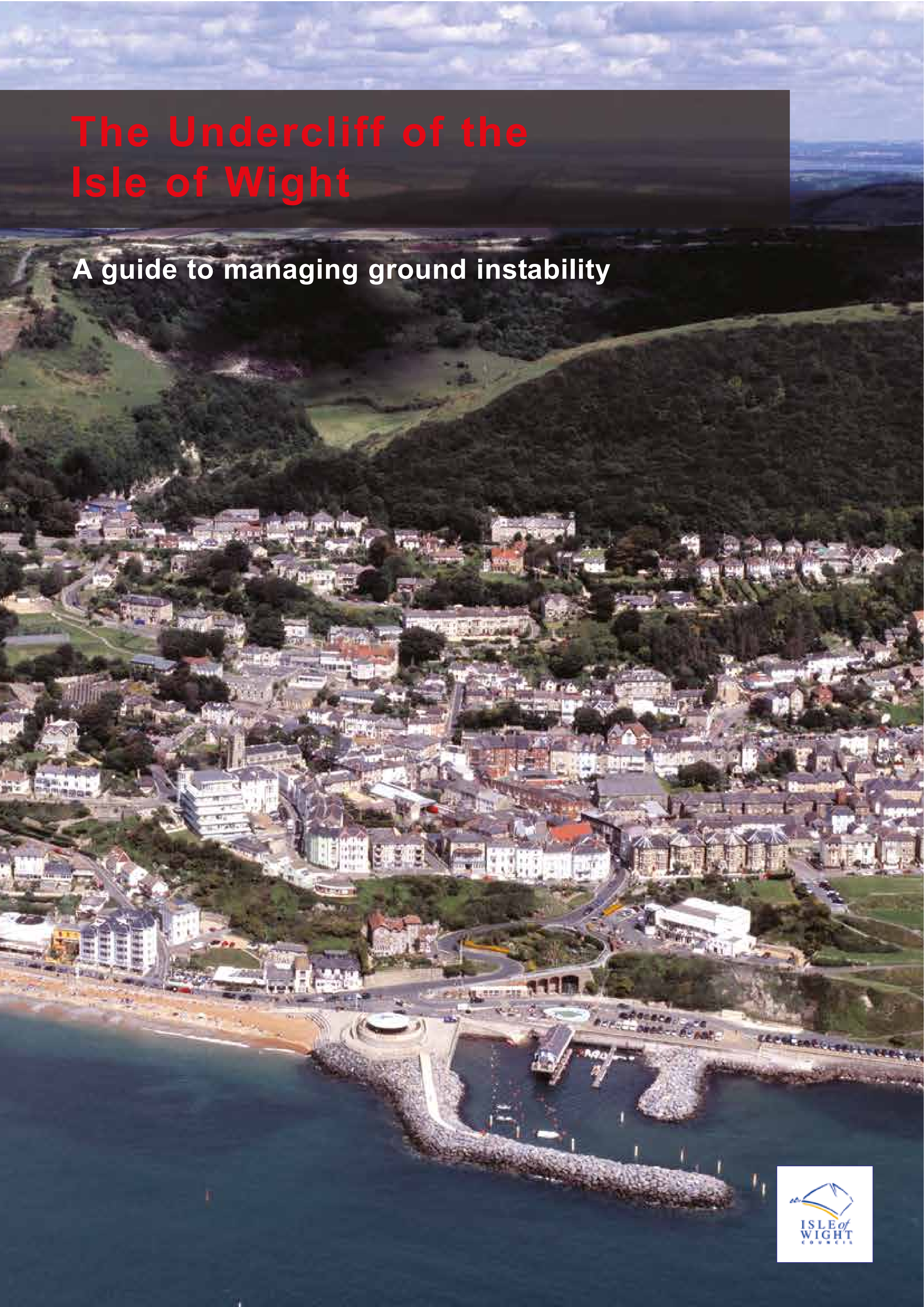
The Undercliff of the Isle of Wight

A guide to managing ground instability



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A guide to managing ground instability

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Acknowledgements

About this guide

This guide has been prepared by the Isle of Wight Council's Centre for the Coastal Environment to promote sustainable management of ground instability problems within the Undercliff of the Isle of Wight. This guidance has been developed following a series of studies and investigations undertaken since 1987. The work of the following individuals, who have contributed to our current knowledge on this subject, is gratefully acknowledged: Professor E Bromhead, Dr D Brook OBE, Professor D Brunsden OBE, Dr M Chandler, Dr A R Clark, Dr J Doornkamp, Professor J N Hutchinson, Dr E M Lee, Dr B Marker OBE and Dr R Moore. The assistance of Halcrow with the preparation of this publication is gratefully acknowledged.

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Cover photo - 'Ventnor from the sea'. Courtesy Wight Light Gallery, Ventnor

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'Ventnor from above the Western Cliffs', 2003

Executive Summary

The Isle of Wight Undercliff represents one of the most scenic parts of the Isle of Wight coastline. Its natural beauty arises from its geological history together with the ongoing processes of coastal erosion and landsliding. Extending for a distance of 12km from Blackgang in the west to Bonchurch in the east, and including the town of Ventnor and the villages of Bonchurch, St Lawrence, Niton and Blackgang, the Undercliff is the largest urban landslide complex in north-western Europe. Following on from studies by earlier researchers the former Department of the Environment (DOE) commissioned an investigation of ground movement problems in Ventnor in 1987 in order to assist the preparation of national planning policy guidance for areas affected by ground instability. The results of this study verified many of the issues and misconceptions relating to ground movement and following this the DOE pilot study of central Ventnor was extended by the Council to the east and west to include the whole of the Undercliff.

More recently, these surface investigations and field mapping surveys have been supported by valuable information gained from two phases of ground investigations in 2002 and 2005. These sub-surface studies have assisted in confirming the geological structure of the area and have allowed consideration of landslide risk together with the preparation of improved guidance for management of the Undercliff, taking account of the predicated impacts of climate change.

This new guide is intended to provide practical information for all those with an interest in the sustainability of the Undercliff in a clearly illustrated and readable format. It is very much hoped that this new book will prove of real use to those involved with a wide range of interests in the area, including homeowners, who, through good practice, can contribute towards a reduction in the problems of ground movement.

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August 2007

The Undercliff looking eastwards. The coastal landslide complex extends for 12 kilometres from Blackgang to Bonchurch. Phases of landsliding promoted by rising sea levels after the last Ice Age led to its formation, creating a dramatic but beautiful landscape with its own micro-climate.

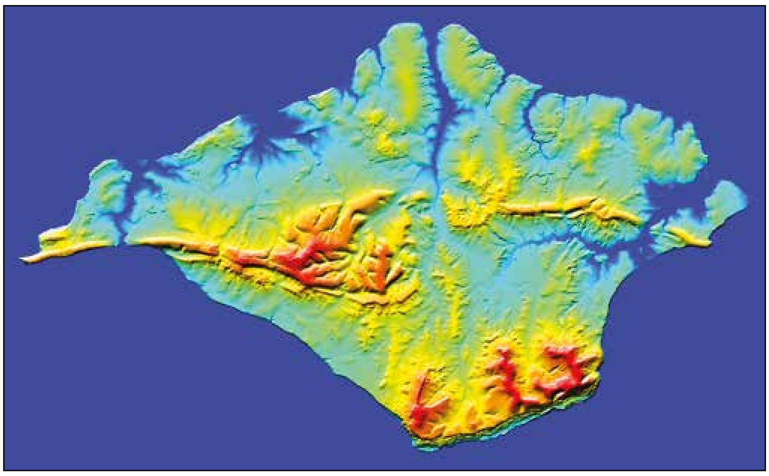
Chapter One
Why is there a ground movement problem in the Isle of Wight Undercliff?

The Isle of Wight Undercliff is considered by many to be one of the most beautiful coastal regions of Great Britain. The striking scenery, so important to the Island's visitor-based economy, is strongly influenced by the underlying geology, landsliding and coastal erosion processes. These same factors present challenges in terms of managing the coastal environment along this part of the Island's coastline.

The Isle of Wight Council has, over many years, been developing and implementing strategies for the sustainable management of coastal instability risk both within the Undercliff of the Island and elsewhere. This has involved leading-edge research into the fundamental causes of the instability and techniques for the management of large landslides in urban areas, and has included the implementation of innovative and environmentally-friendly coastal and geotechnical engineering schemes to help manage the risk.

The town of Ventnor is located on the south coast of the Island within this spectacular complex of ancient landslides known as the Undercliff. It is the largest coastal landslide complex in the United Kingdom and the largest urban landslide complex in north-western Europe. The unusual landscape of the Undercliff, with its relatively warm micro-climate and lush vegetation, supports important habitats for plants and animals, and provides a considerable attraction and a range of interests for visitors. In addition to Ventnor itself, there are important villages located within the Undercliff including Bonchurch, St Lawrence, Niton and Blackgang.

The Isle of Wight Undercliff has been recognised by the government as the most significant ground instability problem in Great Britain. The landslide is deep-seated and generally slow moving, which has allowed the historical development of the area, particularly since the mid-19th century. However, the impact of coastal landsliding and the long term effect of ground movement on the urban environment can be considerable. There is ongoing damage to the urban infrastructure including roads, retaining walls, underground services and buildings. In fact, over the last 100 years, some 50 properties have had to be demolished due to the impacts of ground movement whilst others have sustained significant damage. The annual cost of landslide damage and management measures is estimated to exceed £3 million a year. Despite this, some locations within the Undercliff remain quite stable with ancient structures including churches dating from the 11th century and earlier, as well as stone farmhouses and substantial Victorian buildings, which have remained relatively unaffected.



A computer-generated image of the Isle of Wight. The yellow and red colours represent the high downland of the island. The tract of slipped land on the south coast, the Undercliff, may be seen at the bottom of the image. (Halcrow, 2006)

Taking account of the instability problems within parts of the Undercliff, and the frequent landslide events, a large investment has been made by the government and the Isle of Wight Council over the last twenty years in developing a detailed understanding of the causes of instability, with the aim of achieving long term, sustainable solutions to ground movement problems. This has included in-depth research into the nature of the ground movement, landslide mechanisms and the assessment of landslide risk.

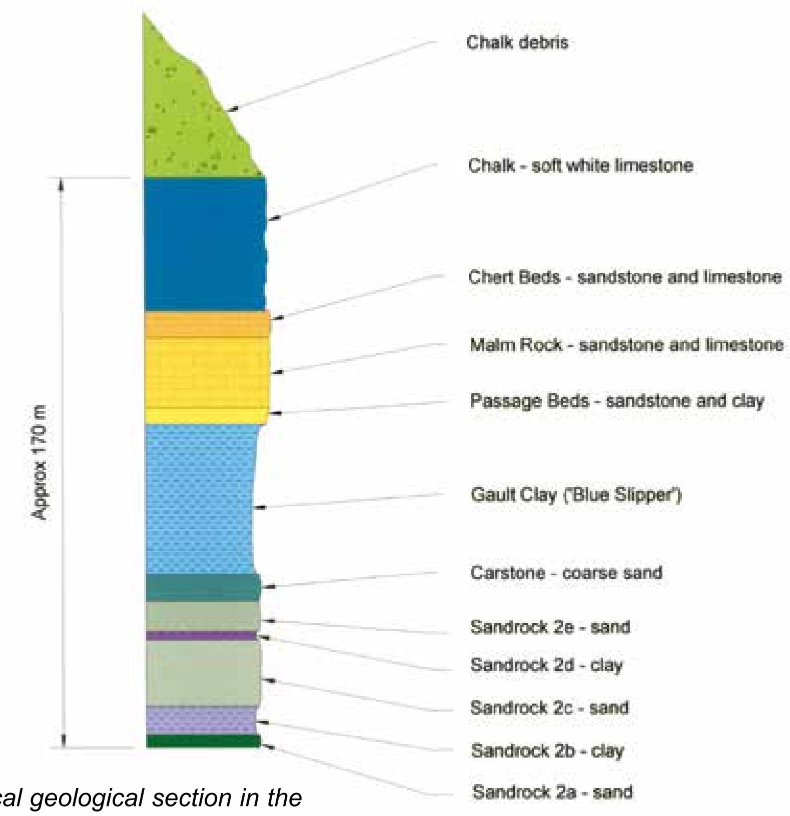
In the late 1980s, the former Department of the Environment (DOE) commissioned a pilot study of central Ventnor to assist the preparation of planning policy guidance for 'Development on unstable land'. Subsequent studies were undertaken in order to:

- determine the nature and extent of the landsliding problems;
- understand the past behaviour of separate parts of the Undercliff;
- formulate a range of management strategies to try and reduce the impact of ground movement.

The programme of work comprised a thorough review of available records, reports and documents followed by a programme of detailed field investigations involving geomorphological and geological mapping, assessments of ground movement rates, a survey of damage caused by ground movement, and a review of local building practices; this has been followed more recently by detailed sub-surface investigations.

The Isle of Wight Council and its predecessors subsequently commissioned several extensions of the original DOE study of central Ventnor to provide coverage for the whole of the Undercliff. The recommendations arising from the studies were developed into a 'Landslide Management Strategy' which has assisted the Council in seeking to manage the instability problems, through, in particular, improved drainage, additional coast protection works, landslide monitoring and prediction and further research.

A particular feature of previous studies has been the dissemination of the findings for both the general public, to increase their knowledge and awareness of the instability problems, and to

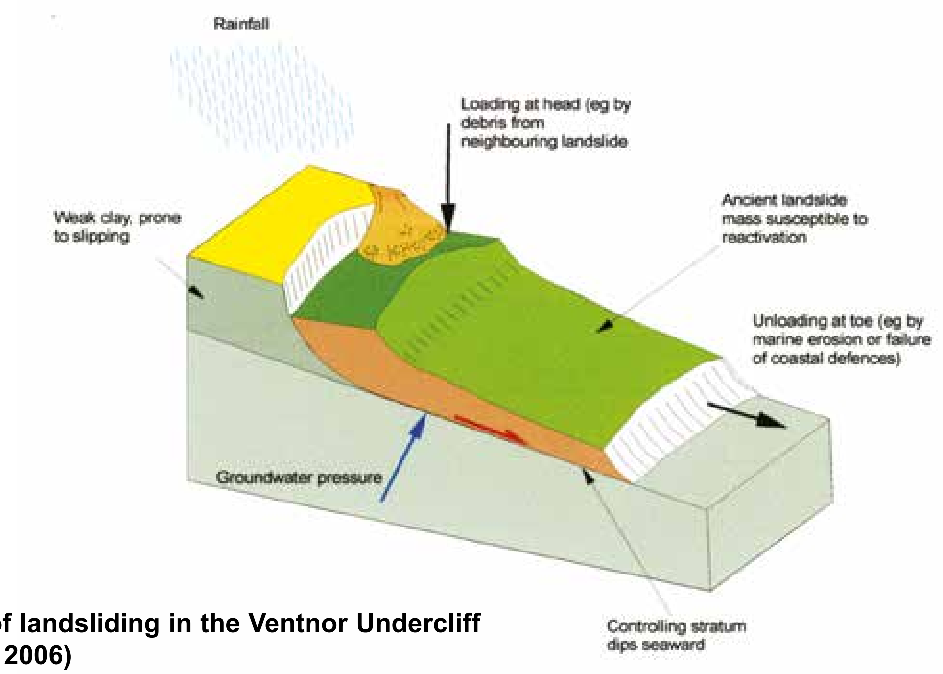


Typical geological section in the Ventnor Undercliff (Halcrow 2006) professional practitioners in landslide management through a series of publications, exhibitions at the Isle of Wight Coastal Visitors' Centre and presentations at international conferences. In fact three conferences have been held on the Isle of Wight (in 1991, 2002, and in 2007 a third four day conference entitled 'Landslides and climate change - Challenges and solutions') also took place in Ventnor.

The landslide management strategy and previous work have recognised the need for detailed sub-surface investigations to verify the mechanisms and causes of coastal landsliding. Initially in 2002, and continuing in 2005, with financial support from the Department for Transport, the Isle of Wight Council commissioned a programme of ground investigations in central Ventnor in order to prepare an interpretative report from the findings including a 'Quantitative Risk Assessment' (QRA). This report has advanced the understanding of the mechanisms and causes of coastal landsliding in central Ventnor and, for the first time, the QRA evaluates the likelihood and consequences of future risk scenarios. This work represents the first phase and conceptual design for a possible civil engineering solution following an options analysis by a team comprising many of the United Kingdom's experts in this field.

This new guide to good practice for managing ground instability is aimed at all those with an interest in the sustainable development to the Isle of Wight Undercliff. It is hoped that the publication will provide, in non-technical language, information which explains the various initiatives that have been promoted by the Council over recent years.

Coastal instability within the Undercliff is controlled, fundamentally, by the underlying geology. The southern part of the Isle of Wight is underlain by sedimentary rocks formed during the Cretaceous Period around 80-120 million years ago. These rocks mostly comprise alternating layers of clays and sandstones of varying thicknesses, capped by Chalk, which formed the downland behind the Undercliff itself.



Causes of landsliding in the Ventnor Undercliff (Halcrow 2006)

*There are several destabilising influences which contribute to the coastal instability, as illustrated in this diagram. The Undercliff is an ancient landslide complex, which first formed thousands of years ago, when climatic conditions were worse than they are today. This has left a legacy of unstable ground prone to reactivation. Some of the destabilizing influences may be regarded as **preparatory factors** which make the slope susceptible to failure without actually initiating it. Others are **triggering factors** which actually initiate slope movement. The most likely triggering factors at present are increases in groundwater pressure, which are closely related to rainfall, and marine erosion at the toe of the system.*

The presence of clay layers within the geological section introduce significant weaknesses within which major landslide slip surfaces have formed; there are several individual units of clay which have been demonstrated to be particularly important in controlling landsliding. The sandstone beds and chalk are more permeable than the clays and are water-bearing; this has an important influence on instability as landslide movements are often triggered by increases in water pressure within the ground. Strata in the Undercliff dip gently seawards by a few degrees, which facilitates the movement of landslide units by gravity towards the sea, and the sea itself erodes material from the toe of the landslide, removing support, which contributes further to the instability problems.

Scientific studies suggest that the Undercliff was formed as a result of two main phases of landsliding which took place after the last Ice Age between 8,000 and 4,500 years ago and between 2,500 and 1,800 years ago, following major changes in climate and sea level rise which resulted in increased erosion along the Island's southern coast.

The landslides within the Undercliff are developed in Lower and Upper Cretaceous rocks, which consist of:

- over 40m thickness of Gault Clay (known locally as 'Blue slipper'); which is
- underlain by sandstone (the Lower Greensand);
- and overlain by massive cherty sandstone (Upper Greensand) and the Chalk above.

Of particular importance are the presence of thin clay layers within the Sandrock (Lower Greensand) which together with the Gault Clay have a very important influence on the stability of the area.

There are three main 'geomorphological units' (landform types) in the Undercliff:

- The Chalk Downs; the upper sections of the south-facing downland behind the Undercliff are unaffected by deep landsliding, although shallow slides in weathered chalk, soil erosion and soil creep may occur occasionally.

- The Upper Greensand bench; lies immediately below the Chalk Downs. This a narrow seaward sloping bench. It is not a continuous feature, being absent from the central part of the Ventnor area. Where present, the bench varies in elevation along its length, indicating that it is partly displaced by subsidence.

- Landslide features; landslide features to be found within the Undercliff include:

  - 'multiple-rotational slides', which occupy a broad zone in the upper part of the Undercliff, giving rise to linear benches which are separated by scarp slopes. These units comprise slipped back-tilted blocks of Upper Greensand and Chalk. Rotated blocks of Upper Greensand are exposed along the coast, especially in the Ventnor Eastern Cliffs and at Orchard Bay, St Lawrence.

  - Sequences of 'compound slides' generally occupy a zone of similar breadth in the lower part of the Undercliff, immediately beneath the zone of multiple-rotational slides. In the Ventnor Park area there is a single continuous ridge of Chalky debris about 500m long and 15-20m high, backed by a broader 'graben' (a depression). Similar features are exposed along the coast at Westfield Cliffs, central Ventnor, Bonchurch and Woody Head, St Lawrence. The grabens landward of these ridges are usually filled with soft materials.

- In Upper Ventnor, a graben-like feature (known as the 'Lowtherville Graben') occurs just landward of the zone of multi-rotational sliding. This feature runs from the Havensbush area, across Newport Road and along Steephill Down Road. It consists of a 20m wide subsiding block of material bounded by parallel fissures. Historically the most serious ground movement problems experienced in Ventnor town have occurred here.

- The Gault Clay scarp, up to 20m high, can be traced through much of the Undercliff west of Ventnor. The scarp slope is occasionally the site of active mudslides and small rotational slides and is believed to mark the surface of exposure of the lower silty layers of the Gault Clay.

- Mudslides have developed on the coast where displaced Gault Clay is exposed, as at Castle Cove where groundwater movements accelerated instability and necessitated improvements to coast protection and stabilisation measures in 1996.

- Rockfalls and small mudslides occur along much of the coastline especially where the exposed landslide debris is unprotected from marine erosion, for example west of Steephill Cove to Puckaster. Slides and rockfalls are frequent at Woody Point, Woody Bay and Binnel Bay where coastal erosion continues.

What causes ground movement?

Before considering those factors which cause ground movement in the Undercliff, it is important to stress that development has taken place on an ancient landslide complex. As the materials along the landslide shear surfaces are probably at or close to their residual strengths, the slopes can be made to move under conditions that they could have resisted prior to the formation of the Undercliff. Thus, events which cause ground movement along the Undercliff would not necessarily cause problems on slopes or similar materials elsewhere.

Coastal erosion has long been appreciated to be a significant factor in the long term instability of the Undercliff. Most of the urban frontage has been protected by coastal defences and it is unlikely, therefore, that marine erosion remains a significant cause of slope instability in these areas provided that the defences are adequately maintained. However, the coastal frontages from Monk's Bay northwards towards Luccombe, and west of Steephill Cove (except Reeth Bay, Niton) remain unprotected and unchecked marine erosion (estimated to result in an average retreat rate of 0.2-0.3m per annum) is likely to have a destabilising influence, over time, on the Undercliff landslides in these areas.

Coastal erosion has progressively reduced the overall stability of the Undercliff slopes, and, together with other factors, such as periods of heavy rainfall, has promoted landslide activity. This tends to occur in the winter when rainfall totals are higher and evaporation rates are lower, and consequently much of the rainfall is 'effective' in raising groundwater levels. The relationship between landslide activity and winter rainfall is not a simple one. Some landslide systems are more sensitive to rainfall events whilst others appear only to show signs of movement during extremely rare conditions.

The fact that ground movement does not always occur when winter rainfall thresholds are exceeded highlights the importance of other factors in controlling landslide activity. Here it is useful to consider rainfall events as 'triggering' movements in systems where the effects of coastal erosion or human activity have 'prepared' slopes for failure by reducing the 'Factor of Safety'.

It is probably no coincidence that the number of reported landslide events has increased with the spread of development throughout the Undercliff over the last one hundred years or so. Whilst this partly reflects better records of ground movement, it is also true that development itself has acted as a destabilising influence in parts of the Undercliff. For example, development has involved 'cut and fill' operations to establish plots for houses or acceptable gradients for roads on steeply sloping hillsides. These operations have promoted local instability problems in some cases by changing the surface profile of the Undercliff slopes to a less stable configuration.

Potentially the most serious destabilising activity associated with development has been the artificial recharge of the ground water table. Uncontrolled discharge of surface water through soakaways and leaking drains has contributed to raising the groundwater table to a level where heavy winter storms could trigger movement. Any deterioration and leakage of services such as foul sewers, storm drains, water mains and service pipes add to the problem.

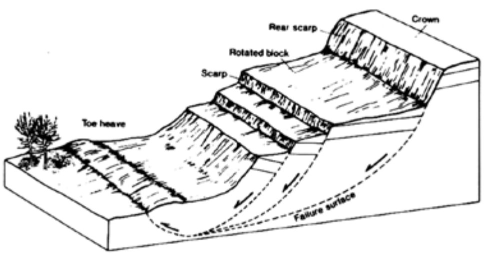
What is a landslide?

All slopes are under stress due to the forces of gravity. If the forces acting on a slope exceed the resisting strength of the materials that form the slope, the slope will fail and a landslide occurs. This might involve the displacement of a body of relatively intact material, the undersides and margins of which are marked by ruptured surfaces or zones known as 'shear surfaces'. Blocks of material then move 'en masse' over its shear surface, although displacement inevitably leads to internal stresses which result in the break-up of the moving mass.

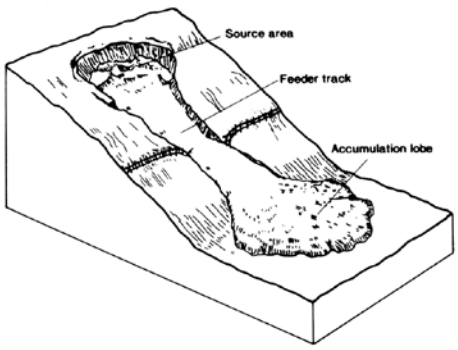
In general, the resisting strength of the materials decreases as the clay content rises. Clay slopes, therefore, are particularly prone to landsliding. Slides also occur frequently on slopes developed in a combination of impermeable fissured clays overlain by massive, well-jointed caprocks of limestone or sandstone.

Types of Landslides

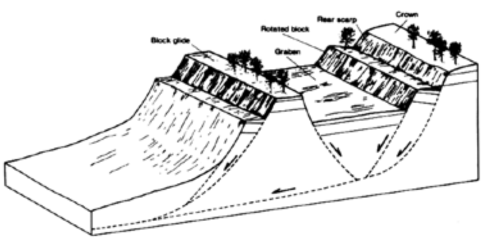
The Undercliff comprises three main types of slide;



Multiple-rotational slides (left) involving a series of slipped, back-tilted blocks each underlain by a circular failure surface that merge to form a common basal shear surface. These mainly occur at the rear of the Undercliff

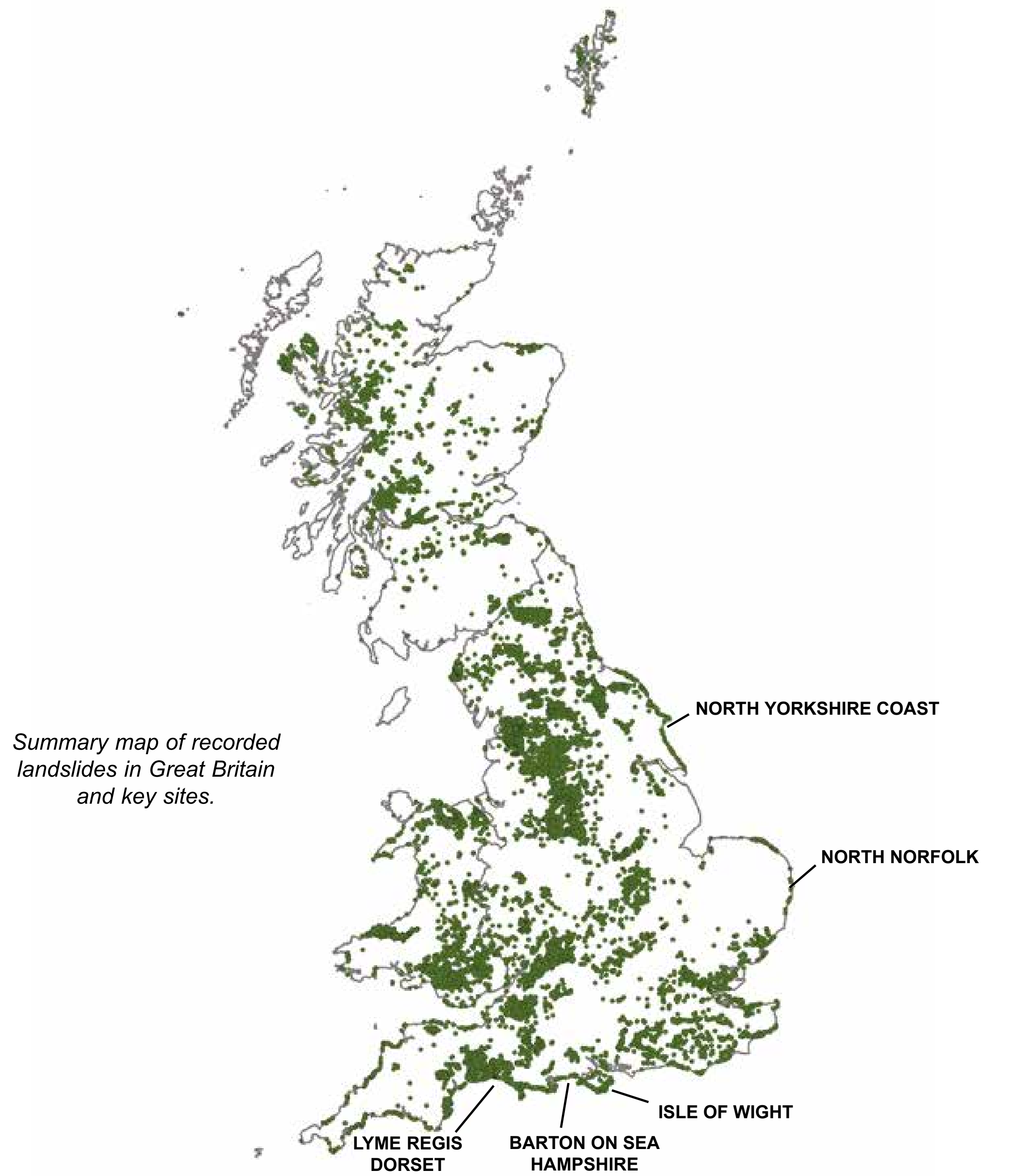


Mudslides (right) are relatively slow moving, lobate masses of clay-rich debris sliding over translational shear surfaces. Theses slides generally comprise a steep source area from which debris is supplied, a feeder track and a more gently inclined accumulation zone or lobe. They are commonly found on the Gault Clay scarp and along the coast where they occur on displaced blocks of clay.



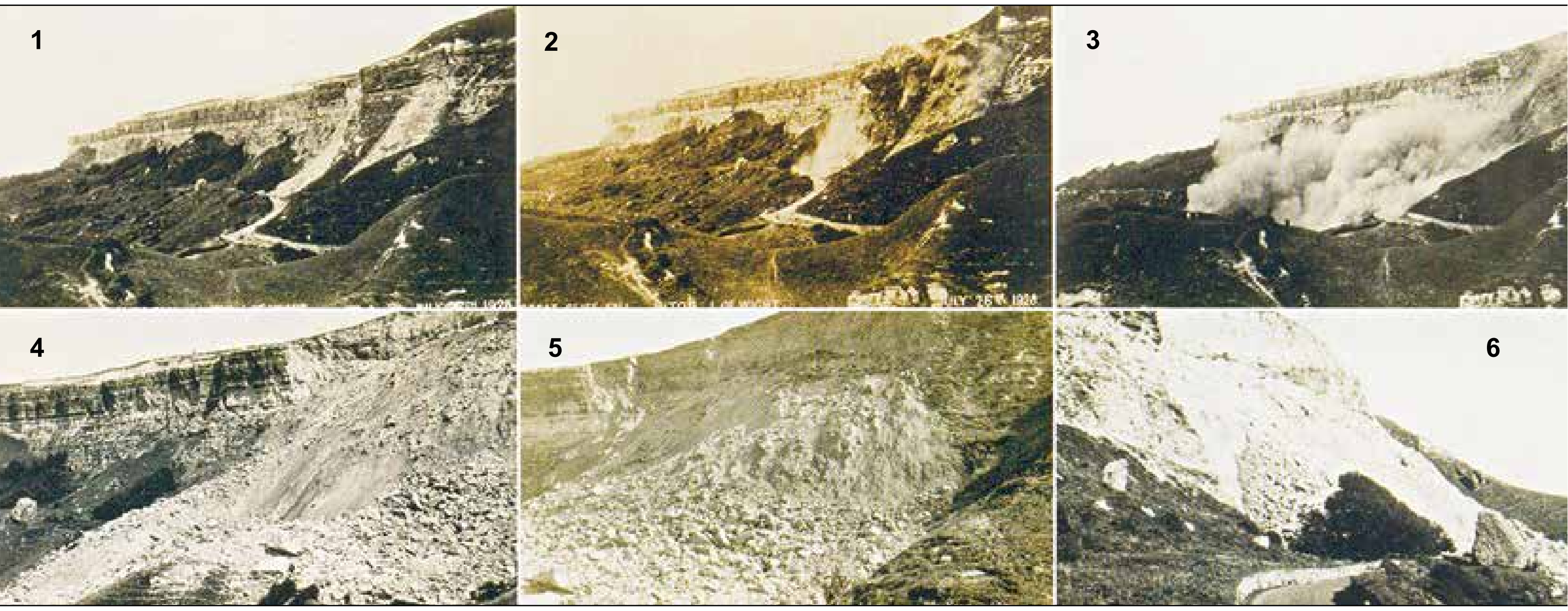
Compound slides (left) characterised by markedly non-circular shear surfaces. This type of slide involves the lateral displacement of a block forming an elongate ridge and the creation of a low-lying depression or graben immediately upslope, for example at Newport Road, Upper Ventnor and at Park Avenue, Ventnor

Throughout Great Britain there are known to have been about 14,000 recorded landslides (see figure below) some of which present a similar problem to those faced in the Undercliff where development has occurred on unstable land. Classic examples of landslides formed in these settings include the massive coastal slides at Folkestone Warren in Kent and along the Dorset coast. Similar conditions exist along the south coast of the Isle of Wight, where the Gault Clay is overlain by a massive Cherty sandstone, the Upper Greensand.



Location of landslides recorded in the British Geological Survey's National Landslide Database. The National Landslide Database is being developed as the definitive source of information on landslides in Britain . It currently holds 14,200 records of landslides, and new records are being added every year.

The massive debris lobe extending into Watershoot Bay near Blackgang following the Gore Cliff rockfall of July 1928. The failure from the rear scarp blocked the old Undercliff Road between Niton and Blackgang and caused collapse of the coastal slope which had become saturated following several months of rainfall.



The famous great cliff fall at Gore Cliff, Niton was captured in a remarkable sequence of photographs by a holidaymaker.

Chapter Two
What is the scale of the instability problem?

Ground movement has been recognised as a problem in parts of the Isle of Wight Undercliff, and elsewhere on the Island, for nearly two hundred years with notable consequences for the communities of Ventnor, Luccombe, Bonchurch, St Lawrence, Niton and Blackgang. Although archaeological finds suggest that ground movements occurred during prehistoric times, the earliest recorded event was provided by Worsley (1781) "huge fragments of rock and earth frequently fall from the cliffs between Binnel and Steephill".

In 1906 evidence given by Mr Strachan of the British Geological Survey to the 'Royal Commission on Coastal Erosion', provides a clear description of movements in Ventnor at that time; "the movement appears to be continuing very slowly … it is the experience of the Surveyor that flights of steps which are taken straight up and down the cliff have occasionally to be lengthened. The ground, by moving downwards, leaves gaps in these flights of steps, and they have to put in occasionally a few more steps to complete the staircase."

During the first half of the 20th century a number of landslide events were reported between St Lawrence and Niton. These included rock falls from the steep cliffs behind St Lawrence, subsidence of the Undercliff Drive and coastal cliff falls. Of particular note was the dramatic rock fall at Gore Cliff, Niton, in 1928. The most significant period of movement occurred during the winter of 1960/61. Cliff falls, collapsed walls and settlement were reported throughout the Undercliff following the heaviest autumn rainfall since records began in 1839. Over the last fifteen years there has been growing public awareness of ground movement issues following research by the government and the Isle of Wight Council's Centre for the Coastal Environment, which has resulted in the publication of reports, maps and the opening of a Visitors' Centre in Ventnor.

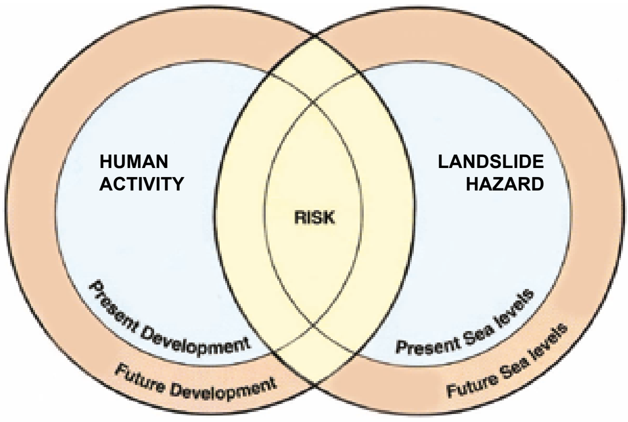
The terminology used when discussing natural events such as these and their impact on society can be very confusing and it is not uncommon for terms like hazard, risk and vulnerability to be used to describe the same concepts.

A **hazard** describes the chance of a potentially damaging ground movement event occurring within the area, i.e. ground movement constitutes a hazard.

Risk means the possible losses arising as a result of ground movement, i.e. the community is at risk from ground movement.

Vulnerability describes the degree of loss or damage to a particular element of the town or community, e.g. buildings, underground services, economic activities. Different elements will face different levels of risk from the ground movement hazard.

The concept of risk and hazard and the interaction of the human environment



Landslide Hazard, Human activity and risk.
(Adapted from DOE)

The concept of risk as the interaction of the human environment with the physical environment is illustrated above. Only when the two systems are in conflict do hazards such as landsliding become a threat to the community. Of particular importance is the fact that as urban development increases, intensifies or spreads into vulnerable areas so the potential impact of hazards also increases.

Ground Instability Problems

Building damage, off Bath Road, Ventnor 1960 (top left); Gore Cliff Cottage, Blackgang, 1994 (middle left); the loss of Sandrock Spring Cottage, Blackgang, 1978 (bottom left); damage to Green Roofs, Luccombe, 1988 (middle top); Gore Cliff, Niton, 1928 (middle bottom); landslips at Blackgang, 1912 (top right), 1920 (middle right); the great landslip at Luccombe, 1910. Main picture - landslide at Undercliff Glen in 2001.

with landslide hazard is illustrated in the figure on page 15. Only when the two systems are in conflict does landsliding become a threat to the community. Of particular importance is the fact that as urban development increases or intensifies the potential impacts of landsliding are much greater, particularly in the context of climate change.

What are the impacts of ground movement?

The occurrence of ground movement within the Undercliff has resulted in a range of problems for the local community. Judging from an historical review it appears that these problems have increased over the last century or so. This is undoubtedly a reflection of the fact that urban development itself has increased the vulnerability of the community to ground movement damage by concentrating people, resources, assets and underground services in a limited area. A landslide management strategy has been developed by the Council to try and counter this.

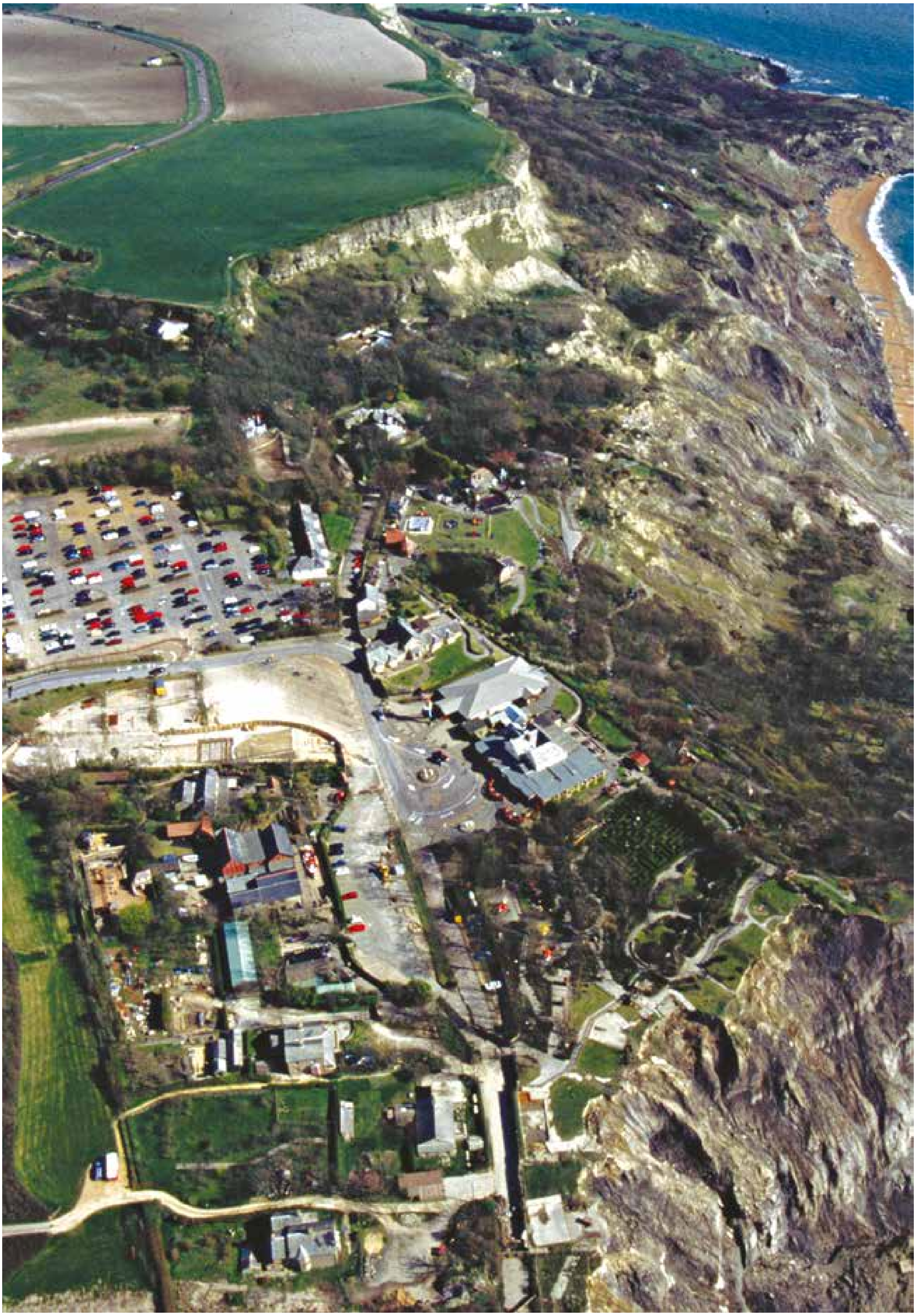
As part of the Ventnor Undercliff studies a systematic review of damage due to ground movement within the Undercliff was carried out. This research indicated that much of the developed Ventnor Undercliff (79%) was affected by only slight, negligible damage due to ground movement. Around 6% of the study area was affected by moderate damage, whilst the remaining 15% was affected by serious or severe damage due to ground movement.

It is emphasised that serious ground movements and damage are generally concentrated in localised places; most of the intervening areas have shown negligible damage due to ground movement. In many locations buildings have survived for long periods without evidence of damage (e.g. Bonchurch Old Church, which is believed to be nearly a thousand years old).

In those areas that have suffered damage it is also the case that the foundations and building styles are often unsuited to accommodating ground movement. However, it is important to recognise the predicted impacts of climate change which may result in an increase of winter rainfall of between 26-30% by the year 2080. The consequences of this are being investigated by the Council in order to seek a solution to mitigate such adverse effects.

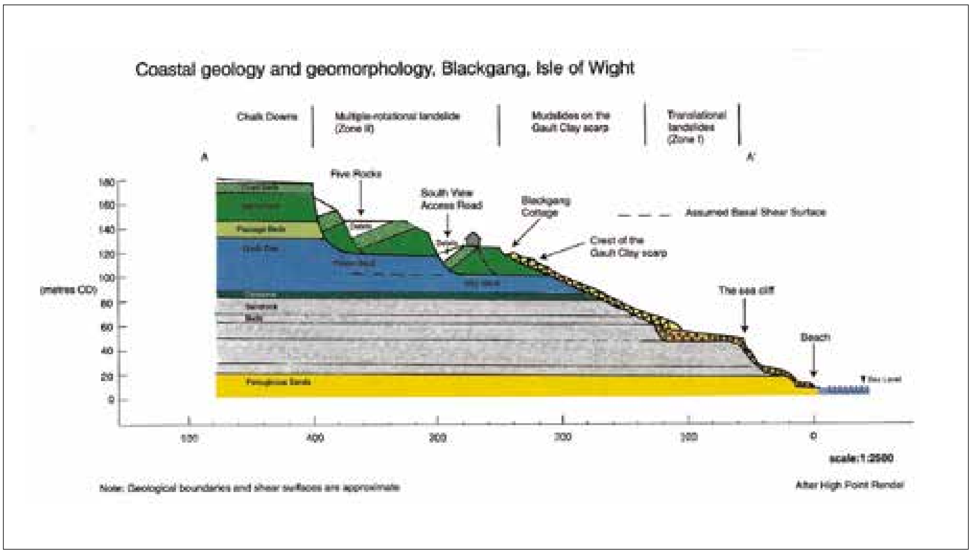
The landslides forming the Undercliff can be considered to be 'marginally stable', whereby the resistance to change just exceeds or balances the disturbing forces operating at any time. Occasionally the disturbing forces (such as extreme rainfall) exceed the resistance of the landslide and ground movement events occur to bring about a new equilibrium or a more stable landform.

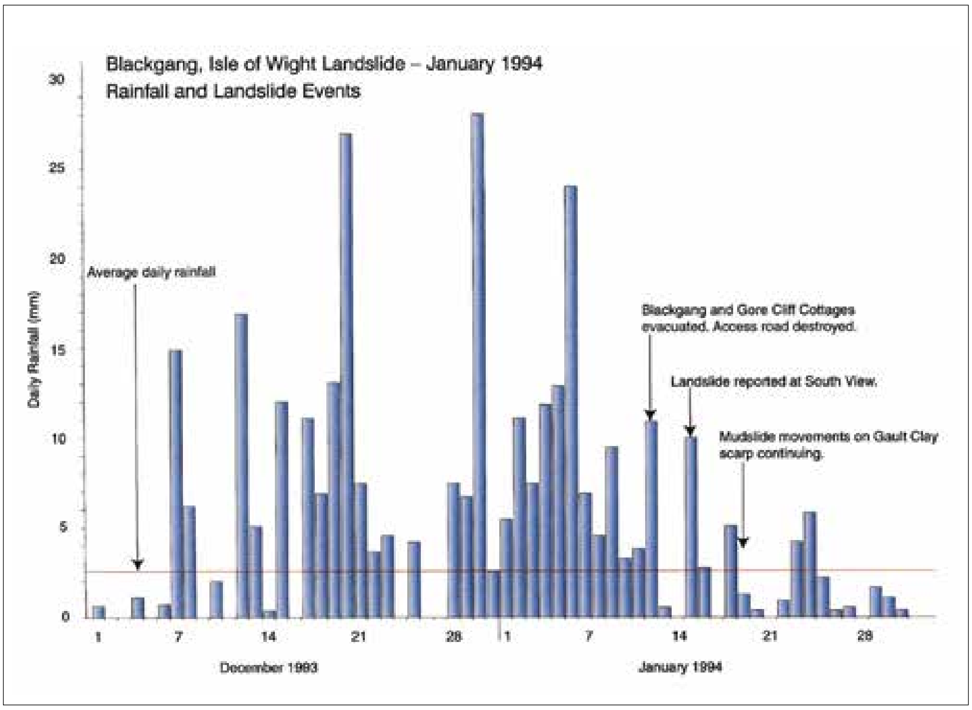
Within the Undercliff, some landslide systems are more resistant to disturbing forces than others. Contemporary field evidence and past records of landslide events and ground movement support this fact. By understanding the sensitivity of different landslide units within the Undercliff it is possible to develop an understanding of the probability of landslide occurrence or reoccurrence particularly taking account of the impacts of rainfall during the autumn and winter periods.



A view of Blackgang village and coastline following the extensive landsliding of January 1994

The Blackgang frontage from the south-east





At Blackgang on the south-west coast the underlying cause of coastal cliff recession and landslide activity is persistent marine erosion of the cliff base which has continued for centuries. The coastal slopes have a long history of deep-seated landsliding. The main trigger for a major landslide that occured in January 1994 was intense rainfall in the 10 preceding days which amounted to 153 mm. The combination of antecedent and high intensity rainfall together with the unloading and over-steepening of the coastal slopes resulting from marine erosion was, therefore, responsible for triggering the major landslide event on the evening of the 12th January

Chapter Three
Investigating and assessing ground movement problems

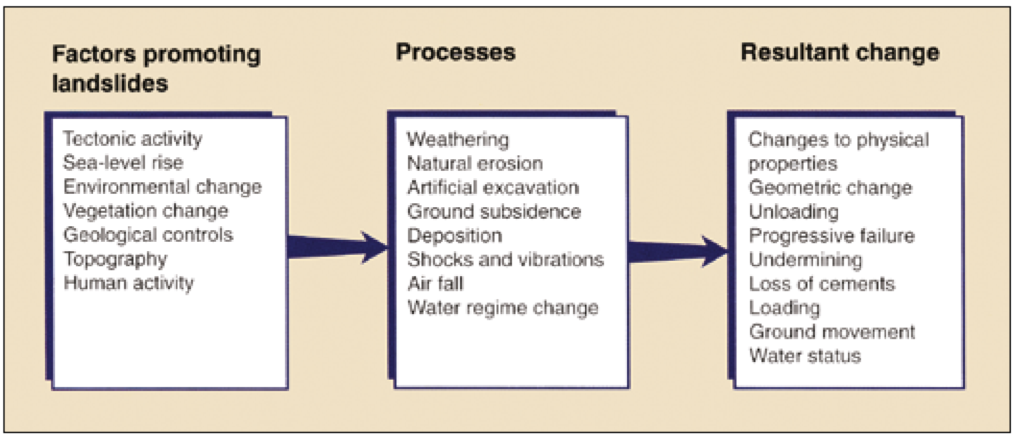
The identification and assessment of instability problems usually commences with an in-depth study of existing information. This general assessment allows an overview to be made of ground conditions in the Undercliff by bringing together information from a wide range of sources. With this information in place, it is possible to develop plans and policies to addressing the particular instability problems and to identify those areas where risks may affect existing and proposed developments.

The most commonly used techniques available to assist a preliminary landslide investigation include a review of existing sources of literature, geological and other hazard maps that may be available, past engineering reports, aerial photographs and satellite images. The depth of a particular assessment will depend on the resources available. However, it is usual to undertake a geomorphological interpretation which may be based on an overview of existing information or field mapping or a combination of both approaches.

A comprehensive examination of coastal landslide potential within part of the Ventnor Undercliff was commissioned by the former Department of the Environment in 1987. This three year study commenced with a review of available records, reports and documents followed by the preparation of geomorphological maps based on field surveying. Furthermore, a survey of damage caused by ground movement including a visual inspection of damage to roads, walls, buildings and information on underground services, assisted in understanding the extent of the problem. These surveys were supported by a land-use survey and a review of local building practices. This information, also drawing upon the results of past site investigations, assisted in identifying the nature and extent of landsliding within the Undercliff and the types of contemporary movements taking place including the magnitude and frequency of events and their impact. Furthermore, the information assisted in assessing the nature of land use at risk and the vulnerability of structures to ground movements of different intensities.

All this information was incorporated in a Geographical Information System (GIS) which allowed the factors influencing the distribution and frequency of contemporary movements to be summarised on a 'ground behaviour map'.

As part of this review it was necessary to identify which key factors were responsible for promoting landslide activity in the Undercliff, including consideration of the natural and human processes that might accelerate ground movement, and to highlight the changes that have resulted from these activities. Clearly the impact of development and human activity within the Undercliff has been a significant contributory factor in terms of ground movement events.

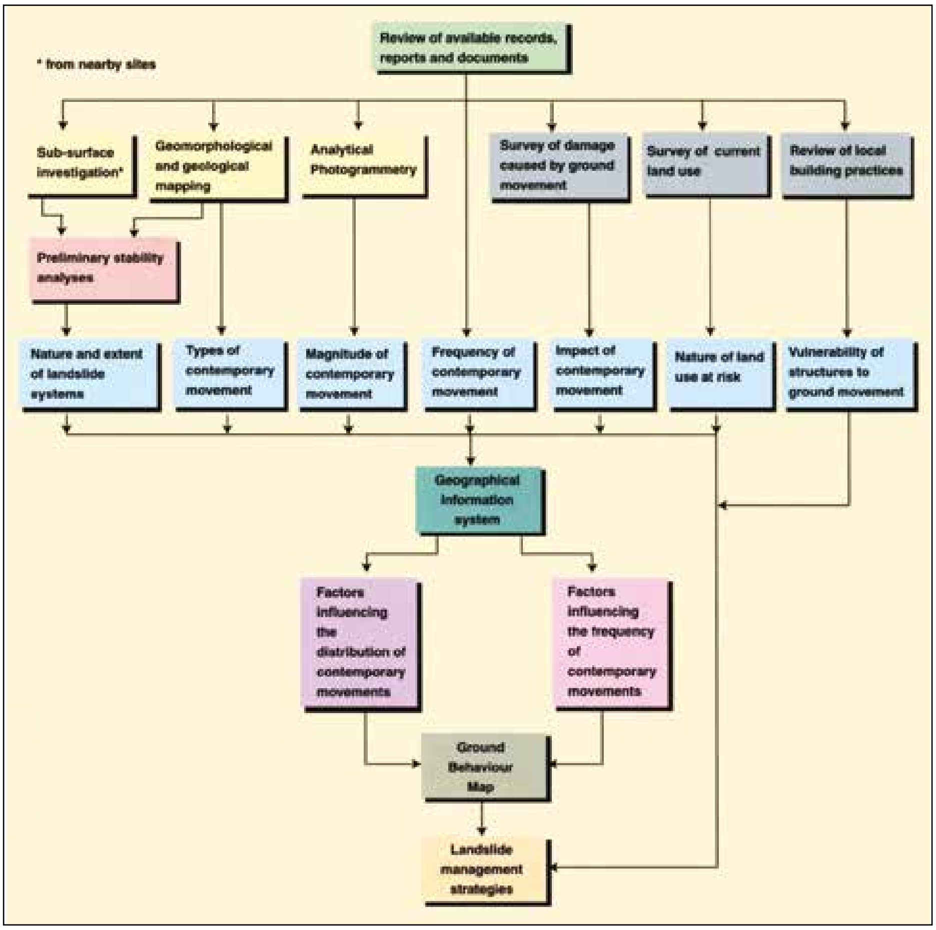


The nature of the landslide hazard faced by the Undercliff community has been defined by producing maps of contemporary ground behaviour. These maps have been prepared drawing on information such as records of damage caused by ground movement as well as data from other sources. Through these methods an understanding of the following components of landslide hazard and risk has been achieved:

- the extent of the landslide complex, systems and the processes involved in its evolution;
- the types of contemporary ground movement taking place;
- the magnitude of contemporary ground movements;
- the frequency of landslide events;
- the causes of landslide events and their temporal variation;
- the impacts of ground movement in built-up areas;
- the nature and extent of property at risk;
- the vulnerability of different styles of construction to ground movement.

The comprehensive investigation commissioned by the government is illustrated in the figure below. Recent ground investigations involving the drilling of a series of boreholes in a line from Upper Ventnor extending down through the town to the seafront has confirmed much of the surface geomorphological assessment work undertaken between 1988 and 1991 as well as providing valuable additional information.

Following the completion of the Department for the Environment study, the former South Wight Borough Council, and then the Isle of Wight Council, commissioned further studies allowing the whole of the Undercliff to be mapped to a similar standard.



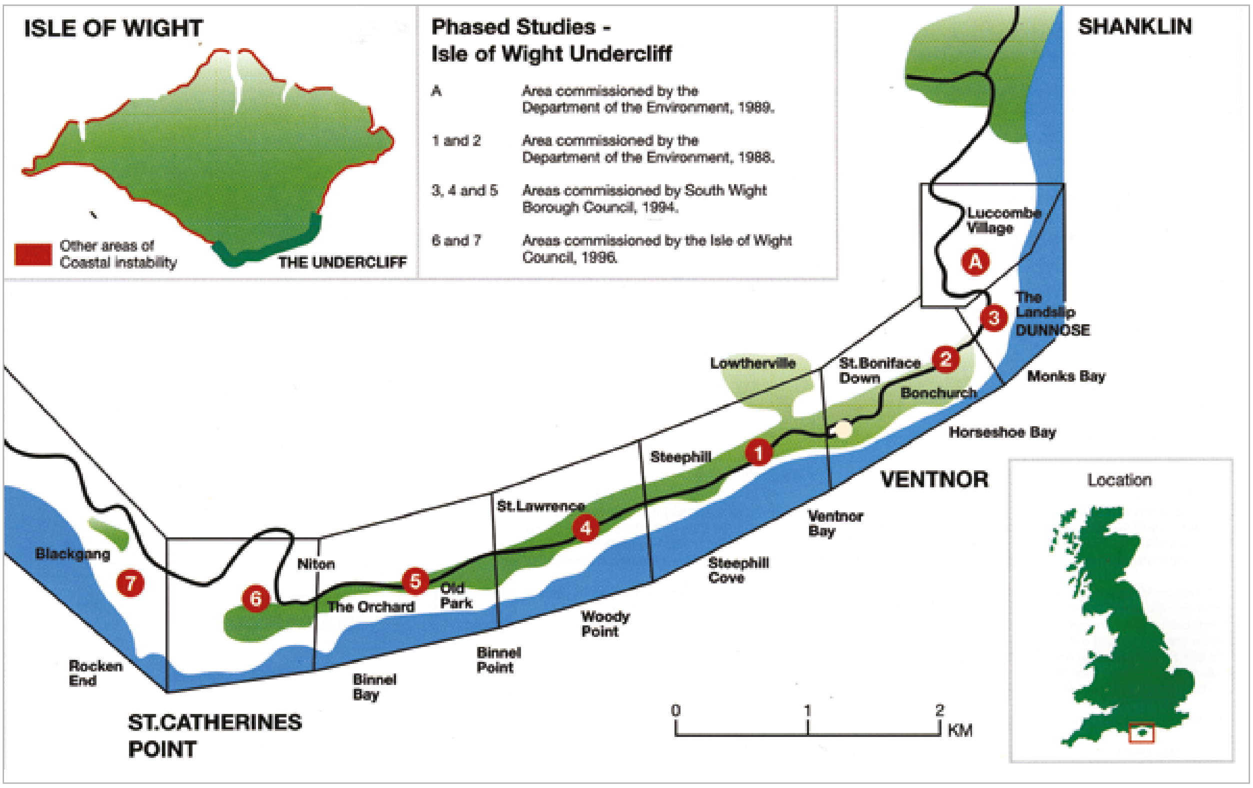
Ventnor coastal landslip potential assesment (1988-91); the approach adopted for the study.

The mapping process involved the preparation of three principal map types. The first was the '**geomorphological map**' which provides a summary of the surface form of the landslide and the surrounding area and shows the relative positions of the main geomorphological units occurring within the landslide, as well as the nature and extent of individual landslide units. This information provides a foundation for study and investigation of landslides such as the Undercliff.

The second map called '**ground behaviour**' seeks to define the hazard resulting from ground movement. This map presented, for the first time, the nature and extent of different landslide features as well as the processes which have been operating in the Undercliff over the last two hundred years. By drawing together this information an understanding of the key components of landslide hazard and risk in the Undercliff was achieved.

Taking account of this information it was then possible to prepare the third series of maps called '**planning guidance**'. The planning guidance maps were developed to provide information to support the statutory planning system. The maps indicate the suitability or otherwise of different parts of the Undercliff for development and provide advice for Development Control on the type of survey that may be required to support a development proposal. This may vary, depending on the classification of the site concerned, from a desktop study and walkover survey to a detailed site investigation.

It is recognised that some areas are unsuitable for development and a policy of avoidance has to be implemented. With this additional information informed decisions can be made through the planning process, which will guide development away from areas at risk and assist in avoiding problems arising from ground instability in the future. The sequence of the three map types together with their respective keys can be viewed on the following pages using an abstract from part of St Lawrence as an example.



KEY:

DOWNLAND FEATURES:

Chalk downs

- Convex slopes of the Chalk downs
- South facing relic dry valleys; remnants of a periglacial stream network.
- High angle shallow translational failure of weathered Chalk and head deposits.
- Truncated north facing relic drainage channels.
- Upper Greenasnd plateau and benches.

UNDERCLIFF LANDSLIDE FEATURES:

Rotational landslide failure zone II (Failure within Gault Clay)

- Rear- scarp; near vertical cliffs developed in Upper Greensand and Chalk.
- Talus slopes at base of rear scarp incorporating Upper Greensand and Chalk debris.
- Multiple-rotational failures within Gault clay comprising buried backtilted blocks of mainly Upper Greensand beneath a mantle of superficial debris.
- Multiple-rotational failures within Gault clay comprising buried backtilted blocks of Upper Greensand and Chalk beneath a mantle of superficial debris.
- Low-lying depressions landward of the multiple-rotational blocks characterised by soft ground and localised ponding.
- Degradational zone of multiple-rotational blocks above the failure boundary Zone I and II.

Gault Clay scarp (boundary between Zones I and II)

- Gault Clay scarp and talus slope.
- Boundary between failure Zones I and II.

Compound landslide failure zone I (Failure within Sandrock).

- Upper Greensand ridge: elongated ridge of backtilted Upper Greensand blocks with steep reverse slopes.
- Chalk and Upper Greensand ridge: elongated ridge of backtilted Chalk and Upper Greensand blocks with steep reverse slopes.
- Lower Greensand ridge: elongated ridges of sub-horizontal blocks of Carstone and Sandrock.
- Low lying depressions landward of the ridges, with soft ground bounded by steep scarp slopes.
- Degradation zone developed in Lower Greensand; active shallow translational and rotational failures within Sandrock incorporating Upper Greensand debris, with gently sloping benches and steep scarp slopes.

Mudslides

- Inland shallow mudslides developed in Gault Clay: active shallow failures developed in Gault Clay including Upper Greensand and Chalk with gently sloping benches and steep scarp slopes.
- Shallow mudslides developed upon the Gault Clay scarp.
- Coastal shallow mudslides

Coastal cliffs

- Coastal cliffs formed of Upper Greensand and Gault Clay debris.
- Coastal cliffs formed of in-situ Lower Greensand.

Fluvial features

- Stream valley; buried channels and contemporary valley floors formed of Upper Greensand and Chalk infill and recent alluvium.
- Pond
- Spring
- Wet ground

Artificial slopes

- Made ground: artificial cut and fill slopes.

Notes

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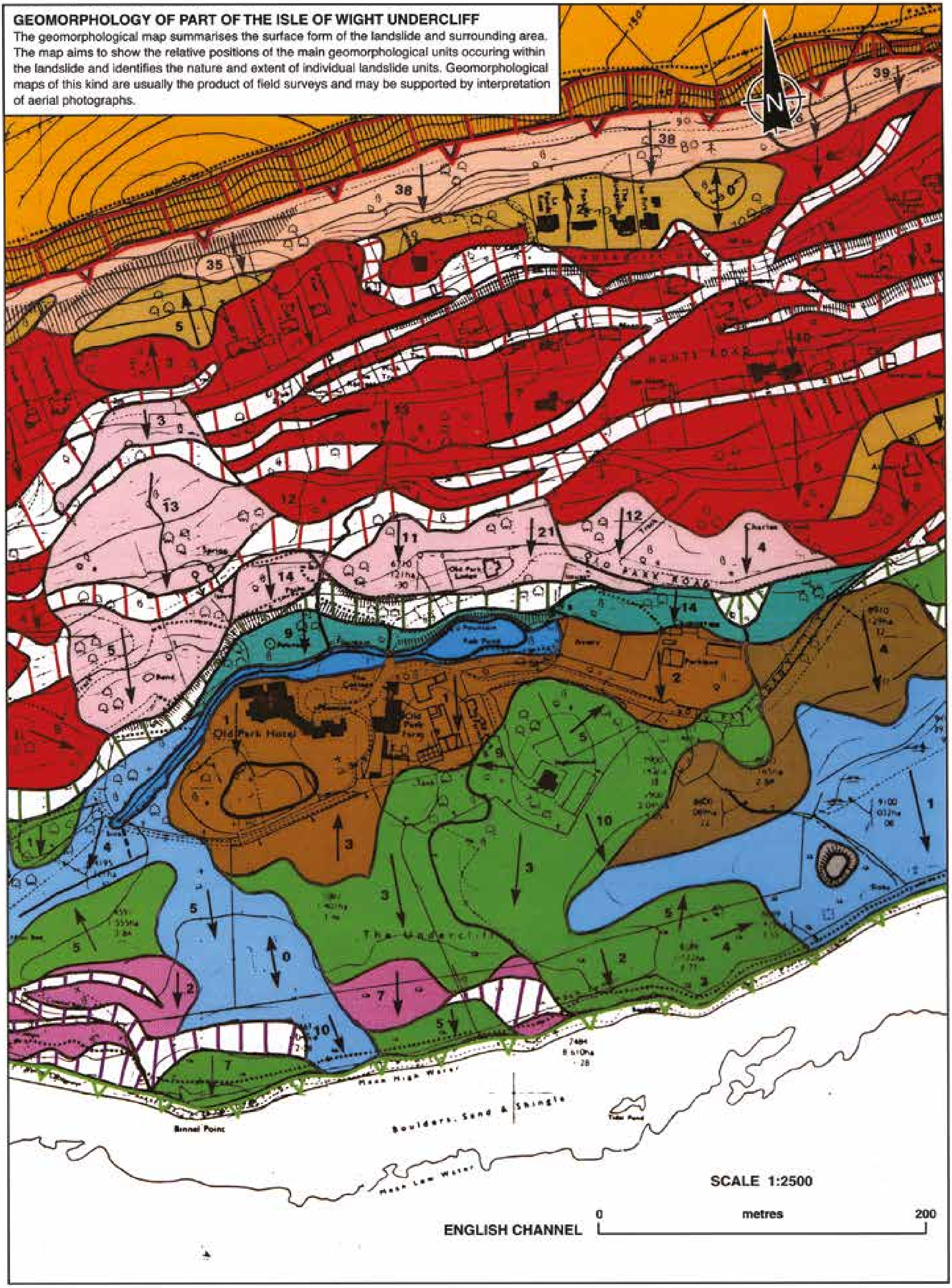

GEOMORPHOLOGY OF PART OF THE ISLE OF WIGHT UNDERCLIFF

The geomorphological map summarises the surface form of the landslide and surrounding area. The map aims to show the relative positions of the main geomorphological units occuring within the landslide and identifies the nature and extent of individual landslide units. Geomorphological maps of this kind are usually the product of field surveys and may be supported by interpretation of aerial photographs.

KEY:

CONTEMPORARY PROCESSES	IMPACT
Chalk downs	
Predominately stable slopes, although soil creep and surface erosion may occur.	Minimal.
Areas which could be sites of flash flooding and debris flow activity in exceptional storm conditions	Property downslope may be damaged by flood water or rapidly flowing debris.
Areas susceptible to shallow translational slides involving soil and weathered chalk.	Minimal, although fast moving debris may damage property or block roads at the base of the slope.
Upper Greensand bench	
Areas prone to slow settlement, probably less than 1mm per year. Gradual extension of master joints within the Upper Greensand can lead to the development of fissures or vents, up to 40m deep. Only a limited number of vents have been recorded in the last 200 years.	Properties situated within these areas have been affected by differential horizontal and vertical movements, together with forward tilt. This has resulted in light structural damage. Collapse of the ground surface into fissures or vents constitutes a significant threat to safety.
Rotational slides	
Major scarp slopes: degradation of scarp slopes is generally limited to slow superficial movements. In places these slopes may be susceptible to rock fall or debris slide activity.	Where roads and structures have been sited on scarp slopes moderate to severe damage has been caused by the slow bulging and cracking of walls and pavements. In a number of cases failure of retaining walls has led to rapid ground movement, causing damage to property. Wall collapses pose significant threat to safety.
Landslide bench: area affected by occasional large scale movements involving the disruption and rotation of blocks and assorted landslide debris, differential shearing between blocks and major settlement.	Areas affected by these movements are largely undeveloped. Serious to severe damage to footpaths, roads and some structures has been reported in the past. The extension of activity may cause the undermining of structures at the crest of the landslide.
Landslide bench: area affected by intermittent settlement (>10mm) of displaced blocks of material along pre-existing shear surfaces, which has led to the formation of fissures, tension cracks and gradual subsidence.	Properties situated on these benches have been affected by differential horizontal and vertical movements, rotation, torsion, forward tilt and subsidence. Differential movement has been greatest at the back of the bench where the shear surface meets the ground surface. The cumulative effects of this movement has resulted in serious and severe damage to property.
Landslide bench: areas where imperceptible ground movement (<10mm per year) has been reported in the past although for much of the time benches are inactive.	Most properties situated on these benches have been largely affected by ground movement. However,in places the cumulative effects of ground movement has resulted in moderate and slight damage to property.
Landslide bench:no landslide events have been recorded in these areas during the last 200 years. These areas have been either inactive or subject to imperceptible movement.	Most property is unaffected by ground movement, although in places the cumulative effects of ground movement may result in slight damage to property.
Landslide bench:no information is available with respect to the occurrence and rate of past movement.	The effects of ground movement, if any, are unknown. Further investigations will be necessary to assess ground behaviour.
Degradation of the Gault Clay scarp	
Major scarp slope: Scarp slopes prone to superficial movements, particularly during wet winter periods. Movements are generally slow and imperceptible.	Ground movements have led to moderate and serious damage to properties, roads and paths through the extension of tension cracks at the crest of the slopes, heave at the toe of the slope and torsional movements upon the slope.
Mudslides: Active mudslides developed on the Gault Clay scarp with seasonal movements in excess of 100mm per year, mostly occuring during the wet winter months.	Active mudslides generally occur outside the developed area. In the past the extension of such features has led to severe damage to property and infrastructure.
Subdued slopes of the Gault Clay scarp. Generally stable slopes with few past reports or contemporary evidence of significant ground movement.	Most property and infrastructure is unaffected by ground movements, although in places the cumulative effects of movements may result in slight damage to property.
Compound slides	
Elongated ridges and scarps; ground movement problems have been minimal along the ridges, although slow superficial movements have been recorded along the scarp slopes.	Most properties situated on these ridges have been unaffected by ground movement. However shallow slides on the scarp slopes may cause slight damage to property from falling debris.
Elongated ridges and scarps; no information is available with respect to the occurrence and rate of past movement.	The effects of ground movement, if any, are unknown, further investigations will be necessary to assess ground behaviour.
Mudslides	
Large areas affected by active mudsliding involving the degradation of the compound and multiple rotational failure zones. Mudslide movements are generally seasonal although rapid movement could occur in exceptional circumstances. Movement rates in excess of 100mm should be expected but on occasions movements measured in meters is likely.	Damage to properties and structures situated within these areas is generally moderate to severe. Footpaths and roads are especially vulnerable where they cross the mudslide units. Movements may result in property at the head of the units being undermined. At the foot of the slopes, fast moving runout may overwhelm or cause serious damage to structures.
Areas of currently inactive shallow mudslides and small rotational slips. Only limited information is available with respect to the occurrence and rate of past movement.	Little is known of the behaviour of these areas. Further investigations will be necessery to assess the impact of development in these areas.
Areas of very rare or no records of contemporary mudslide movement.	The effects of ground movement, if any, are unknown. Further investigations will be necessary to assess the impact of development in these areas.
Coastal cliffs	
Unprotected coastal cliffs prone to rock and debris falls, slides and spalling.	Falls and slides prevent a threat to public safety. Property adjacent to the cliff top may be undermined by coastal erosion. Unloading of the toe of the Undercliff will promote the destabilisation of the landslide complex.
Coastal cliffs protected by sea walls, which have been prone to occasional rock and debris falls slides and spalling.	Falls and slides represent a threat to public safety. Property adjacent to the cliff top may be undermined by coastal erosion.
Soft ground	
Areas which have been subject to imperceptible settlement of soft ground.	Properties situated within these areas may be affected by very gradual vertical movement and tilting. In the past this has resulted in slight and negligable damage, although localised cases of moderate and severe damage have occured.
No information is available with respect to the occurrence and rate of past settlement.	The effects of settlement, if any, are unknown.

Notes

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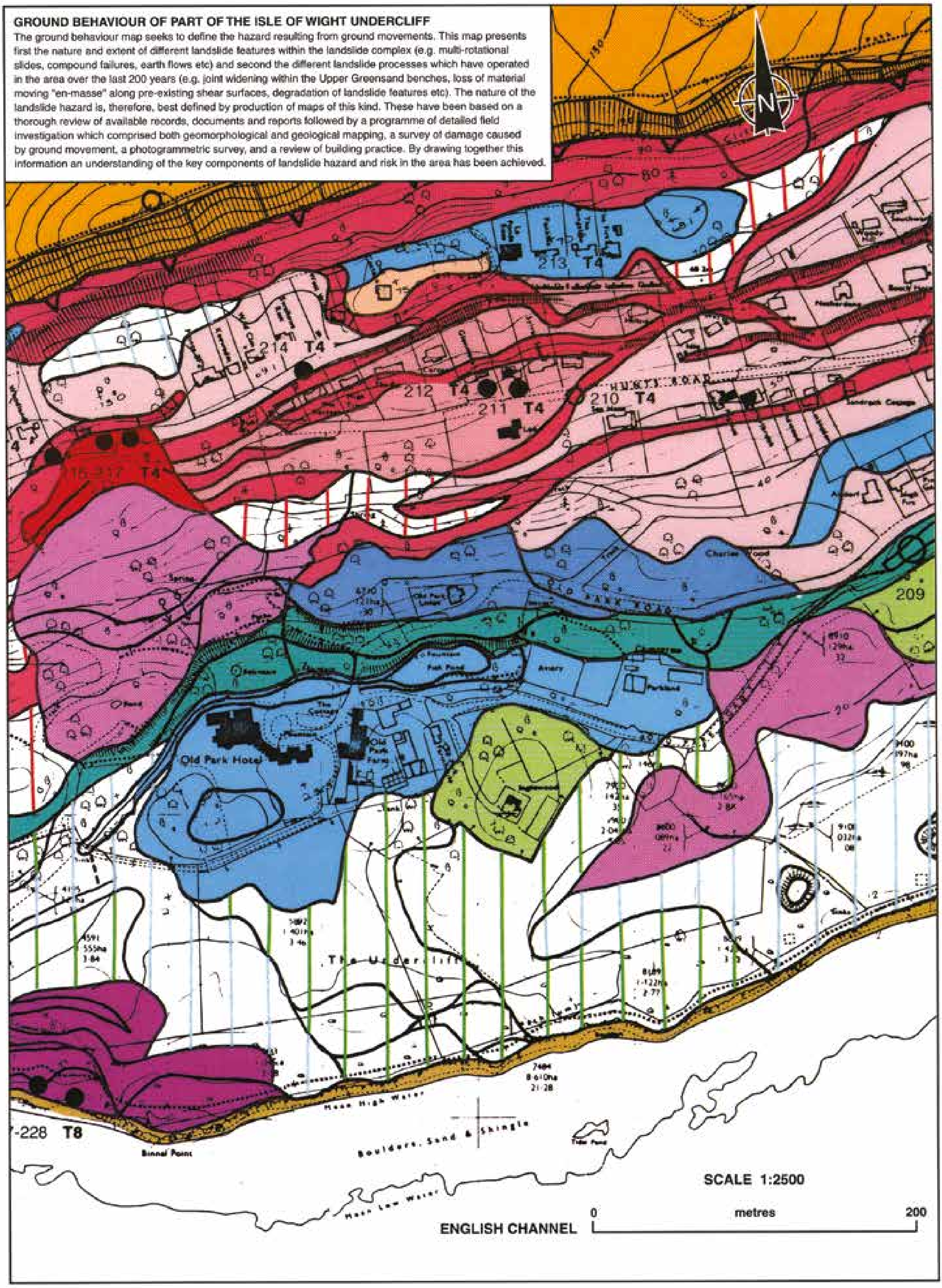
GROUND BEHAVIOUR OF PART OF THE ISLE OF WIGHT UNDERCLIFF
The ground behaviour map seeks to define the hazard resulting from ground movements. This map presents first the nature and extent of different landslide features within the landslide complex (e.g. multi-rotational slides, compound failures, earth flows etc) and second the different landslide processes which have operated in the area over the last 200 years (e.g. joint widening within the Upper Greensand benches, loss of material moving "en-masse" along pre-existing shear surfaces, degradation of landslide features etc). The nature of the landslide hazard is, therefore, best defined by production of maps of this kind. These have been based on a thorough review of available records, documents and reports followed by a programme of detailed field investigation which comprised both geomorphological and geological mapping, a survey of damage caused by ground movement, a photogrammetric survey, and a review of building practice. By drawing together this information an understanding of the key components of landslide hazard and risk in the area has been achieved.
N
213 T4
214 T4
212 T4
211 T4
210 T4
209
Old Park Hotel
The Undercliff
-228 T8
Binnel Point
Mean High Water
Boulders, Sand & Shingle
Mean Low Water
ENGLISH CHANNEL
SCALE 1:2500
0
metres
200

KEY:

DEVELOPMENT PLAN		DEVELOPMENT CONTROL
(green)	Areas likely to be suitable for development. Contemporary ground behaviour does not impose significant constraints on Local Plan development proposals.	Results of a desk study and walkover survey should be presented with all planning applications. Detailed ground investigations may be needed prior to planning decision if recommended by the preliminary study, or Local Authority.
(orange)	Areas likely to be subject to significant constraints on development. Local Plan development proposals should identify and take account of the ground behaviour constraints.	A desk study and walkover survey will normally need to be followed by a ground investigation or geotechnical appraisal prior to lodging a planning application.
(red)	Areas most unsuitable for built development. Local Plan development proposals subject to major constraints.	It is likely that many planning applications in these areas may have to be refused on the basis of ground instability. Should development be considered it will be preceded by a detailed ground investigation, goetechnical appraisal and / or monitoring prior to any planning application.
(grey)	Areas which may or may not be suitable for development but investigations and monitoring may be required before Local Plan proposals are made.	Areas need to be investigated and monitored to determine stability conditions. Development should be avoided unless adequate evidence of stability is presented.

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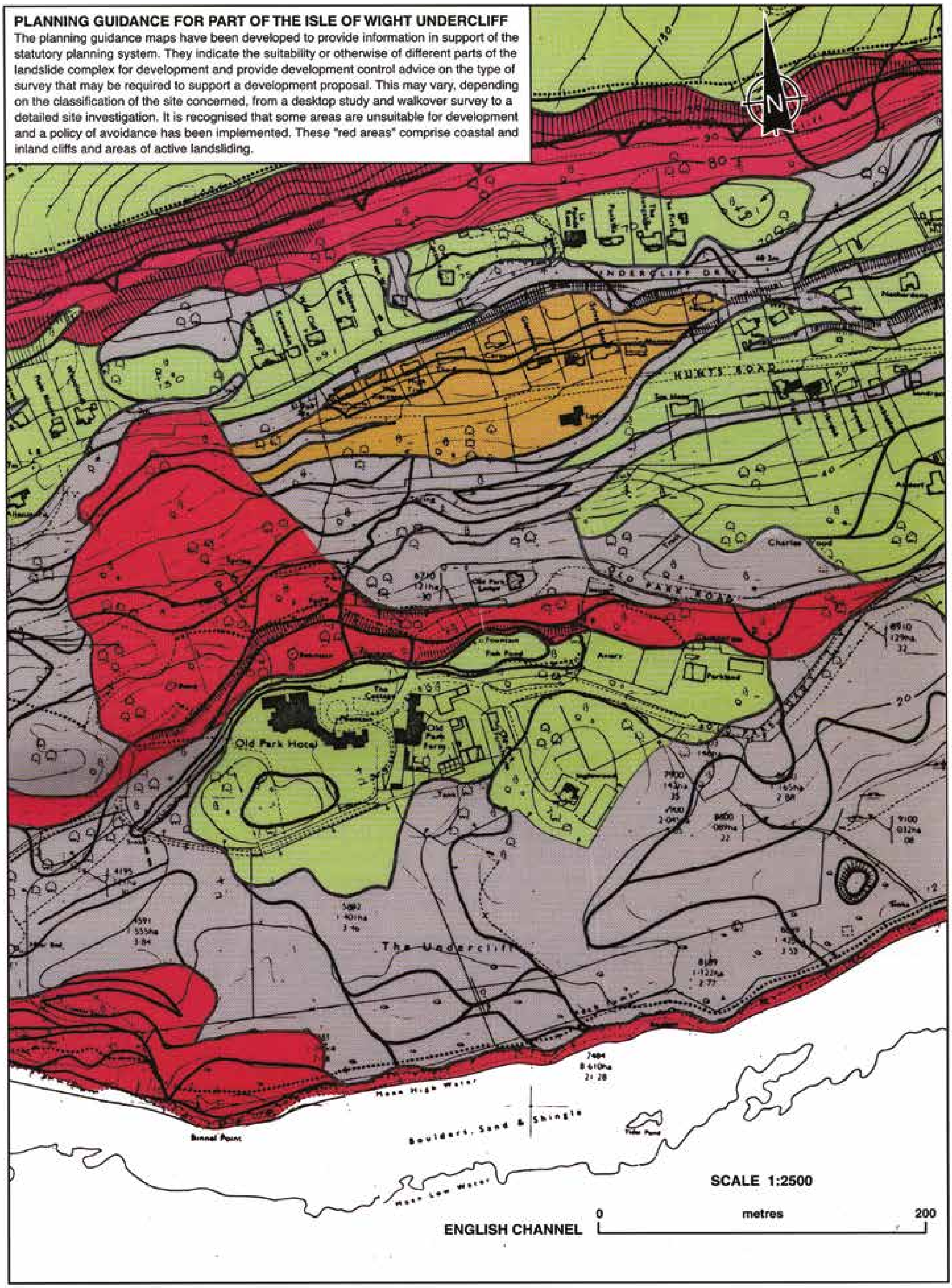


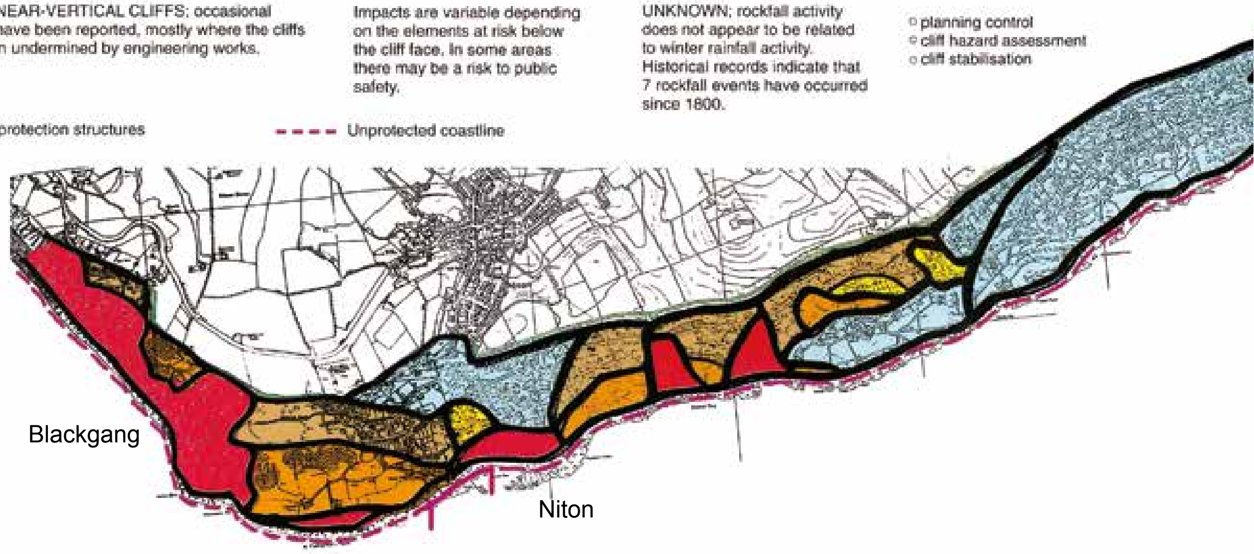
PLANNING GUIDANCE FOR PART OF THE ISLE OF WIGHT UNDERCLIFF

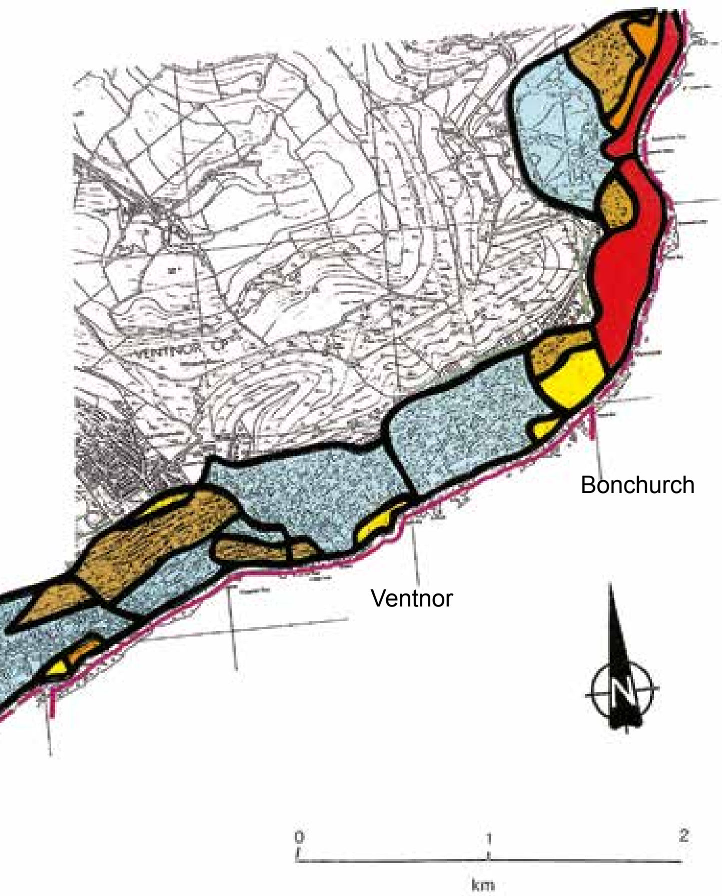
The planning guidance maps have been developed to provide information in support of the statutory planning system. They indicate the suitability or otherwise of different parts of the landslide complex for development and provide development control advice on the type of survey that may be required to support a development proposal. This may vary, depending on the classification of the site concerned, from a desktop study and walkover survey to a detailed site investigation. It is recognised that some areas are unsuitable for development and a policy of avoidance has been implemented. These "red areas" comprise coastal and inland cliffs and areas of active landsliding.

CONTEMPORARY PROCESSES ▶	IMPACT ▶	RELATIVE SUSCEPTIBILITY ▶	MANAGEMENT OPTIONS
INACTIVE ANCIENT LANDSLIDES; no significant ground movement has been recorded in the last 200 years. These areas have been largely inactive or subject to imperceptible movement.	Most property has been unaffected by ground movement, although in places cumulative effects of ground movement has resulted in slight damage to property.	VERY LOW; significant movements have not occurred in response to winter rainfall totals experienced in the last 150 years.	○ planning control ○ building control ○ control of water ○ deep drainage feasibility
INTERMITTENTLY ACTIVE ANCIENT LANDSLIDES; areas where imperceptible ground movement has been reported in the past with infrequent periods of accelerated movement involving the opening of tension cracks and ground subsidence.	Some properties have been affected by differential settlement resulting in rotation, torsion, forward tilt and subsidence. The cumulative effects of ground movement has in places resulted in moderate damage to property.	LOW; periods of accelerated movement have occurred in response to winter rainfall totals that can be expected on average, every 100 years or more.	○ planning control ○ building control ○ control of water ○ deep drainage feasibility ○ monitoring ○ cavity surveys
AREAS OF DEGRADING ANCIENT LANDSLIDES; areas affected by intermittent large-scale ground movements involving the disruption and rotation of landslide blocks, differential settlement and extensive fissuring.	Differential movement has resulted in serious and severe damage to property, infrastructure and the public highway.	MODERATE; periods of large-scale ground movement have occurred in response to winter rainfall totals that can be expected on average once every 50 years.	○ planning control ○ building control ○ control of water ○ monitoring ○ deep drainage feasibility ○ land drainage
AREAS OF ACTIVELY DEGRADING ANCIENT LANDSLIDES; areas affected by frequent large scale and occasionally rapid ground movements.	Extensive ground movements have resulted in severe damage to the public highway and has caused the abandonment of affected properties.	HIGH; large-scale ground movements have occurred in response to winter rainfall totals that can be expected on average once every 5 years.	○ planning control ○ monitoring ○ land drainage
ACTIVE LANDSLIDES; areas involving large-scale, occasionally rapid ground movements within well-defined landslide/mudslide systems.	Extensive active ground movements have occurred in largely undeveloped areas.	VERY HIGH; ground movements are very sensitive to rainfall which can be expected to occur on average every year, particularly during the winter months.	○ planning control ○ land drainage
INLAND NEAR-VERTICAL CLIFFS; occasional rockfalls have been reported, mostly where the cliffs have been undermined by engineering works.	Impacts are variable depending on the elements at risk below the cliff face. In some areas there may be a risk to public safety.	UNKNOWN; rockfall activity does not appear to be related to winter rainfall activity. Historical records indicate that 7 rockfall events have occurred since 1800.	○ planning control ○ cliff hazard assessment ○ cliff stabilisation

Coast protection structures

Unprotected coastline





Legal and administrative frameworks for addressing ground instability in the Isle of Wight Undercliff landslide complex, UK.

The Isle of Wight Council is the Coast Protection Authority for the Isle of Wight as well as being the planning authority and highway authority; the Council is also a major coastal landowner. Research commissioned by the government (1988-91) at Ventnor assisted in the development of national policy guidance for development on unstable land. Coastal and geotechnical studies now inform planning policy guiding development away from areas at risk. This knowledge also assists the Council in managing coastal defences and important coastal highways as well as informing health and safety policies.

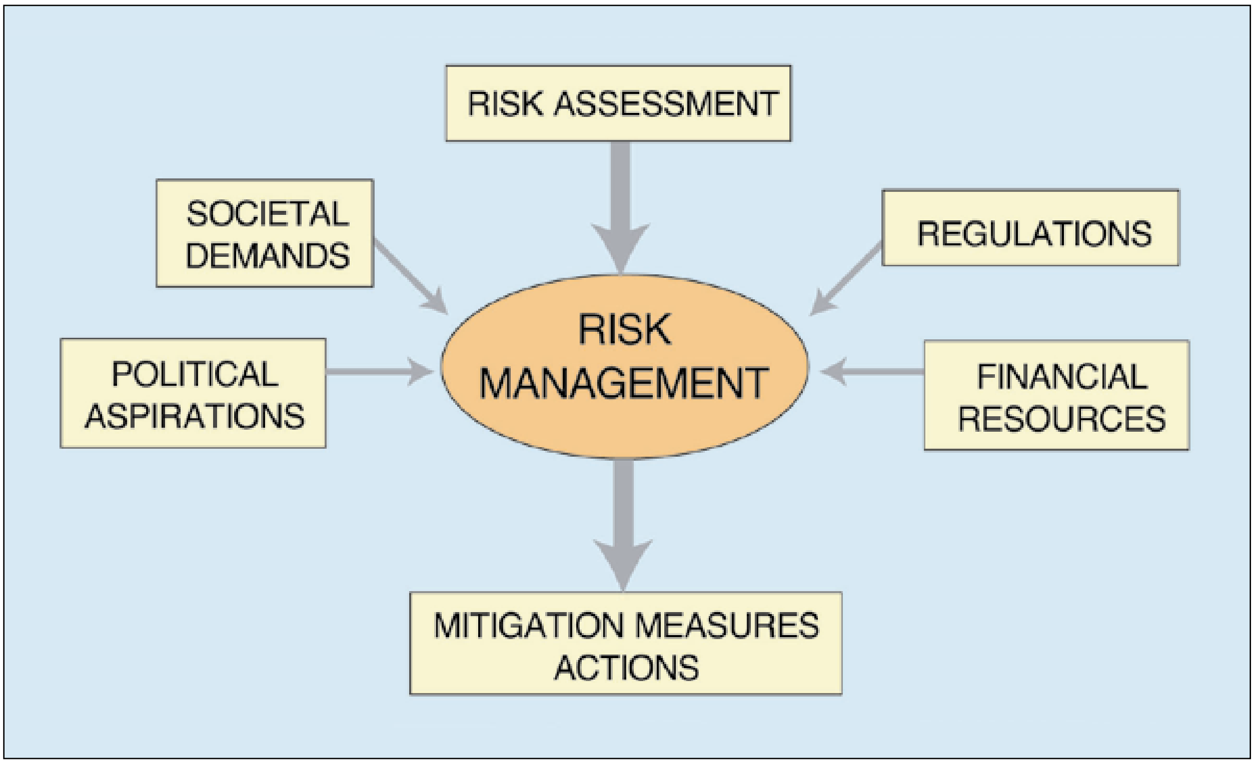
Summary ground behaviour map of the Isle of Wight Undercliff

Coastal landslide, Niton Undercliff, Isle of Wight, UK affecting a caravan park and the A3055 coast road. The landslide event followed prolonged winter rainfall in 2000/01

Chapter Four
How can ground instability problems be managed?

Since 1993 the Isle of Wight Council has endeavoured to encourage a co-ordinated approach to the management of ground instability problems through its 'Landslip Management Committee'. By bringing together professional interests, including local authority coastal management, planning, building control and highways staff alongside estate agents, construction industry representatives, service companies and insurers, a united professional approach to instability problems can be achieved. Local residents can also play a significant role by implementing good practice relating to property maintenance and land management. The challenge is to raise interest and awareness with homeowners who may have little knowledge of the history or extent of ground instability in their area. Climate change also presents significant challenges for those responsible for managing landslides and it is necessary to provide information to residents which explain potentially worsening scenarios. This chapter describes how the Council is transmitting climate change and landsliding issues to local stakeholders and residents within the Undercliff.

Landslide management has been practiced for the last fifteen years on the Isle of Wight and forms an effective means of helping to address the impacts of ground movements around the Island's 110km coastline. This process has involved the interpretation of field and desktop studies and the results of ground investigations. The results have helped to address the health, safety, economic and social issues in locations such as the Ventnor Undercliff and other vulnerable frontages along the Island's northern coast. The landslide management approach avoids the shortcomings of the 'emergency response' and instead concentrates on pre-planning and preparation, allowing longer-term, more sustainable planning decisions to be made which are in line with the planning policy framework. With the support of a 'landslide management strategy' it is possible to address the different mitigation opportunities and to put policy into practice.

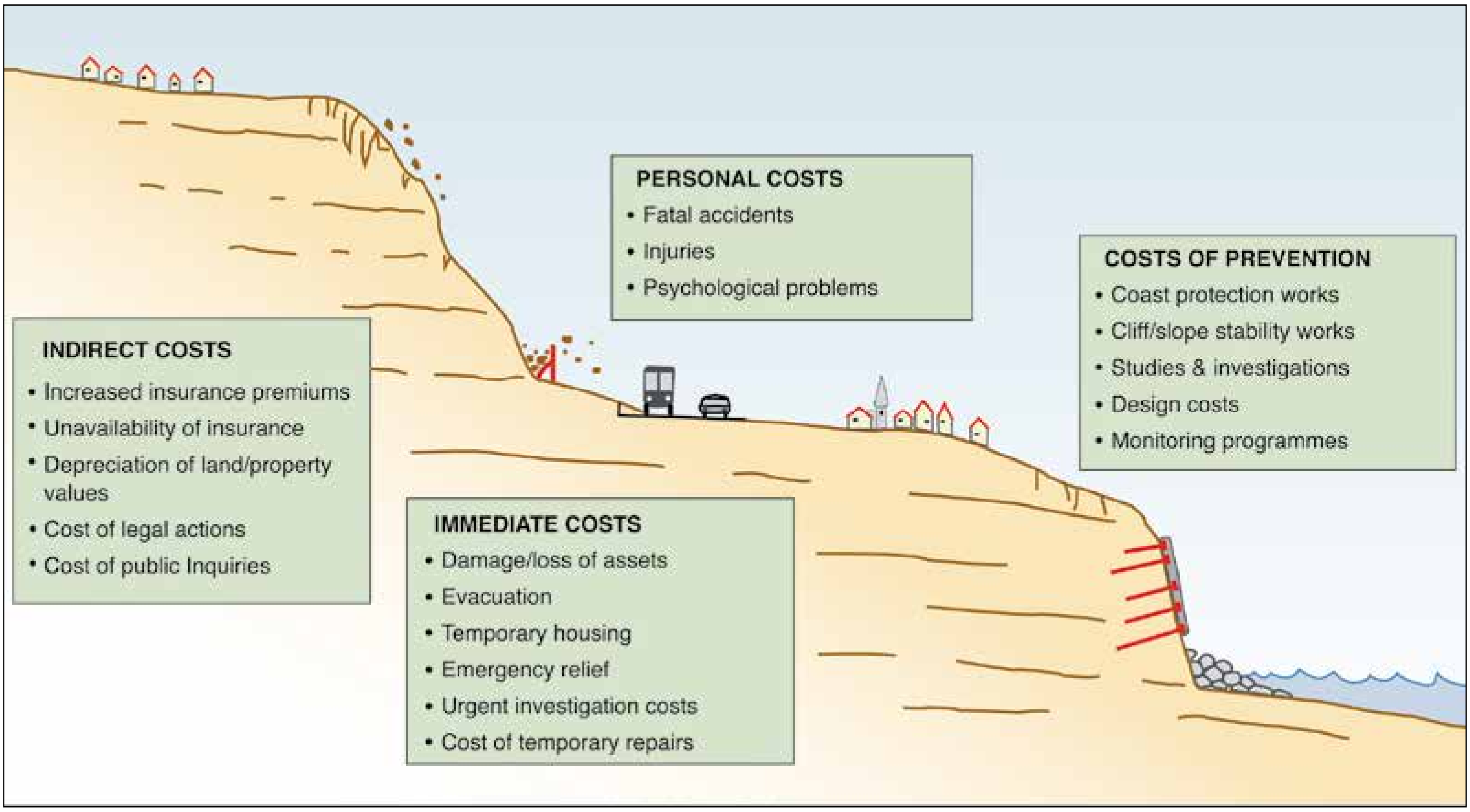


The constraints to be taken into account in Landslide Risk Management.
(Adapted from Leroi et al. 2005).

In recent years scientific research has provided a wealth of additional technology and techniques that have assisted the understanding of ground instability problems. At a local level lessons learnt from a number of major landslide events on the Isle of Wight have also highlighted the role that human activity can play in instigating ground movements. As development pressures have increased the occupation of more stable and commercially attractive locations, there has been a demand also to extend new development into adjacent areas where there may be greater physical constraints because of problems such as instability. Such developments, particularly in the absence of effective planning policies, may lead to costly mistakes posing risks to life and property. These can usually be avoided if appropriate planning and landslide management strategies are in place, which have taken full account of ground conditions in their formulation.

It has been concluded (Jones & Lee, 1994) that landslide problems are not unpredictable 'acts of god', entirely natural events that can at best only be resolved by avoidance or large-scale civil engineering works. The role of human activity in initiating or reactivating many coastal slope problems should not be under-estimated. In areas such as the Isle of Wight where urban development has taken place on coastal landslides, the problems tend to be related to slow ground movement and progressive damage to property, services and infrastructure (Doornkamp et al, 1991). In such circumstances many problems can be reduced if there is a programme of active landslide management in place, where the local community is able to come to terms with the situation and learn to 'live with landslides' (Noton, 1991; Lee, 1997; McInnes, 2000).

The Council's Landslide Management Strategy (see Figure opposite) aims to reduce the likelihood of future ground movements by seeking to control the factors that cause ground movement and by limiting the impact of future movement through the adoption of appropriate



Financial consequences of coastal erosion and landsliding. McInnes 2006 (Adapted from Jones & Lee 1994) planning and building controls (Lee & Moore, 1991). Ground instability in the Undercliff has, in fact, been addressed in a number of ways but the key tasks have been:

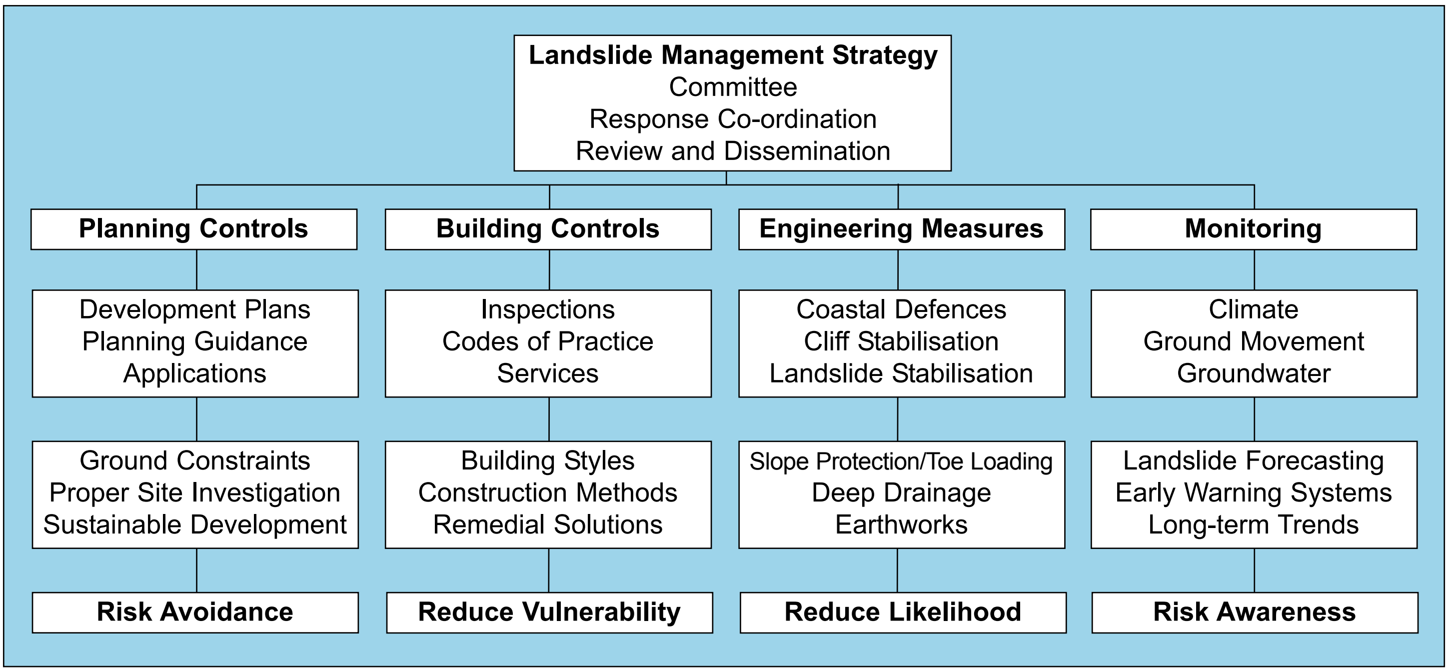
- preventing unsuitable development through sound planning controls and building control measures;
- monitoring ground movements and weather conditions using a range of automatic and manual recording instruments and stations;
- seeking to improve ground conditions through a range of measures aimed at controlling water in the ground as well as coast protection schemes which reduce marine erosion at the toe of the landslide;
- a major awareness-raising programme for the benefit of both professionals and the general public living and working in the area.

Involving stakeholders in landslide management

To implement the Landslide Management Strategy, a Management Committee comprising key professionals from the Council (coastal management, highways, planning and building control), the water industry and other service industries, surveyors, estate agents and insurers meet twice a year. The Committee assesses progress on implementation of the Strategy and exchanges information on new initiatives being led by the Isle of Wight Council and others.

Consultation and information exchange with Undercliff residents

There has been a long history of consultations over ground conditions within the Ventnor Undercliff and, therefore, many residents are aware of the geological situation. The town is attractively located with development on the various landslide benches offering panoramic sea views over the Victorian town, the adjacent spectacular coastline and the English Channel and the property market is healthy.



Isle of Wight Council 'Landslide Management Strategy'

On completion of the Department of the Environment (DOE) Ventnor pilot study study in 1991 the first of a range of display boards were assembled covering the following themes:

- What is the history of ground movement in the area?
- What is the scale of the problem?
- Why is there a ground movement problem?
- What causes ground movement?
- How can we define landslide hazard?
- How can the landslide problems be managed most effectively?
- What is the local authority doing to help?
- What can developers do?
- What can estate agents, solicitors and insurers do?
- What does the future hold if the community works together with the local authority?

The display was accompanied by a four page explanatory leaflet entitled 'Land Stability in Ventnor and You'. A temporary information centre provided the opportunity for interested residents not only to read the display boards, but also to ask questions and discuss any problems or concerns that they had with the local authority technical staff or its consultants, confidentially if required.

The information being disseminated by experts at the 'Geological Information Centre' was not entirely straightforward. However, the final paragraph from the DOE summary report provided a basis for explanation:

"There is no reason why there should not be confidence in Ventnor from a building, insurance or financial development point of view. This is true so long as sensible use is made of the technical information presented in the report and obtained from future monitoring exercises, and that the proposed landslide management strategies are implemented" (Doornkamp et al. 1991).

As a result of the success of the temporary information centre as a dissemination point, a permanent display opened in 1998 within the Isle of Wight Coastal Visitors' Centre based in Ventnor. The town has been able to turn the geological situation to its advantage and capitalise on the interest in geological, coastal and environmental tourism and education.

The Centre for the Coastal Environment has produced a series of information leaflets that have been distributed to every homeowner in the area together with more comprehensive reports which provide a wealth of information on the range of landslide management measures that have been promoted by the Council.

Over the last ten years four different information leaflets have been circulated to all 2,600 property owners and a range of reports and technical information have been provided with financial support from the Council.

The European Union LIFE Environment Programme (L'Instrument Financier de L'Environnement - European Commission 1997 and 2001) has also provided financial support for landslide risk management initiatives. In particular a LIFE Environment study led by the Council entitled 'Coastal change, climate and instability' (McInnes et al. 2000) allowed the development of the landslide management work on the Isle of Wight Undercliff to be taken forward.

As part of the Landslide Management Strategy the feedback from local residents is regarded as very important. During the course of the LIFE project a survey was conducted which showed that

a high percentage of residents (over 60%) had lived in the Undercliff over ten years and the majority were aware of ground instability issues at the time of moving into the area (82%). It is interesting to note that approximately 50% of those who intended to move to the Undercliff had obtained information on ground condition from surveyors, consulting engineers or estate agents.

The Council was encouraged to note that of those who sought its advice on ground instability, some 90% found the advice very helpful or helpful and 66% of those who responded to the Council survey had read the key report on ground movement in the Undercliff. It was very pleasing to note that all those who responded had found this report to be either very informative (55%) or informative (45%). It should be noted, however, that over the previous four years some 25% of those responding had moved into the area, which indicated a significant turn-over in occupation of residential properties. As a result this demonstrated the need to continue to provide up to date information for residents on a regular basis.

One particular concern as far as property owners are concerned has been difficulty in obtaining insurance in certain parts of the Undercliff, often due to a lack of knowledge over the true extent and nature of ground instability conditions. Certainly the DOE study assisted the process by indicating those areas where the risk is greatest. It was encouraging to note, therefore, from the resident's survey that 76% of those questioned had been able to obtain full insurance, including subsidence cover, in 2003, rising to 94% by 2006.

The Centre for the Coastal Environment believes that a significant contributory factor to this statistic has been the availability of better information and guidance for local residents as well as for insurers over the intervening period. The residents survey was updated in 2006 as part of the 'Response' LIFE project (McInnes et al. 2006) and the results provide further support for the Council in terms of the value of this kind of information for non-technical users (see next page).

ADVICE TO HOMEOWNERS ON GROUND INSTABILITY IN THE VENTNOR UNDERCLIFF, ISLE OF WIGHT
Comparative Residents' Survey Results 2000 and 2006

			2000	2006
1.	Number of residents participating in the survey.		475	490
2.	Location of properties within the Undercliff:	Bonchurch	28%	28%
		Ventnor	65%	66%
		Steephill	2%	1%
		St Lawrence	3%	3%
		Niton	2%	2%
			100%	100%
3.	Resident in the Undercliff (years):	0-5	25%	27%
		5-10	15%	20%
		10-20	30%	35%
		>20	30%	18%
4.	Were you aware of ground instability issues when considering buying a property in the Undercliff?		41%	59%
5.	Did you seek any professional advice in relation to the stability of the property you were purchasing?		25%	41%
6.	Did you seek any information relating to ground instability from the Council's Centre for the Coastal Environment?		13%	29%
7.	How helpful did you find the advice and displays at the Coastal Visitors' Centre?:	Very helpful	90%	95%
		Helpful	10%	5%
		Not particularly helpful	-	-
8.	Have you read the Council's eighty page report 'The Undercliff - A review of ground behaviour' (1995)?		48%	61%
9.	How useful did you find the report?	Very helpful	80%	86%
		Helpful	20%	14%
		Not particularly helpful	-	-
10.	The Council published a four page leaflet 'Advice to homeowners' in 2003. Did you receive the leaflet?	Yes	-	72%
		No	-	28%
11.	The Council has been improving advice and information for stakeholders with financial support from the EU LIFE Environment Programme; 'Coastal change, climate and instability' (2000-2003) and ' Response' (Responding to the risks from climate change) (2003-2006). Do you believe it is important for the Council to be involved in EU/International networks to improve information exchange?	Very important	86%	94%
		Important	10%	5%
		Not particularly important	4%	1%
12.	Have you visited the displays about ground instability at the Coastal Visitors' Centre, Ventnor?		45%	52%
13.	Have you been able to obtain property insurance cover for landslip?		76%	94%
14.	Do you regard ground instability as an issue of concern to you?	Very significant	82%	94%
		Significant	12%	5%
		Not particularly significant	6%	1%

The Building Regulations

The Building Regulations are a Statutory Instrument made under powers provided in the Building Act 1984, and apply throughout England and Wales. The current edition of the Regulations is 'The Building Regulations 2000' (as amended) and the majority of building projects are required to comply with them. They exist to ensure the health and safety of people in and around all types of buildings (i.e. domestic, commercial and industrial). They also provide for energy conservation, and access to and use of buildings.

The Building Regulations provide a complimentary mechanism to the Planning System for ensuring land instability issues are considered when permitting development.

Part A of the Building Regulations is quite specific in this;

"The building shall be constructed so that ground movement caused by -
(a) swelling, shrinkage or freezing of the subsoil; or
(b) land-slip or subsidence (other than subsidence arising from shrinkage), in so far as the risk can be reasonably foreseen,
will not impair the stability of any part of the building."

Landsliding is clearly a factor that needs to be taken into account under these Regulations before proceeding with the design of buildings and their foundations.

The Building Regulations apply to building work in general, control of services and fittings and material change of use. However, there are exemptions such as greenhouses and agricultural buildings, temporary buildings, small detached buildings and extensions. The Building Control body ensures that building work complies with the Regulations, and enforcement powers are available if it does not.

A person intending to carry out building work or make a material change of use must submit an application to the local authority or use an Approved Inspector, who will then submit an initial Notice to the local authority.

Whichever Building Control body is engaged, details of the proposed work will be checked and inspections of the work in progress undertaken to ensure compliance with the Regulations, and a final certificate will be issued when the work is completed satisfactorily.

Coastal Protection

The coastline of the Isle of Wight is subjected continuously to the natural processes of weathering and coastal erosion. The impacts of these processes vary from one part of the coastline to another depending on the nature of its geological structure, the durability of the rocks exposed on the coastline and the exposure to waves and tides. Waves and currents transport natural materials around the coastline - eroding in one place, transporting material by the process of longshore drift and depositing it elsewhere. Human activity has taken place on parts of this continuously changing and evolving coastline over thousands of years.

In many cases where development has taken place efforts have been made to protect these assets against coastal erosion and flooding from the sea. This has been attempted in the past, particularly in the 19th and 20th centuries, often through the construction of seawalls, which provide essential protection for many of our coastal towns and seaside resorts.

The natural evolution of the coast together with the expected implications of climate change and sea level rise present a significant challenge to future shoreline management. It is expected that there will be increased levels of risks to many coastal assets. In some places, current approaches to risk reduction will not be viable in the future. However, along the Undercliff a very substantial investment has been made in coastal defences with almost the whole of the developed frontages being substantially upgraded since 1987 with the support of grants from Defra.

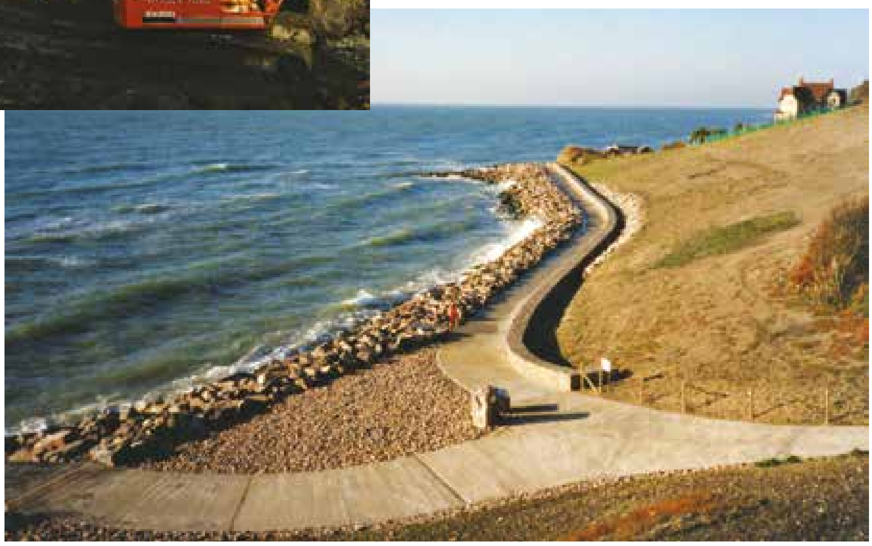
The Council's policy for coast protection in the long term is set out in the 'Isle of Wight Shoreline Management Plan' (SMP). This is a forward-looking document, subject to five yearly review, which sets out proposals for managing the shoreline over three time epochs, 0-20 years, 20-50 years and 50-100 years; the first review of the SMP is currently taking place.

A more detailed assessment of coastal defence measures, drawing on the strategic policies in the SMP, are provided by 'Coastal Defence Strategy Studies', which are nearing completion for the whole of the Island's coast. The strategies establish what type of coastal defence structure is most appropriate for each frontage where proposals are technically, economically and environmentally acceptable; again the Strategy Studies are subject to five yearly review. Both the SMP and the Strategy Studies take full account of the impacts of climate change and provide informal advice for planning policy.

The Bonchurch to Wheeler's Bay coast protection scheme was opened in 1987. Designed for South Wight Borough Council by Lewis and Duvivier, the scheme has eliminated coastal erosion risk for part of Bonchurch as well as assisting in reducing instability.

Coast Protection and Slope Stabilisation

The Western Cliffs along the Ventnor Undercliff (above) are composed of reconsolidated landslide debris. Aggressive erosion can destabilise clifflines with the risk of promoting further instability, which would adversely affect development on the landslide benches behind. In an attempt to reduce coastal erosion along these cliffs rock protection was provided in 1992.



A further scheme on the adjacent frontage at Castle Cove, Steephill was completed in 1996. It has prevented coastal erosion and reduced the risk of landslip; the scheme was grant-aided by the Ministry of Agriculture, Fisheries and Food (now Defra)

Wheeler's Bay coast protection and slope stabilisation scheme, Ventnor

At Wheeler's Bay in the town of Ventnor, the coastal slope, which comprises part of the Undercliff landslide complex, was reactivated following extreme autumn and winter rainfall in 1995. A ground investigation revealed significant slope movements with a Factor of Safety of less than 1. There was serious concern for the stability of a large number of properties sited upslope of Wheelers Bay.

The consequences of coastal landsliding involving loss of the seawall, thereby opening up the frontage to wave attack and further ground movements led to the implementation of a major coast protection and slope stabilisation scheme which was completed in 2000. The work involved advancing the coastal defence line seawards and provision of a substantial rock armour revetment as toe support for a filled and drained slope. The upper part of the slope was extensively soil nailed and turfed.

The coastal slope itself, which was of some ecological interest, was covered with the original soil and vegetation cover was regenerated successfully. The total cost of the project was £1.6 million and was grant-aided by the former Ministry of Agriculture, Fisheries and Food (now Defra). Coastal defence measures such as this form a key element of the Landslide Management Strategy that has been in place for this area since 1993.

General view prior to commencing the works

Soil nailing the upper slope

Constructing the new coastal defences seaward of the existing wall in order to provide support for the slope behind.

A view along the Undercliff looking eastwards from above St Catherine's Point.

Preventing unsuitable development

A central theme of the Undercliff landslide management strategy is to ensure that development is compatible with ground conditions and is not encouraged where the likelihood of movement is high. New property within the Undercliff must be capable of withstanding movement and not lead to a worsening of slope stability at the site or on adjoining land. These requirements are overseen by the Council through the Planning System and application of the Building Regulations (Box N).

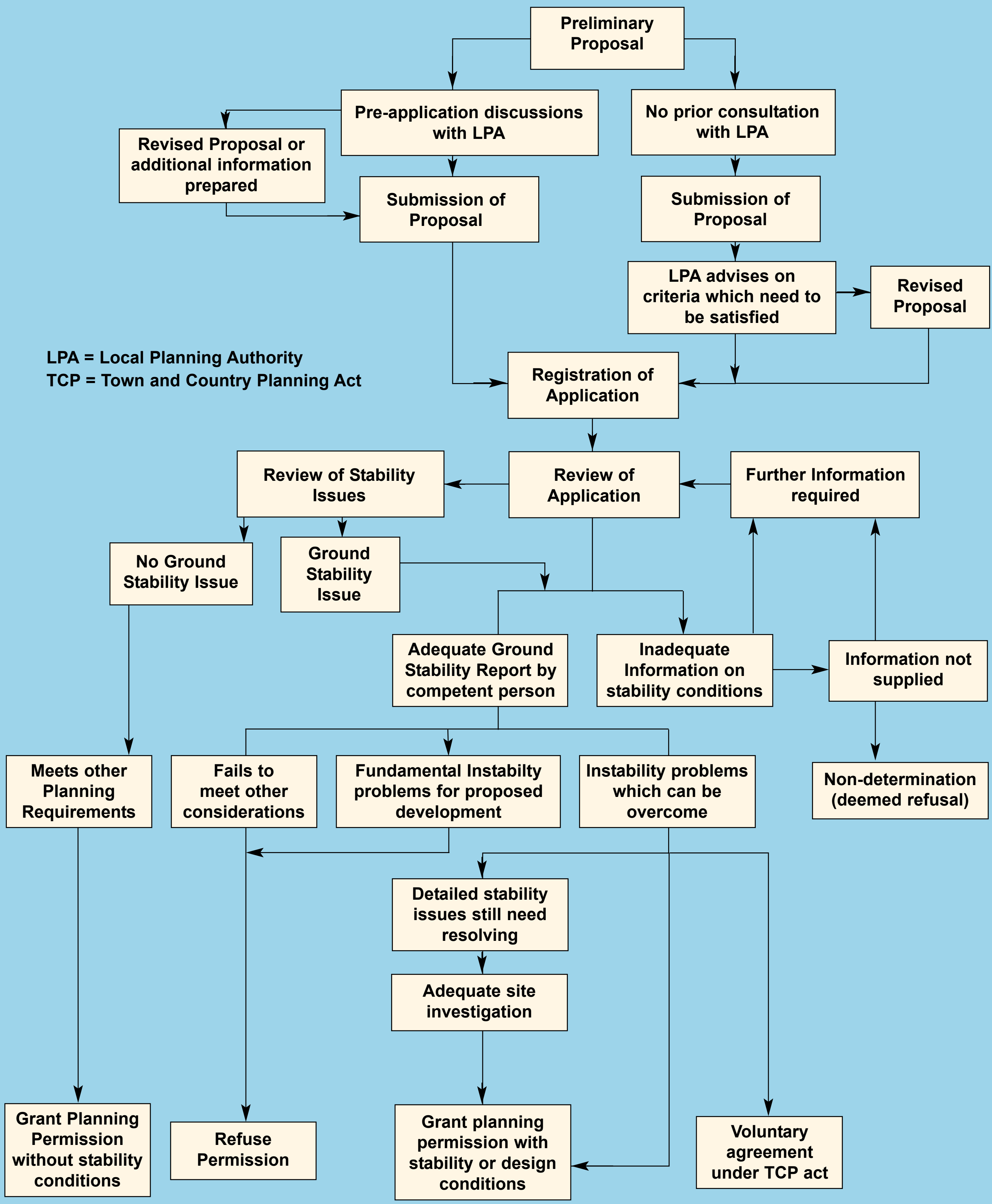
Developments in Great Britain require planning permission. Local planning authorities are required and empowered under the Town and Country Planning Act 1990 to control more forms of development and are responsible under the Building Regulations and the Housing Acts for ensuring standards of construction of development. When reviewing an application for planning permission the local authorities, in England and Wales, have a duty to take into account a range of material considerations, which include potential land instability problems (e.g. ground movement and landsliding). The main aims of considering potential landslide problems at this stage in the planning process are:

- to minimise the risks and effects of landsliding on adjoining property, services, structures and the public;
- to help ensure that various types of development should not be placed in unstable locations, without appropriate precautions;
- to enable unstable land to be appropriately used;
- to assist in safeguarding public and private investment by a proper appreciation of site conditions and the necessary precautionary measures.

The government issued Planning Policy Guidance which advises local authorities, landowners and developers on the role of planning controls as a landslide management tool. The purpose of the guidance is not to prevent development (although in some cases this may be the best response) but to ensure that development is suitable and to minimise undesirable consequences such as property damage or degradation of the physical environment. However, the responsibility for determining whether land is physically suitable for a proposed development and the appropriate technical measures to protect that development, lies with the developer and/or the landowner.

The basic principle of Isle of Wight planning policy is that development should take place within existing built up areas and the remainder of the Island is considered countryside where there is a general presumption against development. In addressing all instability matters over the Island the Council's states:

> "Development of areas known to suffer from instability will not normally be permitted, unless the local planning authority can be satisfied that the site can be developed and used safely and not add to the instability of the site or adjoining land".



Procedures adopted for handling of planning applications within the Undercliff Landslide Complex, Isle of Wight, UK

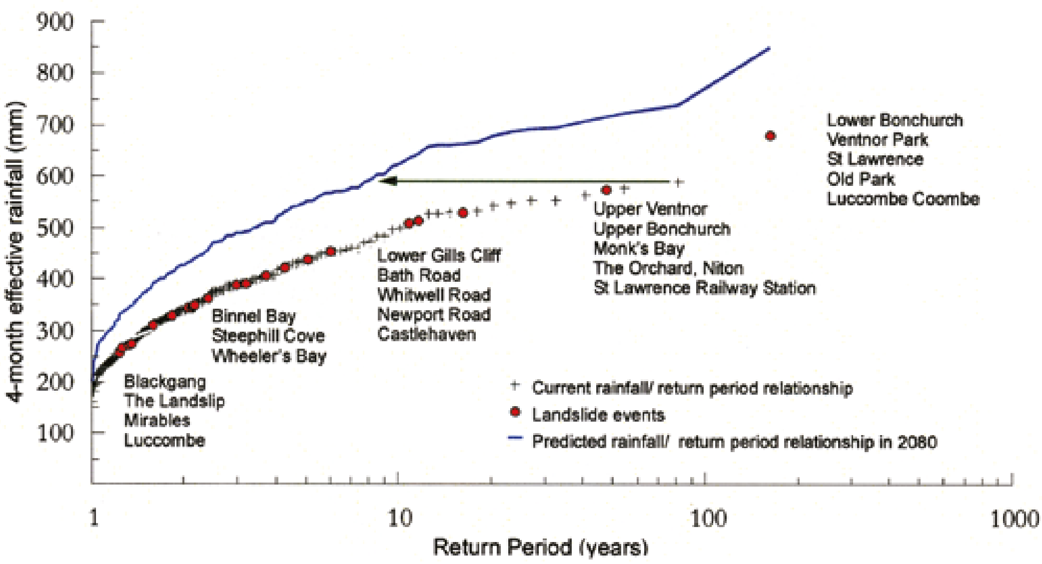
Groundwater and drainage

Many ground movement problems can be linked to high groundwater levels, which in combination with other factors such as coastal erosion or human activity can promote landsliding. Measures which control these factors will assist in reducing the likelihood of future movements but they will not, however, eliminate the risk. Rainfall and groundwater can act in a number of ways in promoting slope failure, first as preparatory factors which work to make the slope increasingly susceptible to failure without actually initiating it (i.e. causing the slope to move from a stable state to a marginally stable state, eventually resulting in a low Factor of Safety). Secondly, as triggering factors which actually initiate movement, i.e. shift the slope from a marginally stable state to an actively unstable state (Lee, 2000).

A common scenario is for a transient event (e.g. an intense storm) to trigger landslide activity after there has been a gradual decline in stability (e.g. a prolonged wet period); i.e. rainfall and groundwater can have both a long term and short term influence on slope stability.

The link between rainfall and landslide activity can be explained in terms of the change as pore-water pressures increase, so the effective shear strength available to resist the destabilising forces declines. Research in the Undercliff has demonstrated a clear relationship between 'effective' rainfall (i.e. that proportion of the rainfall that can contribute to the groundwater table (precipitation minus evapo-transpiration) and groundwater table rise, and the coincidence of landslide movement and high groundwater levels (Moore et al, 2007). Improving ground conditions, therefore, through the control of water can play an important part in trying to minimise the impacts of ground movement in developed areas.

This graph illustrates how landslides in the Undercliff have been triggered by rainfall exceeding certain thresholds, and how this relationship may change in the future. For example, a landslide event which at present may be expected to occur every 100 years may occur every 10 years in the climatic conditions predicted in 2080. (Halcrow 2006)



Management of groundwater and drainage has been approached in a number of different ways including the provision of cut-off drains to intercept groundwater before it enters a landslide area with the aim of achieving a reduction in groundwater pressures, as well as the drainage and disposal of surface water run-off and groundwater from within the landslide area itself. The ability to have an impact on groundwater will depend on the extent, depth and processes of landsliding taking place as well as the nature of the soils and underlying geology and their degree of permeability. In areas where the principal form of drainage is surface water run-off shallower drainage measures are likely to be most suitable whilst deep drainage systems, which may include cut-off drains, wells and adits, are more appropriate for deeper-seated landslides and consideration must be given to the cost benefit of the proposed drainage scheme. This will be related of course to the level of risk posed by the landslide in terms of development and public safety.

Sewers and septic tanks

Many towns and villages have inadequate or aging sewage systems and leakage can aggravate instability problems. Where pipes cross known areas of instability, flexible materials including joints can be provided that can accommodate some ground movements. In Ventnor, a major upgrade of the sewerage scheme was completed to meet the requirements of the European Bathing Water and Waste Water Directives. Southern Water Services sought specialist advice with respect to pipe-laying operations through the landslide system in order to transfer flows from existing short sea outfall pipes to a new treatment works in the town of Sandown 10km to the north-east.

The water company ensured the new pipelines were water-tight, flexibly jointed and routed around areas of greatest ground movement. A relative risk assessment was undertaken and a preferred option was developed from three alternative routes. The study took account of information from the geomorphology and ground behaviour maps that had been prepared for the area. Based on ground behaviour categories which were classified reflecting the magnitude of hazard, a simply subjective method for determining the relative risk or "hazard rating" for each pipeline route was developed. This enabled the various route options to be compared and ranked from best to worst with respect to ground conditions and the magnitude and frequency of recorded landslide and ground movement events.

Wherever possible new pipes should be constructed of materials that can accommodate some limited ground movement. This can be assisted by the use of slip joints.

Sewer laying by Southern Water Services Ltd in High Street, Ventnor. The new main was laid through the Undercliff landslide system following a risk assessment of options assisted by geomorphological studies.

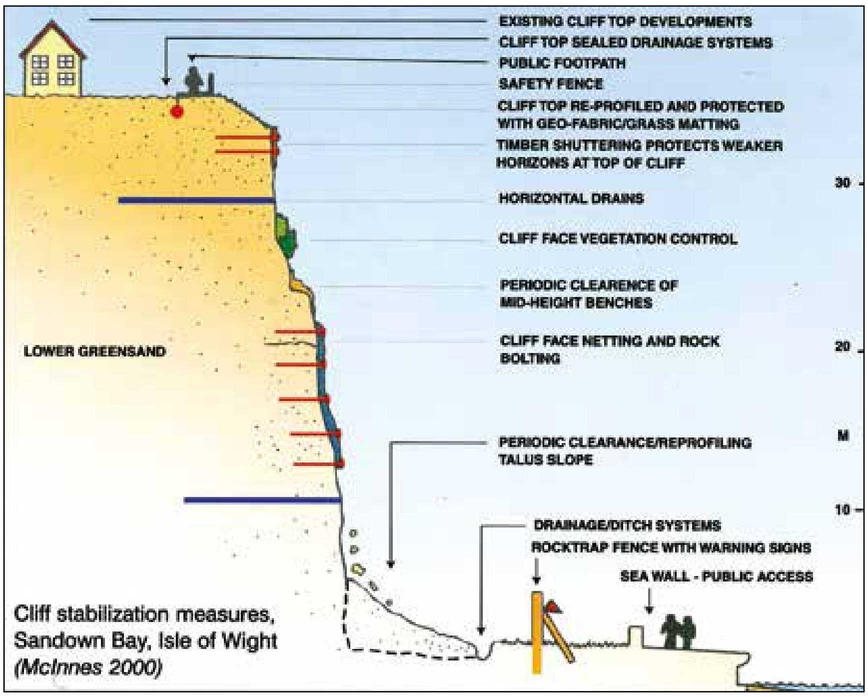
Managing slopes and cliffs

The problem of landslide hazard on sloping ground is most commonly addressed through a range of structural solutions which attempt to address problems associated with ground water levels, loading or excavation of slopes and past human activity. Generally speaking works of this kind reduce risks to development from slope movements or failure but do not prevent risk entirely. For this reason preventative measures are often accompanied by programmes of inspection or monitoring.

In many cases cliff and slope stability engineering works will require planning consent and in some locations it will be necessary to reconcile the demands for improved levels of protection with landscape, nature and earth science conservation interests. Issues of maintaining biodiversity, geological exposures and habitats will have to be weighed up against the socio-economic and sustainability arguments for each site.

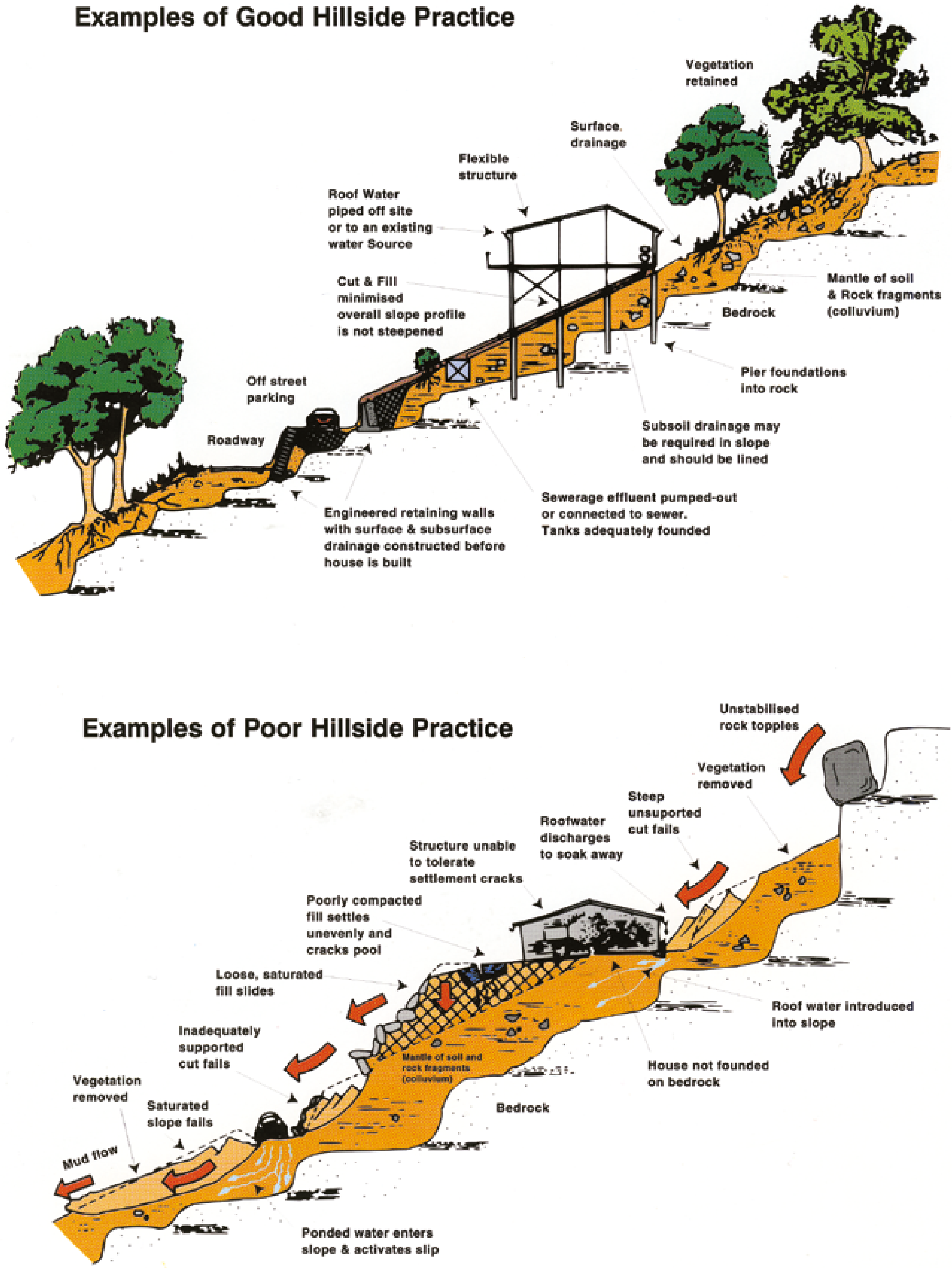
A range of slope stabilisation options exist including "cut and fill" operations which may assist in unloading a slope or providing toe support or slope fill. Drainage works which will divert surface and ground water or ensure more effective drainage through the slope may be by means of either drainage blankets or relatively shallow land drains or deeper cut-off drains which intercept ground water at the top of the slope landward of the area of instability. In some locations horizontal drains have been drilled into the slope to assist in removal of ground water in accordance with an engineering design. Finally, it is possible to remove water through pumping mechanisms again by means of drains or siphons.

Weathering and erosion of slopes can be controlled by means of a number of solutions including through the provision of toe support measures or protection of the surface, for example with turfing and netting. Where slopes consist of rocky outcrops and exposures, public safety may be improved through the provision of netting or rock trap fencing.



Cliff stabilization measures, Sandown Bay, Isle of Wight *(McInnes 2000)*


Cliff face inspection being undertaken by abseiling. Recorded survey data assists in updating the cliff risk assessment



Illustrations of Good and Poor Hillside Practice

This figure is an adaptation from GEOTECHNICAL RISKS ASSOCIATED WITH HILLSIDE DEVELOPMENT as presented in Australian Geomechanics News, Nunber 10, December, 1985, which discusses the matter more fully.

Walls and retaining structures

Slope treatment comprising reprofiling or drainage is a favoured technique for stabilisation. However, there may not always be the available space for techniques of this kind. Where space is confined, particularly in developed urban areas, the use of retaining walls, reinforced earth, soil and rock anchors and other engineered structures may be appropriate. These measures may also accompany slope reprofiling and drainage where they are deemed to be inadequate in providing the necessary level of slope stability on their own. Typically, retaining structures are composed of concrete or stone and may take the form of masonry or concrete walls, criblock structures or gabions (wire baskets filled with stones or rock). In some locations reinforced earth has been used which involved the incorporation of geotextile material within the supporting soil mass. Some of these structures may be accompanied by the provision of vegetation for both stabilisation and aesthetic reasons.

In the case of walls, these may comprise structural retaining walls on suitably designed foundations, sheet or bore piled walls or soil strengthening measures, for example ground and rock anchors or soil nails which may be pre-stressed.

Masonry walls composed of reinforced concrete and faced with natural stone represent a considerable financial investment. Proper design of structures of this kind incorporating drainage provision ensures not only a long life but a high aesthetic standard. (left)

Gabion walls can provide an excellent means of support in some locations. They have the ability to accomodate movement without causing structural damage. (below)

Encouraging appropriate construction activity

Damage to buildings, roads and other infrastructure from ground instability is a common problem but much can be done to try and mitigate against damage caused by ground movements. Some of these measures have been described earlier, for example with respect to management of slopes, walls and drainage systems. Having established the planning framework, which will provide a basis for decision-making in terms of the general suitability of a site for development, it is usually the developer who will undertake appropriate investigations and studies to demonstrate that the particular site concerned is suitable to accommodate the proposed construction activity. The Council holds more detailed maps and reports which can assist in this process first by guiding development to the most suitable areas in terms of ground stability and second by giving advice on the type of further survey or investigation that may be required to support the development proposal.

It is clear, therefore, that the local authority, the developer, the architect and the builder and in due course the occupier of the building, all have a role to play in terms of ensuring that the development is constructed in a most suitable manner to take account of ground conditions, and is maintained adequately in the future to try and reduce the impact of any ongoing ground movements.

What the developer can do

The developer does, of course, have a key interest in ensuring that the site can support his development and that any ongoing or subsequent ground movement will not adversely affect the site and, therefore, reduce its value or marketability. Unfortunately, in many cases proper site investigation does not commence until problems have arisen, often during the construction stage. The undertaking of investigation and remedial works during construction as opposed to prior to commencement can be extremely costly in terms of delays, contractual claims and adverse publicity which may affect the future marketability and insurance of the development. The developer must take account of not just the ground conditions on the development site itself but also the possible impact of the development in terms of adjacent sites which may be adversely affected by the proposal. Again this is a matter which must be addressed at the planning stage and the development proposal must be supported by sufficient information that will allow the local authority to undertake a proper review of the proposal. Studies of this kind should be undertaken by a competent geotechnical specialist who is likely to be registered with an appropriate professional institution. The Planning

Existing development is not always most suited to accommodating ground movement. However, there are measures that homeowners can take in order to reduce the impact of ground instability on their properties

Authority may wish to receive details of the competence of the person undertaking the survey and complete a check list of important issues that must be addressed in the stability report as an aid to assessing the development application.

In terms of construction techniques there are a number of opportunities for minimising the impacts of ground movement through appropriate design. The foundations of buildings are particularly important. Traditional strip foundations can easily fracture causing significant structural damage. Rafts are able to accommodate slight movements and span minor fissures and voids that may form beneath the raft over the lifetime of the building.

In general, simple designs are preferable to more complex structures, with some degree of interlocking or articulation which can accommodate slight movements being most desirable. Lightweight framed buildings which may be of timber with brick or concrete infill or sheet construction materials are likely to be least problematic in the future. Tile or slate hung features can cover minor damage whereas more rigid construction methods or rendering tend to show cracking quite quickly. If movements do occur that affect the raft foundation, this can be accommodated in some situations through the provision of adjustable jacking points as part of the ring beam or foundation design. This method creates the possibility of re-levelling the raft at some time in the future.

In summary, therefore, a residential property on unstable ground could be constructed on a raft foundation with jacking points and should be light weight, low rise, and composed of materials which will not be prone to visible cracking and damage.

Particular attention should be paid to the use of concrete. This should be constructed in small bays with frequent use of expansion joints, and should contain reinforcing mesh. For paths and hard standings areas of blocked paving may be appropriate. Externally, particular attention should be paid to the design of guttering and rainwater down-pipes to ensure that these are of sufficient capacity to accommodate more intense rainfall events and to take account of possible changes in climate which may result in more prolonged winter rainfall. Ideally, roof water and surface water run-off from hard areas should be connected to sealed drainage systems or existing ditches. Some of these issues may well be set out by the planning authority as "conditions for approval" for the development.

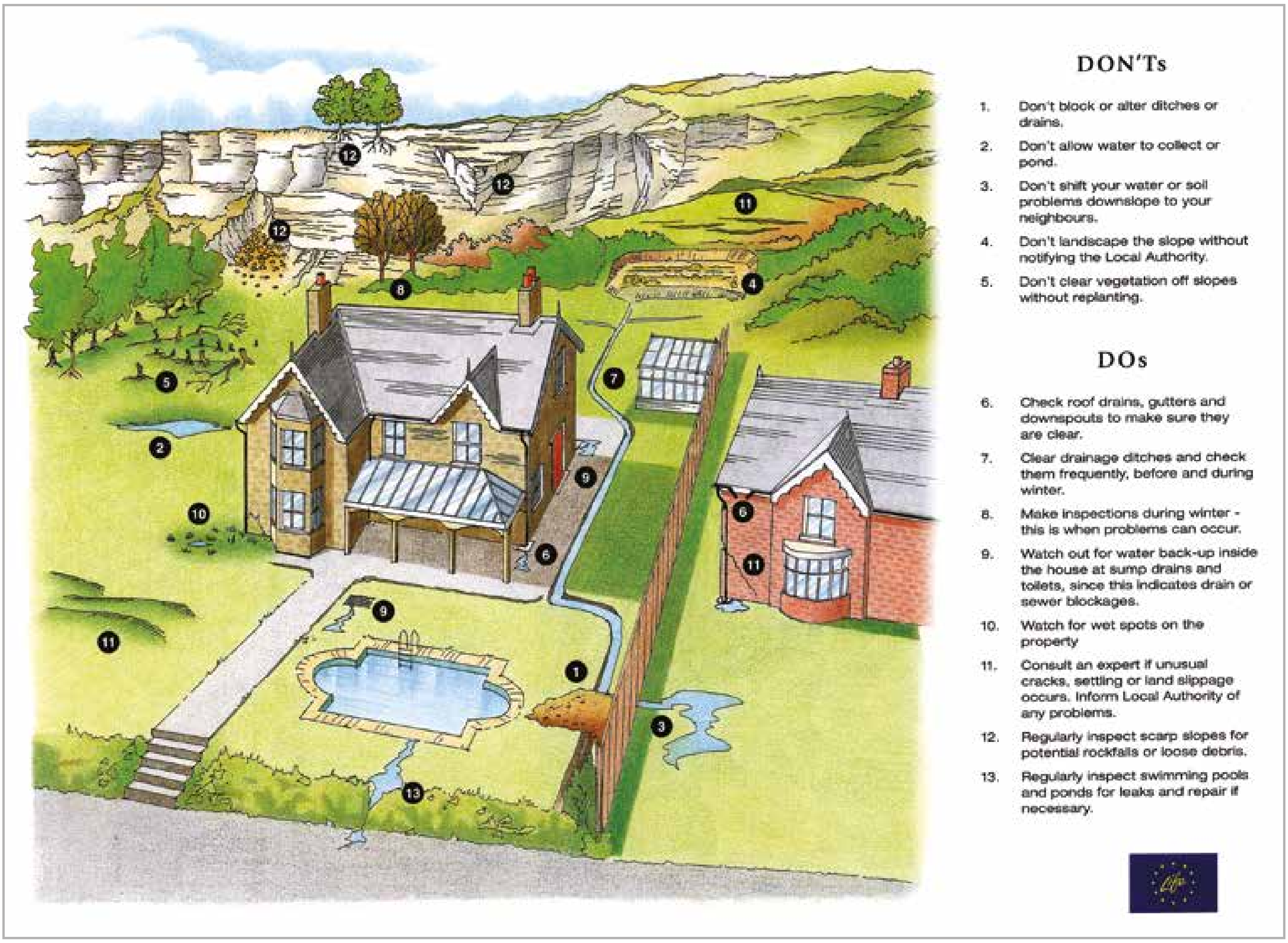
During the course of construction, the developer needs to pay particular attention to on-site management, proper control of earth works in sequence to avoid inappropriate excavations or leaving slopes inadequately supported; unsupported trenches, for example for service supply pipes, should be avoided. Many instability problems arise from poor site management and lack of proper earth works control generally. During the course of construction ground water should not be allowed to pond on site as this may cause problems during construction or at a later date.

What the homeowner can do

Whilst individual property owners may be able to have only a minimal influence on ground instability problems, the cumulative effect of efforts by many homeowners on the landslide system can be significant. Activities such as vegetation clearance, slope regrading, cut and fill operations, lack of maintenance or inattention to leaking pipes can all adversely affect ground stability. Residents, both individually or in groups (by area or by road), can work together to ensure that issues such as maintenance of drainage systems are addressed.

A good time for inspections is in the early autumn before the onset of the autumn/winter rainfall period when guttering and downpipes should be checked for blockages and leakage and road drainage systems and ditches must be cleared. For properties not in the ownership of individuals there is an individual but also a collective responsibility to contribute towards management of the building and its grounds. It is sometimes more difficult for tenants, particularly in large buildings that have been divided into apartments, to ensure that a co-ordinated approach is taken to addressing structural maintenance and drainage problems; this may be addressed through a residents' management committee. Lack of maintenance will make the building all the more susceptible to slight ground movement and so regular maintenance is particularly important.

The figure below illustrates some of the practical problems associated with maintenance of properties in an area of instability and provides guidance with respect to key issues; further information may be obtained from the references at the end of this report or the Council.



'Advice for homeowners in areas of instability.'

Monitoring instability

Monitoring is an integral part of landslide investigation and on-going management because it provides a means of accurately and objectively gauging the stability conditions of unstable or potentially unstable slopes; it can also fulfil an important role in assessing risk. The objectives of monitoring include:

- providing information to assist landslide investigation;
- determining the rate and scale of ground movements particularly in vulnerable locations;
- identifying links between ground movement, rainfall and ground water levels that can be used to develop a methodology for landslide forecasting;
- provide early warning in areas where movements could affect life and property;
- monitoring the effectiveness of landslide management strategies. In addition, instrumentation can help deduce mechanisms of failure as well as assisting in design verification, construction control, quality control, performance of structures and provide legal protection against claims from owners of properties adjacent to construction sites.

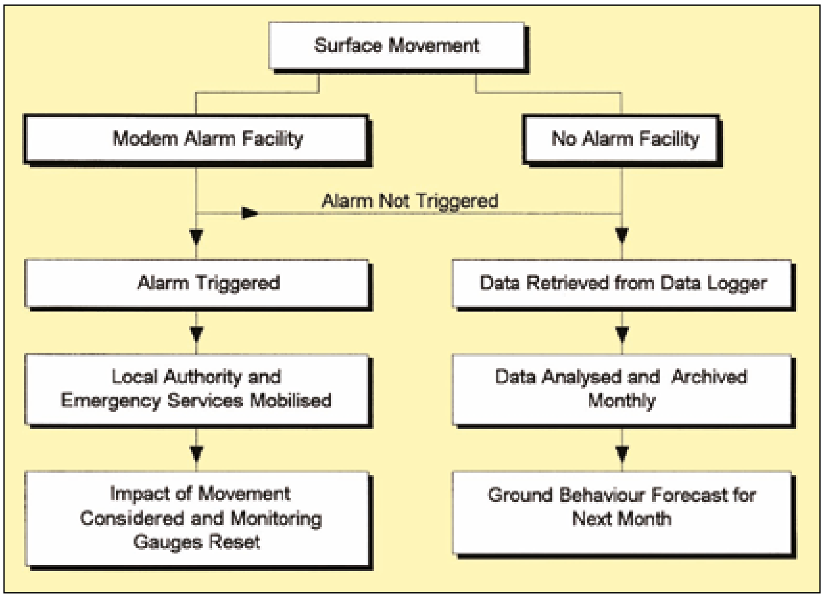
Each investigation and monitoring study presents a unique set of critical parameters. The geotechnical engineer must identify those parameters and then select instruments to measure them. What information is required for the initial design? What information is required for evaluating performance during and after construction? When these parameters are identified, the specification for instruments should be established. This is likely to include the range, resolution and precision of the instruments.

Ground conditions often determine the choice of a specific instrument but in addition instrument performance must be considered. It is necessary to consider minimum performance requirements as well as the cost of the instrumentation, which may increase with its resolution, accuracy and precision.

A range of techniques are available to those seeking additional information on ground conditions. These include both sub-surface and surface systems. Data loggers are often used to record and periodically transfer monitoring data to the operator. A data logger can also be used to provide an early warning system if linked to telephone alarms when recorded ground movements exceed pre-set limits.

In a number of unstable locations, where monitoring has taken place over several years, a monitoring strategy has been established which includes the gathering of data on both meteorology and ground movements. Increasingly taking into account the cost of manual data-gathering, electronic systems are being used allowing easier data acquisition, interpretation and storage. A typical approach is that adopted in the Undercliff as indicated in the figure opposite. Monitoring systems of this kind support manual inspections, assist landowners by increasing their awareness of any hazards that may exist and which may cause nuisance to adjacent owners as well as allowing the provision of baseline data against which climatic change can be assessed. For all the monitoring programmes it is essential that accurate records are kept of inspections and due attention given to trends or changes in the pace of readings. Not only will monitoring systems allow the implementation of an emergency response if required, but also they can provide baseline information and increased scientific knowledge in the area concerned.

The approach to landslide monitoring on the Isle of Wight



An improved understanding of the relationship between rainfall levels and ground movement can help assist in understanding landslide risk. Rainfall and various types of ground movements are monitored continuously by over 200 instruments within the Undercliff.

Taking readings at the weather station in Ventnor Park

Taking inclinometer readings from a borehole along the Undercliff.

Reducing rockfall hazard by scaling, bolting and netting at Ventnor Eastern Cliffs - Spring 2006.

Chapter Five
Climate change and future management

Climate change is inherently variable. Meteorological records from the last two centuries indicate distinct changes in temperature and rainfall. For example, after a relatively cool dry period in Britain during the 1940s we have been experiencing many of the hottest summers ever recorded in recent years. Britain is currently undergoing a series of significant climate change. In addition to the warming trend, the weather is also becoming wetter. At Ventnor, local meteorological records have already indicated that there has been a trend of increasing annual rainfall since the 1920s, which may partly explain the increase in recorded landslide events over the same period. Research, such as that currently carried out at the Hadley Centre at the Meteorological Office, involves the use of sophisticated mathematical models of the atmosphere and the oceans to simulate future changes. In southern England over the next century it is predicted that;

- It will continue to get warmer;
- Rainfall will continue to increase in the winter but may decrease in the summer; however there will be an overall increase;
- Sea levels will continue to rise; the possibility of an increase in the number of extreme rainfall events and storm events.

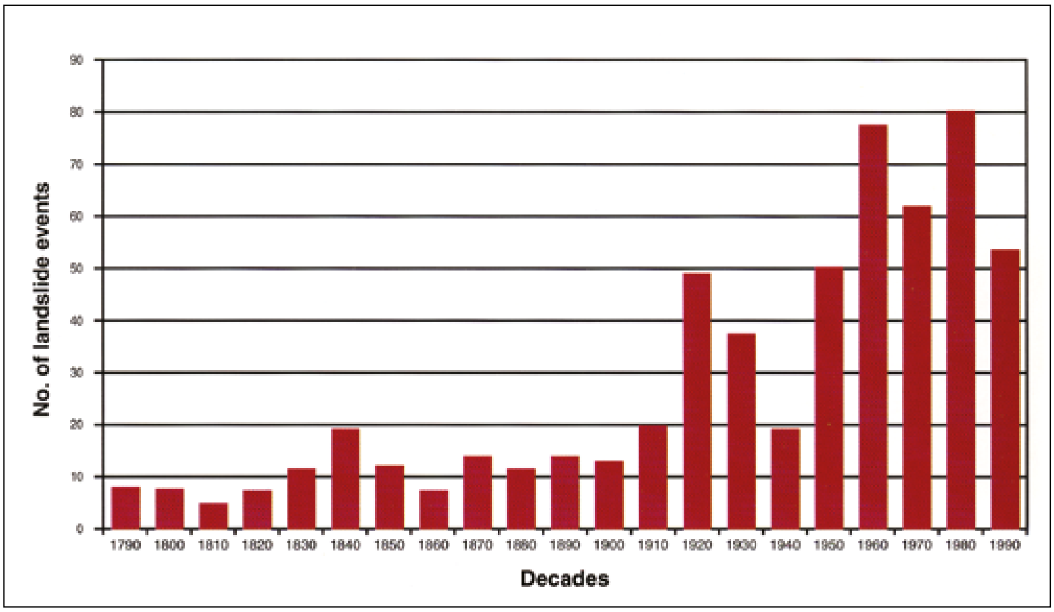
Potentially these predictions would appear to be continuations of current trends observed within the Ventnor Undercliff of the longest rainfall records in the country extending back to 1839.

In order to prepare for potentially worsening climatic conditions which are likely to impact on the stability it has been necessary to consider the possibility of undertaking further civil engineering measures, such as drainage, alongside the Council's current landslide management strategy in order to maintain ground stability at at least current levels.

Reactivation of landslides, Undercliff, Isle of Wight

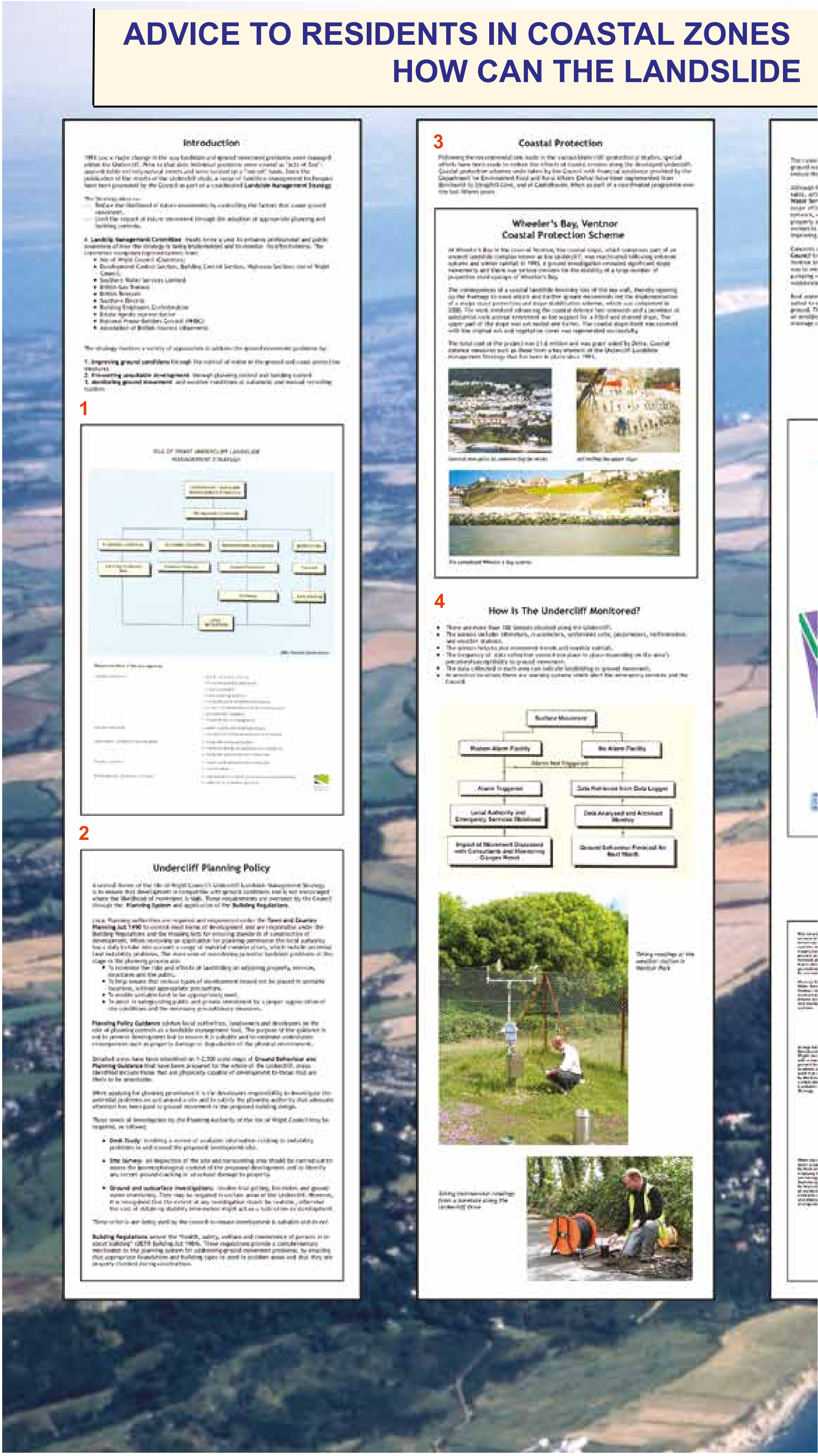
Period	No. Major Events
1839-1880	8
1880-1920	6
1921-1960	12
1960-2007	23

Moore et al 2007



Number of landslides (1790 - 2000) along the central southern coast of England, derived from unstandardised research of reported events, using no magnitude filter and including single events and major reactivations (after Ibsen and Brunsden, 1997 - updated 2000)

In terms of managing coastal risk the local community can play an important role, but this will only be achieved if complex technical issues are explained in a 'non-technical' way. This display panel is one of five designed to explain to coastal residents about landslide risk on the Isle of Wight, UK



The key elements of the advice provided on these display panels are:

1 Current arrangements for managing landslide risk on the Isle of Wight.

2 The role of the Council as planning authority for the Isle of Wight.

3 How coast protection measures can help reduce landslide risk.

4 Landslide monitoring programmes and warning systems.

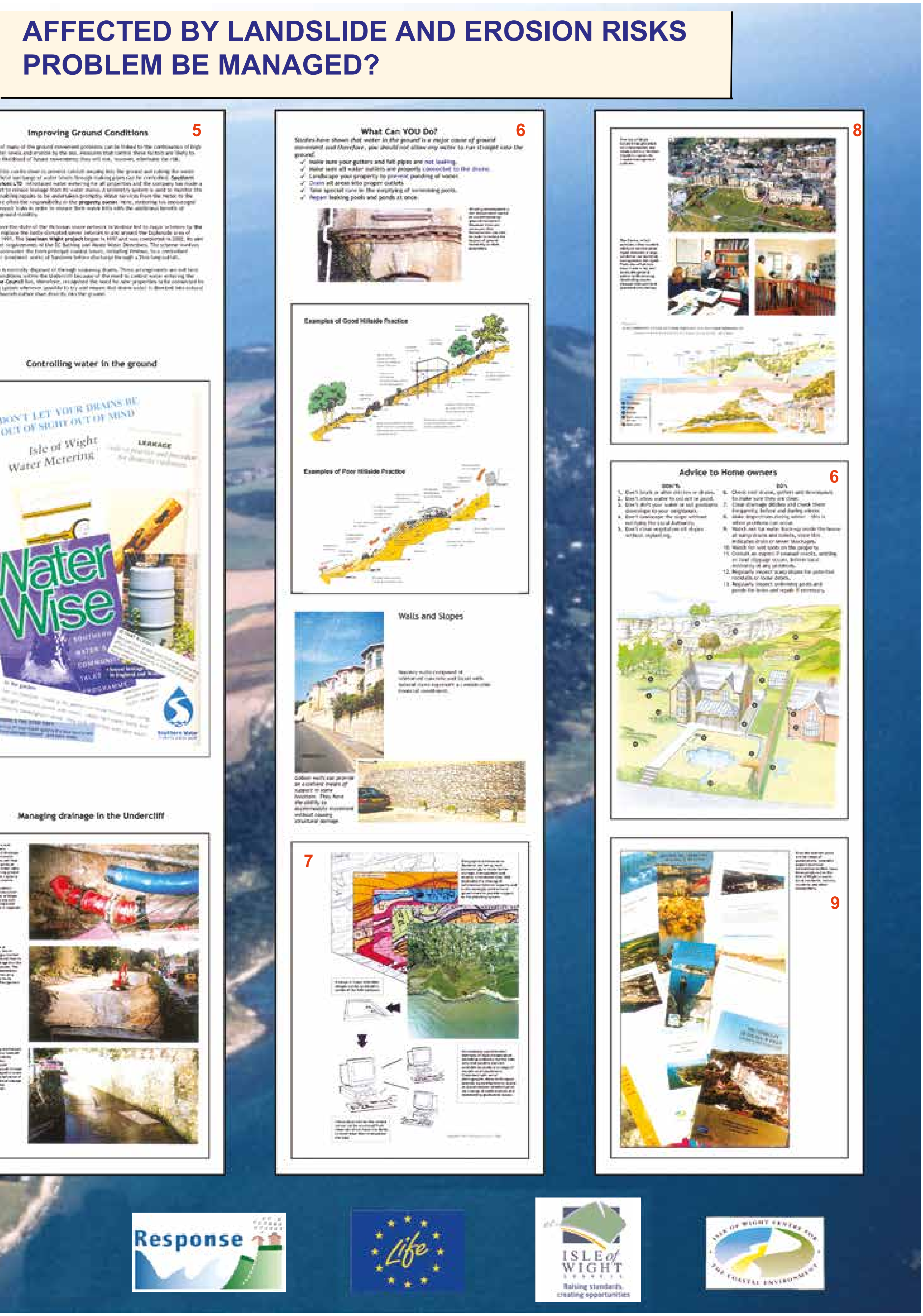
5 Improving ground stability by drainage including measures to reduce water leakage from drains and supply pipes.

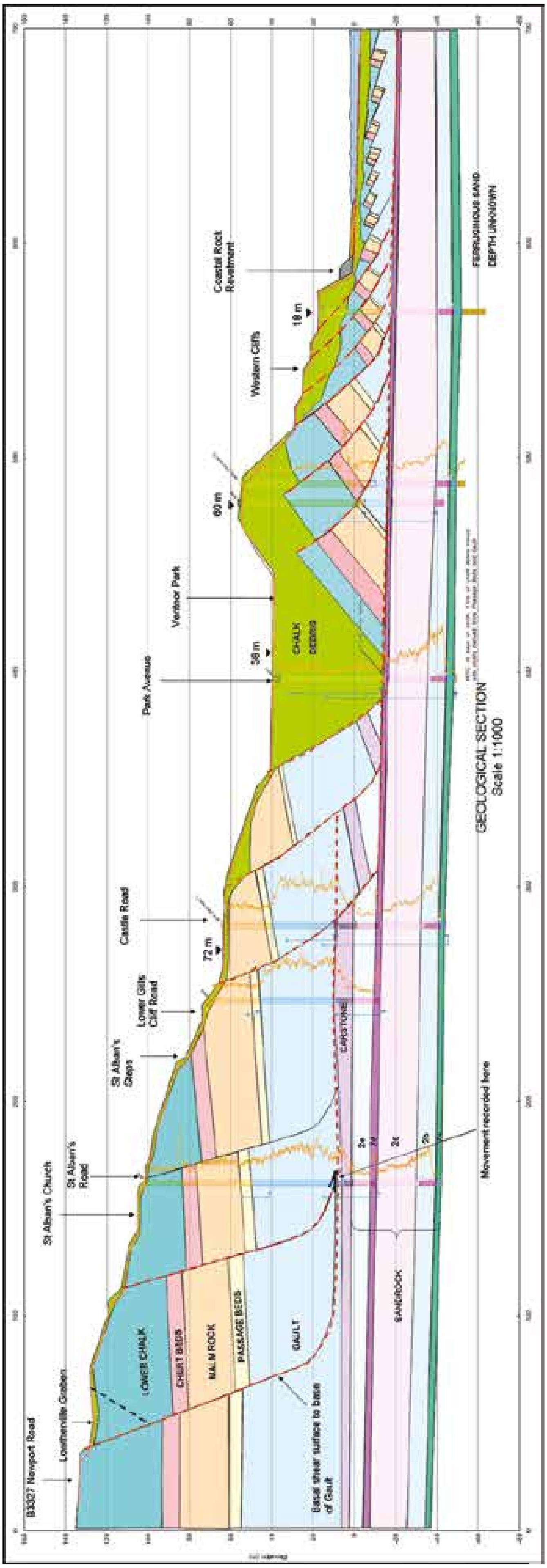
6 What homeowners can do to ensure that management practices on their land are not aggravating ground instability problems.

7 How new technology such as GIS can assist with data management and the provision of public information.

8 The role of the Isle of Wight Coastal Visitors Centre in terms of assisting with public information alongside its educational work.

9 Advice for homeowners and businesses through publications, leaflets and its website.


AFFECTED BY LANDSLIDE AND EROSION RISKS
PROBLEM BE MANAGED?
Improving Ground Conditions
5
What Can YOU Do?
6
8
Controlling water in the ground
Examples of Good Hillside Practice
Examples of Poor Hillside Practice
Advice to Home owners
6
Isle of Wight Water Metering
Water Wise
Walls and Slopes
Managing drainage in the Undercliff
7
9
Response
Life
ISLE of WIGHT
Raising standards, creating opportunities
ISLE OF WIGHT CENTRE FOR THE COASTAL ENVIRONMENT



Schematic landslide model for central Ventnor (Halcrow 2006)

As part of a recent coastal instability study for Ventnor a range of risk management options were evaluated in order to try and identify what additional civil engineering measures may be necessary in order to try and maintain ground stability at the current levels in the context of climate change. Following the completion of a programme of sub-surface ground investigation works it has been possible to prepare a more accurate geological model for central Ventnor (see opposite). With this information it is possible to assess risks of ground movements in various scenarios. By valuing assets that might be affected by ground movements if no action is taken (the 'do nothing' scenario) it is possible to compare the losses that might be incurred against the cost of various protection or stabilisation measures (e.g. coast protection and drainage works). With an improved understanding of the consequences of 'doing nothing' it is possible to calculate the 'benefit cost' or the economic justification for carrying out civil engineering measures. This work has been undertaken for central Ventnor and demonstrates a positive economic benefit for a deep drainage scheme combined with some improvements to coastal defences. Further work is necessary to confirm more precisely the nature of any drainage measures that could be undertaken; and to identify how any such project can be implemented in the future.

Previous studies have confirmed the vital role played by coastal defences in helping to secure the toe of the Undercliff landslide complex. However, although defences are in place along the developed frontages some sections are likely to require upgrading as a result of an increased understanding of the landslide model and the implications of sea level rise, specifically the Western Cliffs frontage, which was first defended fifteen years ago.

The Isle of Wight Council will continue to implement, and develop further, its Landslide Management Strategy for the Undercliff through planning and development controls, landslide monitoring and promoting public awareness. However, the most recent studies have demonstrated that in order to reduce instability risks for Ventnor arising from ground movement in the context of climate change the most sustainable management option is implementation of deep drainage measures alongside coast protection works. This proposal could improve coastal slope stability, and thereby reduce instability risk for the next one hundred years. Combining coast protection works and slope drainage as an integrated scheme has proved successful at many locations around the English coast; elsewhere works have been undertaken without coastal defences.

Whilst the results of the various residents' surveys, (described previously), have proved encouraging it is recognised that there are still significant problems to address in terms of managing ground instability in the future. A key component of the Management Strategy is the monitoring programme, which includes recording meteorological conditions as well as analysis of data from a wide range of sub-surface instrumentation. In total, around the Island's coastline nearly two hundred instruments record ground water levels, settlement, cracking and tilt. The programme benefits particularly from the climatic record which allows comparisons to be made between winter rainfall and ground instability events. Valuable historical data of this kind alongside good local knowledge forms an important tool in terms of assisting prediction, allowing the Council to be best placed to address changing conditions in terms of rainfall patterns in the future. These problems necessitate particular responses by the Council, businesses and local residents, which will be increasingly focussed on adapting to these changing conditions assisted by improved educational programmes.

There is already a significant awareness of the potential impacts of climate change amongst many of the relatively well-informed residents of the Isle of Wight coastal zones. They have been made aware of climate change issues through the influence of the media, which has highlighted through television coverage, natural disasters such as landslides, hurricanes and the El-Nino effects globally as well as through newspaper coverage of events such as these.

Delegates attending the Isle of Wight Council's international conference on 'Landslide and climate change' in May 2007 view the Lowtherville Graben at Upper Ventnor (above). The Isle of Wight Coastal Visitors Centre has an extensive library of both technical and non-technical publications on coastal and ground instability topics (below).

As part of a recent coastal instability study for Ventnor a range of risk management options were evaluated in order to try and identify what additional civil engineering measures may be necessary in order to try and maintain ground stability at the current levels in the context of climate change. Following the completion of a programme of sub-surface ground investigation works it has been possible to prepare a more accurate geological model for central Ventnor.

Media influence	▷ Television coverage of natural disasters - landslides, hurricanes, El Nino effects. ▷ Newspaper coverage of events, newsletters and debates
Influence of public bodies	▷ Publications, guidance, advice to homeowners' leaflets ▷ Updated planning and building control policies ▷ Introduction of 'adaptation to coastal change' strategies
Influence of external organisations	▷ Concerns of the insurance industry - increasing insurance premiums or unavailability of insurance ▷ Results of independent research into changes in geographical range of species, crops - possible extinctions; changes in weather patterns
Perception of local residents	▷ Observations of increasing frequency and severity of landslide events ▷ Changing weather patterns e.g. drier summer, more disturbed weather, wetter winters ▷ Changes in insect and plant life, including new species from France ▷ Shared concerns over climate change impacts amongst local community.

Factors influencing public perception of climate change in the Isle of Wight Undercliff (McInnes, 2007)

At the western end of the Undercliff between Niton and Blackgang the coastline is relatively undeveloped. The natural processes of erosion and landslip continue uninterupted.

Responding to the impacts of climate change on Europe's coast

Affrontare i rischi derivanti dal cambiamento climatico nelle zone costiere

Répondre aux risques liés au changement climatique dans les zones côtières

Response

RESPONSE: European LIFE Environment Project 2003-2006

Summary Leaflet **Brochure riassuntiva** **Dépliant résumant le projet**

ISLE of WIGHT COUNCIL
Raising standards, creating opportunities

www.coastalwight.gov.uk/response

Welcome & introduction

'Response' (or 'Responding to the risks from climate change') is a three-year Project supported by the LIFE financial instrument of the European Community, launched in December 2006. The Project provides a framework for understanding and preparing for the impacts of climate change around the European coastline.

The publications described in this leaflet can assist organisations managing the coastline in assessing and prioritising the risks arising from climate change impacts on natural hazards, to inform the planning process.

The Project has demonstrated regional-scale mapping of coastal evolution and risks, taking account of the impacts of climate change. It has also examined the current and future costs of coastal natural hazards, to encourage cost-effective solutions. Nine Partner organisations in the United Kingdom, Italy, France and Poland have participated, led by the Isle of Wight Council's Centre for the Coastal Environment, UK.

Climate change - the challenge

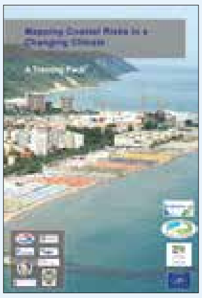
The Intergovernmental Panel on Climate Change predicts that climate change impacts will include sea-level rise, increased winter rainfall and more intense storm activity -a growing threat for many coastal communities affected by coastal erosion, flooding and landsliding, and an increasing challenge for the local and regional authorities responsible for addressing the resulting risks.

"Winning the battle against climate change concerns us all. The time of theoretical debates about climate change is over, we need practical and effective actions."
EC Environment Commissioner Stavros Dimas
(Brussels, 7th July 2006; SPEECH/06/444)

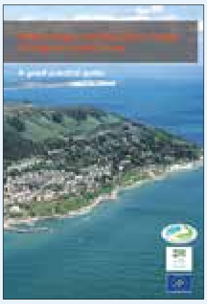
"We need to adapt to the climate change that is inevitable because of the massive accumulation of past emissions. We are far from helpless in the face of this challenge. There are many things we can do to reduce risks and protect ourselves from the extreme weather associated with climate change. Climate change still tends to be perceived as an environmental concern. But it has profound implications for jobs, growth, health and almost all other aspects of human well-being, including security."
UN Secretary-General Kofi Annan
(New York, 28th September 2006; SG/SM/10665/ENV/DEV/903)

RESPONSE Project Publications

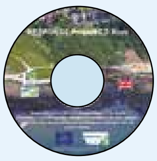
The RESPONSE Project has prepared an information pack in English, French and Italian containing advice for managing risk in coastal areas of Europe; it contains:



"Training Pack": Coastal evolution and risk mapping
The Training Pack demonstrates how to produce maps that show the future pattern of coastal evolution and risks across a region (or sediment cell), which take account of the impacts of climate change. These maps can provide an understanding of the pattern and scale of coastal change and assist in targeting resources effectively. The Training Pack also contains evidence on the importance of taking cost-effective action now to prevent worsening impacts in a changing climate.



"Good Practice Guide": Advice on coastal risk reduction
The Good Practice guide contains advice on sustainable coastal risk management and examples from around Europe and the world of how the growing impact of natural hazards on coastal communities can be addressed and reduced.



"CD-Rom of Resources": A toolkit for action This CD-Rom contains full information on each stage of the mapping process (summarised in the Training Pack). It also contains Case Studies from the RESPONSE Project Study Areas in the UK, France and Italy, which provide practical experience of producing the risk maps in a range of environments. Plus additional features.

Conclusions

When geomorphological and other studies are carried out in an area of instability such as the Undercliff, the process of investigation and scientific assessment can raise a range of concerns with different groups within the community ranging from local government staff to insurance companies, estate agents, developers and property owners. The proper dissemination of information to the community following studies of this kind will form the key to a successful study. Homeowners in particular, who may have very little knowledge of the history or extent of ground instability problems in the area may be particularly worried about surveys of ground movement. An increasing public awareness through, for example, the publication of an information leaflet has proved to be a helpful approach. It is hoped that this guide together with the displays at the Coastal Visitors' Centre in Ventnor can assist in addressing these concerns.

It has been shown that much can be done to reduce the impact of instability problems through a co-ordinated approach involving all sections of the community as well as the professionals involved in coastal management, planning, highways, the service industries, the insurance industry as well as builders, architects and developers. It is very important for all these groups to work together with the aim of ensuring that instability problems are not aggravated through inappropriate design or as a result of engineering, building and other construction projects.

One way of disseminating information and ensuring a co-ordinated approach is by establishing a management committee within the town or area affected by instability. This group can provide a unified technical approach to the ground movement problem. In addition these professionals can provide support to local and regional government, making use of their particular individual areas of expertise. It is equally important for the Council to explain what measures it is taking to try and mitigate against ground instability. If it can be shown that local government is taking the initiative it will be easier to enlist a response from other groups including homeowners. This may result in an improvement in confidence in the locality concerned and this should assist in allaying concerns and ensuring a much improved level of understanding relating to ground movement issues. In the Undercliff this co-ordinated approach is being achieved through the work of the Isle of Wight Landslip Management Technical Committee.

The insurance industry can also play an important role in assisting mitigation of the costs associated with landslides. Most insurance cover is based on a broad-brush assessment of instability risk by the particular company concerned; this usually takes account of past claims. Enhanced premiums may be charged where the insurance company believes that a higher level of risk exists. In some areas, taking account of the risk, insurance cover may not be available at all.

Much damage that occurs in landslide prone areas is of a relatively minor nature. Insurance companies can lend support to landslide management strategies by requiring homeowners, as a condition of insurance cover, to maintain their properties in a satisfactory condition. Mortgage lenders can also assist in this respect by requiring surveys to be undertaken of particular risk elements such as drainage systems when properties are changing hands.

A major objective of the various geotechnical studies within the Undercliff has been to try and restore confidence in the area concerned through an improved understanding of ground conditions and instability potential. In areas where it is difficult to obtain insurance, insurance companies may reconsider the question of providing cover if information provided by their customers is available which can demonstrate a reduced level of risk.

The key elements of the Council's landslide management strategy involve:

- modifying the hazard to the community by means of engineering works (including coastal defence, drainage measures or slope stabilisation) and improved building practice;
- effective planning controls to guide development to suitable areas and to control the nature of new development;
- improving the understanding of landslide behaviour;
- mitigating the cost of ground movement through insurance and other measures;
- co-ordinating the community response to the problems.

The Isle of Wight Centre for the Coastal Environment, part of the Isle of Wight Council, is based at Salisbury Gardens, Ventnor. The building also houses the Coastal Visitors' Centre which receives numerous school and university groups for educational courses and field visits. A coastal exhibition, a comprehensive technical library and information on ground instability are also available.

Sustainable development within the Undercliff requires ongoing study and wise decision-making taking full account of ground conditions. This can be achieved most effectively by means of a co-ordinated approach to instability management, minimising risks by:

- identifying and understanding the nature and extent of instability;
- guiding development towards suitable locations;
- ensuring that existing and future developments are not exposes to unacceptable risks;
- ensuring that development does not increase the risk for the rest of the community.

It is hoped that the advice and information provided in this guide will be of practical assistance in reducing the impact of instability on the Undercliff community and the lessons and experiences will also prove of value to other locations affected in a similar way.

References and further reading

Brunsden, D. & Lee, E. M. 2000. Understanding the behaviour of coastal landslide systems - an inter-disciplinary view in E. N. Bromhead, N. Dixon, and M-L Ibsen (Eds) Landslides: Research, Theory and Practice. Thomas Telford.

Clark, A. R., Lee, E. M. & Moore, R. 1996. Landslide investigation and management in Great Britain: A guide for planners and developers. Department of the Environment, UK, HMSO.

Clark, A. R., Moore, R. & Palmer, J. 1996. Slope monitoring and early warning systems; applications to coastal landslides on the south and east costs of England. VIIth ISL Trondheim, Vol. 3.

Department for Environment, Food and Rural Affairs (Defra), 2006. Shoreline management plans guidance. Crown copyright, London.

Department of the Environment (DOE), 1991. PPG14 - Development on unstable land. London: HMSO.

Doornkamp, J., Lee, E. M. & Moore, R. 1991. Coastal landslip potential assessment: Isle of Wight Undercliff. Technical Report by Geomorphological Services Ltd for the Department of the Environment, UK. Research contract PECD/7/1/272. London. Department of the Environment, HMSO

European Commission, 1997. LIFE Environment - Information Package 1997-1999. Brussels. European Commission DGXI (XI.B.2).

European Commission, 2001. LIFE Environment in action - 56 new success stories for Europe's environment. Luxembourg : European Commission.

Fell, R., Ho, K. K. S., Lacasse, S. & Leroi, E. 2005. A framework for landslide risk assessment and management. In Landslide Risk Management, Proceedings of International Conference Vancouver, 2005. Balkema.

Geomorphological Services Limited. 1987. Review of research into landsliding in Great Britain. Series E, National Summary and Recommendations. DoE.

Gillarduzzi, A., Clark, A. R., Fort, D. S. & Houghton, J. E. M. 2007. 'Monitoring coastal slope instability within the western Undercliff landslide, Isle of Wight, UK'. Proc. Int. Conf. on 'Landslides and climate change - Challenges and solutions'. Ventnor, May 2007. Taylor & Francis.

Halcrow Group Limited. 2006. Coastal instability risk, Ventnor, Isle of Wight: Interpretative report and Quantitative Risk Assessment. Report for Isle of Wight Council.

Hutchinson, J. N. & Bromhead, E. W. 2006. 'Isle of Wight landslides'. Keynote address to Int. Conf. on 'Instability - Planning and management'. Ventnor, May 2002. Eds: McInnes, R. G. & Jakeways, J. Balkema.

Ibsen, M-L. & Brunsden, D. 1994. Mass movements and climate variation on the south coast of Great Britain. Report for the EU Epoch Programme.

Jones, D. K. C. & Lee, E. M., 1994. Landsliding in Great Britain. London: HMSO.

Lee, E. M. Landslide hazard in Great Britain. Geoscientist Vol. 5, No. 4.

Lee, E. M. 1995. Coastal Planning and Management: A review of Earth Science information needs. London: HMSO.

Lee, E. M. 1997. Landslide risk management: key issues from a British perspective. 227-237, in Landslide Risk Assessment. Cruden and Fell (eds). Balkema, Rotterdam.

Lee, E. M. & McInnes, R. G. 2000. Landslide hazard mapping for planning and management: the Isle of Wight Undercliff, UK, in Living with Natural Hazards, Proceedings of the CALAR Conference, Vienna.

Lee, E. M. & Moore, R. 2007. 'Ventnor Undercliff: Development of landslide scenarios and quantitative risk assessment'. Proc. Int. Conf. 'Landslides and climate change -

Challenges and solutions'. Ventnor, May 2007. Taylor & Francis.

Lee, E. M., Moore, R. & McInnes, R. G. 1998. Assessment of the probability of landslide reactivation: Isle of Wight Undercliff, UK. 8th International IAEG Congress, Vancouver. Balkema, Rotterdam. Vol. 2, 1315-1321.

Leroi, E., Bonnard, Ch., Fell, R. & McInnes, R. G. 2005. Risk assessment and management. In Landslide Risk Management. Proc. Int. Conf. Vancouver, 2005. Balkema.

Marker, B. & McInnes, R. G. 2006. Guidelines on landslides - communicating results. Workshop on Landslide Susceptibility, hazard and zoning. Barcelona.

McInnes, R. G. 1996. A review of coastal landslide management on the Isle of Wight, UK. In Landslides - Glissements de Terrain, Proceedings of the 7th International Symposium on Landslides, Trondheim. Balkema, Rotterdam. Vol. 1, 301-307.

McInnes, R. G. 2000. Managing ground instability in urban areas - A guide to best practice. Newport, Isle of Wight: Isle of Wight Centre for the Coastal Environment.

McInnes, R. G. & Jakeways, J. 1999. LIFE project: Coastal change, climate and instability- an information leaflet. Isle of Wight Council, Newport, Isle of Wight.

McInnes, R. G. & Jakeways, J. 2000. Coastal change, climate and instability. EU LIFE Environment project for the European Commission, Ventnor.

McInnes, R. G, & Jakeways, J. 2000. The development of guidance and best practice for urban instability management in coastal and mountainous areas of the European Union. In 'Landslides: Research, theory and practice'. Thomas Telford.

McInnes, R. G, & Jakeways, J. (Ed) 2002. Instability - planning and management: International Conference Proceedings, Ventnor, Isle of Wight, May 2002. London, Thomas Telford.

McInnes, R.G., Jakeways, J. & Fairbank, H. 2006. EU LIFE 'Response' project Final Report for European Commission, Ventnor, Isle of Wight.

Moore, R. & Lee, E. M. 1991. Ventnor Information Centre - Getting the message across, ground movement and public perception. Report for South Wight Borough Council, Ventnor, UK.

Moore, R., Lee, E. M. & Brunsden, D. 2000. Cowes ground stability study. Report by Halcrow for Isle of Wight Council.

Moore, R., Lee, E. M. & Clark, A. R. 1995. The Undercliff of the Isle of Wight - A review of ground behaviour. Report by Rendel Geotechnics for South Wight Borough Council, Ventnor, Isle of Wight.

Moore, R., Carey, J. M., McInnes, R. G. and Houghton, J. E. M. 2007. 'Climate change, so what? Implications for ground movement and landslide event frequency in the Ventnor Undercliff, Isle of Wight'. Proc. Int. Conf. on 'Landslides and climate change - Challenges and solutions'. May 2007, Ventnor. Taylor & Francis.

Moore, R., Turner, M. D., Palmer, M. J. & Carey, J. M. 2007. 'The Ventnor Undercliff: landslide model, mechanisms and causes, and the implications of climate change induced ground behaviour and risk'. Proc. Int. Conf. on 'Landslides and climate change - Challenges and solutions'. May 2007, Ventnor. Taylor & Francis.

Palmer, M. J., Moore, R. and McInnes, R. G. 2007. ''Reactivation of an ancient landslip, Bonchurch, Isle of Wight: Event history, mechanisms, causes, climate change and landslip potential'. May 2007, Ventnor. Int. Conf. on 'Landslides and climate change - Challenges and solutions'. Taylor & Francis.

Thompson, A., Hine, P. D., Poole, J. S. & Greig, J. R. 1998. Environmental geology in land use planning. Report by Symonds Travers Morgan for the Department of the Environment, Transport and the Regions, UK.