	05.06.15	V.2-349 Replacement Information Panel	V.2-349	IW 36	£600.00	
3500198226	21.12.15	Ventnor Coastal Repairs	V.2-498 / V.2-511 / V.2-556 / V.2-524	IW 36	£168.50	
3500201345	01.03.16	V.2-557 Clearance of access road	V.2-557	IW 36	£410.00	
3500201344	01.03.16	V.2-573 Clearance - Castle Cove	V.2-573	IW 36	£500.00	
3500211528	14.12.16	Clearance Work	V.2-583 / V.2-590	IW 36	£455.00	
3500120745	20.04.12	V.2-357 Repairs to Castel Cove Promenade	V.2-357	IW 36	£3,375.00	
				TOTAL	£23,303.37	**CLIFF WORKS**
				TOTAL £ (exc. Vat)	**£91,131.51** (90 Months)	**BREAKDOWN £7,060.50** (90 Months)

(grey)	= Cliff clearance / Cliff Safety Works
(green)	= Purchase orders raised by P. Marsden
(grey)	= Purchase orders raised by P. Marsden on behalf of L. Ellison
(yellow)	= Purchase order raised by Tricia Stillman (Capital Works - Coastal Fencing)

Undercliff Strategy Study frontage owned or maintained by the Isle of Wight Council

Maintenance cost review period = 90 Months

£91131.51 / 90 months = £1012.57 (per month average for the Undercliff Strategy Frontage over 90 month period - Isle of Wight Council)

£91131.51 / 7.5 = £12150.87 (annual average for the Undercliff Strategy Frontage over 90 month period - Isle of Wight Council)

NOTE:
Ventnor Haven / Castle Haven Maintenance Works not included

TOTAL £ (exc. Vat)	**£1,012.57** (monthly average)
TOTAL £ (exc. Vat)	**£12,150.87** (annual average)

Appendix 10. Defence Appraisal assessment

FINAL

Ventnor Initial Appraisal and Scheme Identification Study (Lot 2) - Defence Appraisal Report

Prepared for

Isle of Wight Council

Dec 2017

CH2M
Lyndon House,
62 Hagley Road,
Edgbaston
Birmingham
B16 8PE

Contents

Document Control

Version	Date	Author	Approved by
Draft for Client comments	June 2017	Jon Denner	Geoff Davis
Final Draft	December 2017	Jon Denner	Geoff Davis

Introduction

This defence appraisal report covers the coastal defences at Ventnor on the Isle of Wight, from Monks Bay to Steephill Cove, as shown by Figure 1. The frontage includes Policy Units IW 30 through to IW 36 from the Isle of Wight Shoreline Management Plan 2 (SMP2) (IWC, Royal Haskoning, EA 2010).

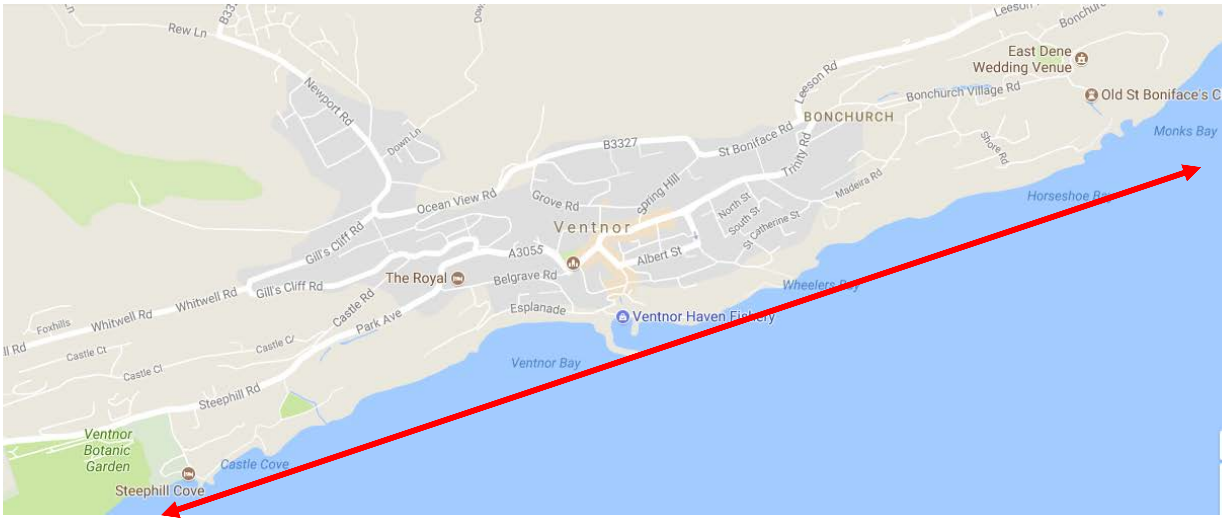


Figure 1: Defence Appraisal Extents

The main purpose of this document is to provide an up to date baseline on the condition of the various coastal defences and features along this frontage, and to appraise these defences in terms of their failure probability.

This report was based on the following information sources:

- Isle of Wight Shoreline Management Plan 2 (IWC, Royal Haskoning, EA 2010).
- South Wight Defence Appraisal (IWC, June 2016)
- Various IWC condition survey reports for specific defences (see Appendix A)
- Visual inspection from a site walkover on 27th and 28th March 2017
- Discussions with Luke Ellison, Coastal Engineer from IWC
- Coastal monitoring data provided through CCO (beach profiles, laser scans of Wheelers Bay)

Summary of defence appraisal

The Isle of Wight Council provided the South Wight Defence Appraisal (IWC, June 2016), which was an update to the defence appraisal that was included in the SMP (IWC, Royal Haskoning, EA 2010). This document has been updated based on the site visit in March 2017 and is presented in this section. A more detailed assessment is provided in the following section of this report.

The condition grade assigned to each defence is appraised relative to the Environment Agency's Condition Assessment Manual, with a Condition Grade 1 being the best condition through to Condition Grade 5, which represents a defence in a very poor or failed condition.

Location and Natural Features	Defence History	Description	Condition Summary	Defence Element	Present Condition (grade)
SWSS - Unit IW 30 **MONKS BAY** OS Grid Reference: **SZ58092, 78132** **SZ57843, 77925** Length: **350m** Brown Carstone and yellow sandrock cliff capped with gault clay. Recharged shingle beach protecting cliff toe. Scattered outlying boulders.	**IW 30 / 001** Concrete groynes constructed around 1900, surrounded with rock armour in 1992. Seawall and rock groyne constructed 1992. **IW 30 / 002** Cliff stabilisation and drainage, reconstruction of sea wall, rock groynes and off shore break water and beach nourishment programme completed 1992. **IW 30 / 003** Concrete groynes constructed around 1900, surrounded with rock armour in 1992-1994.	**IW 30 / 001** Remains of concrete structure. Concrete groyne with rock buttressing to both sides. Concrete seawall with concrete buttress blocks and rock armouring of crest level +4.0m Ordnance Datum Newlyn (ODN). Concrete groyne with rock buttressing to both sides. Concrete decked footway to the rear of the sea wall. Concrete steps with timber handrail. Outfall flap valve. **IW 30 / 002** Rock groyne at eastern end of the main beach. Off shore rock armour breakwater of crest level +2.2m Ordnance Datum Newlyn (ODN), with recharged beach section constructed to +3.0m above Ordnance Datum Newlyn (ODN). The natural rock reef is seen seaward of the breakwater. **IW 30 / 003** Short section of concrete wall with wave return profile. Concrete ramp. Concrete access road to the beach. Short section of concrete wall with wave return profile. Rock groyne at western end, incorporating surface water outlet. Steel sheet piled outfall structure.	**IW 30 / 001** Defences generally in good condition but protection from re-activation of landslides depends on the vulnerability of wall, which in turn depends on wave exposure and the stability/geometry of the wall toe rock. **IW 30 / 002** Rock structures are performing relatively well but relatively onerous shingle recycling requirement due to beach exposure in the bay to the west of the breakwater. **IW 30 / 003** Rock of the groyne is protecting the old concrete groyne and outfall. The good condition of the concrete wall and ramp is dependent on the continual recycling of beach material to this area.	Concrete wall Concrete groynes Rock at wall toe Rock groynes **Overall** Rock groynes Rock breakwater Beach **Overall** Concrete wall Rock groynes **Overall**	Good (G2) Fair (G3) Good (G2) Good (G2) **Good (G2)** Good (G2) Good (G2) Fair (G3) **Good (G2)** Fair (G3) Good (G2) **Fair (G3)**
SWSS - Unit IW 31 **BONCHURCH**	**IW 31 / 001** Concrete groynes constructed around 1900, surrounded with rock armour in 1992 -	**IW 31 / 001** Concrete sea wall with raised parapet of crest level +4.5m Ordnance Datum Newlyn (ODN). Wave return to wall coping and stepped apron. Rock groynes at each end of frontage. Concrete	**IW 31 / 001** Concrete seawalls are aging structures but no significant structural compromise identified. Rock structures helping to	Concrete walls Rock groynes Rock at wall toe **Overall**	Fair (G3) Good (G2) Fair (G3) **Fair (G3)**

Location and Natural Features	Defence History	Description	Condition Summary	Defence Element	Present Condition (grade)
OS Grid Reference: **SZ57843, 77925** **SZ57007, 77579** Length: **983m** Coastal structure protects toe of lower chalk and upper greensand cliffs. Sandy cobble foreshore. Scattered outlying boulders.	1994. Seawall constructed 1979. **IW 31 / 002** Seawall Wheelers Bay to Bonchurch completed 1988.	slipway to beach, ends onto stepped apron. Rock armouring. **IW 31 / 002** Concrete and masonry groyne, buttressed on both sides with rock armouring. Concrete slipway. Outfall flap valve. Concrete sea wall with stepped apron above sheet piled toe parapet of crest level +4.1m Ordnance Datum Newlyn (ODN). Wave return coping section with concrete decking to rear. Timber catch fencing at rear of decking, below cliffs. Two concrete step blocks. Short timber groyne, and remains of old triangular segment flexible groyne (Mobs and English design). Concrete steps. Short timber groyne, and remains of old triangular segment flexible groyne (Mobs and English design). Concrete steps. Concrete slipway. Short timber groyne, and remains of old triangular segment flexible groyne (Mobs and English design). Two concrete steps. Short timber groyne, and remains of old triangular segment flexible groyne (Mobs and English design). Colin's Point outfall. Concrete and masonry groyne around disused outfall pipe. Timber groyne at western end of sea wall.	stabilise bays and prevent undermining of the concrete walls **IW 31 / 002** Main structure is in good to very good condition but overall structure is partly compromised by locally high rates of abrasion damage in the apron, which is exposing steel reinforcement in some locations.	Concrete wall Timber groynes Rock at wall toe **Overall**	Good (G2) Poor (G4) Good (G2) **Good (G2)**
SWSS - Unit IW 32 WHEELERS BAY OS Grid Reference:	**IW 32 / 001** Seawall constructed 1960.	**IW 32 / 001** Concrete steps. Sheet piled toe to concrete sea wall, with wide apron. Stepped toe to sloping concrete revetment of crest level +4.1m Ordnance Datum Newlyn (ODN). Concrete decking.	**IW 32 / 001** Sheet piled toe has failed resulting in significant loss of material under the concrete apron. Despite this, the upper revetment remains in fair condition but overall structure is severely compromised by the toe failure.	Concrete revetment **Overall**	V. Poor (G5) **V. Poor (G5)**

Location and Natural Features	Defence History	Description	Condition Summary	Defence Element	Present Condition (grade)
SZ57007, 77579 **SZ56854, 77431** Length: **283m** Coastal structure protects toe of lower chalk and upper greensand cliffs. Boulder strewn foreshore.	**IW 32 / 002** New concrete toe to existing wall, new concrete slipway. Additional rock armouring. Wheelers Bay Coastal Protection Work completed 1993. Wheelers Bay Coast Protection and Slope Stabilisation Scheme completed Spring 2000.	**IW 32 / 002** Concrete slipway. Concrete wall and rock armouring of crest level +4.3m Ordnance Datum Newlyn (ODN). Remains of timber groyne and outfall. Two outfall flap valves.	**IW 32 / 002** Structure in very good overall condition with no observations of structural stresses in the structure.	Concrete wall Rock revetment **Overall**	V. Good(G1) V. Good(G1) **V. Good(G1)**
	IW 32 / 003 Toe piling 1970. Seawall constructed 1984. Rock armour installed 1984.	**IW 32 / 003** Concrete sea wall with battered face and coping with wave return and rock armouring of crest level +5.6m Ordnance Datum Newlyn (ODN). Outfall. Remains of timber breast work.	**IW 32 / 003** Structure does not provide the equivalent standard of protection as the adjacent, newer IW 32 / 002. No signs of structural failure but rock at toe is of inconsistent size/geometry.	Concrete wall Rock armour **Overall**	Good (G2) Good (G2) **Good (G2)**
SWSS - Unit IW 33 **EASTERN CLIFFS, VENTNOR** OS Grid Reference: **SZ56854, 77431** **SZ56587, 77323**	**IW 33 / 001** Toe piling 1970. Seawall constructed 1984. Tetrapod's installed 1990. Seawall encased 1990.	**IW 33 / 001** Concrete sea wall with battered face and coping with wave return of crest level +5.6m Ordnance Datum Newlyn (ODN). Precast concrete 'tetrapod' units armouring to wall base. Masonry buttress. Remains of timber groyne.	**IW 33 / 001** Ground movement is observed and it is likely this is from deep failure in the chalk. Ground movement has resulted in displacement of the seawall structure and this has been patch repaired but no measures implemented to reduce further movements. Tetrapods remain functional but many have been damaged.	Concrete seawall Tetrapod **Overall**	Poor (G4) Fair (G3) **Poor (G4)**
Length: **300m**	**IW 33 / 002** Original wall construction around	**IW 33 / 002** Concrete steps. Concrete sea wall with steel sheet piled toe, wide toe apron and sloping	**IW 33 / 002** Sheet piled toe has failed resulting in loss of material under the concrete apron.	Concrete wall **Overall**	V. Poor (G5) **V. Poor (G5)**

Location and Natural Features	Defence History	Description	Condition Summary	Defence Element	Present Condition (grade)
Coastal structure protects toe of lower chalk and upper greensand cliffs. Boulder strewn foreshore.	1900. Toe piling and apron constructed 1970.	revetment face above stepped base of crest level +6.0m Ordnance Datum Newlyn (ODN). The wall has a wave return section. Concrete slipway.	Despite this, the upper revetment remains in fair condition but overall structure is severely compromised by the toe failure.		
SWSS – Unit IW 34 VENTNOR HAVEN & EASTERN ESPLANADE OS Grid Reference: **SZ56587, 77323 SZ56291, 77341** Length: **834m** Boulder strewn foreshore. Sandy beach with splays of fine brown flint and chert shingle.	**IW 34 / 001** Collins Point to Swale Groyne Rock Revetment completed June 1995. Seawall reconstructed 1995. Road realignments encasement works completed 2008. **IW 34 / 002** Ventnor Haven completed August 2003. **IW 34 / 003** Southern Water 'Lion Point' pumping station completed 2002.	**IW 34 / 001** Concrete coping section with wave return of crest level +5.9m Ordnance Datum Newlyn (ODN), reinforced at the base with rock Armouring. Concrete and sandbag buttress. Stone masonry sea wall, reinforced at the base with rock armouring. Concrete coping section with wave return. Collins point Outfall surrounded by concrete, sheet piling. Wide former concrete slipway (now disused) at western end of wall. Recent concrete encasement section. **IW 34 / 002** Short rock armoured breakwater arm constructed to a level of +5.5m above Ordnance Datum Newlyn (ODN). Navigation aid. Pontoons. Ventnor haven fishery building. Rock armour breakwater arm to the western end of the haven, with a concrete decked walkway. Navigation aid. Remains of steel sheet piled slipway structure. **IW 34 / 003** Masonry wall fronting Southern Water Pumping Station.	**IW 34 / 001** Good condition of wall and rock armour with no signs of structural stress/damage. **IW 34 / 002** All structures appear to be in very good condition with no cause for concern. **IW 34 / 003** All structures appear to be in very good condition with no cause for concern.	Concrete wall Rock at wall toe **Overall** Rock breakwaters **Overall** Concrete wall Rock revetment **Overall**	Good (G2) Good (G2) **Good (G2)** V. Good (G1) **V. Good (G1)** V. Good (G1) V. Good (G1) **V. Good (G1)**

Location and Natural Features	Defence History	Description	Condition Summary	Defence Element	Present Condition (grade)
	IW 34 / 004 Southern Water 'Lion Point' pumping station completed 2002.	**IW 34 / 004** Stepped concrete revetment.	**IW 34 / 003** All structures appear to be in very good condition with no cause for concern.	Conc. revetment **Overall**	V. Good (G1) **V. Good (G1)**
SWSS - Unit IW 35 **VENTNOR BAY & WESTERN CLIFFS** OS Grid Reference: **SZ56291, 77341** **SZ55306, 76958** Length: **1117m** Sandy beach with splays of fine brown flint and chert shingle. Rock revetment protects lower chalk and upper greensand cliffs. Boulder strewn foreshore.	**IW 35 / 001** Seawall constructed 1848. Seawall refaced 1995. **IW 35 / 002** Seawall constructed 1848. Concrete encasement to existing wall completed 1992. Ventnor Western Cliffs Rock Revetment completed 1992. **IW 35 / 003** Seawall constructed 1848. Concrete encasement to existing wall completed 1992.	**IW 35 / 001** Concrete slipway. Concrete sea wall with stone facing constructed to a level of +4.5m above Ordnance Datum Newlyn (ODN). Concrete coping with decorative cast iron hand railing. Double concrete and stone step access. Timber access steps. Low timber revetment. Two sets of timber access steps. Double concrete and stone step access. Stone faced buttress. Single concrete and stone step access. Three stone faced buttresses. Timber piled groyne and walings. **IW 35 / 002** Stone masonry wall with concrete toe encasement and rock armour revetment fronting the 'Spyglass' Inn. **IW 35 / 003** Stone masonry wall, concrete toe encasement and rock armour revetment.	**IW 35 / 001** Seawall in good condition with no cause for concern. Localised bulging of wall may require a local repair. Beach relatively stable. **IW 35 / 002** Defence strengthened in 1992 with lower encasement and low rock revetment is in good condition with no cause for concern. **IW 35 / 003** Small infill section of wall, which is compromised by groundwater flows through the structure. High retained height.	Concrete seawall **Overall** Seawall Rock revetment **Overall** Seawall Rock revetment **Overall**	Good (G2) **Good (G2)** Good (G2) Good (G2) **Good (G2)** Poor (G4) Good (G2) **Poor (G4)**

Location and Natural Features	Defence History	Description	Condition Summary	Defence Element	Present Condition (grade)
	Ventnor Western Cliffs Rock Revetment completed 1992. **IW 35 / 004** Seawall constructed 1950. Ventnor Western Cliffs Rock Revetment completed 1992. **IW 35 / 005** Ventnor Western Cliffs Rock Revetment completed 1992. Flowers brook outfall encasement 1992.	**IW 35 / 004** Concrete block wall with slight batter and wave return. Faced with cement rendering of crest level +2.3m Ordnance Datum Newlyn (ODN). Rock armour revetment. **IW 35 / 005** Three rock groynes. Remains of timber groynes. Flowers brook sewage outfall encased with steel sheet piles / concrete and protected with rock armour constructed to a level of +4.5m above Ordnance Datum Newlyn (ODN). Steep near vertical cliffs consisting of weak chalks and marls. Rock armour revetment along base of cliff. Terminal rock groyne.	**IW 35 / 004** Damage to the rendering of seawall but overall good condition in combination with the rock revetment. **IW 35 / 005** Rock groynes and continual rock revetment at toe of cliff in good condition.	Seawall Rock revetment **Overall** Rock groynes Rock revetment **Overall**	Poor (G3) Good (G2) **Good (G2)** Good (G2) Good (G2) **Good (G2)**
SWSS - Unit IW 36 **CASTLE COVE & STEEPHILL COVE** OS Grid Reference: **SZ55306, 76958** **SZ54969, 76828** Length: **484m**	**IW 36 / 001** Castle Cove, Ventnor Coast Protection Scheme completed 1996. **IW 36 / 002** Castle Cove, Ventnor Coast Protection Scheme completed 1996.	**IW 36 / 001** Concrete slipway. Rock armour revetment supporting concrete decked access track to Steephill Cove constructed to a level of +4.0m above Ordnance Datum Newlyn (ODN). Stone filled gabion basket rear splash wall. Two concrete step blocks. Terminal rock groyne. Outfall. **IW 36 / 002** Timber pole cribwork groyne, buttressed on all sides and infilled with rock armour stone constructed to a level of +2.95m above Ordnance	**IW 36 / 001** Other than some small movements of the revetment around the steps, these defences are in very good condition but are critical to the stability of the cliffs. **IW 36 / 002** Rock structure appears stable and makes timber elements largely sacrificial/redundant.	Rock groynes Rock revetment Gabions **Overall** Rock groyne **Overall**	V. Good (G1) Good (G2) Good (G2) **Good (G2)** V. Good (G1) **V. Good (G1)**

Location and Natural Features	Defence History	Description	Condition Summary	Defence Element	Present Condition (grade)
Rock revetment protects coastal slope. Sandy beach with splays of fine brown flint and chert shingle. Cobble / boulder strewn foreshore. Subsided greensand cliff at Steephill Cove.		Datum Newlyn (ODN). Concrete buttress. Terminal rock armour groyne.			
	IW 36 / 003 Steephill Cove Coast Protection Scheme completed 1992.	**IW 36 / 003** Toe piled wall encased with concrete and fronted with Purbeck stone. Concrete coping, flush with promenade decking of crest level +4.0m Ordnance Datum Newlyn (ODN). Low splash wall in Purbeck stone and concrete coping at rear of promenade. Rock armour revetment to front of wall. Concrete step block. Concrete slipway.	**IW 36 / 003** Defences constructed in 1992 are in good condition but defences may vulnerable to beach lowering during storms and geotechnical failure.	SSP/conc wall Rock at wall toe **Overall**	Good (G2) Good (G2) **Good (G2)**
	IW 36 / 004 Steephill Cove Coast Protection Scheme completed 2006.	**IW 36 / 004** Private terrace's with masonry stone walls. Encased concrete apron. Island stone masonry wall constructed to a level of +4.25m above Ordnance Datum Newlyn (ODN). Concrete slipway.	**IW 36 / 004** Defences constructed in 2006 are in very good condition but defences may vulnerable to beach lowering during storms and geotechnical failure.	Conc/stone seawall Rock revetment **Overall**	V. Good (G1) V. Good (G1) **V. Good (G1)**
	IW 36 / 005 Rock armour groyne enhanced during Steephill Cove Coast Protection Scheme 2006.	**IW 36 / 005** Timber pole and plank groyne. Concrete wall. Rock armour groyne.	**IW 36 / 005** Rock groyne is functioning but is not of robust design/construction. No signs of structural stress in the concrete seawall.	Rock groyne Concrete wall **Overall**	Good (G2) Good (G2) **Good (G2)**
	IW 36 / 006 Stepped apron constructed 1992.	**IW 36 / 006** Concrete step block. Concrete stepped apron. Stone masonry wall.	**IW 36 / 006** Structures are showing no signs of structural stress and no defects detected.	Conc/stone wall **Overall**	Good (G2) **Good (G2)**
	IW 36 / 007 Seawall constructed around 1950. Wave	**IW 36 / 007** Concrete wall with wave return.	**IW 36 / 007** Structures are showing no signs of structural stress and no defects detected.	Concrete wall Rock at wall toe **Overall**	Good (G2) Good (G2) **Good (G2)**

Location and Natural Features	Defence History	Description	Condition Summary	Defence Element	Present Condition (grade)
	return profile added to existing structure 2007. **IW 36 / 008** Seawall constructed around 1950. Rock armour groyne constructed during Steephill Cove Coast Protection Scheme 1992.	**IW 36 / 008** Short section of buttressed concrete wall constructed to a level of +4.1m above Ordnance Datum Newlyn (ODN). Rock armour revetment. Short rock armour groyne.	**IW 36 / 008** Old seawall which was previously vulnerable is now protected with rock revetment and a rock groyne, which appear to be functioning well with no signs of structural or geotechnical stress	Concrete wall Rock revetment Rock groyne **Overall**	Fair (G3) Good (G2) Good (G2) **Good (G2)**

Detailed defence appraisal

The defence appraisal sheets in this section provide more detail of these defences, their condition and identifies the likely failure mechanisms and an assessment on the probability of failure of these assets. This failure probability information will be used to inform the Quantitative Risk Assessment (QRA).

An annual failure probability has been estimated for each defence with an accompanying annual increase in failure probability reflecting how the defence is expected to deteriorate over time. This has been assessed considering a No Active Intervention (Do Nothing) maintenance programme. The failure probabilities have been appraised by selecting an appropriate probability failure curve as shown below in Figure 2.

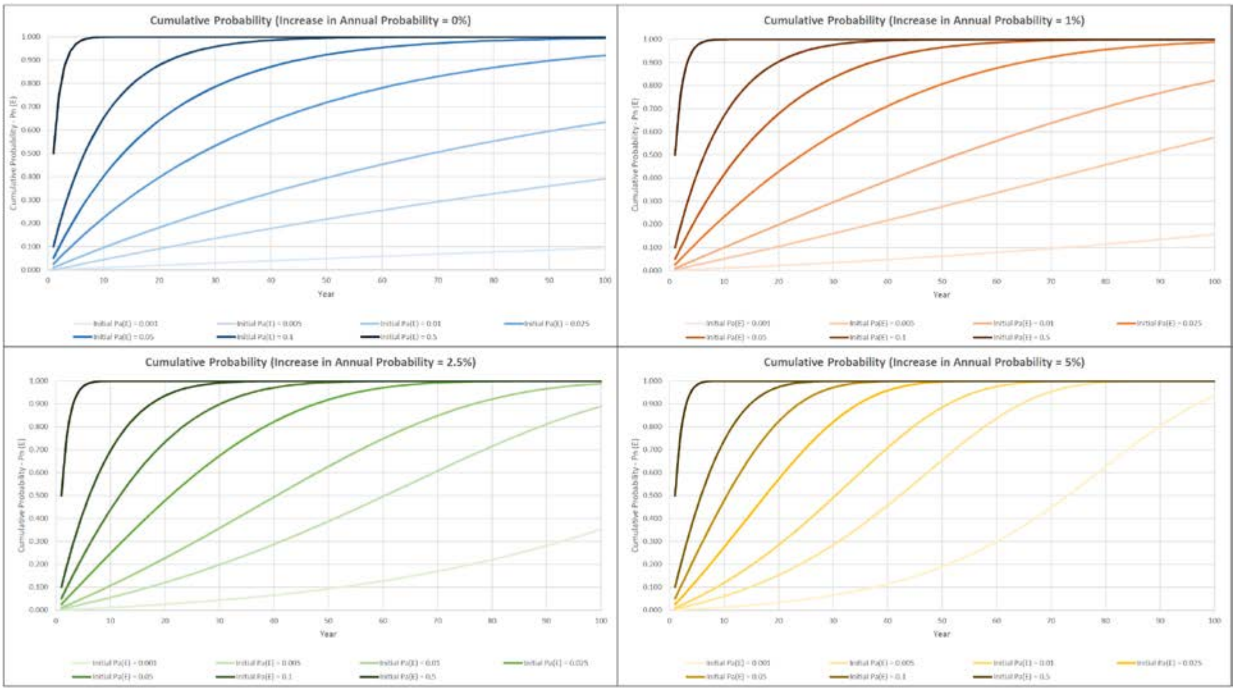


Figure 2: Failure Probability Curves

Defence ID	**IW 30 / 001**	*Description*	**Monks Bay – eastern bays**		
Construction	Concrete wall, concrete groynes with rock buttressing and rock groyne.				
Element Length	154 m	*Crest Details*	+4.0mAOD	*Maintenance*	IoW Council
Foreshore	Shingle beach with scattered boulders	*Structure dependency on foreshore*		High	

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete Wall**	**Concrete Groynes**	**Rock at Wall Toe**	**Rock Groynes**	**Overall**
Structure instability from undermining	Med	Low	Low	Low	Med
Foundation failure – global instability	Low	Low	Low	Low	Low
Foundation failure – settlement	Med	Unknown	Med	Low	Med
Wave forces on structure (unit instability)	Med	Low	Med	Med	Med
Joint failure and material washout	Low	Unknown	N/A	N/A	Low
Structure material failure – toe	Unknown	Unknown	Low	Low	Unknown
Structure material failure – main defence	Med	Med	Low	Low	Med
Wave overtopping – structural instability	Med	N/A	N/A	N/A	Med
Wave overtopping – flooding	Low	N/A	N/A	N/A	Low
Wave overtopping – safety compromised	Low	N/A	N/A	N/A	Low
Structure outflanking	Low	N/A	Low	N/A	Low
Other: Japanese Knotweed damage	Low	N/A	N/A	N/A	Low
Condition Grade (1 Very Good to 5 Very Poor)	2	3	2	2	2
Initial annual probability of failure	0.01	0.05	0.01	0.01	0.01
% increase in annual failure probability	2.5	1	1	1	2.5

Comments

- Defences prevent re-activation of landslides. Historical landslides evident, but no recent failures identified.
- No significant structural failures or damage was identified in main concrete sea wall. Its integrity will be largely determined by the degree of protection provided by the foreshore/beach and the rock protection placed in front of the structure.
- Concrete groynes are surrounded in rock, even if the concrete fails, the rock would continue to function as a groyne, hence overall standard of the frontage's defences is not compromised by the concrete groynes.
- Toe rock may have settled and may be undersized.
- Bays may not be receiving a regular feed of material.
- The overall residual life of the combined system of defences is likely to be linked to changes in wave climate at the seawall, which will require monitoring to determine the point at which the system is compromised.
- Japanese Knotweed identified behind wall (refer to IWC IW30-001 -V.2-294 coastal inspection report).

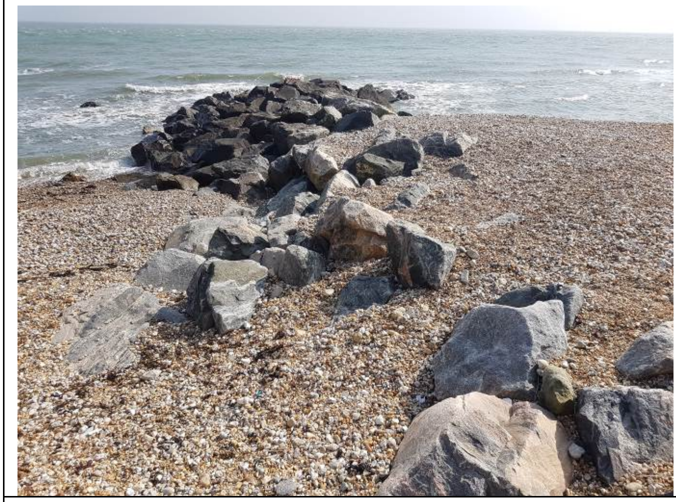
Photo 1:

Photo 2:

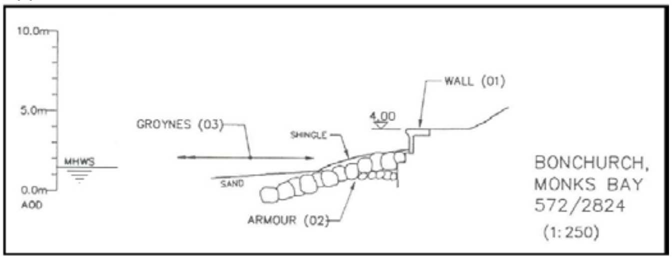
Photo 3:

Photo 4:

Photo 5:



Typical Section:



Map:

Defence ID	**IW 30 / 002**	*Description*	**Monks Bay – central bay and breakwater**		
Construction	Rock groyne to the east with detached breakwater and maintained beach				
Element Length	142 m	*Crest Details*	2.2mOD (rock) 3.0mOD (beach)	*Maintenance*	IoW Council
Foreshore	Shingle beach with some sand and offshore reef	*Structure dependency on foreshore*		Medium	

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Rock Groyne**	**Rock Breakwater**	**Beach**		**Overall**
Structure instability from undermining	Low	Low	Low		Low
Foundation failure – global instability	Low	Low	Low		Low
Foundation failure – settlement	Low	Low	N/A		Low
Wave forces on structure (unit instability)	Med	Med	N/A		Med
Joint failure and material washout	N/A	N/A	N/A		N/A
Structure material failure – toe	Low	Low	N/A		Low
Structure material failure – main defence	Low	Low	N/A		Low
Wave overtopping – structural instability	Low	Low	N/A		Low
Wave overtopping – flooding	N/A	N/A	N/A		N/A
Wave overtopping – safety compromised	N/A	N/A	Low		N/A
Structure outflanking	Low	N/A	N/A		N/A
Other: Shingle movements	N/A	N/A	High		High
Condition Grade (1 Very Good to 5 Very Poor)	2	2	3		2
Initial annual probability of failure	0.01	0.01	0.05		0.05
% increase in annual failure probability	2.5	1	5		5

Comments

- Rock structures are robust structures and even in the event of localised damage these structures would continue to function adequately. Any deterioration in function of these structures would be slow.
- Protection to hinterland is reliant on regular recycling of beach material from the northeast to the southwest. Without this ongoing beach maintenance the slopes behind the western bay would become more exposed and access to the beach would become compromised (direct impact on local fishermen).
- Tombolo behind breakwater is extensive and stable.
- IWC have advised of settlement of the breakwater and localised damage to rock armour

Photo 1:

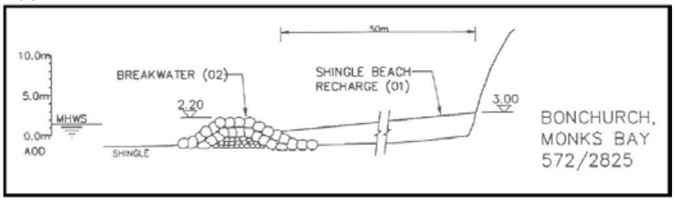
Photo 2:

Photo 3:

Photo 4:

Photo 5:

Typical Section:



Map:

Defence ID	**IW 30 /003**	*Description*	**Monks Bay – western end of bay**		
Construction	Concrete seawall and ramp, rock groyne and outfall				
Element Length	54 m	*Crest Details*	Unknown	*Maintenance*	IoW Council
Foreshore	Shingle/rock	*Structure dependency on foreshore*		Medium	

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete Wall**	**Rock Groyne**			**Overall**
Structure instability from undermining	Med	Low			Med
Foundation failure – global instability	Low	Low			Low
Foundation failure – settlement	Low	Low			Low
Wave forces on structure (unit instability)	Low	Med			Med
Joint failure and material washout	Low	N/A			Low
Structure material failure – toe	Unknown	Low			Unknown
Structure material failure – main defence	Med	Low			Med
Wave overtopping – structural instability	Med	Low			Med
Wave overtopping – flooding	Low	Low			Low
Wave overtopping – safety compromised	Med	Low			Med
Structure outflanking	Low	Low			Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	3	2			3
Initial annual probability of failure	0.02	0.005			0.02
% increase in annual failure probability	2.5	1			2.5

Comments

- Defence standard is strongly linked to beach levels, which are controlled by the gap opening between the breakwater of IW 30 / 002 and the rock groyne (extension of groyne may increase protection to Monks Bay).
- Users of the ramp (fishermen) have in the past maintained the beach levels at the ramp to retain access to the beach. This is in addition to formal shingle recycling typically undertaken annually by IoW at a cost of £3k to £4k per year. This typically involves moving shingle from the bay to the north of the breakwater to the ramp/seawall area of IW 30 / 003. Post-storm loss of beach material has been recorded (refer to IWC IW30-002-003 -V.2-580 coastal inspection report).
- If beach maintenance ceased then the susceptibility to wall undermining would likely increase to High as wall foundations are not very deep and are regularly exposed.

Photo 1:

Photo 2:

Photo 3:

Photo 4:

Photo 5:

Map:

Defence ID	**IW 31 / 001**	*Description*	**Bonchurch – eastern bays**		
Construction	Concrete seawalls and rock groynes (rock surrounding old concrete groynes)				
Element Length	73 m	*Crest Details*	4.5mOD	*Maintenance*	IoW Council
Foreshore	Shingle/boulders	*Structure dependency on foreshore*		Medium	

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete Walls**	**Rock Groynes**	**Rock at Wall Toe**		**Overall**
Structure instability from undermining	Med	Low	Low		Med
Foundation failure – global instability	Low	Low	Low		Low
Foundation failure – settlement	Low	Low	Med		Low
Wave forces on structure (unit instability)	Low	Low	High		Med
Joint failure and material washout	Med	N/A	N/A		Med
Structure material failure – toe	Med	N/A	N/A		Med
Structure material failure – main defence	Med	Low	Med		Med
Wave overtopping – structural instability	Low	Low	N/A		Low
Wave overtopping – flooding	Med	Low	N/A		Med
Wave overtopping – safety compromised	Med	Low	N/A		Med
Structure outflanking	Low	Low	N/A		Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	3	2	3		3
Initial annual probability of failure	0.02	0.005	0.01		0.02
% increase in annual failure probability	2.5	1	1		2.5

Comments

- Extents of rock toe protection and depth of shingle over toe unknown. From site observations and IWC IW31-001-V.2-554 coastal inspection report, it appears that there is some rock at each end of the bay but an absence of any formal or appropriately sized rock in the main central sections.
- Extent of movement of toe rock unknown but likely to have been displacement as rock appears relatively small.
- Whilst the concrete seawalls are old structures, they appear to be warn rather than critically compromised, hence overall rating of fair. Locally there was some reinforcement exposed in the toe in 2015 (refer to IWC IW31-001-V.2-554 coastal inspection report). Condition will continue to deteriorate but addition of toe rock has extended the life of these structures.

Photo 1:

Photo 2:

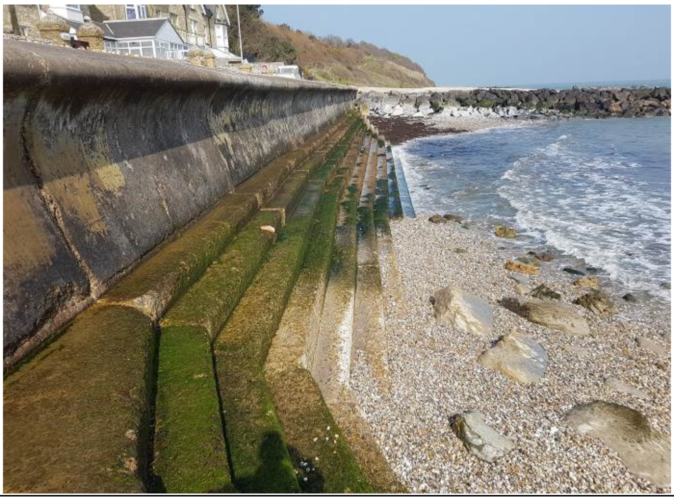
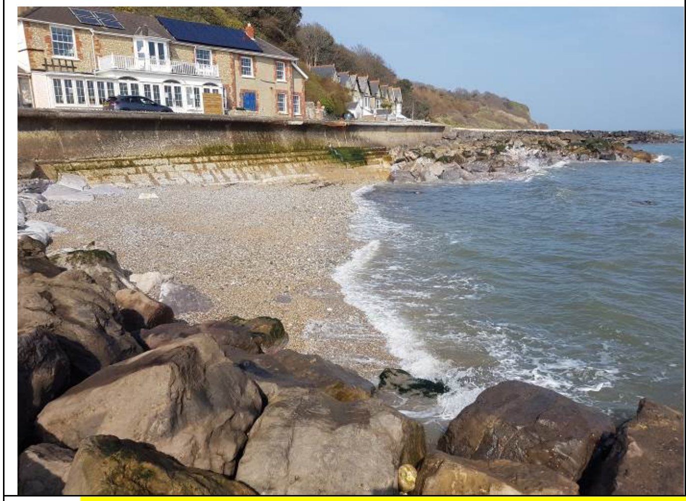


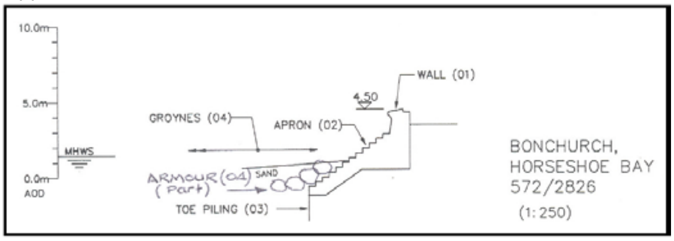
Photo 3:

Photo 4:

Photo 5:



Typical Section:



Map: NOTE – IMAGE INCORRECT AS WALL IN BOTH BAYS AND MIDDLE/WESTERN GROYNE SHOULD BE 31 / 001

Defence ID	**IW 31 / 002**	*Description*	**Bonchurch – cliffs**		
Construction	Concrete seawall with beach control rock groynes at bay ends. Seawall is stepped with rock armour at toe.				
Element Length	910 m	*Crest Details*	+4.1mOD	*Maintenance*	IoW Council
Foreshore	Shingle/boulder/rock	*Structure dependency on foreshore*	Medium		

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete Wall**	**Timber Groynes**	**Rock at Wall Toe**		**Overall**
Structure instability from undermining	Med	Low	Low		Med
Foundation failure – global instability	Low	Low	Low		Low
Foundation failure – settlement	Low	Low	Med		Low
Wave forces on structure (unit instability)	Low	High	Med		Med
Joint failure and material washout	Med	N/A	N/A		Med
Structure material failure – toe	High	N/A	N/A		High
Structure material failure – main defence	Low	High	Low		Low
Wave overtopping – structural instability	Med	Low	N/A		Med
Wave overtopping – flooding	Low	Low	N/A		Low
Wave overtopping – safety compromised	High	Low	N/A		High
Structure outflanking	Low	Low	Low		Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	2	4	2		2
Initial annual probability of failure	0.005	0.05	0.005		0.005
% increase in annual failure probability	5	1	1		5

Comments

- Localized severe abrasion of lower concrete apron platform of structure with reinforcement exposed. Upper sections of seawall generally in very good condition.
- Groynes are in a poor condition but it is not expected that a beach could be held with existing groyne spacing, so function of groynes is largely redundant. Hence, overall condition of defence system remains good as largely dependent on the concrete seawall.
- Risk of structure undermining being managed by rock over the wall toe.
- Historically, cliff falls have damaged the catch fence at the back of the promenade, but such occurrences do not compromise the coastal defence structure.

Photo 1:

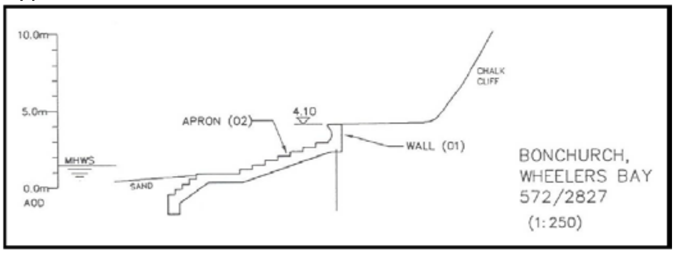
Photo 2:

Photo 3:

Photo 4:

Photo 5:

Typical Section:



Map:

Defence ID	**IW 32 / 001**	*Description*	**Wheelers Bay – eastern section**
Construction	Concrete return wall over concrete revetment with wide apron and sheet piled toe.		

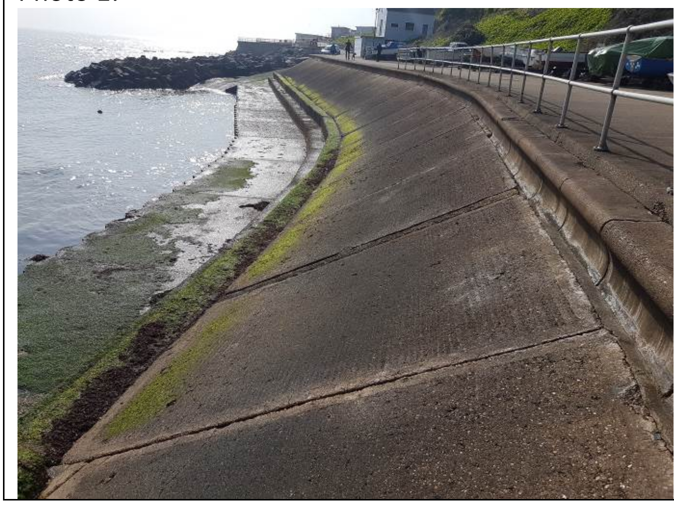
Element Length	133 m	*Crest Details*		*Maintenance*	IoW Council
Foreshore		*Structure dependency on foreshore*		High	

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete revetment**				**Overall**
Structure instability from undermining	High				High
Foundation failure – global instability	High				High
Foundation failure – settlement	Low				Low
Wave forces on structure (unit instability)	Low				Low
Joint failure and material washout	Med				Med
Structure material failure – toe	High				High
Structure material failure – main defence	Med				Med
Wave overtopping – structural instability	Low				Low
Wave overtopping – flooding	Med				Med
Wave overtopping – safety compromised	Med				Med
Structure outflanking	Low				Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	5				5
Initial annual probability of failure	0.2				0.2
% increase in annual failure probability	5				5

Comments

- Sheet piled toe is in a failed state (refer to IWC IW32-001-V.2-290 inspection report from 2010) with extensive eroded holes in the sheet piled toe and loss of fines from beneath the toe. The degree of corrosion should be expected to have worsened since this inspection but tide heights during March 2017 site visit prevented access to re-inspect.
- The extent of washout voids underneath the structure is unknown.
- Despite failure of the sheet piled toe, the revetment and the seawall remains in serviceable condition (no significant movements observed) and the overall structure could have residual life if the toe is reconstructed and voids filled (assuming voids do not extend fully under the structure).
- Beach levels remain low and the sheet piled toe remains exposed.

Photo 1:



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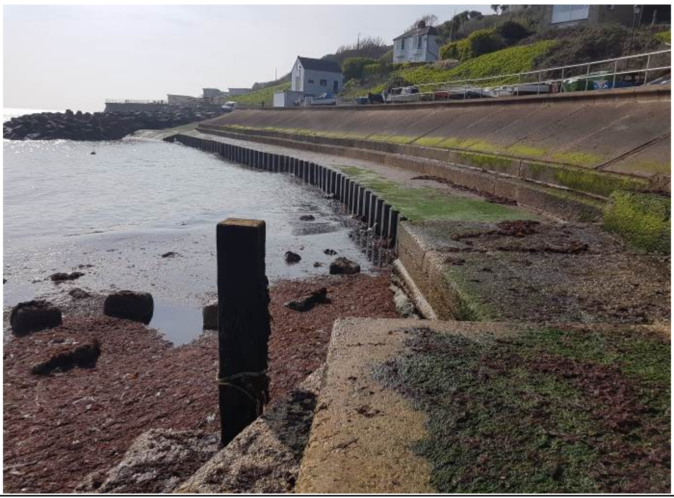
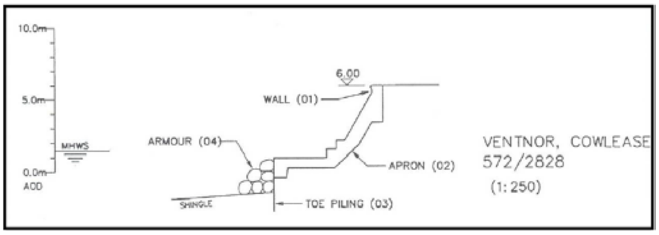


Typical Section:



Map:

Defence ID	**IW 32 / 002**	*Description*	**Wheelers bay – western section**		
Construction	Concrete seawall fronted by rock revetment with slipway				
Element Length	90 m	*Crest Details*	4.3mOD	*Maintenance*	IoW Council
Foreshore	Boulders		*Structure dependency on foreshore*		Low

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete Wall**	**Rock Revetment**			**Overall**
Structure instability from undermining	Low	Low			Low
Foundation failure – global instability	Low	Low			Low
Foundation failure – settlement	Low	Med			Med
Wave forces on structure (unit instability)	Low	Low			Low
Joint failure and material washout	Low	N/A			Low
Structure material failure – toe	Low	Low			Low
Structure material failure – main defence	Low	Low			Low
Wave overtopping – structural instability	Low	Low			Low
Wave overtopping – flooding	Low	Low			Low
Wave overtopping – safety compromised	Med	Low			Med
Structure outflanking	Low	Low			Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	1	1			1
Initial annual probability of failure	0.005	0.005			0.005
% increase in annual failure probability	2.5	1			2.5

Comments

- Structures were built in 1993 and in 2000 as part of the Wheelers Bay Protection and Slope Stabilisation Scheme. No stresses of the structures was observed.
- Rock appears to be in good condition but unknown if rock has settled since construction.
- Access to the slipway may be compromised by adjacent IW 32 / 001 defence condition.

Photo 1:

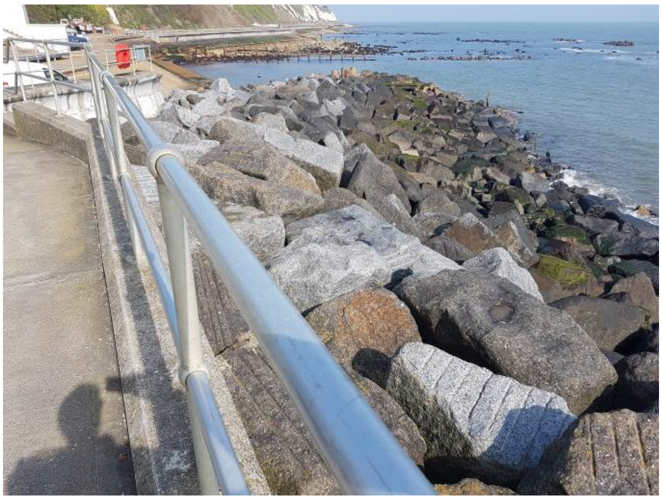
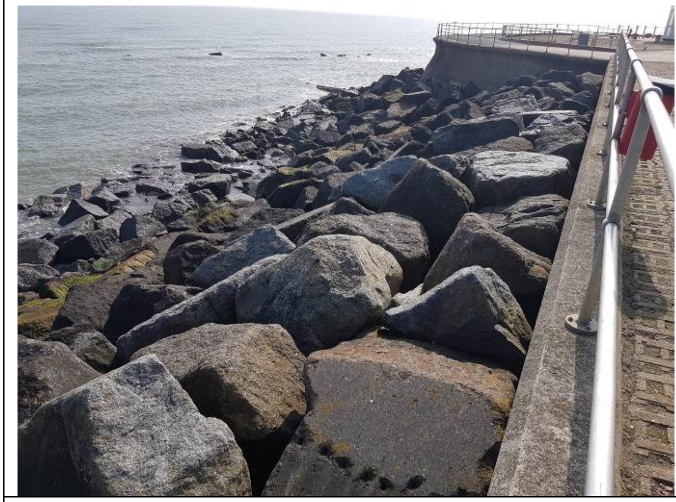
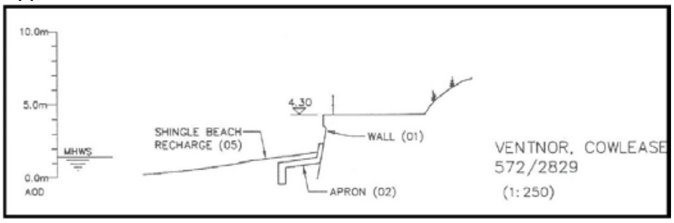


Photo 2:

Photo 3:	Typical Section:
	

Map:

Defence ID	**IW 32 / 003**	*Description*	**Wheelers Bay - point**		
Construction	Concrete seawall with rock armour at toe				
Element Length	60 m	*Crest Details*	4.1mOD	*Maintenance*	IoW Council
Foreshore	Boulders	*Structure dependency on foreshore*	Medium		

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete Wall**	**Rock at Wall Toe**			**Overall**
Structure instability from undermining	Low	Low			Low
Foundation failure – global instability	Low	Low			Low
Foundation failure – settlement	Low	Med			Med
Wave forces on structure (unit instability)	Low	Med			Med
Joint failure and material washout	Low	N/A			Low
Structure material failure – toe	Low	Low			Low
Structure material failure – main defence	Med	Med			Med
Wave overtopping – structural instability	Med	N/A			Med
Wave overtopping – flooding	Low	N/A			Low
Wave overtopping – safety compromised	Med	N/A			Med
Structure outflanking	Low	Low			Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	2	2			2
Initial annual probability of failure	0.01	0.01			0.01
% increase in annual failure probability	2.5	2.5			2.5

Comments

- No evidence of structure failures.
- Rock protection geometry and rock size/quality is not uniform, but does not appear to be adversely compromising the concrete seawall at present, hence, overall condition grade of Good.
- Rock protection and the concrete seawall is lower than adjacent IW 32 / 003, despite being in a more exposed location.

Photo 1:

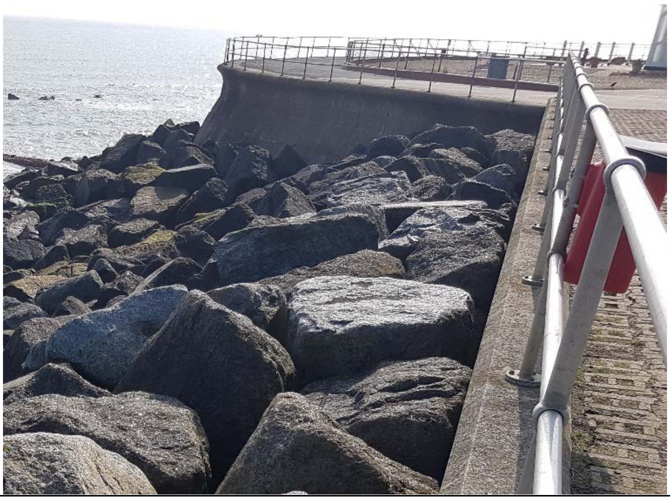
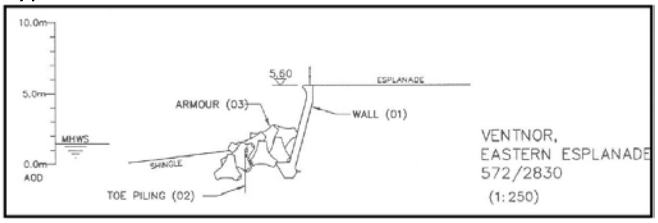


Photo 2:

Typical Section:



Map:

Defence ID	**IW 33 / 001**	*Description*	**Eastern Cliffs – eastern section**		
Construction	Concrete seawall, promenade and concrete Tetrapods at base of the wall				
Element Length	119 m	*Crest Details*	5.6mOD	*Maintenance*	IoW Council
Foreshore	Rock and boulders		*Structure dependency on foreshore*		Med

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete seawall**	**Tetrapods**			**Overall**
Structure instability from undermining	Low	Low			Low
Foundation failure – global instability	High	Med			High
Foundation failure – settlement	Med	Med			Med
Wave forces on structure (unit instability)	Low	Med			Med
Joint failure and material washout	Med	N/A			Med
Structure material failure – toe	Unknown	N/A			Unknown
Structure material failure – main defence	Low	Med			Med
Wave overtopping – structural instability	Low	N/A			Low
Wave overtopping – flooding	Low	N/A			Low
Wave overtopping – safety compromised	Med	N/A			Med
Structure outflanking	Low	Low			Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	4	3			4
Initial annual probability of failure	0.02	0.01			0.02
% increase in annual failure probability	2.5	1			2.5

Comments

- Significant displacement of central/southwest section of wall and promenade. It is suspected that this movement is due to structure loading from ground movements caused by deep clay landslides. CCO comparison of 2015 and 2017 laser scans has identified movement over that 2-year period of up to 30mm as a southerly displacement and vertical settlement of up to 25mm – this is being investigated further.
- Patch repairs to promenade surface following structure displacement (refer to IWC reports IW33-001 V.2-427, V2-430, V.2-536 and V2-547) but currently no measures implemented to prevent further movement.
- Other than the movement (which is serious), there are no other causes for concern with the seawall.
- Although many of the Tetrapods are still in fair condition (IWC IW33-001-V2-329-V2.16), some have failed and it is not possible to identify which have settled or been displaced by ground movements over the longer term. It is assumed that they have displaced with the historical seawall movement. CCO comparison of 2015 and 2017 laser scans identified movement the Tetrapods. Overall, the Tetrapods remain functional.

Photo 1:

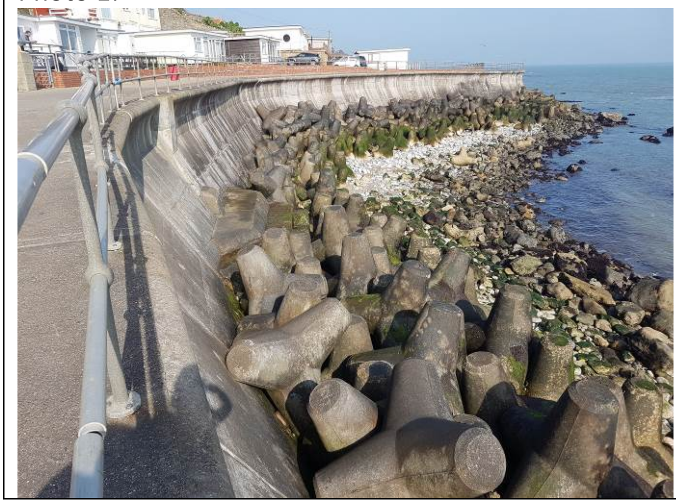


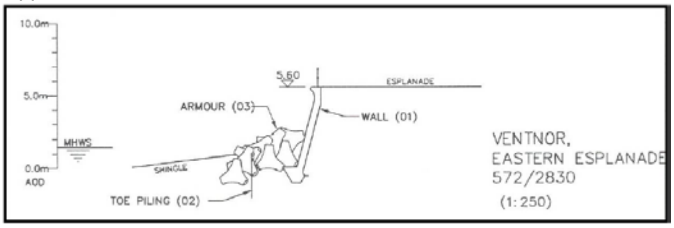
Photo 2:

Photo 3:

Photo 4:

Photo 5:

Typical Section:



Map:

Defence ID	**IW 33 / 002**	*Description*	**Eastern cliffs – western section**		
Construction	Concrete seawall with large apron and SSP toe and slipway				
Element Length	181 m	*Crest Details*	6.0mOD	*Maintenance*	IoW Council
Foreshore	Rock/boulders		*Structure dependency on foreshore*		High

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete Seawall**				**Overall**
Structure instability from undermining	High				High
Foundation failure – global instability	High				High
Foundation failure – settlement	Low				Low
Wave forces on structure (unit instability)	Low				Low
Joint failure and material washout	Med				Med
Structure material failure – toe	High				High
Structure material failure – main defence	Med				Med
Wave overtopping – structural instability	Med				Med
Wave overtopping – flooding	Low				Low
Wave overtopping – safety compromised	Med				Med
Structure outflanking	Low				Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	5				5
Initial annual probability of failure	0.2				0.2
% increase in annual failure probability	5				5

Comments

- Steel sheet piled toe in very poor condition with extensive corrosion holes and material wash out (refer to IWC IW33-002-V.2-330 inspection report). The degree of corrosion should be expected to have worsened since this inspection but tide heights during March 2017 site visit prevented access to re-inspect.
- Despite the failed sheet piled toe, the revetment and the seawall remains largely in serviceable condition.
- CCO comparison of 2015 and 2017 laser scans has identified extensive movement over those 2 years of between 25mm and 50mm lateral southerly displacement between 7mm and 25mm of vertical settlement – this is being investigated further. Evidence of landward rotational slip of slope (refer to IW33-002-V.2-616)
- Beach levels remain low and the extent of washout voids underneath the structure is unknown.
- Historical movement of structure resulting in joint failure (refer to IWC IW33-002-V.2-419 for details).
- Evidence of significant wave overtopping causing localised cliff erosion at this structure during storm/spring tide conditions (refer IWC IW33-002-V.2-569)

Photo 1:

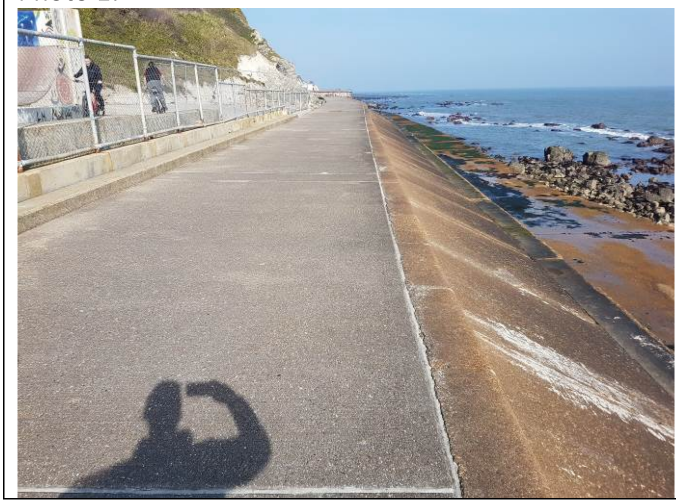
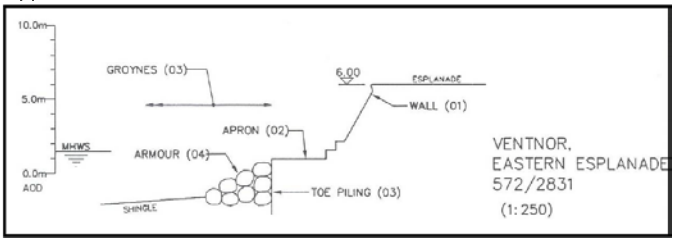


Photo 2:

Photo 3:

Typical Section:



Map:

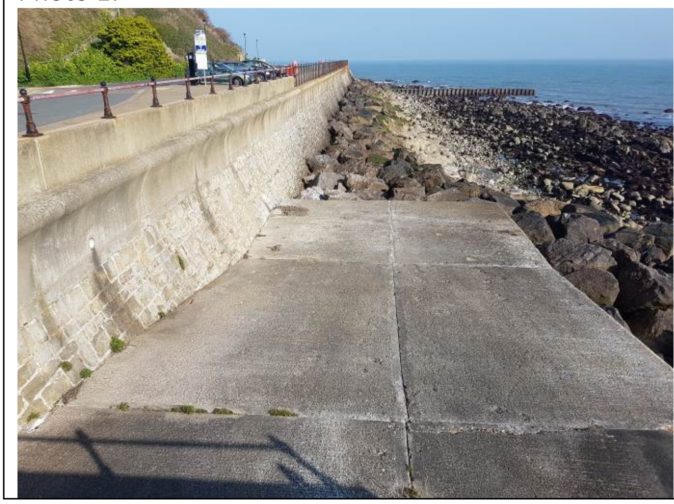
Defence ID	**IW 34 / 001**	*Description*	**Eastern Esplanade**		
Construction	Concrete seawall and promenade with rock armour toe protection				
Element Length	263 m	*Crest Details*	5.9mOD	*Maintenance*	IoW Council
Foreshore		*Structure dependency on foreshore*			

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete Wall**	**Rock at Wall Toe**			**Overall**
Structure instability from undermining	Low	Low			Low
Foundation failure – global instability	Med	Low			Med
Foundation failure – settlement	Low	Low			Low
Wave forces on structure (unit instability)	Low	Med			Low
Joint failure and material washout	Med	N/A			Med
Structure material failure – toe	Low	N/A			Low
Structure material failure – main defence	Low	Low			Low
Wave overtopping – structural instability	Low	N/A			Low
Wave overtopping – flooding	Low	N/A			Low
Wave overtopping – safety compromised	Med	N/A			Med
Structure outflanking	Low	Low			Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	2	2			2
Initial annual probability of failure	0.005	0.005			0.005
% increase in annual failure probability	2.5	1			2.5

Comments

- No evidence of seawall failures or structural stress.
- Rock armour appears to remain in good condition with no obvious signs of displacement or degradation.
- Outfall not included in assessment as not considered part of coastal defence system.

Photo 1:



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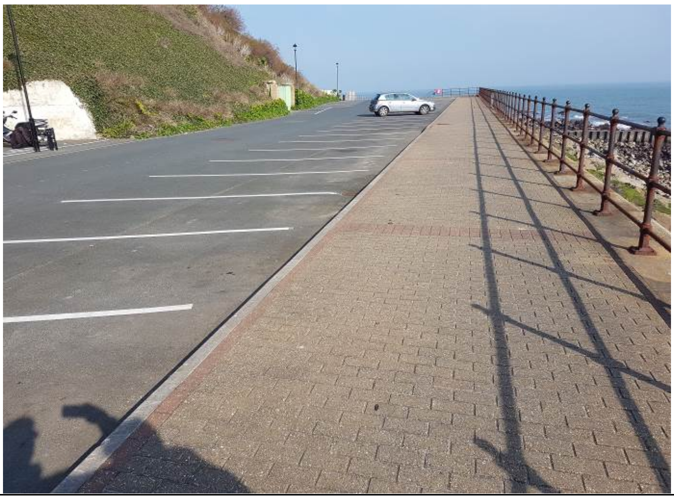

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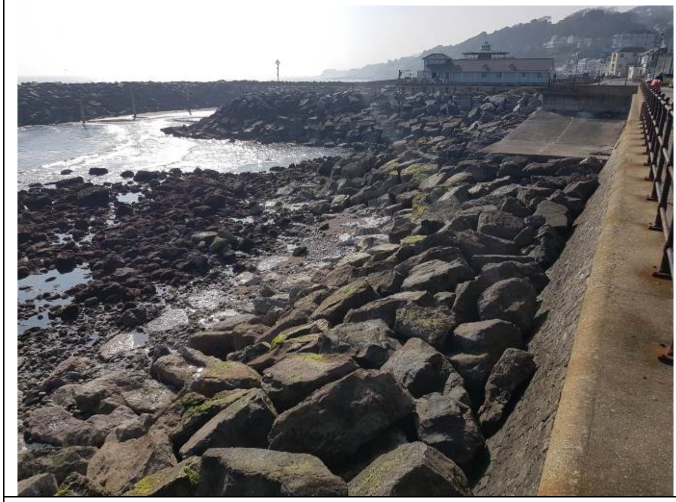
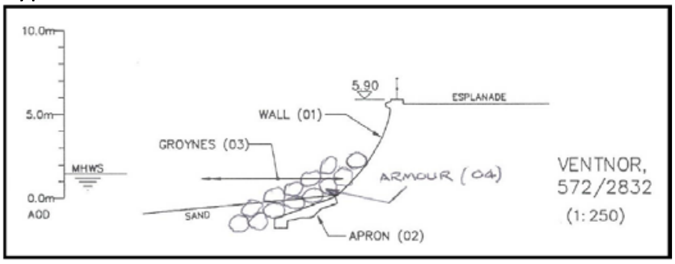


Photo 4:

Photo 5:

Typical Section:



Map:

Defence ID	**IW 34 / 002**	*Description*	**Ventnor Haven - breakwaters**
Construction	Rock breakwater arms to harbour.		

Element Length	504 m	*Crest Details*	5.5mOD	*Maintenance*	IoW Council
Foreshore	Unknown		*Structure dependency on foreshore*		Low

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Rock breakwater**				**Overall**
Structure instability from undermining	Low				Low
Foundation failure – global instability	Low				Low
Foundation failure – settlement	Low				Low
Wave forces on structure (unit instability)	Low				Low
Joint failure and material washout	N/A				N/A
Structure material failure – toe	N/A				N/A
Structure material failure – main defence	Low				Low
Wave overtopping – structural instability	N/A				N/A
Wave overtopping – flooding	N/A				N/A
Wave overtopping – safety compromised	N/A				N/A
Structure outflanking	Low				Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	1				1
Initial annual probability of failure	0.005				0.005
% increase in annual failure probability	2.5				2.5

Comments

- No signs of displacement of rock from within these structures that were constructed in 2003.

Photo 1:

Photo 2:

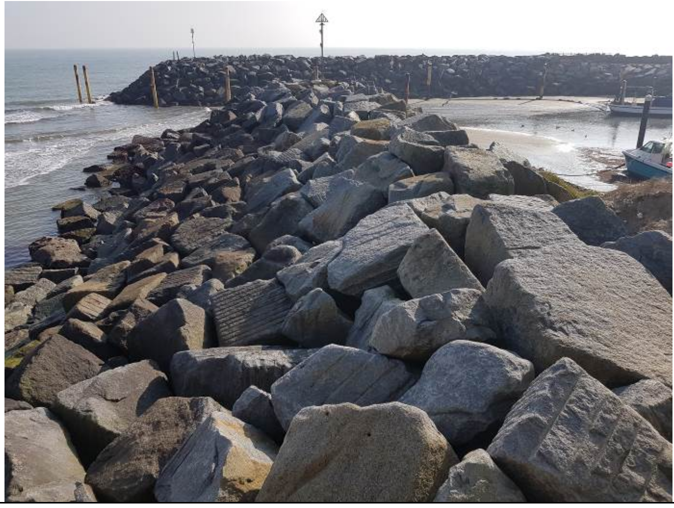


Photo 3:

Photo 4:

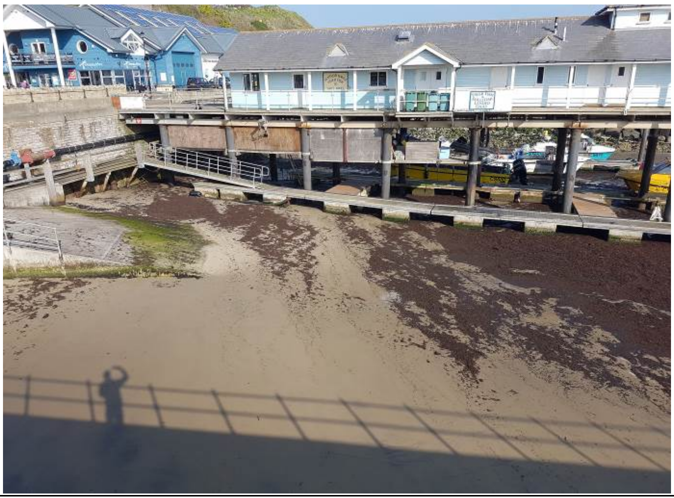
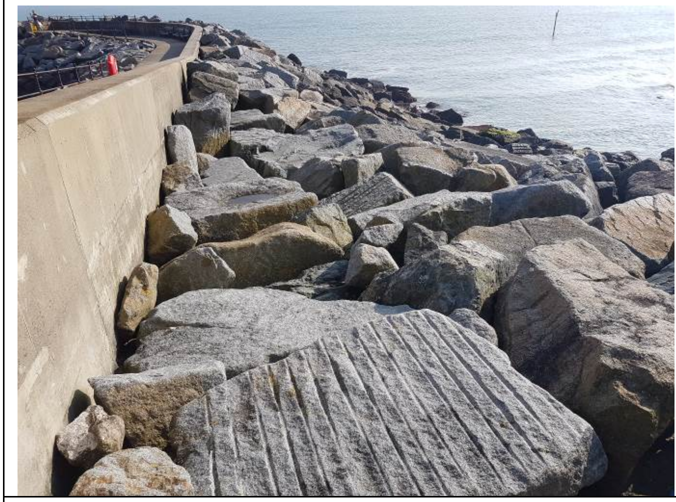


Photo 5:



Map:

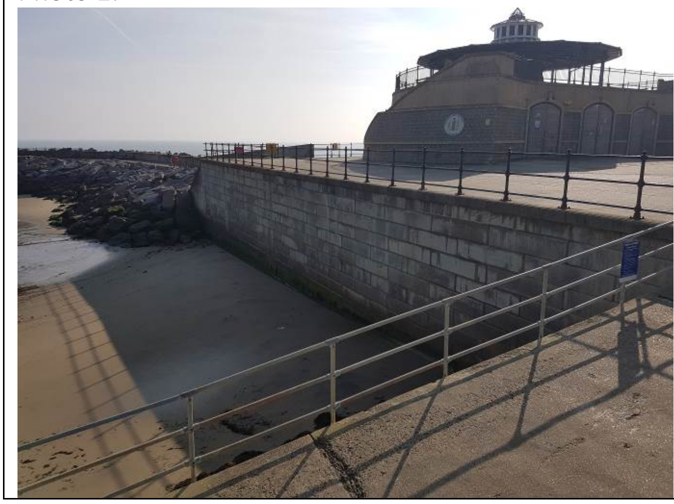
Defence ID	**IW 34 / 003**	*Description*	**Ventnor Haven – pumping station**		
Construction	Masonry wall fronting pumping station				
Element Length	38 m	*Crest Details*		*Maintenance*	Southern Water
Foreshore	Shingle/Sand		*Structure dependency on foreshore*		Low

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete wall**	**Rock revetment**			**Overall**
Structure instability from undermining	Low	Low			Low
Foundation failure – global instability	Low	Low			Low
Foundation failure – settlement	Low	Low			Low
Wave forces on structure (unit instability)	Low	Low			Low
Joint failure and material washout	Low	N/A			Low
Structure material failure – toe	Low	N/A			Low
Structure material failure – main defence	Low	Low			Low
Wave overtopping – structural instability	Low	Low			Low
Wave overtopping – flooding	Low	Low			Low
Wave overtopping – safety compromised	Med	Low			Med
Structure outflanking	Low	Low			Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	1	1			1
Initial annual probability of failure	0.005	0.005			0.005
% increase in annual failure probability	2.5	2.5			2.5

Comments

- No evidence of structural failures or stress in the seawall.
- Rock armour appears to remain in good condition with no obvious signs of displacement or degradation.

Photo 1:



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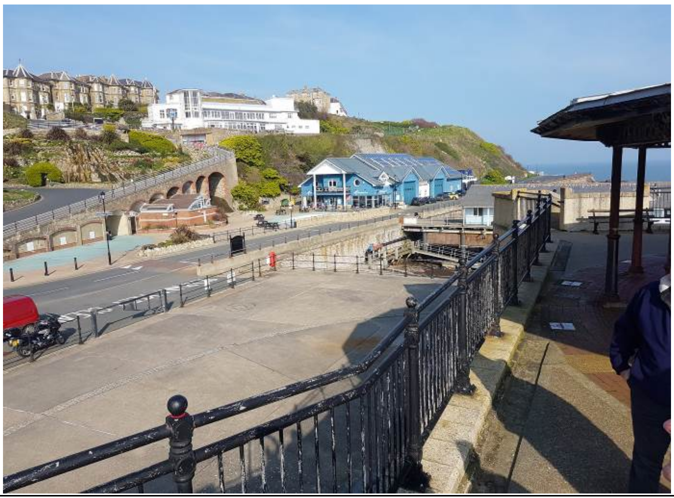
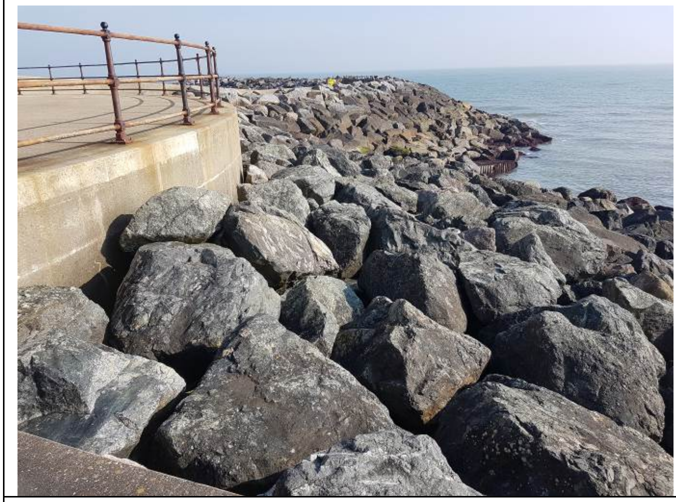
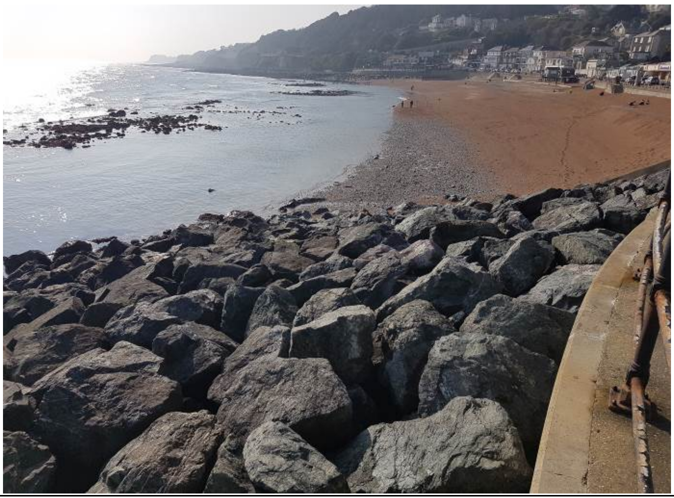


Photo 3:	Photo 4:
	

Map:

Defence ID	**IW 34 / 004**	*Description*	**Ventnor Haven – stepped revetment**		
Construction	Concrete stepped revetment				
Element Length	29 m	*Crest Details*	6.0mOD	*Maintenance*	Southern Water
Foreshore	Sand/shingle		*Structure dependency on foreshore*		Med

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete Revetment**				**Overall**
Structure instability from undermining	Med				Med
Foundation failure – global instability	Low				Low
Foundation failure – settlement	Low				Low
Wave forces on structure (unit instability)	Low				Low
Joint failure and material washout	Low				Low
Structure material failure – toe	Low				Low
Structure material failure – main defence	Low				Low
Wave overtopping – structural instability	Low				Low
Wave overtopping – flooding	Low				Low
Wave overtopping – safety compromised	Med				Med
Structure outflanking	Low				Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	1				1
Initial annual probability of failure	0.005				0.005
% increase in annual failure probability	2.5				2.5

Comments

- No evidence of structural failures or stress in the seawall.
- Beach levels appear to be relatively healthy at the structure. Main risk to the wall and safety of pedestrians is from lowered beach levels and resultant increased wave heights at the structure.

Photo 1:

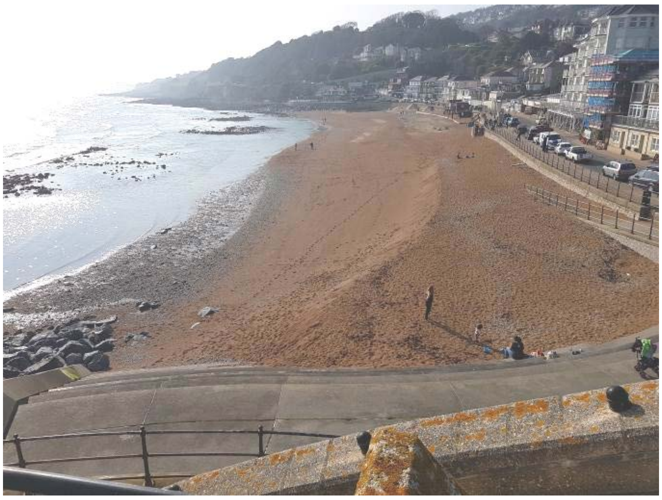


Photo 2:

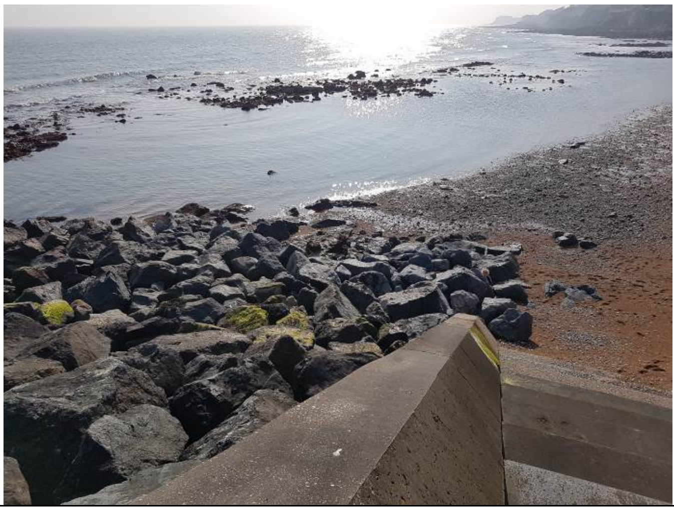
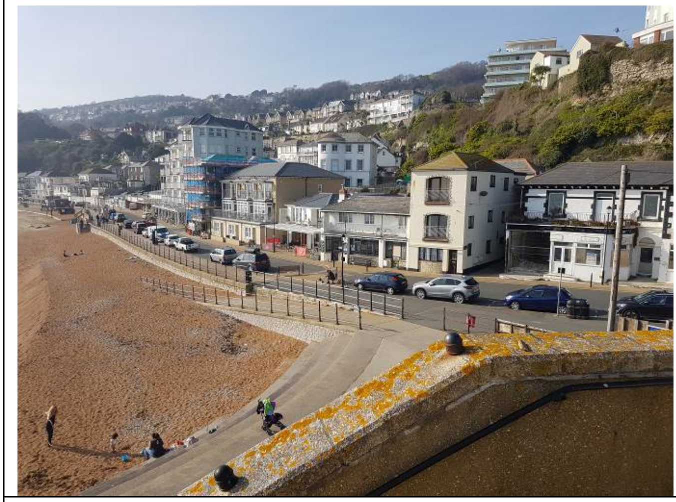


Photo 3:	
	

Map:


01
IW 35 / 001 Slipway
IW 34 / 001 Slipway
IW 34 / 001 Rock Armo
IW 34 / 003
IW 34 / 0
IW 35 / 001 Slipway wall
IW 34 / 001 Slipway wall
IW 34 / 004
IW 34 / 002

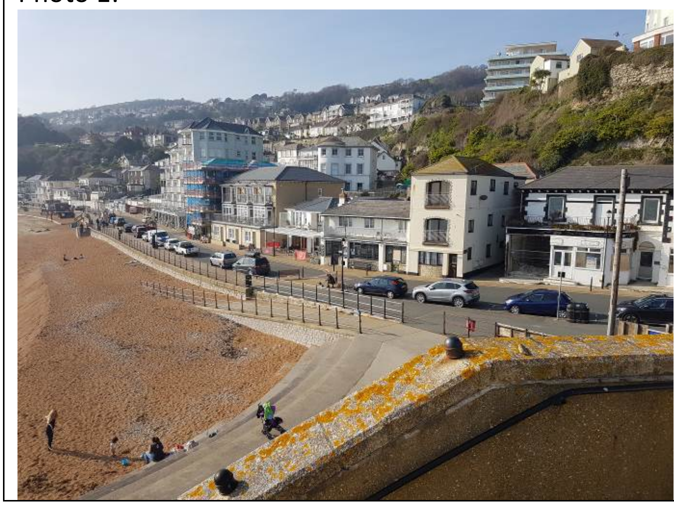
Defence ID	**IW 35 / 001**	*Description*	**Ventnor Bay**		
Construction	Concrete seawall with stone facing and slipway				
Element Length	302 m	*Crest Details*	4.5mOD	*Maintenance*	IoW Council
Foreshore	Sandy beach with splays of brown flint and chert shingle	*Structure dependency on foreshore*		Med	

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete seawall**				**Overall**
Structure instability from undermining	Med				Med
Foundation failure – global instability	Med				Med
Foundation failure – settlement	Low				Low
Wave forces on structure (unit instability)	Low				Low
Joint failure and material washout	Low				Low
Structure material failure – toe	Low				Low
Structure material failure – main defence	Low				Low
Wave overtopping – structural instability	Low				Low
Wave overtopping – flooding	Med				Med
Wave overtopping – safety compromised	Med				Med
Structure outflanking	Low				Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	2				2
Initial annual probability of failure	0.01				0.01
% increase in annual failure probability	2.5				2.5

Comments

- Wall has been in-situ for over 20 years and despite fluctuating beach levels (refer to IWC IWC35-001-V.2-425-V.2.23 inspection report) the overall defence has no signs of structural stress. The exception is in the SW corner where there is a localised bulge and further repairs works may be required in the future. Loss of passive loading when beach sediment lost, which worst-case could reactivate central landslide complex.
- Maintenance requirements such as steps repair (IWC IW35-001-V.2-581) and re-pointing will be ongoing.
- Beach volume is relatively stable (particularly since the building of Ventnor Haven), but there are seasonal shifts in material accumulations within the bay. Likely to be occasional beach recycling requirement.
- The timber piled groyne to the SW of the bay is non-functioning as a beach control structure, but is will be serving a limited function by dissipating some wave energy. It is not considered an integral part of the defence system, so is not included above.
- Timber revetment holding small beach area is not critical to the defence system and is not included above.

Photo 1:



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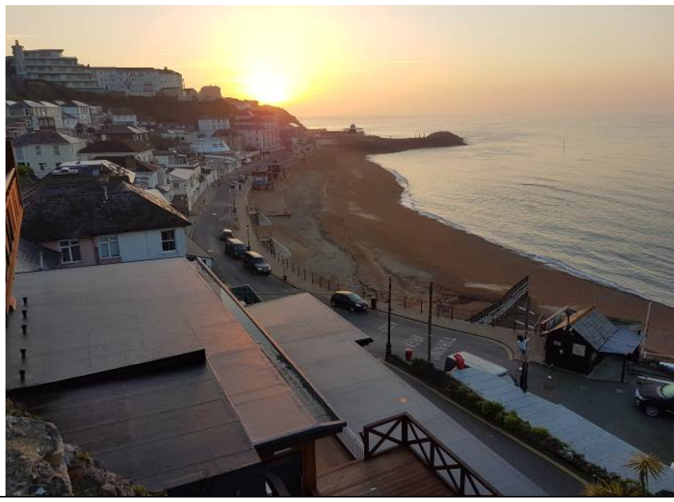
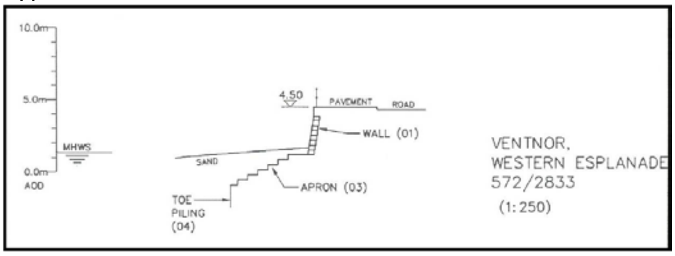


Photo 3:	Typical Section:
	

Map:

Defence ID	**IW 35 / 002**	*Description*	**Spyglass Inn**
Construction	Masonry wall with lower concrete encasement and rock revetment		
Element Length	84 m	*Crest Details*	Unknown
Maintenance	IoW Council		
Foreshore	Boulders	*Structure dependency on foreshore*	Med

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Seawall**	**Rock revetment**			**Overall**
Structure instability from undermining	Low	Low			Low
Foundation failure – global instability	Med	Low			Med
Foundation failure – settlement	Low	Low			Low
Wave forces on structure (unit instability)	Med	Low			Med
Joint failure and material washout	Med	N/A			Med
Structure material failure – toe	Low	N/A			Low
Structure material failure – main defence	Low	Low			Low
Wave overtopping – structural instability	Low	N/A			Low
Wave overtopping – flooding	Med	N/A			Med
Wave overtopping – safety compromised	Med	N/A			Med
Structure outflanking	Low	Low			Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	2	2			2
Initial annual probability of failure	0.01	0.005			0.01
% increase in annual failure probability	5	2.5			5

Comments

- Low rock revetment and lower concrete encasement in front of the structure protects the structure from undermining, limits wave impact and provides toe weight to the structure and cliffs.
- Strengthened structure as a whole is good condition with no signs of structural stress.

Photo 1:

Photo 2:

Map:


IW 35 / 001
IW 35 / 002
IW 35 Rock Armour
IW 35 / 003
IW 35 / 004
IW 35 Rock Armour

Defence ID	**IW 35 / 003**	*Description*	**Western Cliffs – eastern section**		
Construction	Stone masonry wall, concrete toe encasement and low rock revetment				
Element Length	12 m	*Crest Details*	Unknown	*Maintenance*	IoW Council
Foreshore	Boulders	*Structure dependency on foreshore*		Medium	

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Seawall**	**Rock revetment**			**Overall**
Structure instability from undermining	Low	Low			Low
Foundation failure – global instability	High	Low			High
Foundation failure – settlement	Med	Low			Med
Wave forces on structure (unit instability)	Med	Low			Med
Joint failure and material washout	High	N/A			High
Structure material failure – toe	Low	N/A			Low
Structure material failure – main defence	Med	Low			Med
Wave overtopping – structural instability	Low	N/A			Low
Wave overtopping – flooding	Low	N/A			Low
Wave overtopping – safety compromised	Low	N/A			Low
Structure outflanking	Low	Low			Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	4	2			4
Initial annual probability of failure	0.05	0.01			0.05
% increase in annual failure probability	5	1			5

Comments

- Low rock revetment and lower concrete encasement in front of the structure protects the structure from undermining, limits wave impact and provides toe weight to the structure and cliffs.
- Concrete element is in poor condition due to pressures from groundwater, with flows exiting through the structure (refer to IWC IW35-003/4-V.2-617 inspection report). This is compromising the structure giving a high risk of failure from global instability (which could be a quick failure) and washout of material (which would be a slower failure). High retained heights and cliffs behind the structure present an elevated risk of failure.

Photo 1:

Photo 2:

Map:


IW 35 / 002
IW 35 Rock Armour
IW 35 / 003
IW 35 / 004
W 35 Rock Armour
IW 35 Groyne

Defence ID	**IW 35 / 004**	*Description*	**Western cliffs – below car park**		
Construction	Concrete block wall with wave return and low rock revetment				
Element Length	104 m	*Crest Details*	2.3mOD	*Maintenance*	IoW Council
Foreshore	Boulders	*Structure dependency on foreshore*		Medium	

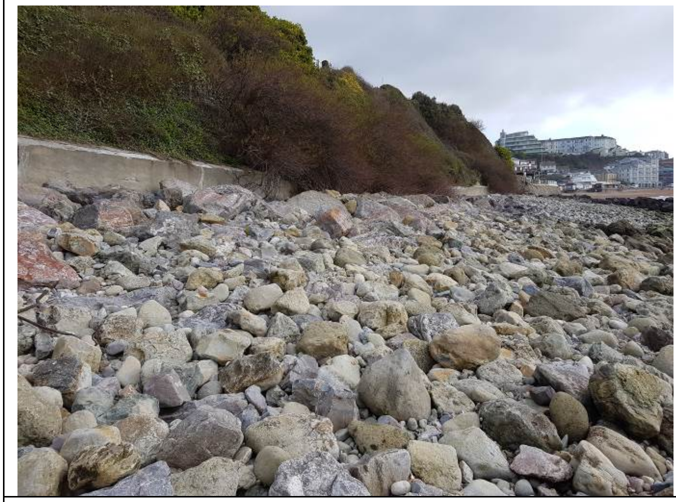
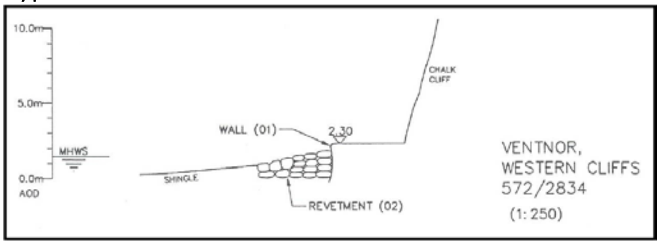
Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete Wall**	**Rock Revetment**			**Overall**
Structure instability from undermining	Low	Low			Low
Foundation failure – global instability	Med	Low			Low
Foundation failure – settlement	Med	Low			Med
Wave forces on structure (unit instability)	Med	Low			Low
Joint failure and material washout	Med	N/A			Med
Structure material failure – toe	Low	N/A			Low
Structure material failure – main defence	Med	Low			Med
Wave overtopping – structural instability	Med	N/A			Med
Wave overtopping – flooding	Low	N/A			Low
Wave overtopping – safety compromised	Low	N/A			Low
Structure outflanking	Low	Low			Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	3	2			2
Initial annual probability of failure	0.01	0.005			0.01
% increase in annual failure probability	5	1			5

Comments

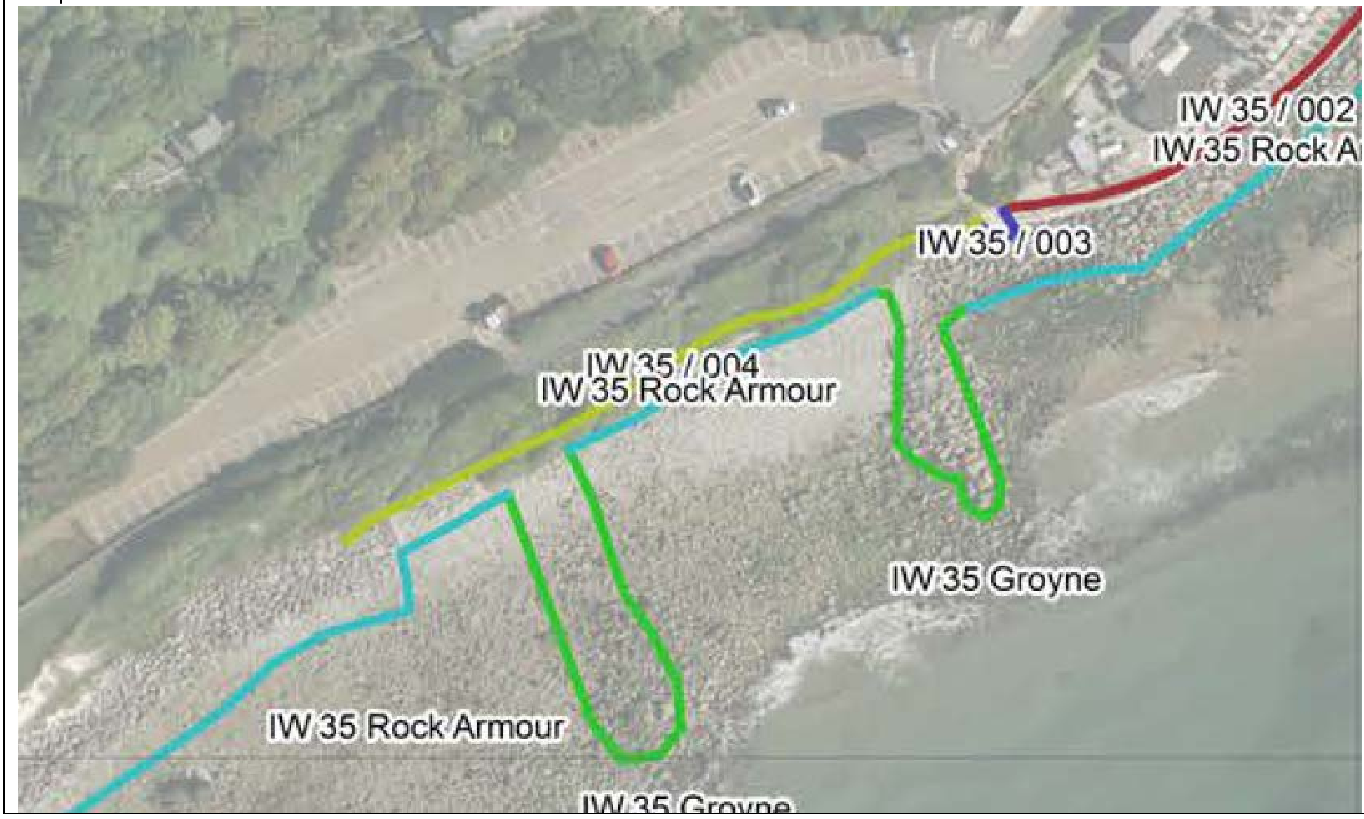
- Rock revetment protecting the old (1950) wall is in good condition.
- Damage to the rendering of the seawall requires maintenance, but in combination with the rock revetment, the overall structure appears to be in good condition (refer to IWC IW35-003/4-V.2-617 inspection report).
- Timber access steps require maintenance but this is not compromising coastal defences.

Photo 1:

Photo 2:

Photo 3:	Photo 4:
	
Typical Section: 	

Map:



Defence ID	**IW 35 / 005**	*Description*	**Western Cliffs – central & western section**		
Construction	Rock groynes and low rock revetment at cliff base				
Element Length	615 m	*Crest Details*	4.5mOD	*Maintenance*	IoW Council
Foreshore	Boulders		*Structure dependency on foreshore*		Low

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Rock Groynes**	**Rock Revetment**			**Overall**
Structure instability from undermining	Low	Low			Low
Foundation failure – global instability	Low	Med			Med
Foundation failure – settlement	Low	Low			Low
Wave forces on structure (unit instability)	Med	Low			Med
Joint failure and material washout	N/A	N/A			N/A
Structure material failure – toe	N/A	N/A			N/A
Structure material failure – main defence	Low	Low			Low
Wave overtopping – structural instability	N/A	Med			Med
Wave overtopping – flooding	N/A	N/A			N/A
Wave overtopping – safety compromised	N/A	N/A			N/A
Structure outflanking	Low	Low			Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	2	2			2
Initial annual probability of failure	0.01	0.01			0.01
% increase in annual failure probability	2.5	2.5			2.5

Comments

- Rock revetment continual along base of the cliff affording good protection to the cliff. Although overtopping is much reduced by the revetment, there will be residual overtopping at the base of the cliff which will allow continuation of slow rates of erosion. Following any further recession of the cliffs the rate of erosion will then fall further as long as the rock structure remains in situ without a compromise in its geometry/stability.
- Rock groynes providing sheltering function to the rocky foreshore, particularly in SW storms.
- All rock structures appear to be in good condition.
- Southern water outfall protected by rock is providing some costal defence function as a groyne. This is considered as a "Rock Groyne" above.
- Section of footpath has been diverted due to landslides; this could be required again in the future.

Photo 1:

Photo 2:

Photo 3:

Photo 4:

Photo 5:

Photo 6:

Map:

Defence ID	**IW 36 / 001**	*Description*	**Castle Cove**
Construction	Rock revetment flanked by rock groynes fronting concrete road with setback gabion splash wall.		

Element Length	231 m	*Crest Details*	4.0mOD	*Maintenance*	IoW Council
Foreshore	Cobbles	*Structure dependency on foreshore*	Low		

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Rock Groynes**	**Rock Revetment**	**Gabions**		**Overall**
Structure instability from undermining	Low	Low	Low		Low
Foundation failure – global instability	Low	Med	Med		Med
Foundation failure – settlement	Low	Med	Low		Med
Wave forces on structure (unit instability)	Low	Low	Low		Low
Joint failure and material washout	N/A	N/A	Low		Low
Structure material failure – toe	N/A	N/A	N/A		N/A
Structure material failure – main defence	Low	Low	Med		Low
Wave overtopping – structural instability	N/A	Low	Low		Low
Wave overtopping – flooding	N/A	N/A	N/A		N/A
Wave overtopping – safety compromised	N/A	Med	N/A		Med
Structure outflanking	Low	Low	Low		Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	1	2	2		2
Initial annual probability of failure	0.005	0.005	0.005		0.005
% increase in annual failure probability	2.5	2.5	2.5		2.5

Comments

- Most elements of this 1996 coastal defence scheme appear to be in good condition with no signs of structural stresses or failure.
- Rock structures are providing toe protection and toe weight to active slopes behind, with no signs of major lateral displacement. However, in the SW corner there may have been 50mm to 100mm of displacement as evidenced in the surface defects at the interface with the concrete steps. Although minor defects, this could be recent evidence of some more significant larger-scale ground movements. Refer to IWC IW36-001-V.2-472 V.2.28 and IW36-001-V.2-511-V.2.28 inspection reports.
- Slipway and concrete structures are all in good condition. Concrete roadway included as an element of the rock revetment above.

Photo 1:

Photo 2:

Photo 3:

Photo 4:

Photo 5:

Photo 6:

Map:

Defence ID	**IW 36 / 002**	*Description*	**Steephill Cove - terminal groyne**		
Construction	Rock groyne				
Element Length	7 m	*Crest Details*	2.95mOD	*Maintenance*	IoW Council
Foreshore	Boulders	*Structure dependency on foreshore*		Low	

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Rock Groyne**				**Overall**
Structure instability from undermining	Low				Low
Foundation failure – global instability	Low				Low
Foundation failure – settlement	Low				Low
Wave forces on structure (unit instability)	Med				Med
Joint failure and material washout	N/A				N/A
Structure material failure – toe	N/A				N/A
Structure material failure – main defence	Low				Low
Wave overtopping – structural instability	N/A				N/A
Wave overtopping – flooding	N/A				N/A
Wave overtopping – safety compromised	N/A				N/A
Structure outflanking	N/A				N/A
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	1				1
Initial annual probability of failure	0.005				0.005
% increase in annual failure probability	2.5				2.5

Comments

- Timber cribwork groyne is largely sacrificial as entirely surrounded/infilled with rock (hence not included above).
- Groyne has important function as a terminal groyne but low risk of failure since timber groyne was upgraded with rock in 1996.

Photo 1:

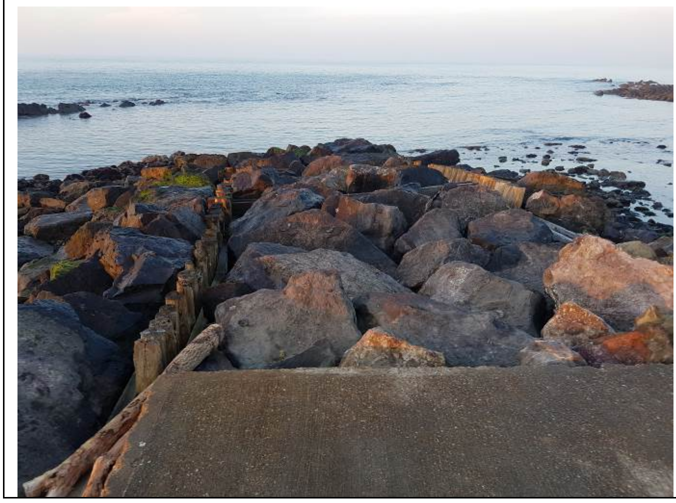
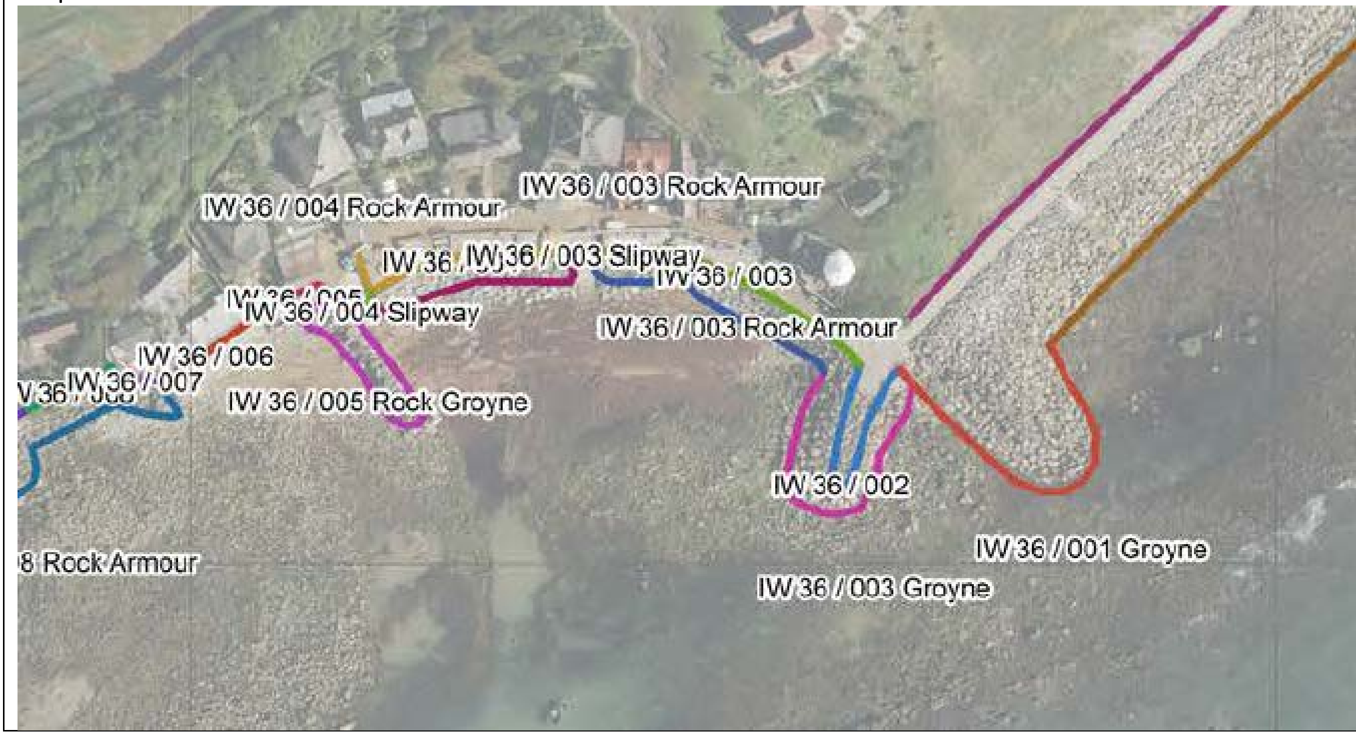


Photo 2:

Map:


IW 36 / 003 Rock Armour
IW 36 / 004 Rock Armour
IW 36 / 003 Slipway
IW 36 / 003
IW 36 / 004 Slipway
IW 36 / 003 Rock Armour
IW 36 / 006
IW 36 / 007
IW 36 / 005 Rock Groyne
IW 36 / 002
8 Rock Armour
IW 36 / 001 Groyne
IW 36 / 003 Groyne

Defence ID	**IW 36 / 003**	*Description*	**Steephill Cove – eastern section**		
Construction	Sheet piles wall encased with concrete, fronted with Purbeck stone with set back splash wall.				
Element Length	60 m	*Crest Details*	4.0mOD	*Maintenance*	IoW Council
Foreshore	Sand/shingle with boulders	*Structure dependency on foreshore*		Med	

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**SSP/conc. Wall**	**Rock at Wall Toe**			**Overall**
Structure instability from undermining	Low	Low			Low
Foundation failure – global instability	High	Med			High
Foundation failure – settlement	Med	Med			Med
Wave forces on structure (unit instability)	Low	Med			Low
Joint failure and material washout	Low	N/A			Low
Structure material failure – toe	Med	N/A			Med
Structure material failure – main defence	Med	Med			Med
Wave overtopping – structural instability	Low	N/A			Low
Wave overtopping – flooding	Med	N/A			Med
Wave overtopping – safety compromised	High	N/A			High
Structure outflanking	Med	Low			Med
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	2	2			2
Initial annual probability of failure	0.005	0.005			0.005
% increase in annual failure probability	5	5			5

Comments

- Despite the defence being in overall good condition, the structure has many vulnerabilities due to its exposure and weak clay founding materials.
- There is anecdotal evidence that the rock level has dropped in front of the structure due to settlement into the weak and soft clays beneath. There was no evidence of scratches to the front face of the structure indicating rock levels had dropped. If the rock has settled, then it has settled relatively uniformly along the defence. It is considered unlikely that the rock levels would have been flush with the deck as the top section of the defence on the seaward face has been clad in rock for aesthetics. There has been no settlement of rock in the eastern end of the bay as this would have damaged concrete steps and the slipway as it settled.
- Beach levels fronting the structure are susceptible to significant lowering during storm events. Following the Valentine's Day storm in 2014, the loss of beach material exposed and then eroded part of the underlying Gault Clay. Beach material has since returned to re-cover the clay.

Photo 1:

Photo 2:

Photo 3:

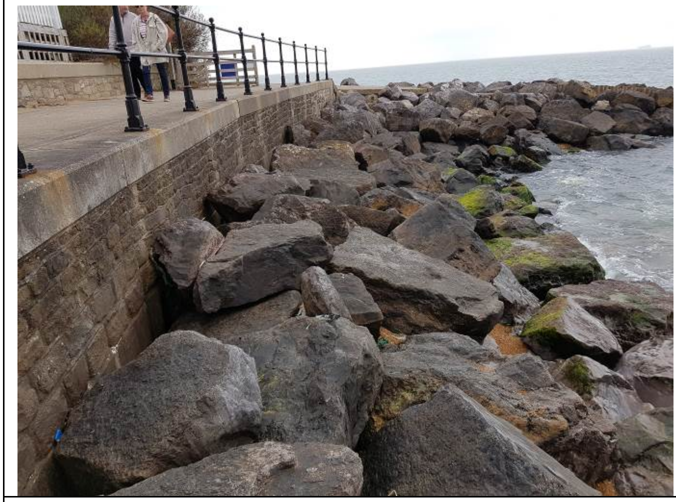
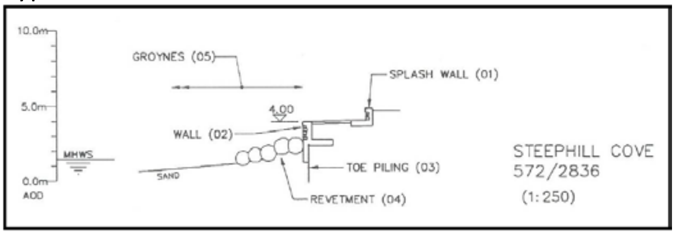


Photo 4:

Photo 5:

Typical Section:



Map:

Defence ID	**IW 36 / 004**	*Description*	**Steephill Cove – central section**		
Construction	Encased concrete apron, concrete/stone walls, concrete slipway and rock armour revetment				
Element Length	51 m	*Crest Details*	4.25mOD	*Maintenance*	IoW Council
Foreshore	Sand/shingle		*Structure dependency on foreshore*		Med

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Conc/stone seawall**	**Rock revetment**			**Overall**
Structure instability from undermining	Low	Low			Low
Foundation failure – global instability	Med	Low			Med
Foundation failure – settlement	Med	Med			Med
Wave forces on structure (unit instability)	Low	Low			Low
Joint failure and material washout	Med	N/A			Med
Structure material failure – toe	Low	N/A			Low
Structure material failure – main defence	Med	Low			Med
Wave overtopping – structural instability	Low	N/A			Low
Wave overtopping – flooding	Med	N/A			Med
Wave overtopping – safety compromised	Med	N/A			Med
Structure outflanking	Low	Low			Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	1	1			1
Initial annual probability of failure	0.005	0.005			0.005
% increase in annual failure probability	5	5			5

Comments

- No evidence of settlement or structural stresses in any of the elements of this 2006 strengthening scheme.
- Poor geotechnical conditions and beach vulnerability to storm lowering present risks to failure and increased exposure to wave overtopping.

Photo 1:

Photo 2:

Map:


IW 36 / 003 Rock Armour
IW 36 / 004 Rock Armour
IW 36 / 003 Slipway
IW 36 / 003
IW 36 / 004 Slipway
IW 36 / 003 Rock Armour
IW 36 / 006
IW 36 / 007
IW 36 / 005 Rock Groyne
IW 36 / 002
8 Rock Armour
IW 36 / 001 Groyne
IW 36 / 003 Groyne

Defence ID	**IW 36 / 005**	*Description*	**Steephill Cove – rock groyne**		
Construction	Rock groyne				
Element Length	23 m	*Crest Details*	Unknown	*Maintenance*	IoW Council
Foreshore	Sand/shingle and boulders	*Structure dependency on foreshore*	Low		

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Rock Groyne**	**Concrete wall**			**Overall**
Structure instability from undermining	Med	Med			Med
Foundation failure – global instability	Low	Low			Low
Foundation failure – settlement	Med	Low			Med
Wave forces on structure (unit instability)	Med	Low			Med
Joint failure and material washout	N/A	Med			N/A
Structure material failure – toe	N/A	Unknown			N/A
Structure material failure – main defence	Low	Med			Low
Wave overtopping – structural instability	N/A	Low			N/A
Wave overtopping – flooding	N/A	Med			N/A
Wave overtopping – safety compromised	N/A	Med			N/A
Structure outflanking	Low	Med			Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	2	2			2
Initial annual probability of failure	0.01	0.005			0.01
% increase in annual failure probability	5	5			5

Comments

- Rock groyne is not of robust design as there is not the interlink and geometry required for this sized rock. There may be some localised displacement of rock but overall the rock structure is functioning.
- No signs of failure of the concrete wall/slabs but construction details unknown.

Photo 1:

Photo 2:

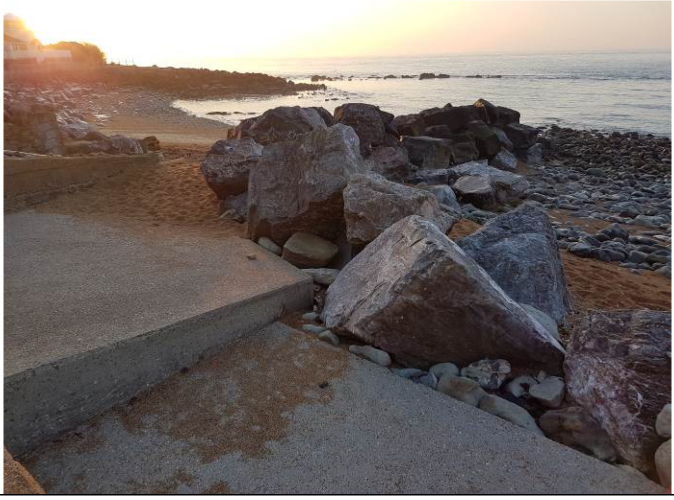


Photo 3:

Map:


IW 36 / 003 Rock Armour
IW 36 / 004 Rock Armour
IW 36 / 003 Slipway
IW 36 / 003
IW 36 / 004 Slipway
IW 36 / 003 Rock Armour
IW 36 / 006
IW 36 / 007
IW 36 / 005 Rock Groyne
IW 36 / 002
8 Rock Armour
IW 36 / 001 Groyne
IW 36 / 003 Groyne

Defence ID	**IW 36 / 006**	*Description*	**Steephill Cove – western section**		
Construction	Concrete stepped wall fronting masonry wall				
Element Length	21 m	*Crest Details*	Unknown	*Maintenance*	IoW Council
Foreshore	Sans/shingle and cobbles	*Structure dependency on foreshore*		Med	

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Conc/stone Wall**				**Overall**
Structure instability from undermining	Med				Med
Foundation failure – global instability	Low				Low
Foundation failure – settlement	Med				Med
Wave forces on structure (unit instability)	Low				Low
Joint failure and material washout	Med				Med
Structure material failure – toe	Unknown				Unknown
Structure material failure – main defence	Med				Med
Wave overtopping – structural instability	Med				Med
Wave overtopping – flooding	Low				Low
Wave overtopping – safety compromised	Med				Med
Structure outflanking	Med				Med
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	2				2
Initial annual probability of failure	0.01				0.01
% increase in annual failure probability	5				5

Comments

- Foundation/toe construction of concrete steps constructed in 1992 unknown, but extensive lower rock foreshore means undermining risk is limited.
- No signs of structural stresses to the defence elements.

Photo 1:

Photo 2:

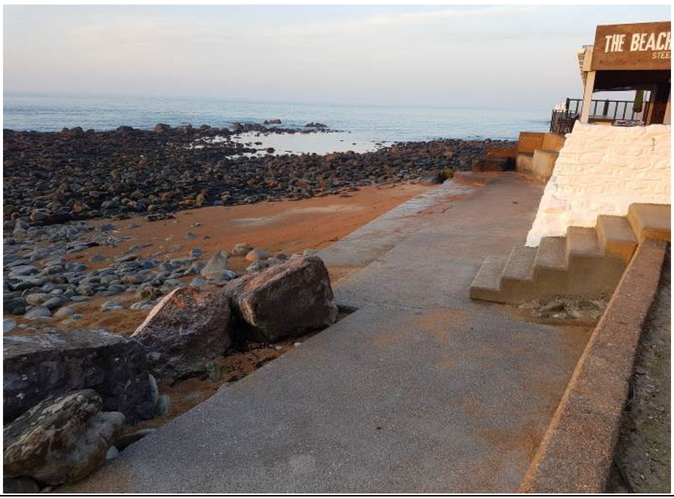
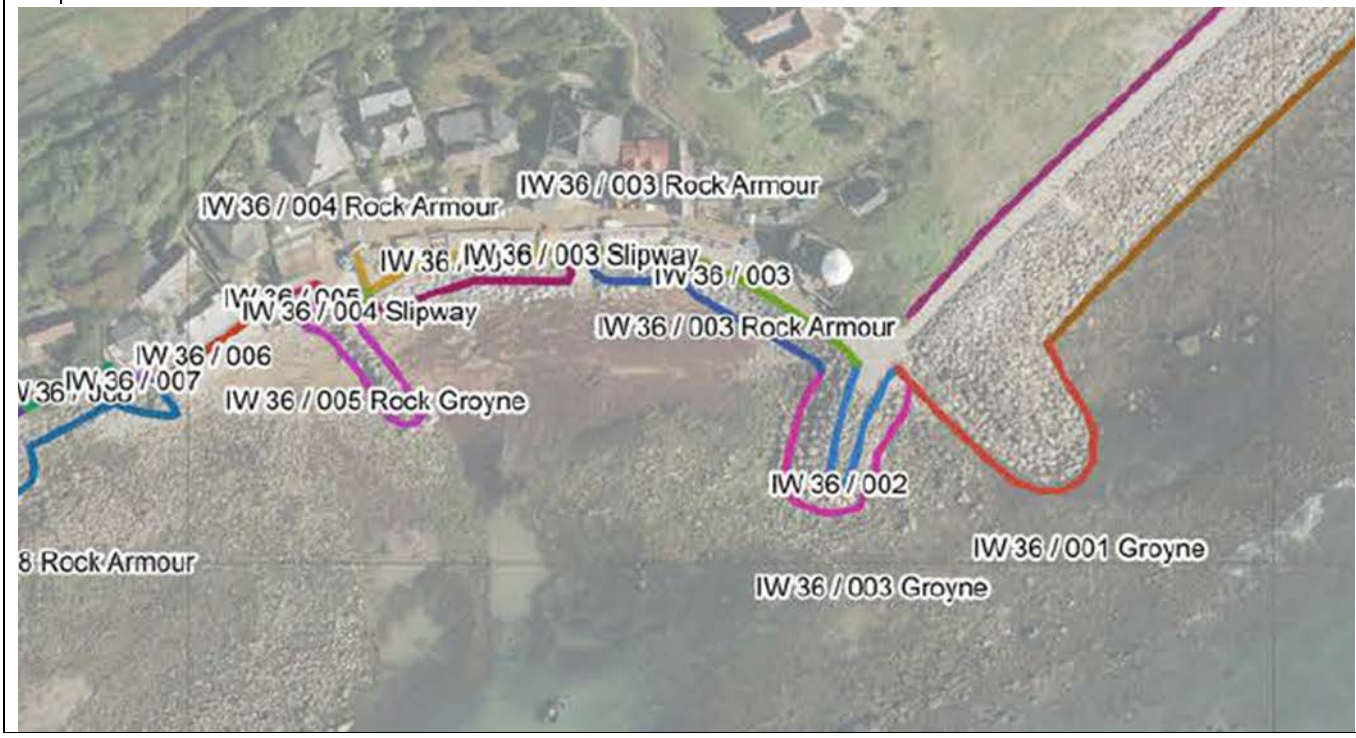


Photo 3:

Photo 4:

Photo 5:

Map:



Defence ID	**IW 36 / 007**	*Description*	**Steephill Cove – western property wall**		
Construction	Concrete wall with wave return and toe rock				
Element Length	10 m	*Crest Details*	Unknown	*Maintenance*	IoW Council
Foreshore	Boulder	*Structure dependency on foreshore*		Med	

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete Wall**	**Rock at Wall Toe**			**Overall**
Structure instability from undermining	Low	Low			Low
Foundation failure – global instability	Low	Low			Low
Foundation failure – settlement	Low	Low			Low
Wave forces on structure (unit instability)	Low	Med			Low
Joint failure and material washout	Med	N/A			Med
Structure material failure – toe	Unknown	N/A			Unknown
Structure material failure – main defence	Med	Low			Med
Wave overtopping – structural instability	Med	N/A			Med
Wave overtopping – flooding	Med	N/A			Med
Wave overtopping – safety compromised	N/A	N/A			N/A
Structure outflanking	Med	Low			Med
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	2	2			2
Initial annual probability of failure	0.01	0.01			0.01
% increase in annual failure probability	5	5			5

Comments

- Upper wave return wall and toe rock added (in 2006) to the original 1950's wall.
- Despite the age of the underlying concrete structure, there appears to be no signs of structural stress or defects of any elements of the defence.

Photo 1:

Map:


IW 36 / 004 Rock Armour
IW 36 / 003 Rock Ar
IW 36 / 003 Slipway
IW 36 / 004 Slipway
IW 36 / 003 R
IW 36 / 006
IW 36 / 007
IW 36 / 005 Rock Groyne
IW 36 / 008 Rock Armour
/ 001

Defence ID	**IW 36 / 008**	*Description*	**Steephill Cove – western cliffs**		
Construction	Concrete wall with rock revetment in front and rock groyne				
Element Length	81 m	*Crest Details*	4.1mOD	*Maintenance*	IoW Council
Foreshore	Boulders		*Structure dependency on foreshore*		Low

Susceptibility of Defence Elements to Failure Mode and Condition Assessment	**Concrete Wall**	**Rock Revetment**	**Rock Groyne**		**Overall**
Structure instability from undermining	Low	Low	Low		Low
Foundation failure – global instability	Low	Low	Low		Low
Foundation failure – settlement	Low	Med	Med		Med
Wave forces on structure (unit instability)	Low	Med	Med		Med
Joint failure and material washout	Med	N/A	N/A		Med
Structure material failure – toe	Low	N/A	N/A		Low
Structure material failure – main defence	High	Low	Low		Med
Wave overtopping – structural instability	Low	N/A	N/A		Low
Wave overtopping – flooding	N/A	N/A	N/A		N/A
Wave overtopping – safety compromised	N/A	N/A	N/A		N/A
Structure outflanking	Low	Low	N/A		Low
Other:					
Condition Grade (1 Very Good to 5 Very Poor)	3	2	2		2
Initial annual probability of failure	0.01	0.005	0.005		0.01
% increase in annual failure probability	5	2.5	2.5		5

Comments

- Original seawall constructed in 1950's is showing signs of age, but due to the addition of rock in front, the structural and geotechnical stresses on this wall are significantly reduced. Even on failure of this wall, the rock would continue to provide relatively good protection to the base of the cliffs.
- Rock revetment and groyne appear to be in functioning condition with no obvious signs of displacement.

Photo 1:

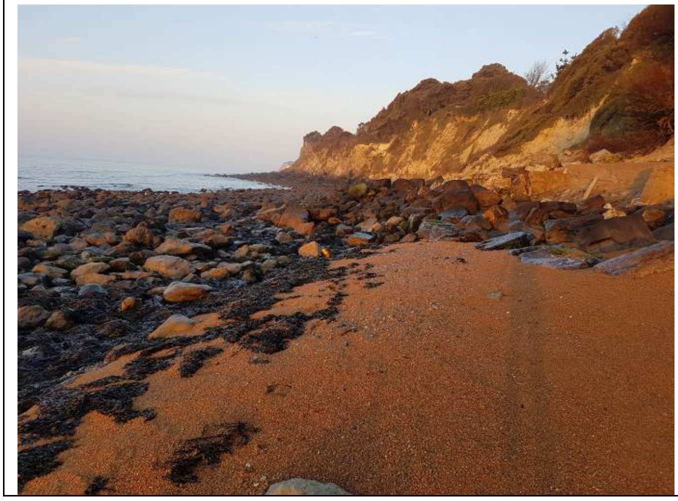
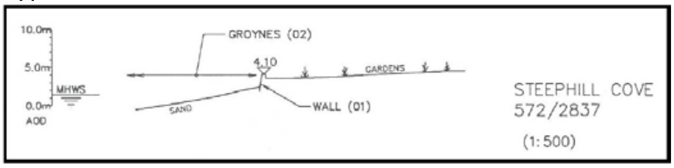


Photo 2:

Photo 3:	Typical Section:
	

Map:

Appendix A
Historical Defence Appraisal and Condition Surveys Reports (from Isle of Wight Council)

Contents of Appendix A:

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID V.2-294

INSPECTION DATE 08.06.10

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

LOCATION V.2.3

RESPONSE M

	Observation Score
Probability	N/A
Injury	N/A

Major	4	8	12	16
Noticeable	3	6	9	12
Minor	2	4	6	8
Negligible	1	2	3	4
	Very Low	Low	Medium	High

DESCRIPTION
Japanese Knotweed identified at Monks Bay.
Historical photographs - See Observation ID. V.2-065.

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY


ACTION
Monitor

INSPECTION DATE 04.07.13

INSPECTED BY Luke Ellison (Coastal Engineering Technician)


COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE	23.04.15
INSPECTED BY	Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

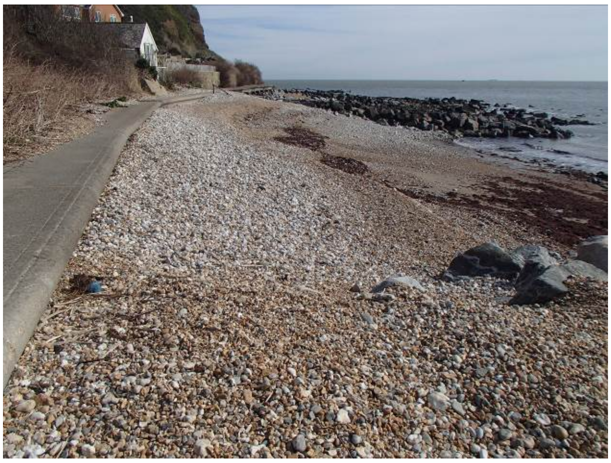
TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID	V.2-580
INSPECTION DATE	31.03.16
INSPECTED BY	Luke Ellison (Coastal Engineering Technician)
LOCATION	V.2
RESPONSE	M

DESCRIPTION
Storm Katie – Monks Bay – Beach removed – Vertical cliff

Carefully remove and dispose of four off exposed concrete filled oil drums, and concrete.

Old stone masonry coastal structure.



COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

ACTION
Monitor / Relocate material

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 19.04.16

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 21.06.16

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

INSPECTION DATE 08.07.16

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

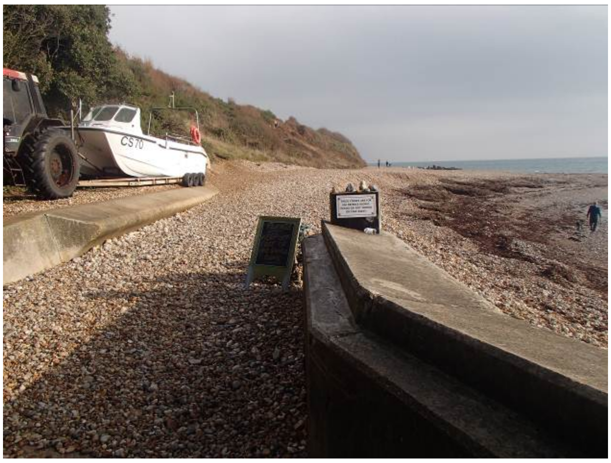
TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 12.08.16

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

INSPECTION DATE 25.10.16

INSPECTED BY Luke Ellison (Coastal Engineering Technician)



COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID	V.2-290
INSPECTION DATE	28.04.10
INSPECTED BY	Luke Ellison (Coastal Engineering Technician)
LOCATION	V.2.14
RESPONSE	M

DESCRIPTION
Condition of steel sheet piling – Wheelers Bay.

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

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TYPE OF INSPECTION – ROUTINE - MONTHLY

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

Total length = 64.5m

Height of sheet piling from foreshore = 1.9m

Width of apron = 4m

Typical view inside large void.

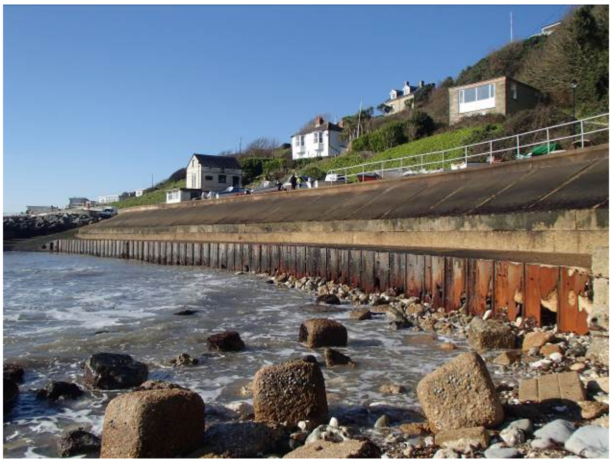
The approximate depth of the larger voids were recorded:
(Typically this relates to lost cobble fill under the concrete apron).

12-13 = 1.92m
15 = 1.42m
19 = 1.49m
25 = 1.2m
44 = 1.7m
47 = 2.9m
49 = 2.0m
52 = 1.85m
54 = 0.2m

ACTION
Monitor / Investigate repairs.

INSPECTION DATE 16.02.16

INSPECTED BY Luke Ellison (Coastal Engineering Technician)



COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID	V.2-329
INSPECTION DATE	11.05.11
INSPECTED BY	Luke Ellison (Coastal Engineering Technician)
LOCATION	V.2.16
RESPONSE	N/A

	Observation Score
Probability	N/A
Injury	N/A

Major	4	8	12	16
Noticeable	3	6	9	12
Minor	2	4	6	8
Negligible	1	2	3	4
	Very Low	Low	Medium	High

DESCRIPTION
Inspection of Tetrapods – Wheelers Bay

After recent dredging of Ventnor Haven, sediment has built up along the Eastern Frontage and has allowed access to inspect the Tetrapods and associated infrastructure.

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

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TYPE OF INSPECTION – ROUTINE - MONTHLY






COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY






COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

CONCLUSION
Very limited / no access to foreshore at this location.

All tetrapods are stable.

Monitor

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID V.2-427

INSPECTION DATE 04.04.13

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

LOCATION V.2.16

DESCRIPTION
Condition of Promenade Joints – Wheelers Bay

Reference Purchase Order 3500139849 – Observation ID's: V.2-390 – V.2-401

Location was last repaired November 2012

Location not repaired V.2-401

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

Location was repaired Nov 2011 and has moved approximately 25mm.

ACTION
Repair dropped concrete repair.
Polysulphide Sealant promenade joints 20m in total (3.5m remaining from purchase order 3500139849).

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 10.04.13

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY


2013/04/10


2013/04/10


2013/04/10


2013/04/10


2013/04/10


2013/04/10

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

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TYPE OF INSPECTION – ROUTINE - MONTHLY

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 15.04.13

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

Locations repaired.

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID	V.2-430
INSPECTION DATE	09.04.13
INSPECTED BY	Luke Ellison (Coastal Engineering Technician)
LOCATION	V.2.16

DESCRIPTION
Wheelers Bay – Joint Repairs

Location 1
Current Joint - Length 1.85m – Width 20mm
Clear / clean joint and seal with polysulphide sealant

Location 2
Current Joint - Length 3.5m – Width 40mm - Slight step between slabs
Cut landward slab 400mm from joint edge, dowel into landward slab, re-cast slab edge with reinforced concrete to remove step flush with existing surfaces. Polysulphide new joint.
Ensure existing ‘normal’ slab joints are retained.

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

Location 3
Current Joint - Length 4.3m – Width 20mm - Slight step between slabs and expanded joint
Cut landward slab 400mm from joint edge, dowel into landward slab, re-cast slab edge with reinforced concrete to remove step flush with existing surfaces. Polysulphide new joint.
Ensure existing 'normal' slab joints are retained.

Location 4
Current Joint - Length 1.9m – Width 40mm
Clean / clear joint and seal with polysulphide sealant

Location 5

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

Current Joint - Length 3.75m – Width 80mm (max) - Slight step between slabs and expanded joint
Cut landward slab 400mm from joint edge, dowel into landward slab, re-cast slab edge with reinforced concrete to remove step flush with existing surfaces. Polysulphide new joint.
Ensure existing ‘normal’ slab joints are retained.

ACTION
Monitor / Repair

INSPECTION DATE 08.05.13

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

Repairs in work

Slab has raised interface, as a result of continuing movement – Length 3.9m.
Instructed contractor to extend repair to cover this additional slab 08.05.13

ISLE of WIGHT COUNCIL

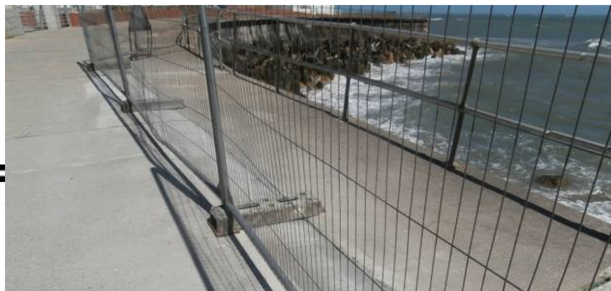
PROTECT – INTERNAL USE ONLY
Directorate of Economy and Environment
Director **Stuart Love**

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 09.05.13

INSPECTED BY Luke Ellison (Coastal Engineering Technician)



COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 15.05.13

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 11.06.13

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID	V.2-536
INSPECTION DATE	11.02.15
INSPECTED BY	Luke Ellison (Coastal Engineering Technician)
LOCATION	V.2
RESPONSE	M

DESCRIPTION
Condition of promenade joints – Wheelers Bay
Reference V.2-427 / V.2-496

Location 1
Existing polysulphide sealant edge has been removed
Total Area 700mm * 50mm (max width)

Location 2
1900mm x 200mm (Including concrete repair)
Total width of joint including existing sealant 50mm
Gap 15mm

Location 3
Length 3700mm
Total width of joint including existing sealant 50mm
Gap 25mm

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

Location 4
Length 2000mm
Total width of joint including existing sealant 65mm
Gap 15mm

Location 5
Length 4100mm
Total width of joint including existing sealant 70mm
Gap 20mm

ACTION
Monitor / Repair

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 23.02.15

INSPECTED BY Luke Ellison (Coastal Engineering Technician)






COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 04.03.15

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

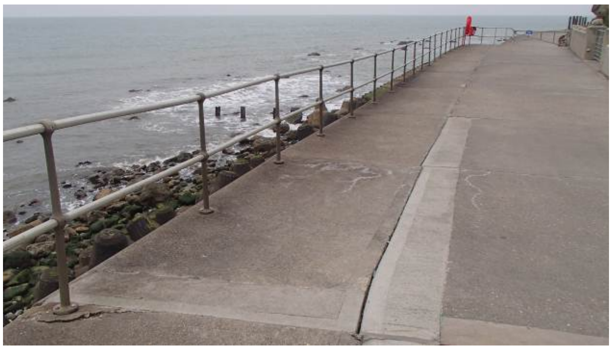
Locations repaired – Observation closed

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID	V.2-547
INSPECTION DATE	27.04.15
INSPECTED BY	Luke Ellison (Coastal Engineering Technician)
LOCATION	V.2
RESPONSE	M

DESCRIPTION
Monitor Joints – Wheelers bay






COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

ACTION
Monitor

INSPECTION DATE 08.06.15

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 16.07.15

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

INSPECTION DATE 22.09.15

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 20.04.16

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 13.05.16

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

Open joints sealed. Raised concrete slab chamfered. Joint repair completed.

- Observation closed

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID	V.2-329
INSPECTION DATE	11.05.11
INSPECTED BY	Luke Ellison (Coastal Engineering Technician)
LOCATION	V.2.16
RESPONSE	N/A

DESCRIPTION
Inspection of steel sheet piling – Eastern Esplanade

After recent dredging of Ventnor Haven, sediment has built up along the Eastern Frontage and has allowed access to inspect the steel sheet piling and associated infrastructure.

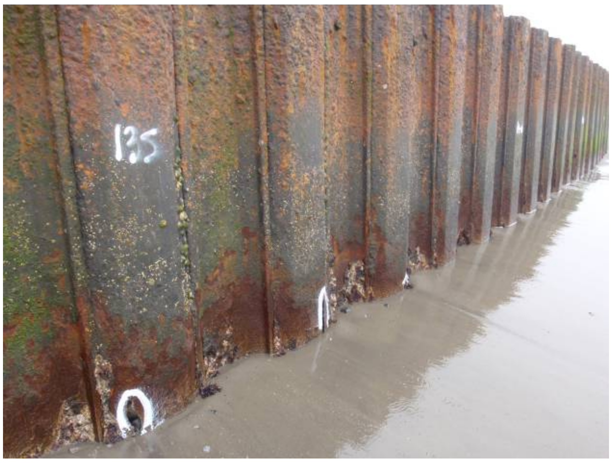
Note: Defects may not also be visible due to the higher sediment levels.

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY



COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

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TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 20.04.16

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID V.2-419

INSPECTION DATE 13.02.13

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

LOCATION V.2.17

DESCRIPTION
Monitor Apron Movement – Eastern Esplanade

ACTION
Monitor

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 13.03.13

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 21.01.14

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

PROTECT – INTERNAL USE ONLY

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

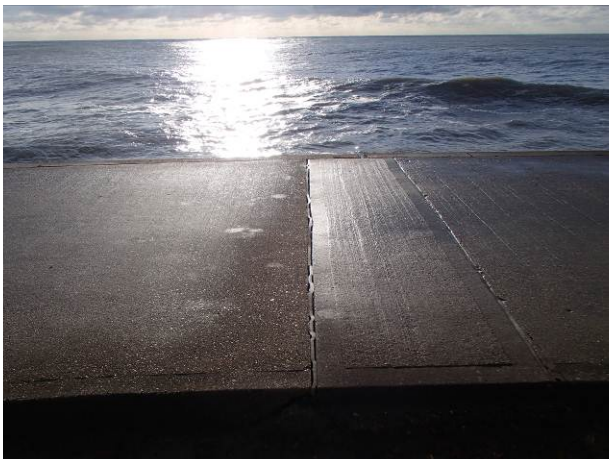
INSPECTION DATE 13.02.13

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

Old repair has popped out exposing void under concrete sloping revetment.

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

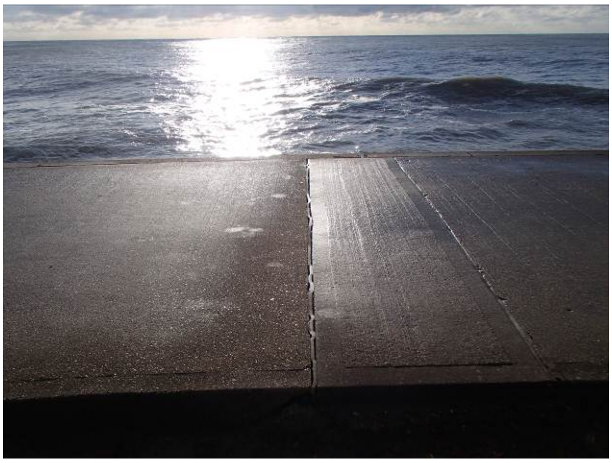


INSPECTION DATE 30.01.15

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY



COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 11.02.14

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 23.04.14

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY




INSPECTION DATE 23.06.16

INSPECTED BY Luke Ellison (Coastal Engineering Technician)


COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID	V.2-616
INSPECTION DATE	16.06.17
INSPECTED BY	Luke Ellison (Coastal Engineering Technician)
LOCATION	V.2
RESPONSE	M

DESCRIPTION
Dudley Road Car Park Footpath Timber Steps – Movement

Steps closed

Stressed joint

Scarp visible

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

Timber rail bend

Displacement of timber steps

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

Location

ACTION
Monitor

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID V.2-425

INSPECTION DATE 03.04.13

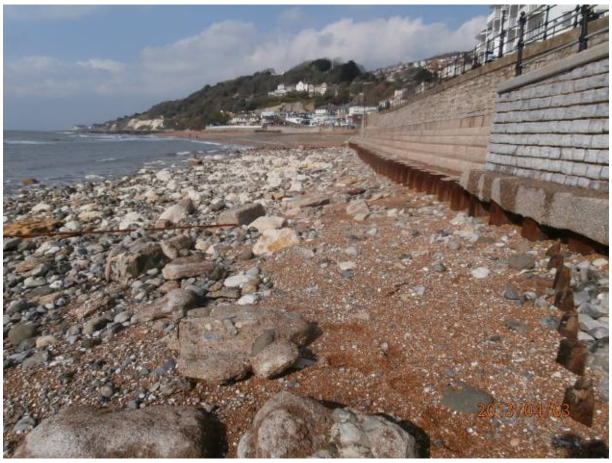
INSPECTED BY Luke Ellison (Coastal Engineering Technician)

LOCATION V.2.23

DESCRIPTION
Low beach Levels – Ventnor Esplanade – Exposed Groyne Structures.

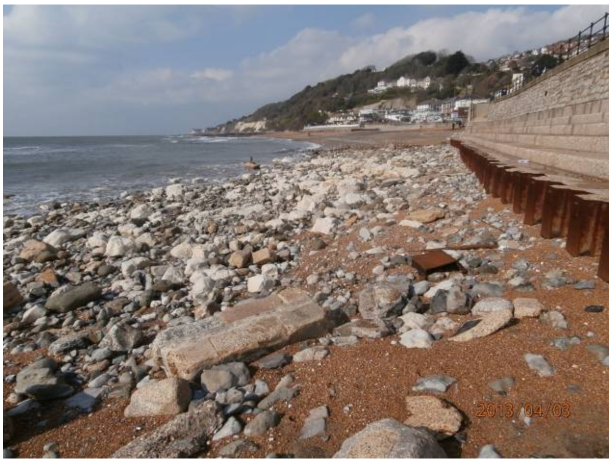
COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

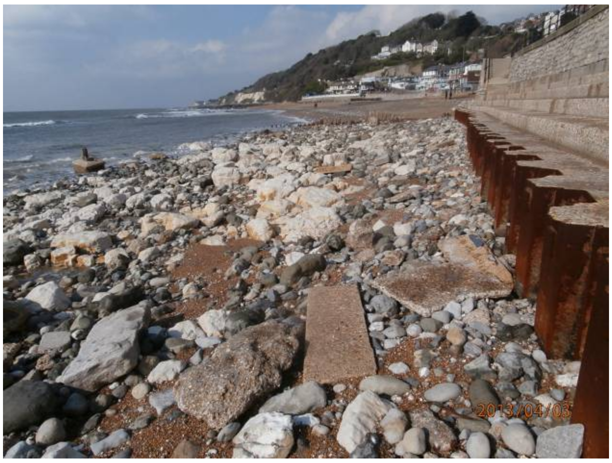
TYPE OF INSPECTION – ROUTINE - MONTHLY

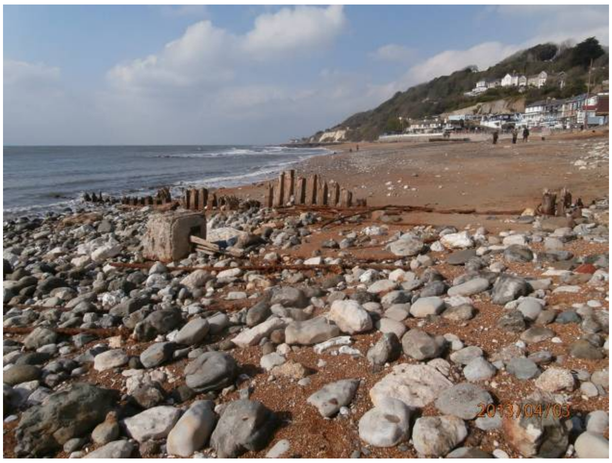


COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY



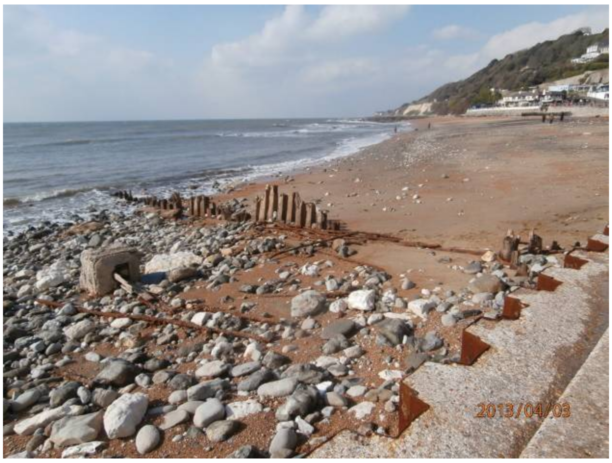




PROTECT – INTERNAL USE ONLY
Directorate of Economy and Environment
Director **Stuart Love**

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY



Remove and dispose of concrete from foreshore

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

Protruding bar

ACTION
Carefully remove and dispose of all loose / protruding metal work on the foreshore.
Carefully trim and dispose of protruding timber groyne spikes.
Ensuring no sharp edges remain.

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 04.04.13

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

Material and protruding elements removed.

Observation closed

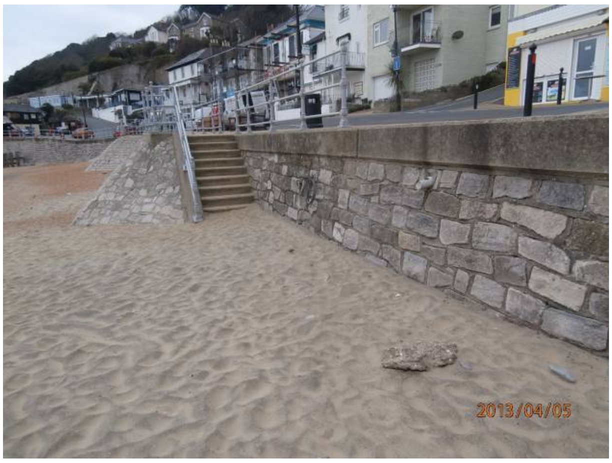
COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 05.04.13

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

Second load of material removed from the foreshore



COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

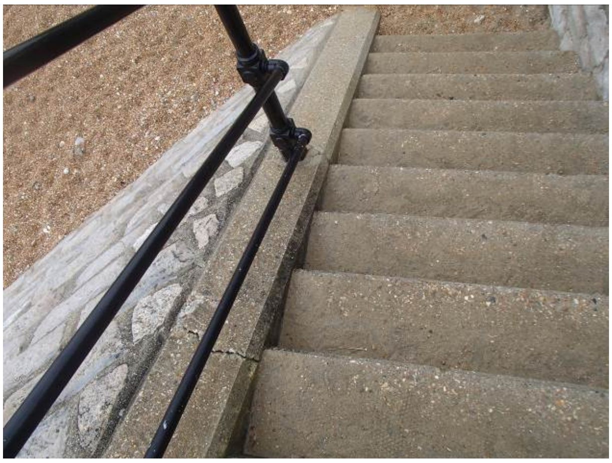
OBSERVATION ID	V.2-581
INSPECTION DATE	31.03.16
INSPECTED BY	Luke Ellison (Coastal Engineering Technician)
LOCATION	V.2
RESPONSE	M

DESCRIPTION
Condition of steps – Ventnor Esplanade

Location

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY



ACTION
Repair

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

INSPECTION DATE 19.04.16

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

Repaired – Observation closed

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID	V.2-617
INSPECTION DATE	16.06.17
INSPECTED BY	Luke Ellison (Coastal Engineering Technician)
LOCATION	V.2
RESPONSE	M

DESCRIPTION
Inspection of Western Cliffs to Spyglass – Ventnor Coastal Structures
From La Falaise Steps




COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

Running water appears to be exiting the cliff at two separate locations

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

Old outfall pipe – no running water

Spyglass - Stone masonry wall

ACTION
Monitor

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID	V.2-472
INSPECTION DATE	17.12.13
INSPECTED BY	Luke Ellison (Coastal Engineering Technician)
LOCATION	V.2.17
RESPONSE	M

DESCRIPTION
Monitor Movement – Castle Cove – Steephill Cove

ACTION
Monitor

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

OBSERVATION ID V.2-511

INSPECTION DATE 08.07.14

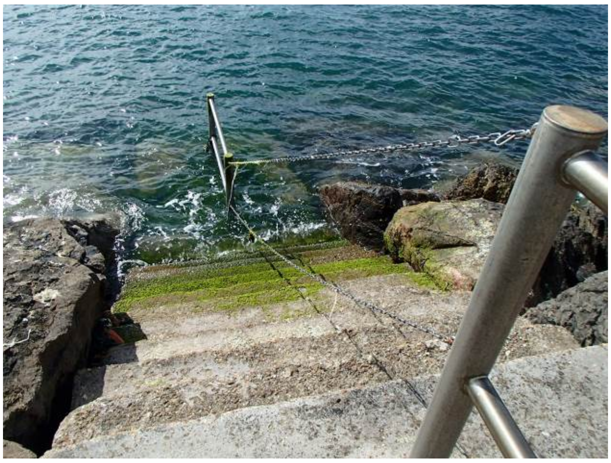
INSPECTED BY Luke Ellison (Coastal Engineering Technician)

LOCATION V.2

RESPONSE M

DESCRIPTION
Castle Cove step block movement

Tight upper chain observed

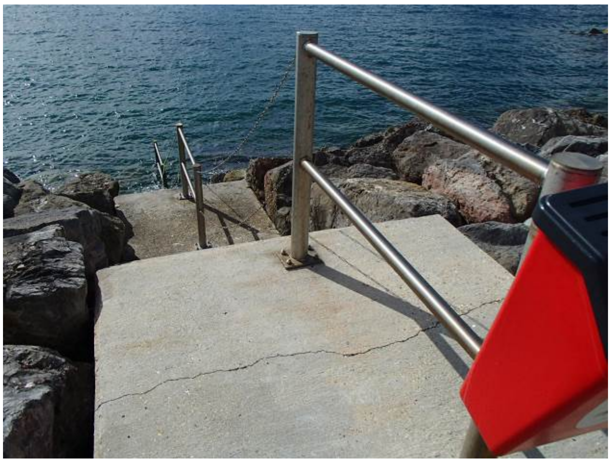


Cracked step block

COASTAL INSPECTION REPORT – SECTION – VEN 2 – MONKS BAY TO STEEPHILL COVE

TYPE OF INSPECTION – ROUTINE - MONTHLY

Cracked step block



ACTION
Monitor
Move spigot onto free chain link to release tension in chain (Lower upper chain)

INSPECTION DATE 16.02.16

INSPECTED BY Luke Ellison (Coastal Engineering Technician)

Chain amended – Observation closed