Barnstaple Flood Defence Improvements

Final Report

August 2015

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Revision History

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Final Report v1.0 June 2015	**Inclusion of Flood Cells E and F Addressed comments on draft report**	**John Galt, Devon County Council Sally Nelson North Devon DC Andrew Austen North Devon DC Simon Dart Environment Agency**

Contract

This report describes work commissioned by Devon County Council by a letter dated 8th September 2014. Devon County Council's representative for the contract was John Galt. Phil Emonson, Chris Smith, Rachel Drabble, Oliver Francis and Angus Pettit of JBA Consulting carried out this work.

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Purpose

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JBA Consulting has no liability regarding the use of this report except to Devon County Council.

Acknowledgements

JBA would like to acknowledge assistance John Galt (Devon County Council), Simon Dart (Environment Agency), Sally Nelson and Andrew Austen (North Devon District Council) for their support and timely supply of data during the commission.

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Executive Summary

Current and future flood risks in Barnstaple are cause for concern for Devon County and North Devon District Councils. The production of a flood defence improvement strategy for the next 60 to 100 years will enable future redevelopment of housing and employment sites, promoting economic development and raise employment opportunities. It will also help to revitalise and regenerate the northern part of the town.

The current and future (2075 and 2115) flood risks from both fluvial and tidal sources were modelled. From these results the numbers of properties at risk was extracted for a range of flood events and the resultant economic damages were calculated within each flood cell. Results were determined for 2015, 2075 and 2115 through modelling and where required an indication of 2045 results through interpolation of the 2015 ad 2075 results. The analysis was carried out to consider six flood cells in Barnstaple labelled as A to F. Flood cell F has been excluded from the analysis of costs and benefits as defences here are imminently being improved as part of the Anchorwood Bank development. These will extend along the entire frontage of flood cell F.

Table 1: Present Value Damages associated with tidal flooding

Present Value Damages (PvD)	2015 (£k)	2075 (£K)	2115 (£k)
Cell A	58	2,727	35,449
Cell B	1,195	68,638	101,112
Cell C	42	2,439	39,522
Cell D	0	0	247
Cell E	40	6,442	81,161
Cell F	Excluded from analysis		
Total	**1,335**	**80,246**	**257,491**

Table 2: Present Value Damages associated with fluvial flooding

Present Value Damages (PvD)	2015 (£k)	2075 (£K)	2115 (£k)
Cell A	4,590	8,864	26,663
Cell B	3,795	29,389	94,430
Cell C	28	3,355	29,108
Cell D	0	184	635
Cell E	3,387	11,386	15,457
Cell F	Excluded from analysis		
Total	**11,800**	**53,178**	**166,293**

A suite of options were considered for each flood cell, and these were modelled to assess how future levels of flood risk could be managed. These included the raising of existing embankments and flood walls, raising of the A361 and cycle track north towards Pilton Community College, and the option of either piling around the existing course of the Yeo through Pilton Park (option 1), or re-routing it along the A39 Pilton Causeway (option 2).

With the proposed flood defences in place in the future, the fluvial and tidal flood risks will substantially reduce compared to the situation in the future without them (Do Minimum). The level of flood risk achieved by both options is essentially the same.

The cost of each option has been estimated. From this work it has been estimated that total costs for all of the proposed flood defence improvements are £26.3 to 67.1m for Option 1, and £20.0 to 44.0m (high cost) for Option 2. These options are likely to be economically viable as they are far less than the potential benefits of the schemes. Timing of the investment is hard to determine at this time and is largely dependent on the rate of increasing sea levels due to climate change. It is

likely different flood cells will be progressed at different times and it may be not all elements of the defences described in this document will be progressed.

Table 3: Total cost associated with Options 1 and 2, including capital costs, 20% preliminaries and 60% optimism bias

Costs including capital costs, 20% preliminaries and 60% optimism bias (£k)	Option 1 - cost		Option 2 - cost	
	Low cost	High cost	Low cost	High cost
Cell A	4,815	8,968	4,815	8,968
Cell B	9,767	36,284	3,045	11,182
Cell C	2,129	4,099	2,479	6,035
Cell D	1,152	2,139	1,152	2,139
Cell E	8,484	15,656	8,484	15,656
Cell F	Excluded from analysis			
Total	26,348	67,146	19,975	43,979

Flood damages and benefits, particularly for the future scenarios, can only be considered indicative as there are many significant uncertainties in these calculations so far in the future. The rate of sea level rise for example is a large influence on the flood risks being predicted and then the damages are influenced by the capping applied on each property which is itself very uncertain.

It is clear from the analysis that flood risk in Barnstaple is predicted to increase substantially over the next 100 years both from tidal sources, as a result of sea level increases, and from fluvial sources, as a result of expected peak flow increases and increased duration of tide locking of outfalls. In future Barnstaple will need more and larger flood defences and many more properties will be relying on flood defence infrastructure. This in itself can bring challenges as residual risk of defence failure or overtopping will exist and may require additional emergency planning.

The rate of sea level rise at Barnstaple and the timing of investment should be monitored and the outcomes of this study kept updated over coming decades. More pressing maintenance needs on individual defences will perhaps be of most immediate concern in Barnstaple to retain existing effective defences.

This study should in part give a framework to help unlock future development potential in Barnstaple. It should also facilitate the consideration of how external funding sources can be used to help fund future flood defences.

Contents

Contents

List of Figures

List of Tables

Abbreviations

AAD ..... Annual Average Damage
AEP ..... Annual Exceedance Probability
AONB ..... Area of Outstanding Natural Beauty
DPLBAR ..... Drainage Path Length
DPSBAR ..... Drainage Slope
DSM ..... Digital Surface Model
DTM ..... Digital Terrain Model
EA ..... Environment Agency
FEH ..... Flood Estimation Handbook
HMWB ..... Heavily Modified Waterbody
JBA ..... Jeremy Benn Associates
LiDAR ..... Light Detection and Ranging
PLP ..... Property Level Protection
PVD ..... Present Value Damages
SHLAA ..... Strategic Housing Land Allocation Assessment
SoP ..... Standard of Protection
SuDS ..... Sustainable Drainage Systems
SSSI ..... Site of Special Scientific Interest
URBEXT ..... FEH index of fractional urban extent
WFD ..... Water Framework Directive

Definitions

Critical infrastructure is classified as the following

- Education establishments
- Electricity
- Emergency services
- Gas
- Health establishments
- Military
- Oil
- Socially vulnerable
- Telecommunications
- Transport infrastructure
- TV, radio and other associated media
- Water infrastructure

Conversion between return period and AEP

Return period (yrs)	2	5	10	20	30	50	75	100	200	1000
AEP (%)	50	20	10	5	3.33	2	1.33	1	0.5	0.1

1 Introduction

1.1 Project background

Current and future flood risks in Barnstaple are cause for concern for Devon County and North Devon District Councils. Resultantly, JBA Consulting was commissioned by Devon County Council to investigate potential solutions to address future flood risk in Barnstaple.

Barnstaple is identified as the sub-regional centre and forms the economic, administrative and commercial centre of Northern Devon. The publication of the draft North Devon and Torridge Local Plan (2014) proposes approximately 4,000 new homes and 26 hectares of additional employment land, both within Barnstaple and in the immediate surrounding areas, between 2011 and 2031. It has been recognised from work by the Environment Agency and in the spatial strategy for Barnstaple within the emerging joint Local Plan (Policy BAR) that a long term flood defence improvement strategy is required to help facilitate this growth.

The production of a flood defence improvement strategy for the next 60 to 100 years for Barnstaple will enable future redevelopment of housing and employment sites, many of which are brownfield sites that can not gain planning approvals due to projected flood risks. The production of this strategy will promote economic development and raise employment opportunities, helping to promote investment (especially in areas such as Pottington), unlocking land potential and raising land values.

The study will explore a variety of conceptual flood alleviation options and determine preferred option(s) for different parts of the town. The study will assess future flooding by addressing the lifetime of development, which is 60 years for commercial uses and 100 years for residential uses. Each of the preferred options will be modelled to assess the impacts on levels of future flood risk. An outline appraisal of the technical feasibility of each option will be undertaken, together with an assessment of cost, environmental impact, and priority.

1.2 Study area

Barnstaple is situated on the tidal stretch of the River Taw, with substantial parts of the town at risk of flooding from the River Yeo, Coney Gut and Bradiford Water and their associated tributaries.

The study area has been split into six separate flood cells as shown on Figure 1-1. These cells are not directly connected hydraulically, which enables options, costs and phasing for each flood cell to be assessed independently. The main study area extends from Bradiford Water in the north, past the Longbridge in the centre of Barnstaple and includes the River Yeo, a major tributary of the Taw which flows through Pilton, and to the south to Newport and Rock Park.

The extent and location of the flood cells was defined by North Devon District Council, Devon County Council and the Environment Agency prior to the study. The decisions were based around the source of the flood risk, the perceived level of risk now and in the future (based on best available data), and future development opportunities as identified in the North Devon and Torridge Local Plan (2014) and the 2013 Strategic Housing Land Allocation Assessment (SHLAA).

Flood cell F has been excluded from the analysis of costs and benefits as defences here are imminently being improved as part of the Anchorwood Bank development. These will extend along the entire frontage of flood cell F.

In addition to the level of flood risk, the Taw-Torridge estuary is a Site of Special Scientific Interest (SSSI), due to major importance for overwintering and migratory populations of wading birds. Furthermore the Taw-Torridge estuary is designated as part of a UNESCO Biosphere Reserve, part of the North Devon Coast Area of Outstanding Natural Beauty (AONB) and Heritage Coast, demonstrating the significance of the area as a scientifically and historically important conservation site.

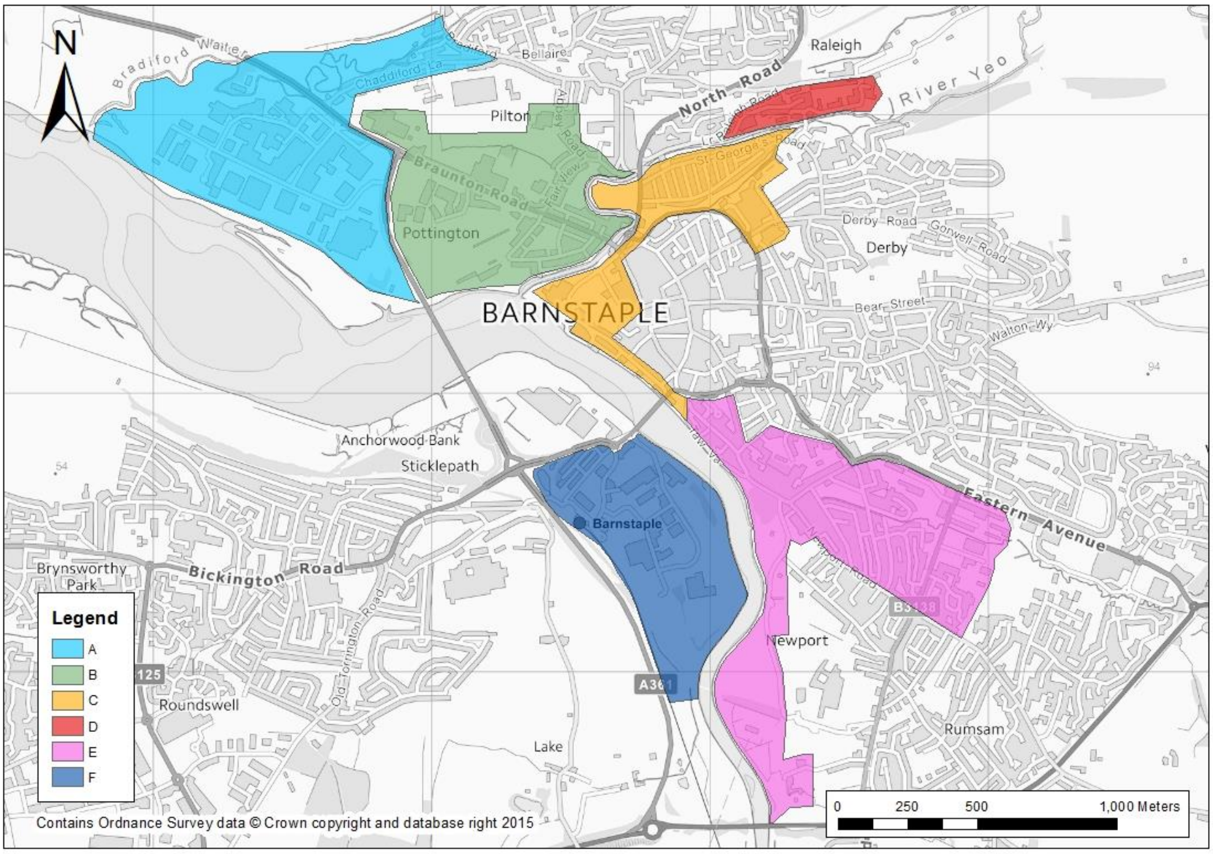

Figure 1-1: Location of Flood Cells in Barnstaple

1.3 Report structure

Table 1-1 Report structure

Element	Chapter
Introduction	Chapter 1
Source, Pathway, Receptors	Chapter 2
Input data, hydraulic modelling and limitations	Chapter 3
Discounted Options	Chapter 4
Flood Cell A	Chapter 5
Flood Cell B	Chapter 6
Flood Cell C	Chapter 7
Flood Cell D	Chapter 8
Flood Cell E	Chapter 9
Flood Cell F	Chapter 10
Conclusions	Chapter 11
Design Input Statement	Appendix A
Engineering Technical Report	Appendix B
Environmental Assessment	Appendix C

2 Source, pathway, receptor model

The Source-Pathway-Receptor model is a useful concept to highlight the processes that are influencing the flood risk in a given area.

2.1 Sources

2.1.1 Tidal

The predominant source of floodwater in the study area is the tidally dominant River Taw, as it flows towards the mouth of the estuary, downstream of Yelland on the North Devon coast. The River Taw rises on Dartmoor to the south of Okehampton, with significant tributary inputs from Exmoor, prior to entering the estuarine environment at Barnstaple. The tidal limit of the Taw is at the A377 road crossing, some 3km upstream of the study area.

The downstream boundary of the model is at Yelland and the water level has been taken from an Environment Agency report ("Extreme Tide Levels in Estuaries and Tidal Rivers in South West Region", February 2011). The results from the hydraulic modelling show that the maximum water level increases from 5.71mAOD at Yelland to 6.08mAOD at the upstream extent of Flood Cell E.

2.1.2 Fluvial

The fluvial sources of floodwater in the study area are the River Yeo, Bradiford Water and Coney Gut. Two additional watercourses, the Venn Stream and the Fremington Stream, are sources of fluvial flooding, but lie beyond the study area and as such were removed from the hydraulic model to optimise run times. Figure 2-1 shows the Flood Estimation Handbook (FEH) derived catchment boundaries of the watercourses assessed within this investigation.

River Yeo

At the confluence of the River Taw the River Yeo drains an area of 84km^2, and overall the catchment is predominately rural (URBEXT2000[1] 0.0044) until it approaches its downstream reach in the centre of Barnstaple. The catchment drains from as far north as Kentisbury, approximately 13km upstream and is characterised by a relatively steep channel gradient (DPSBAR[2] is 137.6m/km). The catchment receives above average annual rainfall (1332mm).

Bradiford Water

Bradiford Water flows in to the River Taw adjacent to the Pottington Business Park on the western edge of Barnstaple. At this location the Bradiford Water catchment area is 33.km^2. The catchment drains from north of Muddiford, and is less urbanised than the Yeo with only a small part of the drainage area encompassing Barnstaple itself. Similarly to the River Yeo the drainage path length is short (DPLBAR[3] is 9.33km) with a steep channel gradient (DPSBAR is 139.4m/km).

Coney Gut

The Coney Gut catchment encompasses an area of 10km^2. The Coney Gut rises from the east of Goodleigh and flows west towards Barnstaple. It is characterised by a small drainage path length (DPLBAR is 4.16km) with a slightly shallower gradient than the other catchments (DPSBAR is 114m/km). Unlike the other catchments the Coney Gut is a more urbanised catchment (URBEXT2000 is 0.102).

[1] index of fractional urban extent

[2] Drainage slope

[3] Drainage path length

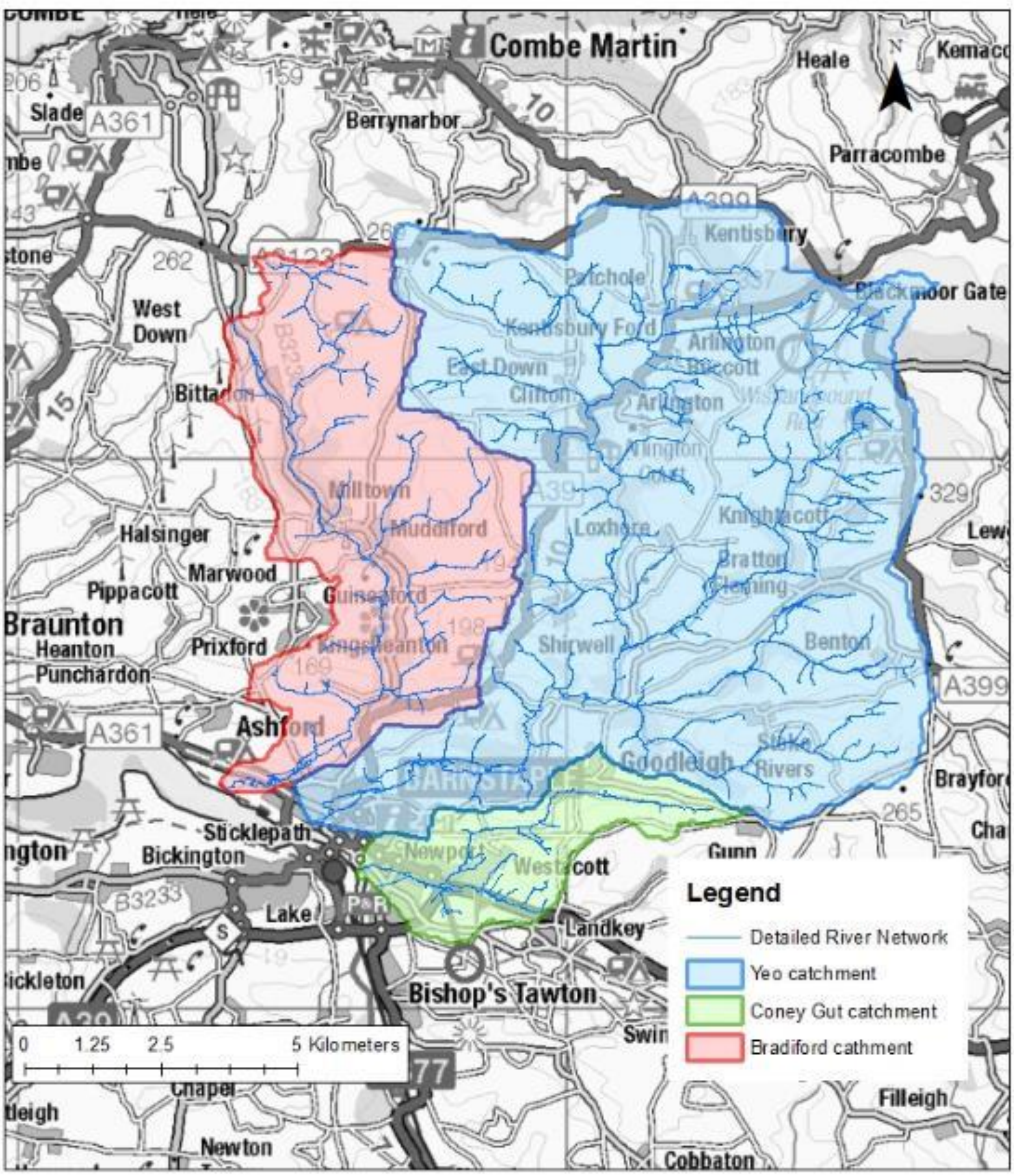

Figure 2-1: Contributing catchments

2.1.3 Surface water

Another significant source of flooding in Barnstaple is that of surface water, caused when the surface water (and combined) drainage systems are exceeded or rainwater cannot infiltrate due to saturated conditions This can cause overland flow, creating inundation problems especially in urban areas where impermeable surfaces exist.

This flood defence improvements study only focuses on fluvial and tidal sources, although will refer to surface water drainage issues where relevant.

2.1.4 Foul sewage flooding

The other potential source of flooding considered is that of foul drainage. During high rainfall conditions, foul drainage systems can become overwhelmed and can cause sewerage to back-up and cause drainage issues at a property level.

Again, foul sewage flooding is not considered within this study.

2.2 Pathways

From a fluvial perspective, the main pathway for flooding is floodplain conveyance following exceedance of channel capacity on the River Yeo, the Bradiford Water and the Coney Gut. Along the River Yeo the main areas of floodplain are immediately downstream of the A39 Bridge at Pilton Park, and upstream of the A39 road bridge in the area adjacent to Raleigh Road. Along the Bradiford Water corridor the main areas of floodplain conveyance are at the Pottington Business Park and areas of Bradiford. The Environment Agency Flood Map identifies large areas of developed land situated within the Coney Gut floodplain. A large proportion of this relates to the risk posed from tidal flooding but further upstream near Rose Lane and Eastern Avenue there are areas susceptible to fluvial flooding. There are two main tidal flood pathways, the first consists of overtopping of existing tidal defences along the banks of the River Taw which would only likely occur during extremely large events; current design standard of protection is mostly greater than 1 in 100 years. The second is tidal conveyance along the River Taw tributaries such as the Bradiford Water and the River Yeo. The Pilton Park area adjacent to the River Yeo is an area susceptible to tidal flooding, the main defences here being set back along Pilton Causeway at the back of the park. Mott Macdonald's 2009 Barnstaple 2D Modelling and Mapping Final Report outlines that Barnstaple is protected by a network of flood defences including raised earthen embankments, concrete flood walls and flapped outfalls. The report outlines:

- River Taw fluvial and tidal flood banks.
- 14 km of raised flood embankments and flood walls stretching from Tawstock upstream to Strand near the downstream boundary of the study area. Built/improved in 1984 to a 1 in 75 year standard of protection for the urban areas of Barnstaple, Sticklepath, Bickington and Bishops Tawton.
- Coney Gut Diversion Channel
- 1 km of tunnel to divert the majority of Coney Gut outfall into the River Taw at SS560322. Built in 1984 the tunnel was designed to a 1 in 100 year standard of protection for the urban areas of Newport, Barnstaple.
- Pilton Park Flood Embankments and secondary defence along Pilton Causeway.
- Raised earthen embankments, concrete walls and re-graded banks around Pilton Park by the National Rivers Authority, last improved in 1992 to provide a 1 in 100 year standard of protection for the residential areas and industrial units of Pilton.
- Bradiford Bypass Culvert
- Bypass culvert channel from SS5501934363 to SS5473934270 and associated flood walls around the depot at the downstream end to provide flood relief from high flows. Built in 2004 the bypass culvert has a 1 in 75 year standard of protection for Bradiford, Pottington and the A361.

There are a number of minor flood walls and embankments along all the tributaries in the study area owned by the Environment Agency, Local Authority and private owners. The majority of these defences are in place to protect properties from fluvial flooding although some locations such as Muddle Brook protect from tidal flooding along the Fremington watercourse.

2.3 Receptors

The principal receptors within the study area are the communities of Pottington, Pilton, and town centre Barnstaple, and the residential and commercial properties and infrastructure contained therein. Historically, there has been both fluvial and tidal flooding along the River Yeo, Bradiford Water and Coney Gut. The 2012 Flood Investigation Report (Devon County Council) indicates that in 1981 139 residential properties, 12 commercial properties and 1 industrial property were flooded in the areas of Lower Raleigh, Newport, Yeo Vale, Rolle Quay and Sticklepath. Furthermore, in 1984 between 150 and 200 properties were flooded in the areas of Pilton Park, Rolle Quay, Fairview, Mill Lane and Yeo Vale. Barnstaple also suffered flooding in 2000 with around 25 residential properties flooding in Sticklepath from surface water following heavy rainfall. Most recently in 2012, at least 5 properties were known to have flooded in Barnstaple from the River Yeo and the river came within 400mm of the top of flood defences at Raleigh Meadows. The Coney Gut also overtopped the bank along Rose Lane. The Bradiford Water also caused flooding of a few properties at Milltown and Muddiford, although the actual number of properties affected is unknown.

3 Hydraulic modelling and results processing

3.1 Sources of information

An existing Environment Agency (EA) hydraulic model of the Taw estuary and tributaries was the primary tool for the assessment. An initial review of this model and its results suggested the model would be an acceptable base for the modelling required for this study.

LiDAR with a resolution of 1m and 2m in both unfiltered (DSM) and filtered (DTM) formats were available for the entire study area. A review of the data indicated that the data were of high quality with no significant filtering issues identified. This data was used to replace existing LiDAR in the model to define key overland flow routes.

OS Master Map was provided for the study area. Master Map data were used to accurately locate the buildings on the floodplain and to assist in applying roughness values to floodplain features.

3.2 Hydraulic modelling

The EA hydraulic model provided was an ISIS-TUFLOW model. The scope of this study did not include for rebuilding of this model, and the initial review confirmed that the software packages used were suitable for delivering the aims to understand flood risk and to assess the suitability of different mitigation options. The 2D modelling approach, such as provided by TUFLOW, is the preferred approach for representing the floodplain particularly in urban areas where there may be complex overland flow routes. There are numerous floodplain features within the model extent which can impact on overland flow routes, including walls, roads and a railway line embankment. ISIS is used to represent the 1D river channel and hydraulic structures within the study area.

The original model was produced in 2008; since then ISIS and TUFLOW have both had a number of updates. The model has utilised recent versions of both sets of software:

- TUFLOW 2013-12-AB-iDP-w64
- ISIS 3.7

3.3 Approach for baseline and options testing

3.3.1 Baseline Model

The model has been updated to include the most recently flown LIDAR and up to date OS Master Map which is used to represent flood plain roughness. The use of these updated data types ensures that any 2d flow routes impacting on the Barnstaple flood zones are represented as best as possible.

The fluvial and tidal boundary conditions have been updated to ensure most recent hydrological approaches have been included.

Peak tidal levels for a range of return periods were taken from the South West Estuary Extremes dataset from the Environment Agency for the downstream extent of the model at Yelland. A tidal profile was developed incorporating tidal surge and astronomical tide and scaled to give the design peak water levels required. These tidal profiles are applied as the downstream boundary of the hydraulic model.

Flow node data has been provided for this project from the Environment Agency from the Devon Hydrology Strategy. To determine the updated inflows to be input into the model the flow node location have been matched to the corresponding model inflow boundary for each watercourse and a multiplication factor was applied to the existing hydrographs. The existing hydrograph profiles had to be used as the flow nodes provided only included peak flow estimates.

The EA provided model incorporated a large selection of watercourses, more than was required for the purpose of investigating the designated flood cells. Due to the model encompassing such a wide area and including so many watercourses the model run times were extremely long; some fluvial model simulations took as long as 45 hours to complete. To address this the Fremington watercourses and the Venn Stream were removed from the model as they did not impact on the designated flood cells. The extent of the River Taw was also reduced.

Figure 3-1 shows the 2D model domain and the modelled watercourses of the River Taw, the River Yeo, the Bradiford Water, and the Coney Gut. To obtain a stable and robust model the Coney Gut watercourse was removed from the overall Barnstaple model and kept as a separate model. This enabled work to stabilise and improve the Coney Gut model to be carried out much more quickly and easily. With the models set up in this way all simulations for the tidal and fluvial events for present day and future climate change scenarios ran successfully.

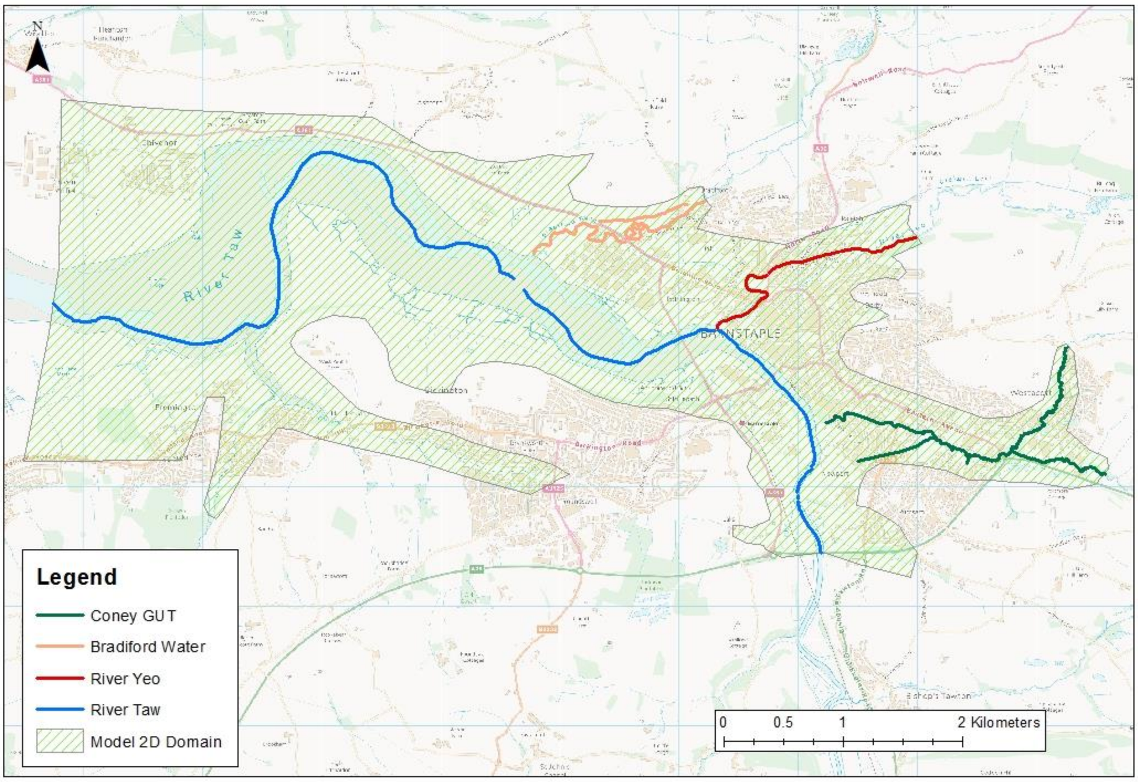

Figure 3-1: Modelled watercourses with 2D domain boundary

Likely changes to sea levels and river flows as a result of climate change is a key part of this study. The National Planning Policy Framework technical guidance on climate change has been applied to the modelling. This gives a 20% increase in river flows for 2045, 2075 and 2115 and increases in sea levels by 0.20m from 2015 to 2045, 0.51m from 2015 to 2075 and by 1.06m from 2015 to 2115. The modelling has been undertaken for 2015, 2075 and 2115. The 2045 horizon has not been modelled but has proved useful to consider in some areas.

The current condition of existing defences has been assessed from the Environment Agency's asset information dataset (AIMS). This showed that all are considered to be in at least a fair condition (condition grade 1-3). The one exception to this is immediately upstream of Rolle Bridge on the River Yeo in front of the new flats in flood cell B where the sheet piling is given a condition grade 4 (poor).

Defences of lower standards have a much increased probability of failing before they are overtopped which is not assessed in this study. An important assumption of the study is therefore that defences are maintained during the study period 2015 to 2115.

AIMS data is also attributed with elevations and a very simple assessment of the standard of protection of tidal defences has been made by comparing these levels with the tidal levels in Barnstaple in 2015 and 2115. This shows that in 2015 the majority of the tidal defences have a 0.1% AEP standard of protection (i.e. will not be overtopped in a 0.1% AEP event not including freeboard). By 2115 many of the defences will likely be overtopped every year.

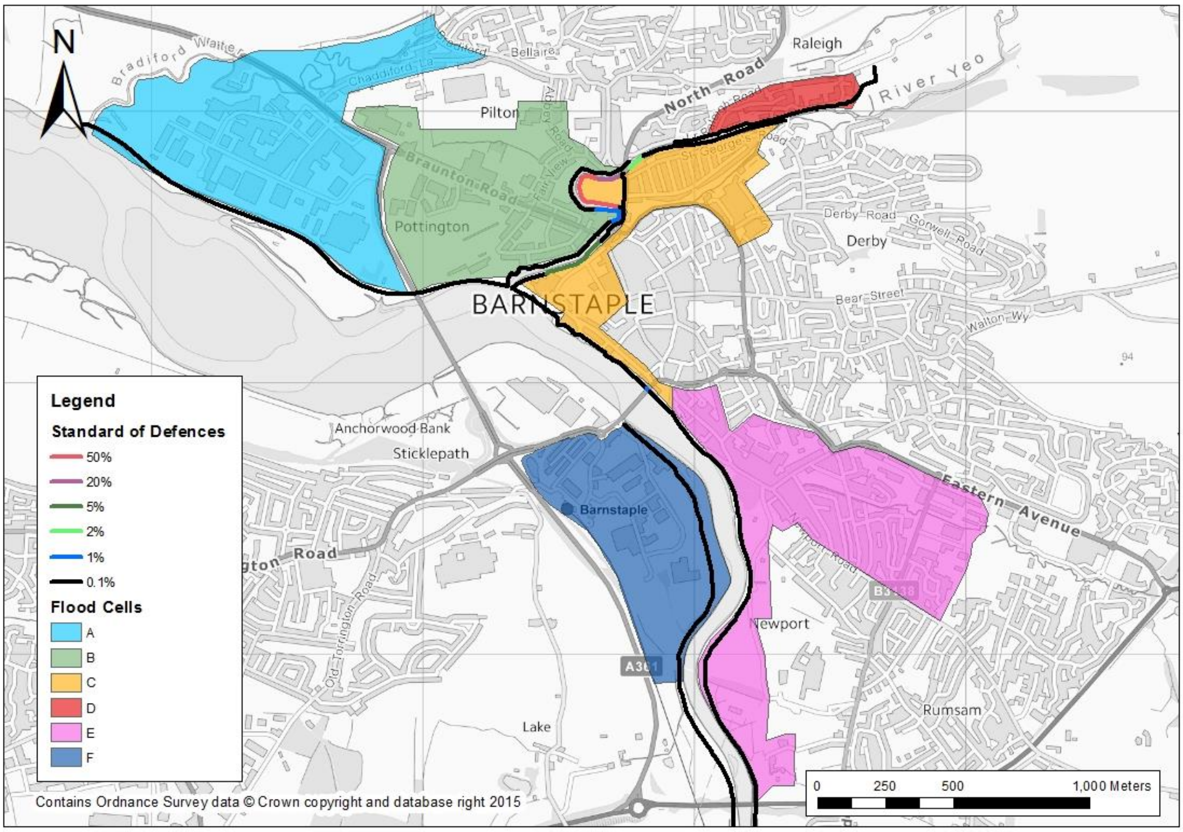

Figure 3-2: Standard of Protection for existing tidal defences in 2015

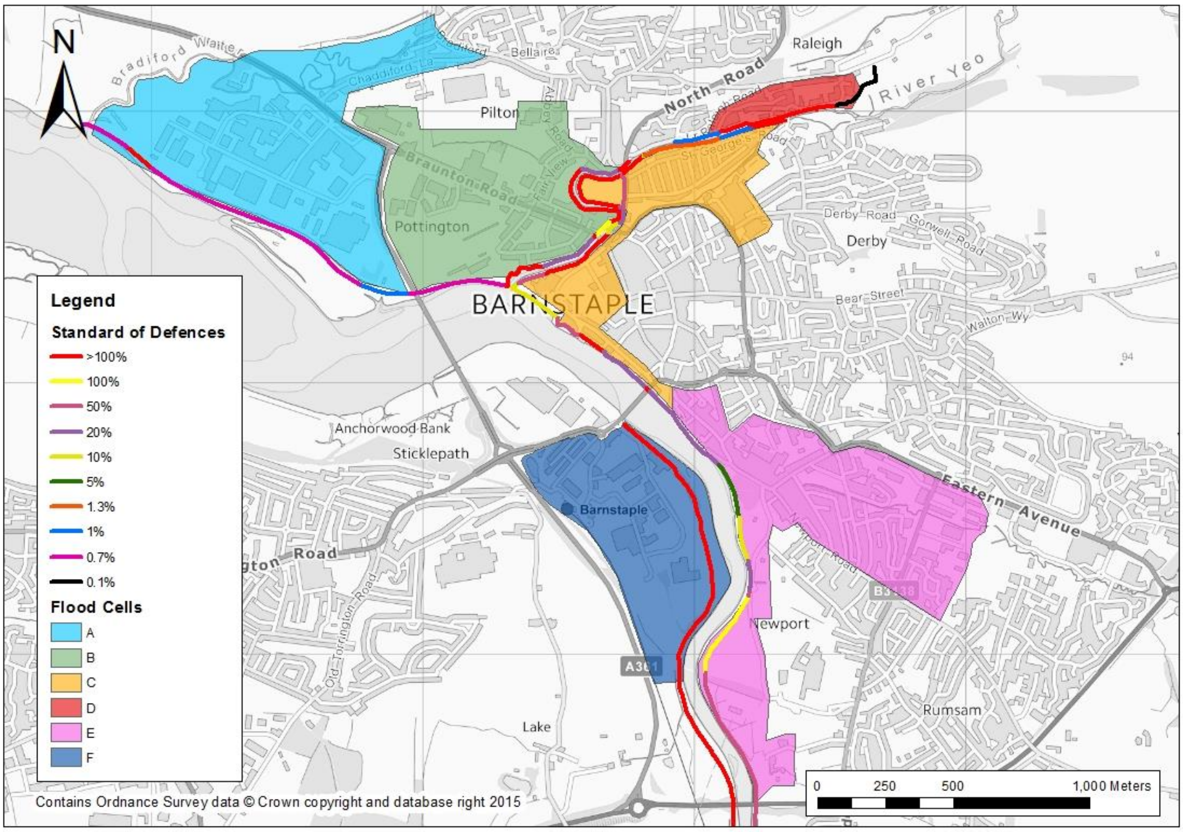

Figure 3-3: Standard of Protection for existing tidal defences in 2115

Note: These figures are derived using Environment Agency defence level data from the AIMS database. There may be some discrepancies between this and the model results which uses different bank level data.

3.3.2 Option Testing

Once the baseline model that encompasses flood cells A-D ran through successfully, the model was used to test as selection of options designated following a meeting with North Devon council and Devon County Council. Even though the model run times had been reduced due to the removal of some of the watercourse it was not feasible to run the options for each flood cell separately. It was therefore decided to combine the proposed options into two options.

The options have been modelled by using a selection of z-lines to either represent raised ground of a proposed formal defence or to increase the standard of protection of a current formal defence. In the model the defences were raised to a level where they would not be overtopped. Using this approach enables the user to look at the water levels for a certain event and identify what defence level would be required to protect against that event. The impact of the options on flood risk to third parties can also be considered.

3.4 Limitations

Developing a hydraulic model requires the application of simplifications and generalisations. As such a number of assumptions are made when building and adapting the model, which can lead to subsequent limitations of the results.

The initial assumption that the EA provided model was in a suitable state to deliver the aims of the project became a serious issue early on in the model development stage. Once the updated LIDAR and Master Map had been included in the model it was run to identify any difference in the model results. The majority of these initial runs went unstable primarily associated with 1d instabilities or related to 1d-2d linking.

Analysis of the schematisation of the 1d ISIS model showed that a significant proportion of the model was outdated. The majority of structures contained within the model were represented using Bernoulli loss units. Even though this is not specifically wrong it is not regarded as best practice and most definitely limits the level of confidence in the reliability of the model to produce a good representation of the in channel flooding mechanisms. Unfortunately it was not within the scope of this project to update the structures so they would be correctly represented within the ISIS model.

The 1d analysis also identified that the 1d roughness has not been designated. Without having a clear representation of the in channel conditions the reliability of the results generated cannot be guaranteed.

Following analysis of the existing model survey it was evident that the model was missing structures especially along the Coney Gut watercourse. It is most likely that these were removed due to instabilities encountered especially at higher return periods.

The Coney Gut watercourse which directly impacts flood cell E has provided extensive difficulties during model development. Numerous adjustments to this modelled watercourse were made to try to improve stability for the largest fluvial flows and climate change scenarios.

Failure of defences has not been modelled in this study. As water levels rise and eventually overtop a defence the probability of the defence failing increases. Once a defence has failed the crest level is reduced, possibly significantly and the flood inundation behind it is likely much greater than that modelled by overtopping alone. Additional modelling could be undertaken to model the impact of defence failure and apply a probability to its occurrence based on fragility curves. However for a high level study like this and with overtopping mainly occurring so far in the future that level of detail is probably excessive.

Joint probability of fluvial and tidal events has not been assessed in any detail. Although tidal design events have been run with a small event river flow and vice versa no analysis or account has been taken of possible extreme events occurring together.

A potential limitation to the hydraulic modelling undertaken is the relatively small amount of updates to the original EA model. The inclusion of up to date LIDAR and Master Map to designate floodplain topography and roughness has been utilised but no additional survey has been acquired. Due to the lack of confidence in how some of the watercourses especially the Coney Gut have been schematised fresh survey would have been advantageous. For the purpose of this study this is not imperative and not within the scope of the project but it would have provided added confidence in the results simulated.

The changes made to the model have been specifically for this study and have involved removing large parts of the overall Environment Agency model. The final model produced is therefore not a direct update to the original Environment Agency model from 2009 and should not be used as such. For future work it is recommended that a more substantial overhaul of the Environment Agency modelling is undertaken, part of which may be to include some of the modifications made for this study.

3.5 Results processing

3.5.1 Model results

The main results from the hydraulic models that are used in the analysis are 2d grids of water depth and level. These are produced for all modelled scenarios.

The National Receptor Dataset (NRD) can be interrogated against the depth grids to give a water depth associated with every property for each model run in 2015, 2075 and 2115. This enables counts of the properties at risk and allows the calculation of economic damages.

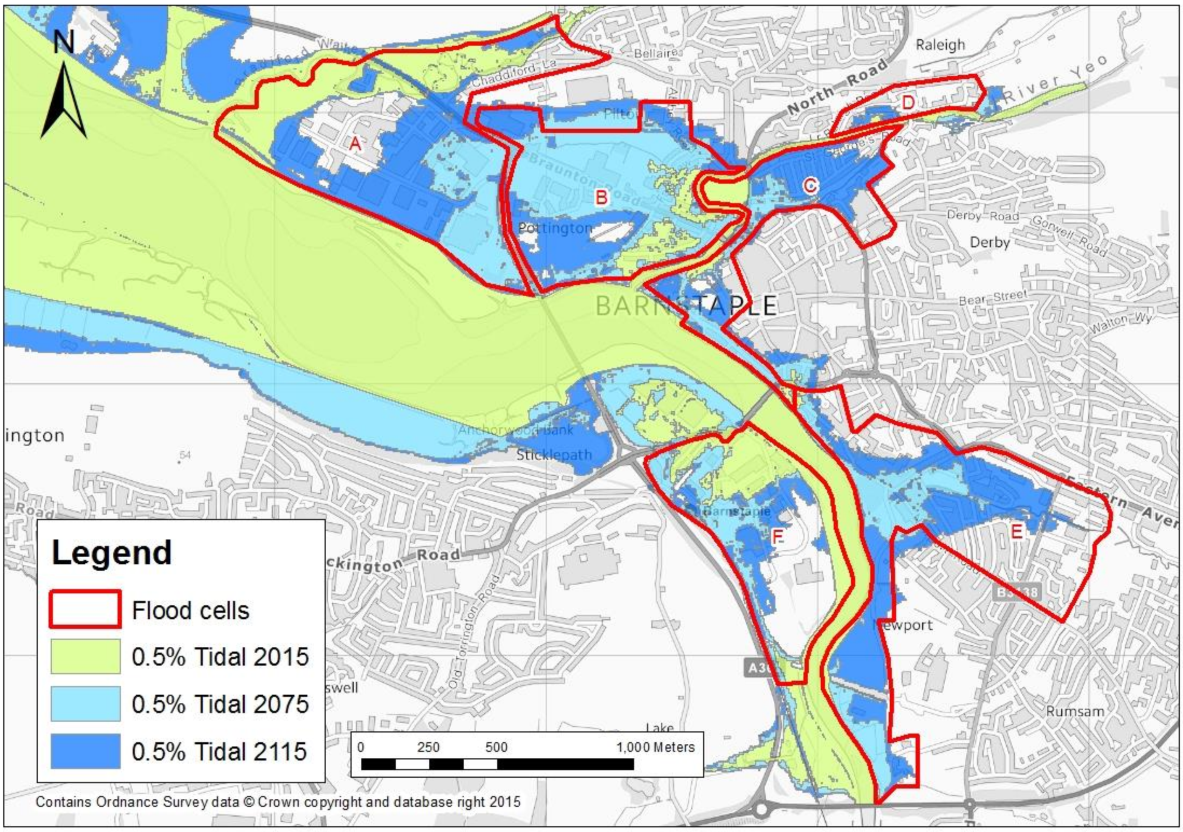

Figure 3-4: Tidal 0.5% AEP outline with existing defences in 2015, 2075 and 2115

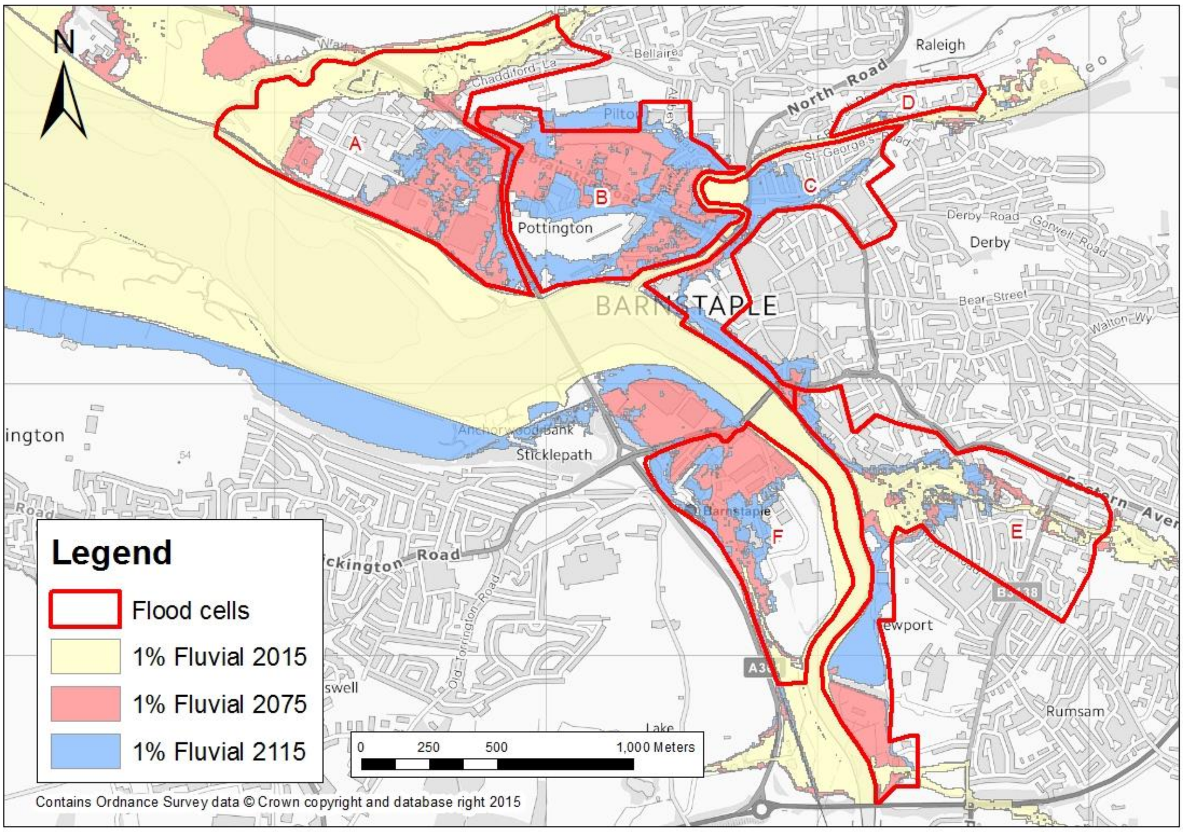

Figure 3-5: Fluvial 1% AEP outline with existing defences in 2015, 2075 and 2115

3.5.2 Economic damages

Economic damages have been calculated for all properties at risk using JBA's FRISM tool which implements the methods of the Multi-Coloured Manual. Given the strategic nature and timescales of the analysis the results should only be considered indicative. They will however give an indication of the economic benefit associated with improved flood defences and can be compared to likely costs of constructing improved flood defences.

Damages for individual properties are calculated for each flood event modelled. These are then aggregated into an Annual Average Damage (AAD) figure for each property. The AAD values are then converted to a Present Value Damages (PvD), assuming a 100 year calculation period, again per property and summed for a flood cell. The PvD is present day equivalent of 100 years' worth of damages at the estimated AAD. Given the nature of the assessment and the large changes being modelled occurring over 100 years the PvD is not an ideal mechanism but gives a simple single figure number for comparative purposes. The PvD of each property has been capped where it exceeds an approximate value of a residential property (assumed £200,000 for this assessment) or a commercial property (an estimate based on floor area and indicative rateable value). Present value benefits are calculated as the difference in the baseline scenario PvD and the option PvD. The present value benefits can be used in the cost benefit comparison. The 2075 and 2115 scenarios have damages and benefits calculated in the same manner as for 2015, essentially assuming they are present day, for comparative purposes. The estimation of damages carried out for this project uses the appropriate methods but is largely indicative, particularly for the future scenarios.

Comparison of option costs and the present value benefits can give an indication of likely viability of a scheme on economic grounds. Looking at this in 2075 and 2115 will also give an indication of when the investment may be required. If it appears that investment prior to 2075 is beneficial an indication whether this is likely before or after 2045 can be given (although this time scenario is not modelled). When required the 2045 damages have been estimated as the 2015 value plus 40% of the increase from the 2015 value to the 2075 value. The 40% reflects the sea level increase from 2015 to 2045 compared to that from 2015 to 2075. It is acknowledged that the change in sea level does not necessarily relate directly to damages but without modelling the scenario it gives an indication of what benefits in 2045 might be.

4 Discounted options

Options for reducing flood risk in Barnstaple in future have been considered. The following options were discussed amongst the project team, and considered not suitable to take further to the options stage.

4.1 Do nothing

In a heavily populated area such as Barnstaple doing nothing in the face of increasing flood risk due to climate change is not an option. A failure to invest in the existing defence assets would result in a significant deterioration in their condition increasing the risk of a breach during a large event. Many areas of Barnstaple are at levels significantly below the defence heights and a breach of the defences would be catastrophic and would have the potential to result in loss of life as well as significant damage to property and infrastructure.

4.2 Do minimum – maintain existing flood risk management practices

With the predicted increase in sea levels over the next hundred years just maintaining the current standard of flood protection is not an option. A failure to improve the defences would result in a significant increase in both the frequency of flooding, the resultant damages from a flood event, as well as increasing the risk of experiencing loss of life.

Do minimum may however be appropriate to continue until such time as a structural defence option becomes viable.

4.3 Demountable defences

These include flood gates, drop in defences, temporary flood walls and other temporary defences (e.g. water filled tubes). These are not feasible options due to the requirements for a permanent flood solution for Barnstaple.

4.4 River restoration

A restoration project would be limited in terms of quantifiable benefits to flood risk mitigation and would only affect the fluvial flooding element of the flood cells in the study area.

4.5 Tidal barrier

This is not a feasible option due to the proximity to the Site of Special Scientific Interest (SSSI) and the fact that the only feasible location would be beneath the A361 crossing which would not protect flood cell A. It would be an extremely high cost option and could only be considered if no other options existed for the other flood cells. A tidal barrier would also present issues in regard to navigation rights which would have to be addressed if it were to be considered.

4.6 Source control measures

These include upland catchment land management and retrofitting of Sustainable Drainage Systems (SuDS) in the urban areas. The flood risk management benefits are very difficult to quantify and they do nothing to alleviate tidal flood risk. Source control measures are being considered by the Lead Local Flood Authority (Devon County Council) and local planning authority (North Devon District Council) on a case by case basis with respect to planning applications. The Coney Gut catchment is a Critical Drainage Area (CDA) and apply higher standard to SUDS.

4.7 Increasing channel capacity

Dredging or channel widening are unsuitable due to the tidal nature of flood risk; increasing channel capacity will do nothing to reduce flood water levels due to the volume of tidal water. Widening of the channel in an urban environment presents difficulties regarding relocation of property, therefore this option would be overly costly when compared to its lack of benefit. Dredging is not a permanent solution and will require regular works to maintain the channel at its dredged capacity, as well as the issues regarding disposal of dredged material. In addition the environmental impacts of dredging or channel widening of the SSSI would need to be fully understood and it is unlikely that would prove acceptable.

4.8 Removal / adaptation of restrictive hydraulic structure at a strategic level

Due to the prevalent tidal flood risk, removal of channel restricting hydraulic is not appropriate to reduce flood risk across the study area as a whole but if the modelling demonstrates that a specific structure or group of structures in a locality is having an adverse effect then the benefit of their removal could be considered on an individual basis.

4.9 Estuary management

Changes to the estuary would be difficult considering the presence of the SSSI and are unlikely to have any measureable benefit in regard to flood risk but some of the other defence options may require compensatory habitat and it may be possible to identify locations to within the estuary to provide this

5 Flood Cell A

5.1 Overview

Flood cell A comprises the westernmost part of the study area and includes the Pottington Business Park and residential properties along the Bradiford Water between Braunton Road and Poles Hill. The flood cell can be split into several distinct frontages:

1. River Taw from A361 to Bradiford Water Outlet
2. Bradiford Water through Nature Reserve
3. Bradiford Water along Chaddiford Lane
4. Bradiford Water along Meadow Road

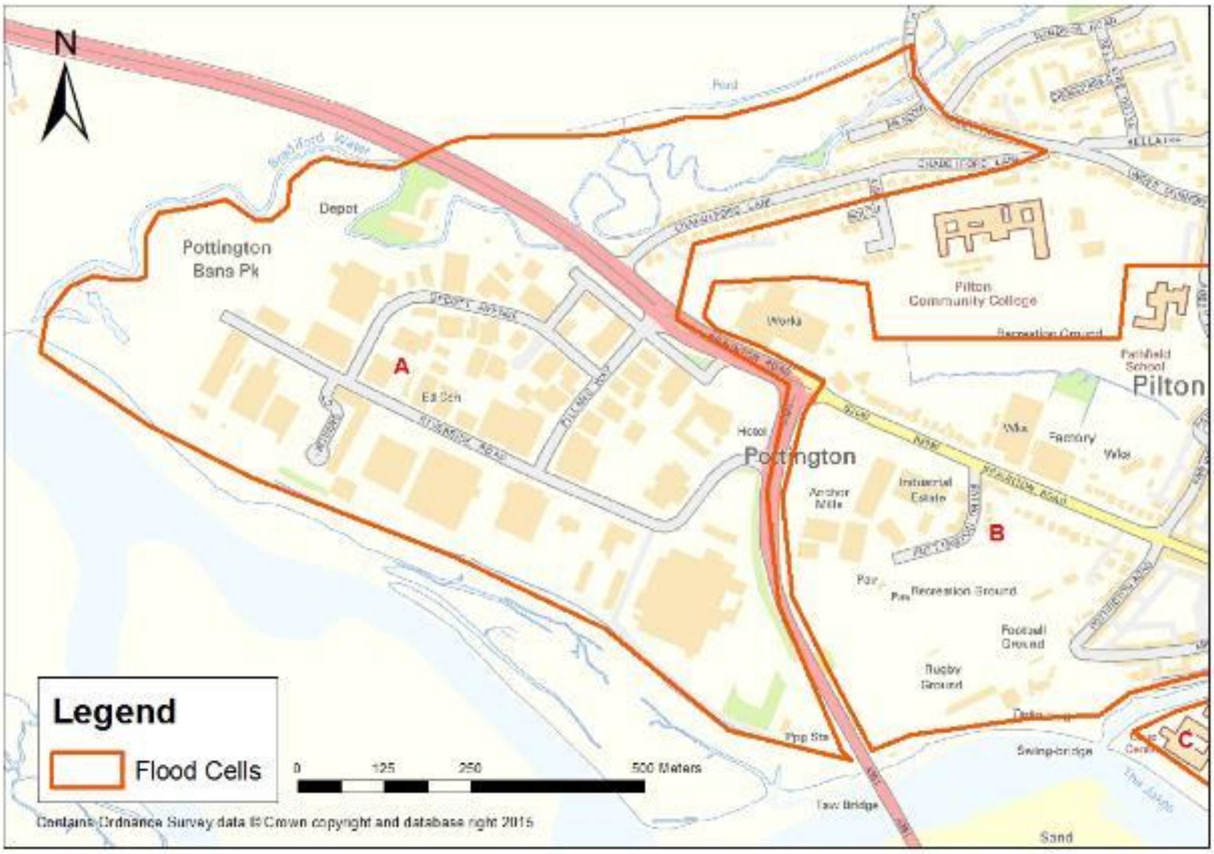

Figure 5-1: Flood zone A boundary

The main frontage is along the River Taw and the existing defence comprises a low height concrete flood wall on top of the disused railway embankment which is now used as the Tarka Trail (Figure 5-2). On the riverward side there is a concrete revetment which affords the embankment some protection (Figure 5-3).

Bradiford Water discharges through a flapped tidal outfall under the Taw defence embankment into the Taw estuary. The tide locked flows of Bradiford Water are a key source of risk in this flood cell.

Figure 5-2 Tarka Trail with concrete flood wall on right hand side

Figure 5-3 Concrete revetment forming bank of River Taw

There are no defences through the Bradiford nature reserve although the Pottington Business Park is elevated above the main reserve.

A number of the properties along Chaddiford Lane are protected by an earth bund running along the rear boundary of the properties.

In the vicinity of Meadow Road there are no formal raised defences although some properties are protected by walls along the channel. There is a low height earth embankment in front of the properties along the right bank of Bradiford Water adjacent to the Mill Leat. There is a formal diversion channel that takes some of the flow away from the residential properties in this area.

5.2 Baseline modelling results

The following tables summarise current and future (2075 and 2115) fluvial and tidal flood risks for flood cell A.

Table 5-1 Flood cell A: baseline tidal and fluvial flood risks

	2015			2075			2115		
	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure
Tidal (0.5% AEP)	0	5	0	0	40	2	12	122	9
Fluvial (1% AEP)	24	23	1	37	76	5	34	89	8

In 2015 flood risks are primarily fluvial and are spread along the length of Bradiford Water from Meadow Road to the outfall. Risks during a tidal event in 2015 are much lower and are from the tide locked Bradiford Water rather than from any direct tidal inundation.

In 2075 fluvial risk still predominate but tidal risks will have also increased. Fluvial risks are from both the tide locked Bradiford Water and flood waters coming from flood cell B (River Yeo). Tidal risk are increased by 2075 but this is not from direct overtopping within flood cell A but rather from overland flow from flood cell B.

By 2115 tidal risks are much greater as direct overtopping of the Taw embankment will start to occur as well as water coming from the tide locked Bradiford Water and from flood cell B. Fluvial risks also increase primarily due to increased overland flow from flood cell B. Importantly by 2115 9 critical infrastructure are shown to be at risk from tidal sources, and 8 from fluvial.

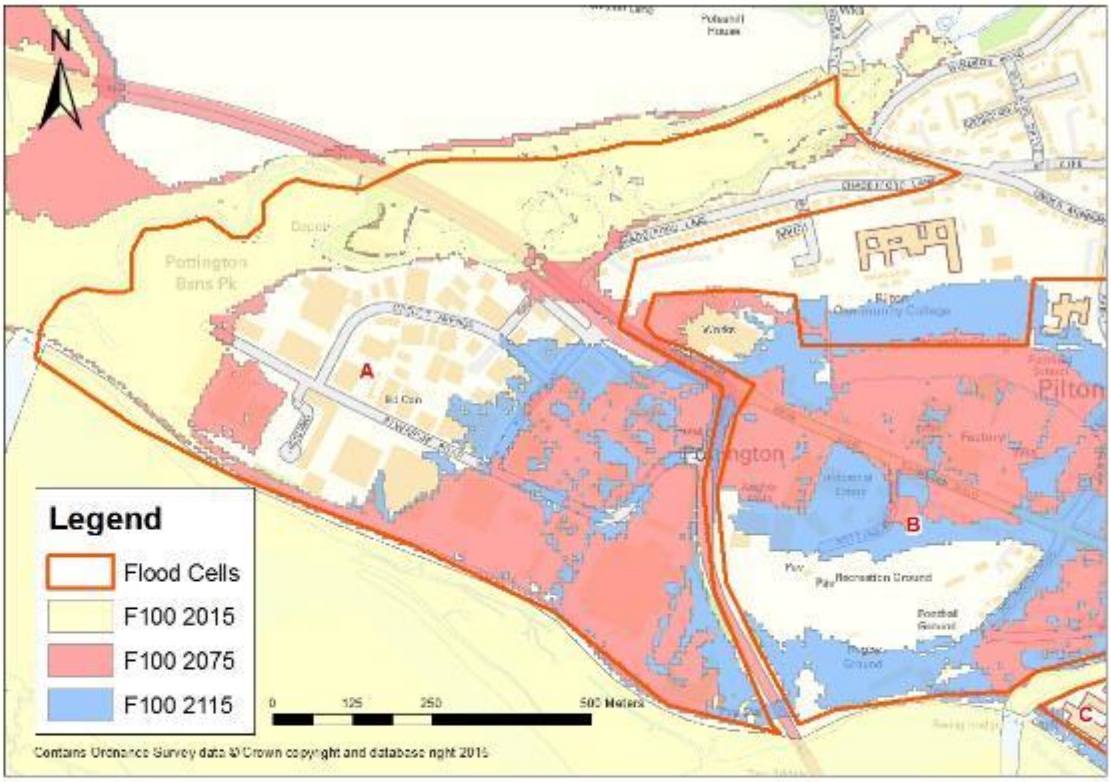

Figure 5-4 Flood cell A: baseline and future fluvial 1% AEP extents

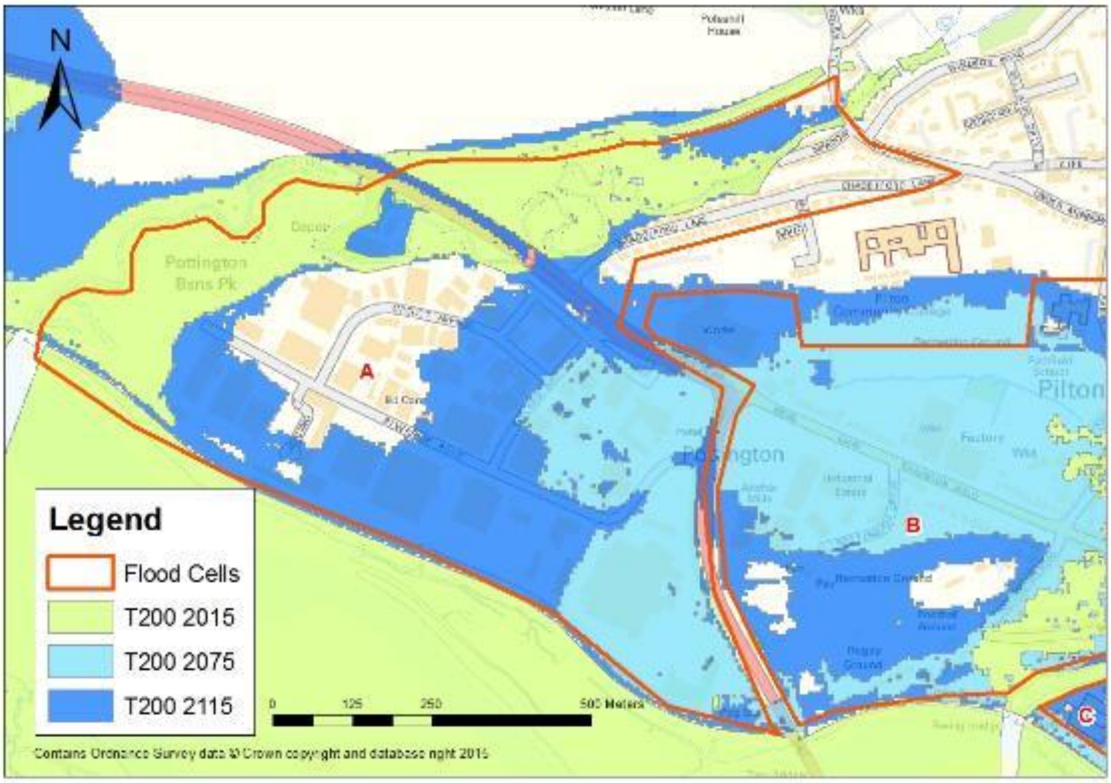

Figure 5-5 Flood cell A: baseline and future tidal 0.5% AEP extents

5.3 Long listed options

The long list technical report is provided in Appendix B, which provides a more detailed assessment of the benefits and disadvantages of each. The following is a summary of the options considered suitable of further consideration for the long term flood risk strategy for flood cell A:

- Piling - Piling is unlikely to be used along the Taw frontage as it would be prohibitively expensive and out of keeping with the existing defence. It is a possibility further upstream along the Bradiford Water where the proximity of properties to the watercourse could rule out other options.
- Revetments - There is an existing revetment within the flood cell but it does not form the primary defence. A revetment is only practical where there is the space to construct it, which rules out its use upstream along the Bradiford Water and limits it to the Taw frontage. If the revetment were to become the primary defence it could result in a narrowing of the Taw in order to achieve the desired height. It may be more appropriate to consider only using new revetments to replace those existing sections which require repairs or maintenance.
- Embankments - Embankments could be used in a number of the frontages for flood cell A as they are in keeping with the existing defences. The present frontage along the Taw (Tarka Trail) could be raised to form a larger embankment on which the cycle route and pathway could be retained. It would also be possible to continue the embankment around along the edge of the Bradiford Reserve. Further upstream the existing embankment along the back of Chaddiford Lane could also be raised although it may require some loss of the rear gardens to the properties. Embankments however are considered unsuitable for the area around Meadow Road.
- Flood walls - Flood Walls could be used throughout Flood Cell A as are easy to tie-in with other types of defence and the low land take means different alignment options are possible.
- Flood storage - Flood storage will only protect the properties along the Bradiford Water affected by fluvial flooding in large events or the combination of a more moderate event with tide-locking of the outlet. In these situations if can be effective but it requires a suitable area of land on which to store the floodwater and enough capacity to retain it for the duration of the event or tide-locking. The storage option for this flood cell could protect properties along the Bradiford Water but it is likely that any storage would need to be constructed outside of the flood cell upstream of Bradiford. It is possible that this could benefit properties outside of the flood cell.
- Flood resilience - Flood resilience is something that should be incorporated in any new development coming forward within the flood cell but it is not something that should be relied on to protect all properties at risk. It is considered that there may be some properties in the Meadow Road area that it could be beneficial for particularly if no alternative options prove feasible.
- Relocation of properties at risk - Relocation of at risk properties is very much an option of last resort where no other option is feasible and the severity of flooding is beyond what flood resilience measures can protect against. There may be properties in the Meadow Road area where this could be required.

5.4 Short list decision making

Having reviewed the sources of flood risk, the receptors at risk now and in the future, the options for flood cell A were short listed as follows:

- Raising of A361 and cycle track north towards Pilton Community College to prevent connectivity of flood cells A and B in extreme future flood events
- Embankment / land raising around edge of Bradiford Nature Reserve to prevent inundation of the Pottington Business Park
- Property level protection (PLP) for properties at risk in Meadow Road area
- Replace the existing tidal defences over time to meet required standards

The tidal influence along the Taw frontage in flood cell A meant that no other suitable option existed, other than repairing and maintaining the existing tidal defence. This is important given the results which show significant tidal inundation between 2075 and 2115. This would also ensure that the Tarka Trail can remain, providing an important tourism feature to the area. Extending a raised defence around the edge of the Pottington Businss Park would ensure that tidal inundation is restricted to the nature reserve, and also any fluvial flows which are tide-locked and back-up on the Bradiford Water do not cause flooding to the commercial premises. Importantly, the flood modelling has shown that in future (2075 and onwards) there is a risk of fluvial flooding from the River Yeo to the west in flood cell B. There is also a flow path shown along Braunton Road by 2115. Therefore a raising of the A361 and cycle track to the north is deemed appropriate.

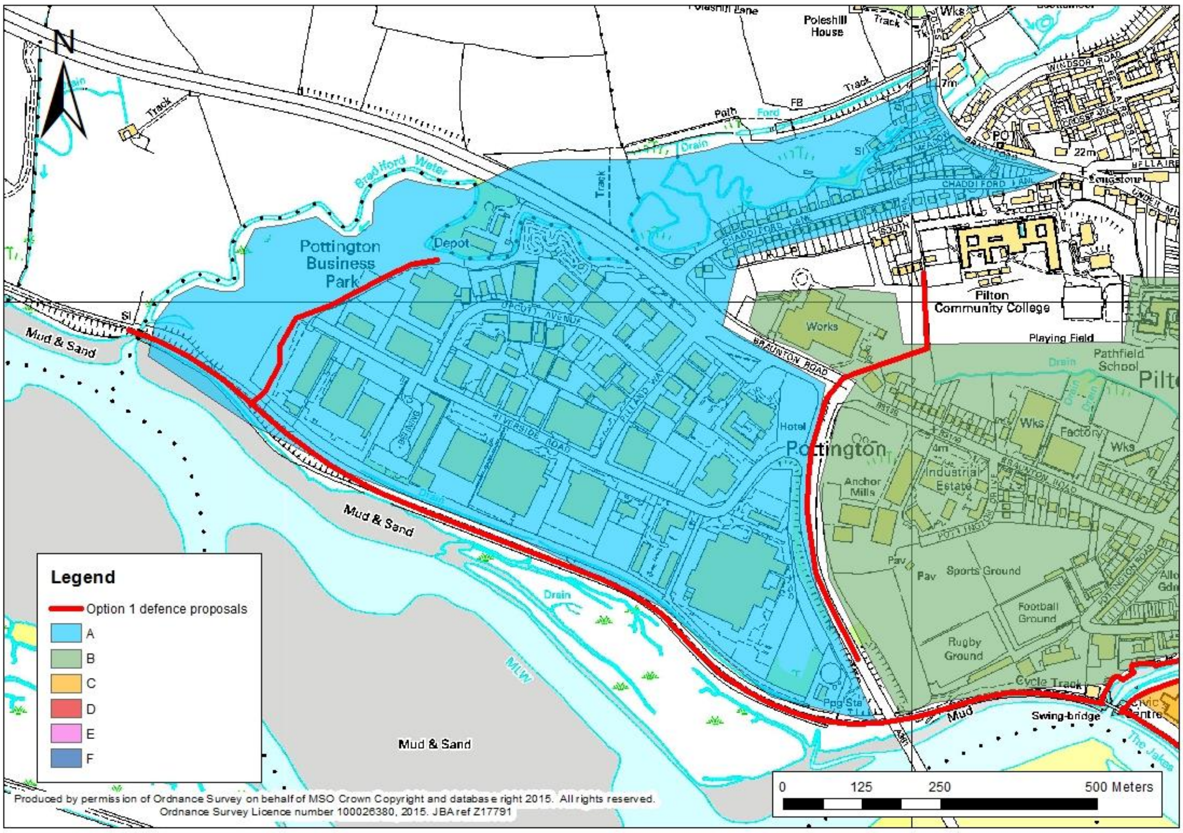

Figure 5-6 Flood cell A: options locations

5.5 Results

5.5.1 Number of properties at risk

Table 5-2 Flood cell A: Future flood risks with proposed flood defence options

	2015			2075			2115		
	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure
Tidal (0.5% AEP)	0	5	0	0	5	0	6	24	0
Fluvial (1% AEP)	24	23	1	30	12	0	30	12	0

Some residual risk will remain with the defence options but far fewer properties are at risk than in the baseline scenario.

Residual fluvial risks in this flood cell in 2075 and 2115 shown in the table above are the number of residential properties at risk along Meadow Road. These are identified for PLP rather than a flood defence scheme, hence still appearing in the property count.

Additional residual risks are also shown in extreme scenarios from the tide locked Bradiford Water flowing onto the A361 and into the industrial estate. This flow route is entirely determined by assumptions for tidal level increases and fluvial flows so is relatively uncertain. Curtailing this flow route would require additional works to raise the A361.

5.5.2 Economic damages

Tidal damages in flood cell A in 2015 are very low but increase to £2.7M in 2075 and up to £35M by 2115. The vast majority of tidal damages are from non-residential properties. Benefits from the defence option mirror the damages closely at around £2.7M in 2075 and £34M in 2115.

Table 5-3 Flood cell A: Present value damages for tidal flood risk now and with proposed flood defence options

	Baseline PvD Tidal (£k)			Future PvD with Options (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Total	Total
2015	£0	£58	£58	-	-	-	-
2075	£0	£2,727	£2,727	£0	£58	£58	£2,669
2115	£453	£34,996	£35,449	£254	£933	£1,187	£34,262

Fluvial damages in flood cell A are significant in the 2015 scenario at around £4.5M but these double by 2075 and more than five times greater by 2115.

The benefits of flood defences in 2075 are estimated as around £1.7M. This does not take into account Property Level Protection on residential properties so there is potential for additional benefits. The bulk of the benefits calculated are for non-residential properties. By 2115 the benefits have increased to over £17M which are again predominantly non-residential.

Table 5-4 Flood cell A: Present value damages for fluvial flood risk now and with proposed flood defence options

	Baseline PvD Fluvial (£k)			Future PvD with Options (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Total	Total
2015	£1,662	£2,927	£4,590	-	-	-	-
2075	£3,018	£5,846	£8,864	£3,651	£3,513	£7,164	£1,700
2115	£2,667	£23,997	£26,663	£4,890	£4,748	£9,637	£17,026

The proposed defence scheme gives greater benefits in relation to tidal flooding, in particular from non-residential properties. However, more residential properties in this flood cell are at fluvial risk. The defence option proposed should deal reasonably well with both types of flooding but a residual risk remains which may need additional PLP measures to address.

5.5.3 Environmental assessment

Flood defence options for flood cell A mostly present risks to biodiversity, given the proximity of the Taw-Torridge SSSI and Bradiford Reserve. Raising the A361 and the embankment around Bradiford Reserve present a risk to biodiversity through the loss of habitat. Raising the embankment around Bradiford Reserve could cause the permanent loss of important habitat, particularly at the southern end of the embankment, where it could impact on the Taw-Torridge Estuary SSSI. Repairing the existing defences also presents a risk to the Taw-Torridge SSSI, particularly if construction encroaches into the river channel and construction materials are released into the aquatic environment. The release of construction materials has the potential to contaminate the surface water, conflicting with the Water Framework Directive (WFD) for the Taw Estuary. These options would need to apply construction best practice and seasonal constraints to avoid significant negative effect on the features of the SSSI and surrounding habitat. There could be an adverse effect on population if the South West Coast Path is damaged or closed during repair of the coastal defences. However, if mitigation measures are implemented and the path remains open, the disruption effects are likely to be low. A detailed Environmental Report is provided in Appendix D.

5.6 Engineering summary

5.6.1 Raising of A361 and cycle track north towards Pilton Community College

The existing defence levels are between 3.66mAOD and 12.30mAOD. A design level of 6.90mAOD has been set using the modelling outputs plus a 150mm freeboard allowance. Therefore, 7.05mAOD has been used as the final defence level.

The A361 and cycle path to the north are to be raised to the design level. This will require large scale highways regrading works, as well as an embankment for the cycle path. The largest raise will be where the lowest existing levels are; at the junction between B3149 and A361, which are in the vicinity of 3.66mAOD.

There are a number of technical risks identified and elements to consider with this solution, including works to the A361, unknown ground conditions, contaminated land, construction accessibility, services information, and health and safety. These are documented in Appendix C.

5.6.2 Embankment / land raising around edge of Bradiford Nature Reserve

The existing defence levels are between 6.33mAOD and 7.02mAOD. A design level of 6.90mAOD has been set using the modelling outputs plus a 300mm freeboard allowance. Therefore, 7.20mAOD has been used as the final defence level.

The proposed embankment will be constructed between the Pottington Business Park and Bradiford Nature Reserve. The embankment will require the following:

- Maximum gradient of side slopes 1:3;
- Minimum crest width 1m to allow maintenance (non-vehicular), in line with the recommendations in the Levee Handbook[4];
- Impermeable core material; and
- A flow path cut off will be included.

The crest may be raised by increasing the height of the embankment; should structural stability allow it. Allowances for future increases in height (up to an additional 500mm) should be taken into account during the detailed design stage

There are a number of technical risks identified and elements to consider with this solution, including unknown ground conditions, contaminated land, construction accessibility, services information, and health and safety. These are documented in Appendix C.

5.6.3 Repair and maintenance to existing tidal defence

A design level of 6.90mAOD has been set using the modelling outputs plus a 150mm freeboard allowance. Therefore, 7.05mAOD has been used as the final defence level.

The ideal option is to construct a new flood wall on the line of the existing defence. Based on the EA Design Guidance a reinforced concrete core and foundation wall is considered as the most technically viable solution. The wall foundation will include a shear key to improve sliding resistance and to increase the flow path for potential flood water. It is envisaged that the wall will be clad with either bricks or stone, dependent on the local planning authority requirements. It should be noted that if a concrete flood wall is unfeasible, possibly due to ground conditions, then a steel sheet pile wall could be utilised instead.

There are a number of technical risks identified and elements to consider with this solution, including unknown ground conditions, contaminated land, construction accessibility, services information, and health and safety. These are documented in Appendix C.

5.7 Cost and benefits

In 2015 the PvD (fluvial) is in the order of £4.5M which is of similar magnitude to the overall option costs so as a whole unlikely to be realisable in the short term. However, considering fluvial issues alone the damages are around £1.7M and costs associated with residential protection (PLP) around Meadow Road are relatively low. As such there is a case to consider PLP at Meadon Road in the short term. Fluvial commercial benefits are less likely to be achieved in the short term given the costs involved with building the new embankment adjacent to Bradiford Water. Tidal 2015 damages are very low.

By 2075 the PvD values are £8.9M fluvial and £2.7M tidal however the benefits of the proposed scheme are in the order of £2.6M fluvial and £1.7M tidal. There remain quite substantial damages being incurred even with the scheme in place. Residential damages can be reduced to some extent by PLP scheme for properties around Meadow Road. There remains some flooding of commercial properties in the larger events with the option in place which reduces benefits. Given the costs are almost as high as the damages (ignoring that benefits may be lower than damages) there is little economic case for undertaking structural works in flood cell A by 2075.

By 2115 however, benefits have increased to around £17M (fluvial) or £34M (tidal) and are now several times greater than the likely scheme costs. The majority of the benefits are in relation to commercial properties. The benefit cost ratio in this flood cell is unlikely to be sufficient to attract full funding so partnership funding is likely to be required. The commercial property holders may be a source of partner funding for flood defences in this flood cell.

[4] The International Levee Handbook, CIRIA, 2013

Table 5-5 Flood cell A: Capital costs and future PvB

	Tidal		Fluvial	
	Low cost	High cost	Low cost	High cost
Capital costs (£k)	2,508	4,671	2,508	4,671
Costs including capital costs, 20% preliminaries and 60% optimism bias (£k)	4,815	8,968	4,815	8,968
Present value benefits 2075 (£k)	£2,669		£1,700	
Present value benefits 2115 (£k)	£34,262		£17,026	

5.8 Flood Cell A proposed outcomes

The proposed outcomes and timescales for Flood Cell A are as given in Table 5-6. The main structural defence options will not be viable until beyond 2075. However, locally around Meadow Road there are significant fluvial damages in 2015 and the case for PLP for these properties should be considered now.

Table 5-6 Flood cell A: Proposed outcomes and timescales

Timescale	Actions	Comment
2015 to 2045	Do Minimum, except consider PLP to residential properties in Meadow Road area.	Benefits are low overall, however there are residential benefits that could be realised locally.
2045 to 2075	Do Minimum, except consider PLP to residential properties in Meadow Road area if not already done so.	Benefits are low overall, however there are residential benefits that could be realised locally.
2075 to 2115	Implement remaining proposed defences.	Options become financially viable now that existing defence levels are more vulnerable to overtopping.

There is some interaction of flood extents and a defence join between flood cell A and flood cell B. Raising of A361 and cycle track north towards Pilton Community College should prevent connectivity of flood cells A and B in extreme future flood events. Tidal defences under the A361 Bridge will change from flood cell A to flood cell B. The design level for the tidal frontage is the same for both.

The Do Minimum option to continue inspection and maintenance to retain or improve defence condition should be continued for all existing defences as these are assumed to remain in place. If an opportunity arises to improve defence standard for some or all of the flood cell earlier than described, e.g. through redevelopment of a site, this should be taken and defences raised to the appropriate design level described for 2115 (generally). The remainder of the flood cell defences can then be added at an appropriate time.

The timing of the actions is largely down to the predicted rate of sea level rise over the next 100 years. This needs to be monitored and the actions and timings reviewed if changes to the assumed rates are apparent.

6 Flood Cell B

6.1 Overview

Flood cell B comprises Pottington and the southern part of Pilton. It extends along the River Taw from the A361 crossing to the outfall of the River Yeo and along the right bank of the River Yeo from the River Taw through Pilton Park to Pilton Quay. The flood cell is predominantly at risk from a tidal event although a small area in Pilton Park is at risk from fluvial flooding. The flood cell can be split into several distinct frontages:

1. River Taw from A361 to River Yeo
2. River Yeo from River Taw to Rolle Street Bridge
3. River Yeo from Rolle Street Bridge to Pilton Quay

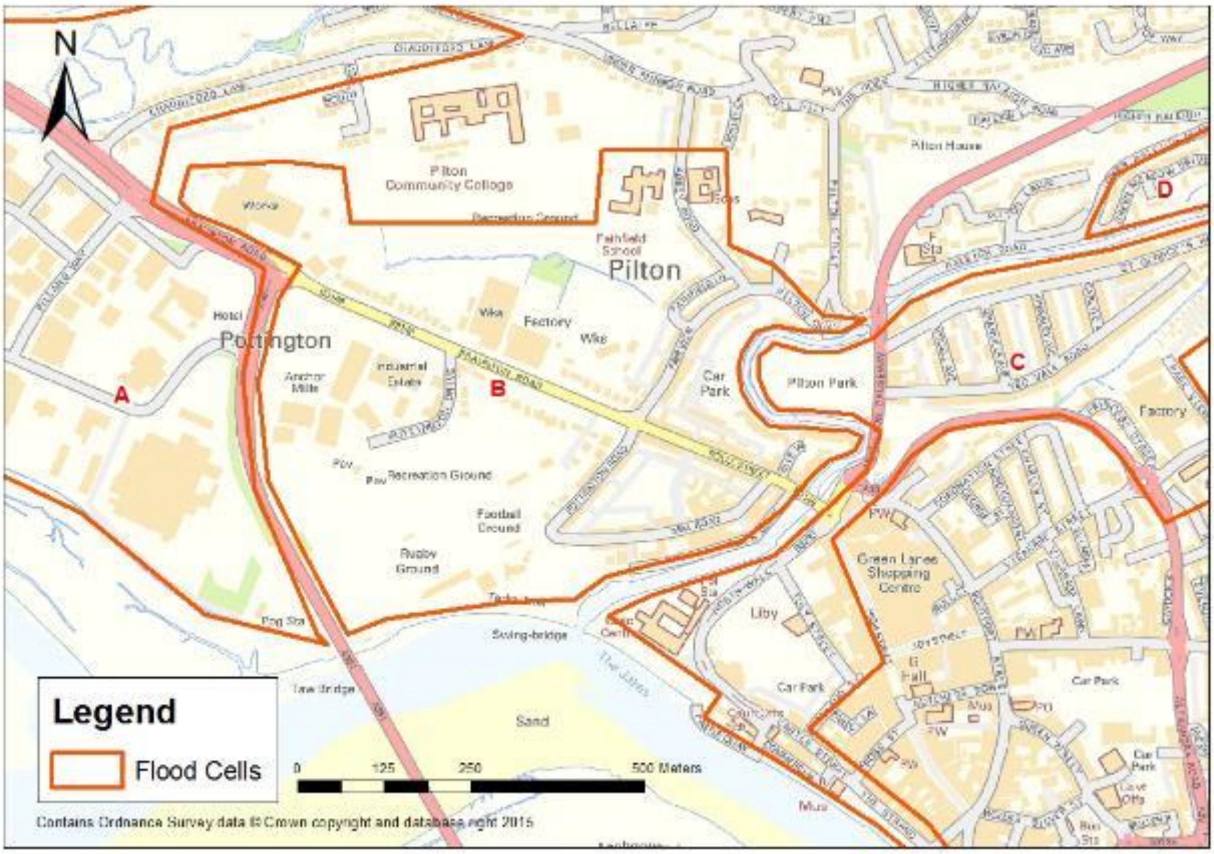

Figure 6-1: Flood zone B boundary

The frontage along the River Taw is similar to flood cell A and the existing defence comprises a low height concrete flood wall on top of the disused railway embankment which comprises the Tarka Trail (Figure 6-2). This runs from the swing bridge and continues as part of the same defence in Flood Cell A. There is a small break in the defence for access to a building on the riverward side just upstream of the A361 crossing. On the riverward side there is a concrete revetment which affords the embankment some protection (Figure 6-2).

Defences along the right bank of the River Yeo are variable. There is a relatively undefined section between the swing-bridge and Rolle Quay. Rolle Quay was rebuilt in the 1980s and comprises a substantial flood wall protecting the properties behind. Upstream of Rolle Street Bridge the new development is protected by a combination of steel sheet piles and concrete flood walls. Moving upstream through Pilton Park, the defence comprises a very steep embankment with gabion baskets protecting the toe. When the embankment finishes a masonry clad flood wall continues protecting the properties along Pilton Quay.

Figure 6-2 Tarka Trail with concrete flood wall on right hand side

Figure 6-3 Concrete revetment forming base of River Taw

Figure 6-4 Embankment in Pilton Park

6.2 Baseline modelling results

The following tables summarise current and future (2075 and 2115) fluvial and tidal flood risks for flood cell B.

Table 6-1 Flood cell B: baseline tidal and fluvial flood risks

	2015			2075			2115		
	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure
Tidal (0.5% AEP)	74	55	0	442	165	8	506	198	11
Fluvial (1% AEP)	0	0	0	108	79	4	460	180	9

In 2015 flood risks are only from a tidal source, with overtopping of the existing tidal defences likely at Rolle Quay and in Pilton Park in a 0.5% AEP tidal event.

By 2075 there will be a very significant increase in both fluvial and tidal flood risks in flood cell B as existing defences become overtopped. Over 600 residential and commercial properties are at risk of tidal flooding, and 187 from fluvial (note that the same property could be at risk from both sources). Very large parts of Pilton and Pottington will be at risk of overtopping of the existing defences, causing not only a high hazard to people but also extremely high direct and indirect economic damages.

By 2115 tidal risks are still likely to be very high, but there will be an increase in fluvial flood risks to commercial and residential properties as the existing defences along Rolle Quay and through Pilton Park are further overtopped.

It should also be noted the condition of the flood embankment on the right bank of the River Yeo opposite Pilton Park is a cause for some concern. The modelling has assumed that this embankment will overtop but not fail. If embankment condition is poor then it could be prone to failure before overtopping occurs, or fail during an overtopping event that could significantly increase risk behind it. While this is not specifically captured in the modelling it is a relevant factor when considering when defences may need improving.

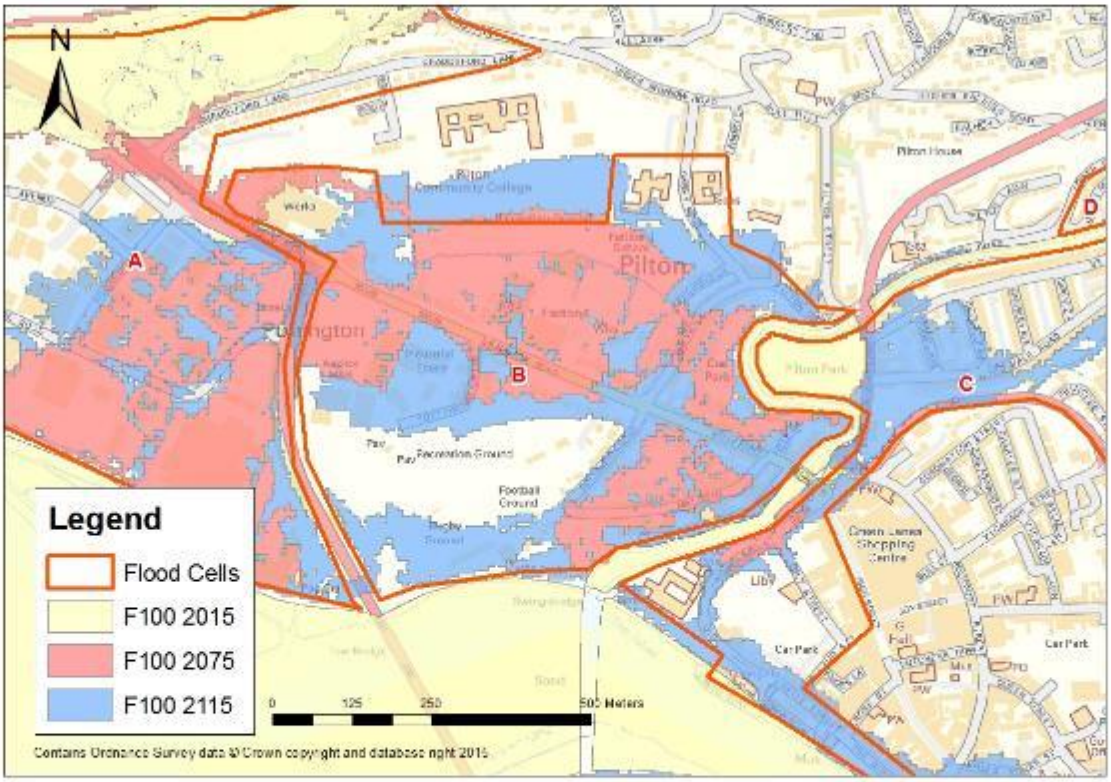

Figure 6-5 Flood cell B: baseline and future fluvial 1% AEP extents

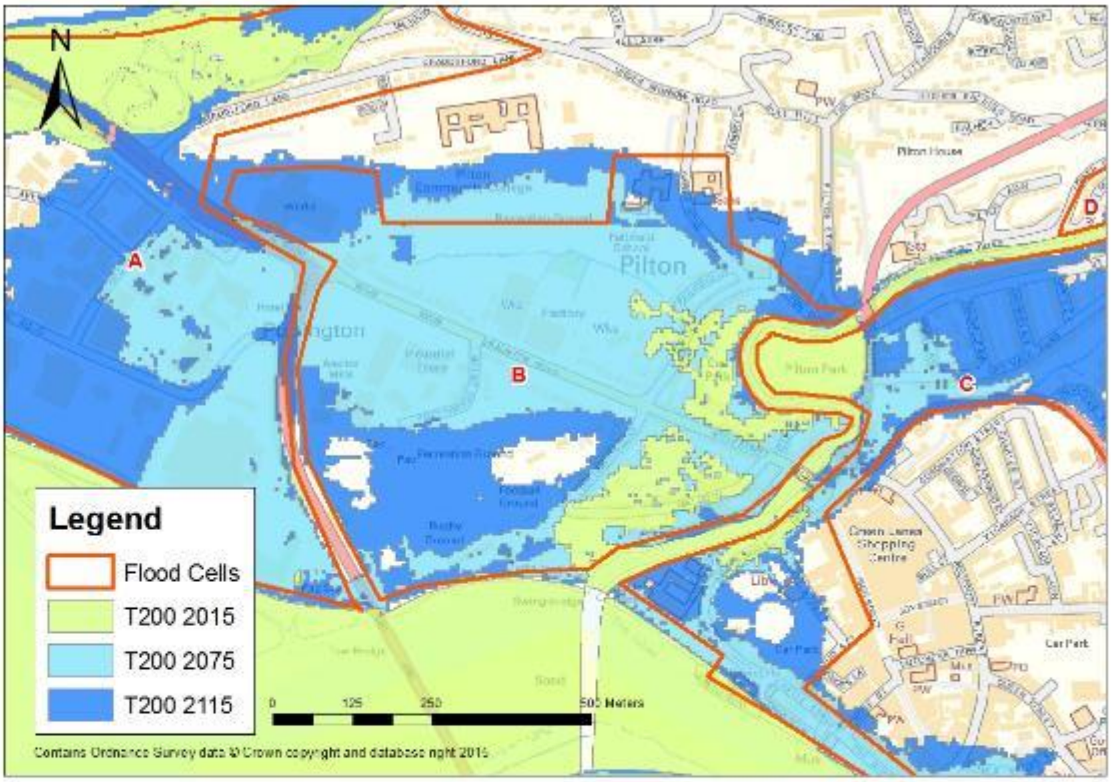

Figure 6-6 Flood cell B: baseline and future tidal 0.5% AEP extents

6.3 Long listed options

The long list technical report is provided in Appendix B, which provides a more detailed assessment of the benefits and disadvantages of each. The following is a summary of the options considered suitable of further consideration for the long term flood risk strategy for flood cell B:

- Piling - Piling is unlikely to be used along the River Taw frontage as it would be prohibitively expensive and out of keeping with the aesthetics of the existing defences along the River Taw. On the other hand, there is existing piling along the River Yeo, and its constrained location makes it ideal for piling.
- Re-routing of River Yeo - It has been considered that south of Pilton Quay the River Yeo could be re-routed from its current course around Pilton Park, to follow a more direct route along the A39 Pilton Causeway, instead of piling around the greater length of Pilton Park. This would open up the park and existing car parking area.
- Revetments - There is an existing revetment within the flood cell but it does not form the primary defence. A revetment is only practical where there is the space to construct it which rules out its use upstream along the River Yeo and limits it to the Taw frontage. If the revetment were to become the primary defence it could result in a narrowing of the Taw in order to achieve the desired height. It may be more appropriate to consider only using new revetments to replace those existing sections which require repairs or maintenance.
- Embankments - Embankments could be used in a number of the frontages for flood cell B as they are in keeping with the existing defences. The present frontage along the Taw (Tarka Trail) could be raised to form a larger embankment on which the cycle route and pathway could be retained. The existing embankment around Pilton Park, on the River Yeo, could also be raised. Embankments are considered to be unsuitable for the area around Rolle Quay due to the constrained location of the frontage.
- Flood walls - Flood walls are an ideal solution for both the River Taw and River Yeo frontages. Flood Walls are easy to tie-in with other types of defence and the low land take means different alignment options are possible. Walls can easily be combined with existing defences, such as to raise the crest of an existing embankment (geotechnical

capacity permitting). Compared to sheet piles, flood walls can be more aesthetically pleasing and can be finished to match the existing style of the surrounding area.

- Flood resilience - Flood resilience is something that should be incorporated in any new development coming forward within the flood cell but it is not something that should be relied on to protect all properties at risk. It is considered that it could be beneficial to retrofit, particularly if no alternative options prove feasible.
- Relocation of properties at risk - Relocation of at risk properties is very much an option of last resort where no other option is feasible and the severity of flooding is beyond what flood resilience measures can protect against.

6.4 Short list decision making

Having reviewed the sources of flood risk, the receptors at risk now and in the future, the options for flood cell B were short listed in to two options, as follows:

Option 1

- Raising of A361 and cycle track north towards Pilton Community College to prevent connectivity of flood cells A and B in extreme future flood events
- Raised wall along Rolle Quay
- Increased parapet (or gates) along Rolle Street Bridge to prevent out-flanking in extreme future flood events
- Piling around existing course of Taw through Pilton Park
- Replace the existing tidal defences over time to meet required standards

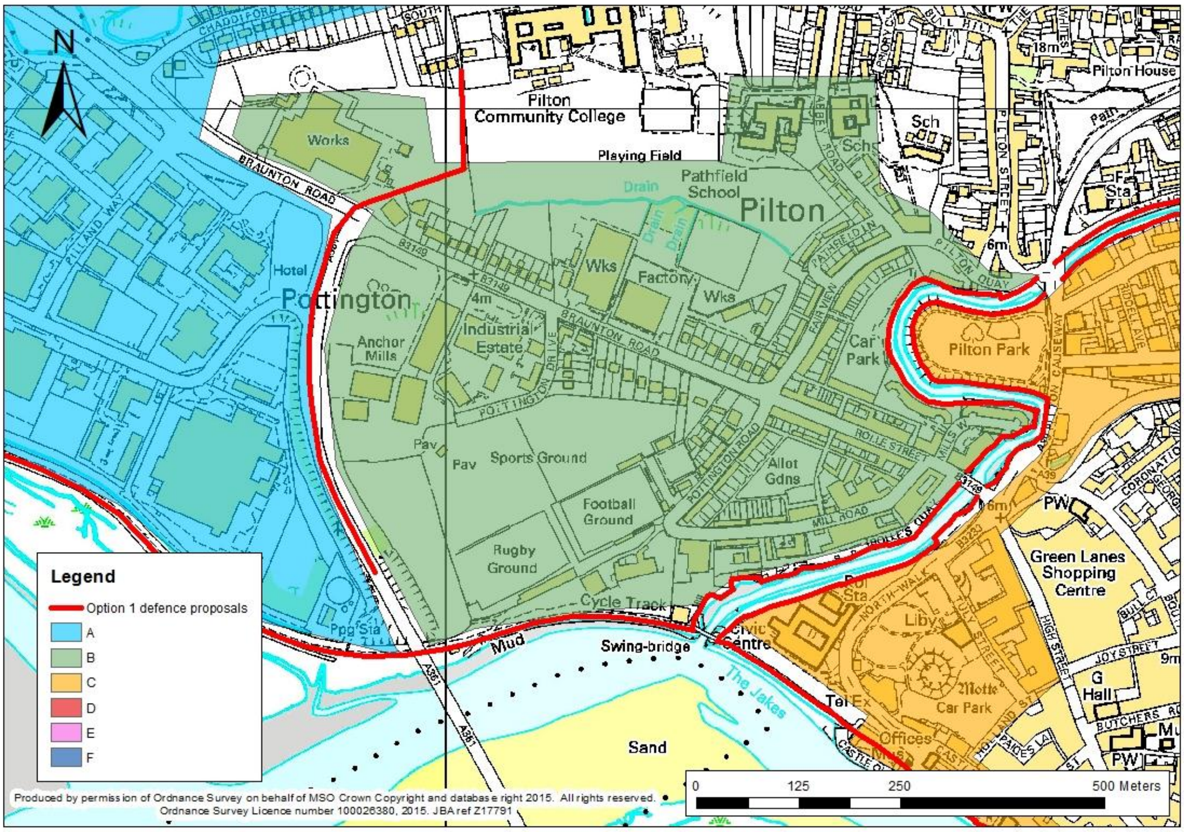

Figure 6-7: Flood Cell B: option 1 locations

Option 2

- Raising of A361 and cycle track north towards Pilton Community College to prevent connectivity of flood cells A and B in extreme future flood events
- Raised wall along Rolle Quay
- Increased parapet (or gates) along Rolle Street Bridge to prevent out-flanking in extreme future flood events

- Re-routing of Taw along A39 Pilton Causeway instead of piling around the existing course of the Taw through Pilton Park
- Replace the existing tidal defences over time to meet required standards

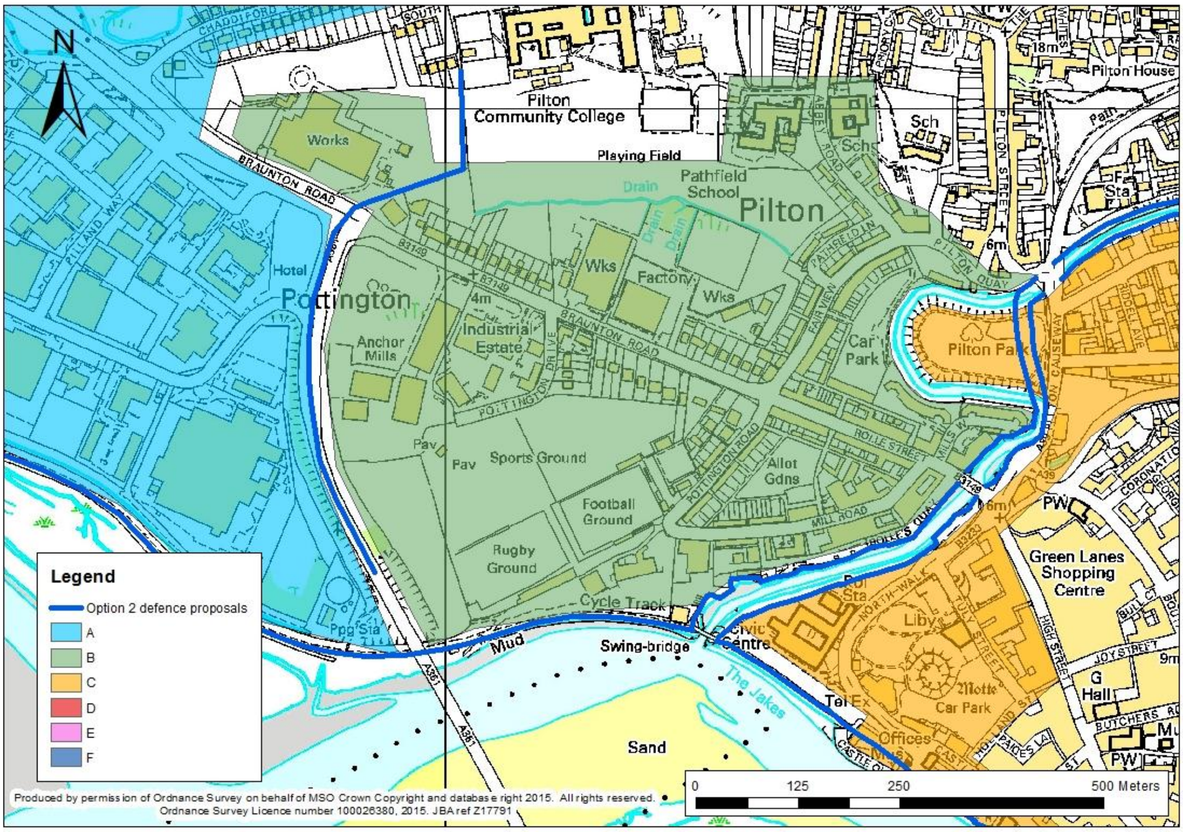

Figure 6-8: Flood Zone B option 2 locations

The tidal influence along the Taw frontage in flood cell B meant that no other suitable option existing, other than repairing and maintaining the existing tidal defence. This would also ensure that the Tarka Trail can remain, providing an important tourism feature to the area. Importantly, the flood modelling has shown that in future (2075 and onwards) there is a risk of fluvial flooding from the River Yeo, extending through Pilton and Pottington. As with flood cell A it was deemed appropriate to include in the options for raising of the A361 and cycle track to the north. The most significant increase of fluvial and tidal flooding in future is around Pilton Park, where existing sheet piling and embankments exist. These would need to be replaced and increased in future to appropriately manage the increase of risk, but as an alternative as option was considered which re-routes the River Yeo along the A39 Pilton Causeway. This was intended to allow comparison of risks and costs for both options.

6.5 Results

6.5.1 Number of properties at risk

Table 6-2 Flood cell B: Future flood risks with proposed Option 1

	2015			2075			2115		
	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure
Tidal (0.5% AEP)	74	55	0	0	0	0	0	4	0
Fluvial (1% AEP)	0	0	0	0	0	0	0	0	0

Table 6-3 Flood cell B: Future flood risks with proposed Option 2

	2015			2075			2115		
	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure
Tidal (0.5% AEP)	74	55	0	0	0	0	0	4	0
Fluvial (1% AEP)	0	0	0	0	0	0	0	0	0

With both options the very significant increase in fluvial and tidal flood risks in the future can be managed to a very low level. There are shown to be a residual risk to four commercial properties at risk in 2115 from tidal sources; this are in fact located in the western-most part of flood cell B, and to the west of the proposed raised cycle track. The risk to these properties is from tidal inundation back along the Bradiford Water.

6.5.2 Economic damages

Economic damages have been calculated to assist in the cost benefit assessment. Flood cell B has very large calculated damages for future flood events, tidal in particular, and capping of the damages has been extensively applied in this flood cell to limit the damages to more realistic levels.

Tidal damages in flood cell B in 2015 are modest at £1.2M showing there is some degree of risk with current defences. Damages rise greatly to £69M in 2075 and up to £101M by 2115. The majority of tidal damages are from residential properties. Benefits from the defence option mirror the damages closely at around £69M in 2075 and £101M in 2115 and both options give the same benefits.

Table 6-4 Flood cell B: Present value damages for tidal flood risk now and with proposed option 1

	Baseline PvD Tidal (£k)			Option 1 PvD Tidal (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Total	Total
2015	£800	£395	£1,195	-	-	-	-
2075	£56,875	£11,763	£68,638	£0	£0	£0	£68,638
2115	£78,561	£22,551	£101,112	£0	£22	£22	£101,090

Table 6-5 Flood cell B: Present value damages for tidal flood risk now and with proposed option 2

	Baseline PvD Tidal (£k)			Option 2 PvD Tidal (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Total	Total
2015	£800	£395	£1,195	-	-	-	-
2075	£56,875	£11,763	£68,638	£0	£0	£0	£68,638
2115	£78,561	£22,551	£101,112	£0	£22	£22	£101,090

Fluvial damages in flood cell B are in the region of £3.8M in 2015 and this will increase significantly to £29M and above £94M by 2115. Both proposed options provide very similar fluvial benefits of around £27M in 2075 and £92M in 2115.

Table 6-6 Flood cell B: Present value damages for fluvial flood risk now and with proposed option 1

	Baseline PvD Fluvial (£k)			Option 1 PvD Fluvial (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Total	Total
2015	£1,569	£2,227	£3,795	-	-	-	-
2075	£22,259	£7,130	£29,389	£885	£1,294	£2,179	£27,210
2115	£76,131	£18,299	£94,430	£936	£1,433	£2,369	£92,062

Table 6-7 Flood cell B: Present value damages for fluvial flood risk now and with proposed option 2

	Baseline PvD Fluvial (£k)			Option 2 PvD Fluvial (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Total	Total
2015	£1,569	£2,227	£3,795	-	-	-	-
2075	£22,259	£7,130	£29,389	£885	£1,288	£2,173	£27,216
2115	£76,131	£18,299	£94,430	£936	£1,425	£2,361	£92,070

The proposed defence scheme gives greater benefits in relation to tidal flooding although both fluvial and tidal pose very significant risks in flood cell B. The defence option proposed should deal effectively with both types of flooding.

6.5.3 Environmental assessment

Increasing the height of the defences along Rolle Quay carry a risk to visual amenity, particularly if the defences increase to a height which disrupts views. This in turn could cause a degradation in the setting of Castle Mount, a scheduled monument. Construction could also have a temporary adverse effect on the setting of this scheduled monument.

Piling through Pilton Park carries a significant risk to biodiversity, as Pilton Park is a key habitat site within Barnstaple, and significant habitat is present in the River Yeo. Piling may significantly damage the aquatic ecology of the River Yeo and also remove vegetation around the edge of the park. Piling also presents a significant risk to surface water and groundwater, as it could mobilise contaminated materials. Construction best practice and seasonal constraints will need to be applied to minimise the risk to biodiversity and surface water, particularly those risks to otter, which have been observed in the River Yeo.

Re-routing the River Yeo would have significant adverse effects on biodiversity, as important habitat will be permanently lost with this option. The change in the hydromorphology and ecology of the river may conflict with the River Yeo's WFD objectives, and could also risk the river becoming a Heavily Modified Water Body (HMWB).

Both piling and re-routing the River Yeo could also significantly change the historic setting and landscape character of the area, potentially having a negative effect on the listed buildings and Pilton conservation area. There is potential for the infilling of the channel associated with the re-routing the River Yeo, thereby potentially increasing the area of public open space.

6.6 Engineering summary

6.6.1 Raising of A361 and cycle track north towards Pilton Community College

A design level of 6.90mAOD has been set using the modelling outputs plus a 150mm freeboard allowance. Therefore, 7.05mAOD has been used as the final defence level.

The A361 and cycle path to the north are to be raised to the design level. This will require large scale highways regrading works, as well as an embankment for the cycle path. The largest raise will be where the lowest existing levels are; at the junction between B3149 and A361, which are in the vicinity of 3.66mAOD.

There are a number of technical risks identified and elements to consider with this solution, including works to the A361, unknown ground conditions, contaminated land, construction accessibility, services information, and health and safety. These are documented in Appendix C.

6.6.2 Raised wall along Rolle Quay

The existing defence levels are between 5.94mAOD and 7.85mAOD. A design level of 6.90mAOD has been set using the modelling outputs plus a 150mm freeboard allowance. Therefore, 7.05mAOD has been used as the final defence level.

The flood wall will be constructed on the existing defence line. Based on the EA Design Guidance a reinforced concrete core is considered as the most technically viable solution. It is envisaged that the wall will be clad with either bricks or stone, in keeping with the style of the existing walls. Maintenance of the existing walls should be undertaken as part of this option.

There are a number of technical risks identified and elements to consider with this solution, including unknown connection with existing defences, ground conditions, contaminated land, construction accessibility, services information, and health and safety. These are documented in Appendix C.

6.6.3 Increased parapet (or gates) along Rolle Street Bridge

The existing defence levels are between 5.94mAOD and 7.85mAOD. A design level of 7.10mAOD has been set using the modelling outputs plus a 150mm freeboard allowance. Therefore, 7.25mAOD has been used as the final defence level.

A solid concrete parapet is proposed, which will act as a flood wall. This will stop water from the River Yeo overtopping the bridge during a flood event. However, this will result in a larger head loss across the bridge, resulting in higher water velocities through the bridge. Consequently, additional scour protection may need to be provided.

Alternatively, the defence will consist of either a demountable flood wall or flood gates across the Rolle Street bridge. A demountable flood wall will require provision of built in foundations; columns may be either permanent or temporary. Wall panels must be stored near to the site to reduce risk of delays once the decision has been made to construct the defence or be suitably robust to remain in place. Instead of a demountable flood wall, flood gates may be utilised. The gates will be required to be designed such that they perform in a similar manner to lock gates; the pressure of the flood water forces the gates closed to affect a good seal. The gates will have seals and a solid surface such as steel should be utilised on the ground to ensure a watertight closure.

There are a number of technical risks identified and elements to consider with this solution, including parapet containment level, scour protection, connection with existing defences, construction accessibility, services information, and health and safety. These are documented in Appendix C.

6.6.4 Piling through Pilton Park

The existing defence levels are between 5.94mAOD and 7.85mAOD. A design level of 6.90mAOD has been set using the modelling outputs plus a 150mm freeboard allowance. Therefore, 7.05mAOD has been used as the final defence level.

Piling through the Pilton Park embankment crest would require that the piles are of sufficient length whereby two thirds of the total pile length is below the surface. Corrosion resistance is advised, using protective coatings. The highest thickness available should be used to enable the design life required from the piles.

There are a number of technical risks identified and elements to consider with this solution, including unknown connection with existing defences, ground conditions, contaminated land, construction accessibility, services information, and health and safety. These are documented in Appendix C.

6.6.5 Re-routing the River Yeo along A39 Pilton Causeway

The existing defence levels are between 5.94mAOD and 7.85mAOD. A design level of 7.10mAOD has been set using the modelling outputs plus a 150mm freeboard allowance. Therefore, 7.25mAOD has been used as the final defence level.

The proposed re-routing of the River Yeo will follow the line of Pilton Causeway, with a new sheet piled wall providing the flood defence. This will require excavations to form the new channel, with the possibility of an embankment against the sheet piled wall to soften the appearance from the Pilton Park side.

Piling through Pilton Park to form a new channel would require that the piles are of sufficient length whereby two thirds of the total pile length is below the surface. Corrosion resistance is advised, using protective coatings and cathodic protection (sacrificial anodes will be applied to the sheet piles). A full corrosion assessment combined with structural analysis should be undertaken to determine the necessary pile thickness to enable the proposed design life.

There are a number of technical risks identified and elements to consider with this solution, including unknown connection with existing defences, ground conditions, contaminated land, construction accessibility, services information, and health and safety. These are documented in Appendix C.

6.6.6 Repair and maintenance of existing tidal defences

The existing defence levels are between 5.94mAOD and 7.85mAOD. A design level of 6.90mAOD has been set using the modelling outputs plus a 150mm freeboard allowance. Therefore, 7.05mAOD has been used as the final defence level.

The ideal option is to construct a new flood wall on the line of the existing defence. Based on the EA Design Guidance a reinforced concrete core and foundation wall is considered as the most technically viable solution. The wall foundation will include a shear key to improve sliding resistance and to increase the flow path for potential flood water. It is envisaged that the wall will be clad with either bricks or stone, dependent on the local planning authority requirements. It should be noted that if a concrete flood wall is unfeasible, possibly due to ground conditions, then a steel sheet pile wall could be utilised instead.

There are a number of technical risks identified and elements to consider with this solution, including unknown ground conditions, contaminated land, construction accessibility, services information, and health and safety. These are documented in Appendix C.

6.7 Cost and benefits

Costs and benefits have been compared for flood cell B. The damages by 2075 far exceed the costs of the scheme and are larger again by 2115. An indicative benefits value for 2045 has been included for this flood cell.

Table 6-8 Flood cell B: Capital costs and future PvB for tidal risks

	Option 1		Option 2	
	Low cost	**High cost**	**Low cost**	**High cost**
Capital costs (£k)	5,087	18,898	1,586	5,824
Costs including capital costs, 20% preliminaries and 60% optimism bias (£k)	9,767	36,284	3,045	11,182
Present value benefits 2045 (£k) indicative	£28,000		£28,000	
Present value benefits 2075 (£k)	£68,638		£68,638	
Present value benefits 2115 (£k)	£101,090		£101,090	

Table 6-9 Flood cell B: Capital costs and future PvB for fluvial risks

	Option 1		Option 2	
	Low cost	**High cost**	**Low cost**	**High cost**
Capital costs (£k)	5,087	18,898	1,586	5,824
Costs including capital costs, 20% preliminaries and 60% optimism bias (£k)	9,767	36,284	3,045	11,182
Present value benefits 2045 (£k) indicative	£14,000		£14,000	
Present value benefits 2075 (£k)	£27,210		£27,216	
Present value benefits 2115 (£k)	£92,062		£92,070	

Costs in flood cell B are the largest of any flood cell. However, the benefits, particularly tidal, have significantly exceeded costs before 2075 suggesting the investment could be prior to that date.

A 2045 scenario in flood cell B has been estimated by looking at the sea level increase from 2015 to 2045 and this is approximately 40% of the sea level increase from 2015 to 2075. Although no damage assessments have been undertaken for the 2045 horizon, applying this proportion to damages would indicate tidal damages for 2045 in the region of £28M. This is still higher than likely costs, although by how much depends on the option and high or low estimate. At best a benefit cost of around 9 is possible. Add to this that the 2015 modelling shows flooding below the 0.5% tidal event and some concern expressed over the future condition of the embankment opposite Pilton Park, a failure of which could result in extreme hazard, it is clear that the flood mitigation option in flood cell B (River Yeo at least) should be further investigated and potentially implemented (depending on outcome of further investigation) prior to 2045.

6.8 Flood Cell B proposed outcomes

The proposed outcomes and timescales for Flood Cell B are as given in Table 6-10. The main structural defence options can be considered in two parts. The defences along the River Taw are of good standard and are not likely to require more than Do Minimum until after 2075, which would tie in with Flood Cell A which they adjoin. The River Yeo defences are modelled as being overtopped below the 2015 0.5% AEP event. More detailed consideration of how to manage these defences needs to be undertaken by 2045.

Table 6-10 Flood cell B: Proposed outcomes and timescales

Timescale	Action	Comment
2015 to 2045	Do Minimum More detailed consideration of improvement works to defences on River Yeo should be undertaken.	2015 benefits are not high enough for full scheme however some defences along the River Yeo are already modelled as overtopping during a 0.5% AEP event leaving flood cell B vulnerable. By 2045 there may be enough benefits to undertake at least part of the scheme.
2045 to 2075	Defence works on the River Yeo will be required.	Benefits expected to far exceed likely costs by 2075.
2075 to 2115	Implement remaining proposed defences.	If not carried out already.

There is some interaction of flood extents and a defence join between flood cell A and flood cell B. Raising of A361 and cycle track north towards Pilton Community College should prevent connectivity of flood cells A and B in extreme future flood events. Tidal defences under the A361 bridge will change from flood cell A to flood cell B. The design level for the tidal frontage is the same for both.

The actions along the River Yeo will also directly influence flood cell C and may need to be carried out at the same time, e.g. re-routing the channel.

The Do Minimum option to continue inspection and maintenance to retain or improve defence condition should be continued for all existing defences as these are assumed to remain in place. If an opportunity arises to improve defence standard for some or all of the flood cell earlier than described, e.g. through redevelopment of a site, this should be taken and defences raised to the appropriate design level described for 2115 (generally). The remainder of the flood cell defences can then be added at an appropriate time.

The timing of the actions is largely down to the predicted rate of sea level rise over the next 100 years. This needs to be monitored and the actions and timings reviewed if changes to the assumed rates are apparent.

7 Flood Cell C

7.1 Overview

Flood Cell C comprises the town centre of Barnstaple and properties along the left bank of the River Yeo in the vicinity of St Georges Road. It is predominantly affected by tidal flooding. The flood cell can be split into several distinct frontages:

1. River Taw from River Yeo to Castle Quay
2. River Taw from Castle Quay to the Old Bridge
3. River Taw from the Old Bridge to Taw Vale
4. River Yeo from River Taw to Rolle Street Bridge
5. River Yeo through Pilton Park
6. River Yeo behind St Georges Road

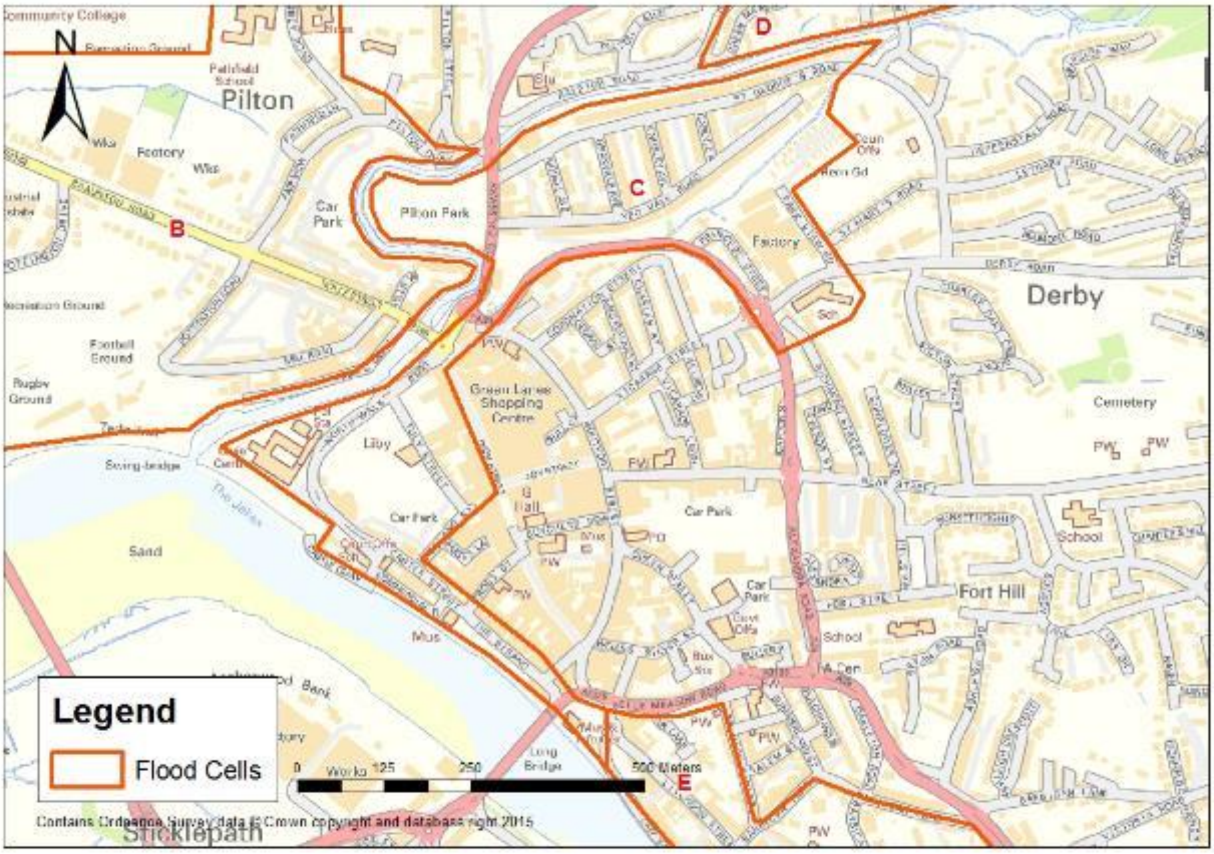

Figure 7-1: Flood cell C boundary

The River Taw frontage is in the centre of Barnstaple and there are a number of key buildings and features along this reach. The existing defences were constructed as part of a flood alleviation scheme in the 1980s and largely comprise flood walls. The section in front of the Civic Centre up to Castle Quay is a low height masonry clad flood wall with a concrete revetment on the riverward side (Figure 7-2). Upstream of Castle Quay the revetment disappears and the banks of the Taw are formed by walls. The primary defence line is set back and consists of masonry clad walls. Upstream of the Old Bridge the flood defence has been built on top of the existing bank walls due to the proximity of Taw Vale and other properties.

Along the River Yeo from the River Taw to Rolle Street Bridge there is no formal defence at present although this site is currently being redeveloped. Upstream of Rolle Street there is a substantial flood wall along the edge of the channel which runs along the back of Pilton Park. Through the park there is a lower earth embankment which has been designed to overtop to allow flood water to be stored in the park. The reach of the River Yeo along St Georges Road is predominantly protected by a substantial concrete flood wall which protects the sunken gardens of the properties along that section. There is a small section at the downstream end of this reach where the defence is higher ground and formed from gabion baskets.

Figure 7-2 Concrete revetment forming bank of River Taw

Figure 7-3 Masonry wall forms the banks of the River Taw

Figure 7-4 Flood wall on the River Yeo (Rolle Street to Pilton Park)

Figure 7-5 Flood wall on River Yeo behind St Georges Road

7.2 Baseline modelling results

The following tables summarise current and future (2075 and 2115) fluvial and tidal flood risks for flood cell C.

Table 7-1 Flood cell C: baseline tidal and fluvial flood risks

	2015			2075			2115		
	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure
Tidal (0.5% AEP)	0	3	2	87	61	4	444	101	8
Fluvial (1% AEP)	0	1	1	0	3	2	150	70	5

In 2015 flood risks there is a low level of risk to a very limited number of non-residential properties from fluvial and tidal sources.

By 2075 there will be a very little change in the number of properties at risk of fluvial flooding, but the tidal risk is forecast to increase significantly. This is due to overtopping near North Walk, and inundation to the North (around Yeo Vale Road), and the South (along North Walk and Castle Street).

However, the most significant increase of both fluvial and tidal risk in the future will be between 2075 and 2115. By 2115 tidal risks are likely to be extremely high, with tidal flooding affecting larger parts of Yeo Vale Road, Granville Avenue, Kingsley Avenue and Carlyle Avenue and the surrounding roads. A similar area, although less extensive, is also likely to be at risk of fluvial flooding overtopping the existing defences along Pilton Causeway and North Walk.

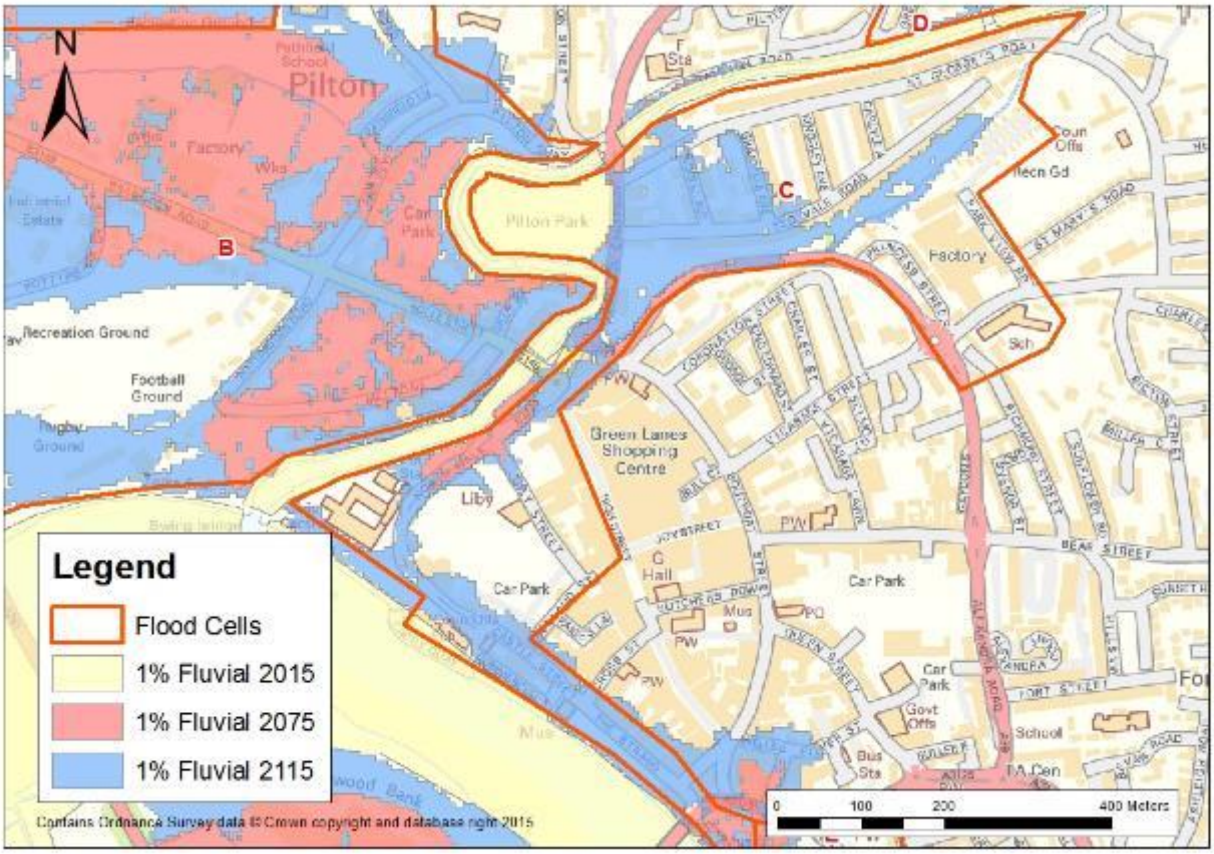

Figure 7-6 Flood cell C: baseline and future fluvial 1% AEP extents

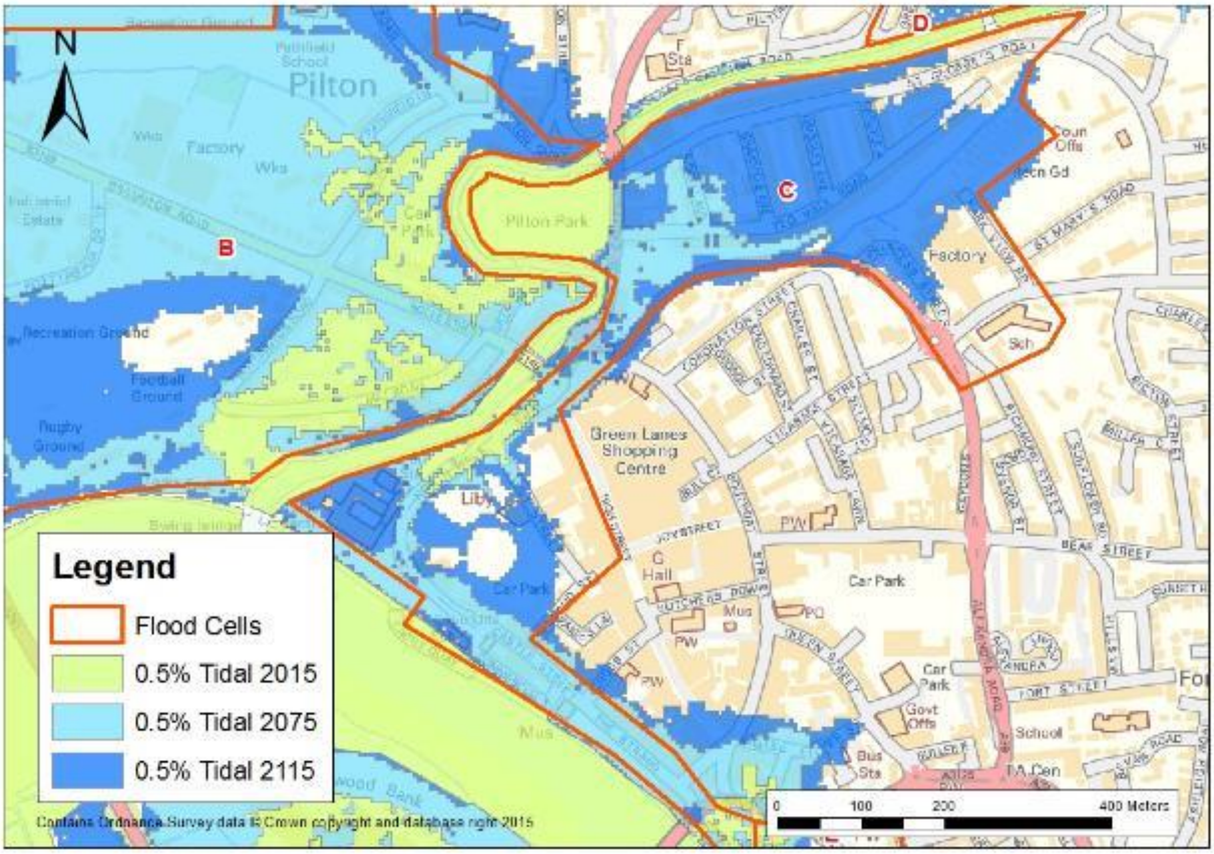

Figure 7-7 Flood cell C: baseline and future tidal 0.5% AEP extents

7.3 Long listed options

The long list technical report is provided in Appendix B, which provides a more detailed assessment of the benefits and disadvantages of each. The following is a summary of the options considered suitable of further consideration for the long term flood risk strategy for flood cell C:

- Piling - Piling is unlikely to be used along the River Taw frontage as it would be prohibitively expensive and out of keeping with the aesthetics of the existing defences along the River Taw. On the other hand, there is existing piling along the River Yeo, and its constrained location makes it ideal for piling.
- Re-routing of River Taw - It has been considered that south of Pilton Quay the River Taw could be re-routed from its current course around Pilton Park, to follow a more direct route along the A39 Pilton Causeway, instead of piling around the greater length of Pilton Park. This would open up the park and existing car parking area.
- Revetments - There is an existing revetment within the flood cell but it does not form the primary defence. A revetment is only practical where there is the space to construct it which rules out its use upstream along the River Yeo and limits it to the Taw frontage. If the revetment were to become the primary defence it could result in a narrowing of the Taw in order to achieve the desired height. It may be more appropriate to consider only using new revetments to replace those existing sections which require repairs or maintenance.
- Embankments - Embankments could be used in a number of the frontages for Flood Cell C as they are in keeping with the existing defences. The present frontage along St George's Road could be raised to form a larger embankment, as could the defences between Yeo Vale Road and Princess Street / Park View Road. The existing embankment around Pilton Park, on the River Yeo, could also be raised. Embankments are considered to be unsuitable for the frontage along the River Taw due to the constrained location of the frontage.
- Flood walls - Flood walls are an idea solution for both the River Taw and River Yeo frontages. Flood Walls are easy to tie-in with other types of defence and the low land take

means different alignment options are possible. Walls can easily be combined with existing defences, such as to raise the crest of an existing embankment (geotechnical capacity permitting). Compared to sheet piles, flood walls can be more aesthetically pleasing and can be finished to match the existing style of the surrounding area.

- Flood resilience - Flood resilience is something that should be incorporated in any new development coming forward within the flood cell but it is not something that should be relied on to protect all properties at risk. It is considered that it could be beneficial to retrofit, particularly if no alternative options prove feasible.
- Relocation of properties at risk - Relocation of at risk properties is very much an option of last resort where no other option is feasible and the severity of flooding is beyond what flood resilience measures can protect against.

7.4 Short list decision making

Having reviewed the sources of flood risk, the receptors at risk now and in the future, the options for flood cell C were short listed in to two options, as follows:

Option 1

- Raise wall opposite Raleigh Road
- Flood relief culverts beneath A39 bridge
- Wall raising along Castle Quay
- Raised existing tidal defence

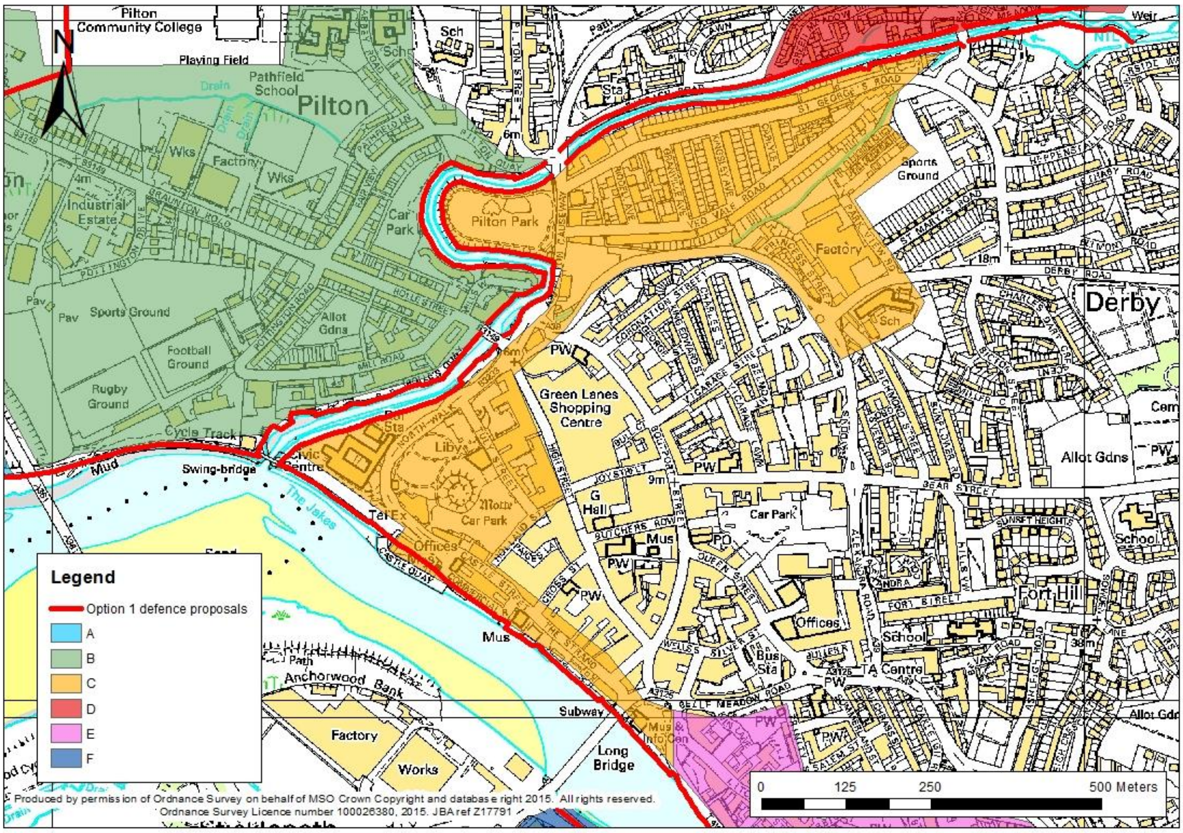

Figure 7-8: Flood Cell C: option 1 locations

Option 2

- Raise wall opposite Raleigh Road
- Flood relief culverts beneath A39 bridge
- Wall raising along Castle Quay
- Raised existing tidal defence
- Re-routing of Taw along A39 Pilton Causeway instead of piling around the existing course of the Taw through Pilton Park

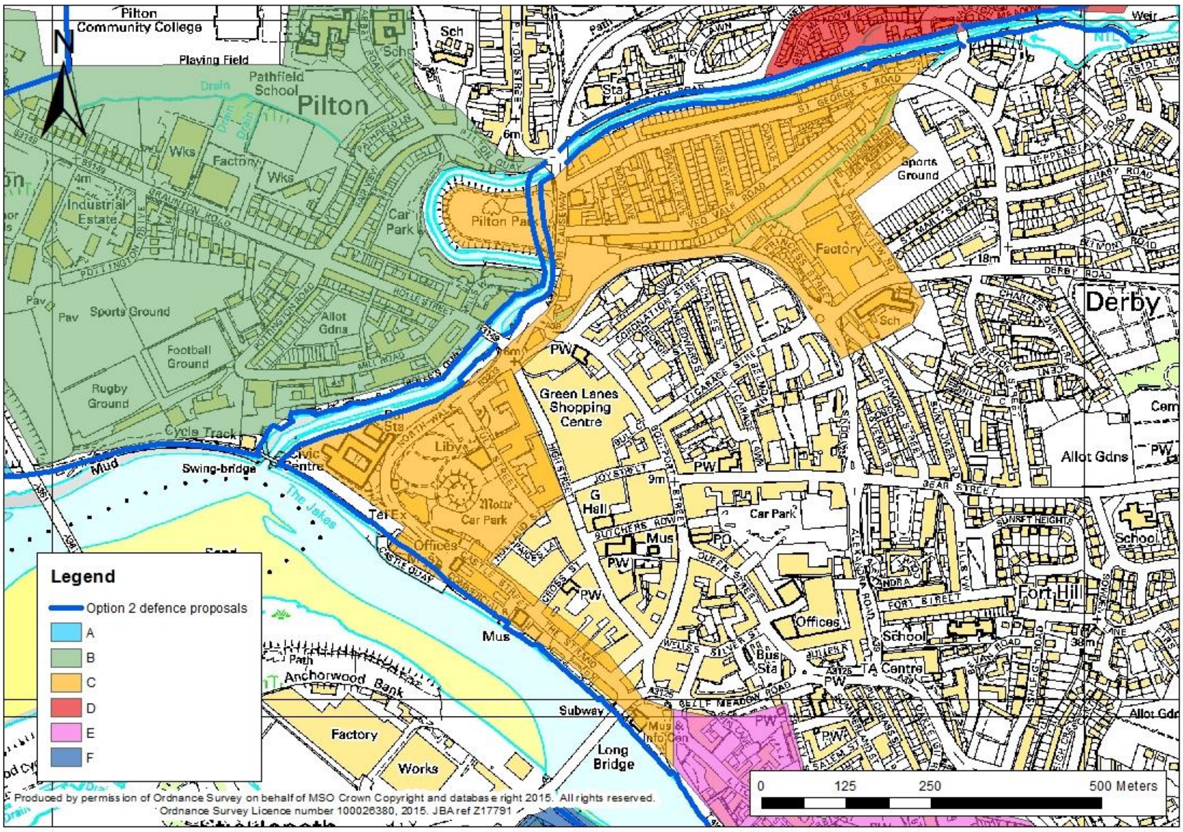

Figure 7-9: Flood Cell C: option 2 locations

7.5 Results

7.5.1 Number of properties at risk

Table 7-2 Flood cell C: Future flood risks with proposed Option 1

	2015			2075			2115		
	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure
Tidal (0.5% AEP)	0	3	2	0	1	1	0	1	1
Fluvial (1% AEP)	0	1	1	0	1	1	0	1	1

Table 7-3 Flood cell C: Future flood risks with proposed Option 2

	2015			2075			2115		
	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure
Tidal (0.5% AEP)	0	3	2	0	2	1	0	2	1
Fluvial (1% AEP)	0	1	1	0	2	1	0	2	1

With both options 1 and 2 the flood risk to residential and commercial property in future is not shown to increase above the current baseline. A small number of non-residential properties may retain some level of risk.

7.5.2 Economic damages

Economic damages have been calculated to assist in the cost benefit assessment. Flood cell C has very large calculated damages for future flood events, tidal in particular, and capping of the damages has been extensively applied in this flood cell to limit the damages to more realistic levels.

Tidal damages in flood cell C in 2015 are very low. Damages rise to £2.4M in 2075 and up to £40M by 2115. The majority of tidal damages are from residential properties. Benefits from the defence option mirror the damages closely at around £2.4M in 2075 and £39M in 2115 and both options give virtually the same benefits.

Table 7-4 Flood cell C: Present value damages for tidal flood risk now and with proposed option 1

	Baseline PvD Tidal (£k)			Option 1 PvD Tidal (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Total	Total
2015	£0	£42	£42	-	-	-	-
2075	£0	£2,439	£2,439	£0	£28	£28	£2,411
2115	£34,033	£5,489	£39,522	£0	£28	£28	£39,494

Table 7-5 Flood cell C: Present value damages for tidal flood risk now and with proposed option 2

	Baseline PvD Tidal (£k)			Option 2 PvD Tidal (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Total	Total
2015	£0	£42	£42	-	-	-	-
2075	£0	£2,439	£2,439	£0	£48	£48	£2,391
2115	£34,033	£5,489	£39,522	£0	£48	£48	£39,474

Fluvial damages in flood cell C have been calculated as £28k in 2015, then increasing to £3.3M by 2075 and to £29M by 2115. The benefits associated with a flood defence scheme are in the region of £3.3M in 2075 and £29M in 2115.

Table 7-6 Flood cell C: Present value damages for fluvial flood risk now and with proposed option 1

	Baseline PvD Fluvial (£k)			Option 1 PvD Fluvial (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Total	Total
2015	£0	£28	£28	-	-	-	-
2075	£3,018	£337	£3,355	£0	£28	£28	£3,327
2115	£25,333	£3,774	£29,108	£0	£28	£28	£29,080

Table 7-7 Flood cell C: Present value damages for fluvial flood risk now and with proposed option 2

	Baseline PvD Fluvial (£k)			Option 2 PvD Fluvial (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Total	Total
2015	£0	£28	£28	-	-	-	-
2075	£3,018	£337	£3,355	£0	£48	£48	£3,308
2115	£25,333	£3,774	£29,108	£0	£48	£48	£29,060

The proposed defence scheme gives greater benefits in relation to tidal flooding, especially in 2115, although both fluvial and tidal pose very significant risks in flood cell C. The defence option proposed should deal effectively with both types of flooding.

7.5.3 Environmental assessment

Raising the standard of protection (SoP) along Raleigh Road is not anticipated to present a risk to the environment as it is not close to any significant environmental features. Risk of negative effects arise from the culverts, as these would involve construction within the river channel. This could cause a permanent loss of river bank and bed habitat, while construction materials could be released into the River Yeo, causing damage to the aquatic ecology and conflicting with WFD objectives.

Increasing the standard of defences and raising the existing defences along Castle Quay risks the setting of Castle Mount, conservation area and the listed buildings along the river front. Archaeological monuments are also present along the river front, those that are unknown may be a risk of damage during construction. An increase in the height of defences present potential adverse effects to landscape character and visual amenity, as it would increase the division between Barnstaple and the estuary, while also affecting views across the valley.

7.6 Engineering summary

7.6.1 Increased parapet along Rolle Street Bridge

The existing defence levels are between 5.94mAOD and 7.85mAOD. A design level of 7.10mAOD has been set using the modelling outputs plus a 150mm freeboard allowance. Therefore, 7.25mAOD has been used as the final defence level.

A solid concrete parapet is proposed, which will act as a flood wall. This will stop water from the River Yeo overtopping the bridge during a flood event. However, this will result in a larger head loss across the bridge, resulting in higher water velocities through the bridge. Consequently, additional scour protection may need to be provided.

There are a number of technical risks identified and elements to consider with this solution, including parapet containment level, scour protection, connection with existing defences, construction accessibility, services information, and health and safety. These are documented in Appendix C.

7.6.2 Re-routing the River Yeo along A39 Pilton Causeway

The existing defence levels are between 5.94mAOD and 7.85mAOD. A design level of 7.10mAOD has been set using the modelling outputs plus a 150mm freeboard allowance. Therefore, 7.25mAOD has been used as the final defence level.

The proposed re-routing of the River Yeo will follow the line of Pilton Causeway, with a new sheet piled wall providing the flood defence. This will require excavations to form the new channel, with the possibility of an embankment against the sheet piled wall to soften the appearance from the Pilton Park side.

Piling through Pilton Park to form a new channel would require that the piles are of sufficient length whereby two thirds of the total pile length is below the surface. Corrosion resistance is advised, using protective coatings and cathodic protection (sacrificial anodes will be applied to the sheet piles). A full corrosion assessment combined with structural analysis should be undertaken to determine the necessary pile thickness to enable the proposed design life.

There are a number of technical risks identified and elements to consider with this solution, including unknown connection with existing defences, ground conditions, contaminated land, construction accessibility, services information, and health and safety. These are documented in Appendix C.

7.6.3 Raising of existing tidal defences

The existing defence levels are between 5.63mAOD and 7.84mAOD. A design level of 7.10mAOD has been set using the modelling outputs plus a 150mm freeboard allowance. Therefore, 7.25mAOD has been used as the final defence level.

The proposed improvements to the tidal defences in flood cell C can be split into three areas:

- Sheet piled walls through the embankment crest in Pilton Park;
- Concrete flood walls between Pilton Park and Castle Quay; and
- Glass flood walls east of Castle Quay.

Piling through the Pilton Park embankment crest would require that the piles are of sufficient length whereby two thirds of the total pile length is below the surface. Corrosion resistance is advised, using protective coatings. The highest thickness available should be used to enable the design life required from the piles.

The flood wall will be constructed on the existing defence line. Based on the EA Design Guidance a reinforced concrete core is considered as the most technically viable solution. It is envisaged that the wall will be clad with either bricks or stone, in keeping with the style of the existing walls. Maintenance of the existing walls should be undertaken as part of this option.

The glass flood wall will be constructed on the existing defence line, likely to be bolted into the existing flood wall. Detailed design will determine the feasibility of this. Maintenance of the existing walls should be undertaken as part of this option. There are a number of technical risks identified and elements to consider with this solution, including unknown connection with existing defences, ground conditions, contaminated land, construction accessibility, services information, and health and safety. These are documented in Appendix C.

7.7 Cost and benefits

Costs and benefits have been compared for flood cell C. The benefits by 2075 do not exceed the costs of the scheme but benefits are around ten times larger than the scheme costs by 2115. A scheme for flood cell C would therefore only seem viable after 2075.

Flood Cell C is on the opposite bank of the River Yeo to Flood Cell B. Works on the River Yeo in Flood Cell B are proposed to occur earlier than the post 2075 horizon suggested for Flood Cell C. If works are being undertaken on Flood Cell B it may be necessary to undertake work on the River Yeo part of Flood Cell C at the same time, e.g. if option 2 with diverting the river were implemented.

Table 7-8 Flood cell C: Capital costs and future PvD for tidal risks

	Option 1		Option 2	
	Low cost	High cost	Low cost	High cost
Capital costs (£k)	1,109	2,135	1,291	3,143
Costs including capital costs, 20% preliminaries and 60% optimism bias (£k)	2,129	4,099	2,479	6,035
Present value benefits 2075 (£k)	£2,411		£2,391	
Present value benefits 2115 (£k)	£39,494		£39,474	

Table 7-9 Flood cell C: Capital costs and future PvD for fluvial risks

	Option 1		Option 2	
	Low cost	High cost	Low cost	High cost
Capital costs (£k)	1,109	2,135	1,291	3,143
Costs including capital costs, 20% preliminaries and 60% optimism bias (£k)	2,129	4,099	2,479	6,035
Present value benefits 2075 (£k)	£3,327		£3,308	
Present value benefits 2115 (£k)	£29,080		£29,060	

7.8 Flood Cell C proposed outcomes

The proposed outcomes and timescales for Flood Cell C are as given in Table 7-10. The main structural defence options can be considered in two parts. The defences along the River Taw are generally of good standard and are not likely to require more than Do Minimum until after 2075, which would tie in with Flood Cell E which they adjoin. The River Yeo defences are of lower standard in places but the economic benefits suggest work would be not be viable until after 2075. However, work on the River Yeo could be carried out in conjunction with Flood Cell B and it may be an earlier scheme could be carried out across the two sides of the river, e.g. if re-routing the river then works would be needed on both sides.

Table 7-10 Flood cell C: Proposed outcomes and timescales

Timescale	Action	Comment
2015 to 2045	Do Minimum. River Yeo works should be considered alongside those in Flood Cell B, i.e. undertake works on both sides of the Yeo.	Benefits in flood cell C unlikely to be high enough to proceed with scheme, unless part can be joined with flood cell B.
2045 to 2075	Do Minimum. River Yeo works should be considered alongside those in Flood Cell B, i.e. undertake works on both sides of the Yeo.	Benefits in flood cell C unlikely to be high enough to proceed with scheme, unless part can be joined with flood cell B.
2075 to 2115	Implement proposed defences on Taw frontage and River Yeo, if not carried out already.	Works on flood cell C only become economically viable after 2075.

There is some interaction of flood extents and a defence join between flood cell C and flood cell E.

The Do Minimum option to continue inspection and maintenance to retain or improve defence condition should be continued for all existing defences as these are assumed to remain in place. If an opportunity arises to improve defence standard for some or all of the flood cell earlier than described, e.g. through redevelopment of a site, this should be taken and defences raised to the appropriate design level described for 2115 (generally). The remainder of the flood cell defences can then be added at an appropriate time.

The timing of the actions is largely down to the predicted rate of sea level rise over the next 100 years. This needs to be monitored and the actions and timings reviewed if changes to the assumed rates are apparent.

8 Flood Cell D

8.1 Overview

Flood Cell D comprises a recent housing development situated between the Lower Raleigh Road and the River Yeo. The nature of this flood cell means that it can be considered as a single frontage.

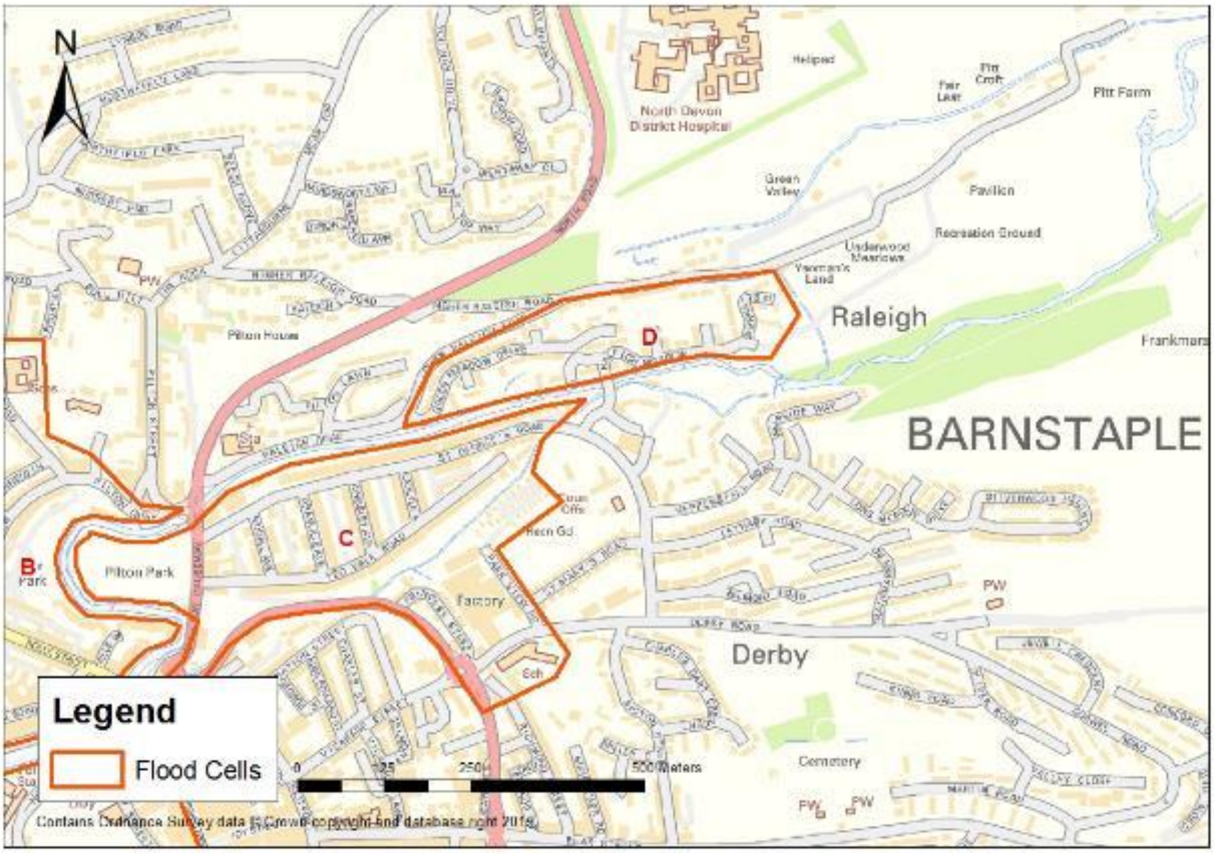

Figure 8-1: Flood cell D boundary

The new development looks to have been constructed within the last 10 years and ground levels across the site were elevated at that time. There is a continuous line of defence provided by a brick flood wall on top of an embankment (Figure 8-2). The flood wall is tied into bridge abutments (Figure 8-3) and there are flood gates (Figure 8-4) included where access to the riverside is required. At the very upstream end the wall stops and defence is provide solely by an embankment (Figure 8-5).

It should be noted that the brick wall defence does not have an impermeable core and would therefore not be compliant with the Environment Agency's latest standards for flood defences.

Figure 8-2: Flood wall on top of embankment

Figure 8-3: Flood wall tied in to bridge abutments

Figure 8-4: Flood gates where access is required

Figure 8-5: Embankment at most upstream point of flood cell

8.2 Baseline modelling results

The following tables summarise current and future (2075 and 2115) fluvial and tidal flood risks for flood cell D.

Table 8-1 Flood cell D: baseline tidal and fluvial flood risks

	2015			2075			2115		
	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure
Tidal (0.5% AEP)	0	0	0	0	0	0	27	0	0
Fluvial (1% AEP)	0	0	0	0	0	0	2	0	0

In 2015 and by 2075 there is shown to be no risk to residential or commercial properties, as the existing defences protect from both fluvial and tidal sources. Although some localised overtopping does occur to the south of Green Meadow Drive this is not extensive enough to cause a risk to properties.

By 2115 the extent of overtopping is slightly greater, with 2 properties at risk from fluvial flooding and 27 from tidal along Green Meadow Drive. This is not direct tidal flooding, but the effects of a locked system on the River Yeo which can't discharge into the Taw estuary during high tidal conditions.

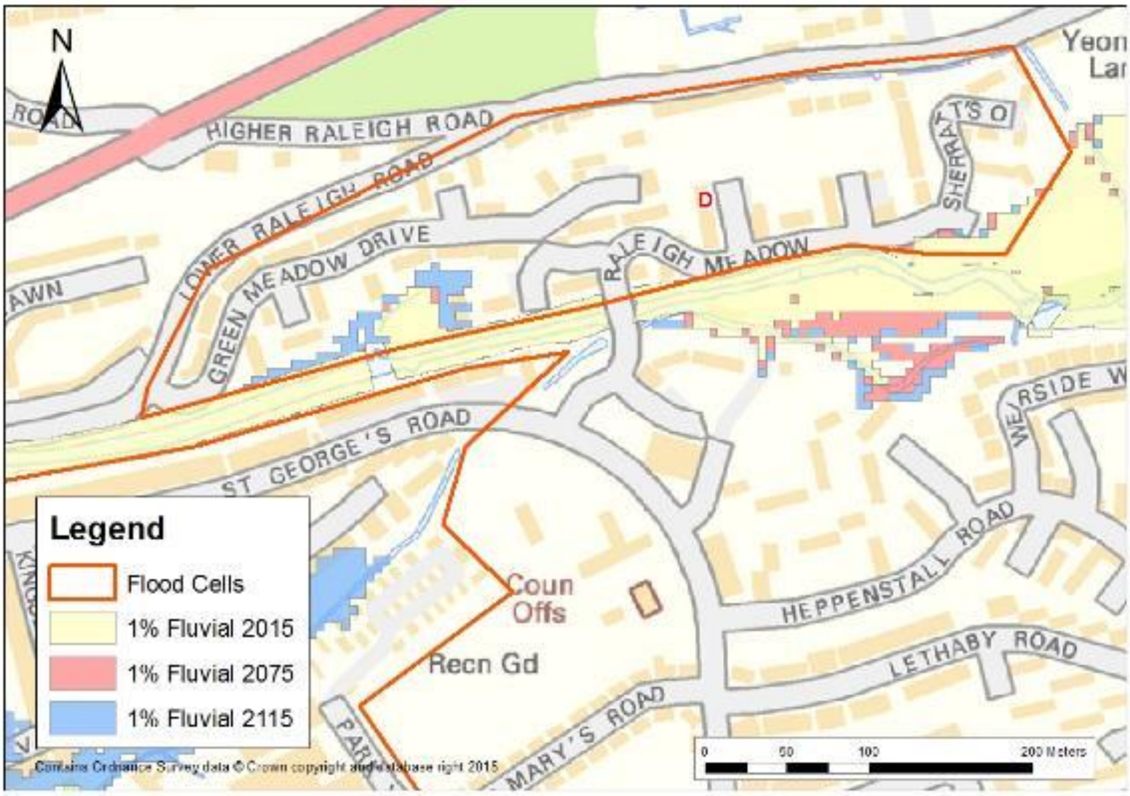

Figure 8-6 Flood cell D: baseline and future fluvial 1% AEP extents

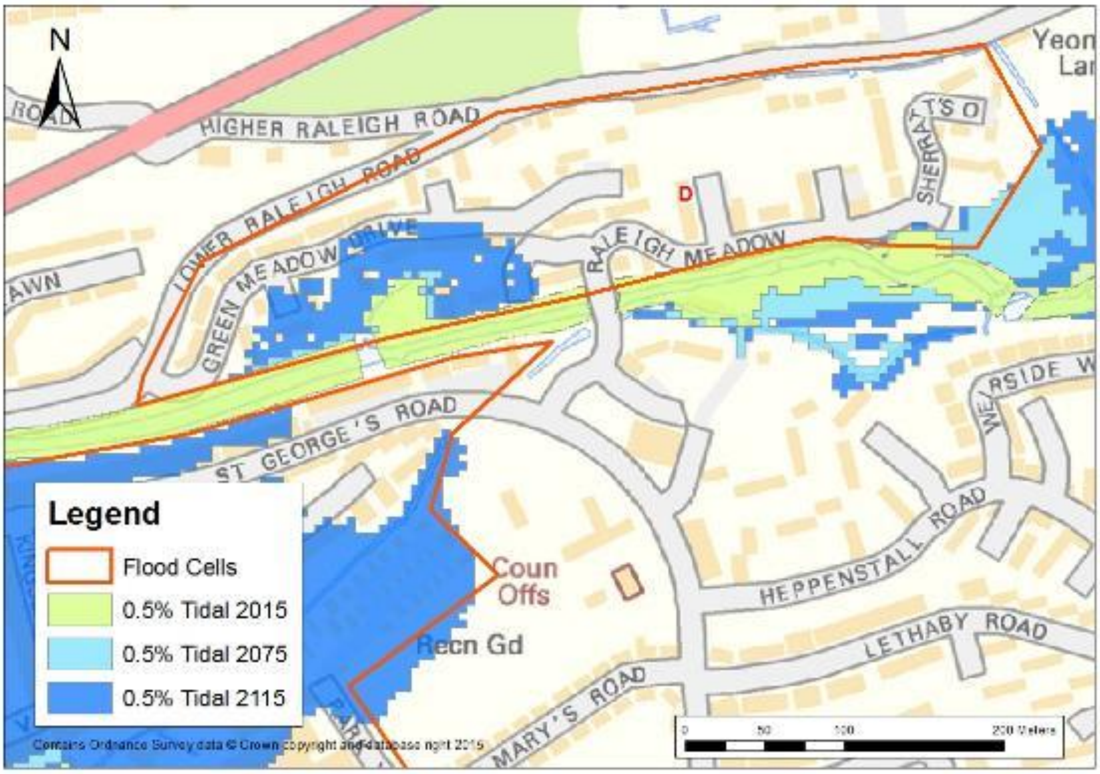

Figure 8-7 Flood cell D: baseline and future tidal 0.5% AEP extents

8.3 Long listed options

The long list technical report is provided in Appendix B, which provides a more detailed assessment of the benefits and disadvantages of each. The following is a summary of the options considered suitable of further consideration for the long term flood risk strategy for flood cell D:

- Piling - Piling is a feasible option along the River Yeo, where the constrained location between water and property makes it ideal. However, it is not in keeping with the aesthetics of the area, is expensive and may be negative ecological impacts.
- Embankments - The existing unsuitable flood wall (without an impermeable core), could be removed to facilitate a raise of the embankment that it is located on. This would both enable an improved Standard of Protection and replacement of a non-compliant defence.
- Flood walls - Flood Walls are easy to tie-in with other types of defence and the low land take means different alignment options are possible. Walls can easily be combined with existing defences, such as to raise the crest of an existing embankment (geotechnical capacity permitting). Compared to sheet piles, flood walls can be more aesthetically pleasing and can be finished to match the existing style of the surrounding area. It should be noted that the existing brick flood walls in Flood Cell D are not suitable to use as a base for a wall raise due to their lack of impermeable core.
- Flood resilience - Flood resilience is something that should be incorporated in any new development coming forward within the flood cell but it is not something that should be relied on to protect all properties at risk. It is considered that it could be beneficial to retrofit, particularly if no alternative options prove feasible.
- Flood storage - Flood storage will only protect the properties along the River Yeo affected by fluvial flooding in large events or the combination of a more moderate event with tide-locking of the outlet. In these situations if can be effective but it requires a suitable area of land on which to store the floodwater and enough capacity to retain it for the duration of the event or tide-locking. The storage option for this flood cell could protect properties along the River Yeo but it is likely that any storage would need to be constructed outside of the flood cell upstream of Raleigh. It is possible that this could benefit properties outside of the flood cell.
- Relocation of properties at risk - Relocation of at risk properties is very much an option of last resort where no other option is feasible and the severity of flooding is beyond what flood resilience measures can protect against.

8.4 Short list decision making

Having reviewed the sources of flood risk, the receptors at risk now and in the future, the options for flood cell D were short listed as follows:

- Replace the existing defences over time to meet required standards

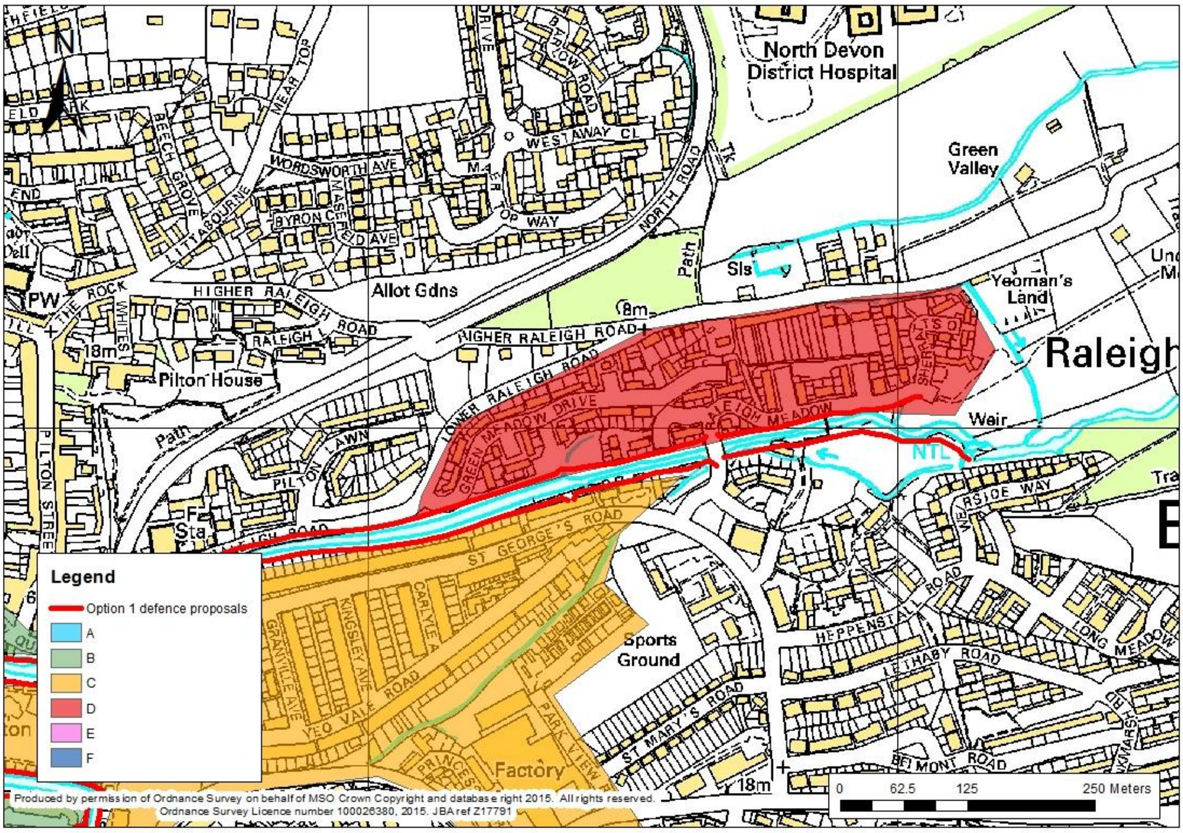

Figure 8-8: Flood Cell D: option locations

8.5 Results

8.5.1 Number of properties at risk

Table 8-2 Flood cell D: Future flood risks with proposed options

	2015			2075			2115		
	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure
Tidal (0.5% AEP)	0	0	0	0	0	0	0	0	0
Fluvial (1% AEP)	0	0	0	0	0	0	0	0	0

In the future with no investment to upgrade the existing defences, the only flood risks to property will be by 2115 and mostly from tidal sources. However, these risks and the smaller risk to properties form fluvial sources can be managed down by upgrading the existing defences.

8.5.2 Economic damages

Costs and benefits have been compared for flood cell D. Given the very limited risks in this flood cell the associated damages are very low.

Tidal damages in flood cell D in 2015 are zero. Damages remain at zero in 2075 and rise very slightly up to £0.2M by 2115. The tidal damages are from residential properties. Benefits from the defence option mirror the damages.

Table 8-3 Flood cell D: Present value damages for tidal flood risk now and with proposed flood defence options

	Baseline PvD Tidal (£k)			Future PvD with Options (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Critical Infrastructure	Total
2015	£0	£0	£0	-	-	-	-
2075	£0	£0	£0	£0	£0	£0	£0
2115	£247	£0	£247	£0	£0	£0	£247

There is a flood defence scheme already in place and that appears to protect this flood cell in 2015 and 2075 with the only flooding predicted in 2075 during a 0.1% AEP event. By 2115 there is a greater risk but to very few properties except in the 0.1% AEP event. Economic benefits in 2115 are in the region of £0.6M.

Table 8-4 Flood cell D: Present value damages for fluvial flood risk now and with proposed flood defence options

	Baseline PvD Fluvial (£k)			Future PvD with Options (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Critical Infrastructure	Total
2015	£0	£0	£0	-	-	-	-
2075	£184	£0	£184	£0	£0	£0	£184
2115	£634	£0	£635	£0	£0	£0	£635

The proposed defence scheme gives greater benefits in relation to fluvial flooding in 2115, although both fluvial and tidal risks in flood cell D are low. The defence option proposed should deal effectively with both types of flooding.

8.5.3 Environmental assessment

Replacing the existing defences to meet design standards present a risk to biodiversity through the potential loss of key habitat. Notable species, such as the common frog, have also been observed in the region, and therefore construction could adversely affect these species. However, the risks are low, and this option also does not present significant risks to other environmental features.

8.6 Engineering summary

8.6.1 Replace the existing defences over time to meet required standards

The existing defence levels are between 6.11mAOD and 8.18mAOD. A design level of 7.10mAOD has been set using the modelling outputs plus a 150mm freeboard allowance. Therefore, 7.25mAOD has been used as the final defence level.

The flood wall will be constructed on the existing defence line. Based on the EA Design Guidance a reinforced concrete core and foundation wall is considered as the most technically viable solution. It is envisaged that the wall will be clad with either bricks or stone, dependent on the local planning authority requirements.

There are a number of technical risks identified and elements to consider with this solution, including connection with existing defences, unknown ground conditions, contaminated land, construction accessibility, services information, and health and safety. These are documented in Appendix C.

8.7 Cost and benefits

Costs and benefits have been compared for flood cell D. Benefits in this flood cell are low given the very limited risks and an existing flood defence scheme.

Table 8-5 Flood cell D: Capital costs and future PvB

	Tidal		Fluvial	
	Low cost	High cost	Low cost	High cost
Capital costs (£k)	600	1,114	600	1,114
Costs including capital costs, 20% preliminaries and 60% optimism bias (£k)	1,152	2,139	1,152	2,139
Present value benefits 2075 (£k)	£0		£184	
Present value benefits 2115 (£k)	£247		£635	

In flood cell D the economic benefits of raising the existing defences are very limited and likely to be lower than the cost of the raised defences. There are existing defences here and future needs may be judged around maintaining the existing defences rather than raising them. The condition and construction of the defences may require significant maintenance at some stage so they retain their effectiveness. An assessment of the current defended scenario against an undefended scenario may be useful to determine the value of maintaining the existing defences.

8.8 Flood Cell D proposed outcomes

The proposed outcomes and timescales for Flood Cell D are as given in Table 8-6. There are very limited benefits in this flood cell and work has already been carried out on defences. There is therefore no justification for additional defence works.

Table 8-6 Flood cell C: Proposed outcomes and timescales

Timescale	Action	Comment
2015 to 2045	Do Minimum.	No justification for defence improvements.
2045 to 2075	Do Minimum.	No justification for defence improvements.
2075 to 2115	Do Minimum.	Benefits in flood cell D unlikely to be high enough for scheme.

The Do Minimum option to continue inspection and maintenance to retain or improve defence condition should be continued for all existing defences as these are assumed to remain in place. If an opportunity arises to improve defence standard for some or all of the flood cell earlier than described, e.g. through redevelopment of a site, this should be taken and defences raised to the appropriate design level described for 2115 (generally). The remainder of the flood cell defences can then be added at an appropriate time.

The timing of the actions is largely down to the predicted rate of sea level rise over the next 100 years. This needs to be monitored and the actions and timings reviewed if changes to the assumed rates are apparent.

9 Flood Cell E

9.1 Overview

Flood Cell E comprises the area to the south of the centre of Barnstaple, extending into the Newport area and along the River Taw frontage. As well as flooding from the River Taw (tidal and fluvial) the flood cell is also at risk from fluvial flooding from Coney Gut and to a much lesser extent the Rumsam Stream.

The flood cell can be split into two distinct frontages along the Taw:

- River Taw from Taw Vale to Rock Park
- River Taw from Rock Park to A361

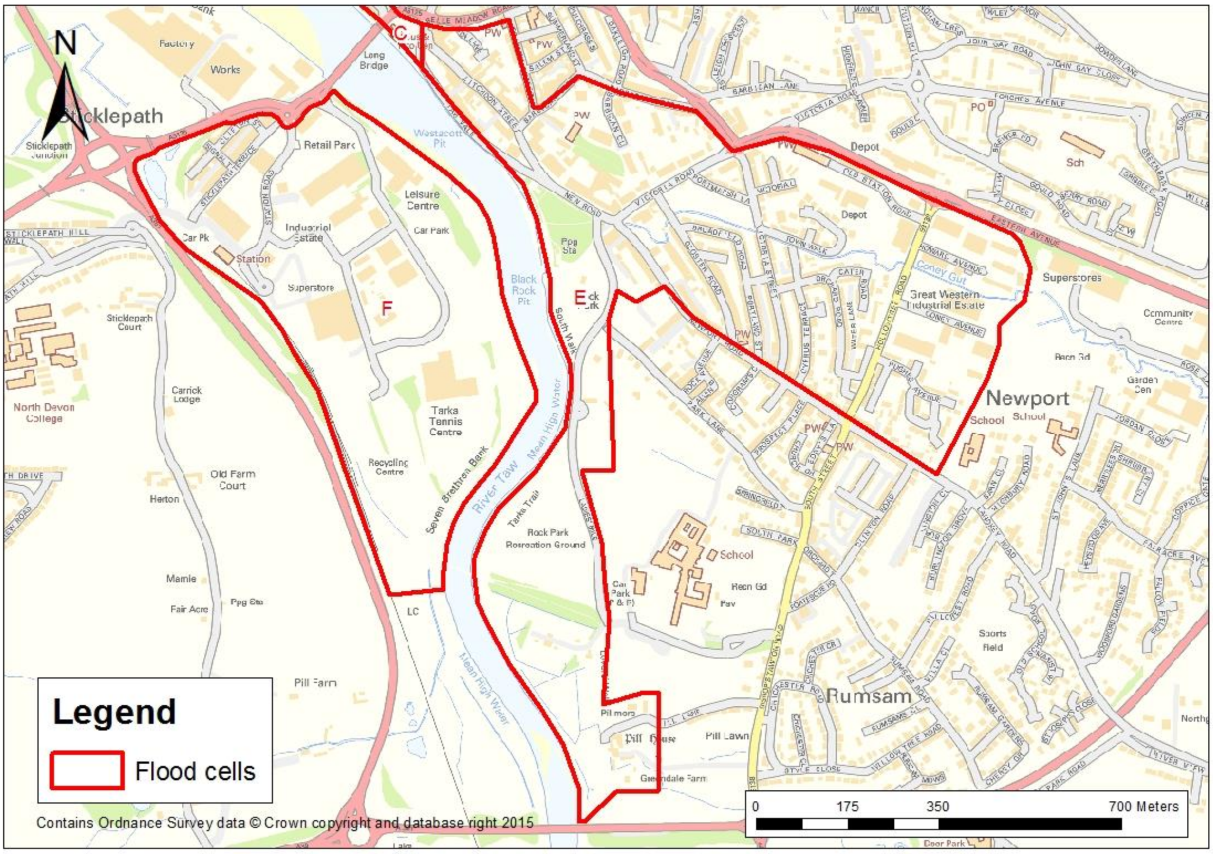

Figure 9-1: Flood cell E boundary

The River Taw frontage from where it joins flood cell C, along Taw Vale along to Rock Park consists of a raised flood wall. From Rock Park to the A361 bridge the Taw frontage is a raised embankment the follows the River Frontage. There is a pathway along the top of the embankment along all this stretch.

Coney Gut is a complex system of which only part falls within Flood Cell E. Just to the east of the flood cell E boundary there is a sluice that limits the flows into the Coney Gut channel through flood cell E. The excess flow is diverted into an overflow culvert that takes the water to an outfall on the River Taw, located upstream of the outfall for the channel flowing through flood cell E. The channel through flood cell E is largely open, has numerous structures and passes very close to many building boundary walls and fences. At the downstream end the channel enters a culvert under Rock Park and outfalls through a flapped outfall.

Figure 9-2 Flood wall along Taw Vale

Figure 9-3 Change from flood wall to embankment into Rock Park

Figure 9-4 Embankment looking south towards A361 bridge

Figure 9-5 Coney Gut channel just upstream of outfall culvert

9.2 Baseline modelling results

The following tables summarise current and future (2075 and 2115) fluvial and tidal flood risks for flood cell E. For flood cell E the fluvial risks are from Coney Gut and Rumsam stream only. No fluvial overtopping of the River Taw is included in the property counts because the tidal overtopping from the Taw impacts more properties than fluvial overtopping (and largely the same properties). This allows Coney Gut options to be separately assessed in terms of costs and benefits more easily and the Taw frontage can be done on the basis on the tidal results alone.

Table 9-1 Flood cell E: baseline tidal and fluvial flood risks

	2015			2075			2115		
	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure
Tidal (0.5% AEP)	1	2	0	115	44	0	617	113	4
Fluvial (1% AEP)	96	31	1	171	42	1	214	47	1

In 2015 tidal flood risk is very low given the substantial tidal defences along the Taw frontage of Flood Cell E. The fluvial risk from Coney Gut is much higher with 120 properties predicted as being at risk in a 1% AEP event.

By 2075 there is predicted to be an increase in fluvial risk to 210 properties at risk. Importantly, by 2075 the 0.5% AEP tidal event is overtopping the Taw defences and flooding around 160 properties.

By 2115 tidal risks are likely to be extremely high, with tidal flooding affecting large parts of Flood ell E and affecting 730 properties. Fluvial risks are also predicted to increase but by a much smaller amount, to around 260 properties at risk.

Without defence works flood risk in flood cell E is predicted to get much worse and the primary source of risk is expected to change from fluvial to tidal after 2075.

The existing flood relief culvert on Coney Gut that diverts flow from the Newport area to the River Taw is included in the modelling but is generally operating at capacity with the inlet surcharged even for moderate events. The embankment and sluice structure into the old Coney Gut channel near the diversion are modelled as being overtopped in the 2015 2% AEP event which is why many residential properties are at risk along Coney Gut despite the existing scheme.

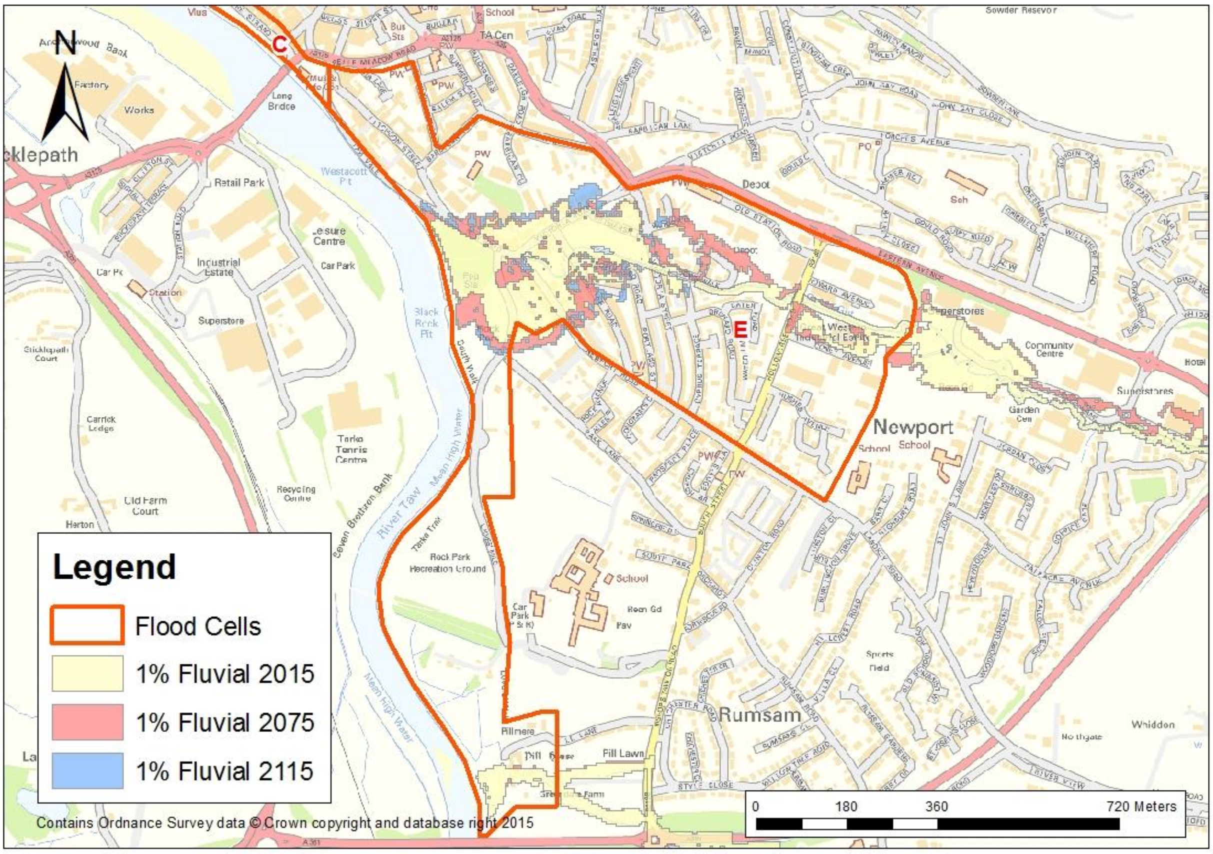

Figure 9-6 Flood cell E: baseline and future fluvial 1% AEP extents (Coney Gut and Rumsam Stream)

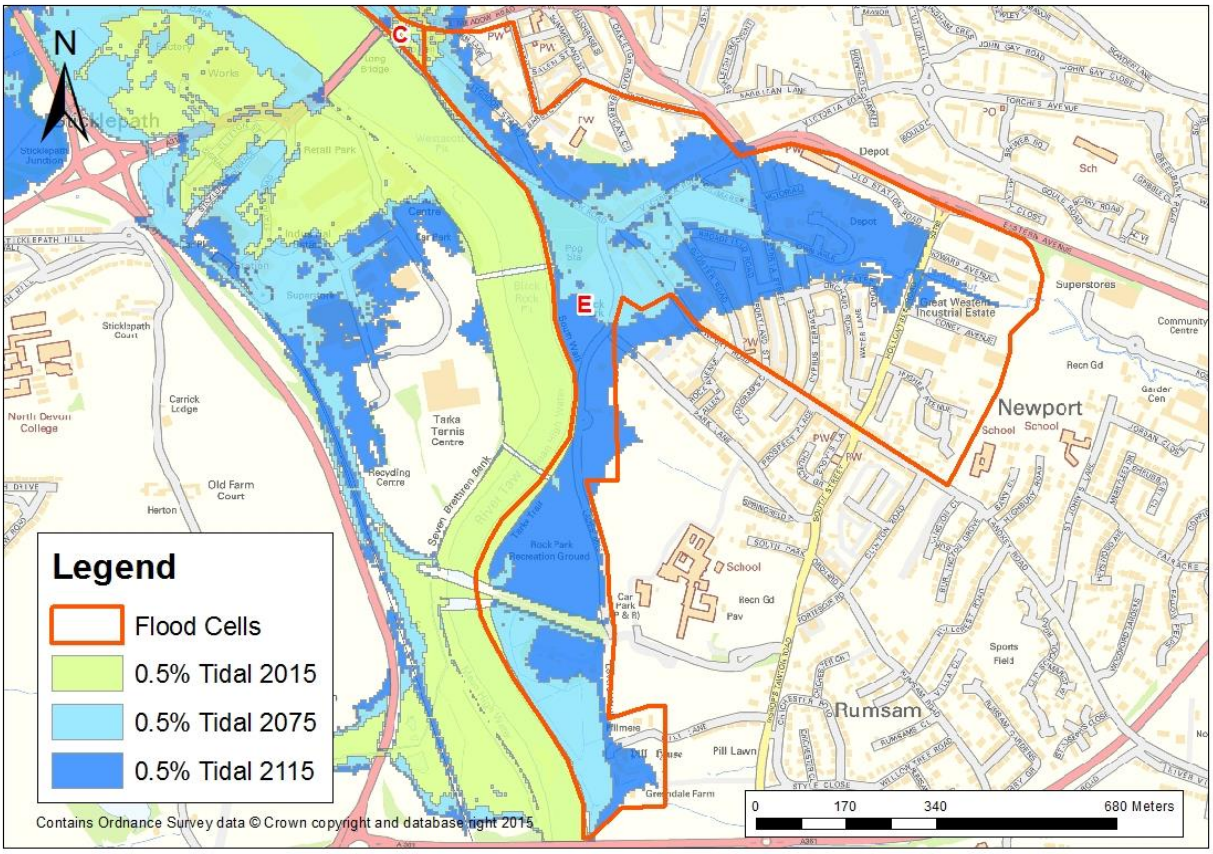

Figure 9-7 Flood cell C: baseline and future tidal 0.5% AEP extents

9.3 Long listed options

The long list technical report is provided in Appendix B, which provides a more detailed assessment of the benefits and disadvantages of each. The following is a summary of the options considered suitable of further consideration for the long term flood risk strategy for flood cell E:

- Piling - Piling is a feasible option along the Coney Gut, where the constrained location between water and property makes it ideal. However, it is not in keeping with the aesthetics of the area, is expensive and may be negative ecological impacts.
- Revetments - There is an existing revetment within the flood cell but it does not form the primary defence. A revetment is only practical where there is the space to construct it which rules out its use upstream along the Coney Gut and limits it to the Taw frontage. If the revetment were to become the primary defence it could result in a narrowing of the Taw in order to achieve the desired height. It may be more appropriate to consider only using new revetments to replace those existing sections which require repairs or maintenance.
- Embankments - Embankments could be used in a number of the frontages for Flood Cell E as they are in keeping with the existing defences. The present frontage in Rock Park could be raised to form a larger embankment. Embankments are feasible in certain positions along the Coney Gut, with available land being the main construction constraint.
- Flood walls - Flood walls are an idea solution for both the River Taw and Coney Gut frontages. Flood Walls are easy to tie-in with other types of defence and the low land take means different alignment options are possible. Where walls already exist they may be raised, depending on structural and geotechnical conditions. Compared to sheet piles, flood walls can be more aesthetically pleasing and can be finished to match the existing style of the surrounding area.
- Flood resilience - Flood resilience is something that should be incorporated in any new development coming forward within the flood cell but it is not something that should be relied on to protect all properties at risk. It is considered that it could be beneficial to retrofit, particularly if no alternative options prove feasible.

- Flood storage area - Flood storage will only protect the properties along the Coney Gut affected by fluvial flooding in large events or the combination of a more moderate event with tide-locking of the outlet. In these situations if can be effective but it requires a suitable area of land on which to store the floodwater and enough capacity to retain it for the duration of the event or tide-locking. The storage option for this flood cell could protect properties along the Coney Gut but it is likely that any storage would need to be constructed outside of the flood cell upstream of Newport. It is possible that this could benefit properties outside of the flood cell.
- Relocation of properties at risk - Relocation of at risk properties is very much an option of last resort where no other option is feasible and the severity of flooding is beyond what flood resilience measures can protect against.

9.4 Short list decision making

Having reviewed the sources of flood risk, the receptors at risk now and in the future, the options for flood cell E were short listed as follows:

- Replace the existing tidal defences over time to meet required standards
- Flood walls along Coney Gut

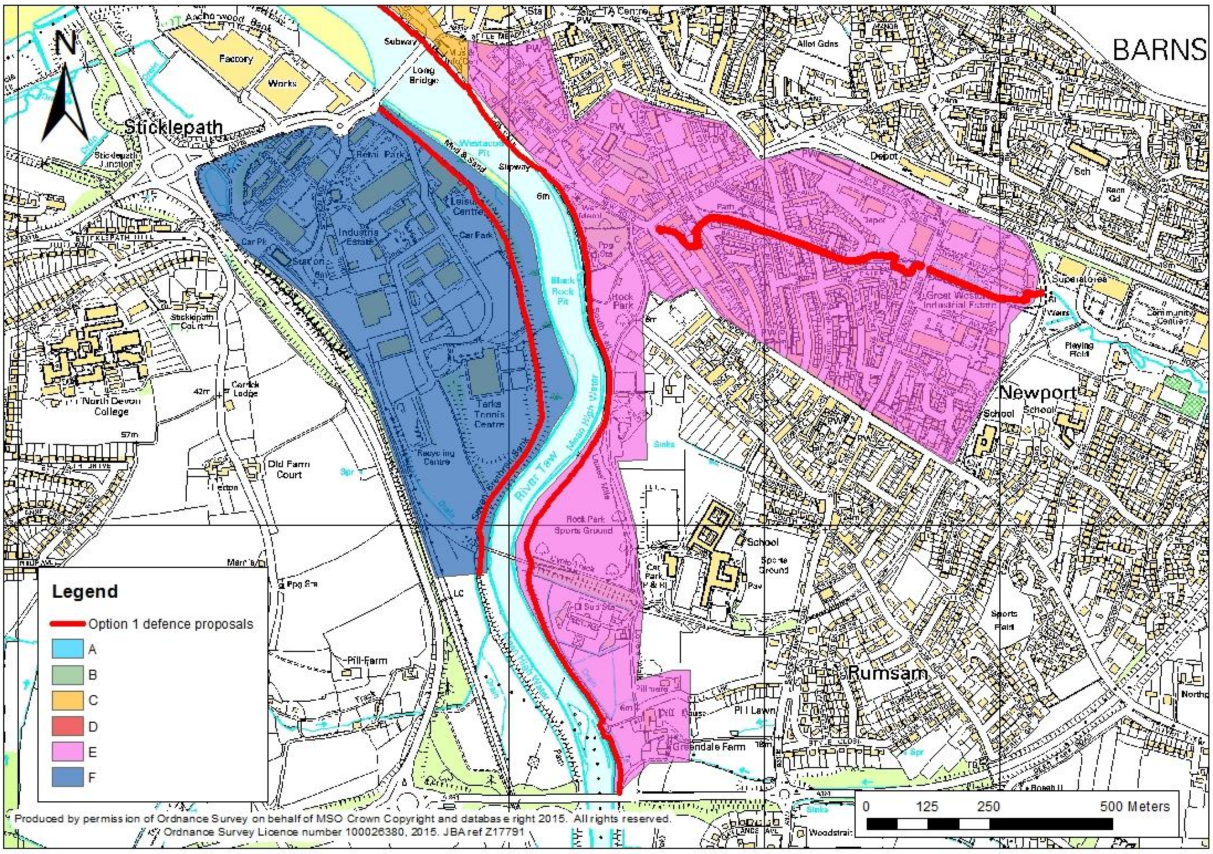

Figure 9-8: Flood Cell E: option locations

9.5 Results

9.5.1 Number of properties at risk

Table 9-2 Flood cell E: Future flood risks with proposed Option

	2015			2075			2115		
	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure	Residential	Commercial	Critical Infrastructure
Tidal (0.5% AEP)	1	2	0	0	0	0	0	0	0
Fluvial (1% AEP)	96	31	1	1	0	0	1	0	0

With the proposed tidal and fluvial options the flood risk to residential and commercial property in future is shown to be very low.

9.5.2 Economic damages

Economic damages have been calculated to assist in the cost benefit assessment. Flood cell E has very large calculated damages for future flood events, tidal in particular, and capping of the damages has been extensively applied to limit the damages to more realistic levels.

Tidal damages in flood cell E in 2015 have been calculated as £40k. Damages rise to £6.4M in 2075 and up to £81M by 2115. The majority of tidal damages are from residential properties. Benefits from the defence option mirror the damages at around £6.4M in 2075 and £81M in 2115 showing the defence option is very effective for mitigating tidal risk.

Table 9-3 Flood cell E: Present value damages for tidal flood risk now and with proposed option

	Baseline PvD Tidal (£k)			Future PvD with Options (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Total	Total
2015	£28	£12	£40	-	-	-	-
2075	£4,519	£1,922	£6,442	£0	£0	£0	£6,442
2115	£73,423	£7,738	£81,161	£0	£0	£0	£81,161

Fluvial damages in flood cell E (Coney Gut only) have been calculated as £3.3M in 2015, then increasing to £11M by 2075 and to £15M by 2115. The benefits associated with a flood defence scheme are also £11M in 2075 and £15M in 2115.

Table 9-4 Flood cell E: Present value damages for fluvial flood risk now and with proposed option

	Baseline PvD Fluvial (£k)			Future PvD with Options (£k)			PV Benefits (£k)
	Residential	Commercial	Total	Residential	Commercial	Total	Total
2015	£2,764	£623	£3,387	-	-	-	-
2075	£9,753	£1,633	£11,386	£200	£0	£200	£11,186
2115	£13,570	£1,886	£15,457	£200	£0	£200	£15,257

9.5.3 Environmental assessment

Improving the defences along the River Taw frontage may cause a permanent adverse effect on BAP habitat in the river, if the defences were to extend into the river channel. Rock Park is a Key Network Site, so construction in this area could cause loss of habitat important for connectivity and therefore have a permanent negative effect on biodiversity. It also has the potential to affect the setting of Newport conservation area, possibly affecting views to the river. This construction along the Taw could also release contaminating materials into the River Taw, conflicting with its WFD objectives. This option could also be in conflict with the recommended mitigation measures for the Taw-Torridge estuary, and therefore set back the river's achievement of GEP.

New walls at Coney Gut are not likely to have a significant effect on biodiversity, as there are relatively few biodiversity features in the area and it is small scale. The setting of listed buildings may be negatively affected, however the majority of Coney Gut is not within a conservation area so the effect is unlikely to be significant, with only the western end of the defences being within the conservation area. Due to the confined nature of Coney Gut, effects on landscape and visual amenity are not anticipated. Construction of new walls at Coney Gut is potentially in contravention with the WFD mitigation measures, which seek to remove hard engineering.

9.6 Engineering summary

9.6.1 Raising of defences along the River Taw frontage

The existing defence levels are between 6.51mAOD and 6.86mAOD. A design level of 7.30mAOD has been set using the modelling outputs plus a freeboard allowance of 150mm on hard defences (e.g. walls) and 300mm on soft defences (defences subject to settlement e.g. embankments). Therefore, 7.45mAOD has been used as the final defence level for hard defences and 7.60mAOD for soft defences.

The proposed improvements to the tidal defences in Flood Cell E (see **Error! Reference source not found.Error! Reference source not found.**) can be split into three areas:

- Glass flood walls between Long Bridge and Rock Park;
- Increased embankment level in Rock Park; and
- Concrete flood walls elsewhere.

The glass flood wall will be constructed on the existing defence line, likely to be bolted into the existing flood wall. Detailed design will determine the feasibility of this. Maintenance of the existing walls should be undertaken as part of this option.

The flood wall will be constructed on the existing defence line. Based on the EA Design Guidance a reinforced concrete core is considered as the most technically viable solution. It is envisaged that the wall will be clad with either bricks or stone, in keeping with the style of the existing walls. Maintenance of the existing walls should be undertaken as part of this option.

Raising the level of the embankments will require the following:

- Maximum gradient of side slopes 1:3;
- Minimum crest width 1m to allow maintenance (non vehicular), in line with the recommendations in the Levee Handbook[5];
- Impermeable core material; and
- A flow path cut off will be included.

There are a number of technical risks identified and elements to consider with this solution, including connection with existing defences, construction accessibility, unknown ground conditions, contaminated land, services information, and health and safety. These are documented in Appendix C.

9.6.2 Flood Walls along Coney Gut frontage

The existing defence levels are not known. A design level of 7.20mAOD has been set using the modelling outputs plus a freeboard allowance of 150mm on hard defences. Therefore, 7.35mAOD has been used as the final defence level.

[5] The International Levee Handbook, CIRIA, 2013

The flood wall will be constructed on the bank line. Based on the EA Design Guidance a reinforced concrete core is considered as the most technically viable solution. It is envisaged that the wall will be clad with either bricks or stone, in keeping with the style of the existing walls. Maintenance of the existing walls should be undertaken as part of this option.

There are a number of technical risks identified and elements to consider with this solution, including tie in with existing structures, proximity of property, unknown connection with existing defences, ground conditions, contaminated land, construction accessibility, services information, and health and safety. These are documented in Appendix C.

9.7 Cost and benefits

Costs and benefits have been compared for flood cell E. The damages by 2075 are similar to the costs of the scheme and tidal damages are much larger by 2115.

Table 9-5 Flood cell E: Capital costs and future PvB

	Tidal		Fluvial	
	Low cost	**High cost**	**Low cost**	**High cost**
Capital costs (£k)	4,419	8,154	4,419	8,154
Costs including capital costs, 20% preliminaries and 60% optimism bias (£k)	8,484	15,656	8,484	15,656
Present value benefits 2075 (£k)	£6,442		£11,186	
Present value benefits 2115 (£k)	£81,161		£15,257	

The Taw frontage and Coney Gut defences can be considered separately. The costs of the scheme in Flood Cell E are approximately 20% for the tidal defences and 80% for the fluvial defences on Coney Gut.

This suggests that by 2075 it is unlikely that improvement to either tidal or fluvial defences will be economically viable as the benefit cost is relatively low. By 2115, however, the tidal defences will have a very strong economic case but the fluvial defences will not as the increase in fluvial damages from 2075 to 2115 is modest.

Coney Gut has an existing scheme already and little recent history of flooding. It will be important to continue monitoring how the scheme performs and make improvements to the model where necessary. It will become more apparent over time whether the existing scheme will be overwhelmed with the frequency that is modelled and whether the damages are realistic.

9.8 Flood Cell E proposed outcomes

The proposed outcomes and timescales for Flood Cell E are as given in Table 9-6.

Table 9-6 Flood cell C: Proposed outcomes and timescales

Timescale	Action	Comment
2015 to 2045	Do Minimum.	No justification for defence improvements.
2045 to 2075	Do Minimum.	Benefits in flood cell E unlikely to be high enough to for scheme.
2075 to 2115	Improve Taw defences. Consider viability of improved Coney Gut defences.	Benefits of tidal flooding far exceed likely costs of tidal defences. Fluvial benefits unlikely to be high enough to proceed with scheme but additional information may be available by this time.

The Do Minimum option to continue inspection and maintenance to retain or improve defence condition should be continued for all existing defences as these are assumed to remain in place. If an opportunity arises to improve defence standard for some or all of the flood cell earlier than described, e.g. through redevelopment of a site, this should be taken and defences raised to the appropriate design level described for 2115 (generally). The remainder of the flood cell defences can then be added at an appropriate time.

The timing of the actions is largely down to the predicted rate of sea level rise over the next 100 years. This needs to be monitored and the actions and timings reviewed if changes to the assumed rates are apparent.

10 Flood Cell F

10.1 Overview

Flood Cell F comprises the area on the west of the River Taw and to the south of the A3125 Bridge. Immediately to the north lies the Anchorwood Bank development site. Flood cell F has been excluded from the analysis of costs and benefits as defences here are imminently being improved as part of the Anchorwood Bank development. These will extend along the entire frontage of flood cell F.

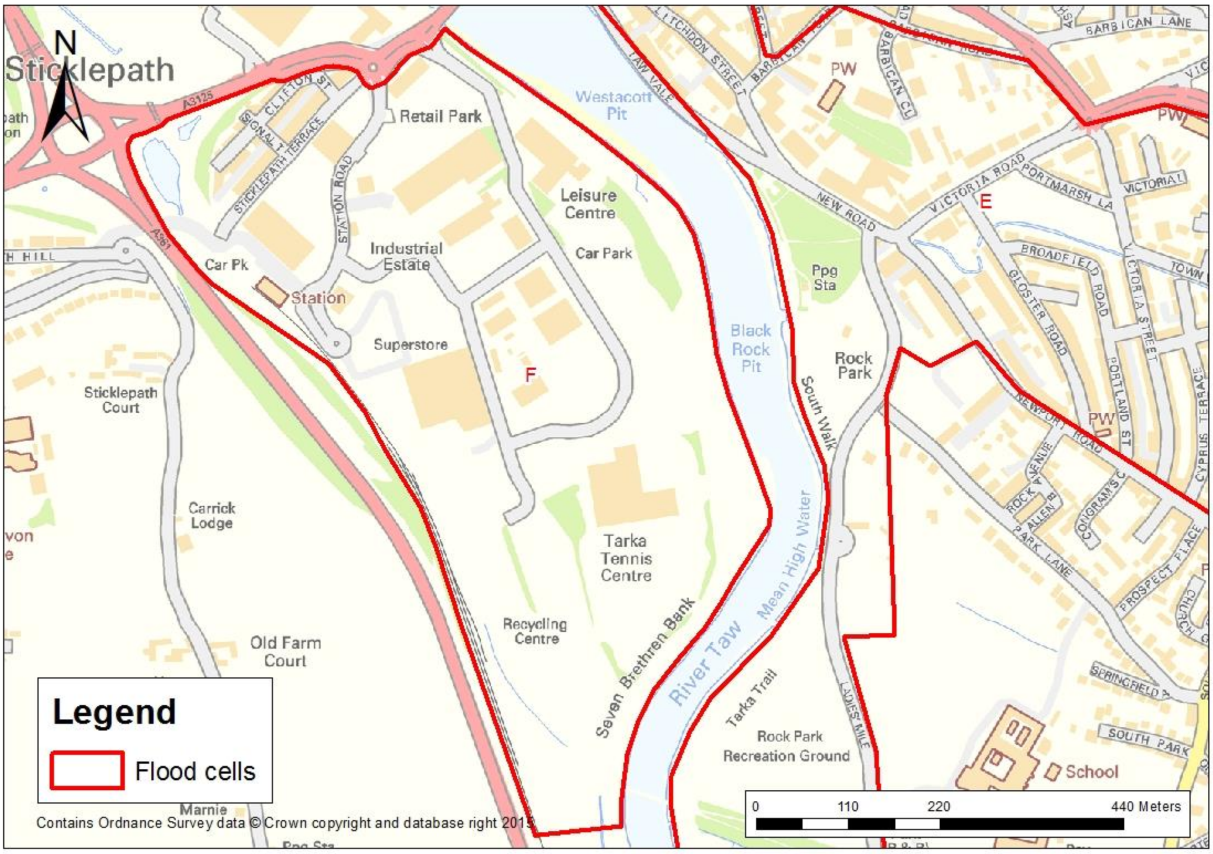

Figure 10-1: Flood cell F boundary

The proposed outcomes and timescales for Flood Cell F are as given in Table 10-1.

Table 10-1 Flood cell C: Proposed outcomes and timescales

Timescale	Action	Comment
2015 to 2045	Defences are being updated imminently.	Anchorwood development is driving these defence improvements.
2045 to 2075	Maintain improved defences.	May be a need to review the defences are still meeting the sea levels being observed.
2075 to 2115	Maintain improved defences.	May be a need to review the defences are still meeting the sea levels being observed.

11 Summary and Conclusions

11.1 Summary

Current and future flood risks in Barnstaple are cause for concern for Devon County and North Devon District Councils. The production of a flood defence improvement strategy for the next 60 to 100 years will enable future redevelopment of housing and employment sites, promoting economic development and raise employment opportunities. It will also help to revitalise and regenerate the northern part of the town.

The current and future (2075 and 2115) flood risks from both fluvial and tidal sources were modelled. From these results the numbers of properties at risk was extracted for a range of flood events and the resultant economic damages were calculated within each flood cell. Results were determined for 2015, 2075 and 2115 through modelling and where required an indication of 2045 results through interpolation of the 2015 ad 2075 results.

Table 11-1 Present Value Damages associated with tidal flooding

Present Value Damages (PvD)	2015 (£k)	2075 (£K)	2115 (£k)
Cell A	58	2,727	35,449
Cell B	1,195	68,638	101,112
Cell C	42	2,439	39,522
Cell D	0	0	247
Cell E	40	6,442	81,161
Cell F	Excluded from analysis		
Total	**1,335**	**80,246**	**257,491**

Table 11-2 Present Value Damages associated with fluvial flooding

Present Value Damages (PvD)	2015 (£k)	2075 (£K)	2115 (£k)
Cell A	4,590	8,864	26,663
Cell B	3,795	29,389	94,430
Cell C	28	3,355	29,108
Cell D	0	184	635
Cell E	3,387	11,386	15,457
Cell F	Excluded from analysis		
Total	**11,800**	**53,178**	**166,293**

A suite of options were considered for each flood cell, and these were modelled to assess how future levels of flood risk could be managed. These included the raising of existing embankments and flood walls, raising of the A361 and cycle track north towards Pilton Community College, and the option of either piling around the existing course of the Yeo through Pilton Park (option 1), or re-routing it along the A39 Pilton Causeway (option 2).

With the proposed flood defences in place in the future, the fluvial and tidal flood risks will substantially reduce compared to the situation in the future without them (Do Minimum). The level of flood risk achieved by both options is essentially the same. The economic benefits associated with the defence options have been calculated for each flood cell in 2075 and 2115 (and an indication for 2045 also given for Flood Cell B).

The cost of each option has been estimated. From this work it has been estimated that total costs for all of the proposed flood defence improvements are £26.3 to 67.1m for Option 1, and £20.0 to 44.0m (high cost) for Option 2. These options are likely to be economically viable as they are far less than the potential benefits of the schemes. Timing of the investment is hard to determine at this time and is largely dependent on the rate of increasing sea levels due to climate change. It is likely different flood cells will be progressed at different times and it may be not all elements of the defences described in this document will be progressed.

Table 11-3 Total cost associated with Options 1 and 2, including capital costs, 20% preliminaries and 60% optimism bias

Costs including capital costs, 20% preliminaries and 60% optimism bias (£k)	Option 1 - cost		Option 2 - cost	
	Low cost	High cost	Low cost	High cost
Cell A	4,815	8,968	4,815	8,968
Cell B	9,767	36,284	3,045	11,182
Cell C	2,129	4,099	2,479	6,035
Cell D	1,152	2,139	1,152	2,139
Cell E	8,484	15,656	8,484	15,656
Cell F	Excluded from analysis			
Total	26,348	67,146	19,975	43,979

Flood damages and benefits, particularly for the future scenarios, can only be considered indicative as there are many significant uncertainties in these calculations so far in the future. The rate of sea level rise for example is a large influence on the flood risks being predicted and then the damages are influenced by the capping applied on each property which is itself very uncertain.

The rate of sea level rise at Barnstaple and the timing of investment should be monitored and the outcomes of this study kept updated over coming decades. More pressing maintenance needs on individual defences will perhaps be of most immediate concern in Barnstaple to retain existing effective defences.

11.2 Conclusions

It is clear from the analysis that flood risk in Barnstaple is predicted to increase substantially over the next 100 years both from tidal sources, as a result of sea level increases, and from fluvial sources, as a result of expected peak flow increases and increased duration of tide locking of outfalls. In future Barnstaple will need more and larger flood defences and many more properties will be relying on flood defence infrastructure. This in itself can bring challenges as residual risk of defence failure or overtopping will exist and may require additional emergency planning.

The rate of sea level rise at Barnstaple and the timing of investment should be monitored and the outcomes of this study kept updated over coming decades. More pressing maintenance needs on individual defences will perhaps be of most immediate concern in Barnstaple to retain existing effective defences.

This study should in part give a framework to help unlock future development potential in Barnstaple. It should also facilitate the consideration of how external funding sources can be used to help fund future flood defences.

Based on the analysis described in this report and the many associated limitations of a study looking so far into the future the outcomes of the study for each flood cell are shown below.

Flood Cell A

Timescale	Actions	Comment
2015 to 2045	Do Minimum, except consider PLP to residential properties in Meadow Road area.	Benefits are low overall, however there are residential benefits that could be realised locally.
2045 to 2075	Do Minimum, except consider PLP to residential properties in Meadow Road area if not already done so.	Benefits are low overall, however there are residential benefits that could be realised locally.

2075 to 2115	Implement remaining proposed defences.	Options become financially viable now that existing defence levels are more vulnerable to overtopping.

Flood Cell B

Timescale	Action	Comment
2015 to 2045	Do Minimum More detailed consideration of improvement works to defences on River Yeo should be undertaken.	2015 benefits are not high enough for full scheme however some defences along the River Yeo are already modelled as overtopping during a 0.5% AEP event leaving flood cell B vulnerable. By 2045 there may be enough benefits to undertake at least part of the scheme.
2045 to 2075	Defence works on the River Yeo will be required.	Benefits expected to far exceed likely costs by 2075.
2075 to 2115	Implement remaining proposed defences.	If not carried out already.

Flood Cell C

Timescale	Action	Comment
2015 to 2045	Do Minimum. River Yeo works should be considered alongside those in Flood Cell B, i.e. undertake works on both sides of the Yeo.	Benefits in flood cell C unlikely to be high enough to proceed with scheme, unless part can be joined with flood cell B.
2045 to 2075	Do Minimum. River Yeo works should be considered alongside those in Flood Cell B, i.e. undertake works on both sides of the Yeo.	Benefits in flood cell C unlikely to be high enough to proceed with scheme, unless part can be joined with flood cell B.
2075 to 2115	Implement proposed defences on Taw frontage and River Yeo, if not carried out already.	Works on flood cell C only become economically viable after 2075.

Flood Cell D

Timescale	Action	Comment
2015 to 2045	Do Minimum.	No justification for defence improvements.
2045 to 2075	Do Minimum.	No justification for defence improvements.
2075 to 2115	Do Minimum.	Benefits in flood cell D unlikely to be high enough for scheme.

Flood Cell E

Timescale	Action	Comment
2015 to 2045	Do Minimum.	No justification for defence improvements.
2045 to 2075	Do Minimum.	Benefits in flood cell E unlikely to be high enough to for scheme.
2075 to 2115	Improve Taw defences. Consider viability of improved Coney Gut defences.	Benefits of tidal flooding far exceed likely costs of tidal defences. Fluvial benefits unlikely to be high enough to proceed with scheme but additional information may be available by this time.

Flood Cell F

Timescale	Action	Comment
2015 to 2045	Defences are being updated imminently.	Anchorwood development is driving these defence improvements.
2045 to 2075	Maintain improved defences.	May be a need to review the defences are still meeting the sea levels being observed.
2075 to 2115	Maintain improved defences.	May be a need to review the defences are still meeting the sea levels being observed.

Appendices

A Design Input Statement

B Long List of Options

C Design Technical Notes

D Environmental Assessment

Offices at

Coleshill

Doncaster

Dublin

Edinburgh

Exeter

Haywards Heath

Limerick

Newcastle upon Tyne

Newport

Saltaire

Skipton

Tadcaster

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