Climate Change & Economic Assessment Report

Church Street Flood Alleviation Scheme PAR

Scarborough Borough Council

31st January 2013

Draft Report

9W5572

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1 INTRODUCTION

1.1 Background

A flood alleviation scheme for the Church Street area in Whitby, North Yorkshire is being progressed as one of the priority schemes from the Whitby Coastal Strategy 2. The preferred strategic option is to implement a capital flood alleviation scheme consisting of a combination of flood walls and flood gates.

A Project Appraisal Report (PAR) is being prepared for submission to the Environment Agency for technical and financial approval. As part of the PAR, a series of options for implementing the Strategy will be appraised against each other. Consideration of standard of protection (SoP) to be provided by the scheme will be included within the appraisal. The effect of climate change on the SoP offered by the scheme over its design life needs to be taken into account.

1.2 Aim of Report

The aim of this report is to describe the climate change assessment that has been carried out for the Church Street Flood Alleviation Scheme in detail to support the summary information included within the PAR document. The process and results will be presented and discussed to show how the short list of options for the PAR has been derived.

This report will also provide the details of the economic assessment carried out for the option appraisal.

The aim of the climate change assessment is to ensure that the economic assessment of the proposed flood alleviation scheme is robust and the scheme takes account of the uncertainties associated with predicting climate change to prevent an over-engineered scheme and inefficient use of funding.

2 CLIMATE CHANGE PROCEDURE

2.1 Guidance

In September 2011 the Environment Agency published *Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities*. This replaces the earlier Defra Supplementary Note to Operating Authorities – Climate Change Impacts (October 2006).

The purpose of the guidance is to ensure that an economically credible appraisal, taking account of the uncertainties associated with climate change, can be made to support Government investment decisions. This will ensure that the most appropriate means of reducing risk is investigated in any one place.

Defra's appraisal policy statement recommends a 'managed adaptive approach' where possible. A managed adaptive approach is based on taking action when particular trigger points are reached, using predetermined interventions. This provides flexibility to manage future uncertainties associated with climate change. A managed adaptive approach would ensure a fairer and more flexible spread of public investment and therefore should be preferred where possible.

In some circumstances a managed adaptive approach may not be technically feasible, or it may be economically more efficient to build in a precautionary element at the outset. In these circumstances a 'precautionary approach' with a one off intervention may be the best option.

2.2 Provision of Change Factors

To assess the potential effects that climate change may have on extreme rainfall, river flood flows, sea level rise and storm surges, change factors are provided by the new guidance. The change factors quantify the potential change to the baseline. It is recommended that options are developed planning for the change factor covering the whole of the decision lifetime. However, rather than base options solely on the change factor, the upper and lower end estimates can be used to refine the options to prepare for a wider range of future change.

The change factors provided in the *Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities* guidance are based on UKCP09 or research using UKCP09 data. Change factors have been developed to allow UKCP09 to be used in a timely and cost effective manner, and provide a consistent approach. Upper and lower estimates of change are provided to help represent the range of future risks.

Although it is anticipated that the eventual change in river flows and sea level rise will lie somewhere within the range of lower to upper end estimates, more extreme change cannot be discounted. To help represent this extreme change 'H++ scenarios' have been included in the guidance in line with UKCP09 approach. These provide an estimate beyond the likely range but within physical plausibility. They can be used to represent more severe climate change impacts for use in contingency planning and help identify the options that would be required.

2.3 Climate Change Assessment Process

In order to assess the impact of climate change on the Church Street Flood Alleviation Scheme the *Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities* guidance has been used to derive a range of climate change predictions for Whitby.

The ISIS modelling work previously undertaken as part of the original Whitby Coastal Strategy identified that flood risk in the River Esk estuary is dominated by tidal levels, with river flows having a negligible effect. The effect of climate change on river flows therefore will have negligible effect on future flood risk and have therefore not been considered further in this assessment.

A range of climate change predictions for sea level rise have been determined for Whitby using the UKCP09 information presented in the new guidance issued by the Environment Agency. Climate change effects over the full 100 year appraisal period have been considered.

3 CLIMATE CHANGE SCENARIOS

A range of climate change predictions for sea level rise (SLR) have been determined for Whitby using the UKCP09 information presented in the new *Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities* guidance issued by the Environment Agency. Climate change effects over the full 100 year appraisal period have been considered.

The advice makes the following recommendations for the different climate change scenarios as shown in Table 1.

Table 1. Recommended Sea Level Rise Climate Change Factors

Parameter	SLR (mm/yr) to 2025	SLR (mm/yr) to 2050	SLR (mm/yr) to 2080	SLR (mm/yr) to 2115
H++ scenario	6	12.5	24	33
Upper end	4	7	11	15
Change factor	Use UKCP09 relative sea level rise medium emission 95% projection for the project location available from the User Interface.			
Lower end	Use UKCP09 relative sea level rise low emission 50% projection for the project location available from the User Interface.			

The User Interface was interrogated for model grid cells at Whitby to obtain the predicted values for sea level rise for the change factor and lower end estimates (relative to a base date of 1990), as shown in Table 2.

Table 2. Predicted Sea Level Rise For Whitby from the User Interface

Parameter	SLR (cm) to 2010	SLR (cm) to 2025	SLR (cm) to 2050	SLR (cm) to 2080	SLR (cm) to 2115*
Change factor	9.1	17	32.5	54.6	84.5
Lower end	5.1	9.4	17.8	29.6	45.5

* UKCP09 only projects to the year 2100, so the remaining 15 years have been estimated based on the average of the proceeding 15 years.

Based on these different scenarios the predicted sea levels for a range of return periods over the appraisal period for the Church Street Flood Alleviation Scheme have been derived, as shown in Table 3.

Table 3. Range of Predicted Sea Level Rise for Whitby for Return Periods

Date	Parameter	1 in 1yr	1 in 3yr	1 in 10yr	1 in 50yr	1 in 100yr	1 in 200yr	1 in 1000yr
2007	Current	3.30	3.45	3.61	3.85	3.99	4.10	4.31
2010	H++ scenario	3.32	3.47	3.63	3.87	4.01	4.12	4.33
	Upper end	3.31	3.46	3.62	3.86	4.00	4.11	4.32
	Change factor	**3.39**	**3.54**	**3.70**	**3.94**	**4.08**	**4.19**	**4.40**
	Lower end	3.35	3.50	3.66	3.90	4.04	4.15	4.36
2025	H++ scenario	3.39	3.54	3.70	3.94	4.08	4.19	4.40
	Upper end	3.36	3.51	3.67	3.91	4.05	4.16	4.37
	Change factor	**3.47**	**3.62**	**3.78**	**4.02**	**4.16**	**4.27**	**4.48**
	Lower end	3.39	3.54	3.70	3.94	4.08	4.19	4.40
2050	H++ scenario	3.61	3.76	3.92	4.16	4.30	4.41	4.62
	Upper end	3.48	3.63	3.79	4.03	4.17	4.28	4.49
	Change factor	**3.63**	**3.78**	**3.94**	**4.18**	**4.32**	**4.43**	**4.64**
	Lower end	3.48	3.63	3.79	4.03	4.17	4.28	4.49
2080	H++ scenario	4.02	4.17	4.33	4.57	4.71	4.82	5.03
	Upper end	3.63	3.78	3.94	4.18	4.32	4.43	4.64
	Change factor	**3.85**	**4.00**	**4.16**	**4.40**	**4.54**	**4.65**	**4.86**
	Lower end	3.60	3.75	3.91	4.15	4.29	4.40	4.61
2115	H++ scenario	4.46	4.61	4.77	5.01	5.15	5.26	5.47
	Upper end	3.83	3.98	4.14	4.38	4.52	4.63	4.84
	Change factor	**4.15**	**4.30**	**4.46**	**4.70**	**4.84**	**4.95**	**5.16**
	Lower end	3.76	3.91	4.07	4.31	4.45	4.56	4.77

4 FLOODCELL 2

4.1 Floodcell Definition

Floodcell 2 is split into two sub-floodcells:

- 2A – northern area at risk in Museum and Church Street car parks, floods as result of overtopping from the slipway between the two car parks. It is isolated from 2B by high ground peaking at 4.78mAOD opposite 53/54 Church Street; and

- 2B – located between 50 Church Street and 2 Church Street, distance of 280m. Floods due to overtopping of low quay levels, which vary along its length.

4.2 Floodcell 2A

The main assets at risk in floodcell 2A are the car parks. The car parks will currently begin to flood in the 1 in 100 year (1% annual probability event). This risk increases to the 1 in 50 year (2% annual probability) by 2050, and 1 in 1 year (100% annual probability by 2115, based on the 'change factor' (most likely) climate change scenario. The car parks already have barriers around them to prevent cars entering the harbour accidently, and therefore it is unlikely that significant damage would occur if the car parks remain unprotected.

In addition 29 properties have been identified as being potentially at risk within Floodcell 2A. An assessment of flood risk for the properties has been carried out for the 'change factor' (most likely) climate change scenario and the results are presented in Table 4.

Table 4. Number of properties at risk in Floodcell 2A under Change Factor climate change scenario

Return Period	2010	2025			2050			2080			2115		
		Low	CF	H++	Low	CF	H++	Low	CF	H++	Low	CF	H++
1 in 1 year	0	0	1	0	1	1	1	1	1	1	1	2	4
1 in 3 year	1	1	1	1	1	1	1	1	1	2	1	2	7
1 in 10 year	1	1	1	1	1	1	1	1	2	2	1	4	9
1 in 50 year	1	1	1	1	1	2	2	2	2	6	2	7	27
1 in 100 year	1	1	2	1	2	2	2	2	5	7	4	14	27
1 in 200 year	2	2	2	2	2	2	2	2	7	12	5	17	28
1 in 1000 year	2	2	5	2	5	7	7	7	12	25	9	27	29

* Low = lower end of predicted range, CF = Change Factor (most likely), H++ = top end of physical plausibility.

The property with the lowest threshold is the Captain Cook Museum, the side of the building forms one edge of the car park. The ground in the car park rises away from the quay edge, cutting off the flow path to the threshold of the museum at the front of the building, therefore flood risk to this property could be easily addressed by fitting flood-proof covers to the airbricks along the wall that edges the car park. If this work was done then there would be no properties at risk under current situation until the 1 in 200 year (0.5% annual probability) event, and there would not be significant numbers of properties at risk until 2115 with climate change.

The Do Nothing present value damages (PVd) over the 100 year appraisal period for Floodcell 2A are £375k (including climate change using change factor scenario). The present value cost estimated for the Floodcell 2A area in the Church Street, Whitby:

Flood Alleviation Scheme Feasibility Study (2012) was £261k (including maintenance over 100 year appraisal period and 60% optimism bias). It would be difficult to justify any flood alleviation works for this area at this time based on a benefit-cost ratio (BCR) of just 1.43.

Table 5. Summary of Economic Appraisal for Floodcell 2A

Climate Change Scenario	Do Nothing PV Damages	200yr SoP Scheme				
		PV Damages	PV Benefits	PV Costs	Net Present Value	Benefit-Cost Ratio
Change Factor	£375k	£3k	£372k	£261k	£111k	1.43
Lower End	£203k	£20k	£183k	£261k	-£78k	0.70
H++	£509k	£4k	£505k	£261k	£244k	1.93

Assessing the sensitivity of the scheme viability to climate change supports the conclusion that a scheme for Floodcell 2A cannot be justified. If climate change is closer to the low end predictions then the PVd will drop to £203k, which is less than the costs, resulting in a BCR of less than unity. In addition the number of properties at risk by 2115 will drop to just 4 at the 1 in 100 year event (1% annual probability). Even if climate change is at the top end of predictions, using the H++ scenario, the PVd would increase to £509k, increasing the BCR only marginally to 1.93. The corresponding increase in number of properties at risk by 2115 would take the total number to 27 at the 1 in 1 year event (1% annual probability), an increase of just 13 properties. This shows that the scheme unviability is not sensitive to the uncertainties over future climate change.

Therefore a scheme for Floodcell 2A based on just the properties at risk in that area is not economically viable.

4.3 Floodcell Interaction

Although Floodcell 2 splits into two sub-floodcells (2A and 2B) they do interact at higher order events once climate change has resulted in sea level rise.

It is recommended that the options for the Church Street Flood Alleviation Scheme focus on Floodcell 2B for the first phase of the scheme. Defences for Floodcell 2A will only be required when climate change results in the two floodcells becoming linked and the defences in Floodcell 2B become at risk of outflanking.

5 WALL HEIGHTS FOR CHURCH STREET FAS

5.1 Change Factor

The 'change factor' is the 'most likely' prediction of climate change from the range presented in Section 3. The sea levels predicted have been compared with the ground levels along the proposed alignment for the Church Street FAS to determine the wall heights that would be required (Table 6). An allowance of 150mm for freeboard has been included on all wall heights, along with an allowance of 100mm for a coping stone (this does not form part of the defence height as coping stones are not integral to the wall and can become broken, dislodged and lost, and therefore cannot be relied on).

Three standards of protection have been assessed; 1 in 50 year (2% annual probability), 1 in 100 year (1% annual probability), and 1 in 200 year (0.5% annual probability).

Table 6. Wall Heights based on Change Factor Climate Change Scenario

Location	Chainage (m)	Ground Level (mAOD)	1 in 50 yr SoP			1 in 100 yr SoP			1 in 200 yr SoP		
			2010	2050	2115	2010	2050	2115	2010	2050	2115
Museum car park	0	3.49	0.61	0.94	1.46	0.75	1.08	1.60	0.86	1.19	1.71
Top of Museum Slipway	45	3.51	0.59	0.92	1.44	0.73	1.06	1.58	0.84	1.17	1.69
Car park to south of slipway	55	4.05	0.05	0.38	0.90	0.19	0.52	1.04	0.30	0.63	1.15
Car park next to pontoon access	165	3.99	0.11	0.44	0.96	0.25	0.58	1.10	0.36	0.69	1.21
Seaman's Hospital Garden	210	3.28	0.82	1.15	1.67	0.96	1.29	1.81	1.07	1.40	1.92
South of Hospital Garden	240	3.56	0.54	0.87	1.39	0.68	1.01	1.53	0.79	1.12	1.64
Opposite 40 Church Street	290	3.52	0.58	0.91	1.43	0.72	1.05	1.57	0.83	1.16	1.68
Opposite 33 Church Street	365	3.95	0.15	0.48	1.00	0.29	0.62	1.14	0.40	0.73	1.25
Opposite Middle Earth Tavern	405	3.52	0.58	0.91	1.43	0.72	1.05	1.57	0.83	1.16	1.68
South of garage	430	3.35	0.75	1.08	1.60	0.89	1.22	1.74	1.00	1.33	1.85
At Penny Hedge steps	465	3.56	0.54	0.87	1.39	0.68	1.01	1.53	0.79	1.12	1.64
Adjacent to Eskside Wharf	505	3.53	0.57	0.90	1.42	0.71	1.04	1.56	0.82	1.15	1.67

* Wall heights include 150mm allowance for freeboard and 100mm allowance for coping stone.

** Yellow cells indicate locations where wall height exceeds 1.1m (minimum height for public safety), red cells indicate where wall height exceeds 1.4m (maximum acceptable height).

From Table 6 it can be seen that the ground levels along Church Street vary significantly, with several low spots along its length. Constructing a floodwall to a specific SoP would result in a wall which would have a height variance of 0.77m. This would have visual implications, with the flood wall appearing to rise and fall in height randomly. Church Street is within a Conservation Area, and the appearance of the flood wall will be of importance. In particular the impacts on the vista when looking across the harbour towards Church Street and Whitby Abbey will be important, as there are currently plans to apply for World Heritage Site status for Whitby. Additionally there may be concerns amongst residents that the wall does not appear to be of a consistent height.

There is currently a 1.1m high metal hand-railing along the edge of the footpath on Church Street to separate pedestrians from the edge of the quay wall. Due to the varying height required for the floodwall a hand-railing would have to be installed in addition to the flood wall in order to ensure public safety. The railing would have to be separate to the floodwall, rather than on top of the floodwall to 'top up' the height, in order to avoid placing excess forces onto the wall. In addition, a separate hand railing would allow the wall to be raised in the future if required more easily. The requirement for a separate hand-railing will increase the cost of the scheme and increase the on-going maintenance burden.

5.2 Upper and Lower End Estimates

An assessment of wall heights has also been carried out for the lower end and H++ climate change scenarios in order to assess the sensitivity. These are presented in the tables in Appendix A.

Table 7 provides a sensitivity of the standard of protection (SoP) achieved for the lower end and H++ climate change scenarios, compared to the change factor climate change scenario.

For 2050 predictions the H++ and change factor scenarios are very similar, and therefore a scheme built to change factor predictions would still provide the same SoP should the H++ scenario occur. However should climate change not be as severe as expected then the scheme would provide a higher than expected SoP, although the difference is not extreme.

For 2115 predictions the sensitivity is more pronounced. A scheme built to the change factor scenario, would provide a much reduced SoP should the H++ scenario occur instead, and an excessively high SoP (1 in 1000 year or higher) should only the lower end scenario occur.

Table 7. Standard of Protection Sensitivity for different climate change scenarios

2050			**2115**		
Lower End	**Change Factor**	**H++**	**Lower End**	**Change Factor**	**H++**
100	**50**	50	1000	**50**	10
200	**100**	100	>1000	**100**	10-50
1000	**200**	200	>1000	**200**	50

5.3 Recommended Climate Change Approach

It is recommended that a managed adaptive approach to climate change is applied to the Church Street FAS, rather than a precautionary approach. Defra's preferred approach is managed adaptive unless it is not technical possible or economically feasible.

The proposed strategic option for the Church Street FAS has the following benefits which support a managed adaptive approach:

- Site is easily accessible and the working area is not significantly constrained;

- Majority of scheme is on council owned land and not through private land or gardens;

- Defence type (floodwall) lends itself to future raising; and

- Adaptive measures, such as a larger wall base size, can be built in at the start of the scheme to make future interventions easier and more efficient.

However there are some constraints which would make multiple interventions difficult:

- Church Street is one of the main roads through Whitby and is the major access for the old town on the east bank of the River Esk. During construction it is likely that lane closures will be required on Church Street with the potential to cause major traffic disruption;

- Immediately adjacent to the footpath there are parking bays for residents, these would have to be suspended during construction causing disruption to the residents of Church Street;

- Part of the quay is used by local fishermen to store lobster pots, this activity would have to be suspended during construction, this would have a detrimental impact on their livelihoods;

- Access to the jetties would be restricted during construction, it may be necessary to close the jetties for the duration of the construction. This would adversely impact on the owners and users of the jetties;

- Part of the scheme is on private land (beer garden of a pub and Seaman's Hospital Garden), during construction there would be disruption;

- Whitby is heavily reliant on the tourist industry, and as Church Street is one of the major routes into the town and forms one side of the harbour, any disruption, noise, and unsightly construction machinery could adversely impact on the attractiveness of the town.

It would therefore be beneficial for the managed adaptive approach to have minimal interventions to reduce any adverse impacts from construction. In order to reduce the number of interventions required an element of climate change allowance will need to be built into the design of the scheme at the beginning. If the initial construction includes climate change allowance up to year 2050 based on the change factor scenario, then one intervention at that point would allow the wall to be raised to deal with further sea level rises over the remainder of the design life of the wall (100 years).

The sensitivity analysis carried out on the lower end and H++ scenarios shows that incorporating climate change up to year 2050 would be an efficient solution. At 2050 the H++ scenario is very similar to the change factor scenario; therefore there is little risk that the wall would underperform in terms of the SoP it provides. Should sea level rise by less than expected, in line with the lower end scenario, then the SoP provided by the wall would be greater than expected but the difference is not extreme (as shown in Table 7). The difference in water level between the change factor and lower end scenarios at 2050 is just 150mm, this would not therefore have resulted in a significant 'wasted' cost should the lower end scenario occur.

The intervention at year 2050 will allow the wall raising for further climate change to be tailored according to the amount of sea level rise that has already occurred and the predictions of future sea level rose based on the most current estimates at that time. Should the lower end scenario for climate change occur it may be possible to delay the raising of the wall beyond 2050.

By 2115 the difference in predicted water levels for the different climate change scenarios is more pronounced. The lower end scenario water levels are 400mm lower than the change factor (most likely) scenario, and the H++ scenario water levels are 310mm higher than the change factor. As the time periods involved increase, so does the uncertainty over the amount of sea level rise that will occur due to climate change. Therefore building the wall following a precautionary approach to allow for climate change up to 2115 at the initial construction could result in a wall that is significantly higher or lower than that required. The precautionary approach has significant risks associated with it and is therefore not recommended.

It is recommended that an adaptive management approach should be followed, allowing for one intervention at year 2050. It is recommended that an allowance for climate change up to year 2050 be built into the wall when it is first constructed, and that the base of the wall is built large enough to allow for future raising of the wall without requiring additional works to the base.

5.4 Health & Safety and Planning Considerations

The flood wall will be located along the edge of the footpath along Church Street, following the alignment of the quay wall. There is currently a 1.1m high metal hand-railing along the edge of the footpath to separate pedestrians from the edge of the quay wall. Having a standard 1.1m high barrier between the footpath and the edge of quay is a critical to ensuring public safety. Therefore the flood alleviation scheme will need to maintain the 1.1m barrier either through building the flood wall to a minimum of 1.1m, or by erecting a 1.1m railing adjacent to the flood wall.

The standard of protection (SoP) offered by a 1.1m floodwall would vary along the length of the defence as the ground level varies significantly, with a variance of 750mm (as shown on Figure 1). The SoP would reduce over time as sea level rises. The estimated standard of protection provided by a 1.1m floodwall based on the change factor would be:

- ~ 1 in 1000 year (0.1% annual probability) when constructed;
- ~ 1 in 100 year (1% annual probability) by 2050; and
- ~ 1 in 10 year (1% annual probability) by 2115.

Church Street is within the Whitby Conservation Area and is part of the tourism appeal of the town, with views across the harbour. The properties along Church Street face onto the quayside and enjoy panoramic views across the working harbour. There will therefore be important visual, social and environmental considerations when determining the maximum allowable height for the floodwall. It is likely that a height of 1.4m will be the maximum acceptable, as this will still allow adult pedestrians to see over the top of the wall.

As the maximum acceptable wall height is above the 1.1m minimum wall height for safety, there is potential for raising the wall in future in response to climate change. A 1.4m high wall would provide a standard of protection of 1 in 50 year (2% annual probability) by 2115 along the majority of the length of wall (as shown in Figure 1).

A floodwall with a consistent height above ground level will provide a more unified appearance to the area, and reduce the visual appearance of the defence.

6 OPTIONS CONSIDERED

The options to be considered in the PAR are as follows:

- **Do Nothing:** this will provide the baseline against which the Do Something options will be assessed. This option is the true do nothing; no capital, temporary, emergency or maintenance works will be carried out, and the existing flood risk will worsen over time as sea level rises;

- **Option 1: 1 in 50 year Standard of Protection (2% annual probability):** a floodwall will be constructed to provide a 1 in 50 year SoP including an allowance for climate change up to year 2050. There will be an intervention in year 2051 to accommodate further climate change to ensure that the scheme continues to provide a 1 in 50 year SoP up to the end of the appraisal period.

- **Option 2: 1 in 100 year initial Standard of Protection (1% annual probability):** a floodwall will be constructed to provide a 1 in 100 year SoP including an allowance for climate change up to year 2050. There will be an intervention in year 2051 to accommodate further climate change to ensure that the scheme continues to provide a minimum SoP of 1 in 50 year up to the end of the appraisal period.

- **Option 3: 1 in 200 year initial Standard of Protection (0.5% annual probability):** a floodwall will be constructed to provide a 1 in 200 year SoP including an allowance for climate change up to year 2050. There will be an intervention in year 2051 to accommodate further climate change to ensure that the scheme continues to provide a minimum SoP of 1 in 50 year up to the end of the appraisal period.

- **Option 4: Consistent Wall Height:** a floodwall with a consistent 1.1m height will be constructed to meet the 1.1m height for a public safety barrier along the quay. An intervention will be required in year 2051 to raise the wall to 1.4m in height to reduce the impact of climate change on the standard of protection offered by the scheme.

7 ECONOMICS

7.1 Methodology

Flood risk in the lower reaches of the River Esk estuary and around Whitby Harbour can come from three sources:

1. High river flows – especially when coinciding with high astronomical spring tides or high sea surge events;

2. High sea surges; or

3. Wave overtopping of quayside walls – especially during high astronomical spring tides or high sea surge events.

Modelling work that was undertaken as part of the original Strategy identified that high river flows are the least significant contributor to flood risk in the lower reaches of the estuary, and that tides and waves are far more significant.

It is recognised that it is the crest elevation level of the quayside walls that is the determining factor in preventing flooding during times of high river flow, high tidal states or high sea surges, but the Whitby Harbour piers play a vital role in reducing wave heights in the harbour and estuary that otherwise could lead to overtopping of quay walls.

The economic assessment carried out for the Church Street, Whitby: Flood Alleviation Scheme Feasibility Study, as part of the Whitby Coastal Strategy 2 has been used as the basis for this phase of the project to develop the Project Appraisal Report. The previous economic assessment was carried out in May 2012, it has been updated for the new *Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities* guidance issued by the Environment Agency, and to the correct base date (July 2012).

Values of damages caused by tidal flooding have been calculated using the Multi-Coloured Manual and guidance from Defra and the Environment Agency in order to establish Annual Average Damages (AAD).

To assess the tidal flood risk in Whitby the following methodology has been applied:

- A topographic survey was carried out in February 2012. The information from this survey has been used to determine the flow routes and therefore the areas at risk to improve the accuracy of property numbers affected. The topographic survey included threshold levels of properties; this has been used to update the accuracy of which properties will suffer internal flooding and the internal flood depths for different return periods.

- The damages include direct damage to residential and commercial property, emergency services and authorities' response costs, indirect residential damages, and health damages.

- This information has been used to calculate annual average damages.

- The above step has been repeated using tidal events of different ‘future climate’ predictions, to take into consideration sea level rise.

- The Present Value (PV) damages have been estimated for a period of 100 years with present value taken into account using a declining long term discount rate of 3.5% for years 0-30, 3.0% for years 31-75, and 2.5% for years 76-100 as recommended in the ‘Green Book’.

- The residual life of the quay wall assets has been taken into account; where properties are directly at risk due to collapse of quay walls the AAD for flooding have only been taken up to the end of the residual life of the quay wall asset to avoid double counting.

- As flooding predominantly occurs as a result of tidal inundation, a flooding duration of less than 12 hours has been used and an allowance for additional damage due to salty water has been included in the calculation of damages.

- Capping values have been applied to all properties, both residential and commercial. The property values that are used for the purpose of residential property capping have been calculated based on data from Land Registry for North Yorkshire County Council for July 2012, as shown in Table 9. For non-residential properties, property values provided within the National Property Database (NPD) data have been used to cap flood damage to these buildings. Where values are missing from the NPD, rateable values from the Valuation Office Agency have been used to derive a market value.

Table 9. Average House Prices from Land Registry (July 2012)

House Type	Whitby	England
Detached houses	£264,536	£256,496
Semi-detached houses	£150,299	£153,339
Terraced houses	£126,829	£123,097
Flats	£120,978	£155,314
All dwellings	£169,927	£162,900

Church Street highway will be inundated at the 0.33% annual probability event (1 in 3 years) in the current climate. It is the main approach road to the Swing Bridge on the east bank of the Esk, and is a key access road for the old town. However as the flooding is tidally-dominated, the duration of any traffic disruption would not be significant. The majority of the destinations of the vehicle occupants who would usually use Church Street would be the town centre car parks or residential areas which would also be flooded, and therefore a significant proportion of the vehicles normally on the road would not be travelling during a flood. Whilst the Swing Bridge is the main route over the River Esk directly through the Whitby town centre, the majority of through traffic would be using the high level bridge on the A171 to bypass the busy sections of town and would therefore be unaffected by flooding. Therefore there would be limited traffic disruption, and this damage category has not been quantitatively valued.

Risk to life from tidal flooding was not considered to be a major risk in Whitby due to the flood warning available, short duration of flooding, type of property at risk, and availability of escape routes. Compared with the other benefit categories considered, risk to life from tidal flooding would not have contributed a significant damage value, and therefore it was felt it was not proportional to carry out a damage assessment on this category.

7.2 Do Nothing

The Do Nothing damages have been calculated over the 100 year appraisal period using the methodology above. The damage calculations take into account sea level rise, using the updated climate change predictions for 2012, 2025, 2050, 2080 and 2115, as outlined in Section 3.

The present value Do Nothing damages for Floodcell 2B covering the Church Street area over the 100 year appraisal period are **£8,193k**, including climate change allowances at the 'change factor' level. The number of properties at risk of flooding and the increases over time due to climate change are shown in Table 10.

Table 10. Properties at risk on Church Street

Return Period	2010			2050			2115		
	Res	Com	Tot	Res	Com	Tot	Res	Com	Tot
1 in 1 year	7	0	7	12	2	14	54	7	61
1 in 3 years	10	1	11	40	3	43	54	8	62
1 in 10 years	38	3	41	46	6	52	58	8	66
1 in 50 years	47	6	53	54	8	62	61	9	70
1 in 100 years	54	7	61	54	8	62	62	10	72
1 in 200 years	54	8	62	58	8	66	66	10	76
1 in 1000 years	58	8	66	59	9	68	81	10	91

* Numbers based on 'change factor' prediction for climate change

7.3 Do Minimum

As there are no existing flood defences there will be no difference in the flood risk, and consequently the damages, for the Do Minimum scenario when compared with the Do Nothing scenario. Therefore the Do Minimum does not provide any flood alleviation benefits and was ruled out by the Whitby Coastal Strategy 2.

7.4 Scheme Benefits

The benefits of a flood alleviation scheme for a range of SoP and for a consistent wall height have been assessed and the results are presented in Table 11 and 12, with and without climate change allowances and benefits. The Do Something benefits have been assessed by comparing the residual flood damages for the standard of protection offered by the option to the Do Nothing damages. As the standard of protection offered by the option increases, so do the benefits provided. Option 4, which has a consistent wall height above ground level, provides the lowest benefits, due to its inconsistent standard of protection, which is particularly low in places.

Table 11. Church Street FAS Benefits including Climate Change Allowances

Option		Floodcell 2A		Floodcell 2B		Total
		PV Damages (£k)	PV Benefits (£k)	PV Damages (£k)	PV Benefits (£k)	PV Benefits (£k)
Do Nothing		375	-	8,193	-	**-**
1	50 year SoP	178	197	654	7,539	**7,736**
2	100 year SoP	178	197	370	7,823	**8,020**
3	200 year SoP	178	197	141	8,052	**8,249**
4	Consistent Wall Height	184	191	989	7,204	**7,013**

Table 12. Church Street FAS Benefits excluding Climate Change Allowances

Option		Floodcell 2A		Floodcell 2B		Total
		PV Damages (£k)	PV Benefits (£k)	PV Damages (£k)	PV Benefits (£k)	PV Benefits (£k)
Do Nothing		168	-	6,320	-	**-**
1	50 year SoP	155	13	250	6,070	**6,083**
2	100 year SoP	155	13	211	6,109	**6,122**
3	200 year SoP	155	13	0	6,320	**6,333**
4	Consistent Wall Height	155	13	250	6,070	**6,083**

A sensitivity has been carried out on the climate change allowances. The *Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities (September 2011, Environment Agency)* provides a range of climate change scenarios. The economics for the option appraisal in this PAR is based on the 'Change Factor' scenario which is the most likely scenario. A sensitivity analysis has been carried out on the 'Lower End' and 'H++' scenarios to assess the impact on the viability of the scheme should climate change be less or more than that considered.

The results of the sensitivity testing on the Do Nothing PV damages for the different climate changes scenarios are presented in Table 13. If sea level rise is more severe than anticipated then the impact on the Do Nothing damages is minimal, an increase of just 3%. This is because the majority of the properties affected by flooding are already capped at their market values and therefore will not incur any additional damages. Should climate change be less severe than expected then the Do Nothing damages could potentially decrease by 17%. A reduction of 17% in the preferred option benefits would reduce the BCR to 4.01, which is still a respectable BCR.

The scheme has a managed adaptive approach, with an intervention at 2051. This will allow the scheme to be managed to react to changes in the predicted climate change at that point, by changing the level the defences need to be raised to. This will reduce the costs of the scheme and offset some of the reduction in the BCR. The scheme will therefore remain viable and can adapt despite the current uncertainties over climate change in the future.

Table 13. Climate Change Scenarios Sensitivity Test on Do Nothing Damages

Climate Change Scenario	Do Nothing Damages (£k)	Change
Change Factor	8,568	-
Lower End	7,094	-17%
H++	8,825	+3%

8 RECOMMENDATIONS

8.1 Options for Project Appraisal Report

The options to be considered in the PAR are as follows:

- **Do Nothing:** this will provide the baseline against which the Do Something options will be assessed. This option is the true do nothing; no capital, temporary, emergency or maintenance works will be carried out, and the existing flood risk will worsen over time as sea level rises;

- **Option 1: 1 in 50 year Standard of Protection (2% annual probability):** a floodwall will be constructed to provide a 1 in 50 year SoP including an allowance for climate change up to year 2050. There will be an intervention in year 2051 to accommodate further climate change to ensure that the scheme continues to provide a 1 in 50 year SoP up to the end of the appraisal period.

- **Option 2: 1 in 100 year initial Standard of Protection (1% annual probability):** a floodwall will be constructed to provide a 1 in 100 year SoP including an allowance for climate change up to year 2050. There will be an intervention in year 2051 to accommodate further climate change to ensure that the scheme continues to provide a minimum SoP of 1 in 50 year up to the end of the appraisal period.

- **Option 3: 1 in 200 year initial Standard of Protection (0.5% annual probability):** a floodwall will be constructed to provide a 1 in 200 year SoP including an allowance for climate change up to year 2050. There will be an intervention in year 2051 to accommodate further climate change to ensure that the scheme continues to provide a minimum SoP of 1 in 50 year up to the end of the appraisal period.

- **Option 4: Consistent Wall Height:** a floodwall with a consistent 1.1m height will be constructed to meet the 1.1m height for a public safety barrier along the quay. An intervention will be required in year 2051 to raise the wall to 1.4m in height to reduce the impact of climate change on the standard of protection offered by the scheme.

The Do Something options will adopt a managed adaptive approach to climate change as discussed in Section 5.3.

The Church Street Flood Alleviation Scheme will not include works in Floodcell 2A during the initial construction, it will focus solely on Floodcell 2B (from the jetty in Church Street car park to Eskside Wharf), as discussed in Section 4. However, at the intervention in 2051 to adapt the scheme for further climate change the floodwalls will need to be extended northwards into Floodcell 2A to prevent outflanking of the defences. The outflanking is facilitated by the highway.

Appendix A
Wall Heights

Table 7. Wall Heights based on Lower End Climate Change Scenario

Location	Chainage (m)	Ground Level (mAOD)	1 in 50 yr SoP			1 in 100 yr SoP			1 in 200 yr SoP		
			2010	2050	2115	2010	2050	2115	2010	2050	2115
Museum car park	0	3.49	0.61	0.79	1.07	0.75	0.93	1.21	0.86	1.04	1.32
Top of Museum Slipway	45	3.51	0.59	0.77	1.05	0.73	0.91	1.19	0.84	1.02	1.30
Car park to south of slipway	55	4.05	0.05	0.23	0.51	0.19	0.37	0.65	0.30	0.48	0.76
Car park next to pontoon access	165	3.99	0.11	0.29	0.57	0.25	0.43	0.71	0.36	0.54	0.82
Seaman's Hospital Garden	210	3.28	0.82	1.00	1.28	0.96	1.14	1.42	1.07	1.25	1.53
South of Hospital Garden	240	3.56	0.54	0.72	1.00	0.68	0.86	1.14	0.79	0.97	1.25
Opposite 40 Church Street	290	3.52	0.58	0.76	1.04	0.72	0.90	1.18	0.83	1.01	1.29
Opposite 33 Church Street	365	3.95	0.15	0.33	0.61	0.29	0.47	0.75	0.40	0.58	0.86
Opposite Middle Earth Tavern	405	3.52	0.58	0.76	1.04	0.72	0.90	1.18	0.83	1.01	1.29
South of garage	430	3.35	0.75	0.93	1.21	0.89	1.07	1.35	1.00	1.18	1.46
At Penny Hedge steps	465	3.56	0.54	0.72	1.00	0.68	0.86	1.14	0.79	0.97	1.25
Adjacent to Eskside Wharf	505	3.53	0.57	0.75	1.03	0.71	0.89	1.17	0.82	1.00	1.28

* Wall heights include 150mm allowance for freeboard and 100mm allowance for coping stone.

** Yellow cells indicate locations where wall height exceeds 1.1m (minimum height for public safety), red cells indicate where wall height exceeds 1.4m (maximum acceptable height).

Table 8. Wall Heights based on H++ Climate Change Scenario

Location	Chainage (m)	Ground Level (mAOD)	1 in 50 yr SoP			1 in 100 yr SoP			1 in 200 yr SoP		
			2010	2050	2115	2010	2050	2115	2010	2050	2115
Museum car park	0	3.49	0.61	0.92	1.77	0.75	1.06	1.91	0.86	1.17	2.02
Top of Museum Slipway	45	3.51	0.59	0.90	1.75	0.73	1.04	1.89	0.84	1.15	2.00
Car park to south of slipway	55	4.05	0.05	0.36	1.21	0.19	0.50	1.35	0.30	0.61	1.46
Car park next to pontoon access	165	3.99	0.11	0.42	1.27	0.25	0.56	1.41	0.36	0.67	1.52
Seaman's Hospital Garden	210	3.28	0.82	1.13	1.98	0.96	1.27	2.12	1.07	1.38	2.23
South of Hospital Garden	240	3.56	0.54	0.85	1.70	0.68	0.99	1.84	0.79	1.10	1.95
Opposite 40 Church Street	290	3.52	0.58	0.89	1.74	0.72	1.03	1.88	0.83	1.14	1.99
Opposite 33 Church Street	365	3.95	0.15	0.46	1.31	0.29	0.60	1.45	0.40	0.71	1.56
Opposite Middle Earth Tavern	405	3.52	0.58	0.89	1.74	0.72	1.03	1.88	0.83	1.14	1.99
South of garage	430	3.35	0.75	1.06	1.91	0.89	1.20	2.05	1.00	1.31	2.16
At Penny Hedge steps	465	3.56	0.54	0.85	1.70	0.68	0.99	1.84	0.79	1.10	1.95
Adjacent to Eskside Wharf	505	3.53	0.57	0.88	1.73	0.71	1.02	1.87	0.82	1.13	1.98

* Wall heights include 150mm allowance for freeboard and 100mm allowance for coping stone.

** Yellow cells indicate locations where wall height exceeds 1.1m (minimum height for public safety), red cells indicate where wall height exceeds 1.4m (maximum acceptable height).

Appendix B
Figures

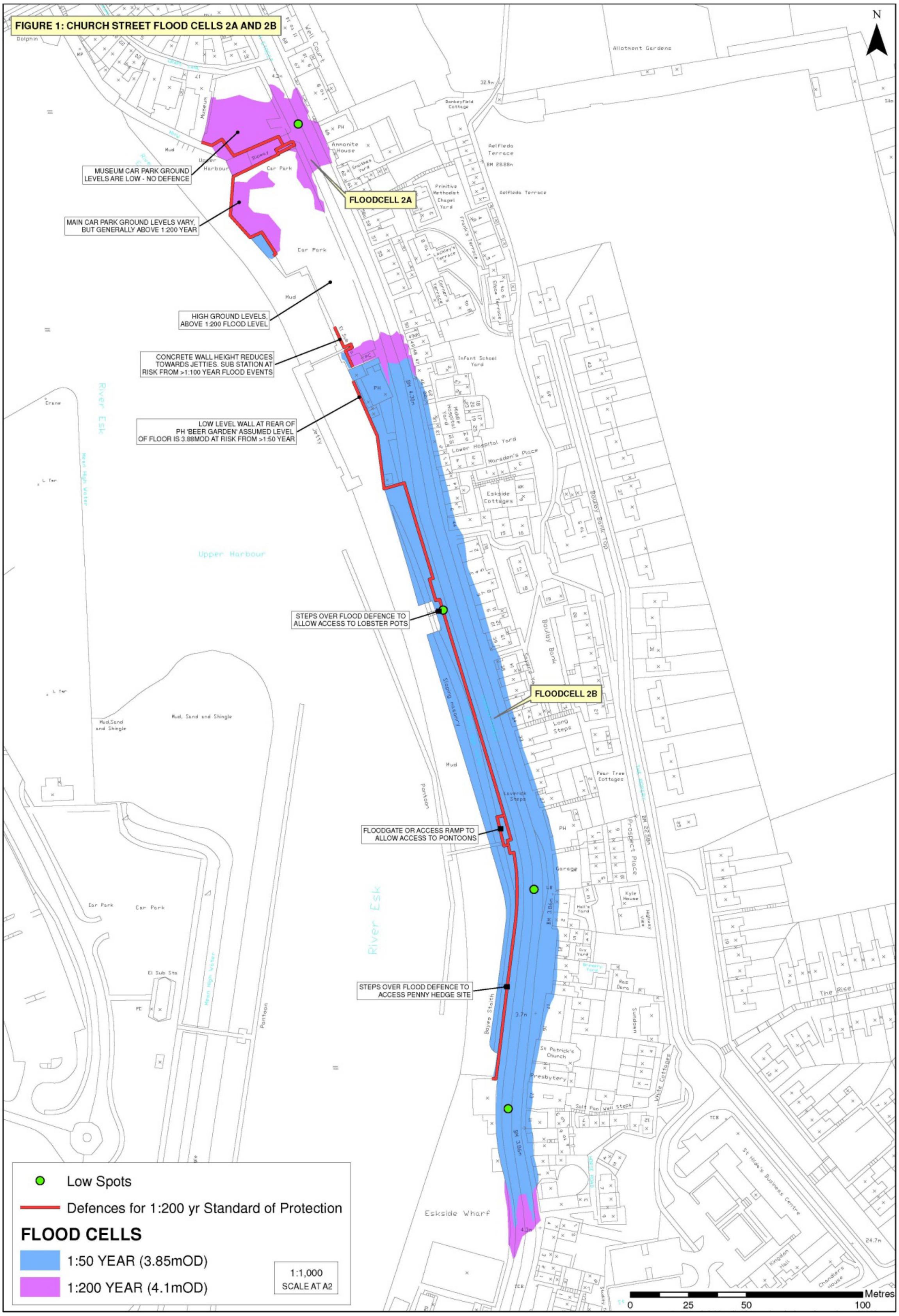
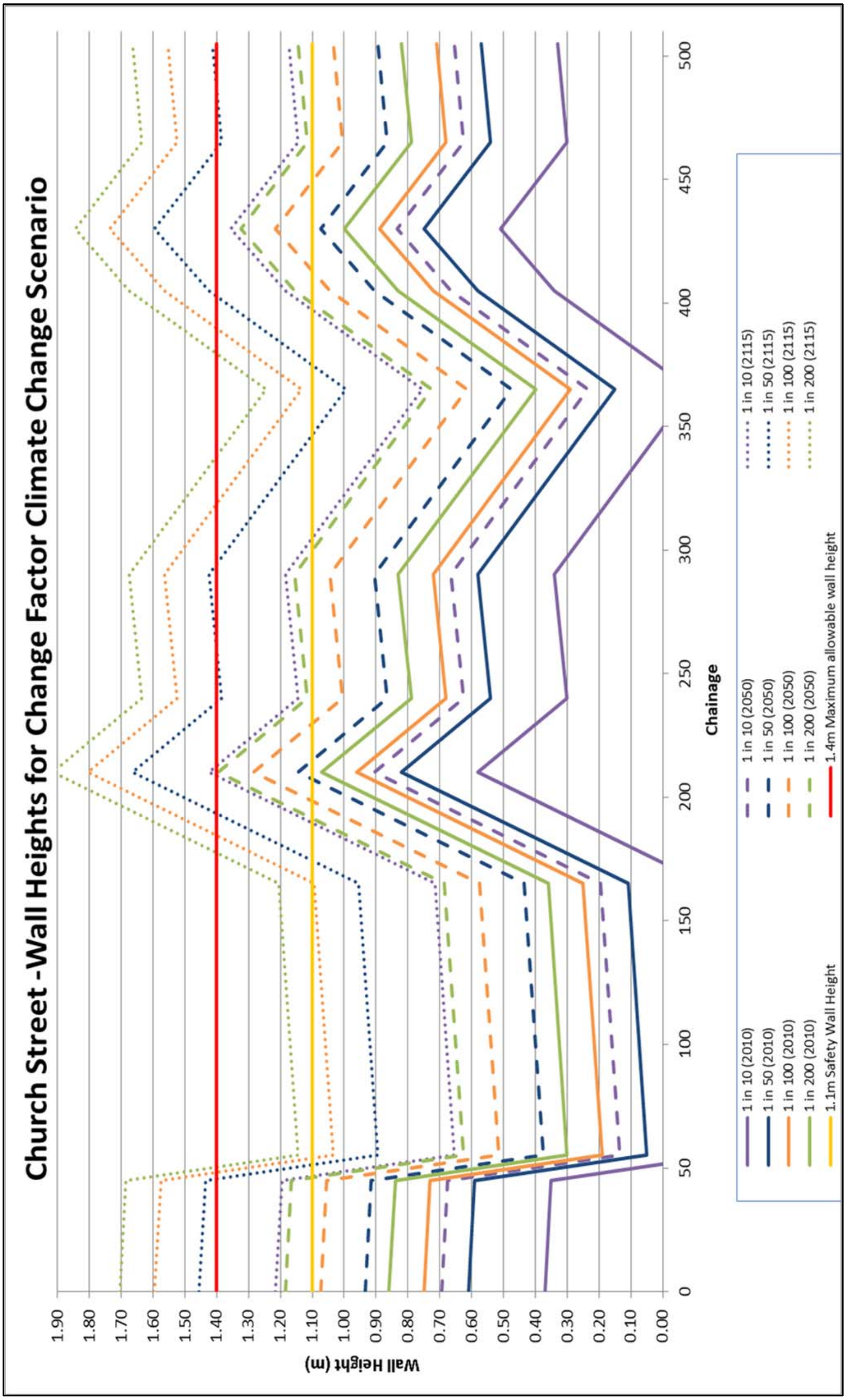
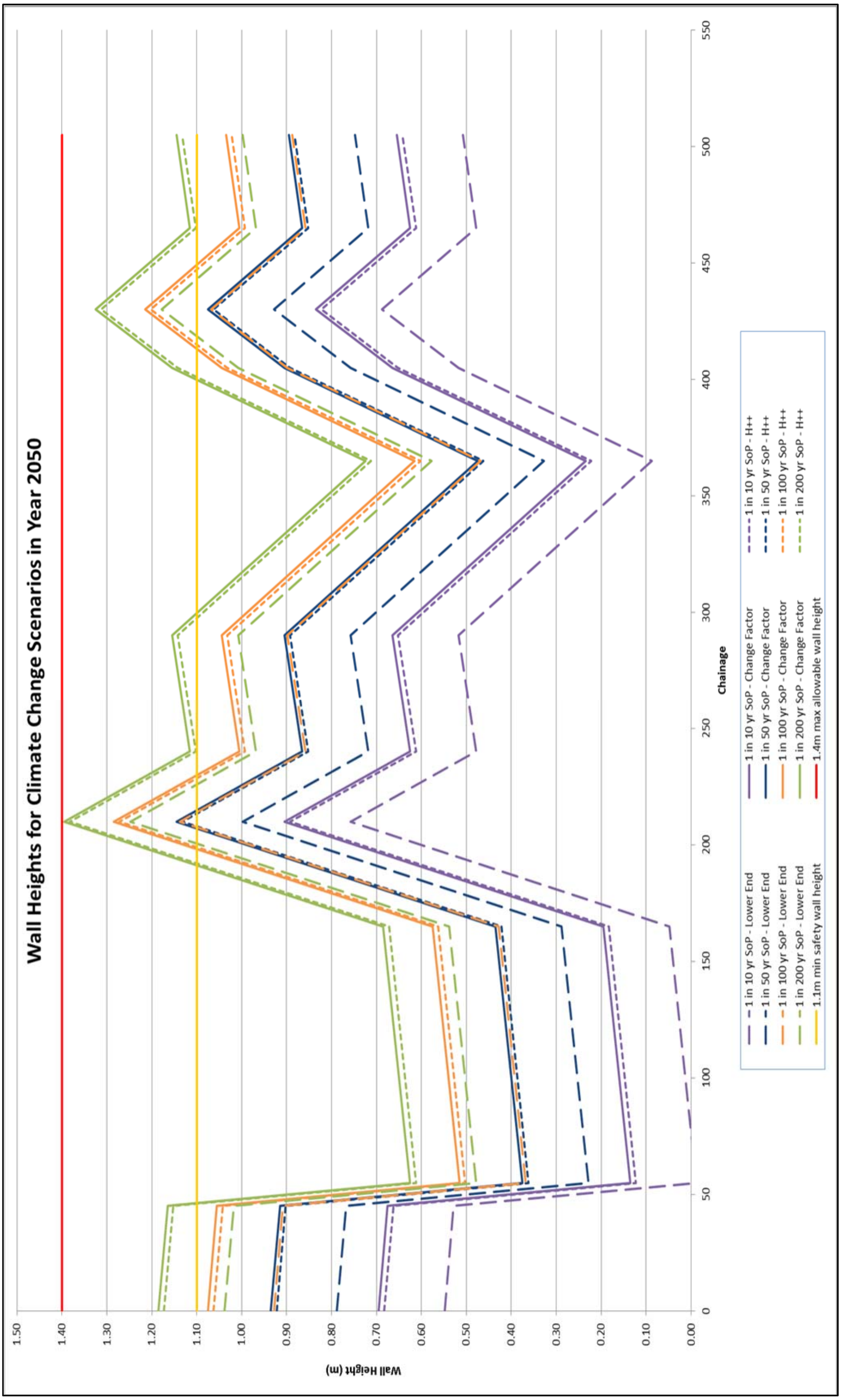
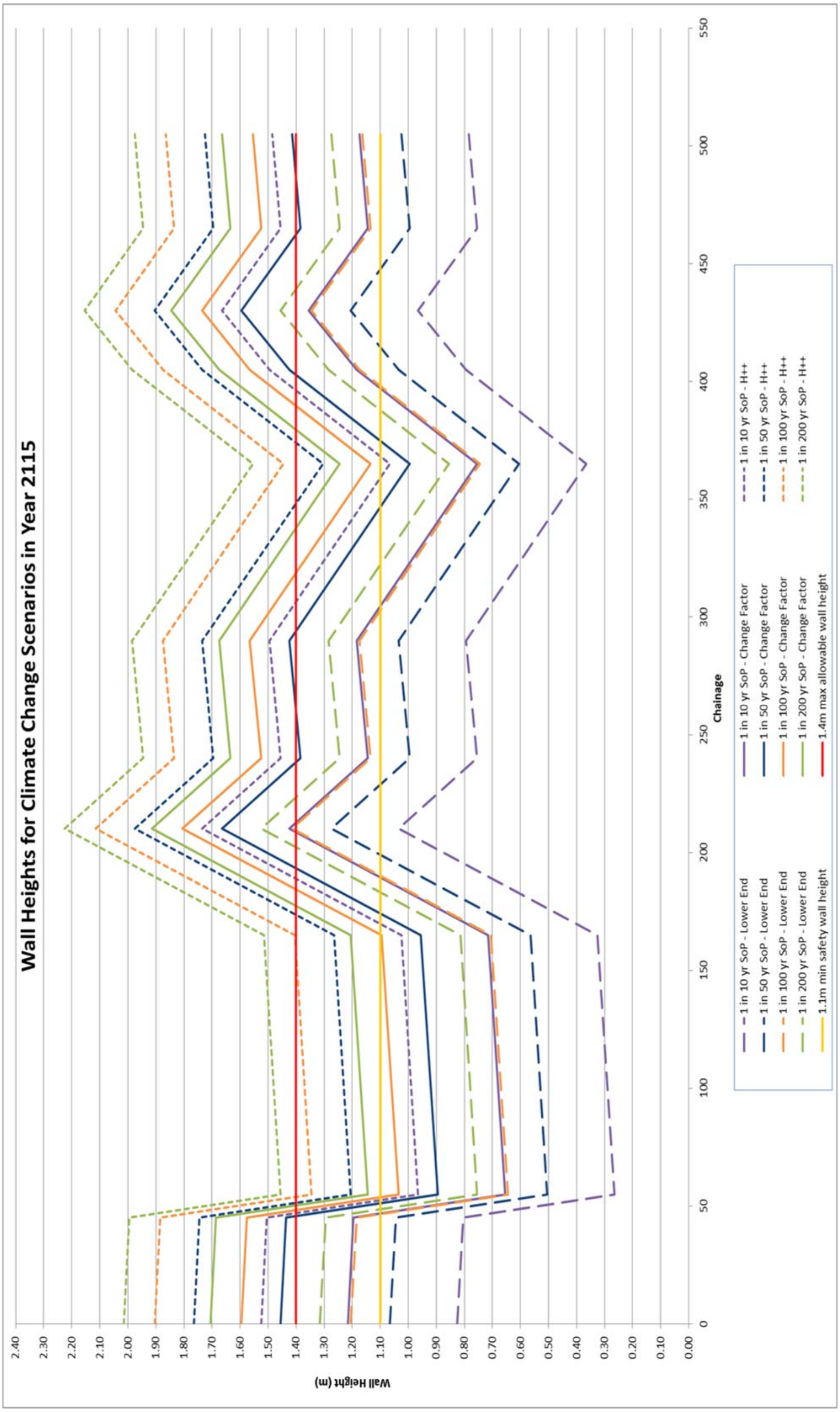


FIGURE 1: CHURCH STREET FLOOD CELLS 2A AND 2B
N
MUSEUM CAR PARK GROUND LEVELS ARE LOW - NO DEFENCE
MAIN CAR PARK GROUND LEVELS VARY, BUT GENERALLY ABOVE 1:200 YEAR
FLOODCELL 2A
HIGH GROUND LEVELS, ABOVE 1:200 FLOOD LEVEL
CONCRETE WALL HEIGHT REDUCES TOWARDS JETTIES. SUB STATION AT RISK FROM >1:100 YEAR FLOOD EVENTS
LOW LEVEL WALL AT REAR OF PH 'BEER GARDEN' ASSUMED LEVEL OF FLOOR IS 3.88MOD AT RISK FROM >1:50 YEAR
STEPS OVER FLOOD DEFENCE TO ALLOW ACCESS TO LOBSTER POTS
FLOODCELL 2B
FLOODGATE OR ACCESS RAMP TO ALLOW ACCESS TO PONTOONS
STEPS OVER FLOOD DEFENCE TO ACCESS PENNY HEDGE SITE
Upper Harbour
River Esk
Car Park
Allotment Gardens
Boulby Bank
Eskside Wharf
St Patrick's Church
Low Spots
Defences for 1:200 yr Standard of Protection
FLOOD CELLS
1:50 YEAR (3.85mOD)
1:200 YEAR (4.1mOD)
1:1,000
SCALE AT A2
Metres
0
25
50
100


Church Street -Wall Heights for Change Factor Climate Change Scenario
Wall Height (m)
Chainage
1 in 10 (2010)
1 in 50 (2010)
1 in 100 (2010)
1 in 200 (2010)
1.1m Safety Wall Height
1 in 10 (2050)
1 in 50 (2050)
1 in 100 (2050)
1 in 200 (2050)
1.4m Maximum allowable wall height
1 in 10 (2115)
1 in 50 (2115)
1 in 100 (2115)
1 in 200 (2115)


Wall Heights for Climate Change Scenarios in Year 2050
Wall Height (m)
Chainage
1 in 10 yr SoP - Lower End
1 in 50 yr SoP - Lower End
1 in 100 yr SoP - Lower End
1 in 200 yr SoP - Lower End
1.1m min safety wall height
1 in 10 yr SoP - Change Factor
1 in 50 yr SoP - Change Factor
1 in 100 yr SoP - Change Factor
1 in 200 yr SoP - Change Factor
1.4m max allowable wall height
1 in 10 yr SoP - H++
1 in 50 yr SoP - H++
1 in 100 yr SoP - H++
1 in 200 yr SoP - H++


Wall Heights for Climate Change Scenarios in Year 2115
Wall Height (m)
Chainage
1 in 10 yr SoP - Lower End
1 in 50 yr SoP - Lower End
1 in 100 yr SoP - Lower End
1 in 200 yr SoP - Lower End
1.1m min safety wall height
1 in 10 yr SoP - Change Factor
1 in 50 yr SoP - Change Factor
1 in 100 yr SoP - Change Factor
1 in 200 yr SoP - Change Factor
1.4m max allowable wall height
1 in 10 yr SoP - H++
1 in 50 yr SoP - H++
1 in 100 yr SoP - H++
1 in 200 yr SoP - H++

Appendix C
Water Levels

Water levels for use in economic calculations for different climate change scenarios:

	Date	Parameter	1 in 1 yr	1 in 3 yr	1 in 10 yr	1 in 50 yr	1 in 100 yr	1 in 200 yr	1 in 1000 yr
Change Factor	2007	Current	3.30	3.45	3.61	3.85	3.99	4.10	4.31
	2010	Change factor	3.39	3.54	3.70	3.94	4.08	4.19	4.40
	2025	Change factor	3.47	3.62	3.78	4.02	4.16	4.27	4.48
	2050	Change factor	3.63	3.78	3.94	4.18	4.32	4.43	4.64
	2080	Change factor	3.85	4.00	4.16	4.40	4.54	4.65	4.86
	2115	Change factor	4.15	4.30	4.46	4.70	4.84	4.95	5.16

	Date	Parameter	1 in 1 yr	1 in 3 yr	1 in 10 yr	1 in 50 yr	1 in 100 yr	1 in 200 yr	1 in 1000 yr
Lower End	2007	Current	3.30	3.45	3.61	3.85	3.99	4.10	4.31
	2010	Lower end	3.35	3.50	3.66	3.90	4.04	4.15	4.36
	2025	Lower end	3.39	3.54	3.70	3.94	4.08	4.19	4.40
	2050	Lower end	3.48	3.63	3.79	4.03	4.17	4.28	4.49
	2080	Lower end	3.60	3.75	3.91	4.15	4.29	4.40	4.61
	2115	Lower end	3.76	3.91	4.07	4.31	4.45	4.56	4.77

	Date	Parameter	1 in 1 yr	1 in 3 yr	1 in 10 yr	1 in 50 yr	1 in 100 yr	1 in 200 yr	1 in 1000 yr
H++	2007	Current	3.30	3.45	3.61	3.85	3.99	4.10	4.31
	2010	H++ scenario	3.32	3.47	3.63	3.87	4.01	4.12	4.33
	2025	H++ scenario	3.39	3.54	3.70	3.94	4.08	4.19	4.40
	2050	H++ scenario	3.61	3.76	3.92	4.16	4.30	4.41	4.62
	2080	H++ scenario	4.02	4.17	4.33	4.57	4.71	4.82	5.03
	2115	H++ scenario	4.46	4.61	4.77	5.01	5.15	5.26	5.47