Guernsey Coastal Defences

Flood Risk Assessment Studies

Volume I - Report

States of Guernsey

March 2012

Final Report

9W2890

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Document title	Guernsey Coastal Defences Flood Risk Assessment Studies
Document short title	
Status	Final Report
Date	March 2012
Project name	Guernsey Coastal Defences – Flood Risk Assessment Studies
Project number	9W2890
Client	States of Guernsey
Reference	9W2890/R/303666/Exet

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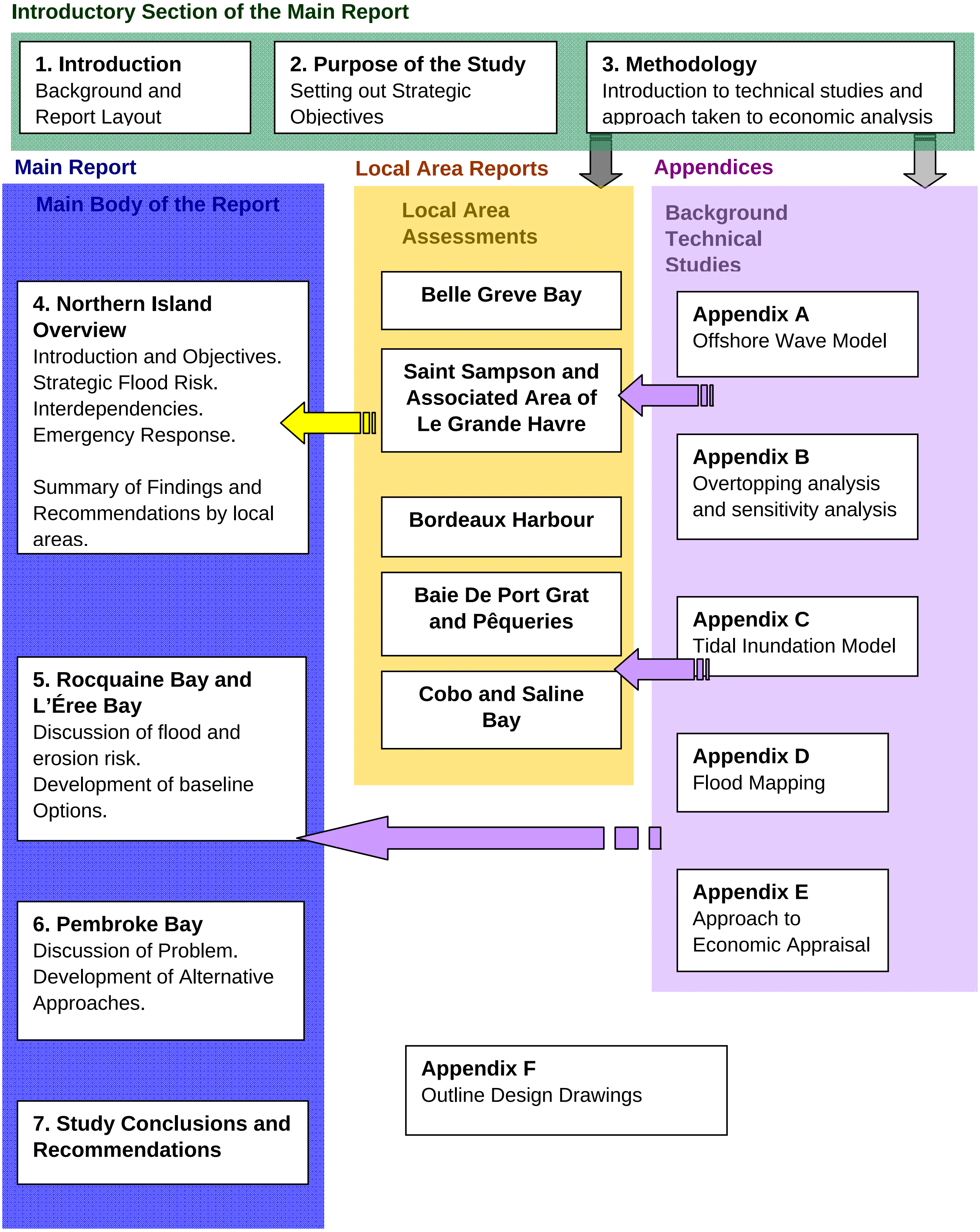
OVERALL REPORT STRUCTURE



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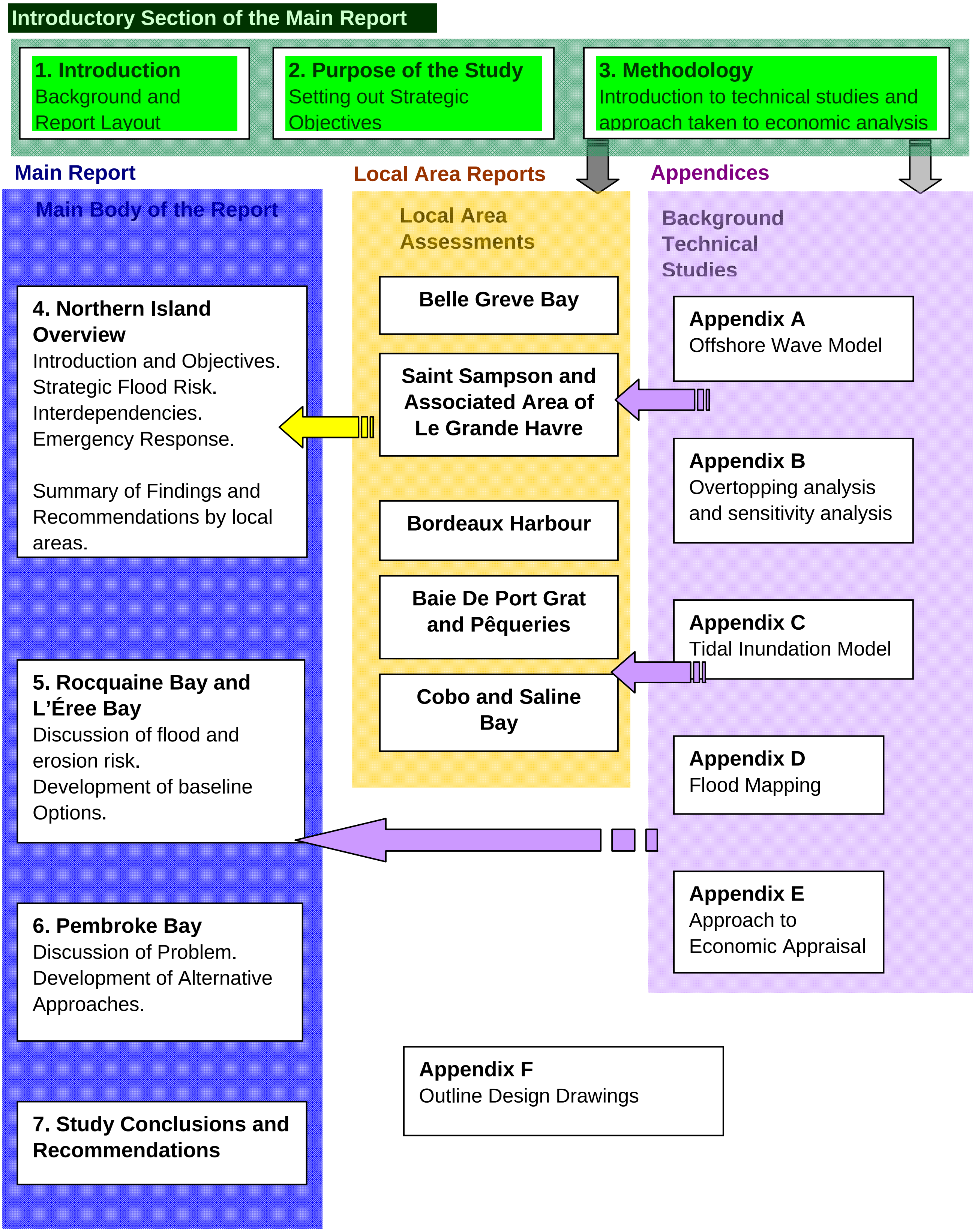


1 INTRODUCTION

1.1 Background

Guernsey is a member of a group of islands known as the Channel Islands, located in the English Channel approximately 45km from the coast of Normandy, France (see Figure 1). Politically Guernsey forms part of the British Isles (as a dependency of the British crown), although physically it is not part of the geological archipelago. Guernsey has an area of roughly 58km^2 and a population of around 60,000.

The topography of Guernsey, shown as an insert to Figure 1, varies considerably. There are a number of lower areas, mostly in the north-east part of the island, which are vulnerable to flooding during present day extreme high tides. This vulnerability will increase with anticipated sea level rise. As a result there is both an existing, and an increased future flood risk to coastal communities.

The majority of Guernsey's coast is densely populated. Residential properties, recreational development and significant industrial sites occupy much of the coastal zone. The entire coastline is exceptionally important for recreation, amenity and for its historic landscape and ecology. Of particular ecological importance is the Lihou Island & L`Eree Headland Ramsar site, as designated in 2006, located on the south-west part of the Island, which contains a variety of habitats from internationally threatened shingle banks, to marshes, reed beds, saline lagoons, and the intertidal area. The site also has a rich biodiversity of flora and fauna, including a wide variety of seabirds, wildflowers, and marine organisms.

A Strategy Report was produced in 1999 by Posford Duvivier, documenting the proposed management intent over the next 50 years for the coastal defences and beaches around Guernsey and Herm. In addition, this Strategy identified issues which required more urgent attention and identified uncertainties which could only be determined from longer term monitoring.

In 2007, Royal Haskoning (formerly Posford Duvivier) provided an update to the Strategy Report prepared in 1999. This Strategy made use of information obtained as part of the beach monitoring programme, implemented following the 1999 Report, as well as drawing together other more general information such as that on climate change and sea level rise. The Strategy update identified a series of critical issues that needed to be addressed through more detailed study. These studies form the basis of this current report and cover the following specific areas:

- the potential flooding of large sections of the northern part of the island, arising from low defence levels at several sections of the coast;
- at Rocquaine /L'Eree Bay, where there is currently a significant risk of flooding and failure of defences;
- at Pembroke Bay, where there is concern over the long term management of defences and the potential need for realigning the old military defences.

Identifying a more robust and sustainable defence for each of these areas depends largely on establishing a good understanding of the physical coastal behaviour and relative exposure to the hydrodynamic conditions (waves and tides) around the Island.

This forms the basis of the initial section of the report providing a baseline for examining the management issues identified above.

Figure 1. Guernsey - Location Plan (inset General Topography).

1.2 Layout of Report

Introduction and General Background Technical Information.

The purpose of the study is discussed in Section 2 and goes on to present an overview methodology to the respective data collection, numerical modelling and economic assessment (Section 3). This background analysis is presented in more detail in Appendices A, B, C and E.

A simple diagram is included at the front of each main section of the report highlighting how different elements of the study fit together. The aim is to assist in navigation of the documents and to point the reader in the direction of supporting information.

Main Body of the Report

The core body of the report is set out in three sections:

Section 4. Northern Island Overview

This sets out the overview of flood risk to the north part of the island and draws together the key findings and local area discussions in relation to this specific element of the overall study. This includes the principle Coastal Units (CUs) from Cobo Bay to St Peter Port where there is a strategic level of flood risk affecting the Island. Within each local area an assessment is made of wave overtopping and flood risk from direct water levels. Options for management are considered and the interactions between sections of the coastline are highlighted. For each of the local areas, a more detailed and, effectively, stand alone report has been provided. These are grouped and bound in at the end of the Main Body of the Report. These stand alone documents (Local Area Reports) cover:

- Belle Greve Bay
- St Sampson and the associated flood risk from Le Grande Harvre.
- Bordeaux Harbour
- Baie De Port Grat and Pequeries
- Cobo and Saline Bay.

Section 5. Rocquaine Bay

The issues at Rocquaine Bay are slightly different from those associated with the northern section of the island, in that here there are very specific concerns over the integrity of sections of defence. While this section of the report draws upon the technical baseline studies underpinning all work covered by the study, this section looks more specifically at the problems of management along the Rocquaine and L'Eree Bay area. This includes consideration of potential risks to the designated RAMSAR site, to the north. This section builds on the recommendations from the 2007 Strategy providing an outline design, with associated standard of protection, and with associated costs for consideration by the Client.

Section 6. Pembroke Bay

This section focuses primarily on the appraisal of coastal defence options for management of the existing defences within the Bay and the potential to re-create the natural realignment of the Bay. A broader review of the anticipated flood risk from elevated water levels has also been undertaken.

Section 7. Study Conclusions and Recommendations
This final section of the report brings together a summary of all the work undertaken throughout the study. The aim of this section is to highlight actions to be taken forward from the work.

The supporting information is contained in the following Appendices:

Appendix A – Development and results of the MIKE21 Offshore Wave Model
Appendix B – Development and results of the AMAZON Overtopping Model
Appendix C – Development and results of the TUFLOW Tidal Inundation Model
Appendix D – Flood Mapping
Appendix E – Economic Appraisal
Appendix F – Outline Design Drawings

Information developed from the studies have also been produced as GIS layers for further use more generally in coastal management around the Island.

2 PURPOSE OF STUDY

2.1 Introduction

This study highlights the importance of appropriate coastal management decision making for the States of Guernsey. The Island is heavily reliant on its shoreline for tourism and marine-based industries as well as being home to many coastal towns and villages. The importance of the internationally designated ecology that the coastline supports is also given primary consideration. This study has identified where future expenditure on defences should be prioritised for communities at significant risk from future coastal flooding. The aim of this is to assist in creating a sustainable future for coastal and coastal risk management for the States of Guernsey and to address the risks associated with climate change and the predictions for sea level rise and potential increasing in the intensity or frequency of storms.

2.2 Strategic Objectives of Study

Guernsey through natural evolution of the shoreline is vulnerable to coastal flooding, erosion and changes to the geomorphology influenced by the low-lying topography and local geology. As a result, as population growth and infrastructure has developed along the Guernsey coastline so has the need for coastal defences. Over time this has led to an extensive and diverse range of coastal defences that can be seen along the majority of the exposed softer coastline.

The study aims to promote management decisions for the coastline into the 22nd century that achieve long-term objectives without commitment to unsustainable defence. In guidance of this are key principles that reflect the aspirations of the States of Guernsey (recognising that some of these are in direct conflict but all are equally important).

- To support an integrated approach to spatial planning, in particular recognising the interrelationships between:
  - Centres of development and surrounding communities;
  - Human activity and the natural and historic environment - in being essential for community identity, wellbeing and vitality and in being highly significant for tourism and economic regeneration.
- To contribute to sustainable communities and development:
  - To maintain and support the main centres of economic activity;
  - To sustain the vitality and support adaptation, resultant from climate change and predicted sea level rise/increased erosion rates, of smaller scale settlements.
- To minimise reliance on coastal defence and increase the resilience of communities where practicable, in particular to highlight where the existing defence approach could lead to areas being particularly vulnerable to extreme storm conditions and high residual risk.
- To maintain or enhance the high quality landscape.
- To support tourism and recreational opportunities.
- To avoid damage to and seek sustainable opportunities to enhance the natural environment in line with natural processes.
- To support the historic environment and cultural heritage where practicable.
- To maintain access to and from the Island.

3 METHODOLOGY

The intention of the study is to provide the States of Guernsey with a broader dataset for future management along the coast, both for the present day scenario and looking forward 100 years. As part of this the methodology objectives include:

- Quantify wave conditions around the Island, accounting for offshore conditions and the bathymetry of the region.
- Quantify extreme water levels around the Island.
- Undertake numerical modelling to inform floodplain mapping and options.
- Quantify damages and options through the economic assessment.

3.1 Data Collection and Baseline Analysis

3.1.1 Topographic Data and Defence Levels

Topographic data was obtained from Digimap and utilised to inform the base flood mapping of Guernsey. As part of this, the information available on watercourses and other possible flood routes or barriers was examined in parallel to inform the hinterland features assessment. Where the current data was felt to be too sparse (typically along the coastal defence structures), additional level data was collated by a Royal Haskoning survey team in December 2010, and used for the respective model development and outline design options. In addition, beach level monitoring data provided by the States of Guernsey to inform topographic beach levels was used as part of the AMAZON overtopping model development.

3.1.2 Extreme Water Levels

Extreme water levels were estimated using tide level data taken from gauging located within the harbour of St Peter Port. A thirteen year tide level time series was assembled from the various records and then analysed to identify the highest levels reached. Statistical analysis was then used to extrapolate rarer extreme water levels not seen in the original record. The range of return periods of the estimated events was from 1:1 year to 1:250 years. The larger return periods explored included values far longer than the tide record on which their estimation was based. This is far from ideal, but not uncommon in extreme water level estimation. The geographic isolation of the island also reduces the scope for cross-comparison with neighbouring sites. A comparison was possible with conditions along the coast of France, where more data exists. This showed a reasonably good comparison in water level differentials.

High tidal flow velocities are experienced around Guernsey, and these are associated with noticeable gradients in water level. This means that tide levels at different locations around the island differ from those observed at St Peter Port. To derive extreme water levels for the whole island, a computational hydrodynamic model was run to simulate tidal and tidal surge flows (see Appendix A). The resulting patterns of high waters were then used to extrapolate the St Peter Port statistics to the whole coast.

High water levels, both tidal and extreme water levels, used in assessing flood risk are shown in the following table (Table 3.1). This is set out covering three general sections of the coast: the East Coast, from St Peter Port to Fontenelle Bay, the Northwest Coast, from Fontenelle Bay to Cobo Bay, and Rocquaine Bay. Further details are provided in Appendix A.

Table 3.1. Water Levels around Guernsey.

Water Levels (m Local Datum Guernsey) Extreme water levels, a combination of normal tidal levels plus surge, are determined from a statistical analysis of highest water levels recorded at St Peter Port (SPP).		**Coastal Area/ Water Level Zone**		
		East (SPP)	**Northwest**	**Rocquaine Bay**
Tidal	Mean Low Water Springs	-3.46	-3.09	-3.30
	Mean High Water Springs	4.24	3.87	4.08
Extremes	1:1	5.22	4.72	5.00
	1:10	5.56	5.04	5.32
Return Period Yrs.	1:50	5.77	5.26	5.54
	1:100	5.87	5.37	5.65
	1:250	5.99	5.49	5.77

Note 1: Chart datum correction for St Peter Port. -5.06m

Note 2: The water surface slope is quite steep at Rocquaine Bay and is not expected to extend beyond the Bay..

Note 3. The water surface slope around the north eastern extent of the island (between St Peter Port and Fontenelle Bay) is quite steep and varies according to specific surge conditions.

The zones and variation in levels in Table 3.1 are shown in Figure 3.1

3.1.3 Sea Level Rise

As discussed in Appendix A, relative sea level is increasing at Guernsey, and this is expected to increase further due to climate change. The magnitude of these changes has been examined by the United Kingdom Climate Impacts Programme (UKCIP), within which different scenarios are considered (Low, Medium and High), defining the range of possible impact. There remains significant uncertainty associated with prediction of some absolute value of resultant sea level rise in any year but in assessing the future flood risk for this study, estimates have been taken based on the High Scenario. Sea level rise has therefore been taken as set out in Table 3.2, defined by epochs, with a nominal year given for the end of each epoch.

Table 3.2. Relative Sea Level Rise (m).

	Epoch 1 (2031)	Epoch 2 (2061)	Epoch 3 (2111)
Relative Sea Level Rise (m)	0.13	0.38	0.9

Note: UKCP09 rates (based on 1990) have been updated to a 2011 base date in the table.

This is in line with practice guidance set by Defra for the UK when assessing strategic flood risk. While this provides a slightly conservative approach in terms of time scale, it highlights the trend of sea level rise. Under a lower scenario, these levels would not be reached until some later date.

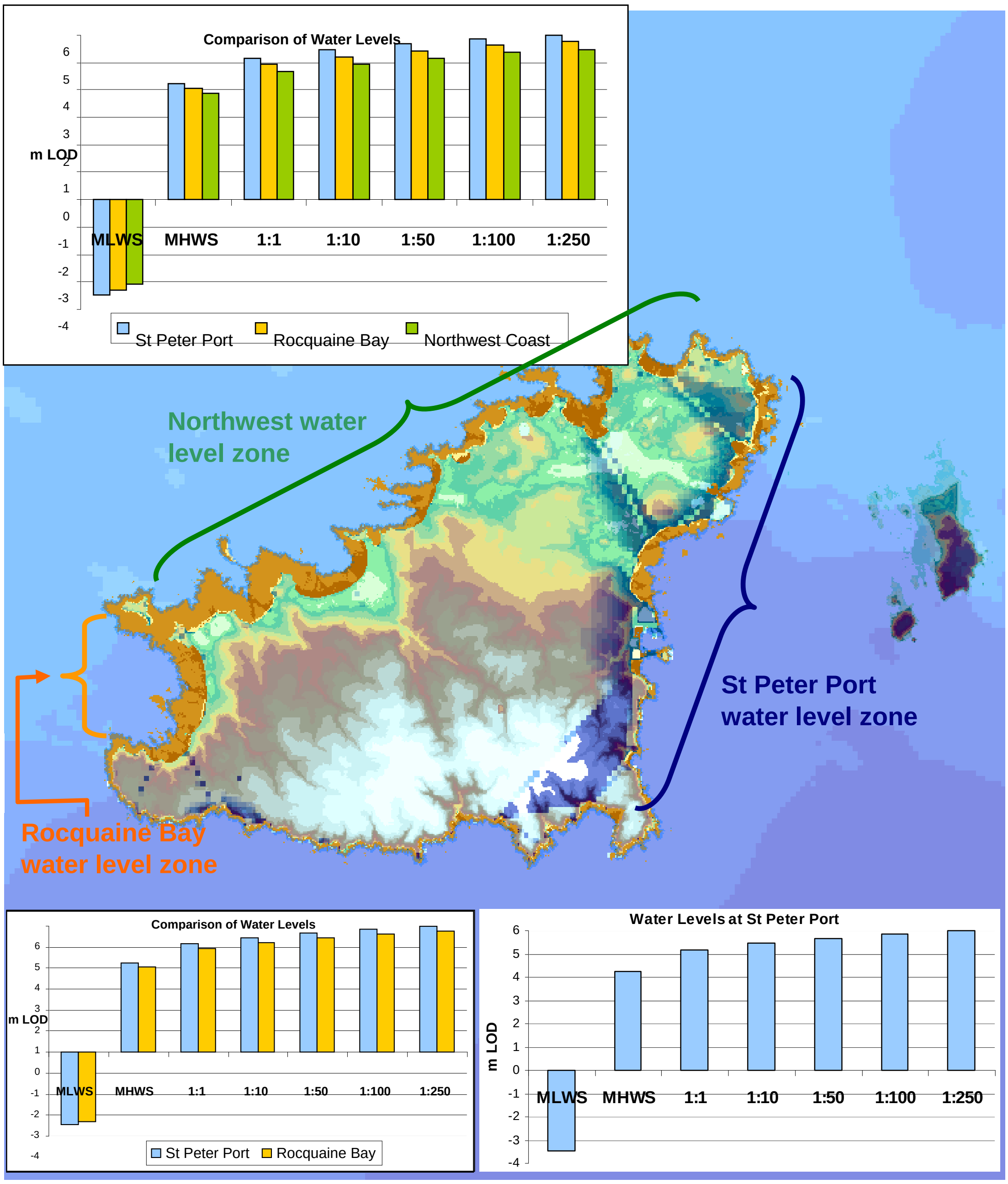


Figure 3.1. Variation in Water Level around Guernsey showing zones used in study.

The 2007 Strategy split the coast in to sections defined as Coastal Units (CUs) and within this into Defence Units (DUs). These are defined in detail later in the report. The water level zones where applied to specific units as discussed later.

3.2 Wave climate

Guernsey is exposed to waves from all directions. The conditions include wind waves generated locally arriving from the directions of the coasts of France and England, and swell propagating down the English Channel and diffracting around the Cherbourg Peninsula, as well as swell arriving from the north Atlantic. The dominant wave climate and the most severe conditions originates to the west, arriving either as north Atlantic long period swell, or as shorter period wind-waves, generated more locally by south-westerly storms.

Typical offshore wave roses for swell and locally generated waves are shown in Figure 3.2.

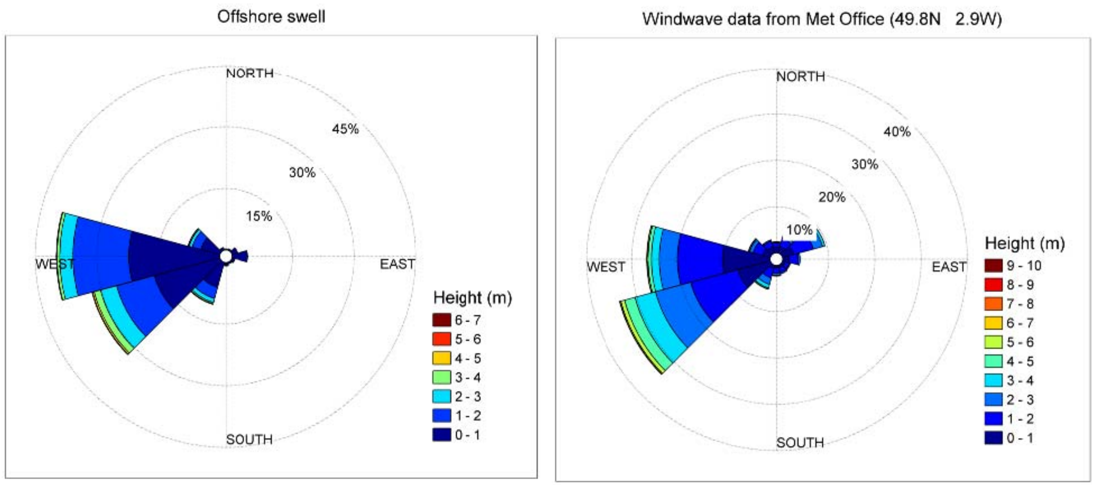


Figure 3.2. Typical Offshore wave climate.

To understand the characteristics of the waves at the shoreline, it is necessary to account for physical processes that transform the waves, such as shoaling, refraction and diffraction. These are controlled by the form of the seabed, depth of water, presence of sheltering headlands and offshore features and the geometry and aspect of the coast itself. The most efficient and accurate way of quantifying these processes (in the absence of measured data taken from a network of offshore wave buoys and nearshore wave recording devices) is to use a numerical model, and in this study MIKE21 SW was used to build one (Appendix A). MIKE21 is an industry standard package, developed by the Danish Hydraulics institute.

3.2.1 Model setup

The MIKE21 model construction involved setting up a calculation grid over a digitised model of the seabed topography. For the Guernsey model this grid extended to the coast of France, and around 100km to the west and 60km to the north (see Figure 3.3). Offshore conditions of waves and winds can then be input to the model at its seaward boundaries, and the model performs the very large number of calculations necessary to simulate transformation across its domain.

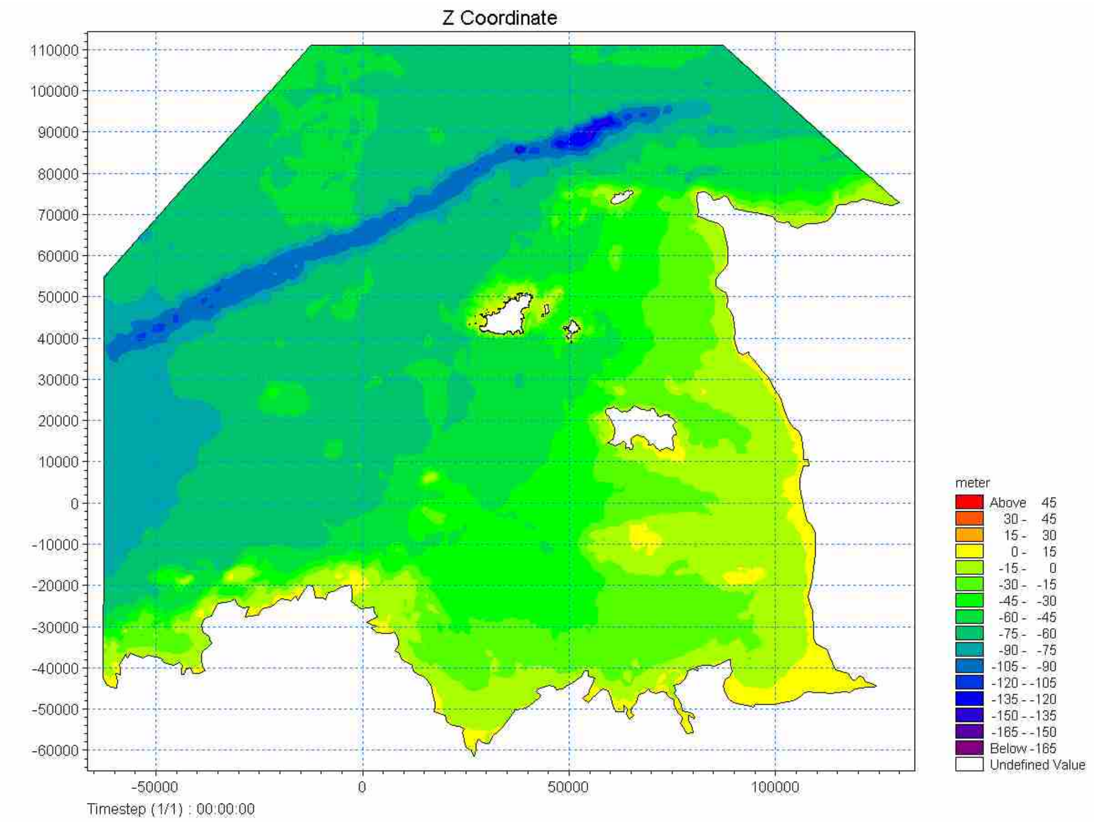


Figure 3.3. Spatial extent of the Guernsey wave model.

The model bathymetry was assembled using the C-Map database. This was supplemented with land-survey data of the shore, which was provided by Digimap.

3.2.2 Run scenarios

The model was used to simulate extreme conditions of combined high water and large waves, from all directions, for a range of return periods (1, 10, 50, 100 and 250 years). An extensive set of simulations were run to identify the water levels and offshore waves that create the most critical conditions at the island's coast. Once identified, these conditions were input to subsequent overtopping simulations, and were also used for wave penetration modelling and to inform the outline design of proposed coastal structures.

All of these simulations represented current conditions. A further set of simulations were run to assess how climate change may affect the coastal flood hazard around the island. In these simulations, the extreme water levels were increased to represent sea level rise and growth in surge levels, using data from the UK Climate Projections (UKCP09).

3.2.3 Generation of inshore wave climates

Simulations were also run for ranges of wave heights and periods, from all directions, to generate wave transformation matrices, using the software package SCATTER, which was developed by Delft Hydraulics. The matrices were combined with offshore wave frequency data (obtained from the UK Met Office) to estimate wave climates at more than fifty locations around the island, which are represented with wave rose diagrams (Figure 3.4). The wave roses were used to interpret wave transformation and to assess sediment transport patterns.

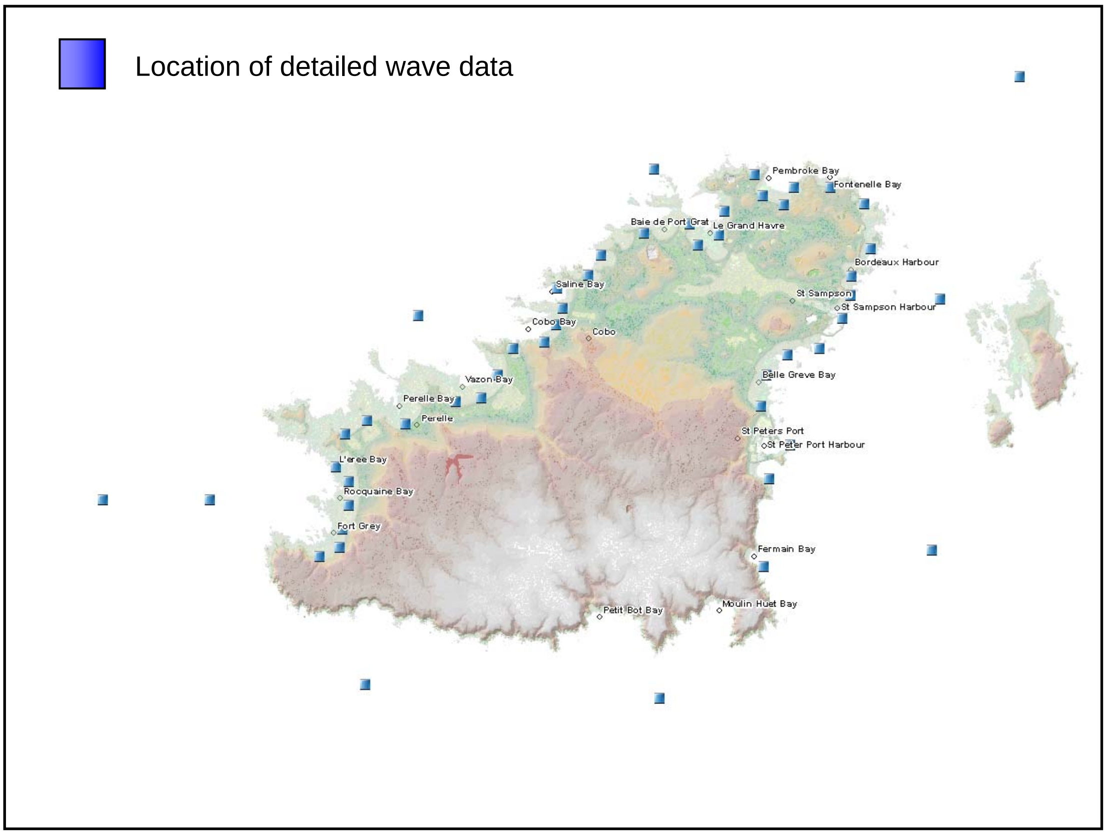


Figure 3.4 Location Plan of detailed wave data.

In addition to the locations specifically required by the proposed studies, wave transformation data was also generated for other areas to create a resource for use by the States of Guernsey to inform subsequent coastal monitoring and management activities.

3.3 Calculation of overtopping rates

Royal Haskoning's in-house modelling software, AMAZON, was used to calculate wave overtopping rates to assess the current situation and future situations for a selection of Defence Units (DU)s. For each DU a representative cross section of the defence was defined, with the rates of overtopping based on wave height, wave period and water level determined for a number of scenarios, return periods and future changes due to climate change. The rates of overtopping were calculated for the 1:1 year, 1:10 year, 1:50 year, 1:100 year and 1:250 year conditions (Appendix B). A review of the overtopping rates gave an initial indication of which locations experienced the highest rates and this knowledge assisted in focusing the work following the modelling.

More detail on the AMAZON overtopping modelling can be found in Appendix B. Further information with respect to previous flooding and overtopping, reported around the island at key locations was obtained in discussion with the States of Guernsey. The

AMAZON model outputs were reviewed in conjunction with this locally based information. It recognised that determination of wave overtopping can be very sensitive to local conditions, water level and estimated return period of wave height and period. This has been examined in Appendix B. It is concluded that the model result, while potentially overestimating overtopping in some areas, provides a good representation of general conditions, particularly with respect to higher (more severe) return period conditions (1:50 year and greater). Discrimination between lower return periods (1:1 year and 1:10 year) events is more difficult to assess given local factors influencing these overtopping rates. The sensitivity of this has been discussed in Appendix B, in relation to local observations, and has been taken into account and is discussed in terms of recommendations and priority future management options along specific frontages. This is discussed within each Local Area Report.

The AMAZON model has also been used to examine proposed design options to provide a comparative assessment of these options (with respect to reducing the amount of overtopping).

3.4 Flood mapping

Using topographic and land use data provided by Digimap, defence survey data, the overtopping from the AMAZON modelling and the water level data from the MIKE21 model, a 2D hydraulic model was built using TUFLOW, a flood modelling program. TUFLOW assists in determining flood flow paths and depths of flood water in locations where wave overtopping has occurred.

Overtopping rates and tide levels for each DU were applied to the terrain at the appropriate locations to determine the flow paths and depths of flood water for each return period and climate change scenario. These results were reviewed on a strategic level to determine where flooding from a particular area led to (or influenced) flooding of other areas. This is discussed further in Section 4 of the report. The results were also interrogated at a property level to determine a range of flood depths at each affected property, which corresponded to the range of return period conditions modelled.

Further information on the TUFLOW flood modelling can be seen in Appendix C and the resultant flood mapping can be found in Appendix D.

3.5 Economic analysis

3.5.1 Potential Flood Damages

Utilising the modelling outputs and potential flood routes from multiple sources, Royal Haskoning assessed the results and evaluated the flood risk area within the study area as had been agreed as appropriate with the States of Guernsey (Appendix E).

A suitable universal property threshold level of 200mm was applied to the ground levels supplied from Digimap; based on a selection of spot-level property checks during our December 2010 survey. This approach provided values for the calculation of flood damages without the requirement for extensive property surveying, which was beyond the remit of the Study.

The economic assessment was predominately completed using methods contained within the Multi Coloured Manual, 2005 (MCM) and Multi Coloured Handbook, 2010 (MCH) produced by the Flood Hazard Research Centre. The appraisal period was 100 years. The implications of climate change were included in the assessment allowing an assessment of potential damages over the 100 year appraisal period.

The economic assessments required a baseline option for benefits to be calculated against. For this report the baseline was developed using the current 'do existing' situation - continual maintenance of the existing coastal and inland structures. This method allowed the damages associated with the overtopping of the defences to be calculated respective to the current situation.

Structures providing flood defence were assumed to be maintained in a functional condition for the next 100 years. Where the risk of structure failure within 100 years was considered significant/likely, the flood mechanism and site was considered in more detail.

Damages were assessed at a number of different return periods for each site to ensure that damages were calculated close to the threshold of flooding and to improve accuracy. Present values damages (PVd) (the discounted total damages that will occur over the 100 year appraisal period) were capped at the local market values, where appropriate. Local and open market property information for Guernsey was derived using the last four quarter prices (to remove seasonal variation), 2009-2010, provided by the Policy Council. The assessment process focused on the assessment of damages and benefits for the highest value assets (residential and non-residential properties). Recreational and agricultural benefits / damages have been identified but not evaluated.

3.5.2 Cost Estimates

Whole life costs were estimated for the options identified. For appraisals in the UK an allowance for Optimism Bias is usually applied to the costs, initially at 60% at appraisal stage, reducing as the designs are developed and finalised. A similar approach was taken in assessing potential management options, allowing for uncertainty.

The discount rate (the annual percentage rate at which the present value of a future pound is assumed to fall away through time) was as set out in the HM Treasury Green Book (the Green Book sets out the core principles for all economic assessment in the public sector for the UK). The discount rates are as follows:

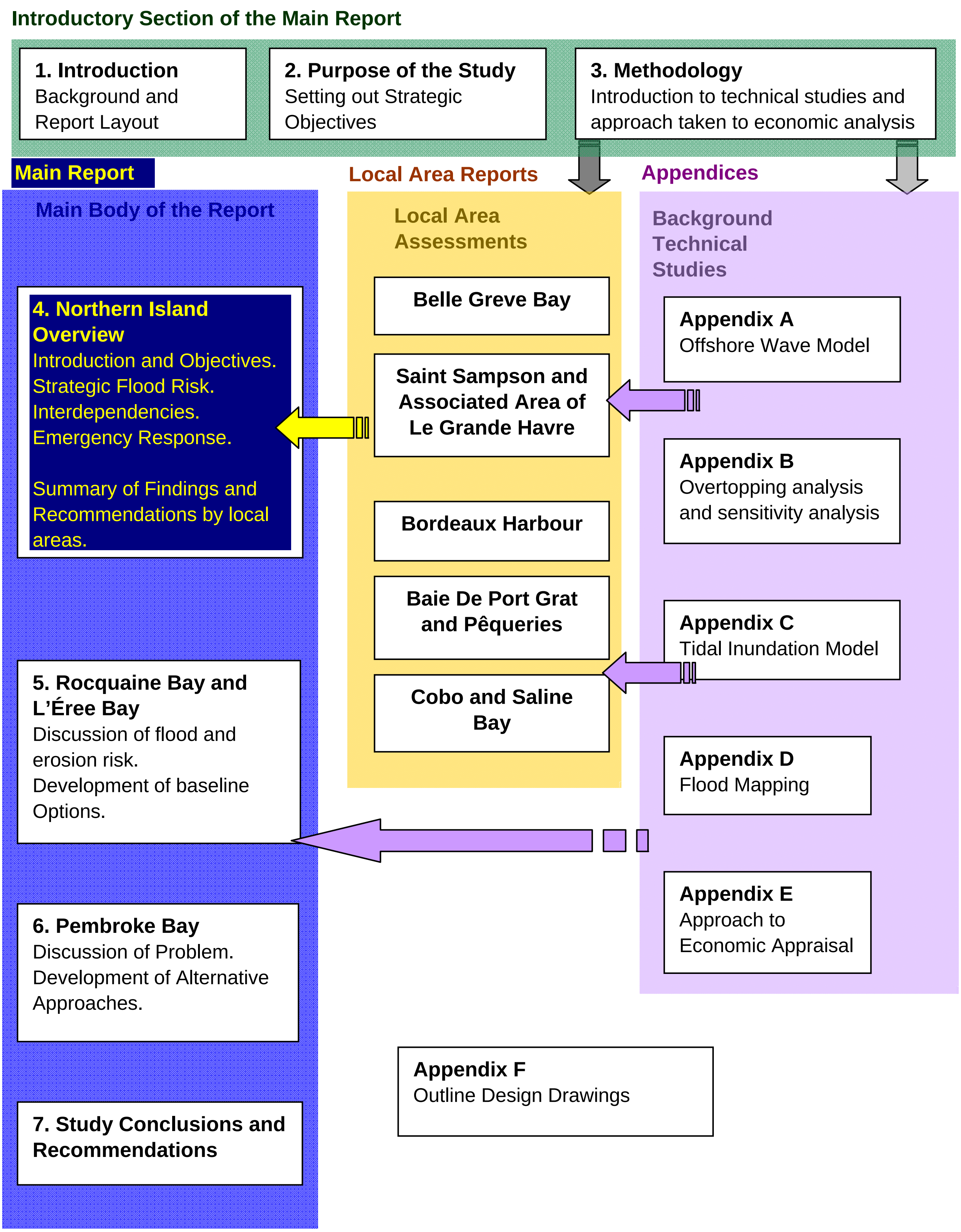
0 - 30 years	3.5%
31-75 years	3.0%
76-125 years	2.5%

Royal Haskoning also undertook a sensitivity analysis and robustness test to determine whether, within the reasonable bounds of confidence that:

- the project is economically worthwhile (benefits outweigh the costs);
- the option choice is robust (where the option choice would not change to another option under reasonable changes to the assumptions made during the appraisal).

The baseline cost of engineering work has been developed using the UK Environment Agency's Flood Risk Management Estimating Guide (update 2010) and previous Royal Haskoning design experience from similar projects. These baseline estimates have then had an uplift multiplier applied to reflect costs appropriate to Guernsey. This uplift makes provision for increased local rates for materials and labour on Guernsey, where considered applicable. A breakdown of costs for all options is provided in Appendix E, including unit rates, and volume calculations for the design options.

OVERALL REPORT STRUCTURE



4 NORTHERN ISLAND OVERVIEW

4.1 Introduction

The northern island study area includes the Guernsey coastline from Cobo Bay in the west to Belle Greve Bay on the east; Coastal Units (CUs) 10 through 19. An initial estimate of potential flood risk was based on the 6m contour as part of the work undertaken by 2007 Royal Haskoning Strategy (2007 Strategy) and is shown in Figure 4.1.

Using this high level assessment, large sections of the Island had been shown to be at flood risk and potentially linked to common defence issues at CUs 10, 11, 12, 17, 18 and 19.

4.2 Northern Island Objectives

The 2007 Strategy identified the need for the flood risk to be considered in more detail, clarifying the actual risk to areas of the hinterland so that:

- Priorities for defence management and guidance for development policy may be approached with more confidence.
- Areas of common risk may be distinguished from areas of local risk.
- The actual probability of flooding or overtopping risk may be better assessed for specific areas, providing guidance for land use planning.

This study, therefore, further develops upon the 2007 Strategy and provides a detailed assessment of potential flood pathways on the northern part of Guernsey. The initial stage of this element of the study has been in considering the high level risk of flooding, either directly, in terms of water levels, or indirectly as a consequence of wave overtopping occurring on extreme water levels, with the focus on identifying the degree to which different areas are interconnected. This then allows subsequent discussion of specific area management covered by the Local Area Reports (LARs) presented as an annex to the main report. The key findings from each area are summarised in sections 4.5 below.

Particular consideration has been given in identifying the potential links between flooding at Cobo Bay and Le Grande Havre, in association with flood risk from the eastern side of the island from Belle Greve Bay through to Saint Sampson. This was the main strategic concern in relation to the northern part of the island, highlighted by the previous strategy.

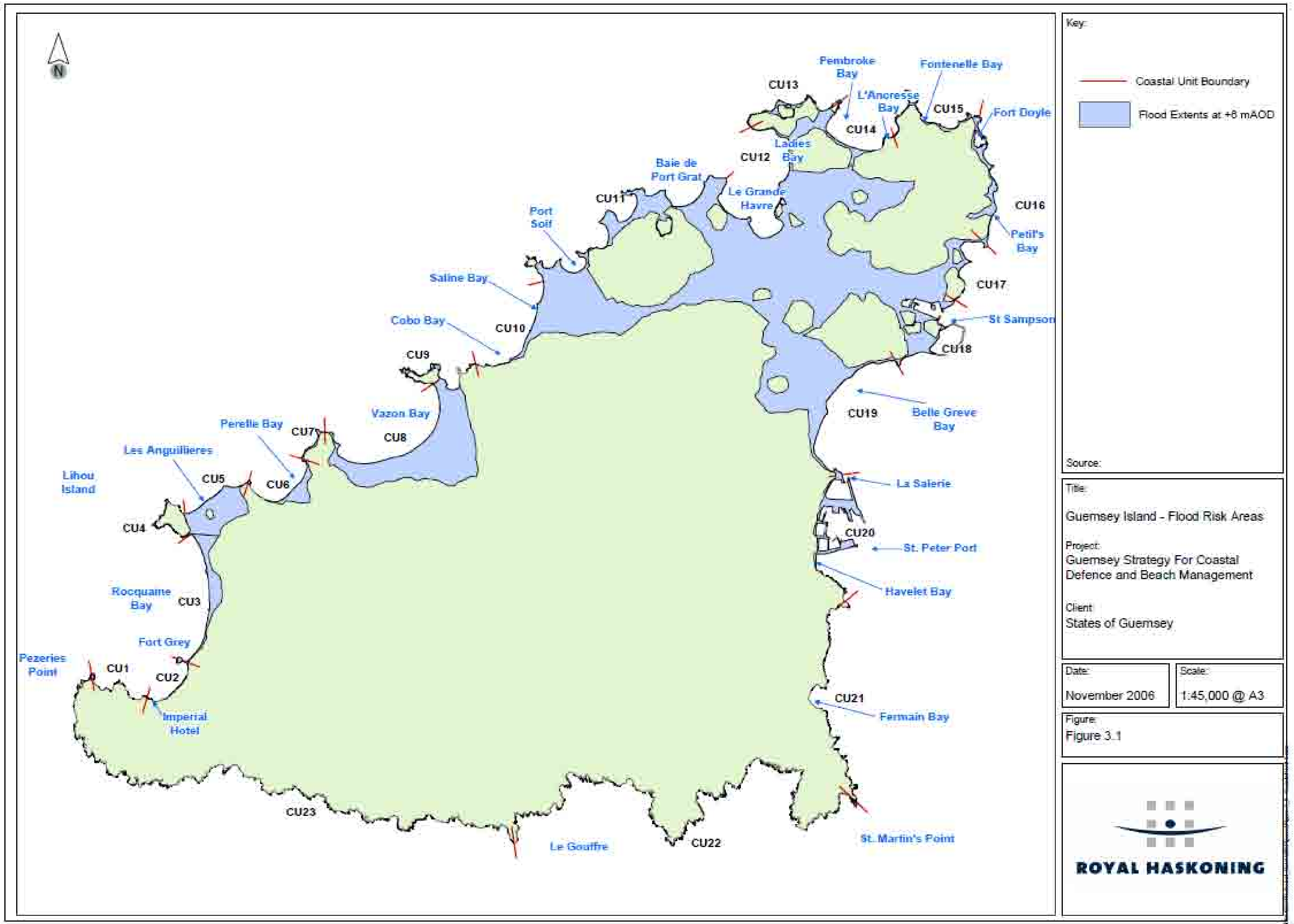


Figure 4.1. Initial Assessment of Flood Risk (based on 6m contour) as taken from 2007 Strategy

4.3 Present Day Flood Risk to the Northern Section of the Island

4.3.1 General Description of Potential Flood Risk Areas

The topography rises to the south across the whole width of the Island between the area directly south of Cobo Bay, through to the higher ground to the north of St Peter Port (figure 4.2)

There is a ridge of high ground to the back of the main flood risk area behind Cobo Bay and a further ridge of high ground to the back of the potential flood zone associated with Belle Greve Bay.

The main area of low lying land lies as a broad valley behind Saint Sampson, with potential flood routes through to the back of Le Grand Havre, Baie de Port Grat and Pequeries on the western side of the Island. To the north of this valley, there is a potential link through to Bordeaux Harbour, with a larger area around Les Closios of low lying land linking in to the main low lying valley.

Existing defences limit overtopping and the period of time when there are flows into the main flood plains during the tidal cycle. As such the extent of flooding may be limited as water spreads out across each basin.

There is also seen to be significant differences in terms of wave heights and their occurrence with extreme water level around the northern part of the Island. On the west and northwest coast, the shoreline defences are subject to higher wave conditions and more significant swell periods. With the exception of the short low defence section at Le Grand Havre at Rousse, defences tend to be above the level of extreme water levels and hence it is the wave overtopping that drives and impacts the risk of flooding.

On the east coast, defences tend to be lower reflecting the lower wave heights. However there are areas, particularly at Saint Sampson Harbour, where defences or the land immediately behind defence are below extreme water level resulting in the potential for large scale flooding once the defence is overwhelmed.

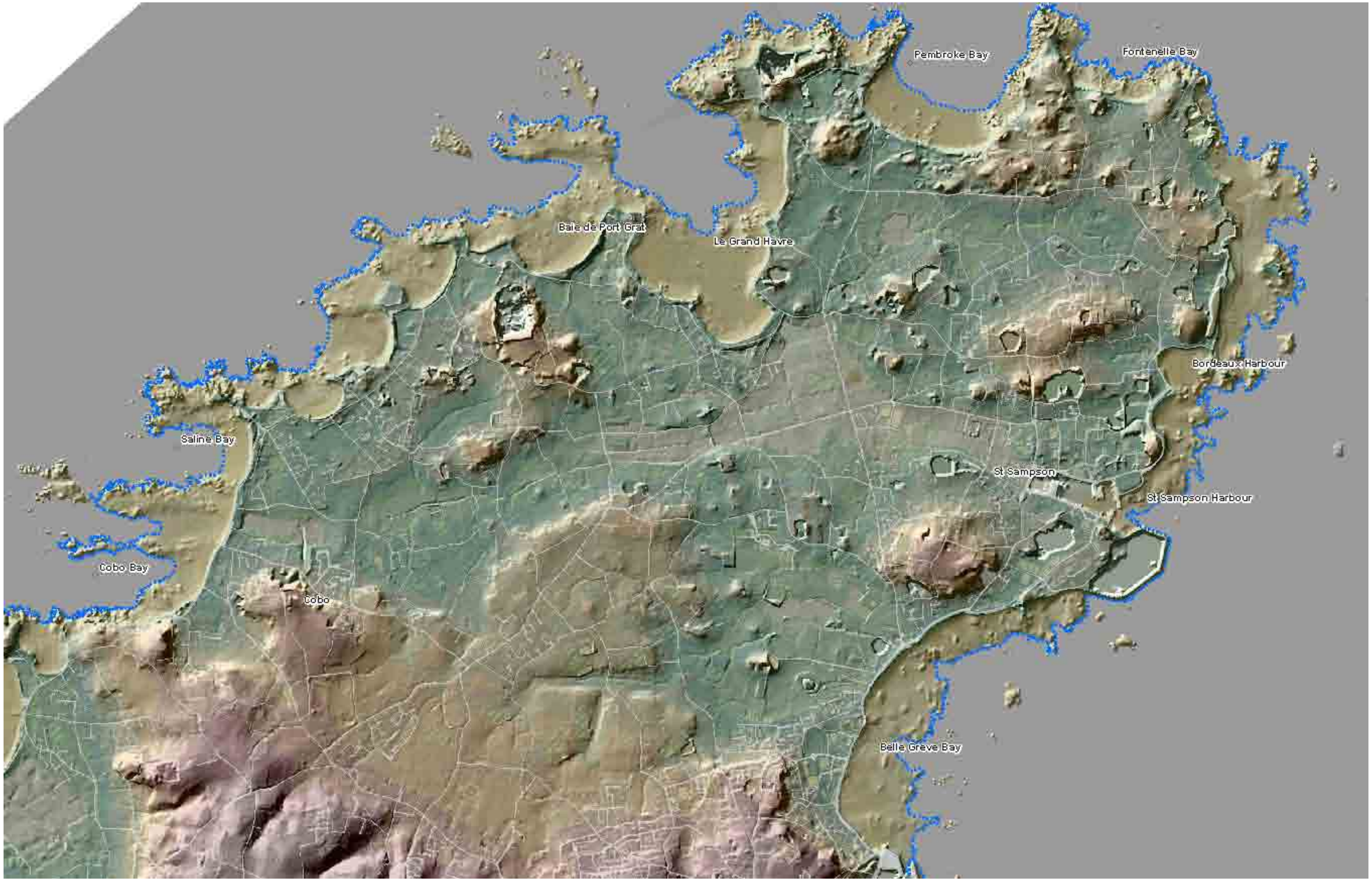


Figure 4.2. Topography of the Northern Section of the Island

4.3.2 Overview of Flood Risk

Several different wave and water level conditions (scenarios) have been examined in assessing possible flood risk. These are discussed in Appendix B. This reflects the difference in conditions occurring on the exposed western side of the island compared to that occurring on the more sheltered east coast. On the west coast, it was necessary to look at different wave directions as well as considering longer period swell and shorter period wind generated waves. From this analysis two principal scenarios for flooding were ultimately considered. This is discussed in Appendix B.

In the first case, flooding has been considered occurring under different water level return periods and the relevant wave conditions impacting on the east coast; in effect considering the worse conditions impacting on the east coast but excluding the high wave energy affecting the west coast. This is described as Scenario 3 in Appendix B. The general flood risk determined under this scenario is shown in Figures 4.3 (a) to (b) for present day conditions. Flood risk mapping is shown in greater detail in Appendix D. Little flooding occurs on the west coast due to these conditions.

The second case considers flood risk occurring due to different water level return periods and wave conditions impacting on the west coast. This is described as Scenario 2 in Appendix B. The general flood risk areas are shown in Figures 4.4 (a) and (b). Flood risk is identified as occurring both along the west coast, principally due to wave overtopping, and as a result of wave overtopping and direct water level flooding particularly at St Sampson on the east coast.

Both cases assume that existing defences are maintained at their present level.

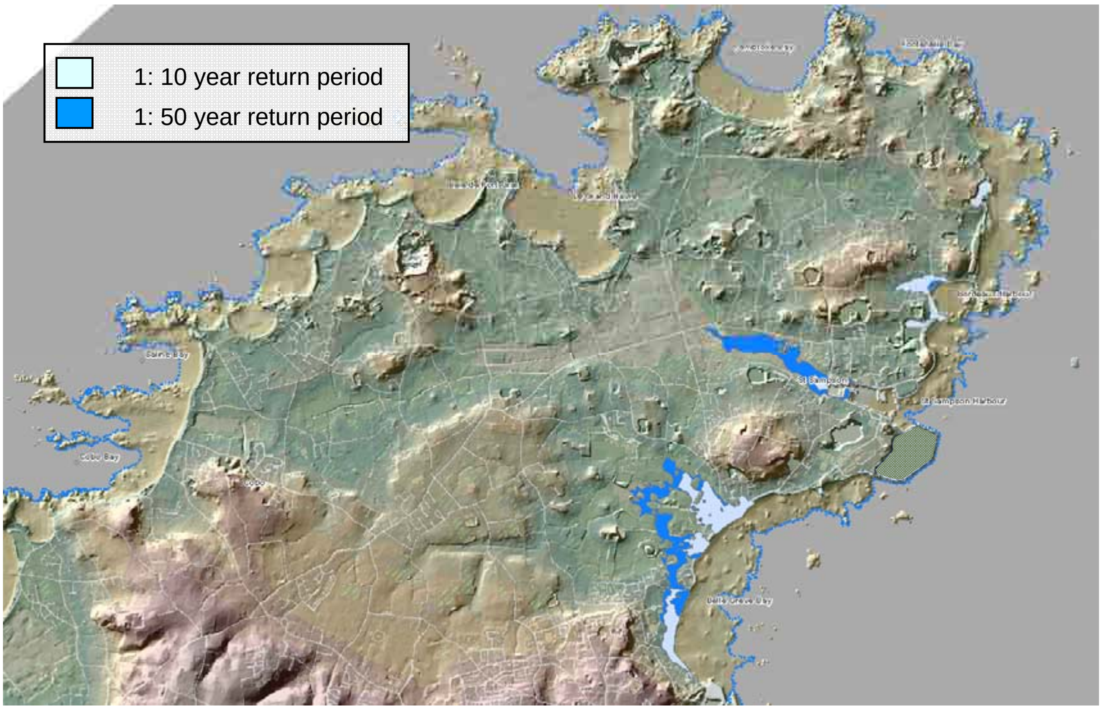
The modelling results have been reviewed in relation to local reports of historic flooding and this is discussed in detail with respect to specific sections of the coast. It is identified that locally, existing defence levels are typically very sensitive to water levels around the 1:10 year conditions and that, for this return period, the overtopping analysis may slightly overestimate the flood risk, taking account of local observation of historic flooding.

Summarising results under the two different scenarios:

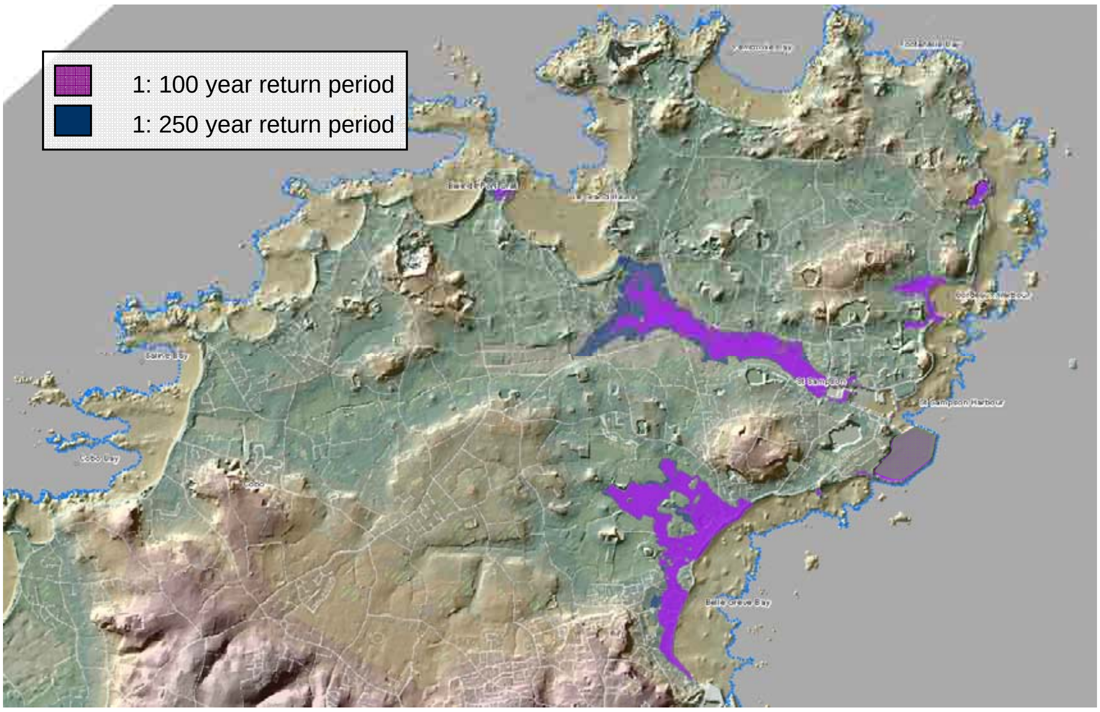
Scenario 3 (worst case for East Coast - Figure 4.3)
Under a 1:10 year condition the analysis highlights the potential for flooding to occur at two independent areas within Belle Greve Bay. More localised flooding occurs at Saint Sampson and at Bordeaux Harbour. Under more extreme conditions the two areas to the rear of Belle Greve Bay combine as one flood area. Flooding becomes progressively more severe within the valley behind Saint Sampson Harbour, with the flood extent extending to the low lying area behind Le Grand Havre on both the 1:100 year and 1:250 year conditions.

The area affected behind Bordeaux Harbour does not significantly grow in size with more severe conditions but the depth of flooding becomes significantly worse.

Figures 4.3 (a) and (b). Flood Risk – Scenario 3, extreme water levels and waves impacting on the East Coast.

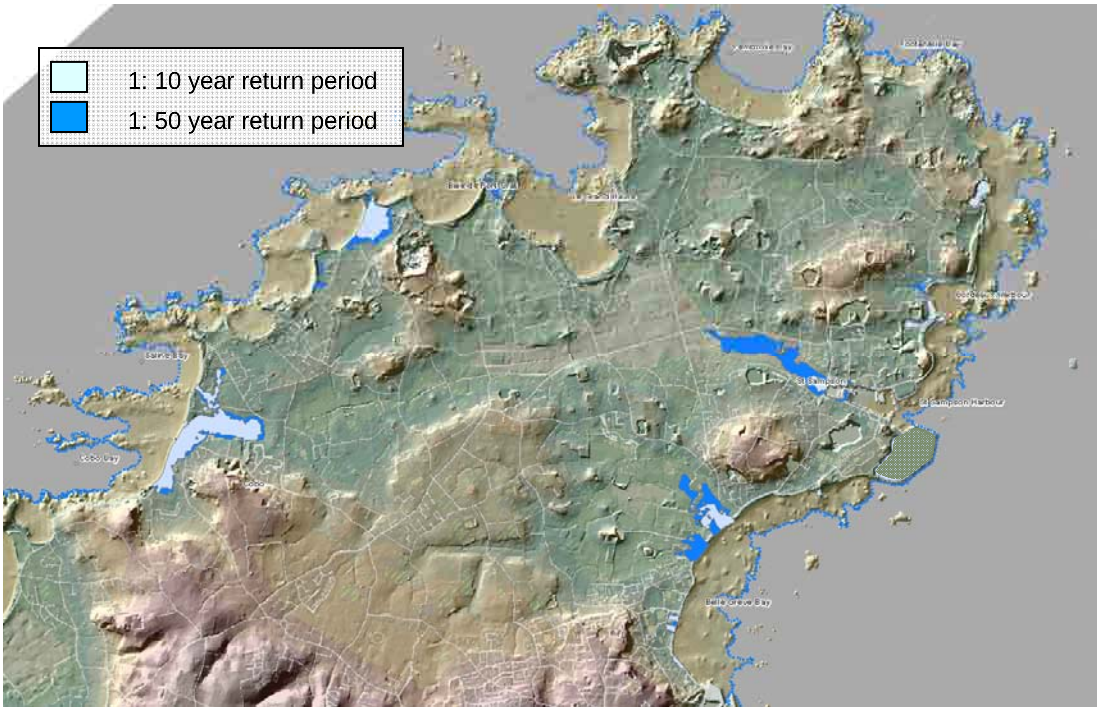


a) Flood risk areas with existing defences for 1:10 and 1:50 year return period.

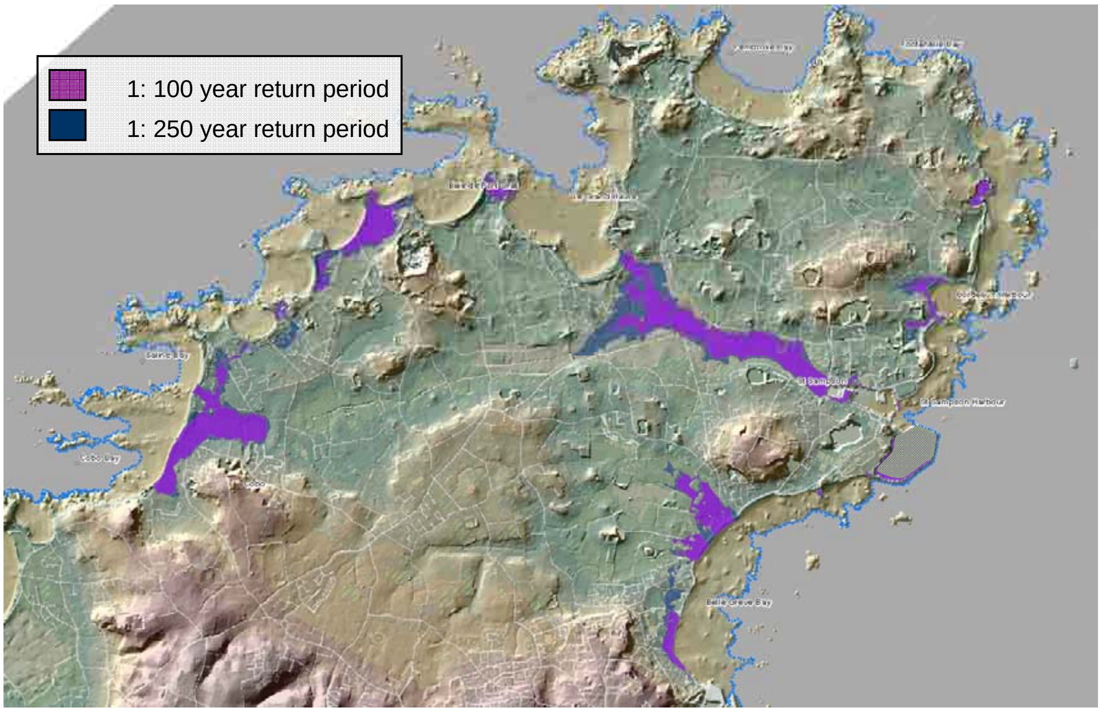


b) Flood risk areas with existing defences for 1:100 and 1:250 year return period.

Figures 4.4 (a) and (b). Flood Risk – Scenario 2, extreme water levels and waves impacting on the West Coast.



a) Flood risk areas with existing defences for 1:10 and 1:50 year return period.



b) Flood risk areas with existing defences for 1:100 and 1:250 year return period.

Scenario 2 (worst case for West Coast – Figure 4.4)
Flooding is driven primarily by wave overtopping at Cobo Bay and within Le Grand Havre but with some flooding still occurring on the east coast driven by lower wave heights on extreme water levels.

In contrast to conditions based on the worse case for the eastern shoreline, it may be seen that the main areas of flood risk appear at Cobo and Pequeries Bay under the 1:10 year event. These areas suffer greater flooding on higher events but the extent of flooding tends to be constrained by the topography. Under a 1:50 year event, flooding might be expected at Baie de Port Grat and this becomes progressively worse on higher events, principally due to the increased wave conditions. On the east coast, under these westerly storm conditions, there is still the potential for flooding to occur at Saint Sampson (where it is primarily the still water level causing the problem) and at Belle Greve Bay (where relatively low wave conditions coupled with high water levels can cause overtopping).

Under the 1:100 year condition it may be seen from Figure 4.4 (b) that the greatest contribution to flooding to the main valley comes from Saint Sampson but there is also a significant contribution from overtopping of the dune ridge to the SW corner of Le Grand Havre. This link becomes more obvious under the 1:250 year condition.

Overtopping at Bordeaux Harbour is slightly less severe under these conditions (such conditions principally affecting the west coast). However, due to the low level of the walls in this area there is the potential still for significant flooding.

The above assessment does not take account of fluvial flooding. However, it is apparent that in certain areas discharge of water from areas affected by fluvial flooding would be exacerbated under more extreme water levels due to the result of tidal locking.

4.4 Summary of Present Day Strategic Flood Risk

4.4.1 Interdependencies

Figure 4.1 set out the initial assumption in relation to strategic flood risk to the northern part of the Island as identified by the 2007 Strategy, based solely on the 6m (extreme water level) contour. This has been significantly refined by the more detailed modelling, taking account of existing defences and revised water level and wave conditions. There is still substantial risk to residential property and life, as well as the basic infrastructure, in terms of roads, schools and commercial property of the Island. This high level strategic risk is shown quite graphically in Figure 4.5 showing the impact of 1:50, 1:100 and 1:250 year flood risk areas through the main valley to the back of Saint Sampson.

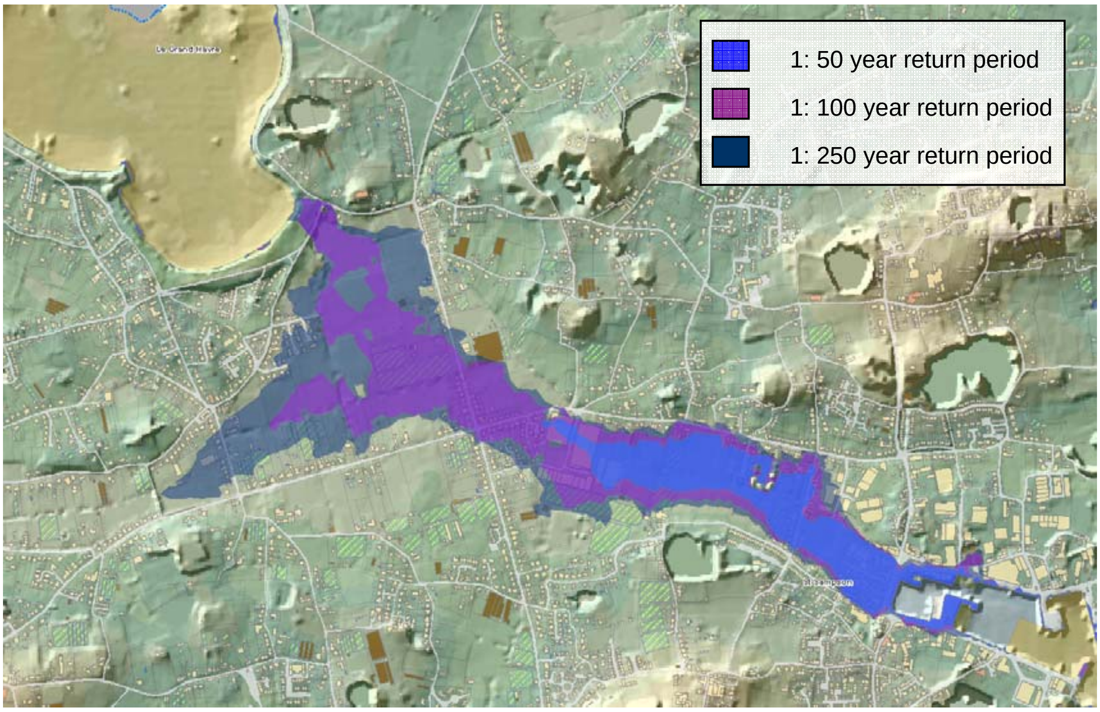


Figure 4.5. Strategic Flood Risk between St Sampson and Le Grande Havre (1:50, 1:100 and 1:250 year return periods).

Under such extreme events, the northern part of the Island would be effectively isolated from the rest of Guernsey for the duration of flooding and, depending on damage to infrastructure, potentially for some time thereafter

In other areas the risk is equally significant affecting local communities, such as at Cobo and Pequeries and at important areas of development, such as to the hinterland of Belle Greve Bay.

The modelling has shown, however, that it is only in terms of the link between Saint Sampson and local sections of defence around Le Grand Havre (present day) and Baie de Port Grat (with sea level rise, discussed below) that the flood risk has a significant connectivity between sources of flooding.

The modelling results show the limit of the risk of flooding from the main valley through to the low lying land around Les Closios and highlight the limit of coastal flooding along the head of the valley towards Cobo.

4.4.2 Emergency Response

The modelling of different conditions has highlighted important considerations with respect to emergency response to coastal flooding. Under the conditions that would cause the most severe flooding on the east coast, it would be anticipated that there would be only limited and local risk affecting the west coast. **The converse is not the case.** When severe conditions occur as a result of high water levels and wave overtopping on the west coast, as a result of typically westerly wave conditions, there is still a substantial risk of flooding particularly at Belle Greve Bay and Saint Sampson on the east coast. Under such conditions, it seems probable that the east coast road may be affected and there would be local flooding on the east coast, even during lower return periods, potentially affecting access and requiring emergency response in these areas in addition to the response required to address risk on the west coast.

4.5 Future Flood Risk to the Northern Section of the Island

The critical factor in future flooding is the increase sea level. Future flood risk has been examined over three epochs: epoch 1 covers the next 20 years (to year 2031), epoch 2 over the following 30 years (to year 2061) and epoch 3, the following 50 years (to year 2111). It may be seen in comparing water levels presented earlier in Tables 3.1 and 3.2 that the main consequence of sea level rise is that the frequency of conditions increases. In effect the change of a present day 1:100 year water level (5.87m with a probability of 0.01) would reduce to less than 1:50 year (probability of 0.05) by the end of epoch 1 and less than a 1:10 year (probability of 0.1) by the end of epoch 2. This comparison of return period is shown in Figure 4.6.

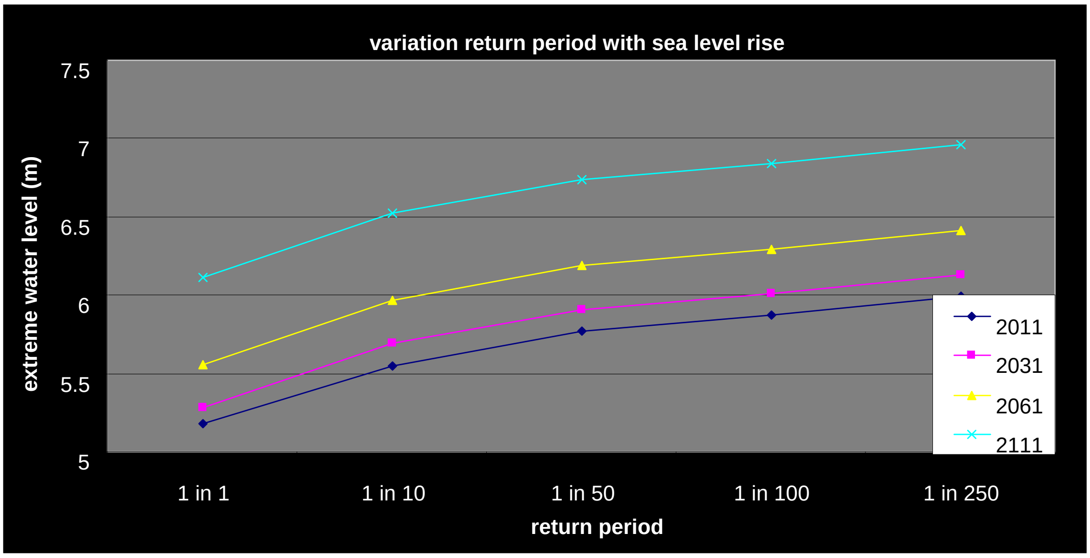


Figure 4.6. Variation in return periods for extreme water levels.

The impact of increasing water levels over time is shown in the flood extents predicted for the 1:250 year return period for different epochs in Figures 4.7 (scenario 3) and 4.8 (scenario 2).

It may be seen from the Figure 4.7 that there is a marginal increase in extent of flooding compared to present day over epoch 1. By the end of epoch 2 (nominally 50 years in the future) there is the potential risk of flooding to the main valley area due to still water level flooding from within Le Grand Havre and that potential flood risk increases significantly, linking fully across the island by the end of epoch 3, with contribution from the area around Baie de Port Grat.

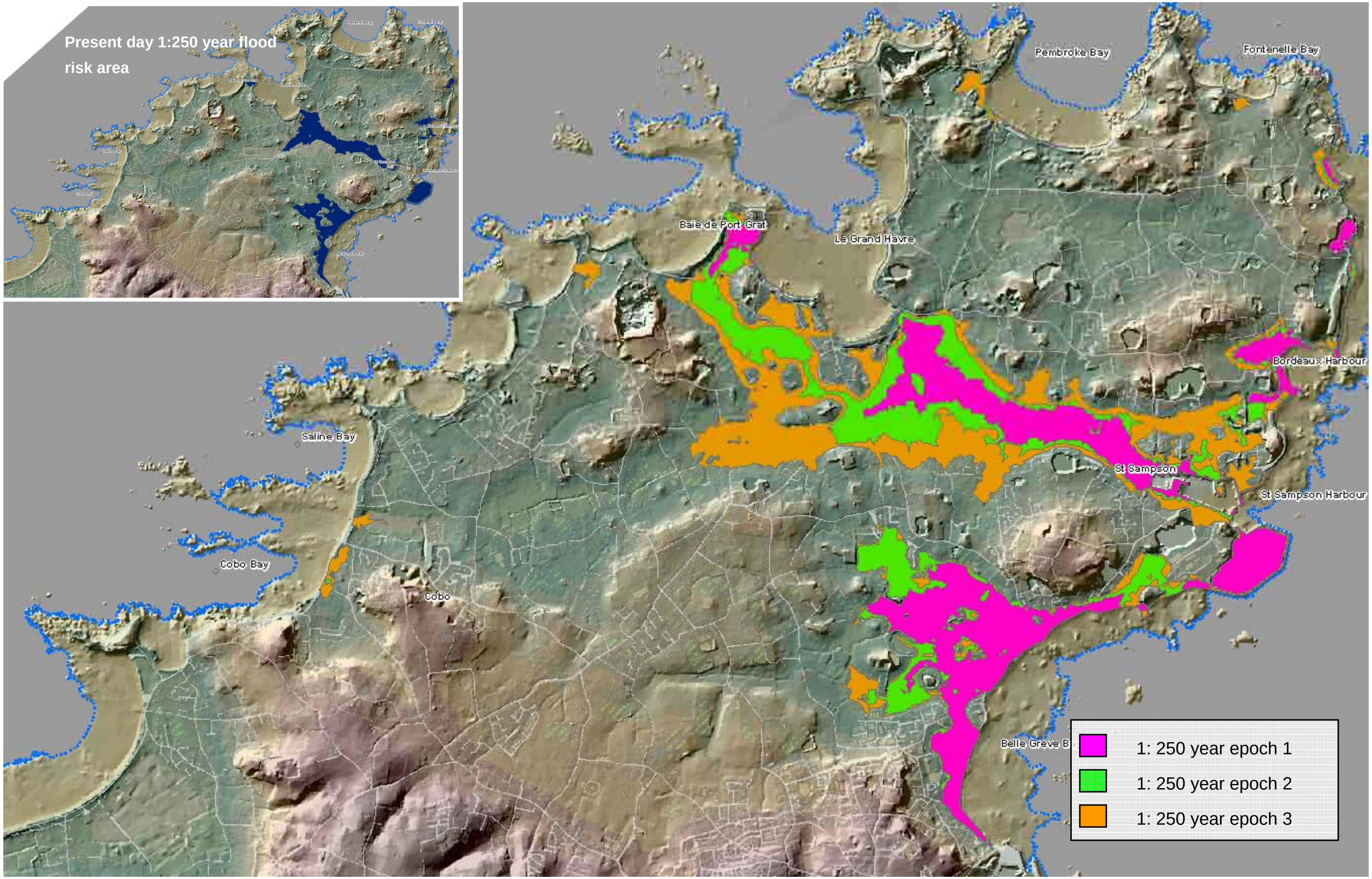


Figure 4.7. Flood Risk Areas Scenario 3 – 1:250 year return period by Epoch (epoch 1 - 2031, epoch 2 – 2061, epoch 3 – 2111)

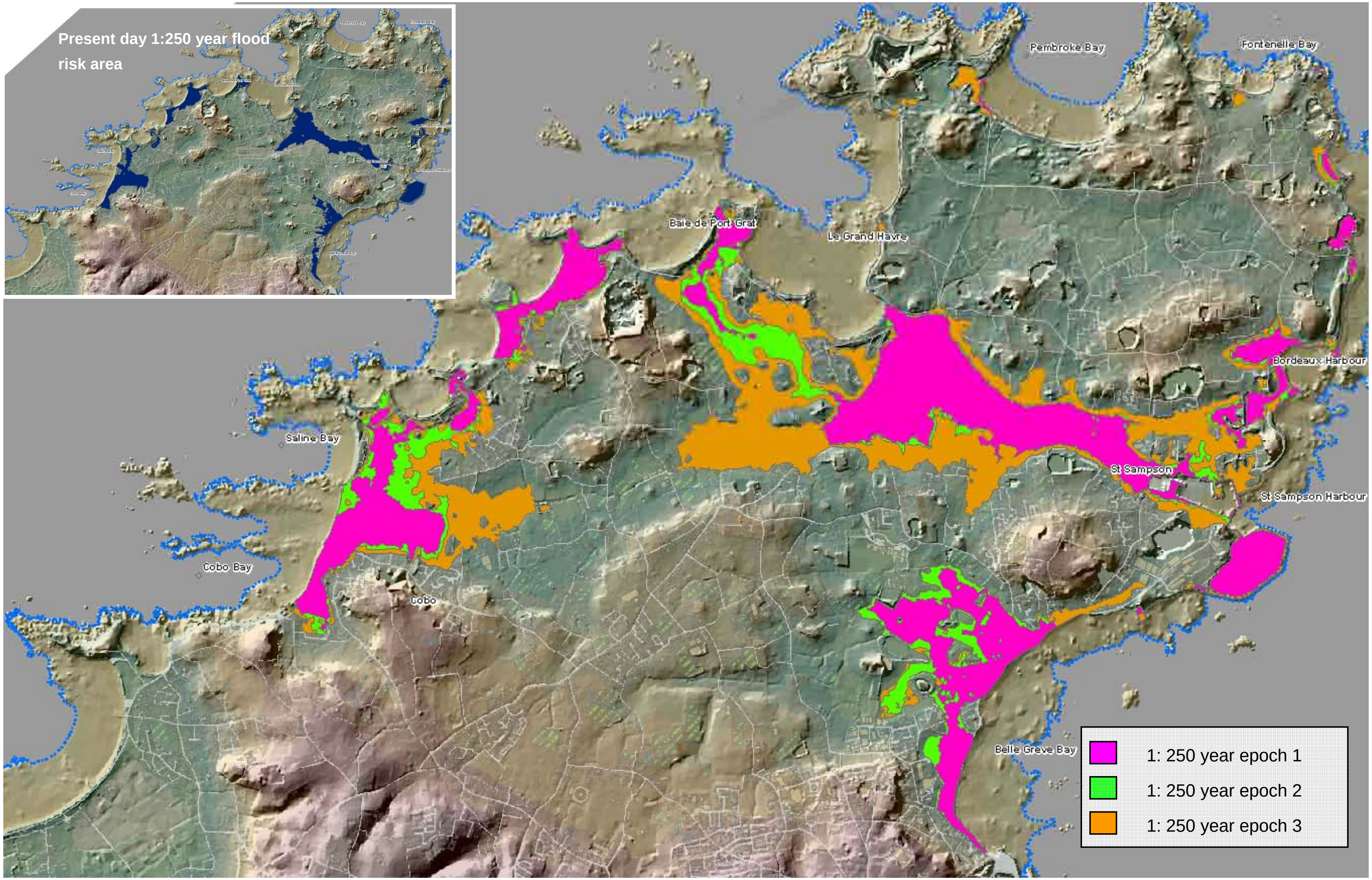


Figure 4.8. Flood Risk Areas Scenario 2 – 1:250 year return period by Epoch (epoch 1 - 2031, epoch 2 – 2061, epoch 3 – 2111)

There is in the longer term the possible risk of flooding originating from Bordeaux Harbour to contribute to flooding within the main low lying valley behind Saint Sampson Harbour. However, even under the long term sea level rise scenario flooding occurring at Belle Greve Bay is separate from flooding within the main low lying valley.

A very similar increase in the pattern of flooding occurs under the different sea level rise epochs for scenario 2 (worst case for the west coast) (Figure 4.8). There is a slightly greater area of flooding under the 1:250 year event by the end of epoch 1, particularly with respect to the valley behind Saint Sampson, reflecting the contribution made by overtopping at Le Grand Havre, and the connection between flooding from Saint Sampson and Baie de Port Grat is still made by the end of epoch 2.

The flood risk at Cobo Bay and at Pequeries become substantially worse over the three epochs but does not develop across the island, and does not, therefore, contribute to flooding from the eastern shoreline.

Even under the most extreme conditions considered, flood water does not penetrate in to the low lying area around Les Closios.

4.6 Management of Local Areas

In considering potential management approaches, therefore, each of the main flood risk areas may be considered quite distinctly, although with respect to Saint Sampson and the main valley area there does need to be some recognition of the contribution to flooding that could occur from the western side of the island. The following sections of the report provide a summary of management at a more local level for the five specific flood risk area around the north of the island:

- Belle Greve Bay
- Saint Sampson and the southwest corner of Le Grand Havre
- Bordeaux Harbour
- Baie de Port Grat and Pequeries
- Cobo and Saline Bays.

These sections draw together the main conclusions developed in the Local Area Reports presented in the annex to this main report.

4.7 Belle Greve Bay

4.7.1 General Description

A location plan is provided in Figure 4.9. The frontage is divided into 9 Defence Units (DUs) and the location of these is also shown on the figure.

Belle Greve Bay, Coastal Unit 19 (CU19), is located along the eastern coastline of Guernsey, north of St Peter Port. The Bay is east-facing and is offered some protection from easterly wave conditions by Herm approximately 6km offshore towards the east.

Along the frontage there is a relatively narrow ridge of higher land falling away landward; providing protection to the low lying inland area from frequent inundation during extreme tides. The development within the Belle Greve area is primarily confined to this coastal strip with some ribbon development extending inland along the route of the main roads which access the hinterland.

The main coastal road runs immediately to the back of the defences over the whole area. The southern section of the sea front has undergone significant redevelopment and many of these new buildings are raised above typical ground levels. There are, however, many older properties at a lower level just to the rear of the main road. Further north, development tends to be residential with properties immediately behind the road as well as extending back into the hinterland.

The area is, therefore, very important both in terms of transport links and for the economic development of the island, in addition to existing residential development.

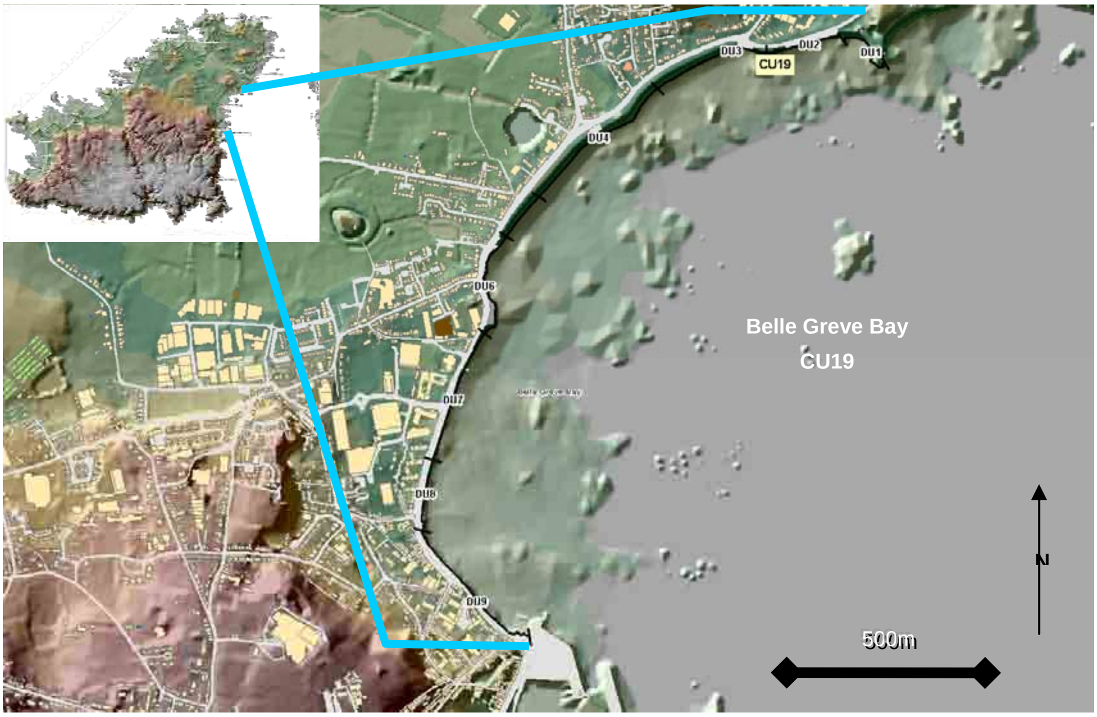


Figure 4.9. Belle Greve Bay

4.7.2 Environmental Conditions.

The water levels are taken from St Peter Port, shown earlier in Table 3.1.

The bay is relatively sheltered being on the east side of the island. Typical wave heights reach approximately 2m on severe conditions, with wave periods in the order of 6 seconds to 7 seconds. The dominant wave direction is from the southwest at the shoreline. The bay can be affected by longer period swell but this has a lower wave height, although these waves are of significantly greater wave period.

4.7.3 Defences.

To the southern section of the frontage (DU 7, 8 and 9) defences are masonry walls in front of the main coastal road. There is a section of higher ground within the centre of the bay (DU6). Defence to the northern section of the frontage comprises initially a section of masonry wall (DU5) but running into the main defence length (DU4), which comprises a natural shingle and earth embankment. At the very northern end of the bay the defence reverts to masonry walls, with slightly higher ground behind.

4.7.4 Overview of Flood Risk

The flood risk modelling indicates the potential for regular overtopping along both the north and south sections of the frontage.

Under the 1:1 year return period, the potential for local flooding from the northern section of DU4 is shown. Local experience suggests that the model may over predict this flood risk. Even so, the plot highlights the general vulnerability of this section of defence due to its lower crest level, the length of the defence and its higher exposure to wave action. There is, however, local overtopping recorded along DU5 with the potential for minor flooding to occur to the sea front.

More extensive flooding is predicted on a 1:10 year event, although this is still specific to individual lengths of defence. The significant increase in flood risk area associated with DU4 is highlighted, with flow into the low lying hinterland. The main source of flooding over the southern section of the bay is predicted from DU9, although there is some contribution from DU8, which may be added to by local wave overtopping caused by the way in which waves interact with the change in orientation between DU8 and DU9. In this area, the flood risk area extends only a limited distance directly in land but has the potential to extend further north into the development area behind DU7.

Flood risk increases significantly on events greater than 1:50 year return period with the potential flood risk areas originating from DU4 and the area behind DU8 and 9 linking through within the hinterland.

The flood risk areas for the frontage are shown in Figure 4.10 for 1:10, 1:50 and 1:100 year return period events. A summary of potentially affected property is shown in Table 4.1. The Local Area Report for this section of the coast provides a more detailed discussion of both the defences and the flood risk.

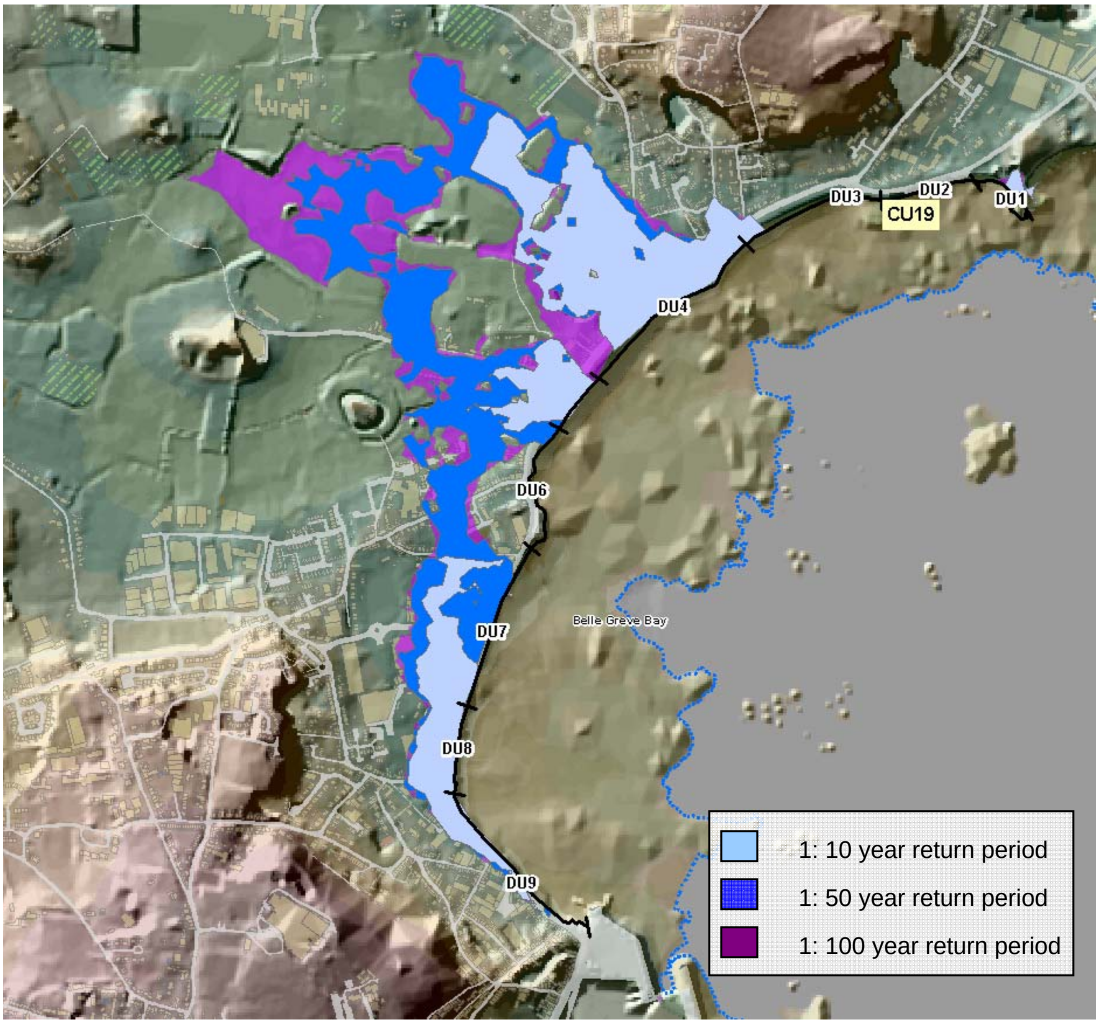


Figure 4.10. Flood Risk Areas

Table 4.1. Properties currently at risk of flooding from 1:n year return period event.

Return Period	Number of Properties At Flood Risk	Notes
1 in 10	235	Areas affected critically depend on water levels. Key areas potentially affected are: DU4 – Vale Road, DU5 – The Osmonds and Clos des Isles, DU8 and 9 – local property behind road and new development area.
1 in 50	378	Flood areas linked behind DU5 through to DU8 and 9
1 in 100	461	All main flood areas linked; flooding from one area could affect other areas.
1 in 250	513	All main flood areas linked; flooding from one area could affect other areas.

4.7.5 Management Summary Conclusions

Notwithstanding the fact that there has been limited flooding incidents in the past, the study modelling shows that the frontage is very vulnerable to increased water levels, on more severe storms and with sea level rise. The modelling indicates that significant flooding could occur on events greater than a 1:10 year return period, with the extent of flooding increasing rapidly with a 1:50 year water level. With sea level rise this risk increases. Even the limited predicted sea level rise over the next 20 years changes the situation, where severe flooding could be occurring on a return period of 1:10 year return period.

Much of the sea front forms a ridge of land with the hinterland falling away behind. Land levels within the hinterland, particularly over the central section of the bay fall away to a level at or below normal spring tide level. The area is important economically and contains up to 500 properties located within the more extreme flood risk area. The main coastal road also runs along the frontage. In terms of damage to property the modelling has identified that, with existing defences levels, present value economic damages over a 100 year period would be of the order of £69 million.

The study highlights that flooding could occur a significant distance in land and that, despite the higher ground at the Hougue à la Perre Battery (DU6) effectively dividing the frontage at the shoreline, there is a risk of flood waters, particularly from the southern section of the bay (DU7, 8 and 9), extending into the low lying area behind the central section of defences (DU4 and 5). As such, in developing a long term plan for management, it would be necessary to consider the frontage as a whole.

The northern section of the bay (DU1, 2 and 3) are less significant in terms of this broader picture. While defence along these sections would need to be improved over time this is in relation to more local flood risk to property.

The study has considered in outline three basic approaches to addressing the long term problems associated with the main part of the bay. These are identified as options S1, S2 and S3 in the Local Area Report:

- S1 – Raise the level of existing defences
- S2 - Local raising and flood proofing of existing defences with the construction of breakwaters and beach recharge.
- S3 - Advancing the line of defence with raising defences level to DU4.

These consider general management approaches over the next 100 years to provide up to a typical 1:250 year standard of defence. These strategic options are summarised in Table 4.2. Costs for the primary elements of defence have not been discounted; however future improvements to defence and on-going maintenance are discounted.

Any of the strategic approaches require significant investment and could potentially have significant environmental impact. There are also significant implications for the use and landscape of the frontage. Options S2 and S3, provide scope for mitigating such impacts but this would be need to be considered in conjunction with land use planning. Option S1 would constrain such opportunities.

Table 4.2 Comparison of Strategic Options for Belle Greve Bay

Strategic Option		Benefits	Disadvantages	Present Value Cost (£k)
S1	Raise the level of existing defence	Provides a basic 1:250 year standard of defence, based on existing structures. Potential amenity improvement to DU4.	Significant visual impact. Increasing difficulty and cost in continuing to raise defences in the future. Concern that this approach may not be sustainable in the very long term with sea level rise, with little scope for adaptation.	6,312
S2	Local raising and flood proofing of existing defences with the construction of breakwaters and beach recharge.	Provides a basic 1:250 year standard of defence. Opportunity for enhanced use of the shoreline. The approach can be adapted to use of the frontage. Provides longer term sustainability.	Still requires raising of some defences and flood proofing. Impact on existing foreshore. High cost and continuing need for topping up beach recharge.	24,539
S3	Advancing the line of defence with raising defences level to DU4.	Provides a basic 1:250 year standard of defence. Opportunity for enhanced use of promenade and sea front. The approach can be adapted to use of the frontage. Provides longer term sustainability.	Still requires raising defences but this can be mitigated by increasing the width of the defence system. Impact on upper foreshore. High cost.	13,452

It is recognised that a strategic approach will require time to develop and will sensibly require consultation between departments of the States of Guernsey and with more general stakeholders affected or at risk. In the interim there would continue to be substantial flood risk. This is discussed below.

Interim Flood Defence Measures

Interim measures consider improvement to defences in the short term, recognising that works would become less effective over the next 20 years with predicted sea level rise. These actions are set out in Table 4.3a (DU4), 4.3b (DU5) and 4.3c (DU8 and 9). In each case a comparison is provided between work done immediately at a local level with that work which would be undertaken under strategic option S1. The aim is to contrast the different level of investment and the residual risk.

Table 4.3a Comparison of Local works to DU4 with Initial stage works under Option S1

Defence unit/ description		Benefits	Disadvantages	Cost (£k)
DU4	Raise the level of existing defence to provide a consistent 1:100 year standard of defence over the unit.	Improves standard of defence to a present day 1:100 year level. Addresses weak point in defence of the area managing significant risk to properties in Vale Road. These works would be compatible with any of the strategic options, allowing further improvement.	The defence standard would reduce to a 1:60 year level in 2031 with predicted sea level rise. There would continue to be some risk on events less than 1:100 years. Wider benefits would only be realised with improvement to DU5.	321
DU4	Raise the level of existing defence over the whole length of DU4 to a 1:250 year level.	Provides a basic 1:250 year standard of defence. Opportunity for enhanced amenity. Does not preclude taking alternative approaches elsewhere. Maintains a 1:100 year standard by 2031, decreasing to 1:35 year standard in year 2061.	Wider benefits would only be realised with improvement to DU5 to the same standard of defence.	982

Table 4.3b Comparison of Local works to DU5 with Initial stage works under Option S1

Defence unit/ description		Benefits	Disadvantages	Cost (£k)
DU5	Raise the level of existing defence to provide a 1:100 year standard of defence over the unit. Include local works to reduce overtopping adjacent to the Pump Station within DU6	Improves standard of defence to a present day 1:100 year level. Improves defence to properties locally. These works would be compatible with any of the strategic options, allowing further improvement. The level of defence could be adapted to minimise visual impacts.	The defence standard would reduce to a 1:60 year level in 2031 with predicted sea level rise. Wider benefits would only be fully realised with improvement to DU8and 9 and, more locally, to DU4.	425
DU5	Raise the level of existing defence over DU5 to a 1:250 year level.	Provides a basic 1:250 year standard of defence. Maintains a 1:100 year standard by 2031, decreasing to 1:35 year standard in year 2061.	Wider benefits would only be realised with equivalent improvement to DU4 and to defences to the south (DU7, 8 and 9). Would potentially preclude adapting to a different strategic approach in this area. Potentially significant visual impacts.	744

Table 4.3c Comparison of Local works to DU8 and 9 with Initial works under Option S1

Defence unit/ description		Benefits	Disadvantages	Cost (£k)
DU8/9	Raise the level of existing defence to provide a 1:50 year standard of defence over the southern section of the bay.	Improves standard of defence to a present day 1:50 year level. Improves defence to properties locally and reduces the risk of flooding through to the hinterland of DU5. These works would be compatible with any of the strategic options, allowing further improvement. There would be minimal visual impact.	The defence standard would reduce to approximately 1:15 year level in 2031 with predicted sea level rise. There would be a need to raise defence further over the next 10 years. There would still be significant risk on events greater than a 1:50 year return period.	1,307
DU 7/8/9	Raise the level of existing defence over the southern section of the bay to a 1:250 year standard.	Provides a basic 1:250 year standard of defence. Protects against flooding through to hinterland of DU5. Maintains a 1:100 year standard by 2031, decreasing to 1:35 year standard in year 2061.	Wider benefits would only be realised with equivalent improvement to DU4 and DU5. Would potentially preclude adapting to a different strategic approach in this area. Potentially significant visual impacts.	3,696

The total value of interim works would be of the order of £1.5 million, providing a significant economic benefit; Present Value damages (PVd) could be reduced by some £50 million. However, as highlighted in the above tables the actual risk increases substantially over the next 20 years.

Undertaking works immediately does allow sometime within which to develop a longer term approach to management that would address this increasing risk over the whole area.

4.7.6 Recommendations and Action Plan

It is recommended that the results and conclusions of the study are used to initiate consultation on long term management of Belle Greve Bay.

Three baseline options are presented and while option S3 is seen as providing a balance in terms of cost, benefit and opportunity for a long term sustainable management approach, elements of the alternative options may further open opportunities not immediately apparent from purely a flood risk management perspective.

It is, therefore, recommended that all options are presented in developing discussion and consultation, with a preliminary recommendation that option S3 (advancing the line) is considered overall to be the preferred general approach.

Developing and confirming a long term strategy is essential and needs to be taken forward with a degree of urgency given the increasing risk posed even by predicted sea level rise over the next 20 years.

In the interim, there are measures that offer potentially important short term reduction in present risk. These are considered to offer good economic value in terms of the additional protection they would afford. They would still leave the frontage vulnerable to more extreme conditions and there is still significant risk to property and disruption to the use of the area, particularly over the southern section of the bay. The proposed works would, however, be compatible and beneficial in terms of longer term management, in that such works could be incorporated within a longer term strategic approach.

It is therefore recommended that local defence raising work is undertaken to:

- the lower section of DU4, to bring this up to a consistent level of 7.7mLOD.
- DU5, in looking at local improvement to defence levels and replacing flood barriers.
- DU 8 and 9, in undertaking minimum raising of the defence by 0.3m with a coping to the existing walls.

To gain maximum benefit from the works it would be recommended that they are undertaken immediately alongside consultation and development of a longer term plan for the area.

4.8 Saint Sampson and Associated Area of Le Grand Havre

4.8.1 General Description

A location plan is provided in Figure 4.11. The St. Sampson area has been subdivided into 6 defence units covering the St Sampson Harbour area (Coastal Unit 18), the main focus of discussion within this section of the report. On the west coast Le Grande Havre is divided into 6 defence units. The location of relevant defence units are shown on the figure.

Saint Sampson is located north east of St Peter Port and Belle Greve Bay and immediately south of the next study area, CU17, Bordeaux Harbour.

The town centre surrounds the inner harbour on the east and south face, with more industrial developments including the shipyard, various heavy industry firms and the Guernsey Power Station located predominately on the north side. Land reclamation works have been undertaken south of the harbour entrance, and along the perimeter of Bulwer Avenue. Other industrial infrastructure is protected by the more recent rock revetment and breakwater structures, which also provide a safe mooring haven for approximately 140 smaller vessels. The main coastal road runs through Saint Sampson across the ridge of high ground to the back of the Harbour, The Bridge. This is a key transport route between the north and south of the island. Other principal transport routes between the north and south run across the valley behind St Sampson. St Sampson and its Harbour provide an essential commercial and industrial area of the island and there is significant commercial development of the low lying land within the hinterland. The main residential development is set back to either of side of the Harbour and to the higher ground either side of the main valley. The main shopping centre of St Sampson lies around and to the back of the harbour and there are areas of residential property both within this and across the valley floor further within the hinterland.

The local area and the main valley behind is, therefore, very important in terms of sustaining the economic value of Guernsey, in terms of the important transport links and in terms of residential development.

4.8.2 Environmental Conditions.

Water levels taken for the analysis are based on St Peter Port, shown earlier in Table 3.1. The numerical tidal modelling has shown that there is a significant water level gradient to the north of St Peter Port, through the strait between the main island and the island of Herm. This variation in water surface changes over the tidal cycle and results in stronger tidal flow through the area around high water. The values taken for the St Sampson may vary from those at St Peter Port on surge events. This does, however, depend on specific surge conditions.

Actual wave penetration of near shore waves within the harbour is relatively low and is not considered to be a key factor in the assessment of flood risk.

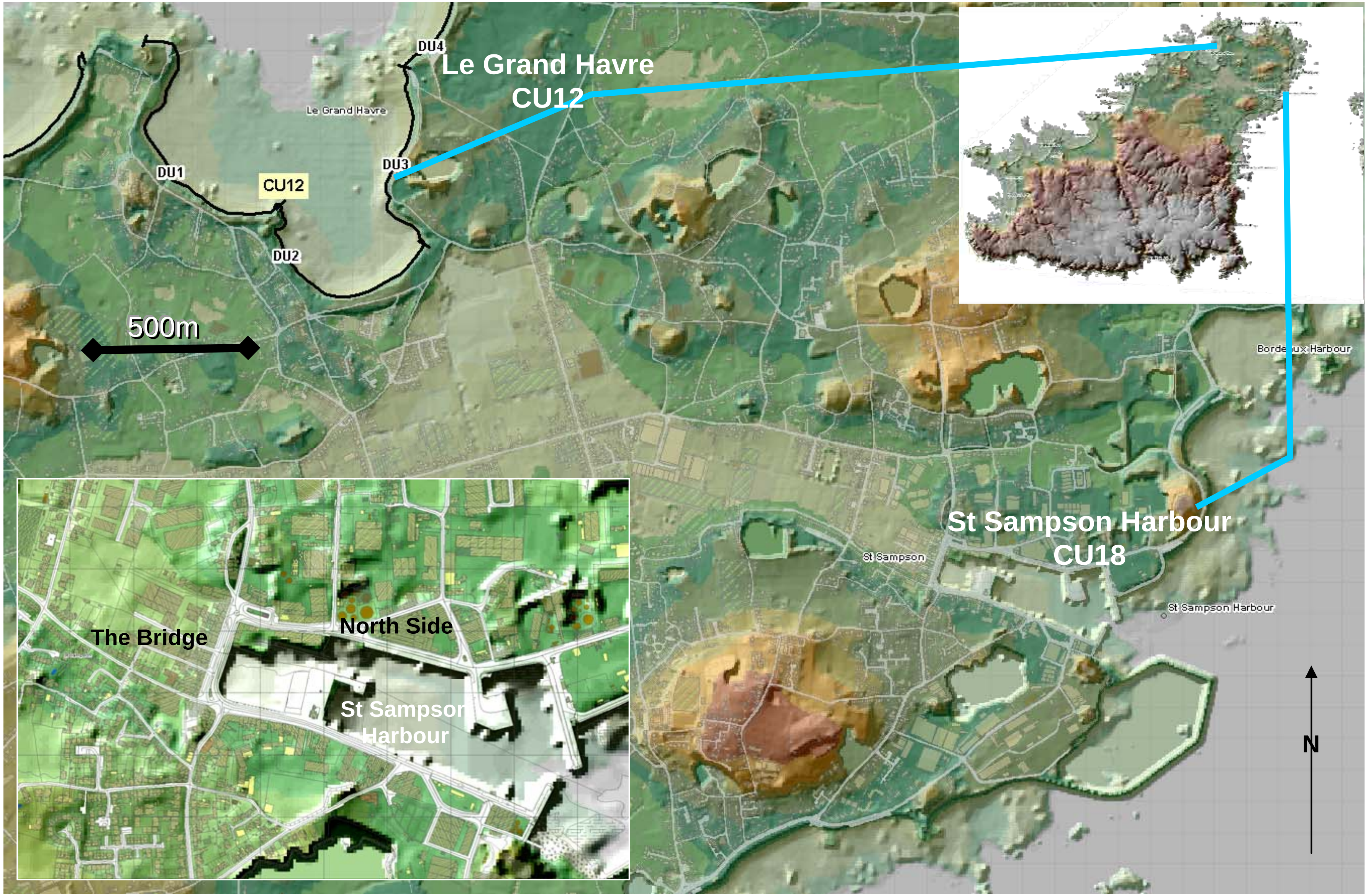


Figure 4.11. St Sampson Area

4.8.3 Defences.

Defences to north and south of the harbour area are not considered to be at significant risk from overtopping or direct flooding affecting the area strategically. Defences within the harbour area include the main harbour structures which protect the harbour from wave action. Within the harbour itself the principal defences are the harbour walls and quays which give way to the harbour operational area and the roads around the harbour. Generally to north and south of the harbour area the level of the road and land rises in land. A critical section of defence, providing essential flood defence to the main hinterland area to the west of the harbour, is the Bridge. This ridge of land, over which the main road runs, falls away rapidly in level down to the valley behind.

4.8.4 Overview of Flood Risk

The assessment of flood risk has identified a very extensive area of flood risk associated with the defences at Saint Sampson. The main flood risk is due to the potential weiring of still water levels across the high ground ridge at the back of the Harbour.

The volume of water overtopping the back ridge of Saint Sampson limits the degree of flooding that would occur under different return periods. Flooding on extreme conditions (1:250 year return period, present day) effectively fills the length of the valley, with flood water reaching to the back of Le Grand Havre. Under this return period event there would also be significant overtopping of the earth bank on the seaward side of Le Route de Islet due to wave action within Le Grand Havre.

Around Saint Sampson Harbour there are limited areas of flooding that affect harbour operations and the main road to the southern side. On the northern side of the Harbour flooding under very extreme conditions might approach levels that could affect the fuel storage area but is unlikely to cause flooding to the power station.

Flooding on to the Bridge can occur on extreme water levels in excess of 1:1 year return period. The modelling highlights the high degree of sensitivity around the 1:10 year event, both in terms of level and in terms of the time over which water levels would exceed the defence level. Over a 1:50 year event, the predicted peak water level is 0.4m above the average level of the road, with a substantially greater flow over the Bridge. The analysis highlights how even small changes in sea level rise become critical to risk in the area.

The level of defences elsewhere around the harbour is at a similar level to that of the Bridge but is more generally backed by rising land.

The flood risk for the area is shown in Figure 4.12 for 1:10, 1:50 and 1:100 year return periods. A summary of potentially affected property is shown in Table 4.4. The Local Area Report for this section of the coast provides a more detailed discussion of both the defences and the sensitivity of flood risk. Potential flood damages are determined based on the modelled flood extents. Discounted value of damages taken over 100 years amounts to £59 million.

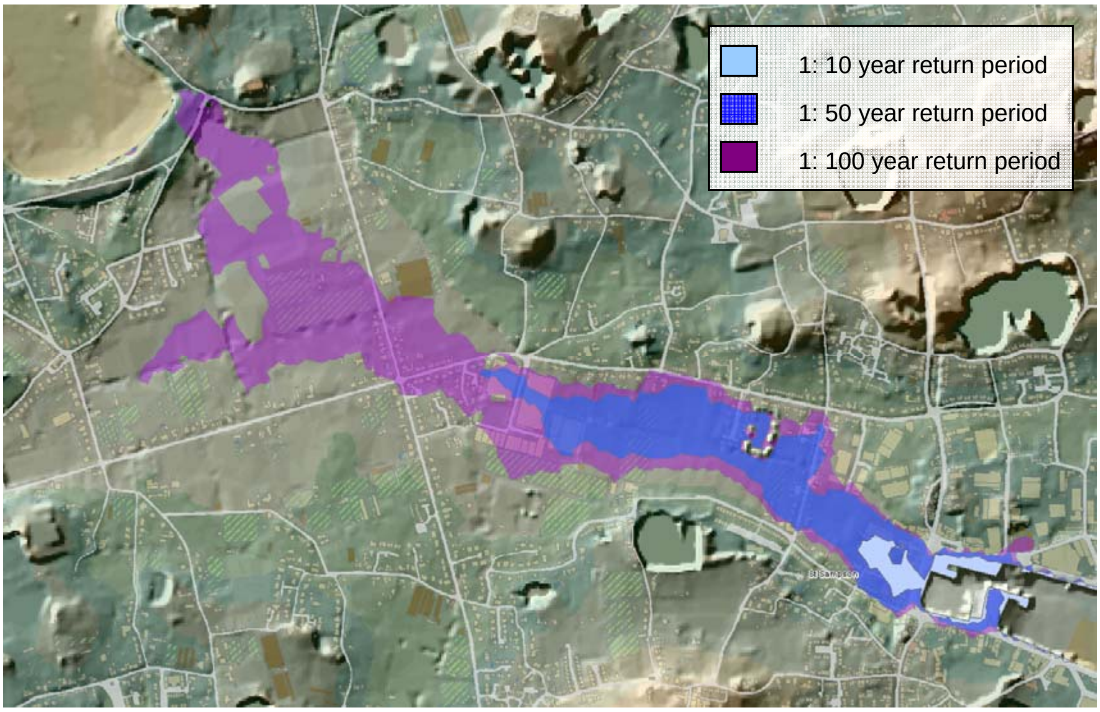


Figure 4.12. Flood Risk Areas

Table 4.4. Properties currently predicted to be at risk of flooding for different return periods

Return Period (yrs.)	Number of Properties At Flood Risk
1 in 1	0
1 in 10	2
1 in 50	124
1 in 100	246
1 in 250	355

4.8.5 Management Summary Conclusions

The modelling has highlighted that there is a significant flood risk to the hinterland. Experience of flooding indicates that there have been occasions when water levels have reached a critical level where there has been a real threat of significant water overflowing the Bridge. The rate of overflow increases rapidly with increased water level and it may be concluded that exceedance of this threshold is around water levels predicted as occurring on a level slightly greater than a 1:10 year return period. In considering this sensitivity, the modelling has shown that with water levels at a level of the 1:50 year return period extensive flooding would occur.

Given the large area at risk, the rate at which flooding to the valley behind St Sampson would happen and the threat this poses to property and potentially life plus the severe disruption flooding of the valley would cause, it is considered that this risk must be addressed with a degree of urgency.

Associated with this issue, the modelling of tide levels around the island has identified that taking levels from St Peter Port as representative of levels at St Sampson may slightly over predict water levels. As part of monitoring sea level rise, consideration should be given to establishing a tide gauge at St Sampson. This is not considered critical to present strategic decisions but would provide greater confidence in timing and design in the future.

The study shows that while there is more general risk to assets around the harbour, this would tend to be a more manageable with a more progressive level of flooding, with flood waters receding as the water levels decrease.

In looking at potential options for management, the main focus for immediate work has been on addressing the risk at the Bridge. Three strategic options have been considered. The first (S1) looks at providing improved flood defence around the edge of the harbour. This would require raising the defence level eventually all around the harbour. In this approach, it would be necessary to continue defence around much of the inner harbour area to ensure that flooding to the north and south of the harbour would not still result in flooding across the Bridge. This does incur additional initial cost, but does include providing greater protection to areas to the north and the south. Further work would be undertaken as the risk due to sea level rise increases.

The second option (S2) focuses work at the Bridge looking at incorporating flood defence within redesign of the highway. This work potentially offers opportunity for a more integrated approach with development of the western end of the harbour. The initial cost would be less than option S1 but would only be sensibly carried out if undertaken as part of other works for the area. Critical to this would be looking at ways in which road levels, specifically to the north and south of the Bridge, could be raised as part of a long term approach to flood risk management. This would need to consider how future works could be integrated with such road raising to provide long term continuity for defence levels. Future work would address the residual local risk, as this increases with sea level rise. It is concluded that this option allows greater adaption and better integration with future planning for the area.

The final option (S3) looks at a longer term solution by providing flood gates to the entrance to the harbour. These works would be considerably more expensive and in order to address the current flood risk would need to be taken forward with a degree of urgency. There might be scope for combining these works with earlier work undertaken as phase 1 of either option S1 or S2. However, in this case much of the flood risk benefit would already have been addressed. As such the more major works involved with S3, would need to be undertaken far more from a perspective of improving the operational use of the harbour. This would clearly need to be examined from this perspective in collaboration with harbour operators and users.

The broader scale risk of flooding has been considered by the study, in looking at the possible risk of flooding from Le Grande Havre. There are areas at the western end of the valley that could contribute to flooding of the valley. This risk would over the longer term negate to some degree works undertaken at St Sampson and would need to be addressed. This has been allowed for in developing the long term costs of options but is not considered to be something that needs to be addressed immediately. Planning of such works could be linked to monitoring of sea level rise.

Table 4.5 provides an overall comparison of the three options, briefly summarising the benefits and disadvantages concluded above.

Table 4.5 Comparison of Strategic Options for St Sampson

Strategic Option		Benefits	Disadvantages	Present Value Cost (£k)
S1	Raise the level harbour walls	Provides a basic 1:250 year standard of defence, based on existing structures. Works could be phased but would need to be extended around much of the inner harbour.	Significant visual impact. Increasing difficulty and cost in continuing to raise defences in the future. Disruption to use of the harbour. High initial cost Limited opportunity to adapt to monitoring of rate of sea level rise	5,804
S2	Local protection to Bridge. Subsequent local defence based on monitoring of sea level rise.	Provides a basic 1:250 year standard of defence. Opportunity to adapt design of initial works to incorporate development planning. Opportunity to adapt future works to future development and timing based on sea level rise.	Significant impact on use of highway and use of the Bridge. Need for co-ordinated development of design. Local flood risk over years between phased work.	4,588
S3	Flood gates at the Harbour entrance	Provides a basic 1:250 year standard of defence. Opportunity for development of harbour. Avoids works and impact around harbour.	Requires discussion with harbour users and may limit harbour use. High cost.	17,399

4.8.6 Recommendations and Action Plan

It is recommended that works are undertaken with a high degree of urgency to address the very substantial risk of flooding from overtopping of the Bridge at the western end of St Sampson Harbour.

If there is scope to integrate these works with redesign and development of the highway and surrounding area of the Bridge, then this would be recommended as the preferred option. If this was feasible, then this would be taken forward as Option S2, providing a more staged approach to addressing the more local flood risk issues around other areas of the harbour. Associated with this work would be the need to examine local flood risk resilience measures to properties to the south of the harbour. At the same time consideration would be given to improving flood risk reduction through local works to industrial harbour premises along the north side of the harbour. The intent of this strategic option would be to look at future works to improve defence to north and south of the harbour in response to sea level rise.

If this approach is not considered appropriate or feasible in developing flood risk within plans for improvement to the highway at the Bridge, then the recommendation would be to undertake works to raise the back and immediate side walls of the harbour area independently (option S1).

These works would be more costly and more extensive but would address some of the local flood issues to north and south of the harbour.

The general recommendation is, therefore, to undertake full consultation between departments of the States of Guernsey, alongside more general consultation with stakeholders and harbour users, using the results of this report as the basis for discussion. The intent would be that a decision is made over the next year so as to allow design of flood risk protection works to the main valley as rapidly as possible.

Subsequent works would be subject to longer term planning, associated with future development planning of the harbour area. From a flood risk perspective the urgency for further work would be driven by sea level rise and there would be a recommendation that monitoring of sea level rise is developed for the island including monitoring of water levels at St Sampson.

Option S3, considered more major works for constructing a barrier or flood gates at the harbour entrance. Such works would offer potential for longer term flood risk management but would be driven primarily by possible opportunities for future use of the harbour. While this option would not, therefore be recommended solely from the perspective of flood risk management, development of this option would not be ruled out as providing possible flood risk reduction in the future.

4.9 Bordeaux Harbour

4.9.1 General Description

Bordeaux Harbour is situated north of Saint Sampson on the north east coast (Figure 4.13). The Bordeaux Harbour area has been subdivided into 8 Defence Units, and the locations of these are shown on the figure.

Bordeaux Harbour provides shelter and mooring for small vessels and forms the only natural sheltered bay on the north east coast. The settlement of Bordeaux Harbour extends towards the higher ground of the northern coast; with a smaller number of properties located along the western Harbour edge, segregated from the main developed area by a narrow strip of undeveloped grazing pasture. This grazing pasture forms the bottom of a shallow valley at the inland extent of the Harbour creating a natural drainage route for the surrounding land. The high ground surrounding the Harbour is formed from Diorite intrusive igneous rock, compared to the lowland valley formed from alluvium deposits. The western edge of the Harbour has been created by back-filled material, likely during the construction of the masonry seawall.

The principal road from Saint Sampson and St Peter Port, to the north of the island, runs along the western side of the Harbour, with a minor road to a local visitor car park running adjacent along the northern section of the Harbour. There is a former refuse facility located to the higher land to the north of the harbour.

Bordeaux Harbour is an important local community and tourism area, providing mooring and catering facilities. There is a key road running through the area which forms part of the main strategic transport route and bus service. The semi natural landscape is an essential quality of the Harbour and surrounding area, however there are records of an old refuse site which could be a source of contamination.

4.9.2 Environmental Conditions.

Water levels taken for the analysis are based on St Peter Port, shown earlier in Table 3.1. The numerical tidal modelling has shown that there is a significant water level gradient to the north of St Peter Port, through the strait between the main island and the island of Herm. The values taken for the Bordeaux Harbour may, therefore, vary from those at St Peter Port on surge events. The actual level on extreme events could be up to 0.1m lower than the levels shown in the table. This does depend on specific surge conditions.

In terms of locally generated waves in the nearshore area, waves can be developed from both the north and the south, with waves from the north tending to be higher (typically up to 2m in height). The harbour is sheltered from waves from the north and the more typical wave height may only reach about 0.8m at the harbour entrance. The harbour also experiences swell waves of a similar height but which only gain access to the harbour on very specific directions. Within the harbour, although waves tend to spread once through the entrance, there are quite specific interactions with defences (particularly DU4) such that the wave may build as it runs along the face of the defence.

This is all discussed in more detail in the Local Area Report presented as an annex to this main report.

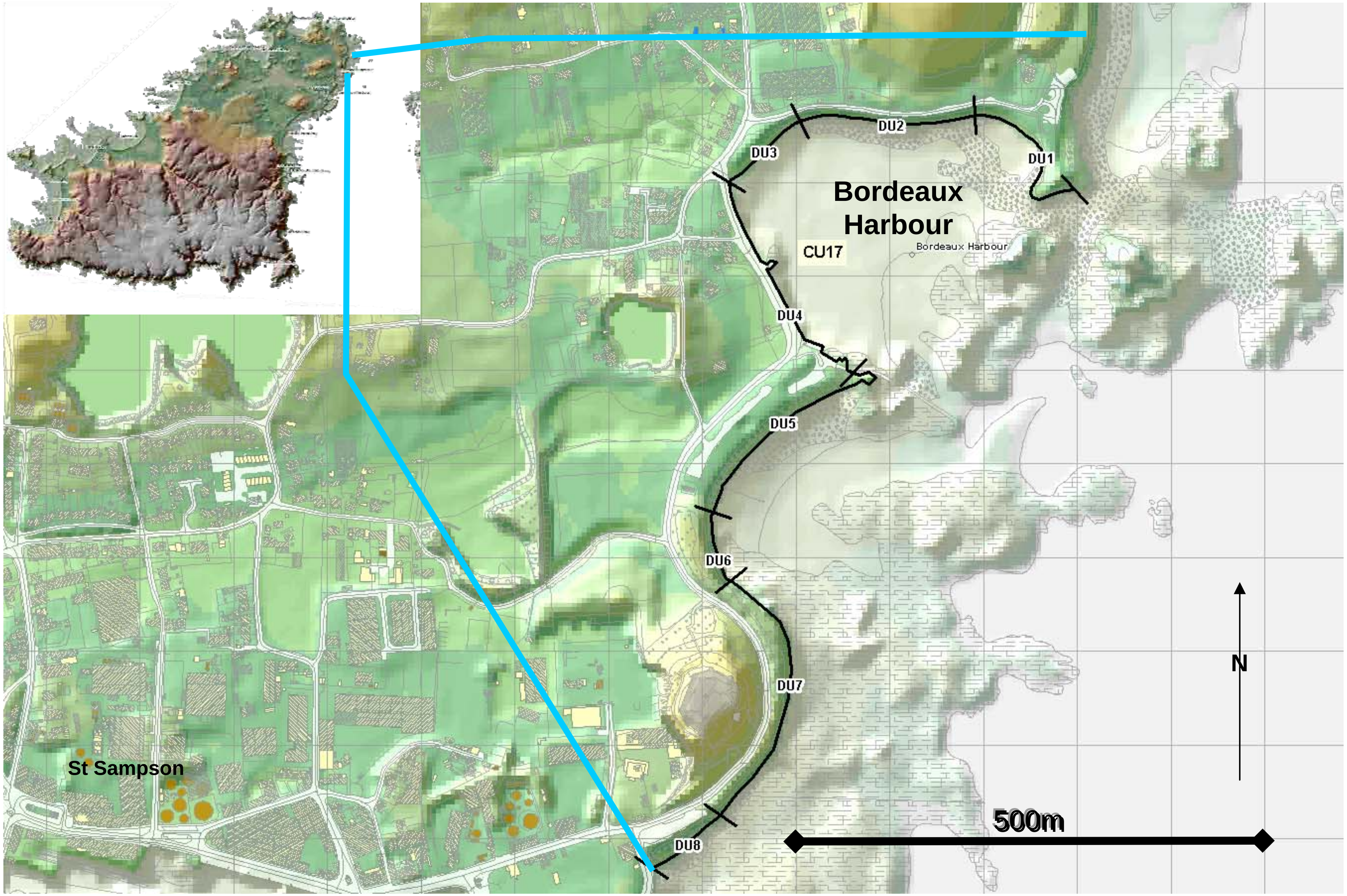


Figure 4.13. Bordeaux Harbour

4.9.3 Defences.

The Bordeaux Harbour frontage has been divided into eight defence units as shown in Figure 4.13. Four units are defined within the harbour area and four define the open coast south of the harbour.

Over much of the northern section of the harbour the defence (DU 1, 2 and 3) comprises a relatively natural embankment, reinforced by a rock revetment. The western side of the harbour is defended by a masonry wall (DU4). The action of waves along this wall has tended to maintain low beach levels in front of this section of defence.

Defences DU5 and 6 are relatively natural shingle and earth embankments, reinforced locally by rock armour. The defences DU 7 and 8 are hard defence to high ground.

4.9.4 Overview of Flood Risk

The main defence lengths contributing to flooding of the Harbour area are along DU4, with the low crest level of the sea wall, and across the area of dunes in DU3 and the lower section of DU2. Given that DU3 and the western section of DU2 are largely natural defences built up by wave action, it is quite reasonable that on very high water level and wave conditions that these two sections of the frontage would be overtopped. There is potential for flooding to occur across DU5 on the open coast.

The modelled flood risk for the area is shown in Figure 4.14 for 1:10, 1:50 and 1:100 year return periods. It may be seen that the volume of water potentially overtopping defence DU4 effectively fills the main low lying areas on a 1:10 year event, with higher return periods adding to the depth of water but not significantly to the extent of flooding. This has been reviewed in relation to local reports of flooding. There is evidence of overtopping along DU4, although overtopping of the severity predicted from the modelling has only been recorded on two occasions in the recent past. On both occasions waves were reported as weiring over the defence to a depth of about 0.3m.

From this evidence, the assessment is made that the model does overestimate the degree of overtopping on lower return period events. However, from the description of the flooding events the mechanism for flooding seems to have been correctly interpreted. The threshold for overtopping along DU4 appears to be around the 1:10 year return period but with very severe overtopping likely to occur on levels greater than this.

While this potentially reduces the most immediate risk to properties, particularly to the north of the village, it still leaves properties at significant risk now, to events above the 1:10 year level and vulnerable to more regular flooding with sea level rise over the next 20 years. Such flooding would have a significant economic consequence for the area and would cause severe disruption to the highway through the area. The economic damages occurring over a 100 year period are assessed as being of the order of £10.7 million.

A summary of potentially affected property is shown in Table 4.7. The Local Area Report for this section of the coast provides a more detailed discussion of both the defences and the sensitivity of flood risk.

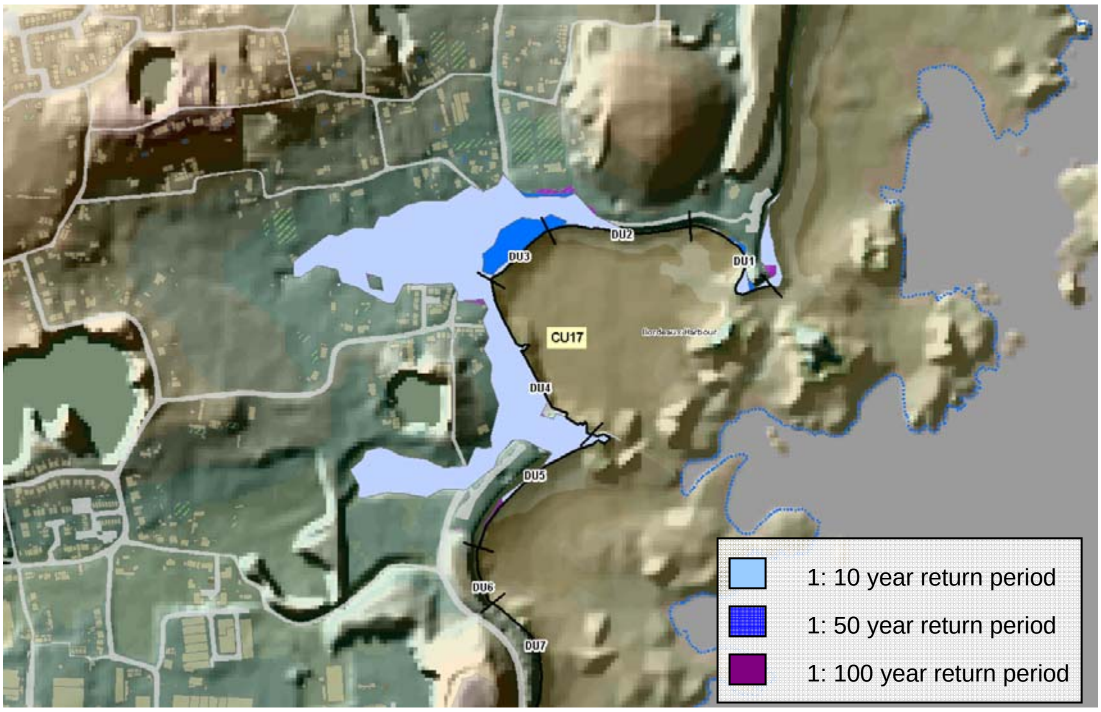


Figure 4.14. Flood Risk Areas

Table 4.7 Properties modelled as at risk of flooding from 1:n year return period event.

Return Period	Number of Properties At Flood Risk
1 in 1	13
1 in 10	27
1 in 50	44
1 in 100	50
1 in 250	66

4.9.5 Management Summary Conclusions

The examination of the Bordeaux area has shown that the frontage is vulnerable to local but quite extensive flooding. While modelling has indicted that there is quite significant risk on storm conditions as low as a 1:1 year event, experience of flooding to the areas suggests that the onset of severe flooding is more probably around the 1:10 year level.

The main flood risk, initially, is due to waves building as they run along the face of DU4. However it only requires a small increase in water level for water to flood directly over the crest of the wall. The tidal modelling has indicted that actual surge levels at Bordeaux Harbour may be less than those taken in the analysis based directly on St Peter Port. This cannot be relied upon, without more local data, as there is shown to be some variation depending on specific surge conditions. Even if this is taken into account, on a 1:50 year water level, there would be direct flooding over the wall.

Taking account of local observations and allowing for wave action, it is concluded that the onset of severe flooding could occur on a 1:10 year return period. The degree of overtopping increases rapidly with increase in water level.

The modelling also highlights other weak spots in the defences. Along DU2, to the northern frontage, there is seen as being a significant risk that would result in flooding to the northern part of the village. This section of defence has suffered damage in the past, although there has been no record in the recent past of flooding. As discussed above, the model may over-predict the level at which this risk occurs but, again with relatively limited increase in water level this risk is seen as being real.

Further south, south of the main harbour, there is a risk identified from overtopping of DU5. This would contribute to the flood risk to the area behind DU4.

Overall, therefore, it is concluded that, while modelling may over-predict the frequency of overtopping and flooding, there is a threshold level (between a 1:10 and 1:50 year return period) at which very substantial flood risk occurs to the village and use of the area. With sea level rise, even over the next 20 years, the frequency of flooding would be far more significant. Flooding potentially threatens some 50 to 60 properties as well as causing major disruption to the road network.

In looking at potential options for management, while some immediate improvements might be made to modify wave action along DU4 and locally improve the condition of the defence along DU2, this would only act as a stop-gap measure. If the basic defence standard is to be improved than more substantial works would be required.

Three options are considered. The first strategic option (S1) considers purely raising the level of defence. This could be untaken by improving the crest level to DU4 and DU2, while also strengthening the embankment behind the dunes between these two defence lengths. However, to take this forward over the long term is not seen as being sustainable. There would be a severe impact on the character of the area and substantially greater reliance on the integrity of the defences.

A further option has looked at reclamation within of the harbour. The aim of this approach would be to create greater width within which higher defences could be established without having such a significant visual impact on the character of the area. This option (S3) could provide a high standard of defence to the village and while changing the character and use of the area could offer other opportunities for developing use of the area. This option is significantly more costly and would need to be developed through discussion with the local community. The option is only set out in general outline.

An alternative approach (S2) is for realignment of the main defence line, such that the intent would be to in effect abandon DU4 as a front line defence to the village. The aim is not necessarily to abandon the wall and road, although this might be seen as a long term option, but to realign the main flood defence to provide protection to the main village area. Properties directly behind DU4 would remain at risk to the same standard as at present. An embankment would be constructed to the north of these properties. These works, together with work to improve the northern section of defence, could be developed upon in the future, providing typically a defence standard to a 1:50 year level in to the future. These options are discussed in the Local Area Report, with outline drawings showing how the options could be developed.

Table 4.8 provides an overall comparison of the three options, briefly summarising the benefits and disadvantages concluded above.

Table 4.8 Comparison of Strategic Options

Strategic Option		Benefits	Disadvantages	Present Value Cost (£k)
S1	Raise the level of defences	Provides a basic 1:50 year standard of defence, based on existing structures. Improvement to defences would be carried out in line with sea level rise.	Very significant visual impact. Increasing difficulty and cost in continuing to raise defences in the future. Disruption to use of the harbour. Limited opportunity to adapt use of the area. High dependency on defences. Continued damage on more severe conditions. (£1.8 million PVd)	1,996
S2	Raise levels of defence to the north with set back embankment. Abandon DU4 as a main defence.	Provides a basic 1:50 year standard of defence to the min village. Opportunity to adapt future works in the future, timing based on sea level rise. Sustainable in the long term.	No additional defence to properties behind DU4. Need to redesign traffic network. Continued damage on more severe conditions and potential loss of use of properties behind DU4. (£1.8 million PVd)	1,241
S3	Reclamation	Provides a basic 1:250	Significant change to the	£6,988

within sections of the harbour.	year standard of defence. Opportunity for developing use of the area. Sustainable in the long term.	character of the area. High cost.	

4.9.6 Recommendations and Action Plan

It is recommended that works are undertaken to improve the standard of defence to the village.

The recommended option is for realignment of defences in addressing the flood risk from DU4, and the construction of an embankment to the north. Associated with these works would be the need to improve the standard of defence to DU2 and, overtime to improve defence behind the dune system at DU3. There would be the need to examine possible transport routes through the area and in the longer term to improve defence to the south behind DU5.

There is scope for more immediate works to reduce wave action causing flooding along DU4 and to locally improve the condition of DU2. These works would be compatible with the main option, supporting continued use of the road and area behind DU4. Improvements to DU2 would be incorporated within further improvement to DU2. The sub-option for reducing wave action would need to be examined in more detail.

4.10 Baie de Port Grat and Pêqueries

4.10.1 General Description

A location plan is provided in Figure 4.15. The frontage is divided into 10 Defence Units with the area of Port De Grat and Pequeries, together with the further unit (DU1) within the Le Grande Havre area (CU12).

Baie de Port Grat, including the low lying land of the Rousse headland, and Pêqueries, CU11 and 12, are located on the northwest coast of Guernsey (Figure 1.1). The frontage in general comprises a series of small bays between harder headlands. There is significant development at both Pêqueries and behind Baie de Port Grat. These areas are largely protected by a ridge of land between the shoreline and the road. Just within Le Grand Havre there is a short section of low defence protecting a potential flood risk area to the back of Baie de Port Grat.

The area is important for casual recreational use, mainly for walking around the open ground of the headlands. The area behind the Rousse Headland contains a small boat park and car park, with a small slipway and jetty servicing moorings in the lee of the headland. The main coastal road serving the north west of the Island from Cobo Bay to Pembroke Bay, runs along the coast behind Portinfer (DU7), Baie de Pêqueries (DU8) and Baie de Port Grat (DU10), before turning inland behind Le Grand Havre. At Rousse, the eastern end of the unit, the most prominent feature is the Napoleonic loopholed tower and adjoining open battery, built on the summit of the headland.

Both Portinfer and Baie des Pêqueries provide suitable intertidal feeding areas for a range of wading birds. Further to the north east, Pulias Pond is immediately behind the storm beach at the back of Baie de Pulias, and often is exposed to saline water at high tide. The site, which is a Site of Nature Conservation Importance (SNCI), provides suitable feeding for a number of bird species including little egret, little stint and occasionally night heron.

4.10.2 Environmental Conditions.

Water levels for the frontage are based on levels for St Peter Port, adjusted to take account of lower levels shown to apply to the northwest coastline as set out earlier in Table 3.1.

The main open coast frontage is exposed wave heights in the order of 3m, for local generated waves, and to 3.5m, for swell waves. Both wave types at the open coast are predominately from the north westerly direction with a minor spread in direction observed for wind waves.

Within Le Grand Havre, the wave climate is significantly lower than on the open coast, reducing further within the lee of the headland. Even under these conditions, a significant swell and locally generated wave height can approach the critical frontage, leading to the observed local erosion around sections of the frontage.

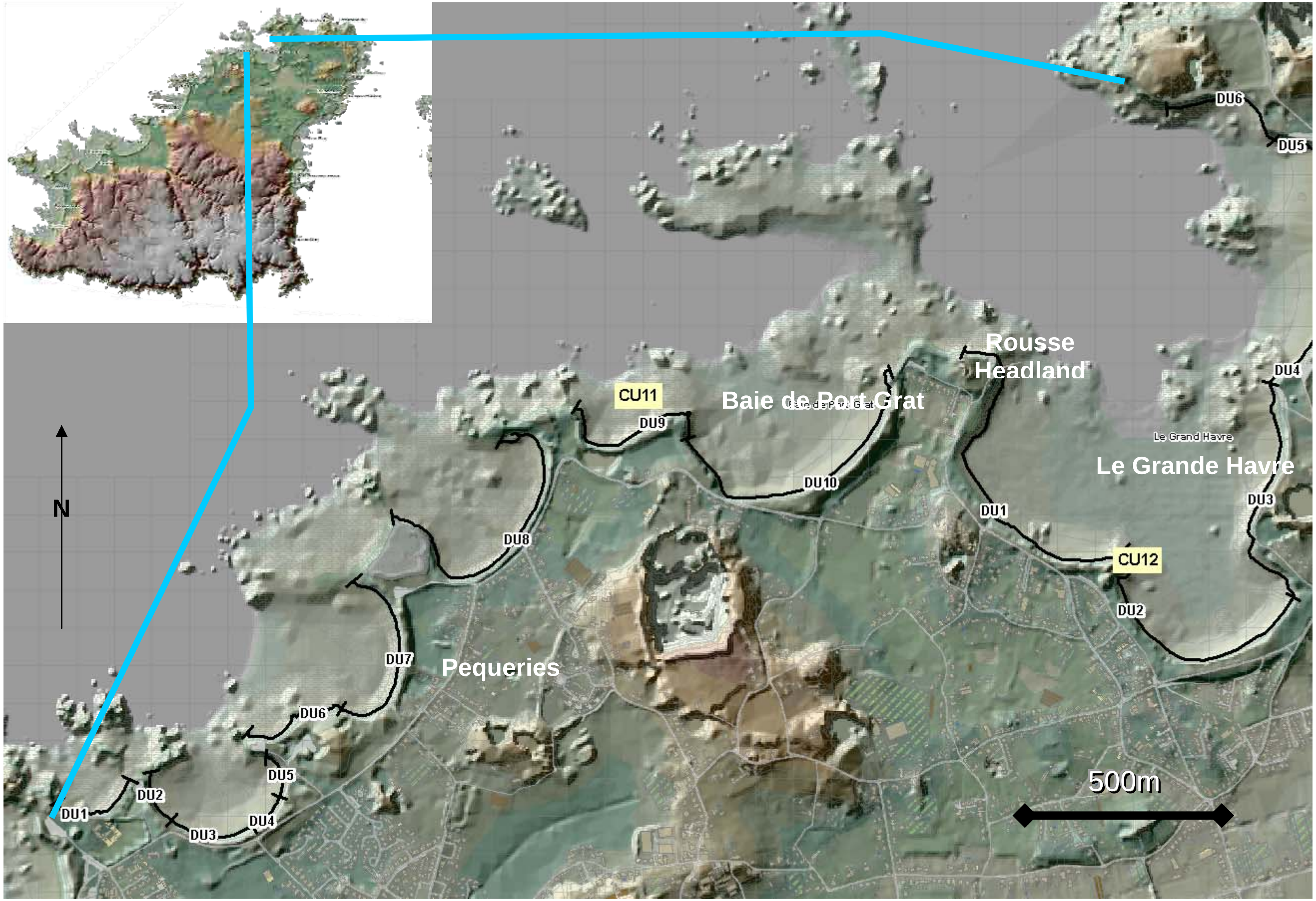


Figure 4.15. Rousse Headland, Baie de Port Grat and Pequeries

4.10.3 Defences.

Much of the critical frontages in relation to flood risk are defended by rock revetments, with local shorter sections of sea wall. The rock revetments typically are in moderate to poor condition, particularly on the seaward face of Rousse Headland. The defences act both as protection against erosion as well as providing a flood defence.

Within Le Grande Havre the defence comprises a low earth bank and road.

4.10.4 Overview of Flood Risk

There are two principle and distinct flood risk areas covered by the frontage, that to the north behind Baie de Port Grat, linking through to the central area of the Rousse Headland and potentially beyond to the central valley cutting across the Island, and more locally to the area around Pequeries. In addition there is identified a more local risk issue occurring at DU5 to the south of this area, shown in Figure 4.15.

The potential extent of flood risk is shown in Figure 4.16. This shows the areas at risk for the present day 1:10, 1:50 and 1:100 year return period events.

The modelling shows that only on an extreme event with anticipated sea level rise (over possibly the next 50 to 100 years) is there a significant risk that flooding from the Baie de Port Grat area would contribute to flooding more generally across the main northern section of the Island.

At Rousse Headland there is a significant risk to properties within the low lying land, with the potential threat coming both from the west and the east sides of the headland.

The ridge of land running along the northern section of the Baie de Port Grat, is clearly indicted as a significant barrier to flooding. This barrier is under pressure from erosion.

The village at Pequeries is very vulnerable to flooding even under present day extreme water levels and that this vulnerability comes from both overtopping along the main frontage (DU8) as well as from frontages to the north (DU9) and the south (DU7). The extent of flooding to this area is limited by higher ground behind. Flooding in this area would cut off the main coastal road.

A summary of potentially affected property is shown in Table 4.9 and 4.10, covering the areas of Rousse Headland and Pequeries respectively.

The Local Area Report for this section of the coast provides a more detailed discussion of both the defences and the sensitivity of flood risk.

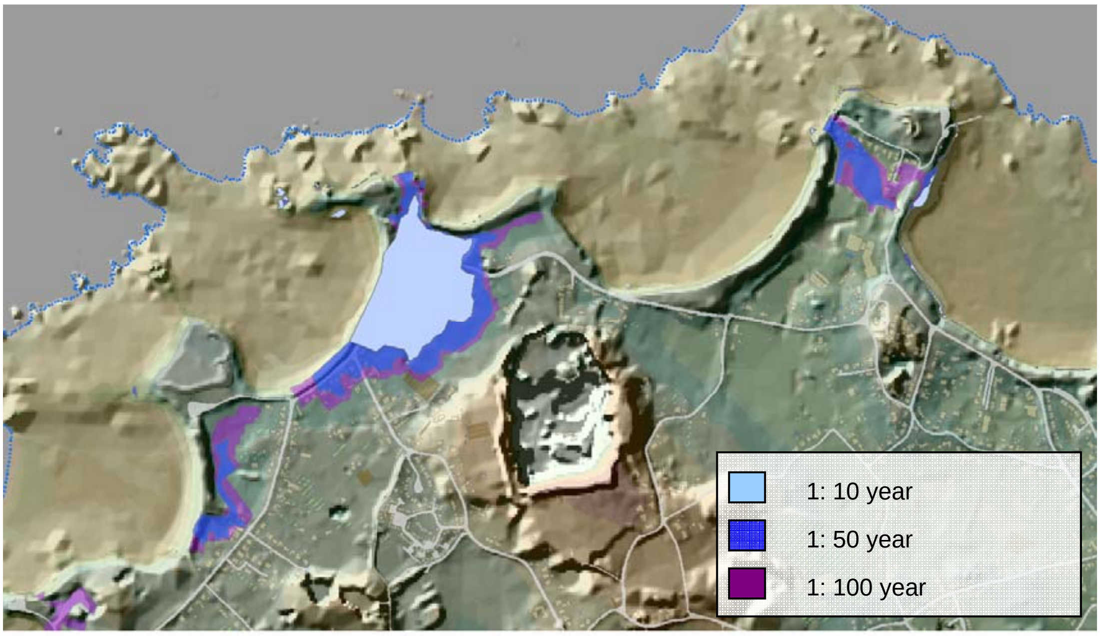


Figure 4.16. Flood Risk Areas

Table 4.9. Properties currently at risk of flooding from at Rousse Headland.

Return Period	Number of Properties At Flood Risk
1 in 1	0
1 in 10	0
1 in 50	14
1 in 100	27
1 in 250	39

The discounted economic damages would amount to some £1.3M.

Table 4.10. Properties currently at risk of flooding from at Pequeries.

Return Period	Number of Properties At Flood Risk
1 in 1	0
1 in 10	10
1 in 50	34
1 in 100	48
1 in 250	71

The discounted economic damages would amount to some £4.7M.

If there should be a breach occurring as a result of over topping in either location, then damages may be increased.

4.10.5 Management Summary Conclusions

The modelling has shown that there are two main areas of flood risk within this area: to the Rousse Headland and to the village of Pequeries. These areas are not directly connected, apart from the flood risk to the coastal road which links communities along the coast. There is a small risk of local flooding from the defence in the south at DU5.

With respect to the two main areas:

- At the Rousse Headland, properties at risk are located in an area of low lying land, in some places below normal tide level, with the risk that a sudden failure of defences could isolate properties and result in serious flooding. The most imminent risk of failure is from the section of defence to the northwest side of the headland, where the existing defence is in poor condition. On higher water levels the short section of defence within Le Grande Havre would also be overtopped by still water level. It is concluded that there is, therefore, both economic risk to properties and that the sudden on set of flooding could result in risk to life.
- At Pequeries, there is risk of quite regular overtopping of the main defence to the main bay. This could result in flooding to the low lying land to the north of the village, affecting some properties in this location and affecting the coastal road. This area could also be affected by flooding occurring from defences to the north along DU9 and the headland to the north of the Pulias Pond. The risk increases significantly on higher water levels, affecting a larger section of the village. The existing condition of the rip rap defence along the main bay, together with the narrow width of the embankment behind, means that severe overtopping could result in breach of the defence. In addition to the main sections at risk there is a risk of flooding from the south (DU7) which develops on higher water levels.

While it is concluded that, in both areas, the flood risk area is local, in the longer term, with sea level rise, the risk of flooding at the Rousse Headland could result in wider flooding in to the large low lying valley cutting across the northern part of the Island towards St. Sampson. This risk would substantially increase if there were erosion of the substantial bank behind the defence to Baie de Port Grat.

The nature of defences in the area means that options for management, in outline, are quite limited. In both areas only one strategic option for continued management has been considered; in both areas this is for improvement to existing defences. In the case of the Rousse Headland, to sustain future long term management of the area, there is little option but to continue raising defence levels and this will mean that there will be increased reliance on these defences. As such, there will continue to be a serious residual risk that defences are overtopped on events greater than the designed standard of defence. This needs to be considered in terms of long term planning of further development in the area. The aim of the strategic option for management is based on providing a consistent standard of defence to a level of a 1:100 year return period.

In the case of Pequeries, the long term sustainability of defence needs to be considered in relation to actual sea level rise. There is more scope for long term adaptation of the village, in that much of the village is to rising land behind the coastal plain. The main risk is to the sea front properties and the coastal road. In developing an approach to management, the option for defence looks to provide defence to a 1:100 year standard over the next fifty years, with the need to review the approach over the longer term.

The management approaches are summarised in Table 4.11.

Table 4.11 Summary Strategic Options

Strategic Option	**Benefits**	**Disadvantages**	**Present Value Cost (£k)**
The Rousse Headland/ Baie de Port Grat			
S1 Improve defence to the north of the headland and raise the level of existing defence. These works assume that long term erosion defence of Baie de Port Grat continues.	Provides a basic 1:100 year standard of defence, based on existing structures. Opportunity to phase works in response to sea level rise.	Continued significant residual risk. Low economic benefit – (damage avoided PVb £1,313k), relatively high cost. Modification of road to the Headland and some adaption of boat yard.	1,013
Pequeries			
S1 Improve and raise defence to main bay. Construct new embankment to north and future improvement to defence from the south.	Provides a basic 1:100 year standard of defence over the next 50 years.	Little opportunity for phasing work (minor improvement possible). Continuing residual risk. Relatively low economic benefit – (residual risk £81k, damage avoided PVb £4,650k), relatively high cost. Concerns over long term sustainability.	2,124

In addition to the above it is concluded that the flood risk identified in relation to DU5 is relatively minor and that no works would be required immediately to this area. This would need to be reassessed in relation to sea level rise.

4.10.6 Recommendations and Action Plan

It is recommended that the results and conclusions of the study are used to initiate consultation on long term management of the key areas at risk.

In the case of the Rousse Headland, the more immediate risk is seen as being in relation to the condition of defence to the northwest of the headland. However, in addressing this it is recommended that local improvements are examined in detail in relation to the bank within Le Grande Havre to ensure that the standard of defence is to a consistent level. It is recommended that works are undertaken in this area to address potential weak areas and that alongside this, work is undertaken in a manner such that further improvement may be undertaken over the next 20 years.

It is further recommended that, in association with the future works to the area inside Le Grande Havre, a new flood embankment is constructed behind the erosion protection on the northwest face of the headland.

The breakdown of costs are shown in Table 4.12.

Table 4.12. Estimated costs of phased work, Rousse Headland

Element			Construction cost + fees (£k)	Optimism Bias (£k)	Discounted cost (£k)
	Description	Year			
L1	Improve defence to Les Dicqs road (L1a, b, c) Improve condition to rock revetment (L1d).	0	392	235	627
L2	Raise defence to les Dicqs road (L2a, b) Embankment to south (L2c) Embankment to west (L2d).	20	424	254	353
Additional works					
Maintenance					33
				Total discounted cost	**1,013**
			Total capital cost	***£1,305***	

At Pequeries, it is recommended that the main works of improving the main defence and construction of the embankment to the north are constructed over the next five years. In the interim, the condition and response of the main revetment would need to be monitored and particular attention should be paid to flood warning for the area. Associated with these responsive measures, there may be the need to carry out local repairs to the existing revetment if damage occurs. Any such works should be undertaken in such a manner that they may be sensibly incorporated within a longer term design. This would include selection of suitable rock armour for any works such that it is of a size appropriate to longer term design requirements.

The breakdown of costs for the staged works are shown in Table 4.13.

Table 4.13. Estimated costs of S1, Pequeries

Element			Construction cost + fees (£k)	Optimism Bias (£k)	Discounted cost (£k)
	Description	Year			
L1	Improve rock revetment L1a Construct northern embankment L1b	0	1,282	769	2,051
L2	Embankment to south (L2a)	20	88	53	40
Additional works					
Maintenance					33
				Total discounted cost	**2,124**
			Total capital cost	***£2,192***	

There will continue to be a serious residual risk that defences are overtopped on events greater than the designed standard of defence. This needs to be considered in terms of long term planning of further development in the area. In the case of Pequeries, the long term sustainability of defence needs to be considered in relation to actual sea level rise. There is more scope for long term adaptation of the village, in that much of the village is to rising land behind the coastal plain. The main risk is to the sea front properties and the coastal road. In developing an approach to management, the option for defence looks to provide defence to a 1:100 year standard over the next fifty years, with the need to review the approach over the longer term. It is recommended, therefore, that longer term management of both areas is discussed in terms of planning and development control and that initial consultation is held both between departments of The States of Guernsey and with local residents.

Further detail of the costs and discussion of options is provided in the Local Area Report.

4.11 Cobo Bay and Saline Bay

4.11.1 General Description

A location plan is provided in Figure 4.17. The frontage is divided into 4 Defence Units (DUs) as shown in the figure.

Cobo and Saline Bay form CU10 along the northwest coast of Guernsey. The Bays are flanked by the headlands of Lion Rock and Les Grandes Rocques, with development within the low lying land behind

Development is primarily confined to the coastal strip and the immediate area inland. Adjacent to the coast there is a lowland area between the two bays that has limited development, but functions as an important local playing field amenity. Further development inland of Cobo and Saline Bays is mostly confined to the low lying land with some development of the higher ground to the immediate south. The main coast road serving the west coast of the Island runs along the coastal strip, running immediately behind the seawall and in front of the sea front properties.

As stated in the 2007 Strategy, the coastline in this area is heavily defended with a combination of masonry seawalls with intermittent toe protection and larger concrete military enclosures from the Occupation of the Island. The seawalls are fronted with a mixed sandy and shingle beach that varies in width, and which is influenced by the large, nearshore rock outcrops. There is limited longshore sediment movement within the bay resulting in localised drawdown of beach material during winter storms. This process is frequently reversed during calmer summer periods and is a normal annual variation.

The area is one of the key areas for tourism, particularly in relation to the use of the sandy beaches in the area, but also as a centre for use of the adjacent shoreline and headlands. Management of the area has to take account of this coastal use, together with the use of the area for boat launching.

4.11.2 Environmental Conditions.

Water levels for the frontage are based on levels for St Peter Port, adjusted to take account of lower levels shown to apply to the northwest coastline as set out earlier in Table 3.1.

The general coastline is exposed to a combination of swell waves and more locally generated waves from a wide range of directions between southwest and northwest. However, as may be appreciated from Figure 4.17, the two bays gain significant protection from the extended rock outcrops, running over 1km seaward of the actual shoreline.

Waves approaching the shore tend to be funnelled through the valleys between these rock outcrops and waves are focussed by refraction and diffraction on to quite specific sections of defence. Generally, such a process tends to mean that the dominant wave direction at the shore is from the west but with local variation in height and direction with

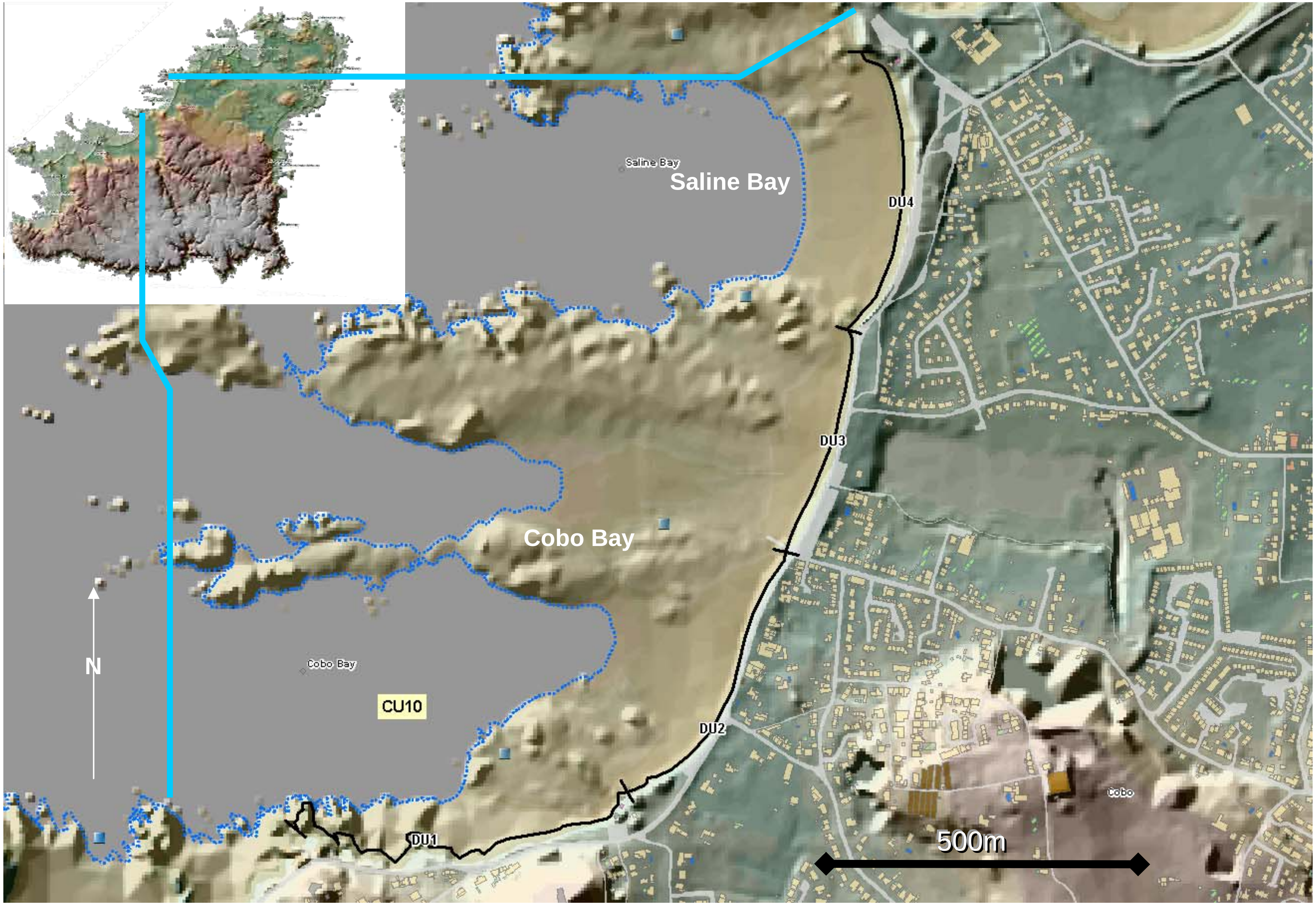


Figure 4.17. Cobo and Saline Bays

respect to the orientation of defences at the shore. This can give rise to specific issues of overtopping, predominantly due to swell waves, to the specific issues in relation to scour and the way in which the beach levels can vary along the frontage. The Local Area Report, presented as an annex to this main report discusses the detailed wave modelling that has been undertaken in examining the sensitivity of the frontage to specific nearshore wave conditions.

4.11.3 Defences.

The defences are generally in good condition and comprise masonry and concrete walls over much of the central and southern sections of the area, with a small length of rock revetment giving way to a natural dune frontage within Saline Bay. The defences over the main area of concern act to reinforce a natural beach barrier in front of lower lying land behind. This is shown in Figure 4.18.

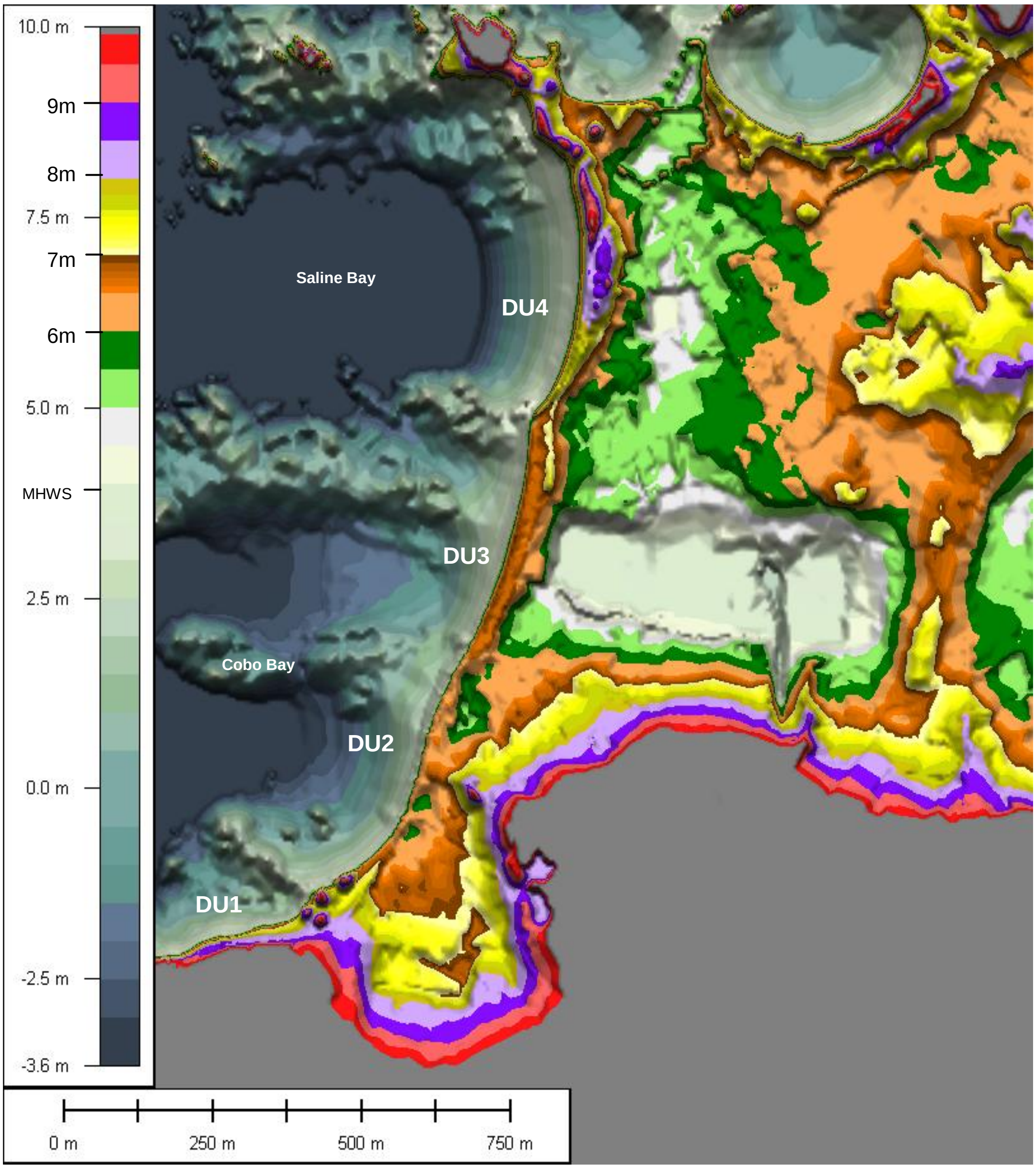


Figure 4.18. General topography of the area.

4.11.4 Overview of Flood Risk

Under present day water levels the main area of flooding is to the central valley. The main risk is predicted to occur from DU2 with water flowing north into the valley. There is some contribution, on the extreme event shown in the figure, for water to be coming directly from DU3 and from a short southern section in DU4.

The frontage is shown as being sensitive to these different wave conditions and this does make statistical determination of overtopping return periods complex. However, this sensitivity reduces as water levels on higher return periods, and with sea level rise, are considered. Along DU2, the typical freeboard of the wall on the 1:1 year event is approximately 2m, above still water level. This freeboard reduces to 1.5m on a 1:50 year water level condition and the modelling indicates a potential ten-fold increase in overtopping as a result.

Overtopping of the sea walls has been observed on a regular basis, in particularly along sections of DU2 and the southern section of DU3. Generally, these locations for overtopping risk on lower return period events, identified through local knowledge, are well represented by the modelling. This is shown in Figure 4.19, showing the predicted (modelled) areas of overtopping on an annual basis. However, it is also recorded that there has not been significant wider spread flooding in recent times. Clearly the ability for water to drain back seaward from the road will alleviate the risk of flooding over a wider area. The various walls to the landward side of the road behind DU2, together with the presence of properties and garden walls within the critical flood pathway would be a major factor in restricting wider spread flooding and encouraging seaward drainage to happen. On more extreme conditions wider spread flooding would be expected.

Figure 4.19. Model prediction of flooding on an annual occurrence.

Overall, it is concluded that the typical standard of defence against flooding affecting the sea front properties and use of the main coastal road is in the order of a 1:10 year return period and that damage to property and severe disruption may occur on events above this level. The combined standard of defence to the general hinterland, affecting properties and buildings within the main valley, is in the order of a 1:50 year event. This critically depends, in detail, on the integrity of the various local property boundary walls through the area behind DU2, acting as a flood defence.

Over the next 20 years with sea level rise, the combined standard of defence would reduce to a 1:10 year return period.

The risk to the actual integrity of the sea walls and defences is less imminent, although the variation in beach levels at present can expose the sheet piled toe to DU2. Maintaining the condition of the defences is clearly critical and the above assessment is made on the basis that existing defences are maintained.

The general flood risk on higher return periods for the whole area is shown in Figure 4.20. Table 4.14 sets out the properties potentially at risk based on the model results.

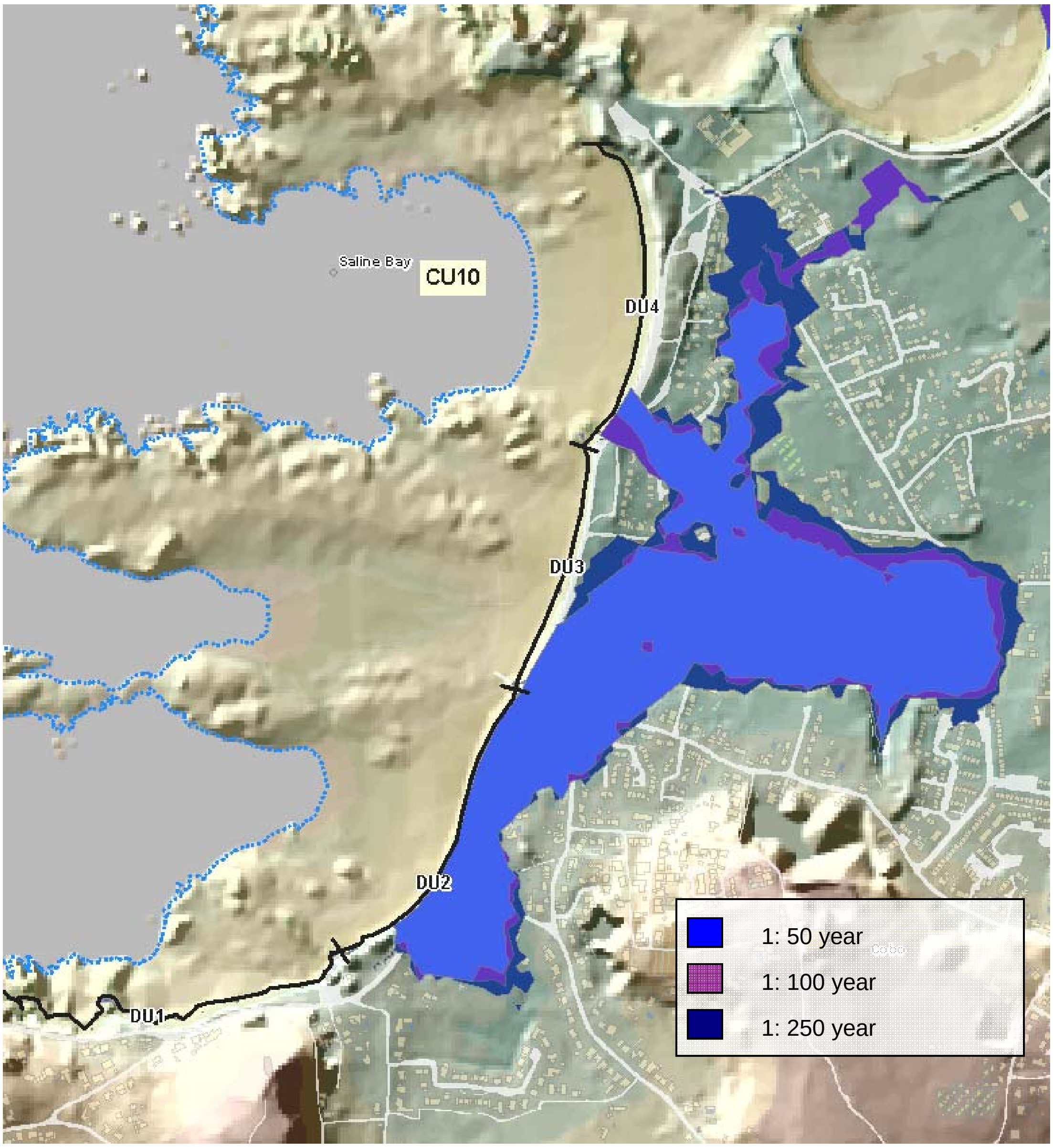


Figure 4.20. Flood Risk Areas

Table 4.14. Properties currently at risk of flooding at Cobo and Saline Bays.

Return Period	Number of Properties At Flood Risk
1 in 1	41*
1 in 10	124
1 in 50	154
1 in 100	181
1 in 250	265

- Note. At the 1 in 1 year return period results indicate that 41 properties in the immediate Cobo Bay area are currently as risk, primarily as a result of overtopping at DU2. These properties are located along the flood water flow path behind DU2. This would depend on the effectiveness of local property walls which have not been accounted for in the modelling.

4.11.5 Management Summary Conclusions

The study has highlighted the potentially significant risk to property and the coastal road within the area. Modelling indicates that the typical standard of defence is in the order of a 1:10 year return period event. This has been assessed in relation to local reports of flood incidents and the overall assessment is that the defence standard for the area as a whole, including the onset of significant flooding to the low valley within the centre of the village, may be more realistically set at a 1:50 year return period event. .

This takes into account the complex interaction of specific wave direction causing critical conditions for overtopping and the combination of assessing return period of swell and locally generated waves.

One area of specific concern, however, is to the area defended by DU2 across the southern section of the village. With respect to the defence itself and the road immediately behind, it is recorded that overtopping occurs several times a year. Here, the defence standard locally, immediately behind the wall is in the order of a 1:10 year return period event, at which point there are serious flooding issues that might affect local properties and use of the road.

The modelling has indicated, at this location, that there is a flood route through from the sea front to the low lying valley area and that in excess of 100 properties could potentially be affected. The modelling has not, however, included the various private boundary walls to properties at the sea front and through the built up area; this being at a level of detail beyond the scope of this strategic study. Subject to detailed examination of this critical area, therefore, the study concludes that with respect to the wider area this combination of formal and informal defences provides a standard of defence in the order of a 1:50 year level. The potential economic damages, discounted over the next 100 years, amount to some £71 million.

Over the short term, it is concluded that, while local flooding is a significant issue, with appropriate flood warning put in place the present situation can be managed with potentially acceptable levels of economic damage.

The extent and risk of flooding is critically dependent on water levels. The modelling has shown that the possible volumes of water overtopping defences, at DU2 and along the other critical sections of defence (the southern sections of dU3 and DU 4) increase substantially between a 1:50 year condition and 1:100 year condition. Over the next 20 years, with sea level rise, therefore, the flood risk will increase to a level that may be considered unacceptable.

In considering potential options to address this, two strategic approaches have been considered. The first (option S1) considers raising existing levels along critical areas of defence. The second (option S2) develops in outline an approach using nearshore breakwaters and beach replenishment. This second option builds upon the natural shape of the bays to reduce wave impacting on the existing defence line. The two options are summarised in Table 4.15.

Table 4.15 Summary Strategic Options

Strategic Option		Benefits	Disadvantages	Present Value Cost (£k)
S1	Raise defences levels to DU2 and DU 3, with minor improvements to the southern corner of DU4.	Provides a present day 1:100 year standard of defence, based on existing structures. (this would decrease over time).	Continued significant residual risk. Difficult to sustain the defence standard even in the medium term and consideration would have to be given to adaption of land use. Significant visual intrusion on the frontage and potential loss of amenity beaches in the future.	2,925
S2	Construct nearshore breakwaters with beach replenishment. Lower raising of wall to DU2.	Provides a basic 1:100 year standard of defence which may be sustained in the future. Potential amenity improvements, with wider beach area, and maintained low sea walls. Opportunity to adapt the outline position of breakwaters to improve and accommodate boat use. Some opportunity for phasing works. Reduces maintenance of existing defences.	Very high cost (although providing still a good cost benefit). Significant change to the aspect of the frontage.	25,945

If works were delayed over the next twenty years consideration could be given to local improvement to DU2 in the interim and this would remain compatible with the longer term strategy.

4.11.6 Recommendations and Action Plan

In term of strategic options:

- Option S1 is considered to be unsustainable in the long term as is not seen as delivering an acceptable approach in maintaining the use and amenity of the area.
- Option S2 is considered to provide a viable long term approach to management that delivers both an acceptable level of risk reduction and potential wider benefits to the area. This strategic option is therefore recommended.

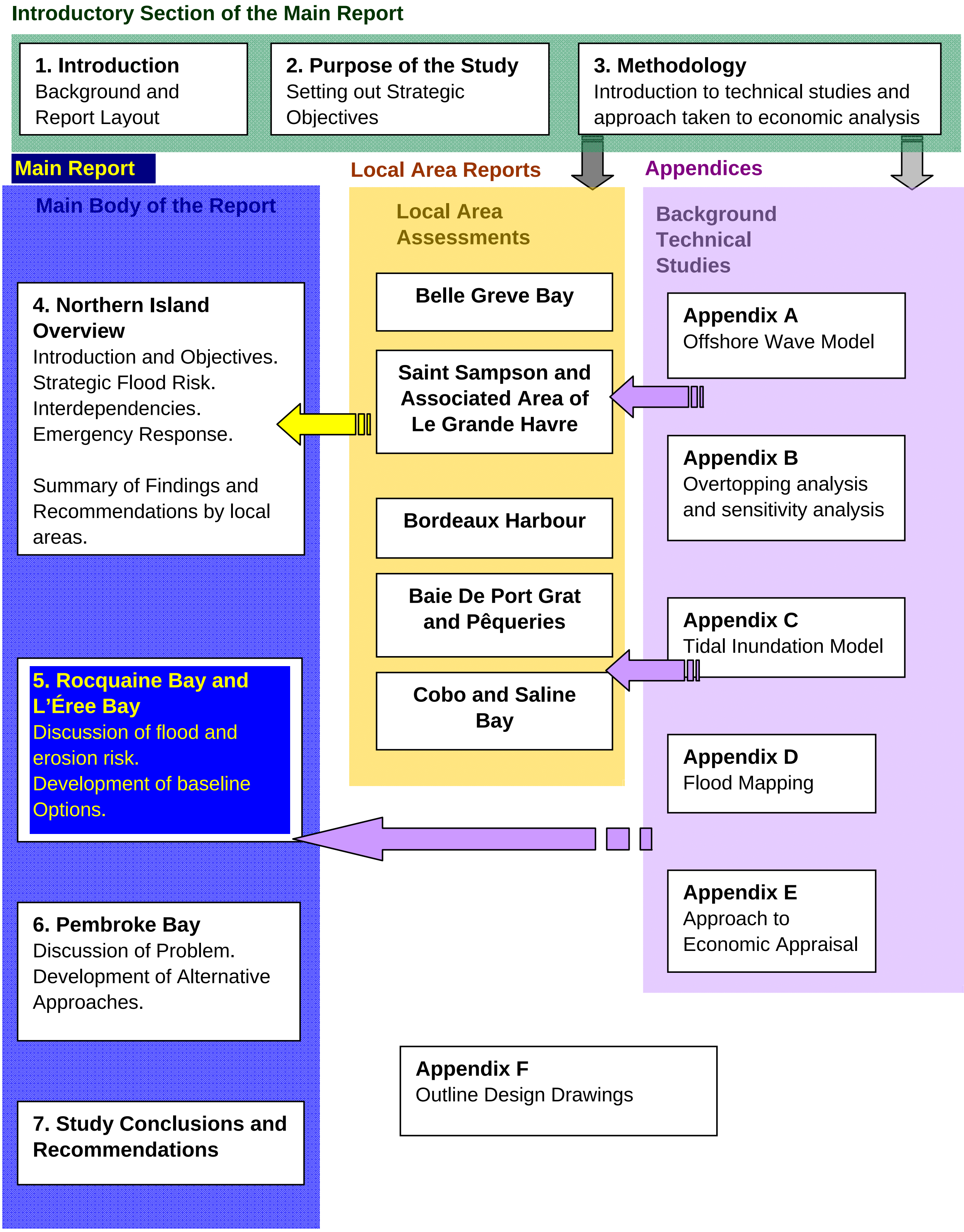
If present levels of risk as discussed and assessed in this document are considered acceptable, then it is recommended that option S2 is developed further in detail such that works are undertaken within the next 20 years.

A delay of 20 years may be considered acceptable if an appropriate flood warning system is put in place to address the immediate risks on more severe wave and water level conditions.

Furthermore, it is recommended that a detailed examination of private defences walls, condition and level, is undertaken over the line of the potential flood route to the rear of DU2. Consequent to this survey, local improvements might be carried out to DU2 with the potential to raise the wall by some 0.5m to reduce both the general risk to the wider area and to address more frequent flooding to the road and potentially to properties along the sea front.

It is further recommended that the results and conclusions of the study are used to initiate consultation on long term management of the area to gain an understanding of issues that may influence the design and placement of nearshore breakwaters. Associated with this is the recommendation to continue to monitor beach levels and, more generally, to monitor sea level rise.

OVERALL REPORT STRUCTURE



5 ROCQUAINE BAY AND LÉREE BAY

5.1 Introduction

This section of the report deals with the more specific issues and problems associated with Rocquaine and L'Erée Bay. The study area extends 1.9km between Fort Grey and L'Erée Headland and includes both Rocquaine Bay and L'Erée Bay (Figure 5.1). The frontage has been divided into 5 Defence Units (DUs), these are shown in Figure 5.1.

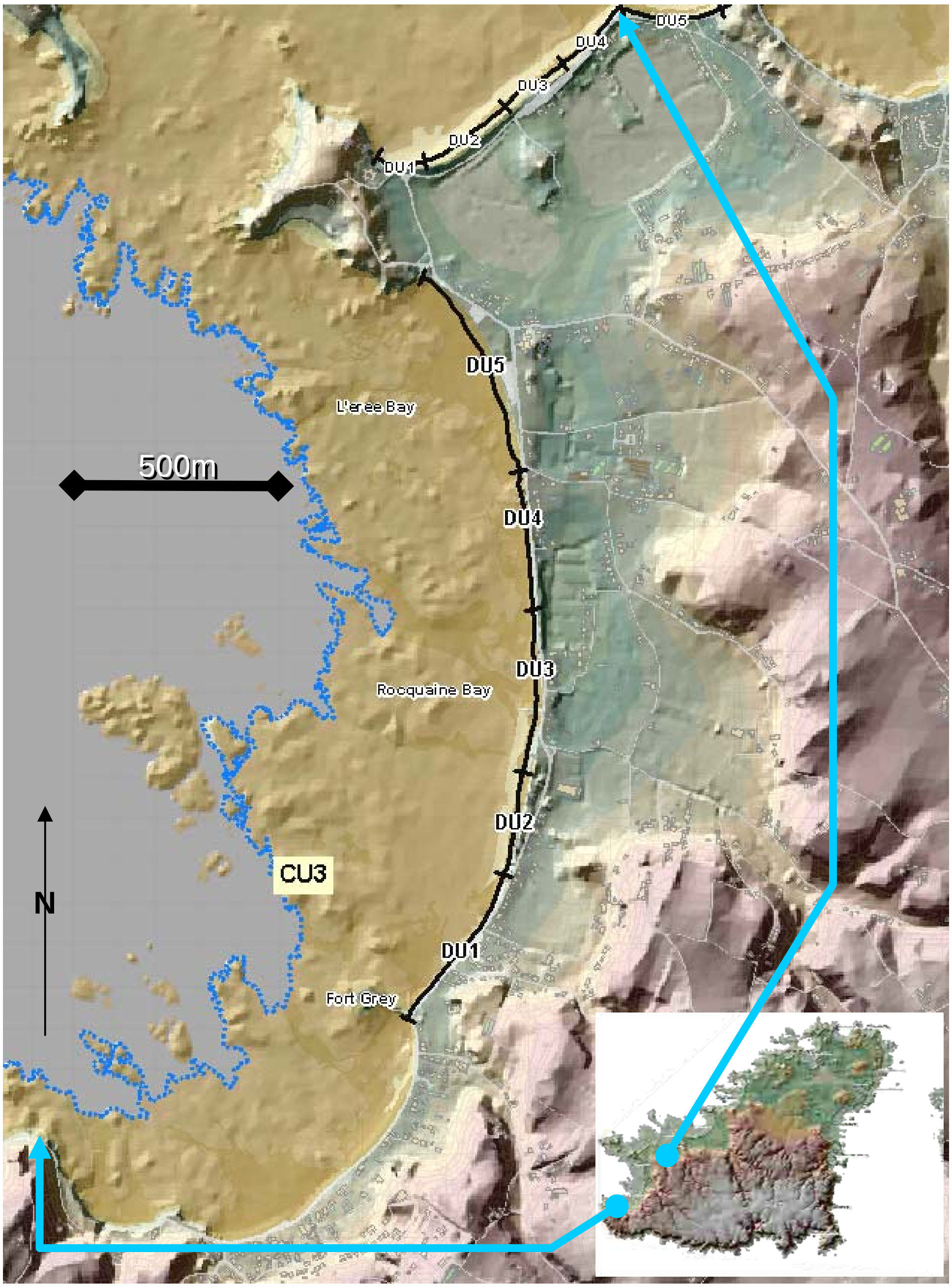


Figure 5.1. – Location plan of Rocquaine Bay.

Sections of the area are subject to flood risk and there is concern over the behaviour of the beaches and how this reflects on management of defences. In addition, the 2007

Strategy identified and discussed concerns with respect to the condition and integrity of the defence covering DU4 and the northern section of DU3, highlighting the need for specific works to address this problem.

This section of the report, therefore, considers the more general aspects of risk management over the whole area but takes this into more detail in considering the options for specific defence improvement along the vulnerable central section of the frontage. To the north of the area is the ecologically important Ramsar site. The potential management impacts on this area are also considered.

5.1.1 Review of Issues Identified by the 2007 Strategy

The Strategy identified different problems associated with different sections of the frontage. These issues are highlighted in Figure 5.2 and are summarised below.

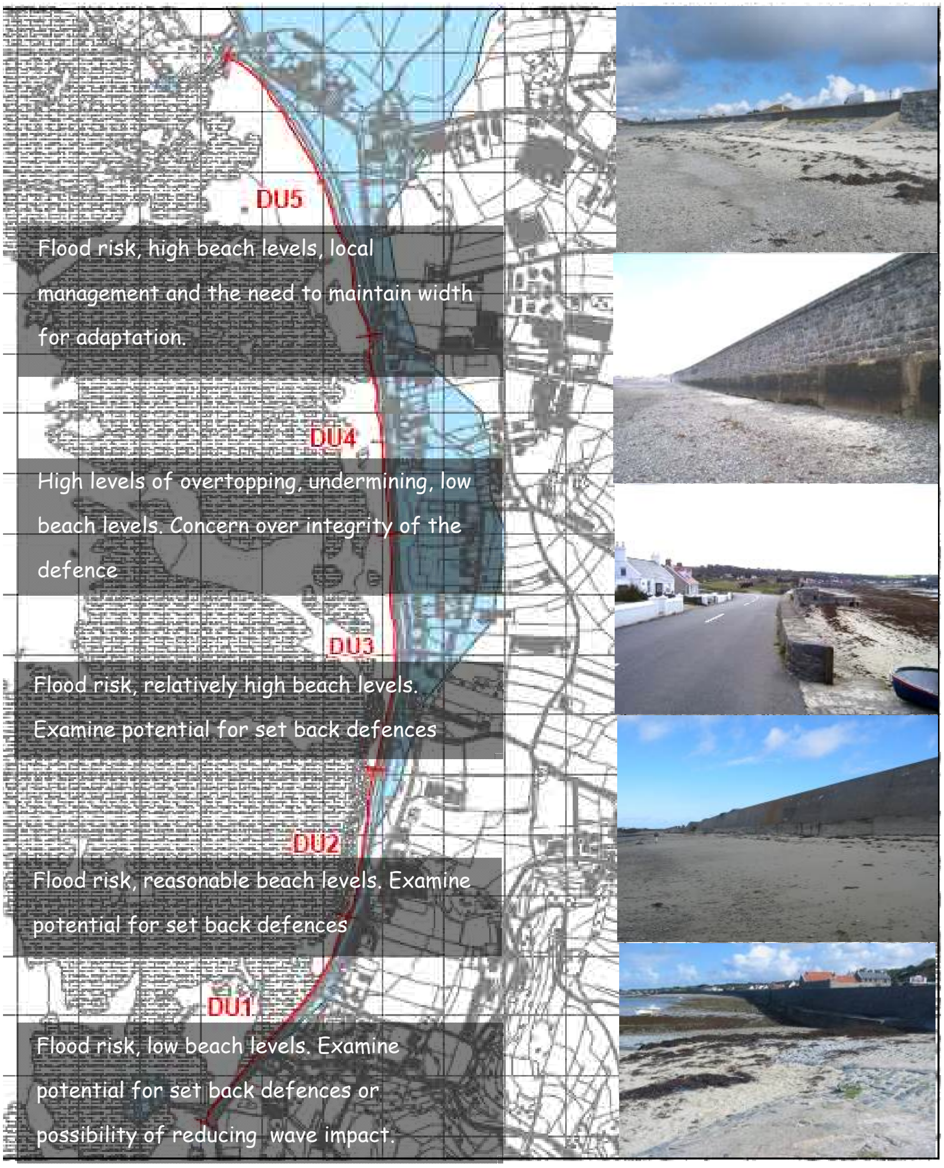


Figure 5.2. Summary of issues from 2007 Strategy.

- At the northern end of the Bay, while there has been seen from monitoring, significant movement of sediment and change in beach profiles, this area was considered to be relatively stable. The main issues identified were how the defence approach might be improved to maintain better protection to the existing sea wall and to what degree defences might need to be raised to address potential flooding and longer term response to sea level rise. There was also an issue directly influencing the risk to this area in relation to the future recommended policy of managed realignment for the bay to the north of the L'Erée headland.
- Within the centre of the bay, the main issues were seen as being the threat to the massive seawalls covering DU4 and the northern section of DU3. Coupled to this was the issue of overtopping.
- To the southern section of the bay, there was local variation in the level of the beach along the frontage. While this was seen as being a longer term issue in relation to integrity of the wall, there was significant risk of overtopping in this area.

To address these various elements of study, the initial sections of the report describe the general condition of defences and how this relates to the understanding of the behaviour of the coast, alongside an examination the flood risk.

This is followed by a discussion of outline management approaches, reviewing in more detail the recommendations from the 2007 Strategy. This is followed by a more detailed analysis of the issues relating to the wall at DU4, assessing different scheme options and making specific recommendations for safeguarding defence in this area.

5.2 Description and Base Line Information

5.2.1 General

The local community comprises a mixture of residential development, small holiday rental accommodation, glasshouses and general agriculture. The coast road, as along much of the west coast, runs fairly closely to the perimeter of the bay, with only limited areas of semi-natural coastal habitat now remaining immediately behind the defences.

Although not as important for recreational activity as some of the bays further to the north, Rocquaine Bay is still well used, particularly at its northern end. Here the sandy beach in the lee of the L'Erée headland provides safe swimming and is attractive for a wide range of beach activities. There is a large car park and picnic site located at the northern end of the unit opposite the L'Erée Hotel. Boat launching and access to the beach is well catered for, with four slipways situated at various points within the Bay. The relative shelter provided by Fort Grey makes this a popular mooring area for small fishing and pleasure boats.

The 2007 Strategy defines this area as CU3 and identifies that the management intent is to maintain the current defences to the area and the assets in the area. However, the strategy acknowledges that in some areas there may be potential for realignment or incorporating a set back form of flood defence protecting the low lying areas behind the road. Any defence approach will need to consider how to reduce the wave overtopping and maintain/improve the current seawalls stability.

To the north of the study frontage is the important Ramsar site, this is described below.

5.2.2 Ramsar Designated Site

Located slightly inland from L'Erée Headland, the 426 hectare Ramsar site encompasses La Claire Mare, La Rousse Mare (the Colin Best Nature Reserve), the shingle bank Les Anguilieres, the western end of L'Erée Headland, Lihou Island and the area of coast between the northern end of L'Erée and Le Catioroc including La Chapelle island. The seaward extent of the site is bounded by straight lines between the highest points of various reefs and rocks (Figure 5.3).

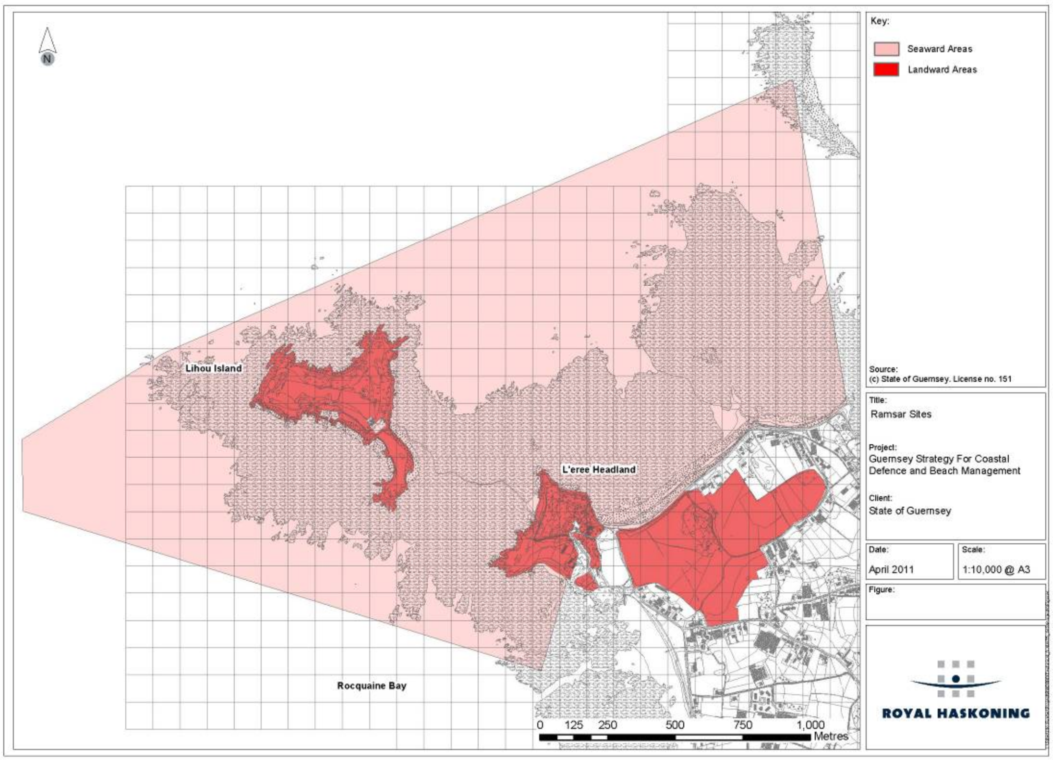


Figure 5.3. Key attributes of the Ramsar site.

The site contains an amazing variety of habitats including rocky, gravely and sandy shoreline, the sublittoral zone, coastal grassland, salt marsh, reedbed and saline lagoon, vegetated shingle banks, seagrass *Zostera beds* and wet grassland, which are internationally threatened habitat types. The area also has a rich cultural heritage with many important archaeological and historical remains, and L'Eree Headland has been identified as one of 11 Areas of 'Geological Importance' in Guernsey.

The site management plan is currently in draft and therefore there are no confirmed conservation objectives in place at present. However, the management plan will integrate a number of existing management plans for the area including the draft management plan for Lihou Island, the Shingle Bank management plan, and management plans for the La Société Guernesiaise reserves of La Claire Mare and La Rousse Mare. Conservation objectives within these plans include:

- Maintain & enhance mosaic of habitat types;
- Maintain & enhance botanical diversity;
- Maintain & enhance animal diversity, especially of breeding species;
- Safeguard all notable plant & animal species;
- Ensure provision of adequate sea and flood defence;
- Allow scientific study & research;
- Safeguard site for the future; and
- Education.

The Ramsar site includes a number of features that are vulnerable to external influences and therefore consideration on the effect of human and natural changes on the stability of the ecosystems should be considered. Items contributing to this risk include:

- General disturbance from human activities e.g. shore-gatherers failing to turn rocks back, leading to loss in biodiversity due to exposure to sun/desiccation.
- The Ramsar site contains two patches of saltmarsh habitat, which is extremely scarce in the Channel Islands. The La Rousse Mare saltmarsh is maintained by keeping the drainage sluices partially open, thus allowing seawater to enter under the shingle bank to the north at high tides, flooding the lowest areas of land. Any changes in these drainage sluices will have implications on the saltmarsh habitat.
- Seagrass beds (Annex 1 habitat within the site) are highly sensitive to changes in turbidity and wave exposure, smothering and changes in nutrient levels.
- There very important species-rich, marshy fields on the east side of La Claire Mare, and an area of reedbed that contains some rare and sensitive flora. Any saline intrusion into this area will result in changes to the habitat and loss of the associated sensitive flora and fauna.
- Development within the site may impact up bird species through direct disturbance or though habitat or resource alteration.

The 2007 Strategy highlighted the risk of breaching of the shingle bank along Les Anguilieres and the potential flood risk to the hinterland. The Strategy also highlighted the possible flood risk from the L'Erée Bay frontage due to wave overtopping.

5.2.3 Description of the Physical Features of the Study Area

The bay is formed within the two main headlands at Pleinmont, at the south-western extent of Guernsey and Lihou Island, connected by a causeway to the main island at the north of the study frontage. The larger bay is divided into two sections by the rock outcrop of Fort Grey, the study area being to the north of Fort Grey.

The beach in the area consists of a predominantly sandy upper foreshore with some localised pockets of shingle. The beach to the northern end of the frontage is quite extensive, but beach levels are generally low throughout the southern and central sections of the unit. Rocky outcrops are located lower down the beach towards the low water mark. At the southern end of the bay a small beach has formed in the lee of Fort Grey. The short length of breakwater to the north of the fort is felt also to influence this build up.

The general morphology of the bay together with the hinterland topography is shown in Figure 5.4. The typical nearshore and inshore wave climate is also shown. From the figure it may be seen that much of the northern section of the frontage is formed as a ridge at the shoreline, falling away to lower lying land behind. There is a significant valley running from the higher ground behind the coast, coming down to the coast in behind the southern section of DU4/northern section of DU3. There is a strong indication that this valley (which is infilled with clay) runs out across the foreshore at this point, with a lower section of foreshore and an absence of outcropping rock at low water. The low lying land associated with this valley behind the defences is separated from the low lying land further north by a neck of high ground at the northern end of DU4. There is also an outcrop of rock along the upper foreshore at this location.

Over the southern section of the bay the land levels behind the shoreline tend to rise.

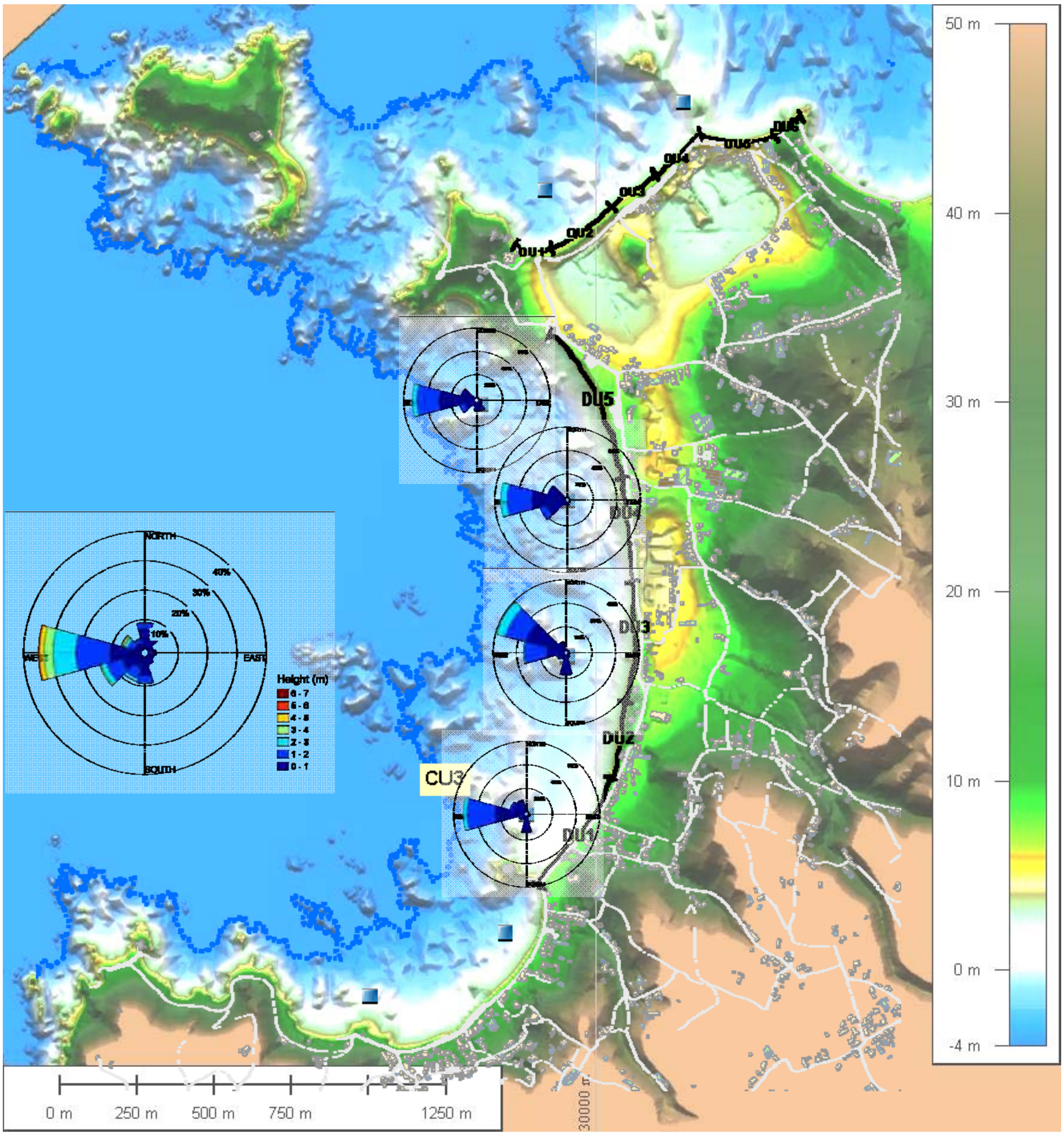


Figure 5.4. general morphology and topography, showing nearshore and inshore wave climate.

5.2.4 Water Levels

The Guernsey hydrodynamic model, produced for this study, has given greater understanding of the critical water levels around the coast (previous estimates have not accounted for spatial variation in water level around the island, resulting from high tidal flows). The extreme water levels analysis indicates slightly reduced water levels over this section of coast compared to St Peter Port. The typical level difference is approximately -0.22 m, as discussed in Section 3 of the report. This drop is consistent with tidal flow from the west southwest and has been used to adjust anticipated astronomic tides for the area. Table 5.1 also accounts for future sea level rise due to climate change, based on the discussion of results of UKCP09 provided in Appendix A.

Table 5.1. Extreme Water levels.

Extreme water levels (return period)	**Still Water Level (m LOD Guernsey)**			
	Present day 2011	Epoch 1 2031	Epoch 2 2061	Epoch 3 2111
250	5.77	5.9	6.19	6.74
100	5.65	5.8	6.07	6.62
50	5.54	5.68	5.96	6.51
10	5.32	5.46	5.75	6.29
1	5.00	5.14	5.42	5.97

5.2.5 Wave Climate

The dominant wave direction for the area is from the west to south west sector for both swell and locally generated wave conditions. Figure 5.4 shows the general wave climate in the nearshore area and the modification of wave direction as waves move into the inshore area of the bay. The figure shows this for wind generated waves, although a similar pattern is seen for longer period swell waves. It may be seen that the local variation in the sea bed causes significant difference in inshore wave direction as waves approach the shore.

It can be seen that the closer the waves are to the shore, the more they conform to a narrower range of directions. The most seaward wave rose shows significant wave activity from 195 to 285 degrees (note that some transformation will have already occurred before the waves enter this area).

Overall the wave modelling shows that the general alignment of the shoreline over the northern section of the bay is quite well aligned to the wave direction as waves bend further as they approach the shore. Over the central section of the bay there is slight misalignment and this would be consistent with the observed trend for erosion in the centre of the Bay. In effect the defence line is forward of where it would naturally wish to be. The curious redirection of net wave direction towards the south would indicate that waves in this area are more significantly affected by the change in elevation of the lower rock outcrops. This is reflected in the lower beach levels at the wall at the northern end of DU1 and the development of the beach just to the north of Fort Grey as sediment is moved south along the toe of the defences.

This variation is seen more clearly from the results from the detailed modelling undertaken as part of the study (Figure 5.5). Figure 5.5 is a more detailed image of wave transformation around Rocquaine, for one wave condition (a 3.6 metre, 10.6 second wave approaching from 210 degrees). As waves approach the shoreline they tend to spread from a westerly direction within the bay, as indicated by the thicker dashed arrows drawn on the model results.

At the northern end of the Bay it can be seen that further transformation of the nearshore waves tend to bring waves more in line with the beach front in this area.

Over the rest of the Bay, at the larger scale, the effects of refraction can be seen in the gradual clockwise turning of the wave direction as it approaches the shore. The importance of shoaling, wave focussing and shadowing can also be seen in the wave heights around the rocky protrusions offshore of the Bay. Diffraction effects are very strong around main southern headland, causing waves to re-orientate towards Portelet Harbour.

At the more detailed level, it is seen that local sections of the defence along the study frontage are out of alignment with the natural shoreline shape. This is very evident in practice along DU4, where the low beach level allows higher waves to impact at the wall, even on relatively low water levels. This is shown in Plate 5.1.

Plate 5.1. Wave impact and spray overtopping of DU4 at lower water levels.

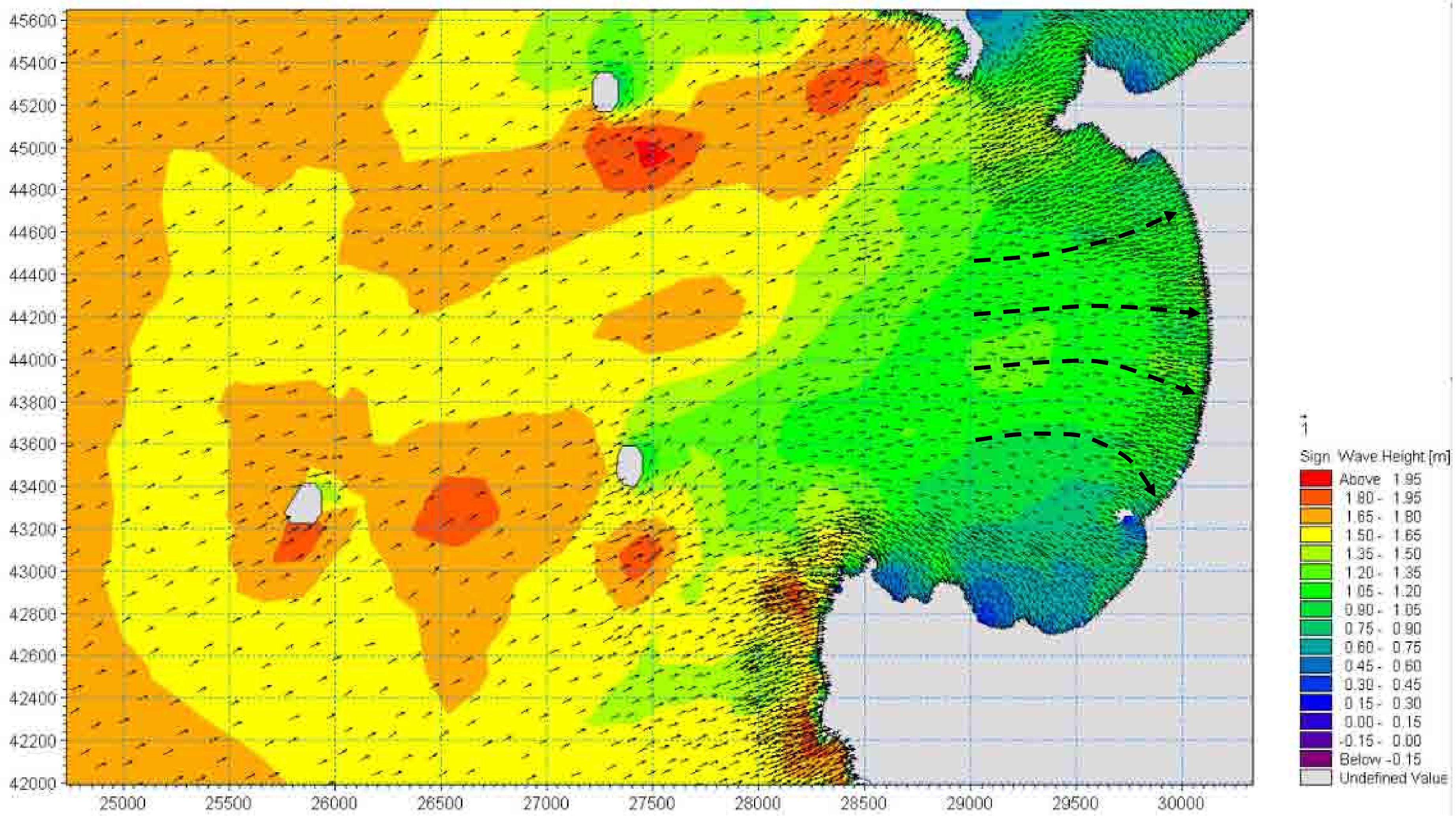


Figure 5.5. Transformation of a 3.6 m, 10.6 second offshore swell wave approaching from 210 degrees; colour indicates wave height, arrows indicate height and direction.

5.2.6 Foreshore and Defences

The entire frontage of this unit is protected by man-made defences; approximately two-thirds are constructed of vertical masonry walls, and one-third is a variety of concrete walls, and includes some defences built during the Occupation of the Island. Plates 5.2 a) and b) illustrate typical defences along the central section of the frontage.

Various lengths of wall throughout the frontage have been modified with additional toe protection in the form of concrete or masonry aprons to protect the defences from the lower beach levels.

Plate 5.2 a and b. High walls along Rocquaine Bay; exhibiting undermining and sheet pile exposure particularly at DU4 (Plate b).

A brief description of each defence unit is provided below, working from north to south.

DU5 (Plates 5.3 and 5.4)
This section typically comprises a low concrete wall with a compartmented masonry revetment down to a relatively high sandy beach. The wall is backed by a concrete promenade with a low crest wall to the rear.

Plate 5.2. DU5 - L'Eree Bay northern section

There is a more vertical section of wall at the northern end of this unit with steel sheet piling.

The land behind the wall is relatively wide but low, falling away to the main coastal road and areas of property. To the rear of this the land falls away further to the marsh land behind the shingle bank Les Anguilieres.

There is a relatively healthy beach covering the unit, although there are occasions when beaches level drop exposing the toe of the revetment. The beach is critical in reducing wave heights and in providing security to the toe of the defence.

The southern section of the units is defined by the change in wall type and the outcrop of rock which has been developed as a slipway, within DU4.

The beach levels to the south are retained to a degree by the presence of the rock outcrop but the general level of the beach does reduce in level, moving into DU4.

Plate 5.4. DU5 looking south from the northern end.

DU4 (Plates 5.5 and 5.6)

This critical section of the frontage comprises as series of high masonry walls behind which is the main road and properties (Plate 5.4). The land behind the road falls away rapidly to the low lying land and valley described earlier.

Of particular concern has been the large seawall comprising the main central and southern sections of DU4. This wall has been undermined and the sheet piling below the massive concrete toe is regularly exposed (Plate 5.6). There is very little detailed documented information showing the construction of this wall, however, the visual assessment indicates that the wall is relatively thin in cross section. Examination of the topographic data indicates that the wall has been constructed across the line of a valley which comes to the coast at this point (discussed earlier in relation to Figure 5.4). Based on this assessment, along with the fact that sheet piles have been driven below the wall, it is a reasonable conclusion that the shore platform in this area would comprise of soft clays or beach material infilling the old valley. This wall appears to run out above the hard rock outcrop further to the north and there is further evidence of rock underlying sections of the wall to the south. Beach levels along the frontage are generally very low. There has been recent damage to the crest of the wall which has been repaired and the wall is regularly subjected to heavy overtopping.

Plate 5.5. Central section of DU4 showing the change in beach levels across the frontage.

Plate 5.6. Central section of DU4 showing the large concrete toe an exposed sheet piles.

DU 3 (Plate 5.7)
This section of the frontage comprises at the northern end a masonry wall, supported at its toe by a width of masonry revetment. The road runs immediately behind this section of wall with properties behind and within the low lying land to the rear.

To the centre of the unit is one of the main slipways and adjacent to this, both to the north and the south the beach levels start to build in comparison with the level along DU4 (Plate 5.7).

South of the slipway the defence principally comprises a series of concrete walls constructed during the Occupation of the Island. The walls are relatively massive and change significantly in shape and orientation. These walls are backed by a width of higher scrub land, with the road set slightly further back. To the southern half of this section the general level of the land behind starts to rise slightly.

Plate 5.7. DU 3 looking north to DU4.

DU2 (Plate 5.8)

This Unit comprises a section where the concrete walls tend to be more consistent in shape and where the beach levels tend to be more consistently high. The defences are backed by slightly higher ground although the road and properties are still at a relatively, lower level than the crest of the defence.

To the southern end of the unit, where the main coastal road returns to running more directly to the back of the sea defence, the beach levels again tend to fall and coupled to the lowering of the crest of the sea wall in this location, there is an area that suffers regularly from overtopping (Plate 5.8). This has resulted in damage to the edge of the highway.

It may be seen from Plate 5.9, that the defence line tends to curve back along this section in comparison with the line of the toe of the beach. There is still significant variation in beach levels in front of the wall and it may be seen from Plate 5.8, showing the variation between DU2 and DU1, that the defence line to the south effectively pushes forward again such that the beach level at the toe of the defences reduces in level.

Plate 5.8. DU 2 looking north.

Plate 5.9. DU 2 looking north from DU1 showing the change in the level of the beach.

DU1 (Plates 5.9, above and 5.10)
This final section of the study area reverts back to high masonry walls.

Over much of the unit the beach levels are low and relatively stony. It can be seen from Plate 5.9 that there is finer sediment present in the area but there is little capacity in terms of width, due to wave action against the wall, for the frontage to develop a beach.

Sediment tends to be moved from in front of the main section of the defence to form the beach at the southern end in the lee of Fort Grey (Plate 5.10).

Plate 5.10. Looking south from DU2 showing the change in the level of the beach along DU1.

The road runs immediately behind the wall with a continuous row of properties behind the road. These properties are protected to a degree by garden walls and by the fact that they are built on rising land behind the sea wall (Plate 5.11).

Plate 5.11. DU 1 showing the local defence behind the road

5.3 Analysis of Flood Risk and Beach Response

5.3.1 Erosion and Coastal Change

A major influence on the condition and future management of the defences is the behaviour of the shoreline and respective beach levels. The beach levels along this frontage are found to vary significantly both as a result of changes in specific wave conditions and in relation to specific orientation and position of the defences in different sections of the frontage.

Monitoring of beach levels has been undertaken over the northern section of the bay (DU5). An initial analysis was carried out using this data as part of the 2007 Strategy. This indicated that the beach sediment could be drawn down the beach but that under other conditions sediment was moved back to the upper beach area. Further monitoring data has been considered in this report and the results are shown in Figure 5.6.

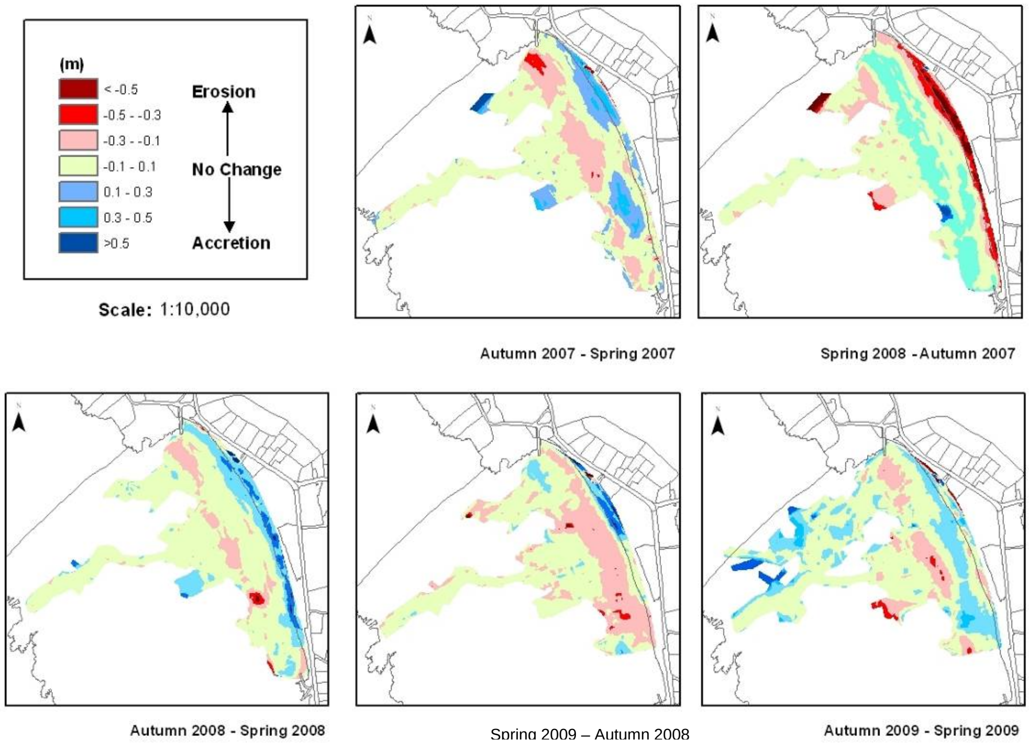


Figure 5.6. Comparison of beach levels at the northern section of Rocquaine Bay

This confirms the earlier conclusions and demonstrates that, while there are periods when the toe of the defence is exposed, there is good capacity for beaches to recover. The overall conclusion is that this section of the frontage is generally well aligned to net wave action and that overall there seems little loss of sediment from the local system.

To the south the picture is one of continuing lowering of the foreshore. The main defence in the area has in the past been underpinned with a massive concrete toe, constructed on sheet piles. As discussed earlier, the wall is founded over an area of clay, rather than rock. It is reasonable to suppose that when the concrete toe was constructed, this toe was taken below the then existing beach levels. It may be concluded, therefore, that since this time beach levels have eroded significantly, potentially by as much as 1m to 2m. The sheet piles below the wall are now regularly exposed and are therefore subject to increased levels of corrosion and abrasion. Critically, the erosion is eating into the clay platform such that there is much less capacity for beach levels to recover.

Comparing the alignment of this frontage in relation to typical wave direction it is seen that the defence line is well forward of the natural alignment of the general shape of the bay. If the defence should fail, it would be expected that the shoreline would rapidly set back, opening into the low lying valley behind. The indicative reshaping of the shoreline is shown in Figure 5.7. Typically the alignment would be held by the outcrop of rock at the northern end of DU4 and it has been assumed that the alignment would continue to be controlled at the southern end.

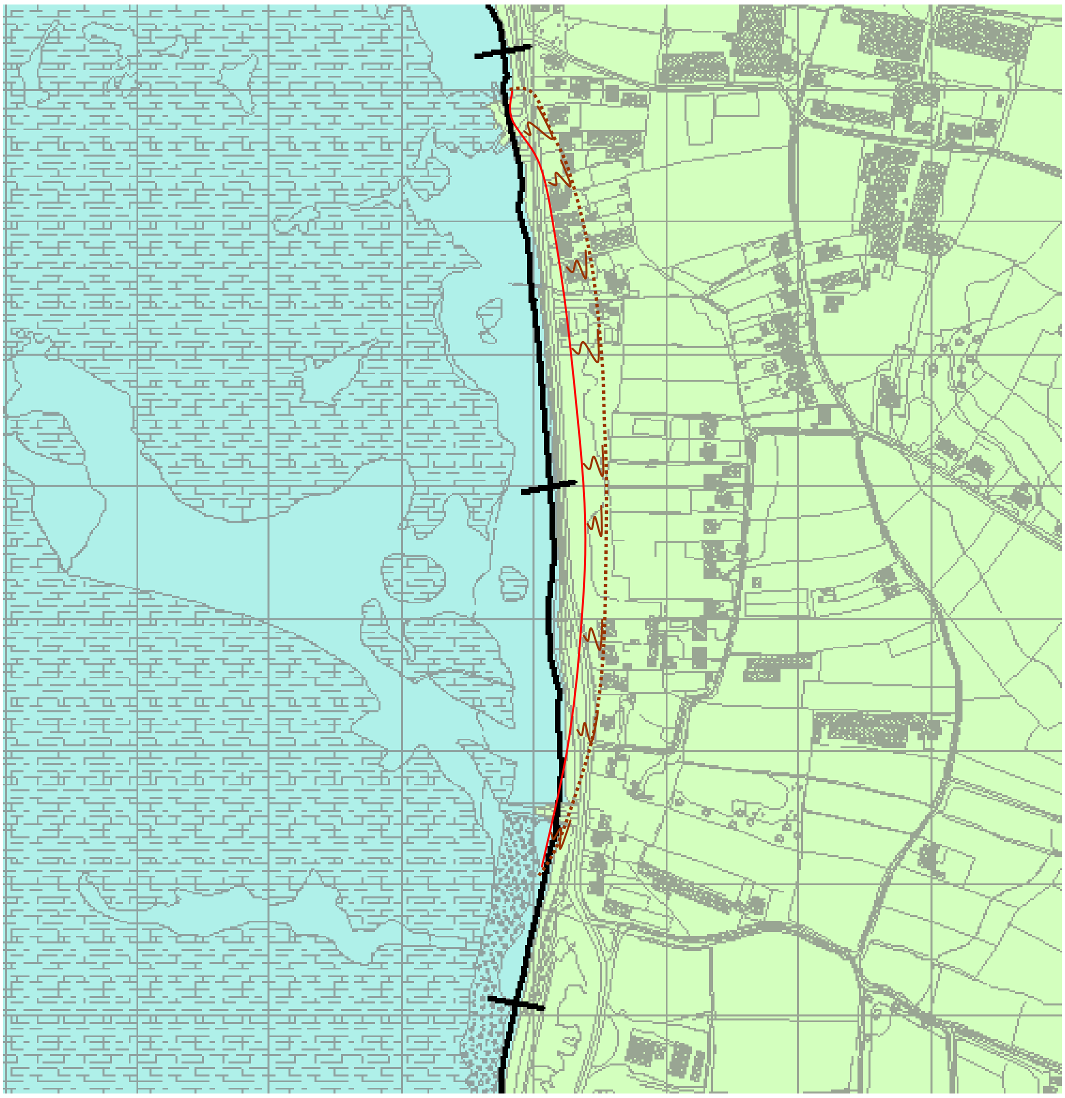


Figure 5.7. Indicative area of erosion in DU3 and DU4

Along this section to the south of DU3 and through DU2, beach levels are relatively high. The beach, and alignment of the shoreline, is held forward by the higher expanse of rock outcropping along the lower foreshore. This both acts to change the direction of waves and causes waves to break further offshore.

While beaches are generally higher across this section of the frontage they still allow significant wave energy to impact on the defences.

The level of the foreshore drops along much of DU1. Here, the foreshore appears to be stronger than areas to the north. While there has been work in the past to underpin this wall, the foreshore has not dropped as significantly as along DU4 and DU3. The wall is out of alignment with a natural shoreline plan shape and this does encourage scour against the wall. This can be seen in Plate 5.12.

Plate 5.12. DU1 showing the misalignment of the defence

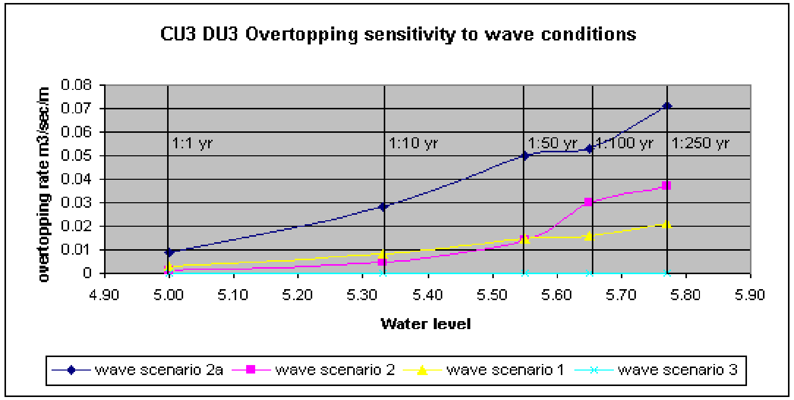
The level of the foreshore, the depth of water on different states of the tide, together with the profile of different sections of defences influences the degree of overtopping that occurs along the frontage. This is discussed below.

5.3.2 Wave Overtopping.

The wave model results have been used in the analysis of wave overtopping at different sections of the frontage. Surveys were undertaken to define typical profiles and these were used in running the wave overtopping model for the area. The results of this analysis are shown in Table 5.2. The sensitivity of overtopping to critical water levels are shown in relation to DU3 and DU4 (Figure 5.8). This is further discussed in Appendix B.

Table 5.2. Modelled overtopping rate (swell wave conditions, scenario 2).

Defence unit	Description	Length (m)	Crest level	Overtopping rate (l/ sec/ linear m) by return period (years).						
				1:1	1:10	1:50	1:100	1:250	1:250 Epoch 3	Notes
DU1	Seawall	414	8.79	0	1	3	5	6	67	Relatively low beach. Local defences behind road
DU2	Seawall	250	11.17	0	0	0	0	1	3	Local overtopping at southern end (as DU1)
DU3	Seawall	393	8.31	0	5	14	30	37	203	Lower section at northern end
DU4 (p1)	Seawall	103	8.57	1	7	14	16	21	162	Very low beach levels
DU4 (p2)	Seawall	224	8.70	0	0.2	3	6	10	81	Protected by rock outcrop
DU5 (p1)	Seawall	120	8.84	0	1	2	4	7	58	Vertical section at southern end
DU5 (p2)	Reveted seawall	140	8.32	0	1	4	6	13	169	High beach levels allow wave breaking on lower water levels
DU5 (p3)	Reveted seawall	174	7.66	0	2	5	9	17	266	
DU5 (p4)	Seawall	88	7.36	0	1	6	9	17	261	



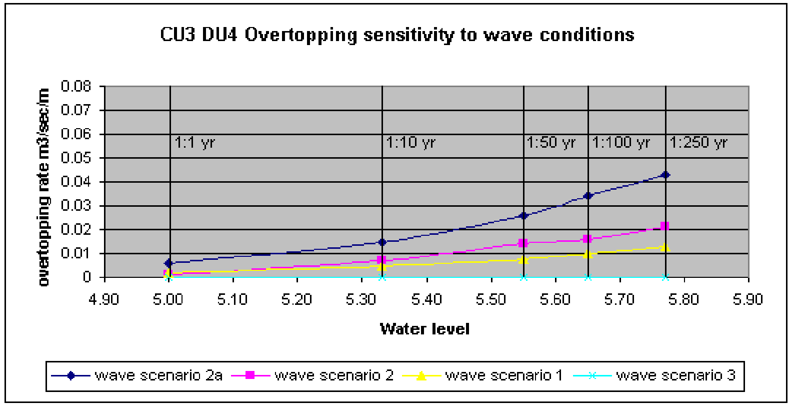


Figure 5.8. Sensitivity of overtopping rates with water level and wave conditions for DU3 and DU4. (this is discussed further in Appendix B)

The overtopping rates are discussed in relation to observed historic occurrence in Appendix B. Severe overtopping is known to occur along DU3 and DU4. In addition heavy spray comes over the walls even on relatively low water levels. This is not included within the model.

Critical areas are clearly shown as being along the DU4 and DU3 units, with severe overtopping occurring on a regular basis. It is significant that the slightly higher beach levels and the outcrop of rock to the northern end of DU4 results in much lower levels of overtopping. However, even here, with higher water levels, overtopping can become critical. Along DU5, the high beach levels allow waves to break over the foreshore. As water levels increase more significant overtopping is predicted.

There is a significant level of overtopping predicted for DU1, and this is borne out from observations. However, the rate of increase with water level is substantially less then elsewhere along the frontage due to the greater shelter provided to this section of the bay and as a result of the level of the defence. In this area, the local defences at the back of the road provide protection to properties.

The sensitivity to water levels is shown in the final column of results in Table 5.2, setting out the extreme overtopping rates for a 1:250 year event with 0.9m sea level rise over the next 100 years. These rates increase by nearly an order of magnitude compared that those predicted under a similar 1:250 year event at the present time.

5.3.3 Analysis of Flood Risk

The overtopping rates have been used to model flood risk areas. The results of this analysis are shown in Figures 5.9 a) and b).

The topography behind the seawall varies, with levels increasing towards the south of the bay. This is in contrast to the expanding lowland area at the north of the Bay, funnelling down to the low lying Ramsar site. Ground levels immediately landward of the coastal defences, particularly at DUs 3, 4 and 5 form a narrow ridge along the highway alignment and then rapidly drop away, forming low areas susceptible to collecting water during periods of high wave overtopping. The most pronounced of these areas is located behind the predominately undeveloped area of DU3.

Properties within these low lying areas are potentially at risk of flooding during episodes of fairly low overtopping due to the collection of water. The inability of these areas (particularly between the coast road and Rue des Vucheris/Rue des Marais) to satisfactorily drain water, due to tidal locking of the outfall during an overtopping event, would further increase the risk of extensive property damage.

There is, however, relatively good drainage of the road and drainage holes in the crest of the sea wall.

The model shows that, even under very severe conditions, flooding tends to be contained within the distinct low lying area behind the defences. The most regular flooding is shown to be along the critical section of wall between DU3 and DU4. The model predicts that flooding could occur in this area on a 1:1 year event. This might be mitigated some what by the front walls of properties and drainage within the road.

On a 1:10 year event the model is showing flooding occurring to other sections of the frontage.

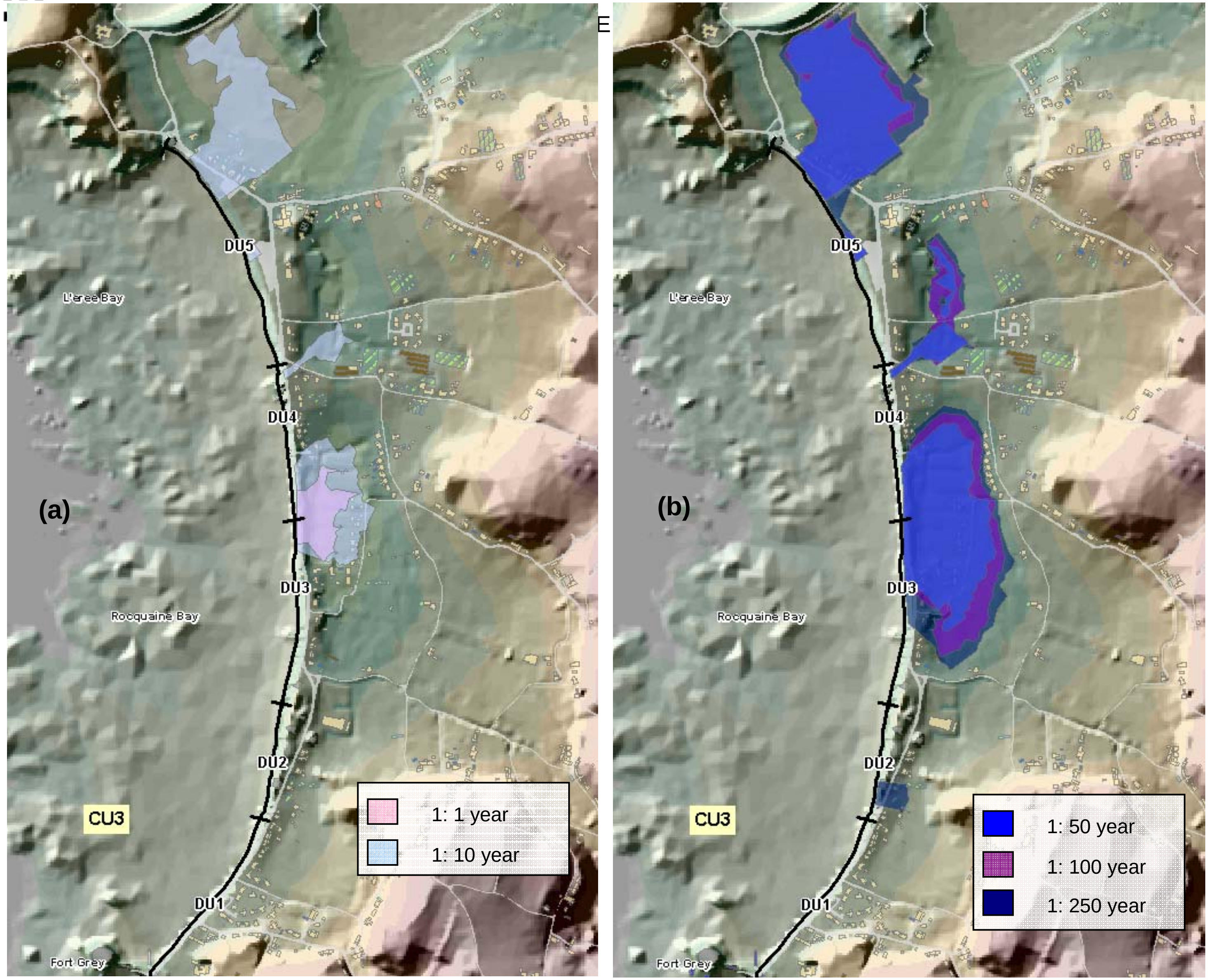


Figure 5.9. Present Day Flood Risk. a) 1:1 and 1:10, b) 1:50, 1:100, 1:250 events

To the north the model indicates that flood waters could flow across and enter the low lying area behind. This may be mitigated by local ground levels directly behind the seawall. However, considering the model results shown in Figure 5.9 (b), based on the fourfold increase in overtopping rates shown in Table 5.2, it seems probable that such flooding of the wider area would occur.

There is a short section of DU4 just north of the rock outcrop and slipway, where on events greater than a 1:10 year event, flooding starts to occur, accumulating in the small low lying basin behind. Plate 5.13 shows this area and the potential for overtopping to the area.

Plate 5.13. Overtopping to the wall just north of the area of rock outcrop

Two properties are situated immediately behind this section of wall, but both are protected by walls at the back of the road. Flooding to the basin behind would not be expected to flood property in events lower than a 1:50 year event, and even on under the most extreme situation, with present day sea levels, properties set further back would not be affected. There is however the risk to both minor roads in to the hinterland and this could isolate properties further south along the coastal road.

Although affected by heavy spray, most of the properties immediately south of the rock outcrop would not be subject to direct flooding. It is only as the low lying basin behind DU4 and DU3 fills, on events greater than a 1:10 year event, that the southern most properties in this area are directly flooded. Flooding would extend to affect some nine properties built in the lower lying section of this basin. Flooding would also cut the road through the valley and make the coastal road impassable. This would complete the isolation of properties further north.

On more severe events, 1:50 or greater, the extent of damage increases significantly within the valley, affecting a further eight properties.

Further south, at the southern end of DU2, the model indicates a local area of flooding on more extreme events. This is in the local area identified at present as being affected by heavy spray causing damage to the road.

Figure 5.10 shows the prediction of flood risk areas with sea level rise over the next 20, 50 and 100 years (epochs 1, 2 and 3) on a 1;250 year event. With the potential for

0.13m sea level rise by 2021, the pattern of flooding remains substantially the same as at present. Flooding remains with distinct low lying areas behind the existing ridge of high ground. With further increase in water levels over the next 50 years, there is potential for much wider spread flooding on severe wave and water level conditions. The properties to the south of the rock outcrop within DU4 are now at direct risk, with flood water filling along the whole low lying area to link through to the low lying area behind Les Anguilieres. This during epoch 3 is shown to affect properties surrounding the low lying marsh land.

There is also the risk of flooding south from the low lying area behind DU3 and DU4, filling the valley to the rear of DU2, with the potential for local flooding along the road and to properties behind DU1.

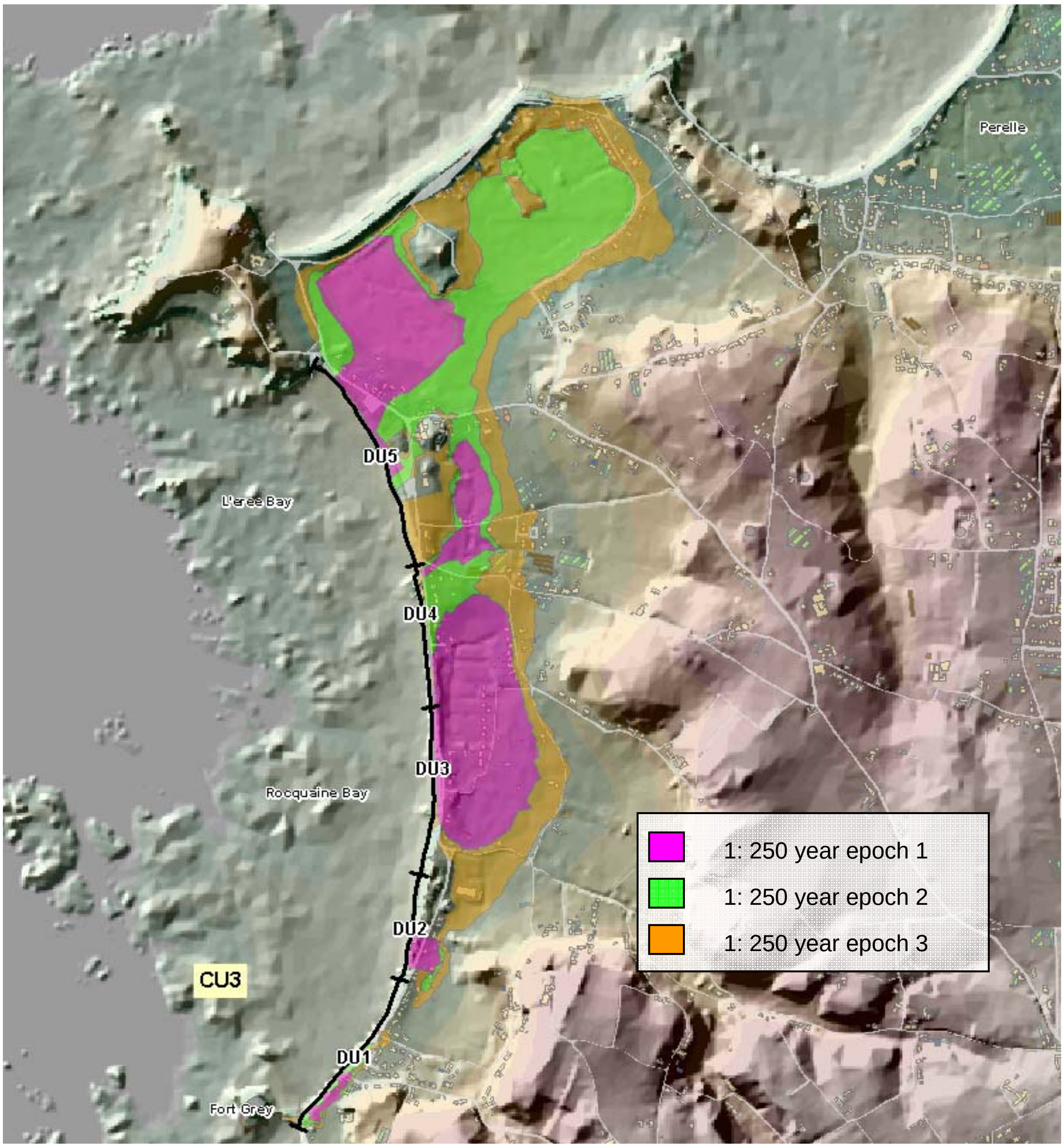


Figure 5.10. Flood Risk Areas predicted by the end of epoch 1, 2 and 3.

The number of properties indicated to be at risk by the modelling in the immediate area of DU4 /DU3 is shown in Table 5.3.

Table 5.3. Properties at risk of flooding in the DU4/3 area from 1:n year return period event

Return Period	Number of Properties At Flood Risk
1 in 1	0
1 in 10	9
1 in 50	17
1 in 100	20
1 in 250	24

This equates to damages as set out in Table 5.4. It may be seen from the table the high level of damages that occur even on more frequent events.

Table 5.4. Flood damages for various return period events.

Return Period Event	Damages (£k)
1 in 10 years	2340
1 in 50 years	2958
1 in 100 years	3029
1 in 250 years	3043

5.3.4 Summary of Flood and Erosion Risk

Over much of the central and northern sections of the bay the flood risk modelling has shown that typically significant flood risk occurs on events greater than 1:10 year return period conditions.

Over the DU5 section, the historical record of flooding suggests that serious flooding may not occur on events below approximately the 1:50 year standard. Under these conditions there is a risk to property and a risk of significant inundation of the ecologically important area behind. Potentially the more immediate risk is from draw down of the beach possibly undermining the sea wall and promenade.

There is a similar level of flood risk to the local area behind the southern end of DU5 and the northern section of DU4. While there is some risk to property within the valley behind, in terms of actual damage, this unlikely to occur on events below a 1:50 year standard.

More significant is the risk to property behind the southern section of DU4 and the northern section of DU3. Flooding in this area restricts use of the road and limits access to a larger number of properties in the area. Coupled to the risk in this area is the risk of failure of the large section of wall which is being undermined.

Typically, in this area where there is no hard rock behind the wall, the retained material behind would immediately cut back to a slope. This retreat would be potentially of some 10m - 40m. This would incur the loss of the road and services running along the road, with the potential immediate loss of properties.

The present condition of the wall in this area has suffered damage to the crest and has been progressively undermined. The residual life of the wall depends directly on the integrity of the sheet piles at the base of the wall and on the overall structural stability as the beach platform continues to be lowered. While there is the possibility that the wall may survive sometime into the future, there is a distinct probability based on existing information, that the wall could fail within the next 10 years. It is estimated that some 20 properties could be affected by the loss of the wall.

Further south, the only immediate problem is seen as being quite local and, at present quite minor. This is to the integrity of the road at the corner where the road returns to the sea front behind the southern section of DU2.

While there is overtopping to DU1, this only really affects the road and is considered manageable at present.

In the longer term, with sea level, particularly into epoch 2, over topping rates increase significantly and there is then significant risk to properties within the valley behind DU4 and DU3 and risk of more wide spread flooding on a regular basis to the village behind DU5.

In addition to the risk of flooding from DU5 within L'Erée Bay, the inland Ramsar site has been assessed in the 2007 Strategy as being at risk from overtopping and breach of the shingle ridge along the northern side of the site, within CU5 (Plate 5.14). A breach from CU5 could result in a flood pathway opening up at the northern end of Rocquaine Bay resulting in a flood risk from elevated still water levels. The recommendation from the 2007 Strategy was to allow this process to develop naturally to sustain the balance of nature conservation interest within the area.

Plate 5.14 LÉree Shingle bank providing protection to Ramsar site from North West (CU5)

5.4 General Management Approaches

At present under existing water levels, management of the frontage can be seen to focus on individual sections of defence:

- o DU5 and the northern section of DU4
- o The main section of DU4 and the northern section of DU3

- o The southern section of DU2 and DU1

The main threat to the frontage comes from the very high wave overtopping rates occurring along sections DU3 and DU4 and from the risk of seawall failure in this area.

At the northern end of the frontage, the sea wall is vulnerable to damage when beach levels are low. There is also a risk of quite extensive flooding on more extreme events which will become substantially worse with sea level rise. The future management of the frontage to the north will also open a potential flood risk across the Ramsar site and would impact on the village under more extreme events.

There is on-going risk of flooding to the southern section of the frontage, although this tends to affect primarily the road, with flood protection being provided by the boundary walls to properties at the back of the road. There is, however, regular overtopping observed at DU2 causing localised damage and backfill loss to the area immediately behind the wall. In the longer term flooding will become a more significant issue, but it is still only likely to affect a limited number of properties.

Generally, while economic damages are higher over the central section of the bay, they are relatively low when compared to the potential cost of addressing all the issues. Much of the economic value is based in maintaining the important coastal road; while there is social value in maintaining the community.

A range of potential approaches that could be adopted for management of the whole frontage were developed in the 2007 Strategy. These included:

Option 1 Continue Existing Practice and Minor Works (To Sustain)
Option 2 Raise Local Sections of Seawall (To Improve)
Option 3 Beach Nourishment (To Improve)
Option 4 Beach Nourishment with Detached Breakwaters (To Improve)

Options 3 and 4 were rejected within the 2007 Strategy due to the potentially significant damage to the environmental interests, and the considerable costs involved to undertake capital and maintenance works along the whole of the frontage. A re-examination of these options over the whole frontage confirms these issues; however, there is scope, in developing these approaches more locally with respect to timing and extent.

In the longer term, management of the increasing flood risk will be more difficult and there may be need to relocate properties away from areas of high flood risk. Over the interim period consideration should be given to reduce risk through planning and development control in these areas. Clearly, this longer term management depends on how defences in the area might be managed in the short to medium term and this is discussed in relation to each defence length below; options are discussed for the northern section (N) of the bay, the central frontage (C) and the southern section (S).

5.5 DU5 and management of risk to the northern section of the bay

At present the risk to property is seen as being relatively low and possibly acceptable with the development of an adequate flood warning system to properties within the area. Typically the wall in this area would be expected to have a residual life of possibly some

30 to 50 years, with on going maintenance. However, particularly severe conditions could result in loss of the toe with subsequent failure of the defence.

5.5.1 Outline Options

Three strategic options for ongoing management are outlined below.

Option N1 - Maintain and Localised Sea wall Raising.
This option includes addressing overtopping of the sea wall structure with localised raising. Under this approach, the defence system would include ground raising to the rear of the defence. There would be continued maintenance of the sea wall which would most probably result in the future of the need for a rock toe to the defence as sea level rises and as the beach levels reduce (due to increased interaction with the hard line of defence). In addition to these works at the seaward side, there would need to be a raised bank along the rear, to allow for future natural realignment of the northern coastal unit.

Benefit
This option would improve protection from flood risk to the community behind the area of open ground. In addition, the visual impact of the works would be minimised by making use of the open amenity land. Embankments and short sections of wall at DU5 could provide a superior standard of protection for properties along Les Sabions Road, and the Ramsar site, with only a modest impact on the immediate landscape.

Disbenefit
There may be the need to reposition the car park and accept changes to the landscape of the area. Addressing this purely in terms of maintaining the existing structure would result in loss of amenity as there is increased need to further support the toe of the defence. Typically this may be through the construction of a rock revetment along the frontage as the toe becomes more regularly exposed.

Timing
Although works could be undertaken at any time to landscape higher levels of defence in the open ground to the rear of the defence, it is not immediately required if appropriate flood warning is put in place. It seems more probable, therefore, that works would be triggered by deterioration in the condition of the toe of the defence, with works undertaken to reinforce the toe at the same time as defence levels are raised.

The need for work could, therefore, be delayed until possibly year 25. Beach levels and defence condition would continue to be monitored.

Option N2 - Realignment.
At present the main risk is seen as being to the sea wall due to sudden draw down of the beach, with the potential for loss of the existing sea wall.

Under this option, this could be allowed to occur or more probably defences would be physically removed. This would allow the beach to develop more naturally and for reconnection between the sediment of the beach and the fixed dune behind. In allowing this to happen, the beach would tend to build in height, providing a naturally adapting level of defence inline with sea level rise.

The main difficulty in taking this approach would be at the northern and southern ends of the frontage. It is at these end sections that there is more limited width and potentially greatest risk of flooding. It would, therefore, be necessary to hold forward the beach in these areas with some form of shore connected structures. While, therefore, this option provides a more sustainable and natural form of beach and defence in the area, there would be relatively major works involved in both removing the existing defence and in management of the sections to both north and south.

Benefit
The option would still provide improved flood risk protection to the frontage and to the area behind. The removal of the sea wall would allow a wider and more natural area of beach and dune to develop. This could provide significant amenity benefits as well as removing the future need for further works along the frontage.

Disbenefit
There would be the loss of the existing promenade and in the future, loss of car parking facilities.

Timing
This option could be staged such that initial works were undertaken to increase protection to the north and south. This might be considered over the next 20 years in improving defence to these local areas but might not become critical until year 25. As the sea wall in the centre came under increased pressure a decision would be taken to remove the structure. This might quite probably not be until year 25. Beach levels would continue to be monitored.

Option N3 - Localised Seawall Raising and maintenance of Beach Levels
With sea level rise the linear approach to the frontage defence would result in increasingly frequent and more persistent beach loss. The wave modelling shows that there is sediment available from within the Bay to be brought naturally up onto the beach. There is the option, therefore, to improve sediment retention in front of the sea wall by use of rock groynes.

The spacing of the rock groynes would need to be considered in more detail but may typically be of the order of 50m. The structures would extend potentially some 30m across the beach, with each groyne having splayed ends, to further reduce wave energy. These works could be undertaken as part of on-going management in addressing local areas of erosion. The option as a whole would include for increasing the height of the defence system through landscaping within the open ground between the defence and the road.

This approach would still require larger structures to north and south of the frontage to assist in reducing wave overtopping where the defence is narrow.

Benefit
The option provides improved flood risk protection to the frontage and to the area behind through maintaining the beach levels and landscaping a flood defence within the open

ground to reduce visual impact. It would also reduce the longer term impact of flooding to critical sections to the north and south.

Disbenefit
There may be the need to reposition the car park and works would change the landscape of the area. There may also be some reluctance to have rock structures along the length of the foreshore along with considerable public investment.

Timing
Works could to a degree be undertaken in stages, such that should local sections of the defence be threatened then rock groynes might be constructed to support the toe locally. More generally works might be undertaken in year 25 and triggered by continued monitoring of sea level rise and the beach.

The general outline of options N2 and N3 are shown in Figures 5.11 and 5.12 respectively.

5.5.2 Assessment of Options for the Northern Frontage

In all options it is seen as being sensible to make use of the open land to raise defence levels, reducing the visual impact along the frontage. There is a flood risk to property at present and as such these works could be undertaken over the next five years, although with adequate flood warning in place this might not become critical for some 25 years. The typical cost of undertaking landscaped improvement to reduce flood risk could be in the order of £225,000.

The real issue is associated with the future management of the existing sea wall as continuing with the current management then would not be seen as being sustainable.

Potentially, in some 25 years time, alternative management approaches might be appropriate. Table 5.6 sets out the outline costs of the three options considered above.

Table 5.6. Outline cost of Options for DU5

Option description	Outline cost (£k)
N1. Maintain and improve existing defences with the construction of a rock revetment.	1,200
N2. Realignment with control structures to north and south.	2,375
N3. Maintain existing structure, retain beach with groynes and with control structures to north and south.	1,600

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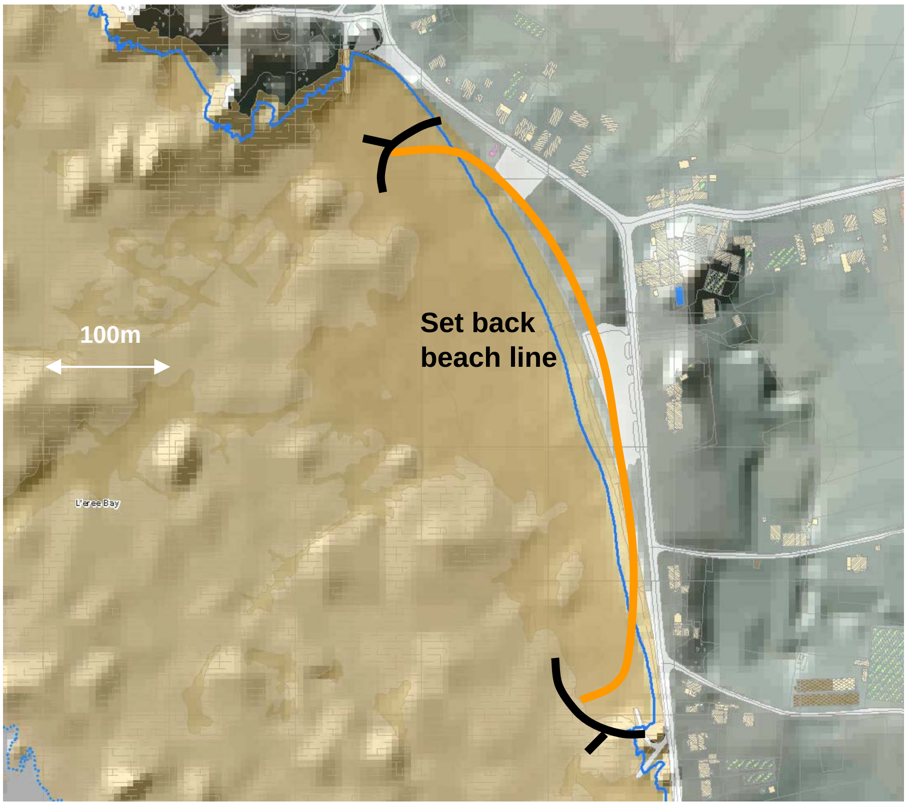


Figure 5.11. Option N2, Realignment

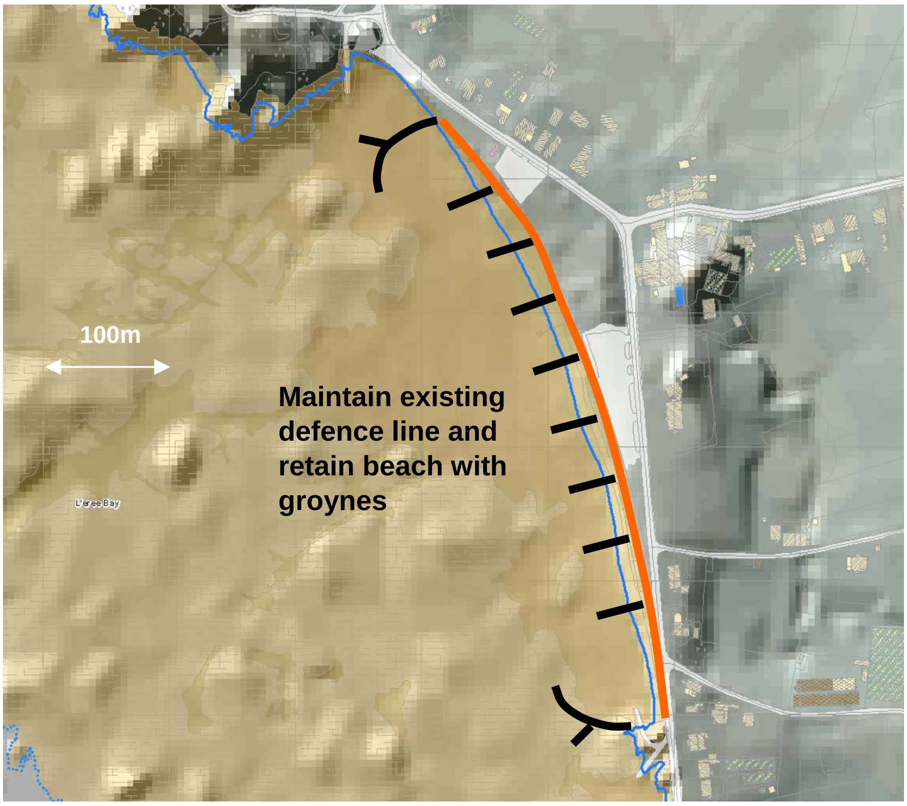


Figure 5.12. Option N3, Beach Retention

Option N1 would result in overall and continuing loss of amenity to the area, increasing the separation between use of the open land and the use of the beach. In the longer term with sea level rise this approach would be more difficult to maintain, with the need for increasing effort in sustaining the revetment. For this reason this basic linear approach is not recommended.

While option 2, does provide a more sustainable approach over the short to medium term, the approach would imply continued retreat in the longer term and this would incur future loss to property and the road. The approach does not make use of existing defences and their removal would be relatively costly. There would still be scope for imposing greater control over the frontage in the future, effectively changing the approach more to that outlined as option 3, but set back further.

Option 3 improves and makes better use of the existing defences. It provides in outline an approach that could be sustained over the short to medium term. In the longer term there may be the need to realign the back defence, building on and adapting the initial approach, controlling the development of this realignment.

Each option would require significant change to management. Given the low priority for major works to be undertaken a final decision may be delayed and based on further monitoring of the beach behaviour and the actual rates of sea level rise. The outline options discussed above could be used, therefore, as the basis for consultation. Should there be sudden draw down of the beach threatening the integrity of the existing defence, it would be recommended that a rock groyned approach were adopted to sustain the wall.

5.6 DU4 and DU3 management of risk to the central section of the bay

The central frontage is presently the most critical section of defence. Purely based on damage to property, there is limited direct economic benefit in supporting any option other than routine maintenance and repair. This does not however take account of the broader social issues or the very major consequence in terms of loss of the road.

However, the routine maintenance is not seen as being sustainable over any significant length of time. In recent years there has been a need to repair the crest wall following damage during storm conditions. The anecdotal evidence is that the wall is not constructed as a typical mass structure and thus the base of the wall is not as thick as might be expected for a typical mass sea wall. The construction of the substantial concrete toe supports this assessment. This mass concrete toe is now very reliant on the sheet piles beneath and the loss of beach and the soft foreshore platform increases+ the potential instability. The residual life of the wall is assessed as being of the order of 10 to 20 years. Further loss of the beach and any increased exposure of the sheet pile or evidence of deterioration of the sheet piles would trigger the need for immediate action to sustain the existing defence.

In managing this, coupled to regular inspection and monitoring, three detailed options are considered.

5.6.1 Options

Option C1 - Combination of Minimum Support to the Wall and Localised Seawall Raising

This option includes addressing overtopping of the sea wall structure with localised raising, while attempting to maintaining the wall through routine maintenance. Under this approach, the existing sea wall structures would be raised to increase the crest levels seaward of the highway, in an effort to reduce the volume of overtopping water currently causing the highway to periodically close. This, given the stability issue of the wall, would be technically difficult to maintain over the longer term.

The immediate problem of undermining could be addressed through the design of a low rock toe to reduce impact below the concrete toe. Such works would have little impact on the overtopping rates but would prevent increasing damage to the sheet piles over the short term. These works might be seen as a wedge of rock extending out some 10m from the toe. This may extend the life of the wall by potentially some 10 to 15 years

Benefit

This approach would have limited benefit in terms of sustaining the sea wall over the next 10 years but could be incorporated within a future, larger scheme.

Disbenefit

The approach would require significant mobilisation, and hence costs, with limited long term benefit.

Option C2 - Scour Protection Rock Revetment and Localised Seawall Raising.

This option would include the construction of a rock revetment over the area affected by undermining, extending the protection to the sheet piles along the toe of the sea wall and providing increased long term stability to the wall. The timescale for this option is influenced by the stability of the wall rather then flood risk. As there is limited information on the geotechnical stability of the structure, if this management intent was selected, the recommendation would be to undertake detailed design with the intent to commence the works within the next five years.

As part of this option development, two different designs were considered, examining the potential level of the rock revetment.

In the first of these options the aim is to provide toe protection and significantly reduce overtopping for all return periods considered. To achieve this, the rock revetment would need to extend significantly above still water levels, typically to a level in excess of 7m, some 1.5m below the crest of the wall, with a beach footprint of potentially 50m. This was not considered to be commensurate with the value of risk reduction.

An alternative design was therefore considered, aiming to provide sufficient support to the wall but accepting that there would still be significant overtopping on the more extreme events with sea level rise. While this would need to be optimised, the outline design would suggest a structure with a footprint of 30m out from the existing seawall and a berm height of 3m below the crest level at DU3. Modelling results indicate that the installation of a rock revetment in the aggressive conditions experienced at Rocquaine Bay would result in only a 15% reduction in overtopping rates at DU3 for the current 1:250 year conditions. For an event up to 1:50 year the structure would be at approximately still water level and would as a consequence deliver a far better reduction in overtopping rates during high frequency events.

Benefit
A rock revetment would provide long term stability to the exposed toe at DU3, preventing scour and undermining along the sea wall. There would also be a significant reduction in wave overtopping volumes on lower water levels together with a lower, but not insignificant, reduction on the more extreme events. This option would ensure that local properties and the coast road were not at risk from a wall failure. This option sustains the road and the community behind over the short to medium term. The wall would be sustained in to the longer term but there would still be significant overtopping by the end of epoch 3. Effectively the works would sustain the defence over the next 100 years.

Disbenefit
The proposed rock revetment would reduce the area of beach available for recreational purposes, significantly reducing the time over which there would be access along the frontage. Properties along the back of the road would still suffer some damage from overtopping on more extreme events. With sea level rise there may be a need for the community to relocate approximately 11 properties situated in the valley behind as the flooding frequency increases.

The outline design is shown in Figure 5.13.

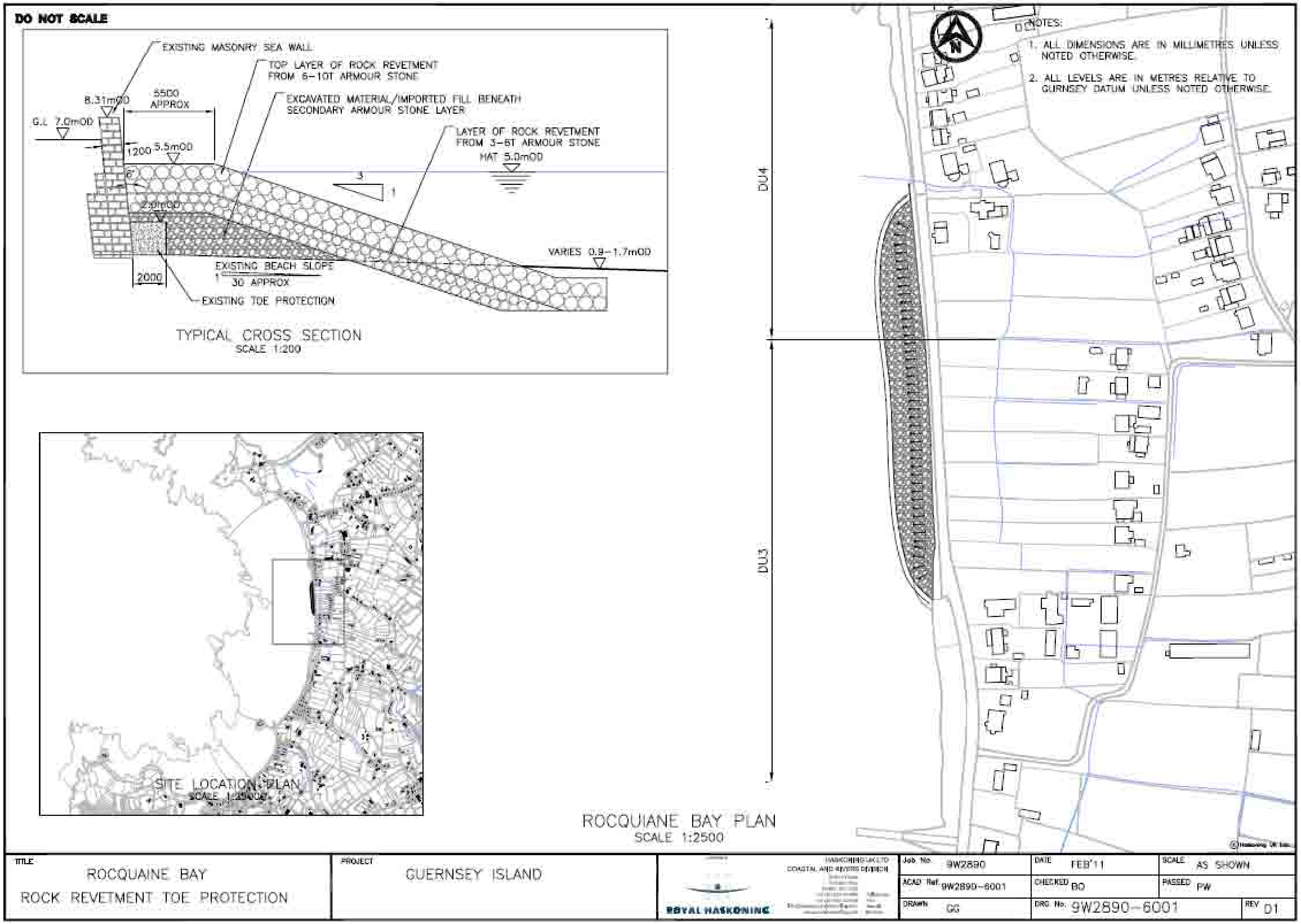


Figure 5.13. Option C2.

Option C3 - Maintain Existing Defence, Scour Protection Rock Revetment, supported by a Managed Realignment of Crest Flood Defences.

One of the most significant constraints of providing flood protection to properties in Rocquaine Bay is the limited width available to develop a practicable and adequate flood defence scheme whilst minimising impact on the surroundings. A potential solution would therefore be to develop option C2, providing additional protection set back from the crest of the wall. However, there would be no value in undertaking such a set back defence without first securing the actual integrity of the sea wall.

To accommodate the local topography, a set back defence would need to be positioned typically 25m from the existing sea wall to contain overtopping water. This would ensure the land seaward of the new wall can drain adequately after the event has passed. Where possible, the defence would be realigned to provide protection to the maximum number of properties. Due to the close proximity of a number of properties to the defence line, the setback defence would need to be aligned at the rear of several properties positioned along Route de Rocquaine and Rote du Grand Port.

Benefit

This option would provide a 1 in 250 year standard of protection to the majority of properties in the area behind the defence for the life of the scheme and would mitigate the future flood risk from sea level rise.

Disbenefit

A number of properties based along the coast road would remain vulnerable to flooding and would not benefit from the full protection of the flood defence. It is envisaged that these properties may be offered individual property protection to reduce the flood risk from more frequent events. However over the longer term, these properties may need to consider relocation. Overtopping of the coastal road is likely to remain an issue, and the frequency of road closures is liable to increase with increased overtopping of the seawall.

This option is not considered to be economically feasible.

Assessment of Options for the Central Frontage

Option C1 is only seen as being a very short term solution. Given the relatively high costs associated with this option, and limited additional benefit in terms of flood risk management, this option is not recommended.

Options C2 and C3 would incur significant costs and the economic benefit in terms of flood risk to properties may not be fully justified. However, these options would provide the benefit of sustaining the community in the area and would maintain the coastal road as existing.

Option C2, provides a potentially acceptable standard of defence against present frequent overtopping and importantly maintains the road. In the medium to long term it would be anticipated that properties within the valley to the rear of the defence would need to relocate. This is considered to be more sustainable for community adaptation rather than attempting to defend fully all property.

Table 5.7 provides overall costs associated with all Options, with Table 5.8 providing a more detailed breakdown of costs associated with option C2.

Table 5.7. Estimated costs of C2, Rocquaine Bay

Option Description	Cost (£k)
C1. Short term toe protection and local raising of the sea wall.	566
C2. Long term scour protection and local raising of the sea wall.	3,295
C3. Long term scour protection and local raising of the sea wall, with realignment of crest defence.	6,071

Table 5.8. Estimated costs of C2, Rocquaine Bay

Element			Cost (£k)	Optimism Bias (£k)	Discounted cost (£k)
	description	year			
1	200m long revetment including 15,600 m3 rock armour	5	1,248	749	1,997
2	Preliminaries and site contingency	5	374	225	599
3	General fees, site investigation and statutory cost	0 - 5	422	253	675
Additional works					
Maintenance.			15	9	24
				Total discounted cost	**3,295**
			Total capital cost	***£3,270,760***	

5.7 Southern (S) Frontage (DU1, 2 and the southern section of DU3).

At present, while there is some overtopping along DU1, there is limited justification for significant improvement to defence along this frontage. There is very local damage that results from overtopping of short length of defence at the southern end of DU2.

5.7.1 Options

Option S1 – Maintain Defence and Localised Seawall Raising / Ground Raising
This option includes the continued safeguarding of the sea wall structure with localised raising of the sea wall / coastal defence. Efforts would be focused on areas with the peak overtopping rates and where damage is occurring behind the sea wall. Under this approach, existing sea wall structures would be raised to increase the crest levels seaward of the highway, in an effort to reduce the volume of overtopping water currently causing the highway to periodically close. Work would also be undertaken to improve the surface locally behind DU2 where damage threatens the integrity of the road.

Work might sensibly be staged such that the improvement work behind DU2 is addressed over the next five years. Subsequent work would be undertaken to address potential undermining to DU1 and wall raising would be integrated with improvement to local property defence. This, subject to community acceptability of road closure might be considered for year 30, depending on sea level rise.

Benefit
This option would continue to contain flooding seaward of the sea wall during lower return periods, maintaining access to the highway and negating the need for additional flood defence assets to be constructed landward of the highway. In addition, the visual impact of the works would be minimised by making use of similar materials when raising the crest levels of the sea wall. This approach would minimise the initial public investment requirements in the area.

Disbenefit
The enhanced raised flood defence will be restricted by both the practicable limit of wall raising and public sensitivity to the increased wall heights and resulting visual intrusion. While large wall heights are present elsewhere on the Island, the community may decide that local amenity and quality of the view is more important than the increased flood protection offered.

While this option provides interim flood protection to properties, the level of the raised defences will be respectively low and due to the exposed nature of the bay, deep water and the high overtopping rates will still be of concern at the face of the sea wall. Sea level rise would further intensify the problem, ensuing the need for additional wall raising in the future. It is highly likely that the level and scope of wall raising required to achieve even a marginal improvement in flood protection would result in unacceptably high seawalls.

Option S2 - Combination of Option S1 and modification of local wave climate
This option is focused on future works (year 30, subject to continued monitoring) to modify the local wave climate in the area leading down to Fort Grey. In this area there is a relatively high, local area of rock running north from Fort Grey which could be

developed as a more substantial breakwater. Coupled to this there may be the need to construct local shore normal structures, at critical positions along the frontage, to support sediment accumulation against the sea wall. These works would change the way in which the waves interact with the frontage along this length, reducing the waves that run along and scour the wall across DU1. This would mitigate the need for further wall raising but there would still be the need for local action to address the damage behind DU2.

Benefit
The main advantage in this approach would be in minimising future works along the current defence line to address potential undermining; rather focusing the defence slightly offshore. There would be scope for general improvement of the amenity use of the area with improved beach levels.

Disbenefit
While potentially proving a more sustainable approach to management in the longer term, the approach would be more expensive than that of increasing toe protection. Additionally, the raising of the rock outcrop may have environmental issues in covering and changing the natural nature of the lower foreshore.

Assessment of Options for the Southern Frontage
Over the next 30 years, the general approach to this section of the Bay under either option would be for continued responsive management and monitoring with local works at DU2. This is based on the assumption that road closures, similar to what is currently experienced, is acceptable to the community. There is not seen to be excessive flood risk to property at present and little economic benefit in undertaking major improvement works immediately.

In the longer term, the defence frontage is likely to be sustained through wall raising and addressing locally the issue of undermining. However, such an approach will become increasingly difficult to manage with sea level rise. This risk would need to be re-assessed as further information on the sea level rates emerge. For example, if rates of sea level rise were seen to be increasing in line with, or more rapidly than at present predicted, then option S2 is likely to be come more attractive in proving long term security to the area.

These general options would not be required in the short term.

5.8 Conclusion and Recommendations.

This section of the main report has examined, in detail, the issues and problems associated with Rocquaine and L'Erée Bay. While modelling has demonstrated significant potential for overtopping and flood risk along the frontage, over the northern and southern units, this is considered to be largely manageable with improved flood warning. Longer term options for management have been considered for these areas.

5.8.1 Northern L'Erée Bay

In the case of the northern L'Erée Bay frontage works might be delayed for potentially some 25 years before, with sea level rise, the need for works might become critical. There is scope for some improvement through landscaping the open area to reduce the immediate flood risk.

It is, therefore, recommended that across this frontage general maintenance and monitoring is continued, while further consultation is undertaken to discuss and develop medium term solutions to increased pressure on defences and increased flood risk, in line with the outline options presented in the report.

Subject to the outcome of this consultation, the study would recommend adopting an approach aimed at retaining beach levels through the use of rock groynes. The outline cost of these works would be of the order of £1.6 million.

In the longer term, there will be significant increase in flood risk and further works may be required during epoch 3 to address this.

5.8.2 Southern Section of the Bay

The study concludes that there is little general justification for significant works for this section of the coast. Minor improvement works could be undertaken to improve risk to the road at the southern end of DU2. This might typically be improving the edge of the road and providing better drainage to deal with overtopping.

In the longer term, there will be increased risk of flooding to the road and potentially to properties to the rear of the road. Consideration may have to be given to raising defences possibly around year 30 to address this. If raising the level of the defence were unacceptable then there would be alternative approaches involving local reduction in wave heights through the use of rock structures constructed within the foreshore area.

This would need to be examined further alongside consideration of the possible impact on the natural environment.

5.8.3 Central Section of the Bay DU3 and DU4.

The study highlights significant short term problems associated with this area. While the most apparent risk relates to the high level of overtopping and subsequent flood risk to the low lying hinterland, the main risk highlighted by the study is to the integrity of the sea wall.

From previous records and an assessment of wave action on the frontage it is concluded that there has been and continues to be significant erosion to the toe of the wall. This is now threatening failure of the wall over a 200m section of the defence. This would lead to rapid erosion, with loss of the road, services and property.

It is acknowledged that the residual life of the wall is uncertain. However, available records would indicate that the main wall is substantially thinner at its base than might normally be expected for a wall of this height. Works have been undertaken to underpin the wall in the past with a massive concrete toe. This has now been undermined and is supported on sheet piles which are now exposed and can be expected to deteriorate at a greater rate.

It is estimated that the wall may continue in its current condition for potentially some 20 years. It seems more probable that failure may occur by year 10. It is therefore concluded that works are needed to sustain the wall earlier than this.

There are limited options for achieving this. Options considering reducing the wave climate or retaining a substantial beach across the frontage have been considered in outline but, confirming an initial assessment under taken in the 2007 Strategy, such an approach would require construction of large offshore structures, which would be both expensive and would have significant impact on the natural environment.

As a result, the study has focussed on more direct options to support the wall. Two basic options have been examined. The first would provide immediate but short term relief, constructing a limited rock toe to the structure. While this could be incorporated within a longer term solution, taking such a staged approach would incur considerable additional cost in term of mobilisation and redesign.

It is therefore recommended that a more permanent solution is developed and undertaken over the next five years. There would need to be regular inspection of the condition of the wall, recording any sign of damage or further exposure of the sheet piles foundations.

The recommended approach would be to construct a substantial rock revetment as shown in outline design in Figure 5.13. The estimated cost of works would be £3.3 million, with initial costs of the order of £700k expended over the next five years in developing the design and gaining statutory approvals.

This approach would reduce overtopping along this critical area. However, even with the works in place there would still be significant levels of overtopping on a 1:250 year event.

ROYAL HASKONING

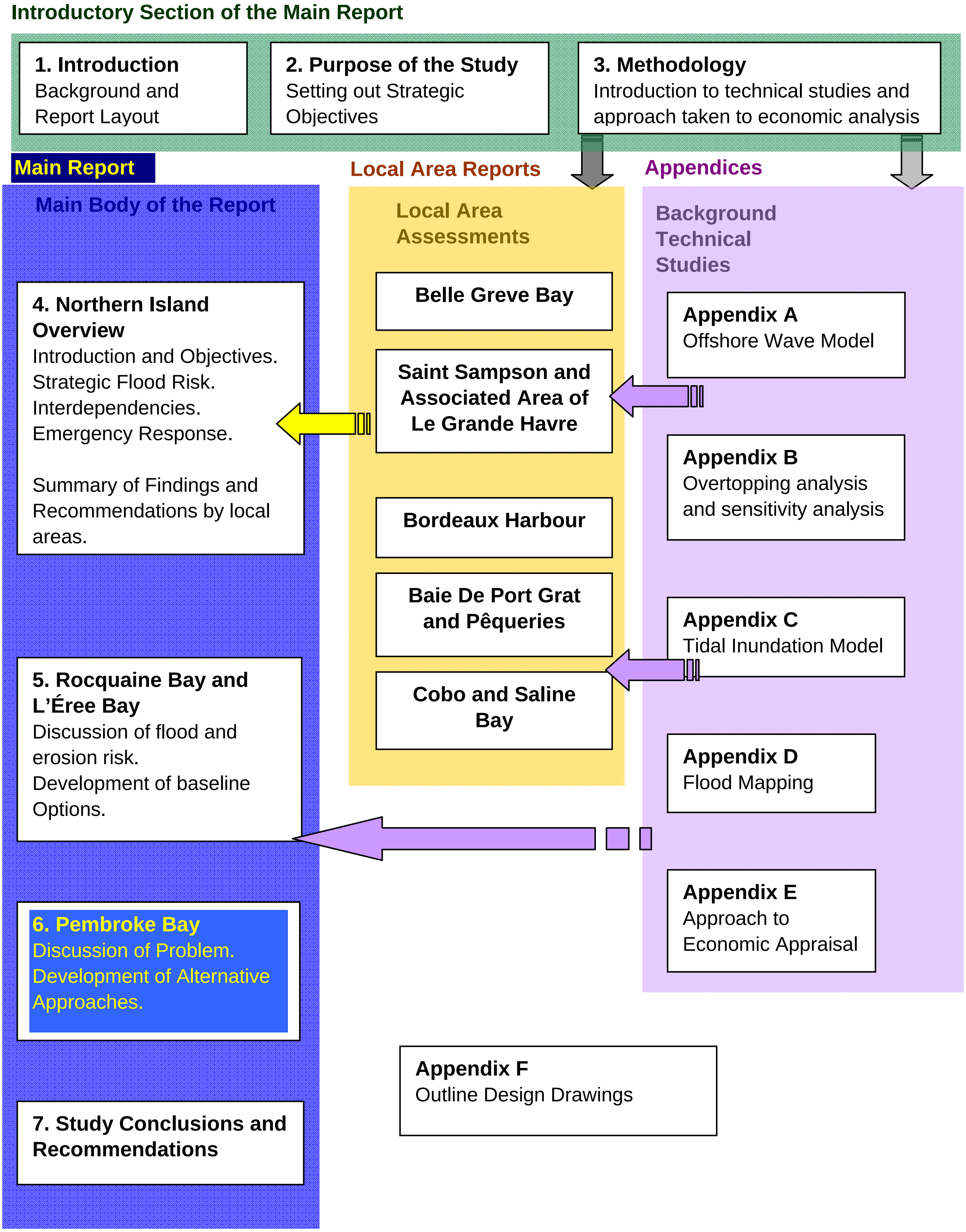
5.8.4 Action Plan

The following actions are therefore recommended and set out in Table 5.9.

Table 5.9. Action Plan for Rocquaine and L'Erée Bay

Year	Defence	Action	Cost (£k)
0	DU3/4	Gain approval for capital expenditure of works to support the southern end of DU4 and northern section of DU3.	
1 -5	DU3/4	Monitor condition of defence.	
1 -5	DU3/4	Develop detailed design, undertake site investigations and gain statutory approvals.	675
5	DU3/4	Construction of rock revetment.	2,596
1 - 5	DU2	Examine local improvement to local area of overtopping. Repair and resurface area.	20
1 - 25	All	Continued maintenance and monitoring.	
1 - 20	DU5	Develop further consultation on future management of the frontage in preparation for medium term works.	
1 - 10	DU5	Consider possible reduction in flood risk through local landscaping	225
20 - 25	DU5	Subject to monitoring development and construct scheme for the frontage	1,600
20 - 30	DU1	Develop risk reduction scheme to frontage.	
All		Review and improve flood warning	
All		Develop planning approach to development control and future development of the frontage.	

OVERALL REPORT STRUCTURE



6 PEMBROKE BAY

6.1 Introduction

Pembroke Bay is formed as a wide northeast opening bay between the two hard rock headlands of Fort Pembroke, to the west, and Fort Le Marchant, on the eastern side (Figure 6.1). The bay is backed by the L'Ancresse Common, which includes one of the main golf courses on Guernsey, as well as being an area important for its heritage and historical landscape and, together with the bay, beach and natural environment, is an important amenity and tourism destination.

Figure 6.1. Location Plan of Pembroke Bay

The backshore of the bay is protected by various sections of old military tank defences, extending in effect around the whole soft hinterland. In several areas these old defences are in very poor condition and have required extensive maintenance in recent years.

The 2007 Strategy defines this area as CU14. The Strategy identifies that, in terms of assets being defended, there is little economic justification for maintaining the existing defence line within the frontage. The recent damage and subsequent works to support the sea wall, particularly to the east of the Bay, are indicative of the on-going pressure on these defences. It is recognised that the area is an important visitor and amenity area, and while the current defence line remains in front of the natural line of the shore, it is unlikely that there would be extensive erosion if defences were abandoned or removed.

When considering potential flood risk, this does exist to the rear of the western-most wall. This is also examined, along with the potential wave reflection from this wall and the impact this has on the shape of the main bay. However, the main focus of work would be in examining how the main frontage responds and would respond under different management options

Therefore the 2007 Strategy recommended a Do Nothing policy but recognises that this may need to be modified by land use planning decisions beyond the scope of issues considered by a coastal defence assessment. The first steps towards taking this forward are to examine more accurately what consequences would arise from abandoning the existing defence line and considering further other alternatives.

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6.2 Objectives

- Establish a more robust wave and water level climate, allowing a more detailed analysis of coastal processes and understanding of the critical influences of the Bay's behaviour.
- To provide an improved assessment of the coastal processes for the frontage, defining the natural alignment of the bay and considering the potential erosion extent should defences or sections of defences be abandoned.
- Based on the above, to examine how the Bay may be managed in different ways, considering approaches such as groynes, offshore structures, local control structures or partial abandonment of existing defences; in addition to re-examining potential future requirements should the existing defence be maintained.
- Also based on the above, examine potential flood risk which might arise from loss of defences or the subsequent roll back of the shoreline.
- To provide specific costed outline options, highlighting potential benefits and disadvantages of different approaches for consideration by consultees.

This element of the larger study draws upon information on tide levels and wave climate presented in Appendix A using this to explain how the bay is currently behaving and how it would behave under different approaches to management. The study sets out the baseline information, assesses the longer term risks in terms of flooding and then discusses this in relation to the coastal processes. From this understanding, the study concludes with a detailed discussion of management options.

6.3 Description and Base Line Information

6.3.1 Description of features

Figure 6.2 shows the general arrangement of Pembroke Bay.

To the west of the Bay is a large rock headland. The associated intertidal and sub-tidal rock platform, upon which this headland sits, runs out to the north some 1.5km from the shoreline, representative of much of the nearshore area of the northwest coast of Guernsey. The eastern headland similarly sits upon a wide intertidal rock shoal but extending only some 500m offshore.

The main area of the Bay is formed within these two massive headlands and comprises a broad expanse of intertidal sand over lying the rock platform, with rock outcrops emerging in places over the foreshore. Two quite large areas of rock are exposed in the central section of the Bay (indicted in Figure 6.2 and shown in Plate 6.1).

To the rear of the old military defences is the L'Ancresse Common. This is an area of

Plate 6.1. The sandy foreshore of Pembroke Bay showing areas of rock outcrop in the distance.

sand and alluvium infill with similar exposure of rock outcrops. Typical land levels rise from around 6m to 6.5mLOD, behind the defences, to levels in excess of 10mLOD before typically falling away across the Common to the main northern coastal road (Les Clotures) and the low lying land around Vale.

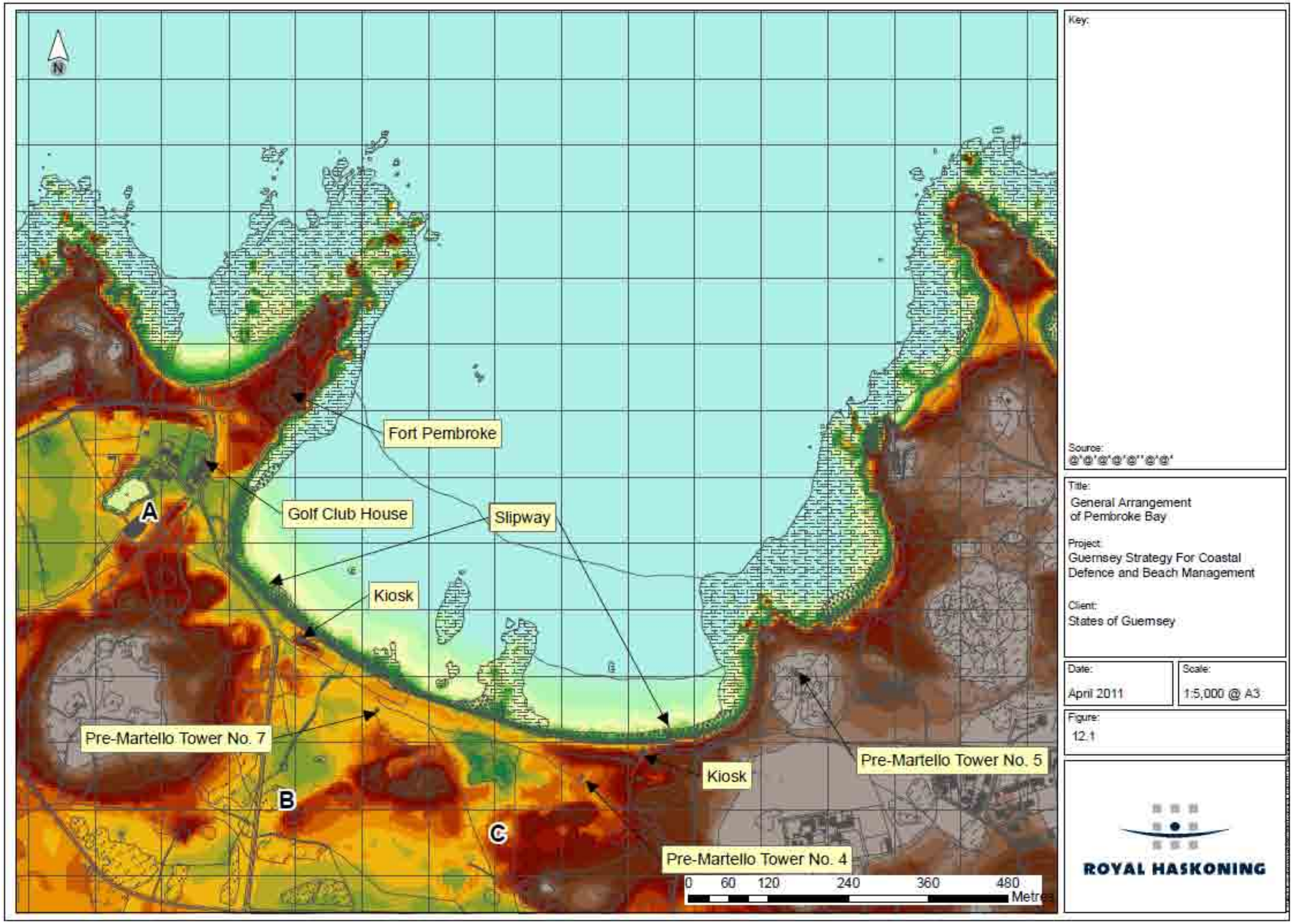


Figure 6.2 General Arrangement of Pembroke Bay showing land features overlying a relief map of the Area.

There are three areas of relatively low lying land running as valleys back from Pembroke Bay, shown on Figure 6.2 as locations "A", "B" and "C".

The Golf Club house and various properties are located within valley "A" and the pre-Martello Tower No. 7 lies to the edge of valley "B". The pre-Martello Tower No. 6 lies to the east of valley "C" (Plate 6.2), with high ground continuing quite close to the shoreline through to pre-Martello Tower No. 5 and the start of the eastern headland.

Plate 6.2. Pre-Martello Tower No. 6, showing also the rising land to the east.

There are two kiosks situated behind the defences. The western one, which has been developed as a restaurant, is located on the relatively low lying land between locations "A" and "B" (Plate 6.3). The eastern kiosk is founded on the higher ground. Both locations have car park facilities, the main car park being at the western end. The main access roads to the Bay run along the western valley "B" and, in the east over the high ground behind the eastern kiosk.

Plate 6.3. Western kiosk and car park.

6.3.2 Foreshore and Defences

The main defence line starts in the west to the southern end of the rock headland. Here there is a short section of quite light rock revetment closing between the main western wall and the hard rock.

The main western wall comprises a mass concrete back wall, with a front berm constructed over a steel sheet pile foundation at the toe of the wall. These sheet piles are exposed to a height of approximately 1m to 1.5m over much of the length of the wall and, although the piles appear not to be corroded through, there is quite severe corrosion (Plate 6.4a). The frontage has a generally low foreshore comprised of small rocks and boulders, devoid of sand apart from at the southern end. There is some evidence that this foreshore has been gradually eroding, with stones bonded to the sheet piles with rust at a level some 150mm above the current level of the general foreshore. The wall has a typical level of 7.2mLOD with the ground levels behind the wall some 1m lower.

Continued loss of beach material (and an associated reduction in the beach level) together with deterioration of the sheet piles is placing the structure at risk. A probable failure mechanism would be the loss of fill material beneath the deck of the front berm with failure initially of this element of the wall. This is likely to cause instability in the main mass concrete wall behind. Failure may be expected over the next 10 to 20 years.

Plate 6.4b shows a photograph (inset), taken prior to construction of the main wall, in comparison with the present situation behind the existing defence. It may be seen that, while the line of defence is set back by potentially some 20m, the backshore did support a narrow dune system, with a sandy upper beach and shingle berm.

At the southern end of the wall the beach turns sandier with a distinct rock berm to the back of the beach. There is a small slipway (Plate 6.4c) acting as the main access point to the beach at the junction between defence lengths DU2 and DU3.

Plate 6.4a. Wall DU2,

Plate 6.4b. Wall DU2, comparison with photograph prior to construction of defence.

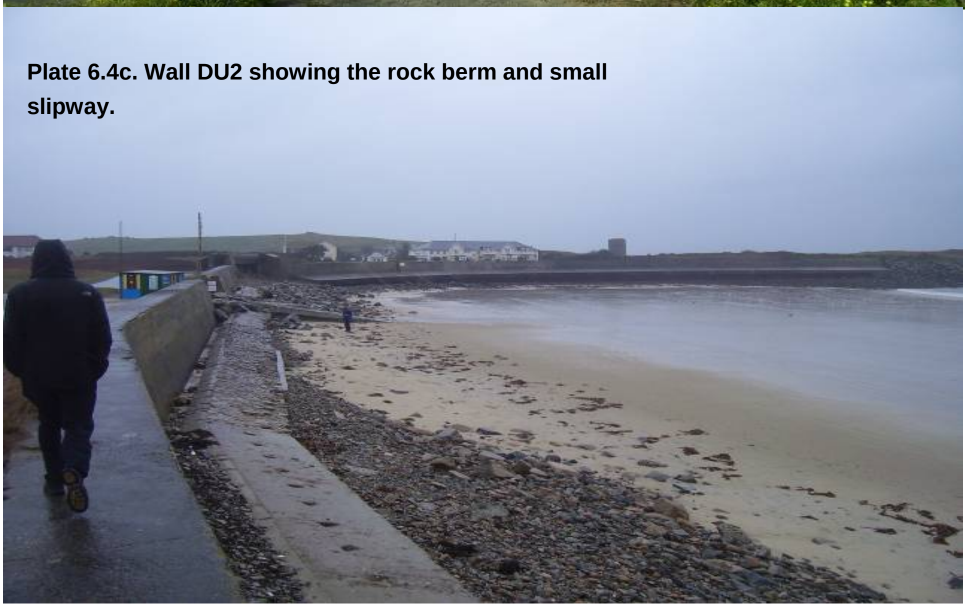


Plate 6.4c. Wall DU2 showing the rock berm and small slipway.

DU3 can be described in several sections but the main defence element is the large mass concrete wall along the backshore.

Over the initial section, running from the slipway in front of the western kiosk, the intertidal sandy beach extends effectively to the toe of the defence, with a small boundary of shingle at the toe. The defence has a substantial concrete toe which has required regular maintenance and repair, especially at the western end where undermining has occurred.

The wall is constructed in straight sections, but each section changes in alignment to reflect the curve of the Bay. However, even small variation in alignment is seen to impact the ability of the beach to maintain a stable shingle toe at the front of the wall. Further east of the kiosk, the shingle bank is wider and is held by the small outcrop of rock at the eastern end of the car park (Plate 6.5).

The wall continues to the east of the rock outcrop but tends to cut across the natural alignment of the Bay (Plate 6.6) such that the shingle bank narrows and disappears. This is compensated for, to some degree, by the second rock outcrop and rock outcropping further down the shoreline allowing sand levels to be retained against the wall.

Plate 6.7 shows the wall beyond the second area of rock, at the point where the wall is taken further forward form the alignment of the bay. There is at this point a marked change in the area behind the wall demonstrating significantly greater overtopping.

This change in alignment also marks a major change in the condition of the wall, with lower beach levels and a severe problem of undermining of the heavy toe. The general condition of the wall to the west is fair, with the main problems occurring at the far western end by the slipway. This section of wall has a typical residual life of some 10 to 20 years with increased maintenance at the western end. To the east of the transition point shown in Plate 6.8, the condition of the wall is poor, with very obvious movement of the wall and regular damage occurring to the toe.

Plate 6.5. Shingle bank east of the western kiosk.

Plate 6.6. Continuation of DU3 between the two main rock outcrops.

Plate 6.7. DU3 looking back towards Pre-Martello Tower No. 7, showing the change in overtopping.

Plate 6.8 shows the variation in the wall over the last four years, despite work to reinforce the toe.

Plate 6.8a and b. Comparison of wall between 2007 and 2011

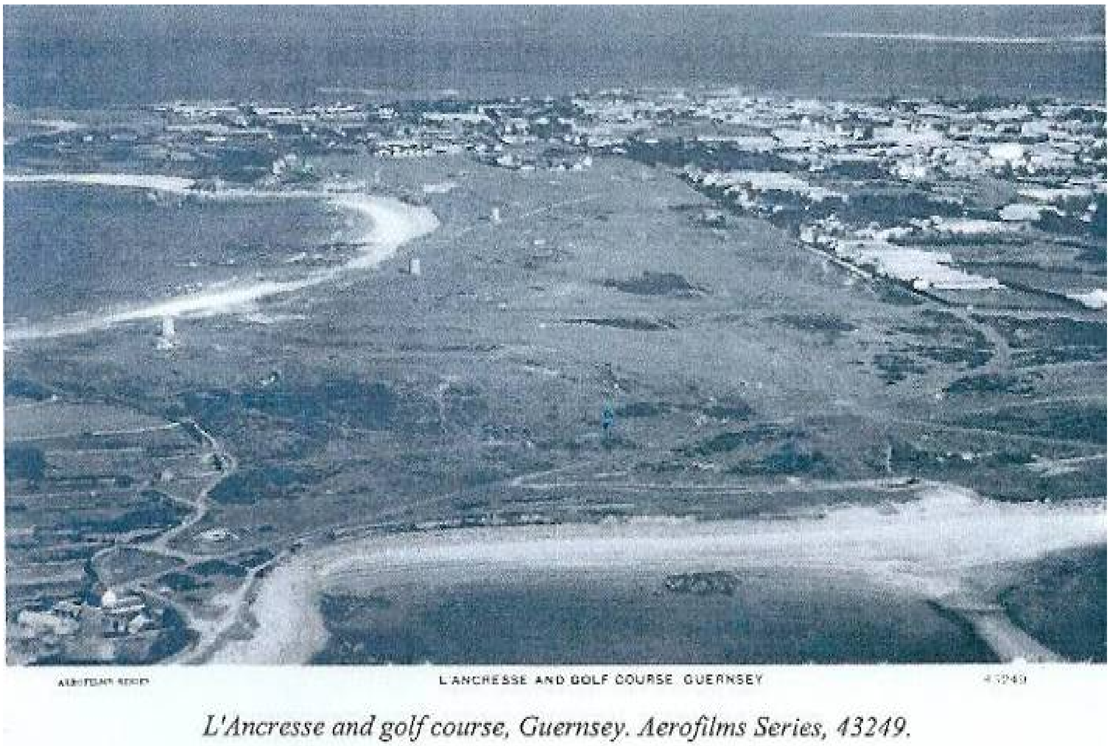
Plate 6.9. DU4 showing the eastern end of DU3 and the eastern slipway.

DU3 continues in front of the kiosk to end at the slipway at the eastern end of the frontage (Plate 6.9). The poor condition of the wall continues through to the slipway with continued undermining and overtopping along the entire frontage. The level of DU3 is 7.2mLOD

To the east of the slipway is a short section of rock revetment, with a higher shingle beach held by the presence of the slipway.

Figure 6.3 shows an air photograph of the bay showing the back of the Bay in the 1930s. It shows a wide sand shingle beach at the eastern end in relation to the position of the pre-Martello Towers.

Figure 6.3 Pembroke Bay 1930



6.3.3 Coastal Conditions

The following information is drawn from the strategic modelling undertaken as part of the overall study and reported in Appendices A, B and C.

Tide and Extreme Water Levels

The Guernsey hydrodynamic model has developed the critical water levels around the coastline (*previous estimates have been taken as equivalent to water levels at St Peter Port). The result was that extreme water levels at Pembroke Bay ranged between 0.22 – 0.23m greater than at St Peter Port (for all return periods). The difference was rounded 0.22m respectively, which were the values associated with longer return period (i.e. more severe) events.

Wave Climate and Exposure

Figure 6.4 illustrates the general offshore wave climate, with the detailed 1:1 year wave conditions modelling for Pembroke Bay shown from a west offshore direction. Results of the wave climate analysis are shown for the two relevant nearshore points, to the west and the northeast of Pembroke Bay. Independent wave roses are shown for swell waves (long period waves originating from outside the area of Guernsey) and for wind generated wave conditions.

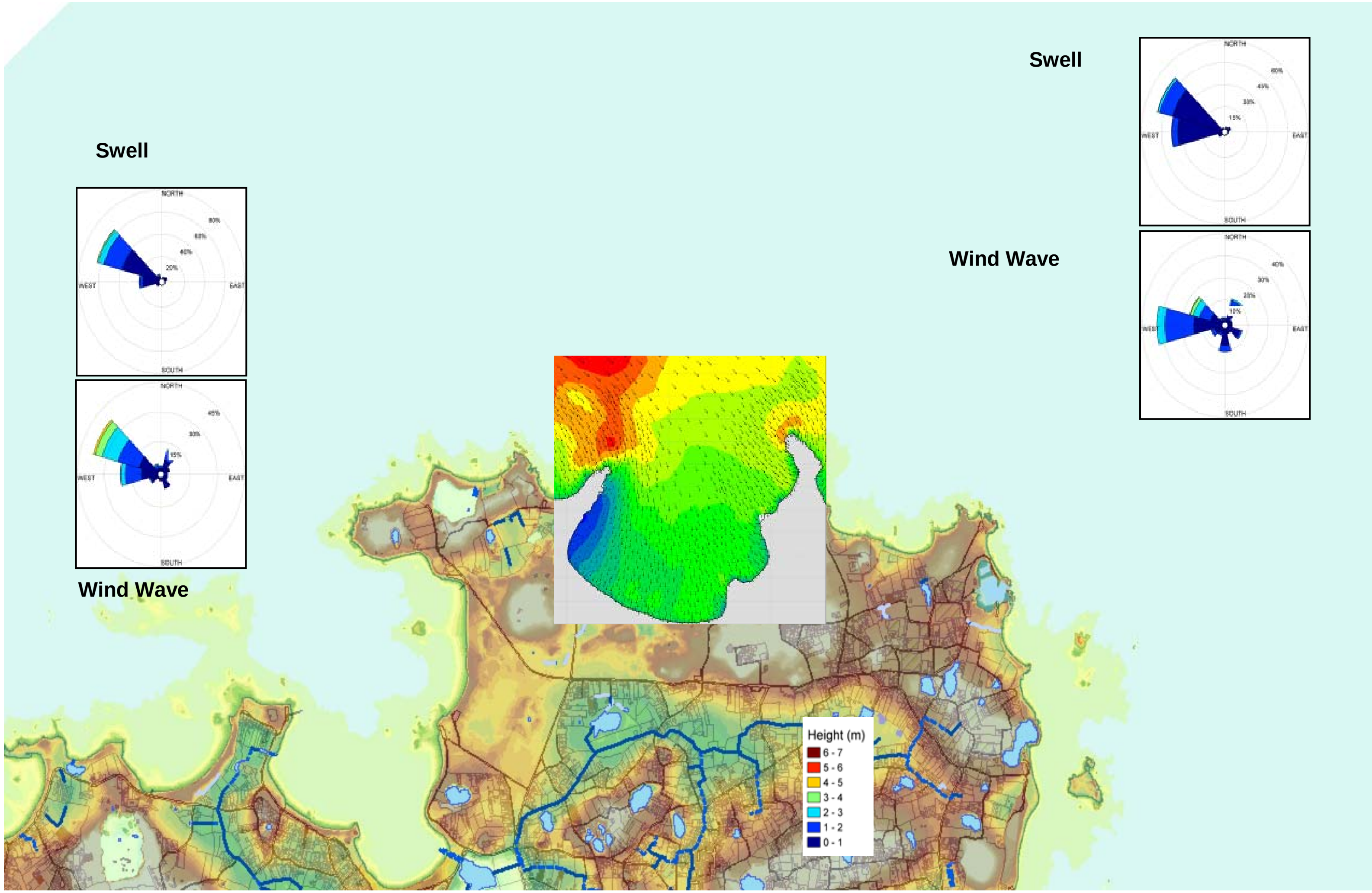


Figure 6.4. Wave Climate at Pembroke Bay.

As with most areas around Guernsey, the wave climate is dominated by waves approaching from the southwest through to northwest. As waves approach Guernsey, they are bent around (refracted) as they encounter the shallow waters surrounding the Island. In this way the dominant wave climate is narrowed to the west to northwest sector. To the northeast of the island the nearshore climate tends to be focussed more from the west.

The plots do however show a significant northeast component of wave energy, which is particularly relevant to exposure within Pembroke Bay.

As waves from a westerly direction approach the shoreline and the Bay, it can be seen that the waves are affected by the shallow waters and shelter extending north from the Pembroke Fort headland, reducing wave heights. Waves are then both refracted and diffracted as they approach and enter the Bay.

The typical nearshore wave climate and specific wave plots, for both wind wave and swell conditions at two points within the bay are shown in Figure 6.5. An important feature of this comparison is in the directions between swell and wind waves. In the case of the wave point to the west of the Bay, the wind wave and swell are closely aligned, with a very consistent wave direction approaching from the north northeast. Typical average wave heights in this area reach between 1m and 1.5m on a 1:1 yr condition. To the eastern side of the bay, locally generated waves tend to approach the shore from a typical northerly direction but with dominate swell tending the approach the shore more from the north northeast. Typical 1:1 year exposure is slightly greater along this side of the bay with wave heights more consistently of 1.5m to 2m.

Figure 6.5 also shows specific model runs for the main offshore directions: c) 240 deg, d) 270 deg, e) 300 deg. Also shown is the model output for the north northeast offshore condition: b) 30 deg.

Considering the main westerly directions, the most obvious feature of the inshore conditions is the decreasing wave heights from east to west across the bay. Along the most western wall (DU2) wave heights are typically below 0.5m. Despite the greater exposure due to the angle of approach into the bay from the north northwest offshore direction, in terms of frequency, it is waves from the more energetic west offshore direction that gives rise to larger waves within the bay.

The Bay opens to the north northeast and it is from this direction, with waves running directly into the bay that gives rise to the most severe wave attack. On a severe storm, waves just offshore of the defences may reach 2.8 to 3m from this direction. Notably, from this direction, the wave exposure along the western wall increases dramatically, with waves of 2m to 3m running very steeply along the face of this wall.

ROYAL HASKONING

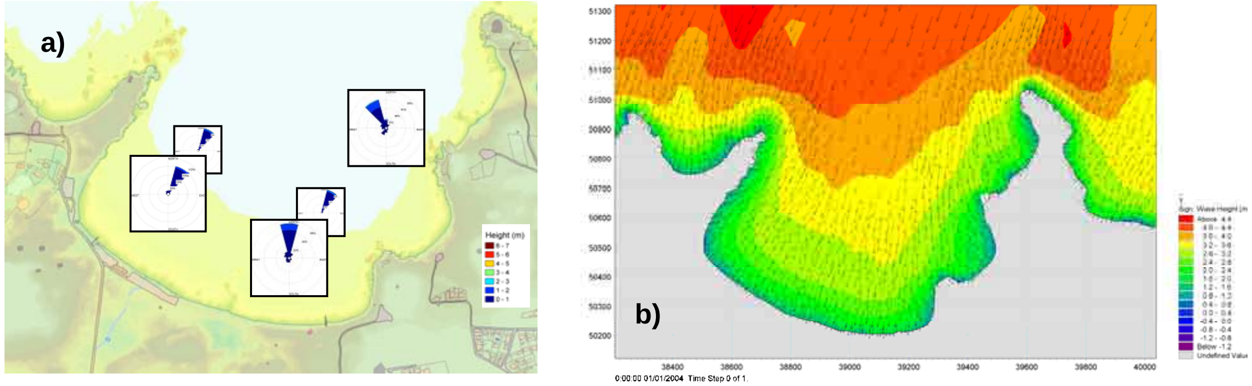
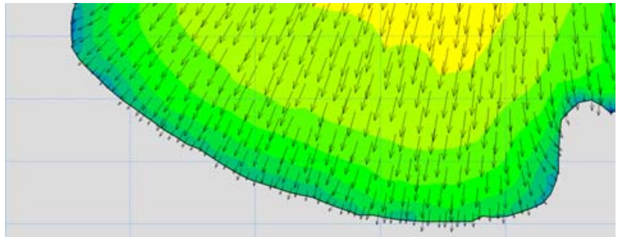
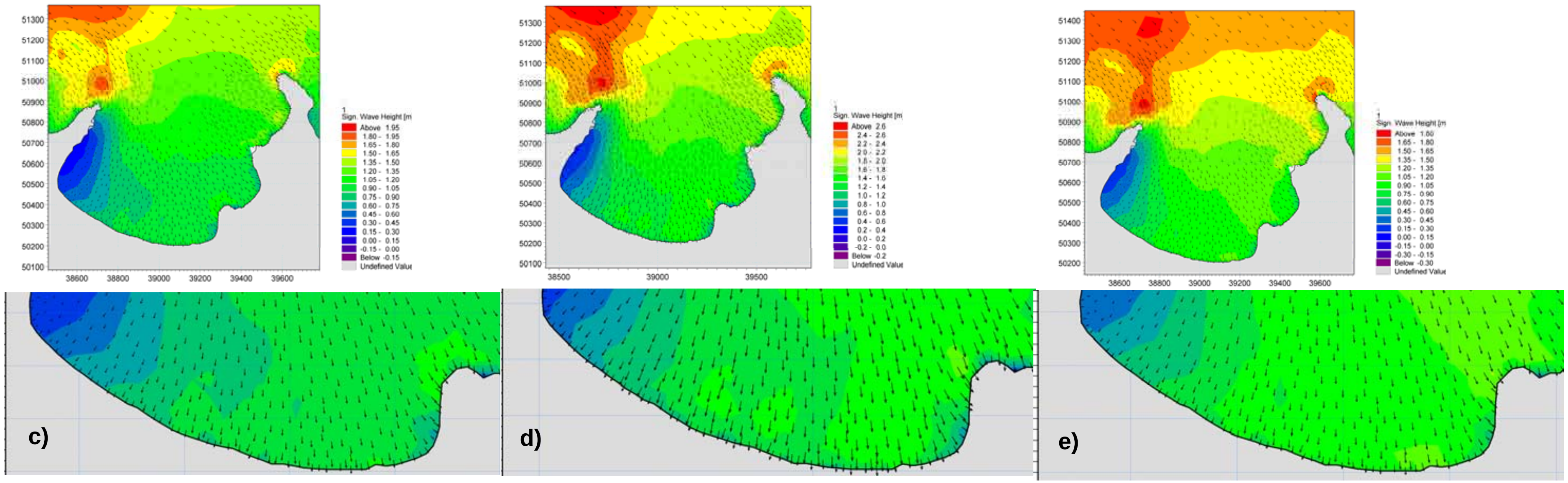


Figure 6.5. Inshore wave conditions.



Offshore: 30 deg, 4.33m. 8.7 sec



Offshore: 240 deg. 3.6m.10.2 sec.

270 deg. 3.19m. 11.8 sec.

300 deg. 1.9m. 8.8 sec.

In terms of direction, as identified previously, swell waves tend to approach the shore relatively normal to the nearshore contours of the bay. Wind waves tend to be more varied with slight obliquity at the defences. This is highlighted in Table 6.1 showing the variation by offshore direction in relation to the orientation of the defences.

Table 6.1. Wave direction with respect to defence

Offshore direction	***270 deg***	***300 deg***	***30 deg***	**Alignment of wall (deg)**	**Normal to wall (deg)**
Location	**Inshore wave direction**				
West end of DU3	30	30	35	124	34
Central	14	11	23	108	18
East end of DU3	353	354	10	95	5
Angle between wave front and wall (from west + , from east -).					
Offshore dir.	***270 deg***	***300 deg***	***30 deg***		
West end of DU3	+4	+4	-1		
Central	+4	+7	-4		
East end of DU3	+8	+7	-5		

Notes:* difference in wave direction compared to that of the defence is expressed as the angle west (+) and east (-). All other directions are given as whole circle baring.

The greatest obliquity is shown to be at the eastern end of the defence, in front of the kiosk. This is consistent with observations (Plate 6.10). There is a similar interaction at the far western end, with waves potentially forming a bore or Mach Stem effect along DU2 on a north north-east storm and more generally waves working at a steep angle into the corner between DU2 and DU3 by the western slipway. The implications of this wave climate on beach and defence behaviour is discussed below.

Plate 6.10. Oblique wave action.

6.4 Examination of Broad Scale Flood Risk

The Strategy identified potential flood risk areas along this frontage but concluded that this was relatively local to the backshore of the Bay, with the exception of the southwest corner.

Figure 6.6 shows a matrix of still water levels in relation to ground levels for the area, for different return period water levels (highest astronomical tide HAT and 1:100 year extreme water level) and for different sea level rise scenarios (present day, epoch 2 and epoch 3).

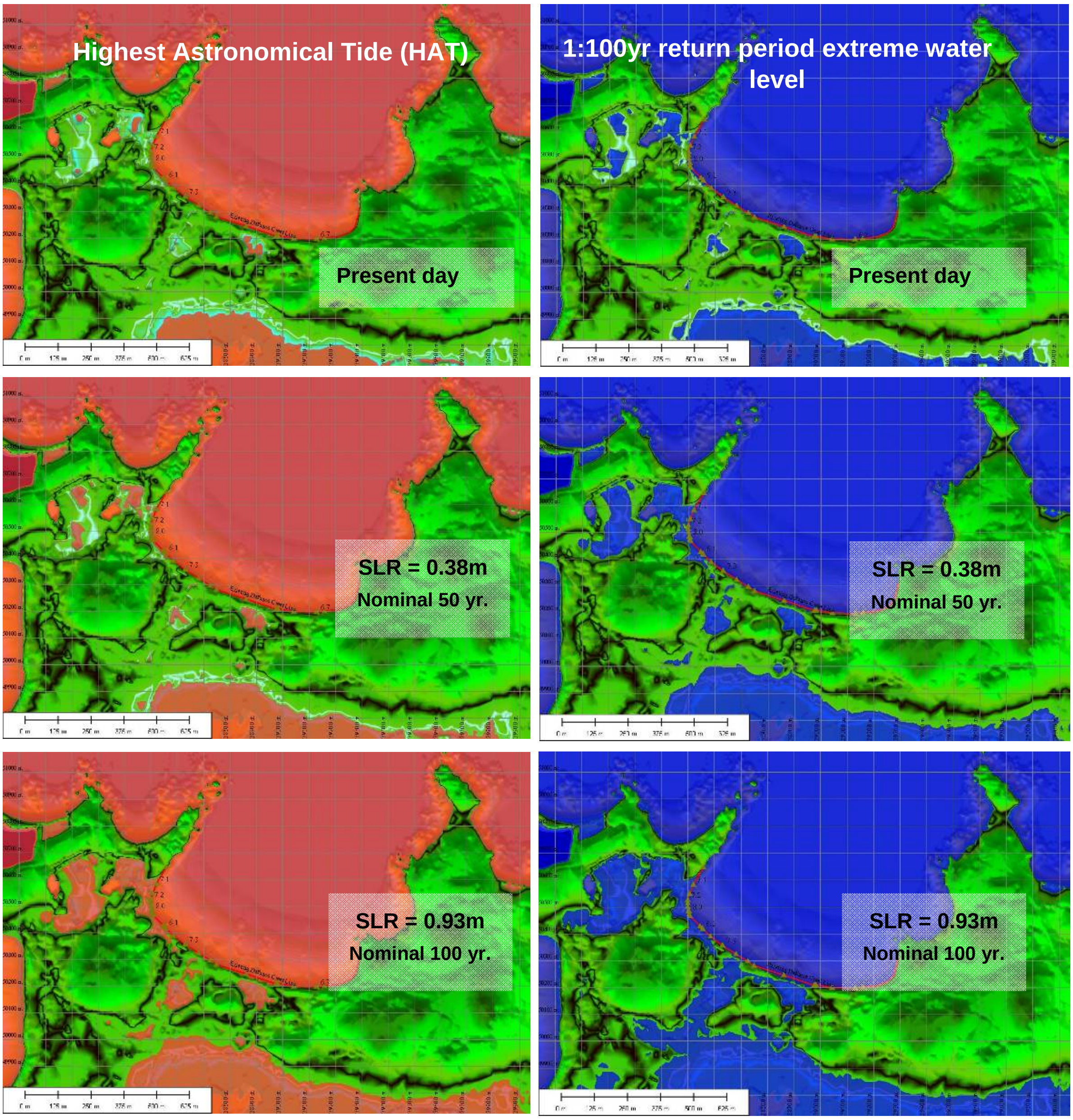


Figure 6.6. Broad scale Flood risk with sea level rise (SLR).

Although there are areas of land in the hinterland below HAT (potential flood areas shown in red), at present the land levels directly to the rear of the bay are such that flooding to the hinterland is unlikely to occur. There is slightly greater risk along the western frontage for the 1:100 year water level, with the sea wall providing the flood defence. However, even here the flood risk is quite local. Overtopping is unlikely to generate sufficient water to cause significant flooding to the local hinterland even along the western frontage.

With 0.38m of sea level rise, for HAT, there would be increased flood risk, similar to that of the 1:100 year extreme at present. In the case of the 1:100 year extreme level in 50 years time, the flood risk to the western frontage increases such that there would be more extensive flooding along the western frontage in the absence of the western walls (DU2 and the western section of DU3). Overtopping is likely to increase and under extreme events this may cause local flooding in the area of the Golf Club house. There might also be flooding to the low lying area, locally to the area referred to as valley “C” in Figure 6.2. The area of the main car park is above the water level but would be subject to increased overtopping. Overtopping would also increase along the eastern section of the bay. This would be due largely to the interaction between the wall and waves.

With sea level rise over the 100 year period, there would be substantially greater flood risk to the western frontage, even on HAT. Although the wall would act as a defence against direct still water flooding, the interaction between waves and the wall would lead to high levels of overtopping. On the 1:100 year water level, severe flooding could occur through the gap by the western slipway but it would only affect the local area. The more significant risk would be through valleys “B” and “C” impacting the main area of L’Ancresse Common and potentially linking through to the large flood zone in the northern section of the island.

While the analysis has shown that there is a major flood risk in the longer term, nominally up to 100 years in the future, management of this risk clearly needs to be taken into account now in developing the present day management approach to the Bay. While the current defence line is capable of providing protection in the longer term, there would be a need to further increase the overall dimensions of the defence to provide long term security. Typically this would require raising defences by as much as twice the level of sea level rise (2m in 100 yrs) to address the risk of overtopping. This would substantially increase the fragility of the defence and increase long term vulnerability of the areas protected which is unlikely to be technically sustainable in the longer term.

6.5 Discussion of Coastal Behaviour

A beach monitoring programme, focused on spring and autumn surveys, has been undertaken by the States of Guernsey over the last decade. This current study has updated the analysis of this information from 2007 through to 2010. A summary of the results of this monitoring is shown in Figure 6.7.

The data collected demonstrates relative change in beach levels between consecutive surveys. The initial plot (upper right hand side of the figure) shows the comparison between autumn 2000 and spring 2001 (winter 2001). The plot immediately below gives the change that occurred over the summer of 2001 and this pattern is continued through the sequence of plots.

The broad pattern of change is for erosion to the back of the beach (shown in red) and deposition lower down the beach (shown in blue). During the summer periods the typical behaviour is for sediment deposition against the back of the beach and lowering of the foreshore lower down the beach. In effect, sediment is being driven up the beach during the summer, during periods when wave conditions tend to be lower and when the process is likely to be driven by the regular longer period swell waves driving across the beach. During the winter, when there is a greater frequency of shorter period, higher waves; the waves impact on the back defence, drawing sediment down the beach.

Beach levels in front of the wall at the eastern end of the frontage are recorded to have varied by as much as 2m over the monitoring period.

This general process provides good evidence that there is no significant overall loss of sediment and that the system, in general, can respond to natural change. The main supply of coarse sediment (shingle and rock) is likely to come from the headlands. This will be relatively low. It is uncertain to what degree sand may be able to be imported from the offshore area.

Quite obviously from the various plots, while there is this large scale long term seasonal behaviour, there is also significant variation at a more local scale. It may be seen that during the winter of 2002, there was quite severe erosion in the area of the upper beach at the western end. This area of erosion tended to fill during the following summer but with some accretion along the lower beach to the east. During the subsequent winter (2003) there was erosion to the eastern section of the bay and some accretion within the western area.

During the winter of 2010, there was severe erosion of the lower beach, particularly to the eastern end, with little benefit gained at the back shore.

These variations can be seen to reflect the differences observed in relation to the wave climate. The process of beach building is well explained by the typical net direction of swell waves entering the bay and working up the normal beach contours. The general sensitivity of wave direction within the bay helps understand the changes in different areas of the beach. This understanding is used in examining in a more detailed manner the different sections of the Bay described below.

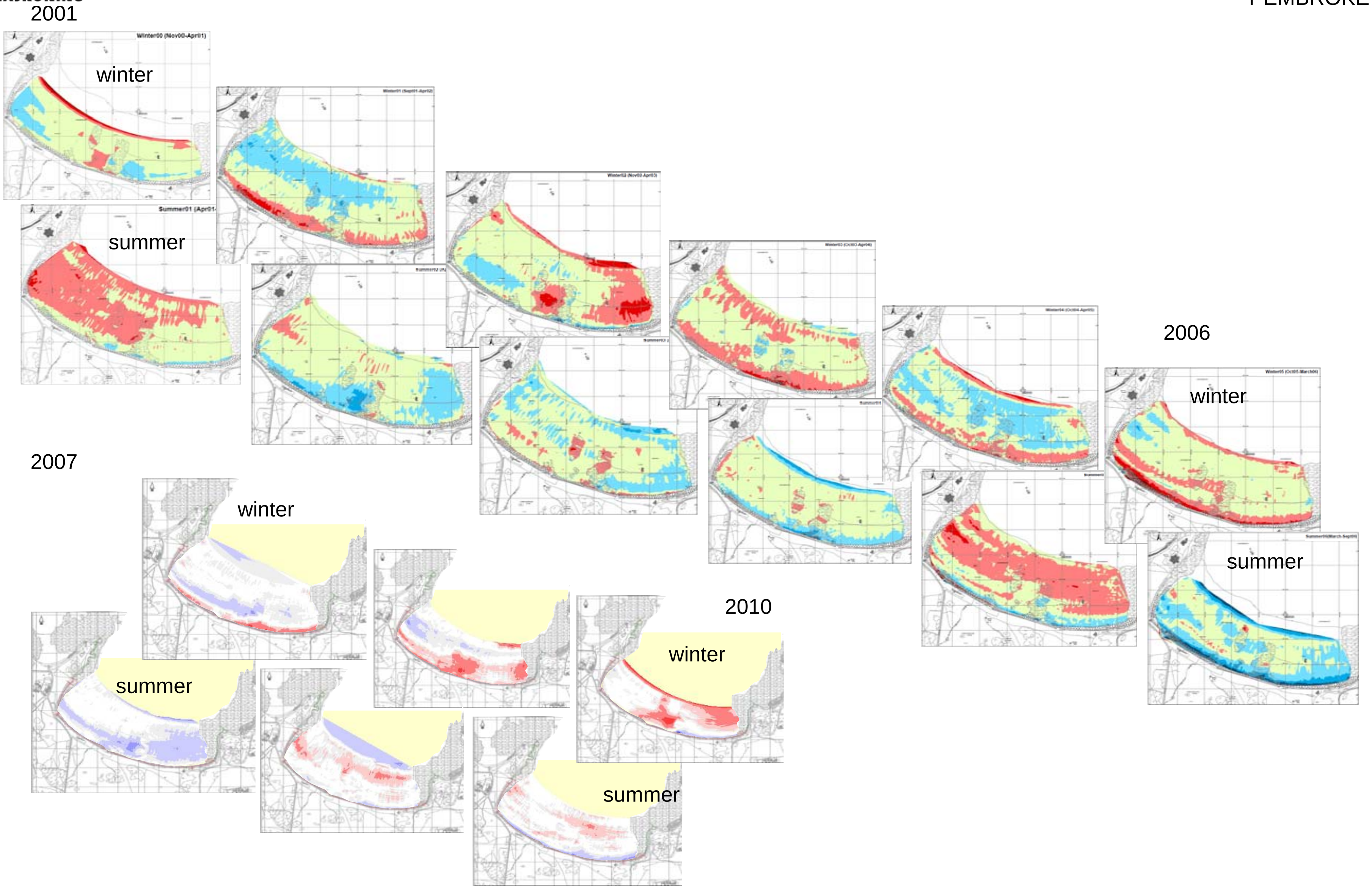


Figure 6.7. Change in beach levels

Western section (DU2)

Generally, beach levels in this area are low, with little sand. Under normal conditions this is a low energy area, wave heights are small in the shelter of the headland and there is limited energy transporting sediment into the area; swell waves tend to move sediment further up the beach. During storms from a north north-east direction, the energy increases significantly, with high waves running along the face of the wall, scouring any sediment and gradually removing the coarser stones littering the area in front of the wall. The modelling suggests that waves will be approaching the wall at a critical angle somewhere between 20 degrees and 40 degrees. The interaction between the incoming wave and the wave being reflected off the wall would generate an edge wave which could be twice the height of the incoming wave. This would be mitigated to some degree where the wave spills onto the lower concrete berm. Even so this action would increase the risk of overtopping and would also pile water up into the corner by the western slipway. The old photograph covering this area (Plate 6.4b) in this area strongly indicates that before the wall was constructed, there was sufficient width to allow waves to spill more gradually along the frontage. However, there is still no evidence of any significant back shore dune and this would be explained by the oblique wave action tending to result in significant long shore drift.

Western Slipway (DU2/DU3)

The increased wave energy in this corner generated along the western wall tends to deposit stone into the corner and this is seen in the relatively high, very coarse, shingle slope. While there is movement of sand into the area, the generally higher energy wave action tends not to allow this sediment to be retained. The area is, under the more westerly wave conditions, still relatively low energy, but wave heights increase as one progresses to the east.

Plate 6.11. Build up of shingle at the southern end of DU2

Considering the angle of wave approach in this corner, it may be appreciated that waves locally at the slipway are significantly out of line with the curve of the wall. Even further east, towards the western kiosk, waves are shown to be approach the wall slightly from the west of north. This contributes to the trend of erosion causing a slow drift to the east.

Records show that the toe to this section of defence is regularly undermined and requires regular repair. This is consistent with the interaction with waves in the area. It may be concluded that the general alignment of the defence is too far forward and would be subjected to regular periods of erosion and a continuing need for management. With sea level rise this problem will become worse. The area is one of the most vulnerable sections of the frontage and is critical to the longer term flood risk management to the local area behind.

Western Kiosk through to the central rock outcrop
The rock to the eastern end of this frontage acts as a groyne. The wave analysis shows how sediment, under all typical westerly storm conditions tend to approach just slightly out of line with the wall and tends, therefore to realign the shingle back beach, exposing the western end of the wall. It would be expected that during storms from the north northeast, waves would be more normal to the wall alignment and would redistribute shingle along the longer length of the wall.

While the rock outcrop maintains control of the drift, the misalignment between the wall and waves is not seen as being too critical. However, there is likely to be a continuing need for repairs as the wall is intermittently exposed. With sea level rise, the pressure on the wall will increase. There would tend to be increased drift to the east and the level of the rock outcrop will be less effective in retaining adequate shingle level in front of the wall.

Central section between the rock outcrops.
The rock outcrop to the western end of this frontage is quite narrow and acts as a cross shore barrier, with little ability to act as a breakwater, modifying the way in which the waves approach the frontage. The larger expanse of rock, further to the east, tends to have a more significant influence on the waves approaching the backshore.

The narrow rock outcrop, therefore, tends to stop shingle moving into this central section, but the rock further down the beach does break wave energy such that finer sand can generally be held over the frontage. This breakwater effect is, however, very sensitive to water level. On lower water levels the rock has a more significant impact on waves, tending to encourage sediment deposition. Under higher water levels, waves can pass over the rock outcrop and can tend to erode sediment against the wall. The monitoring plots for summer 2002 and winter 2003 and winters 2009 and 2010 show this variation quite clearly. Sediment movement against the wall can vary with wave direction and the wall remains too far forward to allow the benefit of the rock outcrops to develop a more stable beach behind.

Eastern section of DU3
This section is under the greatest pressure, with the largest fluctuation of beach levels. There is limited long shore sediment supply to the area, and a strong scouring action due to the oblique wave action in relation to the wall. Sediment supply tends to be from lower down the beach, but the forward position of the wall and the angle of waves along the wall prevents the retention of that sediment. The area is clearly seen from the wave analysis to be the most exposed frontage of the Bay. As a result, the low beach levels, coupled with the higher waves, results in significant over topping. This further acts to destabilise the defences.

Western Slipway.
The slipway acts principally as a groyne. This acts to retain a good shingle upper beach against the higher ground behind. The short section of rock revetment extends slightly forward of where the natural shingle beach would develop.

Overall it may be concluded that over virtually all sections of the Bay, defences are just slightly forward on the natural beach alignment. This is most obvious in the case of DU2 at the western end, where the main issues arise during waves from a north northeast direction and at the eastern end of DU3, where the alignment and forward position of the defence provides no width for development of a natural form of defence. In other areas the defences are generally just slightly out of kilter with wave action, resulting in long term pressure and intermittent vulnerability.

6.5.1 Analysis of the natural form of Pembroke Bay

As a starting point for looking at future management, it is important to consider how the Bay would develop in the absence of defences.

Pembroke Bay is formed as a relative square shape. Although, as discussed above, there are areas where locally long shore sediment drift is an important feature of the backshore, locally, these effects are as a result of the interaction between the dominant wave energy and the defence line. The more natural shape of the Bay would be a shallow sweep in behind the two headlands straightening out over the central section of the bay. This curve would be modified slightly by the natural rock features, and by the relative levels and strength of material backing the bay. The natural bay shape is, therefore going to be very much dictated by the ability of the upper beach to dissipate wave energy approaching quite normal to the general contours of the bay. This can be seen quite graphically in the air photograph from the 1930s, prior to construction of the military defences (Figure 6.8).

Figure 6.8. Pembroke Bay 1930s.

This figure shows a deeper indent to the bay at the eastern end, backed by a solid shingle beach and ridge behind. In the centre of the bay, the influence of the rock outcrop is clearly seen holding the bay slightly forward but with a steeper back cliff behind and by the way in which the rock in the centre of the bay allows the development of a beach and dune ridge over the western side of the bay. Some of the features local to the shore have clearly changed. However based on this photograph together with a historic map from 1938 an approximation can be made of the alignment of the backshore prior to the construction of defences. This is shown in Figure 6.9. The historic map is shown as an insert in the Figure. There appears to have been some form of defence even at this time to the east of the bay in front of a building in this area. This provides a typical baseline for additional analysis of potential erosion that might occur now in the absence of defences in the area.

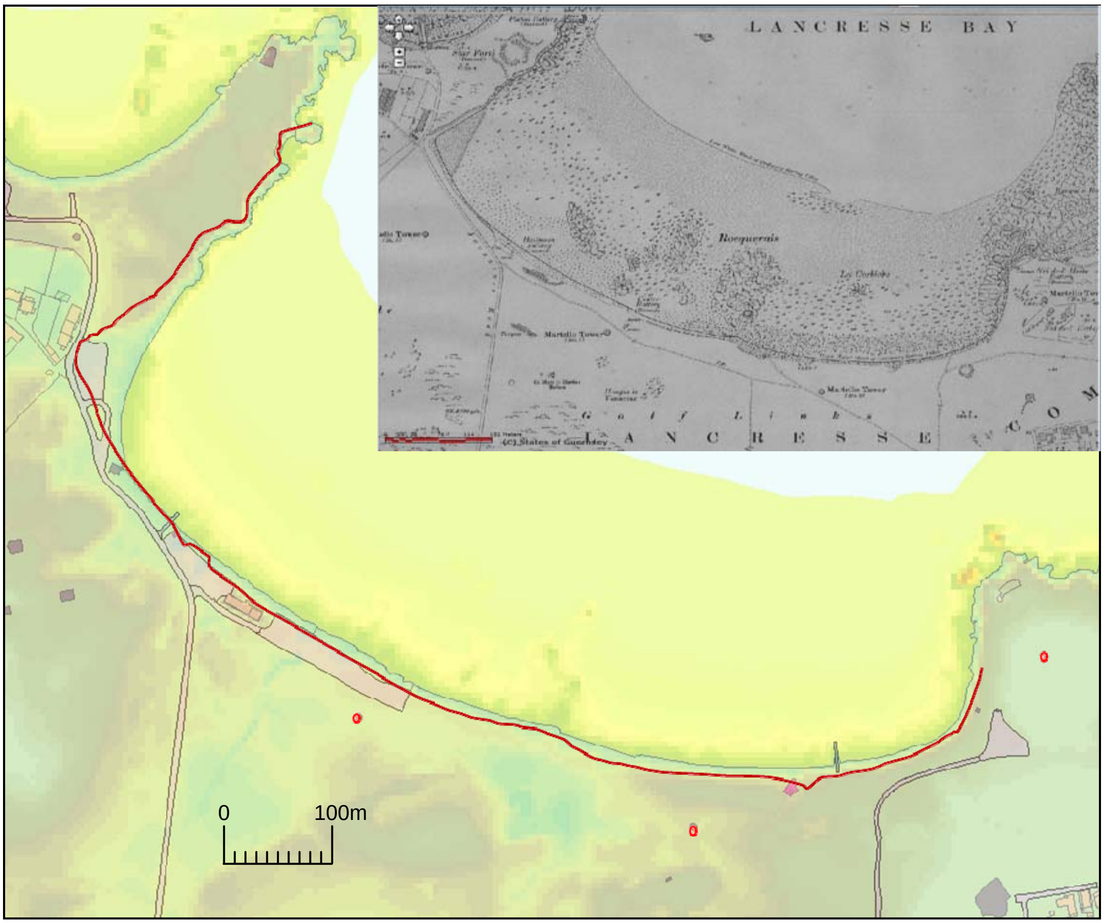


Figure 6.9. Initial Estimate of Erosion based on historic photograph.

The approach taken is based on the beach profile information. Profiles have been taken at various locations around the coastline. This analysis and positions of the profiles are shown in Figure 6.10 (a-i). Profiles a, b and c cover the western half of the Bay, profiles d and e cover the area of the rock outcrop and profiles f, g, h and i cover the east area.

It is immediately apparent that beach levels close to the wall over the western section are generally higher than those to the east. The form of the beach to the western end adopts a more convex shape, consistent with a more nature profile. Further offshore the profiles adopt a more uniform slope.

Figure 6.10 a) profile positions

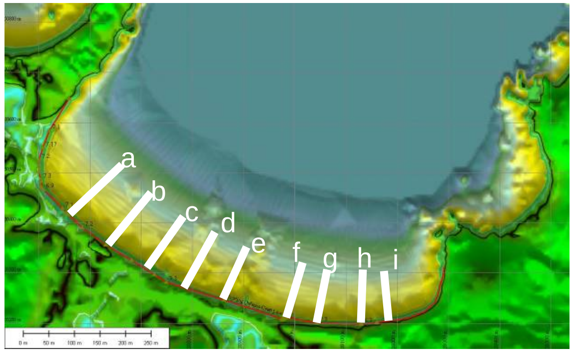


Figure 6.10 b) profiles relative to defence line

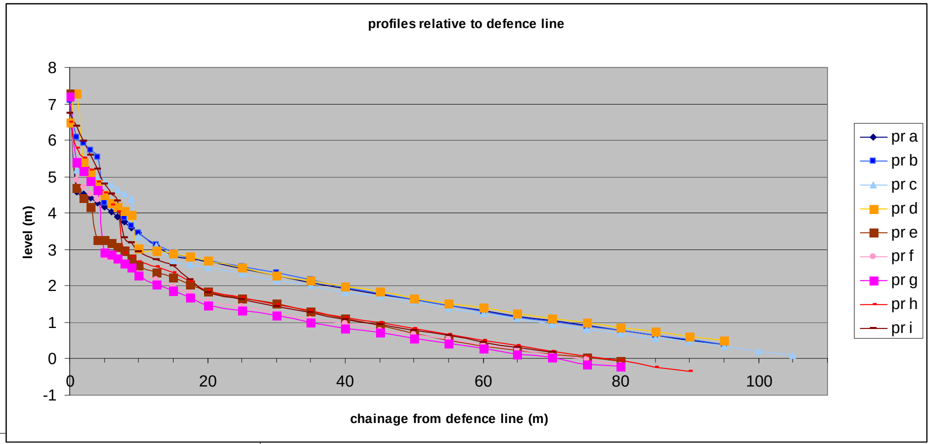


Figure 6.10 c) normalised profiles

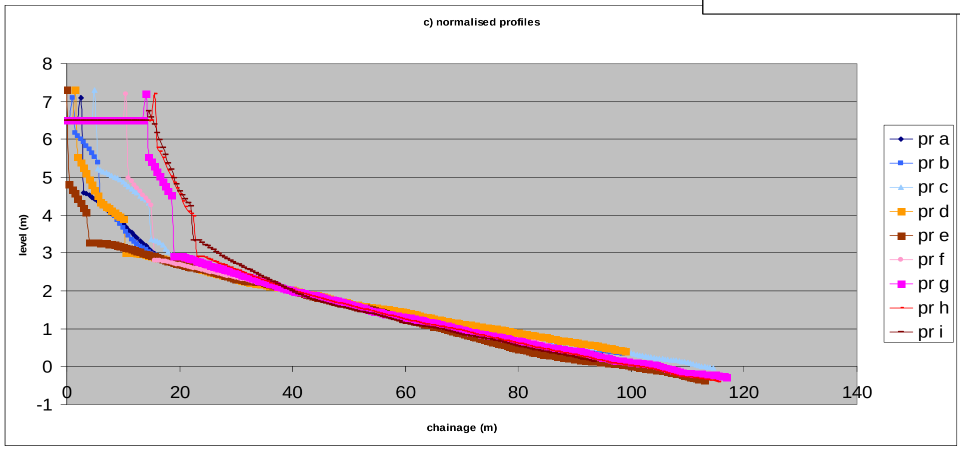


Figure 6.10 d) position of defence in relation to beach.

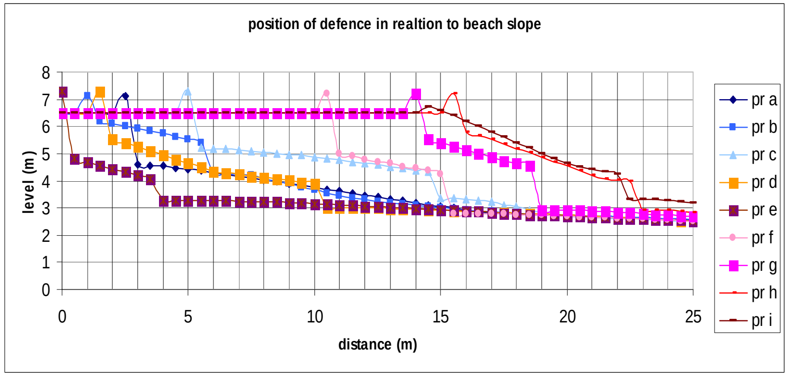


Figure 6.10 Beach profile analysis.

In attempting to assess the degree to which defence may be in advance of the natural line of the beach, it is recognised that the walls themselves would be keeping beach levels artificially low. To correct for this, the profiles have been normalised along their respective chainage at 2mLOD.

This is shown in figure 6.10 c). Profile (e) behind the rock outcrop is taken as the baseline, taking this as a semi natural development of the beach. It can bee seen that profiles (d) and (b) are quite closely aligned to this semi-natural position. Profile (c) is held forward, in effect, by the accumulation of sediment at the crest of the beach, held forward by the groyne effect of the rock.

The profiles most clearly forward are along the eastern end as would be expected. This is shown in more detail in Figure 6.10 d). It is noted that profile (i), at the far eastern end of the frontage is also well forward but this may be explained by the steeper beach as the backshore curves around to the beginning of the rock headland. The beach levels at this location are higher over the upper beach reflecting the stability of the shingle bank created by the shelter of the headland.

Typically from this analysis, it may be seen that in relation to the natural beach form based on profile (e), the western defences are some 5m forward and those to the east some 15m forward.

The profiles give a typical foreshore slope of 1:30 and an upper beach slope of around 1:7.

Given that the level of the wall at profile (e) is still held at the sea wall, it might be anticipated that to complete the profile there would need to be a further set back of some 20m to allow natural development of an upper beach.

Based on this approach the anticipated set back of the shoreline over the frontage may be determined. This is set out in Table 6.3.

Table 6.3. Predicted erosion distances.

Location	Adjustment to alignment (m)	Retreat to a stable crest position (m).
Between western kiosk and slipway	5 -10m	15m – 20m
Western kiosk to rock outcrop.	2m	12m
Central rock section	0	20m
Central rock section to eastern kiosk	15m	35m
East of eastern slipway	5m	5m

As sea level rises, the overall profile of the beach will attempt to adapt. If this change is taken as occurring at MHWS, the probable impact would be for the beach profile to adjust inline with the shallower slope of the foreshore area. Based on this approximation, the horizontal movement of the backshore would be the slope x the rise in sea level. The additional erosion distance is shown in Table 6.4.

Table 6.4. Additional erosion with sea level rise.

Epoch	2011 to 2021	2021 to 2051	2051 to 2101
Additional erosion	4m	9m	15m

The results of this analysis are presented in Figure 6.11 in comparison with the baseline estimate from Figure 6.9.

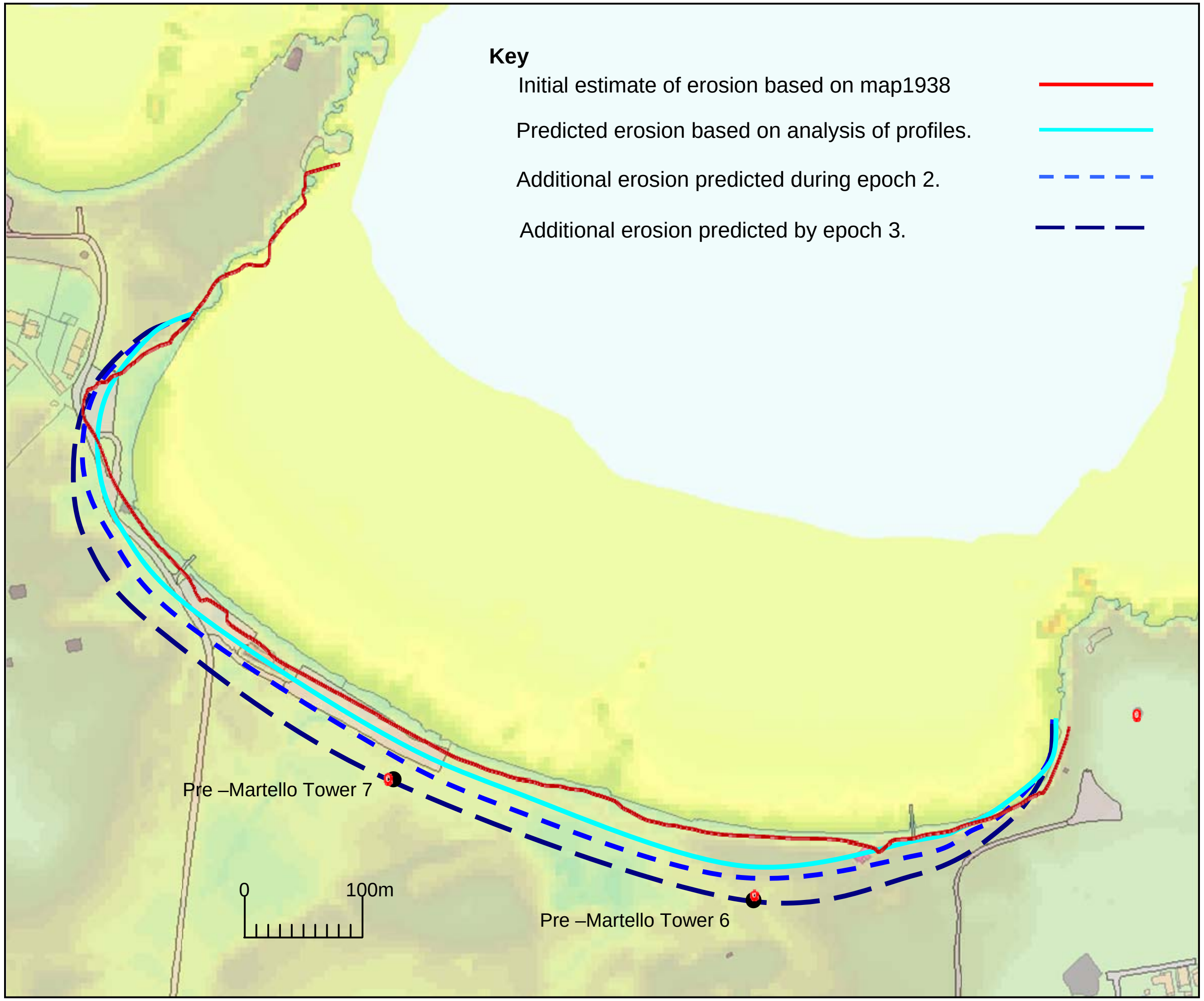
Figure 6.11. Unconstrained erosion lines.

Notes:
Although the erosion lines are based on the beach profiles, it may be seen that the adjustment in alignment brings the shoreline in better alignment with net wave directions.

The erosion lines cut back into higher ground behind the western slipway, in the centre of the bay and at the eastern end. The rate of erosion in these areas may be reduced but would then tend to form a slightly cliffed backshore.

Between these areas of high ground, shingle ridges would tend to form. These ridges would adjust to storm conditions providing a degree of natural flood defence. However, from examination of the old air photograph, there is some indication that shingle has been swept over the ridge at the western end. This would be consistent with the potential sudden change in wave exposure under north northeast storms at this end of the bay.

The road at the western end of the bay could be lost quite rapidly. The two pre-Martello towers could be at risk in the long term depending on the rate of sea level rise.



6.6 Management Approaches

There are a range of potential approaches that could be adopted for management of the frontage. In developing these, it is sensible to bracket the options in looking in outline at two baseline approaches that can be developed; these being the total removal of defences and that of continuing to maintain and improve defences as at present.

6.6.1 Baseline options

Baseline Option 1 - Removal of defences.
The final sub-section 6.5.1 above sets out an option for the natural development of the bay, if all defences were actively removed. It provides one extreme baseline from which to assess the behaviour based on other approaches to management.

The cost of removal of the defences is difficult to define accurately due to the varied nature of individual sections of defence. A typical figure between £2,500 and £3,500 per metre may however be applied; the higher cost being relevant to the larger structures at the eastern end of DU3 and for the western wall (DU2), lengths of approximately 190m and 200m respectively. The remaining central length of 520m is taken at the lower rate. The total cost would be of the order of £2.75M.

Benefit
The primary aim of this approach is to restore the bay to a natural condition allowing the bay to function naturally in the future. The main benefits in such an approach would be in restoring access to the shoreline and to improve that natural amenity of the bay.

The back shore would retreat in line with predicted shape shown in Figure 6.11. Along the main area of the bay there would be an improved sandy beach with areas of sand exposed even at high water. Over much of this area the beach would be backed by a shingle ridge with the potential development of a narrow dune in places. The bay would provide one of the few natural beaches on the island and indeed is one of the few areas where such a beach could be formed. The extent of set back of the shoreline would be limited by the enclosed nature of the bay.

In setting back the line, the natural response at the back shore would be to develop a shingle ridge. This would provide a good level of flood defence across the two main valleys back on to the golf course. This would not provide full protection against extreme water level flooding and further raising of the land may be required to the back of the beach. This could, however, be undertaken through re-landscaping along a line across the common, set well back from the coastal edge. Such works might only be required as sea level rises and as the risk increases in the future, as highlighted in Section 6.4 above. Taking this approach allows a better approach to adaption, creating the opportunity for a more sustainable approach to flood management in the future.

Disbenefit
The obvious and immediate disbenefit would be in the loss of both kiosk and the loss of the main car park areas. There would also be the loss of the amenity area to the western side of the bay and loss of the two slipways. There would also be loss of the heritage value of the military defences.

Associated with the loss of the western sea wall would be the increased risk of flooding to the low lying area to the west. This, initially local flood risk, would develop quite rapidly as the shoreline sets back to its old alignment in this area. The properties would still be well above normal tidal levels and the risk would be from more extreme events. Without action to raise land levels in the area, this flood risk would increase with sea level rise such that properties in the area could be at regular risk from flooding within 50 years and, subject to actual rates of sea level rise would be at risk from normal tidal flooding potentially over a 100 year period.

Flooding is unlikely to impact on the main area of the golf course but in the longer term could affect the Club House.

There would be the loss of the main road behind the beach at the western end of the bay. There is, however, alternative access around the main headland for both properties and to Pembroke Fort.

The two pre-Martello Towers set back behind the bay would not be a risk in the short to medium term. Potentially over the next 100 years, erosion may reach these important historic structures. They would, however, be at the back of a far more stable beach line and local management could sustain these structures without significant interruption to the natural processes.

Baseline Option 2 - Maintain and Improve Existing Defences.
Current practice has been to carry out critical (but reactive) maintenance to sea walls as specific problems have developed. The works undertaken to the sea wall indicate that erosion and undermining around the western slipway and along the eastern section of DU3 has been a long term problem. This has resulted in various works to strengthen the toe of these sections of wall. These toe buttresses have themselves required continuing maintenance to ensure their survival. The most critical area has been at the east end.

At the step in the alignment of the wall, just to the east of the area of rock outcrop, there has been settlement and rotation of the entire wall. This movement is continuing, certainly as a result of undermining, most probably exacerbated by the severe overtopping. No recent works have been undertaken to this section apart from local patching of cracks.

At the eastern end of DU3, in front of the Kiosk, the concrete toe has rotated forward, exposing the toe of the actual wall to undermining with the scouring nature of the waves running along the frontage. The most recent repairs undertaken along this section of the defence were carried out in 2007, infilling the voids and gap between the wall and the concrete toe. In the latest inspection in 2011, it was noted that the toe apron has again moved forward, leaving a weakness to be exploited by the wave action. The recent infilling of the toe over a 65m length will cost in the order of £5k.

The present approach to management can only be considered a stop gap before more major works would be required under this baseline option, to address the underlying problems.

Over the next 5 to 10 years, major works would be required to address these problems and to safeguard other structures around the frontage. The anticipated works are described below.

Plate 6.12. Showing the concrete apron to the eastern wall

On the western wall, in order to secure this structure over the medium term there will be a need to reduce scour and to address the deterioration of the toe piles. The critical element at present is the sheet piles. Under this option the protection would be a rock toe extending up to the concrete apron. This would need to be improved and reinforced with sea level rise, such that the wall would be faced eventually with a larger rock revetment over its full length.

Around the area of the western slipway, there would be on-going maintenance but with the toe being replaced eventually over some 150m of the 310m length by a rock toe. In the future with sea level rise it has been taken that a more substantial rock revetment would be required to safeguard the toe and provide protection against over topping. This work might be delayed over a 50 year period.

The section of wall behind the rock, extending some 210m, is at present less vulnerable to damage. Even so, with continued exposure and sea level rise, a similar approach may have to be taken as described above for the section immediately to the west.

The eastern section of wall through to the eastern slipway is considered to be in the process of failing. Minor works merely patch the problem. The wall is being undermined and each time this occurs, this is likely to increase the overall instability of the wall. In assessing options prior to the repairs undertaken in 2007, the longer term solution of a substantial rock revetment was proposed. This would need to be reinforced over time with sea level rise.

Table 6.5 sets out the anticipated costs associated with on-going maintenance and improvement for each section of the defence. These costs are given as whole costs, not discounted to present day.

Table 6.5. Estimated cost of continued management of existing defences

Location	Length (m)	0 – 25 yrs (£k)	50 - 100 yrs (£k)	Total (£k)
Western Wall DU2	200	200	450	650
Western slipway and Kiosk	310	175	660	835
Wall behind rock outcrop	210	0	450	450
Eastern wall	190	300	300	600
	Total	675	1,710	2,685

Benefit
The primary purpose of this approach is to maintain the existing erosion and flood risk protection provided by the existing defences. This protects the two kiosks and car parks and reduces the flood risk to the local western valley. Over the first epoch use of the coast would continue much as at present, continuing to provide the current amenity value of the area.

There is, however, limited economic benefit derived from this continued defence, as identified by the strategy. The examination of flood risk shows that there is no larger benefit area.

Disbenefit
In fixing the current alignment, there would be an increasing pressure on the defence, with an on-going need for works. Particularly at the eastern end, the critical need to address the failing sections of wall requires significant works and this starts to dictate how this frontage would be managed in the longer term, with further commitment to continued defence.

This applies less immediately over the western and central frontages where works are sustaining the value of the existing defence assets.

Over time, however, there would be a need for greater investment even along these lengths of defence and the overall trend for management would be to encase the whole frontage with rock revetment. This, together with gradually falling beach levels and with sea level rise, less drying upper beach area, would reduce access to and use of the beaches. This would have a significant impact on the amenity value of the area.

As sea level rises, there would be greater reliance on the defence line with greater risk of defences being overtopped and potentially failing.

6.6.2 Alternative Approaches

Both base line options incur significant cost, in the case of Option 1, depending on any phased approach to removal of defences, this cost would occur early on but would notionally reduce to zero into the future. In the case of Option 2, there would still be substantial cost over the initial 20 years, but the main cost would occur over time, with a commitment to increasing cost placed on future generations.

Clearly, to reduce costs there is a further option of walking away from further investment. This Do Nothing approach is considered as Option 3.

Other broad scale approaches were considered within the strategy appraisal; these included major beach recharge and recharge controlled by shore detached breakwaters. These options were costed as £8M and £10M respectively; these options are not considered further.

In considering the two baseline options, there is a clear distinction highlighted between management of the eastern section of defence and that to the west. With respect to the former, there is an urgent need to address the failing walls or to address their failure. In the case of the latter, while there is a continuing problem, this has not reached the same critical condition. There is also seen to be a distinction in use of the two areas, with the western frontage providing protection to the western valley and greater amenity value associated with the car parks, the slightly higher beaches and the road. The natural rock outcrops do also provide a degree of separation in terms of coastal processes. This difference and natural separation may be developed in assessing alternative approaches to management. Based on this, further options considered are:

Option 4 - enhanced protection to the western wall and holding the line over the western section of DU3.

Option 5 - enhanced protection to the western wall and rock groynes along the western section of DU3.

Option 6 - enhanced protection to the western wall and developing shore connected structures to the western section of DU3.

Option 7 - managed realignment along the eastern section of DU3.

These options together with Option 3 – Do Nothing are set out below.

Option 3 – Do Nothing.
Under this approach, rather than positively removing defences, defences would be allowed to fail and the only works undertaken would be to address safety issues.

There would be some cost associated with this option but no significant works would be undertaken.

Major sections of the eastern wall might be expected to fail over the next 5 to 10 years. These defences are large mass concrete structures and would typically fail due to undermining and toppling on to the beach. The structures would be monitored and access behind the structures would be fenced off. As damage was identified there would be a need to close the Kiosk and the small car park.

Once failed, wave action would tend to get behind the walls, undercutting and outflanking adjacent sections of wall. Failed sections of wall would act as low breakwaters, modifying the pattern of erosion behind, tending to form quite steep areas of erosion in the fill material behind. The whole section of wall might be expected to have failed within the next 15 years.

Outflanking would tend to be limited to the west due to the rock outcrop. However, as the general shoreline sets back to the east there may be an increased loss from behind the area of rock, slowly reducing the toe levels at the wall behind.

Potentially the next most vulnerable section of defence would be in the area of the western slipway. In this area failure is more likely to occur quite rapidly during a storm event. Typically this might occur in 10 to 20 years time, with the section of wall becoming increasingly vulnerable to damage as the toe to the wall is lost. There would be continued undermining of the toe and eventual failure of the wall.

Loss of defence in this area could increase the risk of overtopping with wash out and wash over of sediment. As with the eastern section, failure of one section would encourage failure of adjacent sections of wall.

Over the same period of time, there would be continued down cutting of the beach platform in front of the western wall and, as significantly, holes would start to appear in the exposed sheet piling. This would result in voids developing under the concrete berm and this berm may then start to fail. It is uncertain to what degree the concrete berm acts as a support to the main wall behind but it would be expected that there would be undermining and movement of this high retaining structure.

Over the next 20 to 30 years, failure would have occurred along most of the western frontage, with short sections of wall remaining but only acting locally in terms of defence. Over much of the frontage large sections of wall would litter the beach area as the shoreline retreated back. This would not over the long term, necessarily result in a safety risk, although individual sections of failure would need to be assessed with the possible need to remove some sections of failed defence. In particular the western wall is likely to present a problem due to failed and undermined decking and the exposed of the sheet piling.

The cost of managing this is highly uncertain but would be an on-going cost, addressing specific areas. Typically, one might envisage the need to remove the western wall completely, at a cost of some £700,000 some time around year 20 to 30. In other areas, the intent would be only to remove critical sections of failed defence as they posed a risk to safety.

Clearly decisions could be made combining this approach to management with that of actively removing sections of defence as in Option 1. This sub-option may then act to spread cost more effectively and may still allow some planned approach into the future. For example, taking forward this in relation to the eastern frontage, the area where movement of the wall is already happening could, as at present be fenced off, the wall allowed to fail and action then taken merely to tidy up specific areas posing a risk to safety.

In other areas a more structured approach may be required that actually removes the defence.

Benefit
The main benefit would be in reducing costs and spreading the cost of demolition over a longer period of time. Over the longer term there would typically be the same general benefits identified in Option 1.

Disbenefit
There would be no planned programme of change. As such, as defences became more vulnerable there would be the need to evacuate the kiosks in advance of failure and removal of the buildings in a manner determined by the deterioration of the defences.

Over the early years, there would be increased deterioration of the amenity value of the area and areas where visitors to the frontage were excluded from using sections of the sea front and beach.

Over the longer term other damages would occur as identified in Option 1.

The following three options focus on management of the western end of the bay

Option 4 - Enhanced protection to the western wall and holding the line over the western section of DU3.
The main immediate issue along the western frontage results largely from the way in which waves, particularly during significant storms from a north northeast direction, interact with the western wall. This gives rise not only to continued deterioration along the wall itself but also causes erosion at the western slipway and the adjacent wall in this area.

Placing a rock toe along the base of the western wall would to some degree reduce these problems by reducing the level of reflection and reducing the development of the edge wave effect. The cost associated with this is identified as being of the order of £200,000 initially (Option 2).

More effectively, some form of breakwater or groynes could be constructed along the frontage and at the southern end of the western wall. This is shown in a high level outline in Figure 6.12.

These works would not exclude the need for protection along the face of the sheet piles but would significantly improve the effectiveness of this toe while also reducing reflected waves that run along the face of the wall by the western slipway.

The outline estimated cost of the work would be of the order of £600,000 (this includes the cost of the rock toe allowed for in Option 2).

Benefit
The approach outlined above aims to address the exposure created by waves, principally from the north northeast, running along the western wall. This reduces pressure on this wall but would also address some of the scour problems along the

western section of DU3. This would reduce maintenance costs and provide the opportunity for a more stable and higher level of beach in this important amenity area.

If the defences were to be sustained over the full 100 year period, there would still be a need for further work to address the issues of sea level rise. However, the key aspect of moving towards an approach that is addressing the main cause of the problems would be in maintaining the opportunity for adaption in the future.

The approach outlined could be developed further if future defence was deemed sensible. Alternatively, if the initial period of maintaining defences was used to plan an adaptation of use in the area, this approach would still be compatible with any potential future realignment. Future management would be far less driven by the deterioration of existing defences. The main issue would be in addressing the reducing standard of flood defence as sea level rises.

Disbenefit

The main disbenefit is in terms of the additional cost. There would be a cost of the order of £400,000 over and above that estimated in Option 2 during the first 20 years.

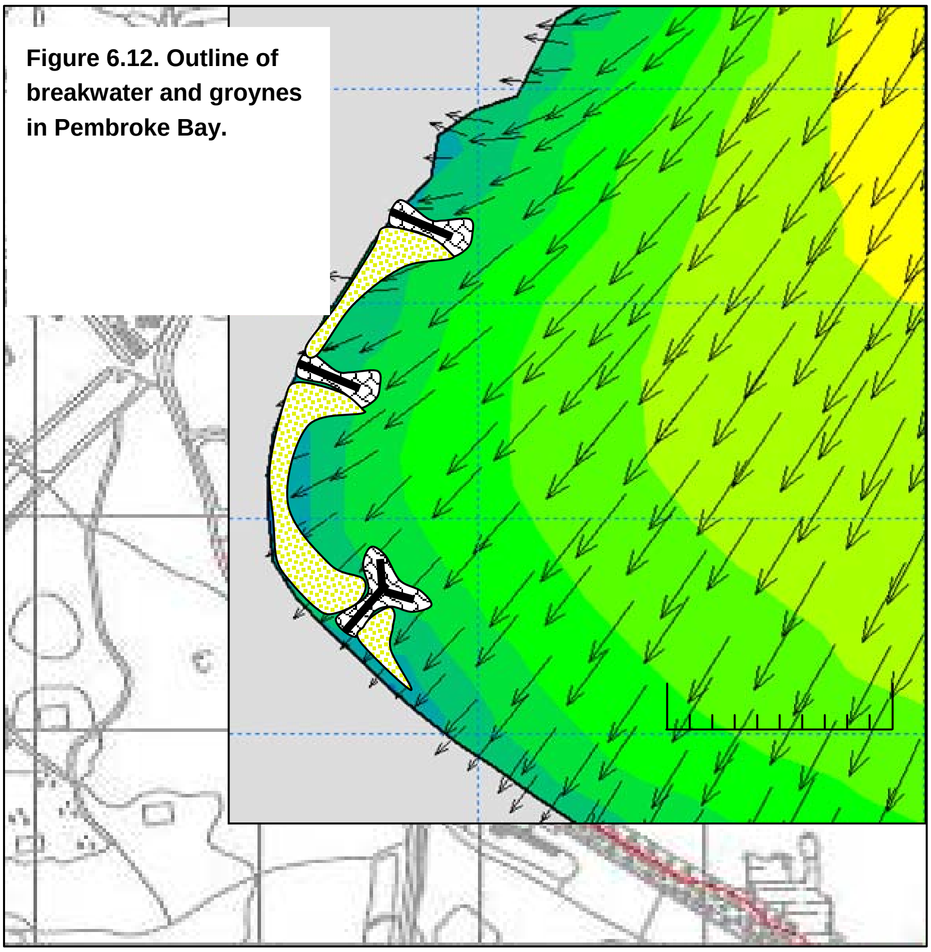


Figure 6.12. Outline of breakwater and groynes in Pembroke Bay.

Option 5 - Enhanced protection to the western wall and rock groynes along the western section of DU3.

Option 4 could be developed further in addressing the vulnerability to the western section of DU3. There would not be the same quite the same benefit in that waves approach this section of defence more normal to the beach crest. However, by placing short rock groynes they would act to improve the stability of the upper beach retaining sediment against the toe of the wall. There would still be the tendency during more severe storms for sediment to be drawn down the beach but not to the same extent as at present.

In outline, groynes would be constructed typically every 50m along the length and would extend possibly some 30m from the face of the wall. This is shown in outline in Figure 6.13.

Typical costs would be of the order of £60,000 per structure. With seven potential, structures covering the frontage, this would amount to an overall cost of the order of £420,000.

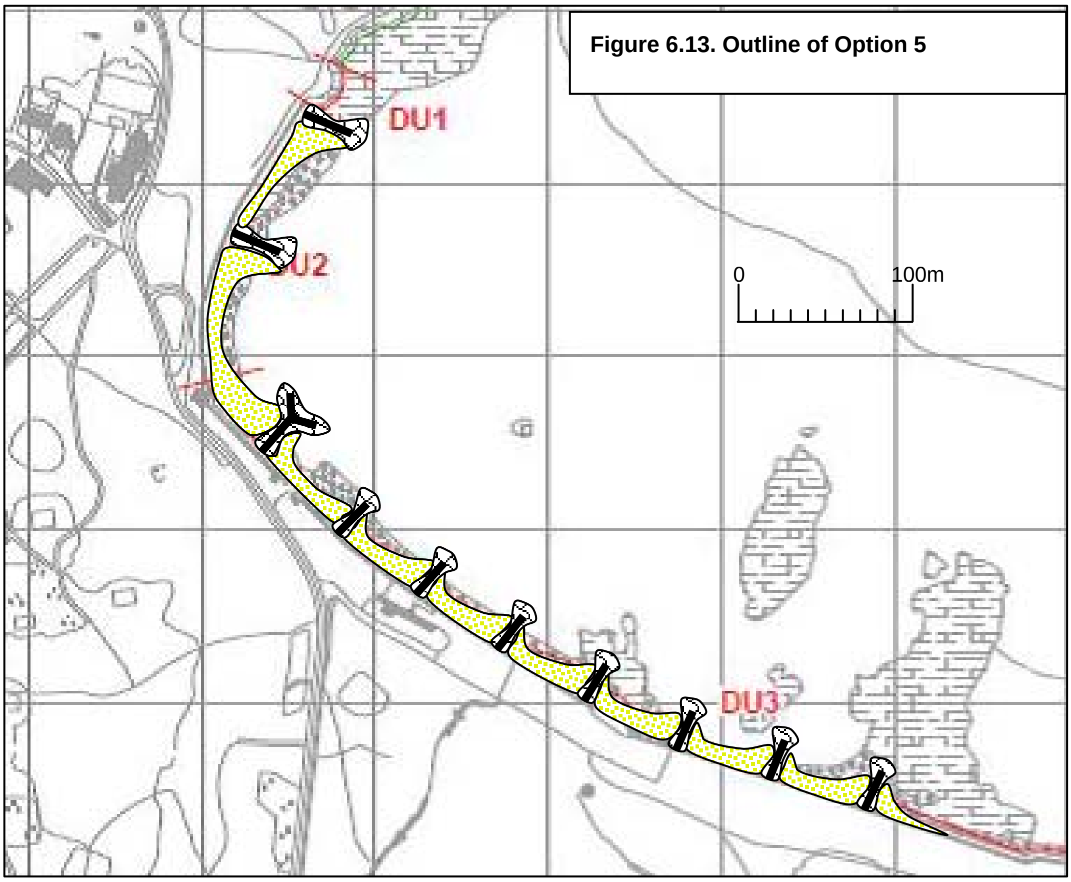


Figure 6.13. Outline of Option 5

Benefit
As with Option 4, the benefit accrues from the additional amenity value provided by a more stable upper beach area and in the longer term from taking a more adaptive approach to management. This option would still require further work over the longer term to address the issues of sea level rise.

Disbenefit

There would be a significant cost involved in the work and while there would be a reduction in on-going maintenance to the existing defences, there actual benefit terms of reduced damages to assets would be minimal.

A further risk associated with this approach would be the possible reduction of sediment movement through to the east. This risk appears small given that the rock outcrop in the centre of the Bay already tends to reduce such drift at present.

Option 6 - Enhanced protection to the western wall and developing shore connected structures to the western section of DU3.

This option further develops on the above options providing significantly greater control of the upper beach. In association with works to the western wall, the intent would be to construct a larger structure in the area of the rock outcrop. This in outline is shown in Figure 6.14.

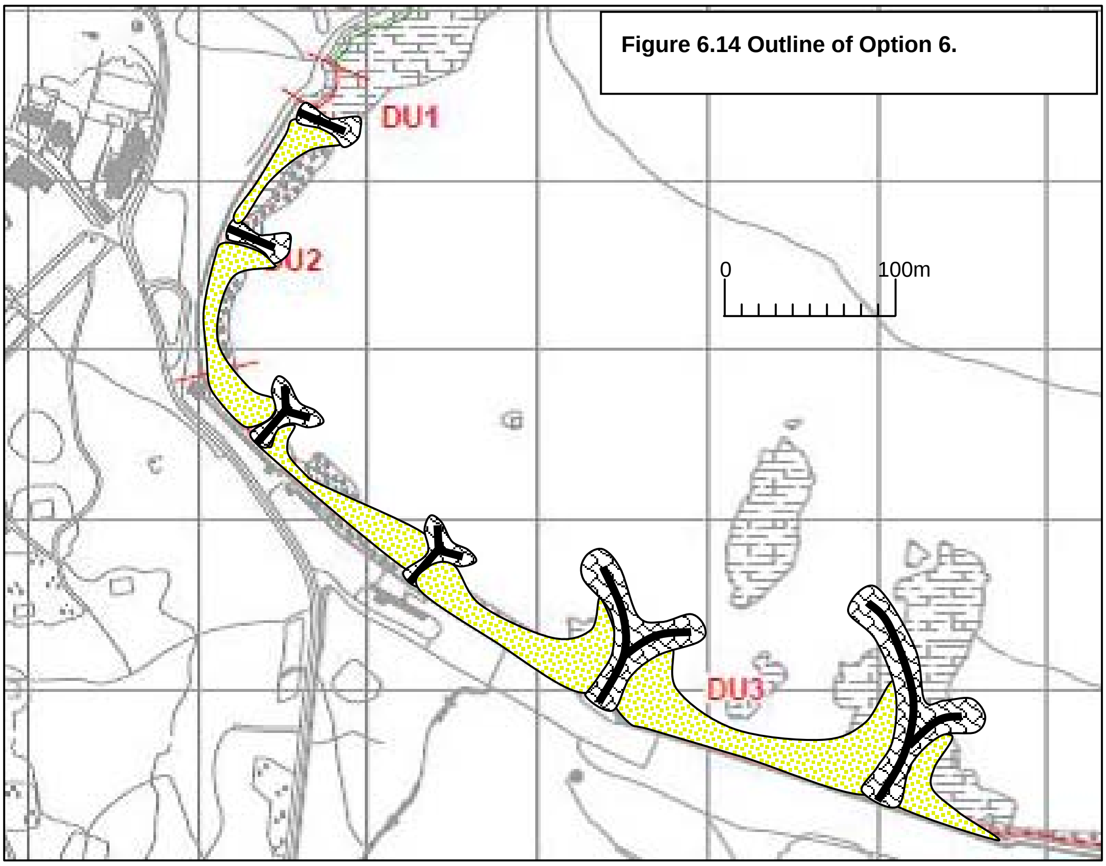


Figure 6.14 Outline of Option 6.

The intent of this approach is, in effect to draw forward the whole shape of the western section of the bay, to create wider beaches and to provide more complete protection to the existing defence line. In doing this there may be the further need to actively recharge the areas between structures so as to avoid material being redistributed as the structures influence the coastal processes. This would need further detailed study and the possible need for physical modelling.

With sea level rise there would be the need for further works but as with other options considered for this area, the approach provides a longer term management that could be adapted to either holding the line or to manage realignment in the future.

Without additional detailed design, there is increased uncertainty within the costs. This uncertainty has however been allowed for. The overall costs, over and above the costs estimated for Option 4, which would form part of the scheme, are in the order of £3M.

Benefit
The option provides a more secure approach to defence over the next 50 years, with the benefit that this approach could be taken forward in a sustainable manner in the future.

There would be improved amenity value in terms of wider beaches and areas of beach that would remain dry over normal tides.

The approach builds on the natural rock base in the centre of the bay reinforcing natural processes.

Disbenefit
There is a significant cost associated with the approach that goes well beyond flood and erosion risk benefits that may be derived from the work.

The large structures would have a significant impact on the landscape of the area, with large structures exposed over much of the tide. These structures could have an impact on the eastern frontage tending to draw sediment into the lee of the most easterly structure and further reducing beach levels to the east.

In summary for the western section of the bay, Table 6.6 sets out the anticipated costs over the initial 50 year period.

Table 6.6. Summary of costs for the western defences

Option	Estimated costs (£k)
1. Removal of defences	2,025
2. Maintain and improve existing	375
4. Enhance protection to DU2 + maintain DU3	775
5. (option 4) + rock groynes	1,020
6. (option 4)+ control structures	3,600

The following discussion focuses on the eastern end of the bay, with two principal options being considered for managed realignment.

Option 7a – Control Structures to Develop the Shoreline in Front of the Existing Defences.

The intent of this option is similar in principle to those considered for the western end of the bay, in that the aim would be to provide a natural defence alignment through use of control structures. This is shown in outline Figure 6.15.

The relatively normal wave approach means that to advance the line of a beach sufficiently to provide continued protection to the toe in this area, structures have to extend a significant distance offshore and provide sufficient shelter to allow waves to spread within the influence of the arms.

Typically, as shown in Figure 6.15, two structures would be used: at the section of wall that is badly undermined as in toppling forward, providing support to this wall, and at the slipway. These structures could be integrated with the various defence approaches taken in managing the western frontage.

The optimum position of the structures would need to be modelled in detail to ensure that a stable beach provides adequate long term protection to the existing defence. There is therefore increased uncertainty in costing this option. There are also significantly greater costs associated with the increased height of the structure in relation to beach levels at the wall. Typical costs are of the order of £1.8M.

Benefit

There is little economic benefit and the prime reason would be to stabilise the existing defence and provide continued protection to the Kiosk. There would be an improved area of beach with some amenity value and the slipway might be improved during the construction of the eastern structure.

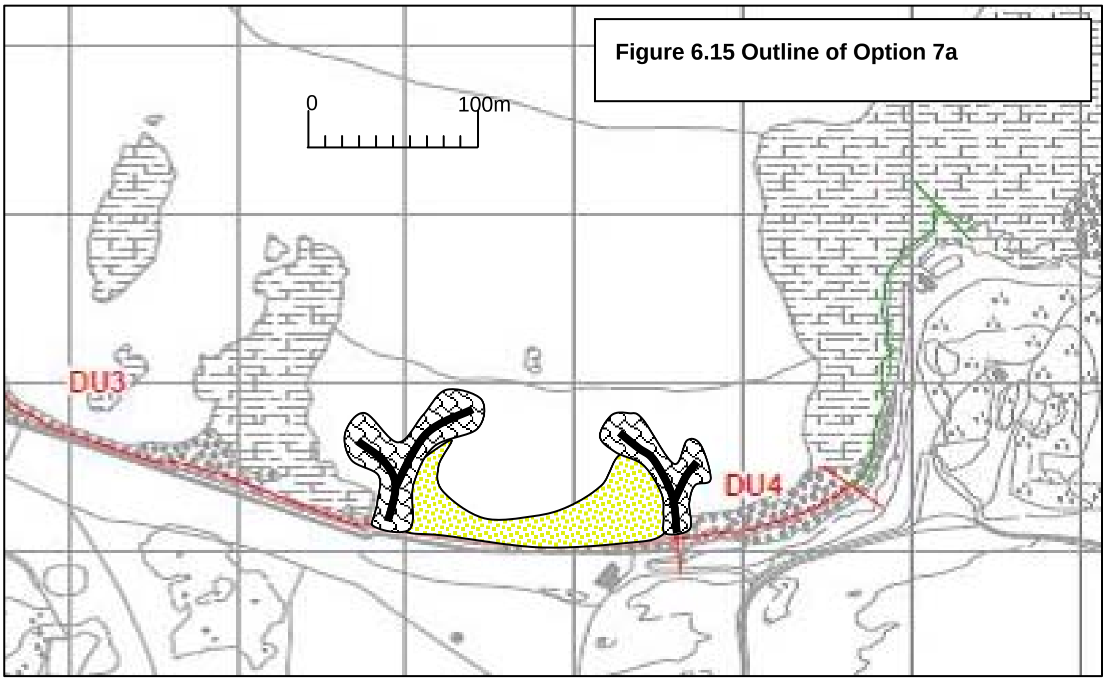


Figure 6.15 Outline of Option 7a

Disbenefit

The main disbenefit would be the extremely high cost associated with the work.

Option 7b – Control Realignment of the Existing Defence.

One of the main difficulties in taking forward the line of defence is the size of structures necessary to create the width needed to hold an adequate beach. The alternative to this would be to allow the existing defence to fail, thus creating width for a beach to develop to the rear of this forward line and to control erosion as this occurs. This is shown in outline in Figure 6.16.

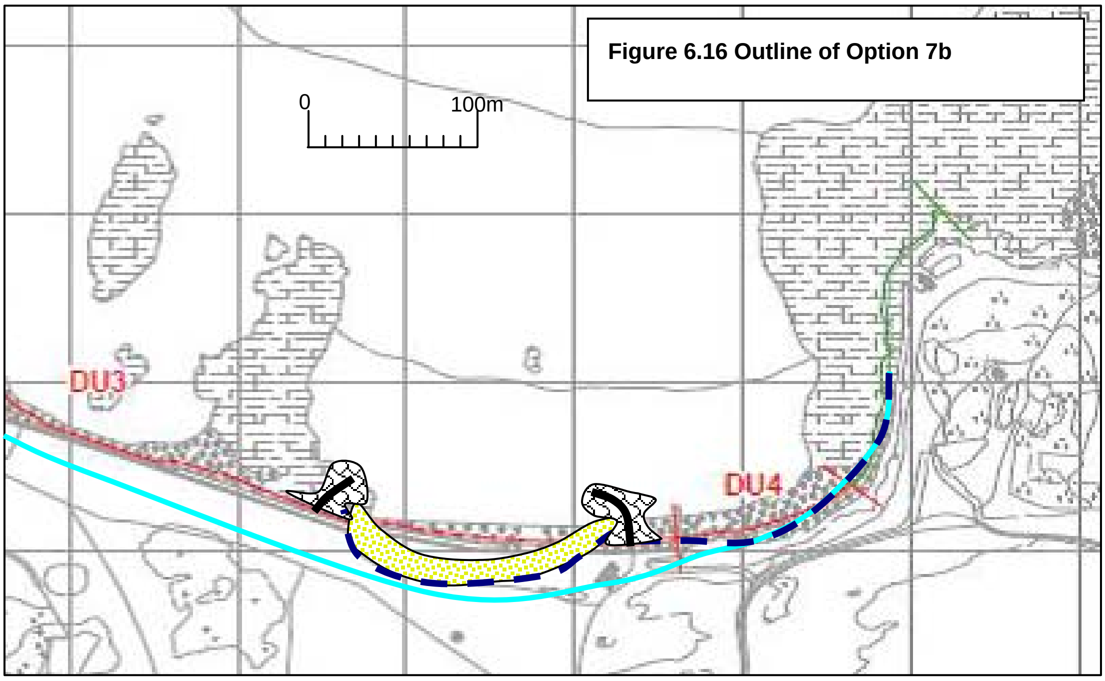
The works would need to be undertaken as part of and as an additional element of works associated with managing the failure or removal of the existing defences. Typically the additional cost would be of the order of £120,000. The aim would be to sustain the defence to the area of the Kiosk and to provide additional protection to the slipway and existing rock revetment

These works might be compatible with works undertaken to the west, allowing controlled adaption of the frontage over the longer term.

Benefits

The main benefits would be in substantially reducing cost of management, maintaining defence to the Kiosk and addressing the immediate problems associated with the wall.

The approach would significantly improve the overall amenity value of the area by allowing development of a semi-natural beach and significantly improving access. The approach would allow sustainable adaptation in the longer term.



Disbenefit
The main disbenefit would be in some additional cost.

In summary the costs associated with different options for management of the eastern end of the bay are set out in Table 6.7.

Table 6.7. Summary of costs for the eastern defences.

Option	Estimated costs (£k)
1. Removal of defences	665
2. Maintain and improve existing	300
7a. Advancing the defence line	1,800
7b Managed retreat Including removal of defences	660

6.7 Conclusions

The aim of this element of the overall study has been to examine and set out potential options for future management of Pembroke Bay in such a manner as to allow and inform further discussion with interested groups and users of the area. As such no recommendations are made, but conclusions are drawn:

- That the Bay may be considered relatively self-contained with respect to both flood and erosion risk.
- There is a significant local flood risk to the western side of the Bay, but this would develop principally as sea level rises in the future.
- The land behind the Bay is at such a level that it is only into the third epoch (50 to 100 years in the future) that there is likely to be any substantial risk affecting the land to the south of L'Ancresse Common. In addressing this in the future, it is seen as more sustainable to landscape the narrow valleys in such a manner

as to achieve a retired level of protection that will not impact on and force the need for works at the sea front.

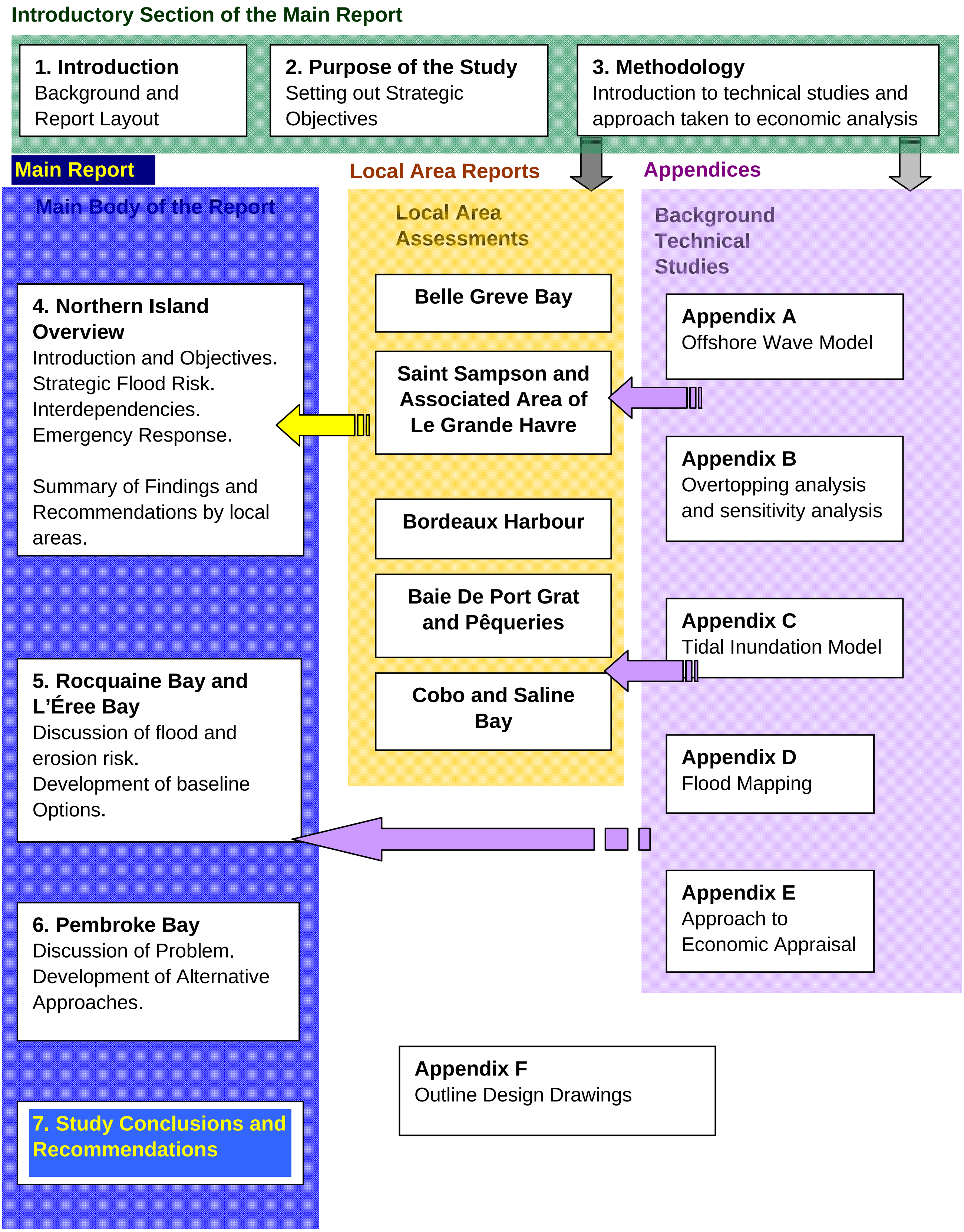
With respect to the behaviour of the Bay it has been found from the modelling work, and supporting general observations and monitoring that:

- The Bay is exposed to waves generated from a variety of offshore directions. Although substantially sheltered from the more westerly wave directions, these offshore waves may still generate a significant wave height within the bay, particularly at the eastern end.
- At the western end the wall in this area receives little wave exposure from the offshore westerly waves but is very exposed to waves from a north northeast direction. The orientation of the wall is such that waves run along this west wall and cause scour of the rocky shore platform. These reflected waves also cause significant damage over the western section of the main frontage.
- At the eastern end of the frontage the main problem is the much higher wave exposure from all offshore directions and coupled to this the scouring effect of waves approaching the wall at an angle.

In terms of management, these wave conditions have resulted in on-going damage particularly at the far west end and at the eastern end of the Bay. Various options have been considered to address these issues. These are presented in the report to assist discussion of future management.

ROYAL HASKONING

OVERALL REPORT STRUCTURE



7 STUDY CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary of Management Issues

This study covers a wide range issues covering many different sections of the coast of Guernsey, highlighting specific problems for management, tailoring approaches to these different issues at different locations, at different scales and different levels of priority and urgency.

With respect to the Northern part of the island, the starting point of this study was the large scale potential risk of flooding identified through the 2007 Strategy; the assessment of this risk was based on assessing land levels in relation to extreme water levels taken for St Peter Port. This study, through the more detailed analysis of extremes conditions, coupled to wave and hydrodynamic modelling, has been able to examine this risk in greater detail. This study has demonstrated that, with the exception of flooding to the back of St Sampson, larger scale inundation is unlikely to occur.

Even with anticipated sea level rise over the next 100 years, taking a 1:250 year return period event, it has been shown that the extent of potential flooding would tend to be limited to specific areas associated with specific sections of the coast. Only in the case of the valley across the island between St Sampson and Le Grande Havre is there any substantive link between flooding on the east and west coasts. The revised flood risk extent (assuming existing defences are maintained) is shown in Figure 7.1.

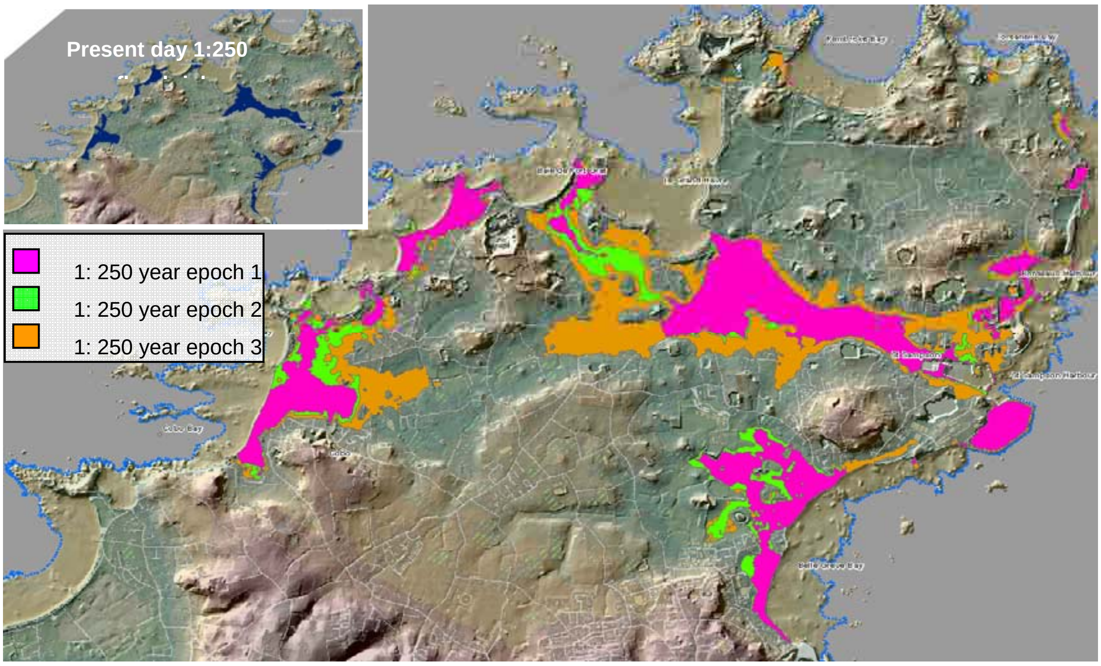


Figure 7.1. Revised Flood Risk Extent over the three epochs to 2111;1:250 year return period

Even so, the potential flood risk linked to specific sections of the coast can be quite extensive, also indicated in Figure 7.1. This has, in each location, serious impacts in terms of direct damage to property and more generally in terms of use of the coastal area and potentially causing major disruption to services, transport and the economy. The study has also highlighted in many areas that flood risk to the local hinterland may occur as a result of overtopping of defences at different locations within any one area. This study therefore demonstrates the need for a strategic approach to defence to address such issues both now, in dealing with existing problems, and with a view to the future in providing sustainable management of increasing risk.

In terms of the main drivers of flood risk, the study has provided a re-assessment of extreme water levels around the island based on measurements undertaken at St Peter Port. This extrapolates from a thirteen year record, to estimate water level return periods through to a value for the 1:250 year return period. This is not ideal and, while providing more accurate values for extremes, there will be the need to build a longer term record from which to regularly re-assess these values. Associated with this is the need to continue to monitor the affects of climate change on sea level. The study bases its assessment on the findings of United Kingdom Climate Impacts Programme (UKCIP). There is strong evidence now for sea level rise but the critical factor is the rate at which this is happening.

The study has used a hydrodynamic model to assess variation of water levels around the island. This has identified significant variation between sections of the shoreline, such that high and extreme water levels associated with the east coast are typically between 0.2m and 0.5m higher than equivalent water levels to the south west and northwest of the island, respectively. This has a significant influence in assessing flood risk in specific areas.

Wave heights around the island also vary significantly. The west coast is exposed to both locally generated waves and longer period swell waves from the open Atlantic. In assessing wave climates various different directions and conditions have been assessed. On the east coast, although this can still, in some areas, be exposed to longer period swell waves, the overall wave climate is much lower.

The study has used different wave conditions and the different water levels to assess wave overtopping over the existing defences. This has been compared, for lower return periods, against historic records of overtopping and flooding. Based on this it is found that many of the older existing defences provide a standard of protection, typically, somewhere in the range of a 1:10 to 1:50 return period. It has been concluded that the modelling tends to overestimate the degree of overtopping that might be expected on a 1:10 year event. However, with the generally low level of many of the defences, the modelling highlights a rapid increase in flooding on slightly higher water levels. There is, therefore, greater confidence that flooding on lower frequency (high return period) events is realistically captured. This sensitivity to water level also means that many areas will be sensitive to the anticipated rise in sea level even over the first twenty years (epoch 1).

Such sensitivity is highlighted in areas such as St Sampson. Under present day conditions, here overtopping of the Bridge is at present critically around a 1:10 to 1:20 year standard. On a 1:50 year event, the degree of overtopping would increase such that, from limited flooding occurring on a 1:10 year event, a substantial extent of the low lying valley behind would be flooded.

In some areas, existing defences provide a relatively low standard of defence. Despite this, it has been concluded that, where this does not lead to substantial risk to life or damage to properties, such a standard may be acceptable with appropriate flood warnings in place. Improvement to defences may, therefore, be triggered by the actual rate of sea level rise, increasing flood risk to the point where more frequent or more significant consequences occur. This is discussed in the report but, in such areas, investment in improving defences may be delayed. In other cases, such as St Sampson or the Rousse Headland, the consequence of flooding is seen as being critical and such areas are identified as having a more immediate need for improvement. In other areas, such at Belle Greve Bay, local improvements are identified as providing significant additional security and recommendations are made with respect to this. This has to be set in a longer term context, ensuring that local actions are taken in a manner that does not exclude more long term sustainable options.

This approach and the rational for prioritising defence improvement work is set out in the risk assessment tables in the next sub-section of the report.

The summary of findings of the study also highlights where serious consideration needs to be given as to the ability to sustain risk management to some communities in the longer term. This would clearly need to be considered in detail with property owners and communities.

In addition to the assessment of flood risk for the northern part of the island, separate analysis has been undertaken for issues relating to Rocquaine and L'Erée Bay and in relation to future management of Pembroke Bay.

In the case of Rocquaine and L'Erée Bay, while there is identified significant flood risk, the main problem relates to the integrity of the massive sea wall to the centre of the bay. Due to erosion at the toe of this defence, there is a real concern that this wall may fail. This would result in the loss of property and the main coastal road. With limited information relating to the form of the defence, it is only possible to make a sensible judgement as to the residual life of this defence. Typically, based on estimated erosion and rates of deterioration, this wall may survive for some 10 years. However, this could be an overestimation and recommendations are made for addressing this problem within the next five years.

In the case of Pembroke Bay, the 2007 Strategy suggested that defences should be realigned, with the opportunity of recreating a more natural beach and backshore, potentially improving use of the frontage. This has been considered in more detail, looking at various options for management. Quite specifically, the report does not make recommendations in this area. The study presents options so that informed decisions may be made of future management of the area.

The following sub-section presents a summary of findings for each of the main areas, presented in tabular form, providing and assessment of risk and urgency. The recommendations of the study are then drawn together as a prioritised action plan.

7.2 Assessment of risk and urgency

The following tables provide an assessment of risk in terms of probability (high or medium frequency of occurrence) and in terms of consequence or impact (high, medium or low). The potential frequency of an event or of the severity of consequence clearly changes over time with sea level rise.

The table then sets out recommended actions for dealing with these consequences.

Priority Actions:	BELLE GREVE BAY CU19	
Risk:	**Present Risk**	**Long Term Risk with sea level rise (epoch 2 and 3)**
High frequency events: 1:1 to 1:20 year return period	**Potentially high consequence of risk to the main coastal road and important development area from overtopping of DU8 and 9.**	**Significantly increased risk of flooding over DU7, 8 and 9, affecting the main development area, increasing from the end of epoch 1 .**
	Medium risk to properties due to overtopping of low levels of the DU4 embankment.	**Regular flooding likely from overtopping of lengths of the DU4 embankment and along DU5.**
	Medium risk locally due to overtopping along the northern section of DU6 and DU5 primarily associated with local wave interaction.	**Medium risk of local flooding to DU3.**
Low frequency events: Less frequent than 1:20 year return period (1:50 year or greater)	**Severe risk of flooding along DU8 and 9, potentially along sections of DU7 on higher events. Potential for wider flooding through to the hinterland.**	**High levels of overtopping along all frontages from the end of epoch 1. Potential still water level flooding along DU9.**
	High risk of flooding under higher waterlevels along DU4, linked to overtopping of DU5.	
	Low risk locally to properties behind DU3.	**Significant impact locally from flooding along DU3.**
Actions		
Short term (see action plan):	• Works to locally raise defences along DU8 and 9, providing an initial standard of defence to a 1:50 year standard providing additional security while undertaking consultation on longer term approach. High Priority • Works to raise DU4 embankment locally to provide a more coherent defence standard to a 1:100 year level. Quick win, high priority. • Local raising of defence along DU 5 with the possible inclusion of improvement to wave interaction along DU6. Medium priority.	
Medium Term Planning (20 years)	• Develop through consultation longer term approach to defence along DU7, 8 and 9. Potential option for advancing the line in conjunction with works to enhance the sea front. High Priority due to potential lead in time. • Comprehensive raising of DU4 embankment coupled with improvement to reduce risk along DU5. Medium Priority assuming short term measures have been undertaken.	
Long Term Planning	• Planning control within low lying hinterland area. • Ensure appropriate levels for future development along the sea front taking account of anticipated sea level rise.	

Priority Actions:	**ST SAMPSON CU18**	
Risk:	**Present Risk**	**Long Term Risk with sea level rise (epoch 2 and 3)**
High frequency events: 1:1 to 1:20 year return period	**Severe risk of still water level overflowing the Bridge with severe local disruption and flooding to properties.**	**Severe risk of still water level overflowing the Bridge with severe widespread disruption within hinterland and flooding to properties.**
	Medium risk of flooding to general harbour area.	**Regular flooding initially to harbour area with increasing risk of flooding to wider area.**
	Very low risk of flooding from the direction of Le Grande Havre.	**Medium risk of flooding to hinterland from the direction of Le Grande Havre.**
Low frequency events: Less frequent than 1:20 year return period (1:50 year or greater)	**Severe risk of still water level overflowing the Bridge with severe widespread disruption within hinterland and flooding to properties.**	**Regular overflow of Bridge with severe risk both locally and to hinterland.**
	High risk of local flooding to general harbour area with potential to flood broader areas, particularly to northern side.	**High risk of flooding to general harbour area with flooding to general hinterland areas.**
	Medium risk (1:100) of overtopping at Le Grande Havre affecting general hinterland areas.	**High risk of overtopping at Le Grande Havre causing significant disruption to hinterland area and risk to property.**
		100 year risk of flooding from other areas (Bordeaux Harbour and local areas of Le Grande Havre).
Actions		
Short term (see action plan):	• Works to address overtopping at the Bridge. Works potentially incorporated within redevelopment plans for the area. High Priority. • Examine opportunity for undertaking more general improved flood risk management to harbour area in association with these works. Medium Priority. • Examine in discussion with Harbour users opportunity for harbour barrage. Low Priority subject to plan for the Harbour.	
Medium Term Planning (20 years)	• Improvement to flood risk management generally to harbour area, if not included with the above. High Priority to north. • Local raising of embankment to the southeast corner of Le Grande Havre. Examine opportunity to raise defences more generally within Le Grande Havre area in association with these works. Medium Priority.	
Long Term Planning	• Avoid development of critical infrastructure within hinterland area. • Review defence requirement to the Power Station. • Review pumping arrangements of the hinterland area. • Review need for additional works within Le Grande Havre if not included above. • Review need for flood defence to exclude risk from Bordeaux Harbour Area.	

Priority Actions:	BORDEAUX HARBOUR CU17	
Risk:	**Present Risk**	**Long Term Risk with sea level rise (epoch 2 and 3)**
High frequency events: 1:1 to 1:20 year return period	**Medium risk to properties and road on events of 1:10 to 1:20 due to overtopping of DU4.**	**Severe risk of still water level overflowing DU4 and overtopping DU2 with more extensive flooding to the general area.**
	Medium risk of damage to DU2.	
	Low risk of flooding from DU5.	**Medium risk of flooding form DU5 and DU 3 contributing to general flooding of the area.**
Low frequency events: Less frequent than 1:20 year return period (1:50 year or greater)	**Severe risk of still water level overflowing DU4 with signifcant consequence to property and the transport system on higher events.**	**Severe risk of still water level overflowing DU4 and overtopping DU2 and DU3 with more extensive flooding to the general area.**
	High risk of flooding from DU2 contributing to genral flooding.	**Increased flood risk from DU5, significantly contributing to general flooding of the area**
	Medium risk (1:100) of overtopping of DU5 and DU3 contributing to general flooding of the area.	
Actions		
Short Term (see action plan):	• Maintain DU4 and improve the condition of defence along DU2 and DU3. High Priority. • Discussion and raise awareness of flood risk within the local community, develop flood warning system. High Priority • Develop long term plan for set back defence to limit flood risk. High Priority. • Undertake construction of set back embankment to limit extent of flooding. Medium Priority. • Potential for reducing wave action along DU4. Low Priority.	
Medium Term Planning (20 years)	• Develop flood warning and evacuation planning for properties remaining at high flood risk. High Priority	
Long Term Planning	• Avoid development within high flood risk area. • Review Relocation of transport routes.	

Priority Actions:	ROUSSE HEADLAND AND BAIE DE PORT GRAT CU11 AND 12	
Risk:	**Present Risk**	**Long Term Risk with sea level rise (epoch 2 and 3)**
High frequency events: 1:1 to 1:20 year return period	**High risk of failure of revetment to north of headland.** **Low risk of local flooding from within Le Grande Havre (Dicqs Road).**	**High risk of flooding to north of headland risk.** **Medium risk of flooding from within Le Grande Havre (Dicqs Road).**
Low frequency events: Less frequent than 1:20 year return period (1:50 year or greater)	**High risk of sudden failure and flooding from both northnand south. Potential risk to life.**	**Very high risk of flooding to area.**
Actions		
Short term (see action plan):	• Improve condition of rock revetment. High Priority. • Construct set back embankment to north. Low Priority. • Improve condition of bank to south of the area. High Priority. • Develop flood awareness and flood warning procedures. High Priority.	
Medium Term Planning (20 years)	• Improvement defences along Dicqs Road. High Priority. • Construct embankment to north (if not already undertaken). High Priority. • Maintain and improve erosion protection to the main Baie de port Grat frontage. High Priority.	
Long Term Planning	• Develop long term planning policy for the area. High Priority.	

Priority Actions:	PEQUERIES CU11	
Risk:	**Present Risk**	**Long Term Risk with sea level rise (epoch 2 and 3)**
High frequency events: 1:1 to 1:20 year return period	**Low risk to properties form flooding to main bay.**	**High risk to properties from flooding to main bay and from the north.**
	Low risk of flooding from the north.	**Medium risk of flooding from Portinfer.**
Low frequency events: Less frequent than 1:20 year return period (1:50 year or greater)	**High risk to properties form flooding to main bay.**	**Very high risk to properties from flooding to main bay and from the north.**
	High risk of flooding from the north.	**High risk of flooding form Portinfer.**
	Medium risk of flooding from Portinfer.	
Actions		
Short term (see action plan):	• Improve rock revetment to main bay. Medium Priority • Construct set back revetment to the north of the village. Medium Priority. • Develop flood warning system. High Priority.	
Medium Term Planning (20 years)	• Improve rock revetment to main bay. High Priority if not already undertaken. • Construct set back revetment to the north of the village. High Priority if not already undertaken. • Improve embankment to Portinfer. Low Priority.	
Long Term Planning	• Develop long term planning policy for the area. Medium Priority. • Planning control on development. High Priority.	

Priority Actions:	COBO AND SALINE BAYS CU10	
Risk:	**Present Risk**	**Long Term Risk with sea level rise (epoch 2 and 3)**
High frequency events: 1:1 to 1:20 year return period	**High risk of disruption to main coastal road.**	**High risk of flooding to properties along sea front and within low lying land.**
	Low risk of flooding to properties.	**Increased risk to integrity of defences due to erosion.**
Low frequency events: Less frequent than 1:20 year return period (1:50 year or greater)	**Very high risk of disruption to main coastal road and risk to sea front.**	**Very high risk of flooding to properties along sea front and within low lying land.**
	High risk of flooding to properties within low lying land.	**High risk of damage to defences.**
	Medium risk to sea walls due to beach draw down.	
Actions		
Short Term (see action plan):	• Improve flood warning to area. High Priority. • Investigate integrity of local defences through built up area behind DU2. Medium Priority. • Local raising to DU2. Medium Priority. • Consult on options for defence improvement. Medium Priority.	
Medium Term Planning (20 years)	• Undertake improvement to defences with construction of breakwaters. High Priority.	
Long Term Planning	• Avoid development within high flood risk area. High Priority. • Develop long term planning policy for the area. Medium Priority.	

Priority Actions:	**ROCQUAINE AND L'ERÉE BAY CU3**	
Risk:	**Present Risk**	**Long Term Risk with sea level rise (epoch 2 and 3)**
High frequency events: 1:1 to 1:20 year return period	**High risk of failure of sea wall alog DU3 and 4.**	**High risk of flooding to low lying valley behind DU3 and 4.**
		High risk of flooding to properties to L'Erée Bay.
	High risk of flooding to low lying valley behind DU3 and 4.	**High risk of flooding behind DU1.**
	Medium risk of flooding to properties to L'Erée Bay.	**Increased pressure on defences DU1 and DU5.**
Low frequency events: Less frequent than 1:20 year return period (1:50 year or greater)	**High risk of flooding to low lying valley behind DU3 and 4.**	**Very high risk of flooding to low lying valley behind DU3 and 4.**
	High risk of flooding to properties to L'Erée Bay.	**High risk of flooding behind DU1.**
	Medium risk of flooding to road behind DU1.	
Actions		
Short Term (see action plan):	• Develop detailed design for improvement to DU3 and 4. High Priority. • Continued monitoring of DU5 and regular inspection of DU3 and 4. High Priority. • Consult on options for defence improvement for DU5. Medium Priority. • Potential improved defence to DU5 through landscaping. Medium Priority. • Local improvement to road behind DU2. Low Priority.	
Medium Term Planning (20 years)	• Develop and undertake improvement to defence along DU5. Medium Priority. • Examine and undertake additional protection to DU1. Medium Priority.	
Long Term Planning	• Avoid development within high flood risk area. High Priority. • Develop long term planning policy for the area. Medium Priority.	

7.3 Action Plan

The following works are recommended by the study over different time periods. The priority is indicated in the final column (H- High, M – Medium, L – Low). All costs include fees, statutory approvals and 60% optimism bias.

Years 0 to 5

Area	DU	Description	Estimated cost (£K)	
CU 19	4	Local raising to embankment	321	H
CU19	8 & 9	Local raising to walls	1,307	H
CU18	The Bridge	Investigate option for incorporating improvement within new development along the Bridge	2,098	H
CU12	1	Improve condition to revetment and minor improvements to Dicqs road	627	H
CU3	4 & 3	Rock revetment to support wall	3,295	H
CU3	2	Minor works to repair road	20	L

Years 6 to 10

Area	DU	Description	Estimated cost (£K)	
CU19	5 & 6	Local raising to walls and possible improvement to wave interaction	425	M
CU17	Set back defence	Set back embankment and improvement to DU2 and 3	983	M
CU11	8 & 9	Improve rock revetment and construct set back embankment	2051	M
CU10	2	Local raising to defence	1000	M

Years 10 to 20

Area	DU	Description	Estimated cost (£K)	
CU19	all	General improvements and integrated approach to sea front	13,452	H
CU18	north	Local defence improvement to north of harbour	2562	H
CU12	2	Raise embankment within Le Grande Havre	334	M
CU12	1	Raise defence to Rousse Headland	352	H
CU11	7	Improve embankment to Portinfer	191	L
CU10	all	Beach control structures and recharge	25,945	H
CU3	5	Local improvement to defence within open land	225	M