Christchurch Bay and Harbour Flood and Coastal Erosion Risk Management Study

Technical Annex 6: Implications of Climate Change

Prepared by

New Forest District Council
and Halcrow Group Ltd

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1 Introduction

Climate change is expected to affect the management of flood and coast defences in a number of ways, of which the main factors are:

- changes in sea level, incorporating global (eustatic) sea level rise and land-level (isostatic) change
- changes in storm surge, due to changes in extremes of barometric pressure, extreme wave climate and wind stresses caused by changing weather patterns
- changes in wind climate affecting extreme events, storminess and wave conditions; wave conditions (wave heights, wave periods and wave direction) ultimately affect the sediment transport regime in an area, which results in changes in the coastal landforms.
- changes in rainfall intensities, durations, and event frequencies, particularly affecting cliff slippage and run-off flooding. Increased volumes of runoff will ultimately affect the coastal currents changing inshore flow patterns.

The inter-relationships between these factors are complex, but are represented in a simplified form in Figure 1. The negative effects of these factors will be evident through changes in flooding, erosion and accretion. Various data from the South Coast of England has been used in the assessments of climate change. The locations of the data sources are shown in Figure 2.

1.1 UK Climate Impacts Programme

The latest guidance on future climate change, including temperature, precipitation, snowfall, wind speeds, relative humidity and fog, seasonality, soil moisture as well as sea levels is provided in the UK Climate Impacts Programme “Climate Change Scenarios for the United Kingdom” (UKCIP 2002), which updates the previous UKCIP 1998 scenarios (UKCIP 1998). This guidance provides four scenarios based on future emissions of Carbon Dioxide (CO_2), which are: Low Emissions, Medium-Low Emissions, Medium-High Emissions and High Emissions (the precise definition of each is provided within the reference). New predictions of future climate change have been produced by the Hadley Centre for five scenarios of future emissions from the Intergovernmental Panel on Climate Change; we however make use of the previous guidance provided.

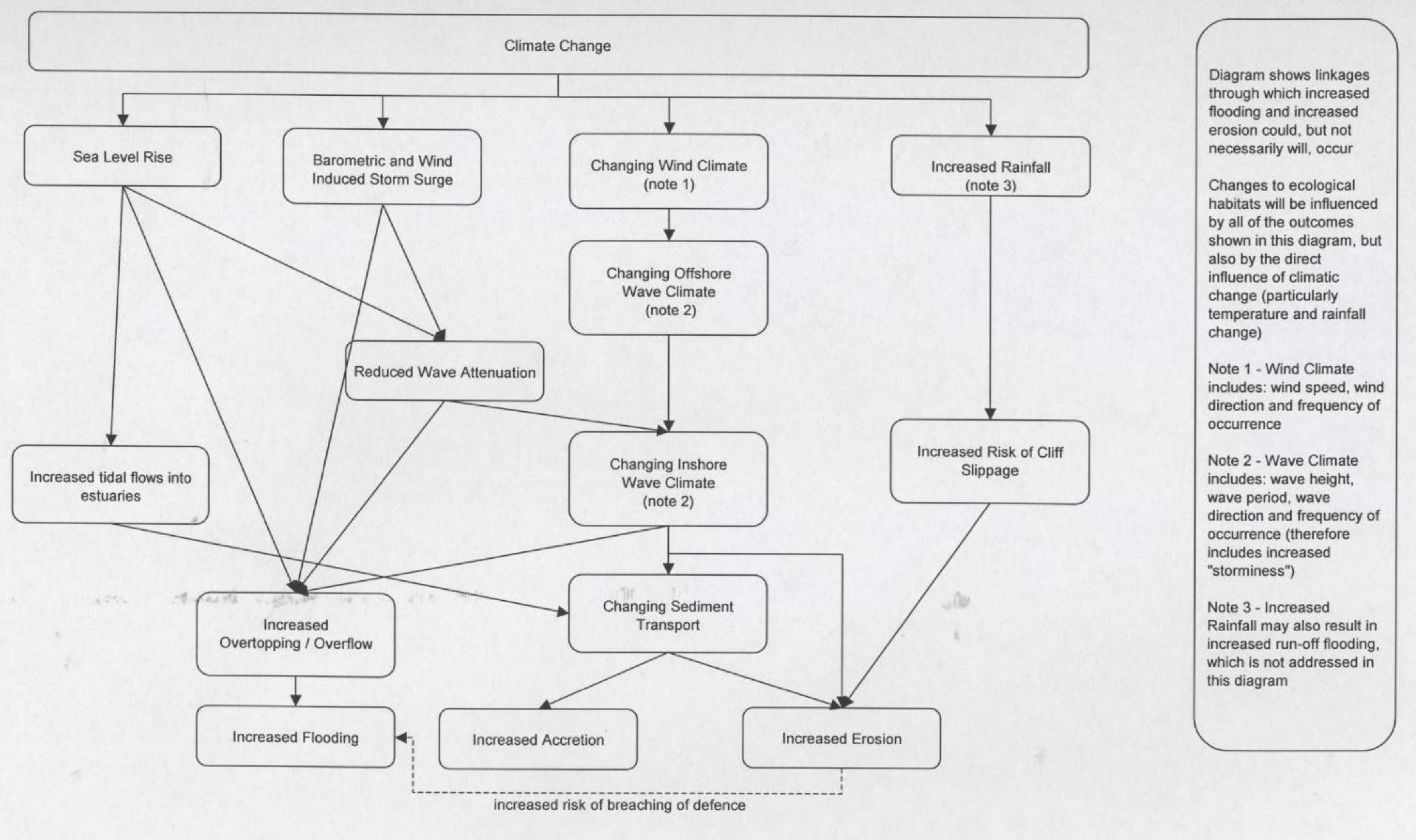

Diagram shows linkages through which increased flooding and increased erosion could, but not necessarily will, occur

Changes to ecological habitats will be influenced by all of the outcomes shown in this diagram, but also by the direct influence of climatic change (particularly temperature and rainfall change)

Note 1 - Wind Climate includes: wind speed, wind direction and frequency of occurrence

Note 2 - Wave Climate includes: wave height, wave period, wave direction and frequency of occurrence (therefore includes increased "storminess")

Note 3 - Increased Rainfall may also result in increased run-off flooding, which is not addressed in this diagram

Figure 1


Lee-on-the-Solent
Shoreham
Newhaven
Bournemouth
Portsmouth
Weymouth
Lyme Bay
Chesil Beach
Poole and Christchurch Bay
Legend
● 'A' Class Tide Gauge
◆ Extreme Wave Conditions Inshore Points
■ Longshore Transport Inshore Points
0 10 20 30 km
M:\Projects\Coastal\WCPBHS\GIS\climatechangedata.apr
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PROJECT
CHRISTCHURCH BAY STRATEGY STUDY
DATE
Dec 2003
TITLE
Locations of Climate Change Analysis Data
Figure 1.2

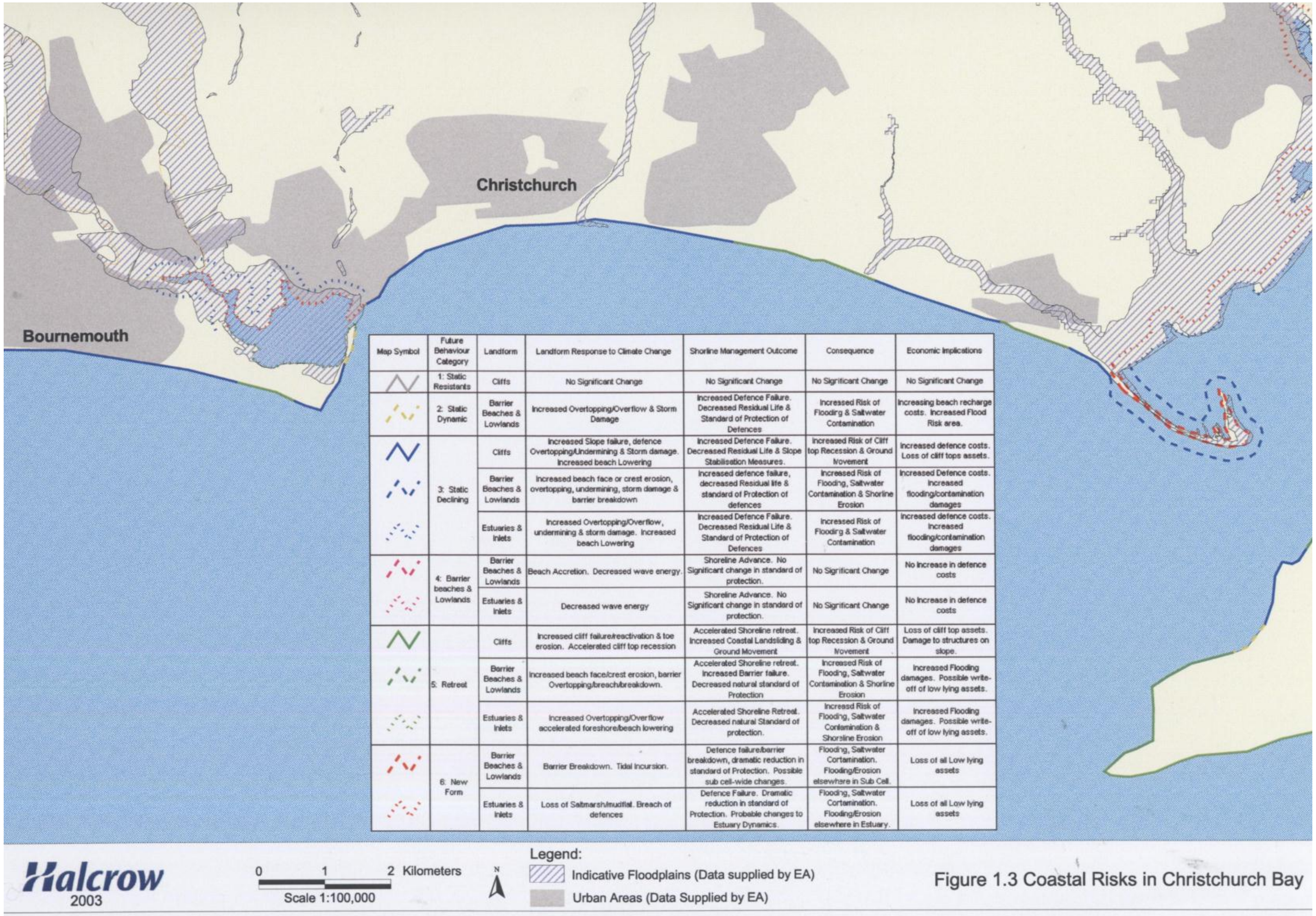
Figure 2

1.2 SCOPAC Study – Preparing for the Impacts of Climate Change

A comprehensive study "Preparing for the Impacts of Climate Change" was recently prepared for the Standing Conference on Problems Associated with the Coast (Halcrow et al, 2001). For detailed information on past change and future predictions, the reader is referred to this document, but a brief summary of the implications of climate change for Christchurch Bay is provided here. In particular the study incorporated a categorisation of the future behaviour of shorelines in the whole SCOPAC area (from Lyme Regis to Shoreham). Within the Christchurch Bay area the shoreline was categorised into 4 types as shown in Table 1. All four forms of shoreline behaviour will respond in different ways to climate change, with differing shoreline management outcomes, consequences and economic implications. These factors are all presented in Figure 3.

Behaviour	Shoreline Processes & Landform Change
Static Declining	Net decline with a negative sediment budget and a static or restrained shoreline e.g. (i) erosion of a relict cliff prior to reactivation of landsliding, (ii) erosion of the beach in front of stabilisation structures that nevertheless "hold" the shoreline (iii) a saltmarsh undergoing coastal squeeze due to a constraining backshore topography or a defence.
Static Dynamic	Cyclic change with balanced sediment budget of barrier beaches and lowlands; increased risk of flooding due to overtopping or overflow with greater risk of saltwater contamination, increased storm damage coupled with increased probability of defence failures, leading to decreased residual life and the standard of protection of defences
Net Retreat	Eroding shoreline migrating landward, but maintaining characteristic form and function of landforms e.g. a retreating cliff coast, barrier beach or spit, or a landward migrating saltmarsh or tidal flat. Includes reactivation of landsliding on a relic cliff (e.g. Black Ven or Blackgang model).
New Form	Establishment of a new characteristic form e.g. (i) breaching and/or fragmentation of a barrier or spit, (ii) replacement of saltmarsh by a tidal flat (iii) deterioration or removal of a defence leading to permanent tidal inundation of the backshore (managed retreat/realignment) model.

Table 1 Shoreline Processes & Landform Change



Map Symbol	Future Behaviour Category	Landform	Landform Response to Climate Change	Shorline Management Outcome	Consequence	Economic Implications
	1: Static Resistants	Cliffs	No Significant Change	No Significant Change	No Sigrificant Change	No Significant Change
	2: Static Dynamic	Barrier Beaches & Lowlands	Increased Overtopping/Overflow & Storm Damage	Increased Defence Failure. Decreased Residual Life & Standard of Protection of Defences	Increased Risk of Floodirg & Saltwater Contamination	Increasing beach recharge costs. Increased Flood Risk area.
	3: Static Declining	Cliffs	Increased Slope failure, defence Overtopping/Undermining & Storm damage. Increased beach Lowering	Increased Defence Failure. Decreased Residual Life & Slope Stabilisation Measures.	Increased Risk of Cliff top Recession & Ground Movement	Increased defence costs. Loss of cliff tops assets.
		Barrier Beaches & Lowlands	Increased beach face or crest erosion, overtopping, undermining, storm damage & barrier breakdown	Increased defence failure, decreased Residual life & standard of Protection of defences	Increased Risk of Flooding, Saltwater Contamination & Shorline Erosion	Increased Defence costs. Increased flooding/contamination damages
		Estuaries & Inlets	Increased Overtopping/Overflow, undermining & storm damage. Increased beach Lowering	Increased Defence Failure. Decreased Residual Life & Standard of Protection of Defences	Increased Risk of Floodirg & Saltwater Contamination	Increased defence costs. Increased flooding/contamination damages
	4: Barrier beaches & Lowlands	Barrier Beaches & Lowlands	Beach Accretion. Decreased wave energy.	Shoreline Advance. No Significant change in standard of protection.	No Sigrificant Change	No Increase in defence costs
		Estuaries & Inlets	Decreased wave energy	Shoreline Advance. No Significant change in standard of protection.	No Sigrificant Change	No Increase in defence costs
	5: Retreat	Cliffs	Increased cliff failure/reactivation & toe erosion. Accelerated cliff top recession	Accelerated Shoreline retreat. Increased Coastal Landsliding & Ground Movement	Increased Risk of Cliff top Recession & Ground Movement	Loss of cliff top assets. Damage to structures on slope.
		Barrier Beaches & Lowlands	Increased beach face/crest erosion, barrier Overtopping/breach/breakdown.	Accelerated Shoreline retreat. Increased Barrier failure. Decreased natural standard of Protection	Increased Risk of Flooding, Saltwater Contamination & Shorline Erosion	Increased Flooding damages. Possible write-off of low lying assets.
		Estuaries & Inlets	Increased Overtopping/Overflow accelerated foreshore/beach lowering	Accelerated Shoreline Retreat. Decreased natural Standard of protection.	Increasd Risk of Flooding, Saltwater Contamination & Shoreline Erosion	Increased Flooding damages. Possible write-off of low lying assets.
	6: New Form	Barrier Beaches & Lowlands	Barrier Breakdown. Tidal Incursion.	Defence failure/barrier breakdown, dramatic reduction in standard of Protection. Possible sub cell-wide changes.	Flooding, Saltwater Cortamination. Flooding/Erosion elsewhere in Sub Cell.	Loss of all Low lying assets
		Estuaries & Inlets	Loss of Saltmarsh/mudflat. Breach of defences	Defence Failure. Dramatic reduction in standard of Protection. Probable changes to Estuary Dynamics.	Flooding, Saltwater Cortamination. Flooding/Erosion elsewhere in Estuary.	Loss of all Low lying assets

Figure 3

1.3 Uncertainties in Climate Change Predictions

Any risk and uncertainty must be dealt with in all decision-making processes. The uncertainties incorporated in climate change predictions must be outlined so that the risks associated with all viable options are clearly understood. When assessing the impacts of climate change it is important not to use just one future climate scenario, but endeavour to compensate for the range of uncertainty by the use of a number of predictions with their associated probabilities.

Uncertainty arises from three main causes: the magnitude of future emissions, the response of the climate to future emissions and natural variability. An exact depiction of the future emissions of greenhouse gases cannot be obtained, however, the use of a number of scenarios within a realistic range of predictions facilitates the decision making process. The response of the climate system to a stimulus is a random event, and thus this uncertainty cannot ideally be quantified. An estimate of the uncertainty can be made by comparison with the results of other models. Natural variability cannot be predicted, however, the uncertainty incorporated in the natural variability of the climate can be quantified, and involves the analysis of output from multiple model runs, with alternative initial conditions.

Although a quantitative depiction of the future is not possible, a qualitative understanding will assist in the selection of viable coastal management options. These options will allow some form of flexibility, to reduce the impacts of climate change.

2 Changes in Mean Sea Level

The UKCIP 2002 summary report states, “As global climate warms, the world’s oceans will expand, causing a rise in the average level of the sea. Many land glaciers will continue to melt, adding to this rise in sea level. Changes will occur to the ice sheets of Greenland and Antarctica, although over the coming 100 years they are unlikely to contribute much to changes in sea level. If climate continues to warm in the longer term, however, both these ice sheets may contribute enough melt water over the next 1000 years to raise global sea level by several metres….”. The change in the level of the sea relative to the land will not be the same everywhere, because of natural land movement; much of southern Britain is sinking at between 1 and 1.5mm per year, and much of northern Britain is rising at between 0.5 and 1 mm per year relative to the sea.”

Past Sea Level Change

The SCOPAC (2001) climate change report advises that the most reliable sources of long-term water level data are the ‘A’ Class gauges, the data from which is collated and verified by the Proudman Oceanographic Laboratory. The changes in recorded sea level at the ‘A’ Class gauges in the vicinity of Christchurch Bay are given in **Table 2.**

Station Name	Start Date	End Date	No of years of Data	Linear Trend & Standard Error (mm/yr)
Newhaven	1993	1997	4	2.51 ± 5.07
Portsmouth	1962	1997	29	1.30 ± 0.56
Bournemouth	1997	1999	3	7.5 ± 5.48
Weymouth	1992	1999	7	7.36 ± 2.23

Table 2 Changes in Mean Sea Level at ‘A’ Class gauges

source: http://www.pol.ac.uk/psmsl/datainfo/rlr.trends last updated 23 Feb 2001

Of the four data sets in the vicinity, only one, at Portsmouth has a duration suitable for providing a reliable representation of sea level rise. There is a harmonic tidal constituent of periodicity of 18.4 years and an amplitude in the range of 100mm. Where data sets are shorter than this duration, as at Newhaven, Bournemouth and Weymouth, the variation in level due to this harmonic constituent can be more significant than the relative sea level rise. Even when this source of uncertainty is disregarded, the values of standard error (being a measure of the scatter of the data either side of the trend-line) for these shorter data sets is 5-10 times higher than for the longer data set at Portsmouth.

The most reliable estimate of past sea level rise from 1960s to 1990s for Christchurch Bay is 1.30 ± 0.56 mm/yr.

Future Sea Level Change

There is considerable uncertainty regarding future sea level rise, as with all of the other climate change factors, which has lead to the approach adopted by UKCIP described in Section 1.1.

The figures for sea level rise in UKCIP 2002 provide high and low scenarios for the increase from the 1960s-90s average to the 2080s; the values for the South West and South East of England are presented in Table 3

	Regional Vertical Land Change (mm/yr)	**Net Sea Level Rise by 2080's**	
		Low Emissions (mm)	**High Emissions (mm)**
SE England	-0.9	190	790
SW England	-0.6	160	760

Table 3 Sea Level Rise Scenarios from UKCIP 2002 (Chp. 6, Table 12, page 75) relative to the 1961 – 1990 period

The figures provide a useful guide as to the range in current estimates of the future change. However, for the purpose of this study the rate of future sea level rise that has been assumed is taken from the Defra Flood and Coast Defence Project Appraisal Guidance - Economic Appraisal (MAFF, 1999), as presented in Table 4. This guidance is understood to have been derived prior to UKCIP 1998 but it is not believed to have been revised by Defra.

	Sea Level Rise by 2050	
	Rate of Sea Level Rise (mm/yr)	**Sea Level Rise (mm)**
Southern	6	300

Table 4. DEFRA Guidance values for future sea level rise

The rate of future mean sea level rise assumed for Christchurch Bay is 6mm/year. In accordance with Defra guidance contained in FCDPAG3, no sensitivity testing of this particular factor was carried out in the study, but the range of potential change by 2080 given in Table 2.2 was noted.

Reduced Wave Attenuation

The general increase in water levels will result in reduced attenuation of waves as they approach the shoreline, in particular through reduction in the loss of wave energy due to refraction, bed friction and wave breaking.

The change in the inshore wave extreme conditions over a 50 year period is, however, likely to be small, being of the order of magnitude of the uncertainty inherent in wave modelling. For example, the bathymetries that are used in the wave modelling are based on historical measurements of the sea bed level, the accuracy of which will be of the order of 200-300mm.

Assuming a 300mm increase in water depth, the increase in maximum unbroken wave height will be approximately 150mm. This amounts to a 2-4% increase in wave heights in the range of H_s=4-6m, which are typical values for the 1:100yr wave conditions. This is small compared to the expected changes in wave energy due to increased wind speeds at offshore locations (as described in Section 4.1)

The reduction in wave attenuation may also influence greater energy wave conditions, particularly through reduced refraction, resulting in waves approaching the shoreline at more oblique wave angles. Again the effect is expected to be relatively small, when compared with the expected future variability of offshore wave conditions (Section 4.2).

The effect of reduced wave attenuation due to higher sea levels is likely to be small, of the order of 2-4% for typical day to day conditions. Under more extreme water level and wave conditions the effect may be slightly greater, but still small when compared to the other climate change factors, such as the expected future variability of offshore wave conditions

Summary of Effects of Change to Mean Sea Level

As shown in **Figure 1.1**, sea level rise may have an effect on:

- flooding through increased overtopping/overflowing
- flooding through increasing inshore wave energy conditions
- increasing potential for the combined tidal and fluvial flooding on tidal rivers
- saltwater intrusion or contamination from sea water inundation
- increase in erosion/accretion activities through increasing inshore wave energy conditions caused by reduced wave attenuation
- erosion/accretion through increased tidal flows into estuaries
- increasing cliff top recession and slope instability
- increased toe erosion facilitating cliff top recession and slope instability
- loss of saltmarshes or tidal flats due to coastal squeeze, which then results in decreased protection of coastal defences
- loss of saltmarshes or tidal flats due to increased erosion rates
- increased cliff top recession may lead to additional sediment supplies to local beaches and estuaries, which may prove to be beneficial

The implications for consideration when identifying the preferred strategy for each of the Management Units are outlined in Table 5.

Christchurch Bay Process Units	
CBY1	Increased risk of failure of existing defences; Increased erosion; Increased risk of flooding from overtopping; Increased risk of saltwater inundation in the SSSI; Increasing risk of saltwater intrusion may result in the loss of distinction between freshwater and saltwater grazing marshes
CBY2	Increased risk of flooding from overflowing, namely in Mudeford Quay; Increased risk of erosion particularly at Highcliffe and Friars Cliff; Increased risk of saltwater contamination; increased risk of cliff top recession and ground movement of soft rock cliffs
CBY3	Increased risk of erosion, especially at toe of slope which may further de-stabilize slopes; Increased cliff top recession and slope instability of soft rock cliffs; Decreased protection of coastal defences; Decreased residual life of slope stabilisation measures
CBY4	Increased slope instability and cliff top recession from cliff failure or landslide reactivation; Increased risk of ground movement; Increased risk of coastal erosion
CBY5	Increased risk of slope instability and cliff top recession from cliff failure or landslide reactivation;
CBY6	Increased risk of flooding; Increased risk of coastal erosion with greater impact when it occurs at toe of cliffs; Increased risk of cliff failure or landslide reactivation
CBY7	Increased risk of flooding; Increased possibility of saltwater contamination; Increased coastal erosion; Possible loss of saltmarshes; Increased risk of failure of existing defences; Increased risk to assets behind Hurst Spit
CHB1	Increased risk of coastal erosion, resulting in possible loss of recreational amenities (beach huts); Increased risk of flooding from overtopping/overflowing; increased risk of inundation and saltwater contamination
CHB2	Possible loss of saltmarshes, mudflats, redbeds and grasslands; Possible saltwater intrusion or inundation; Increased risk of shoreline erosion, increased risk of flooding from overtopping
CHB3	Increased risk of erosion possibly along marsh edge, resulting possibly in loss of grassland; Increased risk of inundation or salt water contamination; Possibility of increased risk of coastal squeeze; Increased risk of flooding
CHB4	Increased risk of failure of existing coastal defences; Increased risk of flooding; increased risk of saltwater intrusion or contamination
CHB5	Increased risk of flooding; Increased risk of habitat squeeze; Possible increased risk of erosion, although area is somewhat sheltered; increased risk of saltwater intrusion or contamination

Table 5. Effects of Changes in Mean Sea Level on Management Units

3 Changes in Storm Surge

Storm surges are increases in sea level above the level of the astronomical tide, caused by low atmospheric pressure, high-energy wave climates and strong winds. Changes in extreme sea levels associated with storm surges will occur once there are changes in the number, location or strength of storms. These changes in extreme sea levels caused by storm surge have been modelled using the POL high resolution (30 km) model, the results of which are presented in UKCIP 2002. The assessment was made by modelling the sea level that has a 2% probability of occurrence in any year (the 1:50 year event), assuming a Medium-High Emissions scenario, with a "central" estimate of 300mm of global sea level rise. The estimates take into account local land movement.

The largest increase in extreme sea level may occur around the southeast coast of England, which experiences both the largest changes in winds and storms and also the greatest fall in height of the land. Under the Medium-High Emissions Scenario, the increase in the 2% occurrence water level event is up to 1m higher in the 2080's than in the present day, compared with the rise in mean sea level under the same scenario of 190mm.

In the scenarios that are illustrated, the Christchurch Bay area appears to experience a mid-range change (not as severe as in the Thames Estuary, but more severe that much of the west coast of England and Wales). The values of mean sea level rise lie within the range of the 2% occurrence water level increases (Table 6). The results of this modelling shows that there is little tendency for extreme sea levels to rise much more than mean sea levels in this area.

	Sea Level Rise by 2080	
	Low Emissions (mm)	**High Emissions (mm)**
SE England (mean sea level)	190	790
SW England (mean sea level)	160	760
Christchurch Bay area (2% occurrence) (1)	c100 ~ 300	c600~900

Table 6. Potential increases in Extreme Sea Levels

Note: (1) values estimated from graphical model output provided in Figures on page 76 of UKCIP (2002).

It is noted that UKCIP (2002) states that the confidence in the results of the extreme water level modelling is less than in the assessment of future rise of mean sea level (Section 1.1). It is anticipated that further research on this item will be included in the next UKCIP assessment.

A study by Lowe and Gregory (1998), suggest that the 1 in 50 year storm surge will increase within the range 0.2 – 0.4 m, the lower values representing the western region and the higher values the eastern region of SCOPAC. For Christchurch Bay a mid range value of 0.3m can be assumed for 1 in 50 year storm surge.

As shown in Table 7, the combined effect on extreme sea levels for the central SCOPAC coastline gives an increase in extreme sea levels of around 84cm for the 1 in 50 year event. This estimate includes the mean sea level rise predictions. A potential increase of about 0.8m in extreme water levels is of great concern for coastal defence structures in the region, as the extreme tide level curves are very flat, thus it is expected that coastal defences will be less resilient to the effects of sea level rise.

Global sea level rise	**Local (UK) additional sea level rise**	**Isostatic land movement**	**Tidal regime**	**Surge changes (1 in 50 year)**	**Total change for 1 in 50 year extreme sea level**
0.41 m	**0.04 m**	**0.08 m**	**0.01 m**	**0.3 m**	**0.84 m**

Table 7. Factors affecting changes in Extreme Sea Levels by 2080

There is evidence that for extreme tide levels an allowance for an increase in storm surge should be included in additional to the increase in mean sea level within Christchurch Bay. However, in the absence of definitive guidance at this time, no such allowance can be accurately predicted.

4 Changes in Wind / Offshore Wave Climate

4.1 Changes in Extreme Wind Conditions

FCDPAG guidelines have stated that the average autumn and winter wind speeds may increase by 1 – 7 % by the 2080's. UKCIP 2002 scenarios show a 2 –8 % increase in winter and spring wind speeds. The wind climate has a great impact on the sediment transport regime, directly or indirectly through changes in the wave climate. Increased wind speeds enhance the possibility that extreme events, storminess and wave impact may become more frequent. All of these factors must be considered when assessing the future impacts of wind climate changes. Changes in wind speeds will also have a major impact on extreme sea levels.

Previously, research has shown that even quite modest changes in mean wind direction can have a marked impact on sediment transport, even reversing the direction of drift in some cases. These factors indicate the need to perform some form of sensitivity analysis on the future changing wind conditions.

The SCOPAC Study (Appendix B: Tables 5 and 6) compares hindcast offshore waves for Poole and Christchurch Bay for the control period (the present climate scenario) and the Medium-High Emissions scenario for the 2080's. The results show small changes in the number of waves in various wave directions. The percentage of waves in the direction sector 90^o-110^o increases from 3.8% to 5.3%, whereas in the direction sector 110^o-130^o there is a decrease in the percentage of the waves from 3.5% to 3.3%.

4.2 Changes in Extreme Wave Conditions

Different beaches behave differently even in response to similar stimuli. So changing the wave climate may produce varying results depending on the beach under consideration. One of the factors that affect the beach response is the sediment size. Sediment sizes may range from sand to boulder beaches. Each beach will have a distinct characteristic and sensitivity.

The SCOPAC Climate Change study (Halcrow, 2001) included modelling of two comparable 10 year wave climates, one of which was representative of the present day and the other representative of year 2080. The modelling was undertaken at four locations along the south coast of England: Lyme Bay, Christchurch Bay, Lee-on-the-Solent and Shoreham. The values of extreme wave conditions of both the control results and the 2080 results are not an accurate prediction of the actual values. However, the comparison of the two demonstrates the potential for magnitude of change.

The study was carried out using daily wind speed data from the Hadley Regional Climate Model, which is run by the Met Office Hadley Centre for each period and hindcasting the wave conditions that would result from each wind time series. The resulting offshore wave conditions were transformed inshore using a wave propagation model MWAVE. The extreme wave conditions at each inshore location were calculated for each 10 year period using standard statistical analysis methods (Table 8).

The analysis at Lyme Bay shows an *increase* in the values of extreme wave conditions of the order of up to 40% (Figure 4). At Lee-on-the-Solent and Shoreham there is an apparent *reduction* in extreme conditions of up to 15% (Figure 5). At Christchurch Bay the *increase* was of the order of 15% at extreme values (Figure 4).

It was concluded by Halcrow (2001) that the exposure of the site within the English Channel is critical in determining the increase/decrease in the extreme conditions. This was supported by the inspection of the wave climate, which showed an increase in wave conditions from the west and a decrease in conditions from the east.

	Significant Wave Height (m)							
	Lyme Bay		**Christchurch Bay**		**Lee-on-the-Solent**		**Shoreham**	
Return period	**control**	**2080**	**control**	**2080**	**control**	**2080**	**control**	**2080**
1:1 yr	5.8	7.2	5.7	5.9	3.1	2.7	5.5	5.3
1:10 yr	7.1	9.6	7.4	8.6	4.2	3.5	7.1	6.8
1:50 yr	8.1	11.3	8.6	10.1	5.0	4.2	8.2	7.9

Table 8 Extreme wave conditions derived from hindcasting of current and future wind conditions

Note: for comparative purposes only – not for design

A review of the wave climate data obtained for the Poole Bay and Harbour Strategy Study supports this finding. In addition changes in all four sets of wave data show a consistent pattern of: (i) a marked reduction in the number of days of calms; (ii) a marked increase in the frequency of day-to-day conditions up to H_s = 3.5m; (iii) a decrease in the wave heights between H_s = 3 – 6m; and (iv) an increase in the wave heights in excess of H_s = 6m. It is likely that this pattern is a feature of the data set and may be due to the particular climate change scenario that was assumed, rather than a generic factor in future climate change.

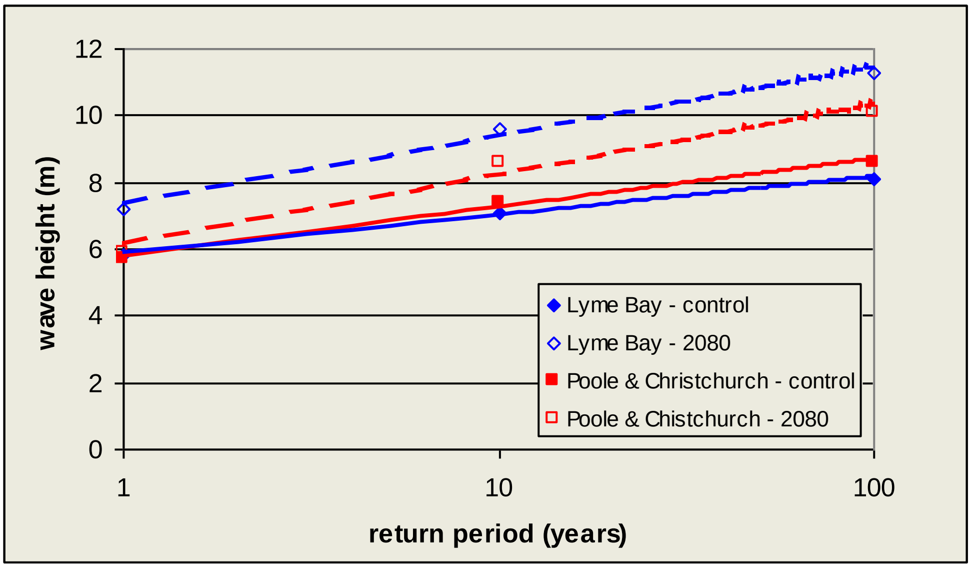


Figure 4 Potential change in extreme wave conditions – Lyme Bay & Poole & Christchurch Bays

The reduction in wave climate may therefore be due to the sheltering in the Lee-on-the-Solent and Shoreham areas, but may also be due to the length of the sets of wind data, which were 10 years. A longer data set, may, particularly at Shoreham have included data in excess of H_S = 6m, which may have resulted in a greater upward trend in the extreme values arising from the statistical analysis.

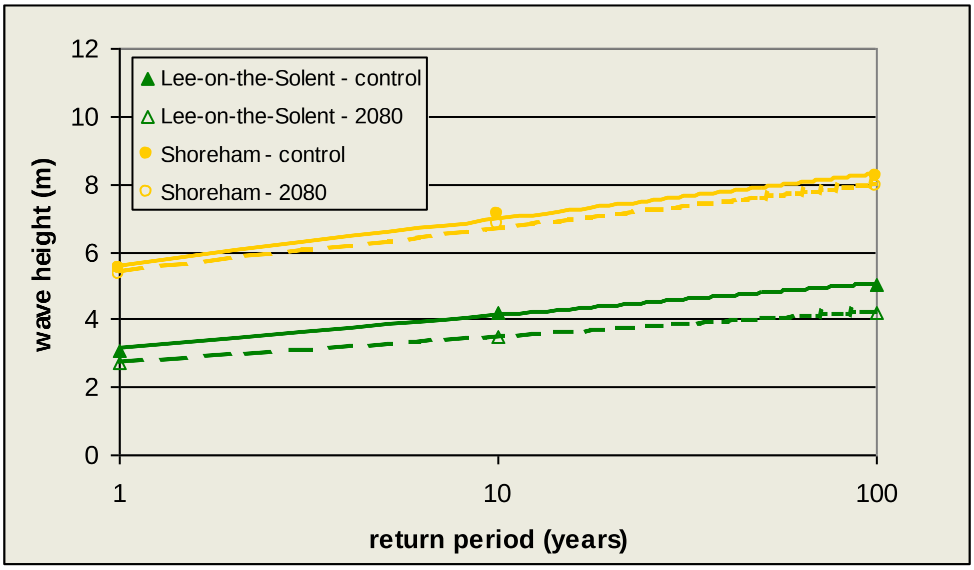


Figure 5 Potential change in extreme wave conditions – Lee-on-the-Solent and Shoreham

This area of uncertainty does not alter the overall conclusion of the work presented in the Halcrow et al (2001) report, which is that an increase in the wave climate at exposed sites is to be expected. A change of 15% in the area of Christchurch Bay & Harbour is a reasonable first estimate. This increase should be applied as a sensitivity test to the predictions of extreme wave conditions contained in Technical Annex 1, rather than the values provided in Table 8.

A sensitivity test of an increase of 15% in extreme wave conditions in the next 50 years provides a reasonable allowance for climate change due to changes in wind and wave climate in Christchurch Bay

As shown in Figure 1, increases in extreme wave conditions may have an effect on:

- inshore wave condition;
- flooding and erosion/ accretion through increasing inshore extreme wave conditions.

4.3 Changes in Overall Wave Climate (Affecting Cross-shore Sediment Transport)

Although research in the dynamics of cross-shore sediment transport is not yet far advanced, it is known that the dynamics of cross-shore sediment is affected by wave and wind activities. Ultimately changes in the wind/wave climate will produce changes in the cross-shore sediment movements. Offshore directed cross-shore sediment transport is believed to be more pronounced during high-energy nearshore conditions, while low energy wave conditions produce shoreward directed sediment motion. Thus extreme climates must produce some change in the cross-shore movement, particularly in the sediment volumes moving offshore. For example, higher waves produce stronger undertow currents, which will tend to pull more sediment offshore. Higher energy waves will also generate a wider surf zone, which will then increase infragravity wave activity, which also effects the cross shore sediment processes. As research continues in this area of coastal sediment transport, it is then imperative that it be included in any assessment exercise of future climate change.

4.4 Changes in Overall Wave Climate (Affecting Longshore Sediment Transport)

The offshore hindcast waves were also used by Halcrow et al (2001) to study the predicted differences in longshore sediment transport under the Medium-High UKCIP 1998 future climate change scenario. The offshore waves conditions were first transformed to a number of inshore locations and then the longshore transport rates were calculated using the Kamphuis (1991) equation.

The calculations were carried out at West Bexington (Lyme Bay), Chesil Beach, Milford-on-Sea and Shoreham. It was found that at all locations the gross drift rates in both directions increased, in response to the increase in the wave conditions and the reduction in the total duration of calms.

At Shoreham and Milford-on-Sea, the existing wave conditions cause a strong predominant net drift in one direction (at both locations the net drift is around 85-90% of the larger gross drift rate). The change in the net drift rates between the control period and the 2080s data set is small at these 2 locations, being less than 20%. In these two cases the affect of the changing wave climate was judged to be small when compared with natural variability of longshore transport.

At Chesil Beach and West Bexington, the existing longshore transport regime is finely balanced between easterly and westerly gross drift rates and the resulting net drift is small, being less than 5% compared to the larger gross drift rate. As a result, the change in the net drift rates between the control period and the 2080s data set is large, resulting in an increase from c1,000m^3/yr to c16,000m^3/yr at Chesil Beach and a switch in the net drift direction from c1,000m^3/yr (eastwards) to c8,000m^3/yr (westwards) at West Bexington. Changes of this scale would have considerable implications for coastal management.

At locations where the longshore drift is found to be predominantly from one direction (the ratio of net drift : larger gross drift is high) there is no evidence for the need for a particular allowance for climate change due to changes in the overall wave climate.

At locations where the longshore drift is found to be finely balanced between the two directions (the ratio of net drift : larger gross drift is low) allowance needs to be made for a considerable change in the regime, possibly involving a switch in net drift direction and/or a manifold increase in the net drift rate.

4.5 Summary of Effects of Change to Wind / Offshore Wave Climates

Increases in extreme wind/wave conditions may have the following effects:

- further increases to sea levels
- more energetic nearshore wave conditions
- increased risk of flooding due to higher waves and increased sea levels
- increasing erosion/accretion activities through increasing inshore extreme wave conditions
- increased risk of slope instability due to erosion especially if it occurs at the toe of the cliff
- possibility of changing patterns of drift, resulting in different patterns of erosion and deposition

The implications for consideration when identifying the preferred strategy for each of the Management Units are outlined in Table 9.

Christchurch Bay Process Units	
CBY1	Increased risk of failure of existing defences; Increased erosion; Increased risk of flooding;
CBY2	Increased risk of flooding, namely in Mudeford Quay; Increased erosion particularly at Highcliffe and Friars Cliff
CBY3	Increased risk of erosion; Increased cliff top recession and slope instability; Decreased protection of coastal defences
CBY4	Increased slope instability and cliff top recession; Increased risk of coastal erosion
CBY5	Increased risk of coastal erosion; Increased risk of slope instability
CBY6	Increased risk of flooding; Increased risk of coastal erosion
CBY7	Increased risk of flooding; Increased coastal erosion; Increased risk of failure of existing defences
Christchurch Harbour Process Units	
CHB1	Increased risk of coastal erosion, resulting in possible loss of recreational amenities (beach huts); Increased risk of flooding or inundation
CHB2	Increased risk of erosion; Possible loss of saltmarshes, mudflats, redbeds and grasslands due to erosion; Increased possibility of flooding
CHB3	Increased risk of erosion; Increased erosion along marsh edge, resulting possibly in loss of grassland
CHB4	Increased risk of failure of existing coastal defences; Increased risk of flooding
CHB5	Increased risk of flooding; Possible increased risk of erosion, although area is somewhat sheltered

Table 10 Effects of Changes in Wind/Offshore Wave Climate on Management Units

5 Changes in Rainfall

Rainfall is a primary cause of coastal instability and landsliding in the SCOPAC region. The additional effects of high runoff volumes from increased rainfall will be manifested in the behavioural patterns of the coastal zone; current changes, nearshore water levels, increased risk to flooding and the resulting change in sediment transport.

SCOPAC studies have predicted that rainfall in winter will be greater (up to 23% increase by 2080) but less (up to 20% reduction by 2080) in the summer throughout the UK.

Halcrow et al (2001), the UKCIP 98 Emissions scenarios were applied to rainfall data from Ventnor. The estimates indicate a 5-6% increase in mean monthly effective rainfall under the Low Emissions scenario and 12-25% increase for the High Emissions scenario (Table 11). It was noted that these estimates are comparable with the historic trend of increasing annual rainfall at Pinhay of 10% in the period 1868-1998 and at Ventnor of 20% in the period 1839-2000.

	Sep – Nov		**Dec - Feb**	
	mm	**% change**	**mm**	**% change**
Effective Rainfall $_{mean}$ 2000	76.4	0	67.4	0
Low 2080	80.2	5	71.7	6
Medium-Low 2080	84.4	11	74.6	11
Medium-High 2080	82.7	8	81.8	21
High 2080	85.2	12	84.0	25

Table 11 Change Scenarios of Monthly Effective Rainfall at Ventnor for 2080
Source: Halcrow et al (2001)

However, the new scenarios issued by the UKCIP suggest a slightly drier future than the 1998 scenarios. Annual rainfall totals are expected to show little change or even a slight fall. However the wetter winters will see an increase in rainfall of up to 30%, with the drier summers experiencing a decrease in rainfall of up to 50%, in some regions.

Table 12 gives some estimates of the expected changes in the rainfall patterns for the region in which Christchurch Bay is located. Some research is indicating that the distribution and intensity of precipitation may also vary, with more rain potentially falling in heavier bursts; a factor that is critical in determining the severity of flooding.

	Change in annual average daily temperature		**% Change in Summer Precipitation**		**% Change in Winter Precipitation**	
	Low Emission	**High Emission**	**Low Emission**	**High Emission**	**Low Emission**	**High Emission**
2020's	0 - 1	1 - 2	0 – (-15)	0 – (-15)	0 - 15	0 - 15
2050's	1 - 2	2 - 3	-15 – (-30)	-30 – (-45)	0 - 15	15 - 30
2080's	2 - 3	4 - 5	-15 – (-30)	-45 – (-60)	0 - 15	15 - 30

Table 12 Estimates of the change in rainfall patterns in the UK (values estimated from Southwest maps of England available on www.ukcip.org.uk/climate_change/regional_maps.html)

FCDPAG guidelines recommend testing sensitivity to rainfall predictions by additional 20% in peak flow or volume over 50 years. On the basis of the assessment at Ventnor, a sensitivity test of an increase of 20% in effective rainfall appears to be a reasonable allowance for climate change.

Based on an increase of 20 % in rainfall, Table 13 gives maximum estimated precipitation values for the winter months at Chrischurch Bay, using the rainfall data from Ventnor.

	Sep – Nov		**Dec - Feb**	
	mm	**% change**	**mm**	**% change**
Effective Rainfall $_{\text{mean}}$ 2000	76.4	0	67.4	0
Estimated Rainfall for next 50 years	91.7	20	80.9	20

Table 13 Estimates of the maximum rainfall in Christchurch Bay

A sensitivity test of an increase of 20% in effective rainfall in the next 50 years provides a reasonable allowance for climate change in Christchurch Bay

5.1 Summary of Effects of Change to Rainfall

Increases in rainfall may have the following effects:

- reactivation of relic landslides due to elevated groundwater levels
- elevated groundwater levels during winter months, possibly leading to increased cliff top erosion and slope instability
- increased ‘drying-out’ of soils during summer months
- changes in the nearshore current patterns, at rivers which will carry greater flows to the coast, possibly increasing the risk of coastal erosion
- increased erosion activity will increase the risk of cliff slippage
- changes in the nearshore sedimentation patterns, at rivers which will carry greater sediment loads to the coast and within the harbour
- greater possibility of flooding or overtopping during winter months
- increased possibility of ‘flash -flooding’ during the winter months

The implications for consideration when identifying the preferred strategy for each of the Management Units are outlined in Table 14.

Christchurch Bay Process Units	
CBY1	Increased risk of failure of existing defences; Increased risk of flooding; Increased risk of erosion
CBY2	Increased risk of flooding, namely in Mudeford Quay; Possibility of increased erosion particularly at Highcliffe and Friars Cliff; Increased cliff instability particularly at Highcliffe
CBY3	Possibly increased risk of erosion; Increased cliff top recession and slope instability especially at Naish Farm;
CBY4	Increased slope instability and cliff top recession particularly at Barton; Increased risk of coastal erosion
CBY5	Increased risk of slope instability and cliff top recession; Increased risk of erosion in particular loss of fine sediments offshore
CBY6	Increased risk of flooding; Increased risk of landslides; Increased risk of coastal erosion
CBY7	Increased risk of flooding; Increased risk of coastal erosion
Christchurch Harbour Process Units	
CHB1	Increased risk of flooding or inundation; Increased potential for harbour sedimentation
CHB2	Possibility of increased flooding risk; Increased potential for harbour sedimentation or increased deposition of sediment onto grasslands or saltmarshes
CHB3	Possibility of increased flooding risk; Increased potential for harbour sedimentation
CHB4	Increased risk of flooding; Increased potential for harbour sedimentation
CHB5	Increased risk of flooding; Increased potential for harbour sedimentation

Table 14 Effects of Changes in Rainfall Levels on Management Units

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