

***RIVER AVON TIDAL FLOOD RISK
MANAGEMENT STRATEGY***

Short List Options Report

July 2016

Prepared for Bristol City Council

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Background

This project will deliver a Tidal Flood Risk Management Strategy (TFRMS) (the 'Strategy') for the area of Bristol at risk of flooding from the River Avon, including the city centre (between Cumberland Basin and Netham) Shirehampton and Avonmouth. Downstream and upstream impacts will be considered, including Pill and Portbury.

The flood risk in the study area is dominated by tidal events and this is the focus of the study. The development of the Strategy will be underpinned by an appraisal of management options of 'strategy alternatives' to address present and future tidal flood risk. The Strategy will recommend the preferred programme of adaptive measures identifying when measures are needed and how they will be funded.

The report follows on from the Long Listing report which identified for further assessment 39 Strategic Options, each comprised of a number of measures spanning 100 years in 3 time epochs.

This report describes the process by which those 39 options have been narrowed down to a short list, comprising a total of eight Strategic Options. The short list of options will be used during future appraisal work to develop the preferred strategy.

The short-listed Options taken forward to the next stage of the project will be assessed in further detail and further stakeholder engagement will take place before a single preferred Option is selected.

Studies Undertaken

The following technical studies have been completed:

- Numerical modelling of flood risk for the Do Nothing and Do Minimum Options, as well as selected modelling of aspects of barrier options. The CAFRA Workstream 3 model has been modified to represent the Do Nothing (walk-away) scenario and a series of model runs completed to represent different tidal events over the three epochs. The model was then modified to represent the Do Minimum (continue with existing defences) scenario and run for a range of tidal events over the three epochs.
- Assessment of Do Nothing and Do Minimum flood damages. Flood extents have been mapped, and damages have been calculated using the methods mandated by the Environment Agency's procedures for flood and coastal risk management studies.
- Concept design of measures and assessment of technical feasibility. A range of measures to protect Bristol from flooding have been conceived, and their feasibility assessed. Measures include property level protection, a number of variants of a tidal flood barrier and a number of variants using flood walls. In the case of tidal flood barrier this has included numerical modelling to test whether the barrier is able to pass fluvial flood flows without causing an increase in fluvial flood risk.
- Costing of measures.
- Environmental assessment

Taken together, these studies form a basis for understanding the flood risks which Bristol faces from tidal events over the next 100 years, and the measures by which those risks might be mitigated.

Flood Risk – Now and Future

The modelling work has shown that Bristol currently faces a significant risk of tidal flooding and that this risk will increase substantially over the next 100 years.

In Epoch 1, a 1 in 200 year (0.5%) event under a Do Nothing scenario would result in the flooding of around 2700 properties. Under the more realistic Do Minimum scenario which reflects current practices, the number of properties at risk would be around 1000.

By Epoch 3 the potential consequences of a tidal event are extremely severe, and the difference between the Do Nothing and Do Minimum scenarios becomes more marginal, as rising sea levels negate the presence of many existing control structures. In a 1 in 200 year (0.5%) event, some 4300 properties would be flooded in the Do Nothing scenario, and large areas would have flood depths of more than 1m. In the Do Minimum scenario some 3700 properties would be affected in the same event.

In a Do Nothing scenario it is estimated that the present value of flood damages would exceed £1.8 billion over the 100 year period until 2115.

These figures exclude any properties built after 2011, or any which are planned to be built in the affected areas. Flood risk currently constrains development in many areas of the city.

Appraisal and Comparison of Options

Each Strategic Option comprises a sequence of measures, extending over the three epochs. Information from the technical studies has been used to put together a concept and description of each Option.

Assessment of each Option has then focussed around the following criteria, derived from the Project Objectives:

- Flood risk and Health and Safety
- Sustainability
- Environment
- Whole life cost
- Navigation and marine activities
- Deliverability

A multi-criteria analysis has been used to assess each Option against these criteria, using a score to reflect the positive, neutral or negative impact of the Option.

The Options were then ranked according to their total scores, and initially 8 options were proposed for the shortlist. Following a moderation and rationalisation process by the technical team (AECOM with BCC, Paul Sayers (adviser to BCC) and the Environment Agency) seven options were selected for the shortlist.

The seven options include a broad range of approaches, from highly precautionary to highly adaptive. Not all of the options meet all of the objectives. Acceptability of options – including environmental impact, whether they meet BCC aspirations for development and whether they are affordable – will be considered in the next stage of the study.

Conclusions

The following seven options have been identified as the highest scoring and it is recommended that they are taken forward to the short list assessment stage:

Option Number and title	Epoch 1 (2015-2030)	Epoch 2 (2030-2065)	Epoch 3 (2065-2115)
23 - High Defences – High Defences – High Defences	Linear flood walls built to protect Bristol to a 1 in 200 year standard or higher, for the next 100 years	Walls maintained, standard falls over time but remains better than 1 in 200	Walls maintained, standard falls over time to 1 in 200 in 2115
9 - PLP – High Defences – High Defences	Property level measures used to mitigate flood risk	Linear flood walls built to protect Bristol to a 1 in 200 year standard or higher, for the next 100 years	Walls maintained, standard falls over time to 1 in 200 in 2115
10 - PLP – Narrow Barrier – Narrow Barrier	Property level measures used to mitigate flood risk	'Narrow' tidal flood barrier built to protect Bristol to a 1 in 200 year standard or higher, for the next 100 years	Barrier maintained, standard falls over time to 1 in 200 or higher
17 - Low Defences – Low Defences – High Defences	Linear flood walls built to protect Bristol to a 1 in 200 year standard or higher in 2015.	Additional linear flood walls built to protect Bristol to a 1 in 200 year standard or higher in 2030.	Additional linear flood walls built to protect Bristol to a 1 in 200 year standard or higher until 2115, with existing walls being raised or replaced as necessary
21 - Low Defences – Narrow Barrier– Narrow Barrier	Linear flood walls built to protect Bristol to a 1 in 200 year standard or higher, for the next 30 years	'Narrow' tidal flood barrier built to protect Bristol to a 1 in 200 year standard or higher, for the next 100 years	Barrier maintained, standard falls over time to 1 in 200 or higher
36 - Do Min – Do Min – High Defences	Do Minimum approach, no new defences	Do Minimum approach, no new defences	Linear flood walls built to protect Bristol to a 1 in 200 year standard or higher until 2115
6 – PLP – Low Defences – High Defences	Property level measures used to mitigate flood risk	Linear flood walls built to protect Bristol to a 1 in 200 year standard or higher in 2030.	Linear flood walls built to protect Bristol to a 1 in 200 year standard or higher until 2115, with existing walls being raised or replaced as necessary

2. PROJECT BACKGROUND

Effective strategic tidal flood risk management is essential for the city of Bristol, not just because of the threat to lives and property, but also because of the risk of long-term reputational damage to the city's attractiveness and economic prosperity.

This project will deliver a Tidal Flood Risk Management Strategy (TFRMS) (the 'Strategy') for the area of Bristol at risk of flooding from the River Avon, including the city centre (between Cumberland Basin and Netham) Shirehampton and Avonmouth. Downstream and upstream impacts will be considered, including Pill and Portbury. The study area is shown in Figure 1 and Figure 2.

The flood risk in the study area is dominated by tidal events and this is the focus of the study. The development of the Strategy will be underpinned by an appraisal of management options of 'strategy alternatives' to address present and future tidal flood risk. The Strategy will recommend the preferred programme of adaptive measures identifying when measures are needed and how they will be funded.

2.1 Strategy objectives

The objectives of the Tidal Flood Risk Management Strategy, as set out in the Baseline Review are as follows:

1. To develop an agreed understanding of flood risk from now until 2115 and to quantify the impact of this risk on the existing development and infrastructure, and future proposals.
2. To confirm intervention options that form components of an adaptive strategic approach to maintain an acceptable level of flood risk from now until 2115 (subject to review on the basis of the preferred intervention(s) timing and type).
3. To evaluate the justification for investment and recognise the different drivers and priorities of BCC and the Environment Agency.

2.2 Previous studies and recommended options

A number of studies investigating the flood risk in Bristol have recently been undertaken. In 2011 Bristol City Council commissioned the Bristol Central Area Flood Risk Assessment (CAFRA) to develop an understanding of flood risk on tidally-influenced watercourses within the Bristol City boundary. CAFRA was divided into four workstreams, and also included a parallel harbour study. Workstream 1 collected and reviewed existing hydraulic models, studies and survey data. Workstream 2 considered joint probability to derive boundary conditions for the CAFRA numerical modelling. Workstream 3 detailed the hydrodynamic model build and assessment of the predicted flood risk. And finally, Workstream 4, alongside the harbour study, scoped fluvial and tidal flood risk management options. Recent updates to the CAFRA study have been carried out in 2014 and 2015.

In 2013 the First Phase Feasibility study was undertaken to appraise strategic options to manage the flood risk in central Bristol, from present day to 2110. The study identified strategic interventions, undertook a high level economic appraisal of options and recommended a strategic flood risk approach. Given the changing flood risk profile over the next century an adaptive approach that progressively improves the flood risk management by building on the outcomes of previous interventions was advocated by the study. Based upon the shortlist of options, a series of interventions were recommended by the First Phase Feasibility study:

- Improved flood forecasting, warning and planning;
- Early raised defences at low spots along the riverside to reduce the risk of overtopping into the floating harbour;
- Local interventions and improved operational resilience to lower residual fluvial and pluvial flood risk as part of a wider flood risk management strategy; and
- Longer term strategic protection against storm tides with an allowance for sea level rise, the most likely measure being a citywide solution involving a tidal barrier.

The CAFRA studies and First Phase Feasibility Study were undertaken at high level strategic scales, with a number of limitations and constraints. These are described in the Baseline Review Briefing Note.

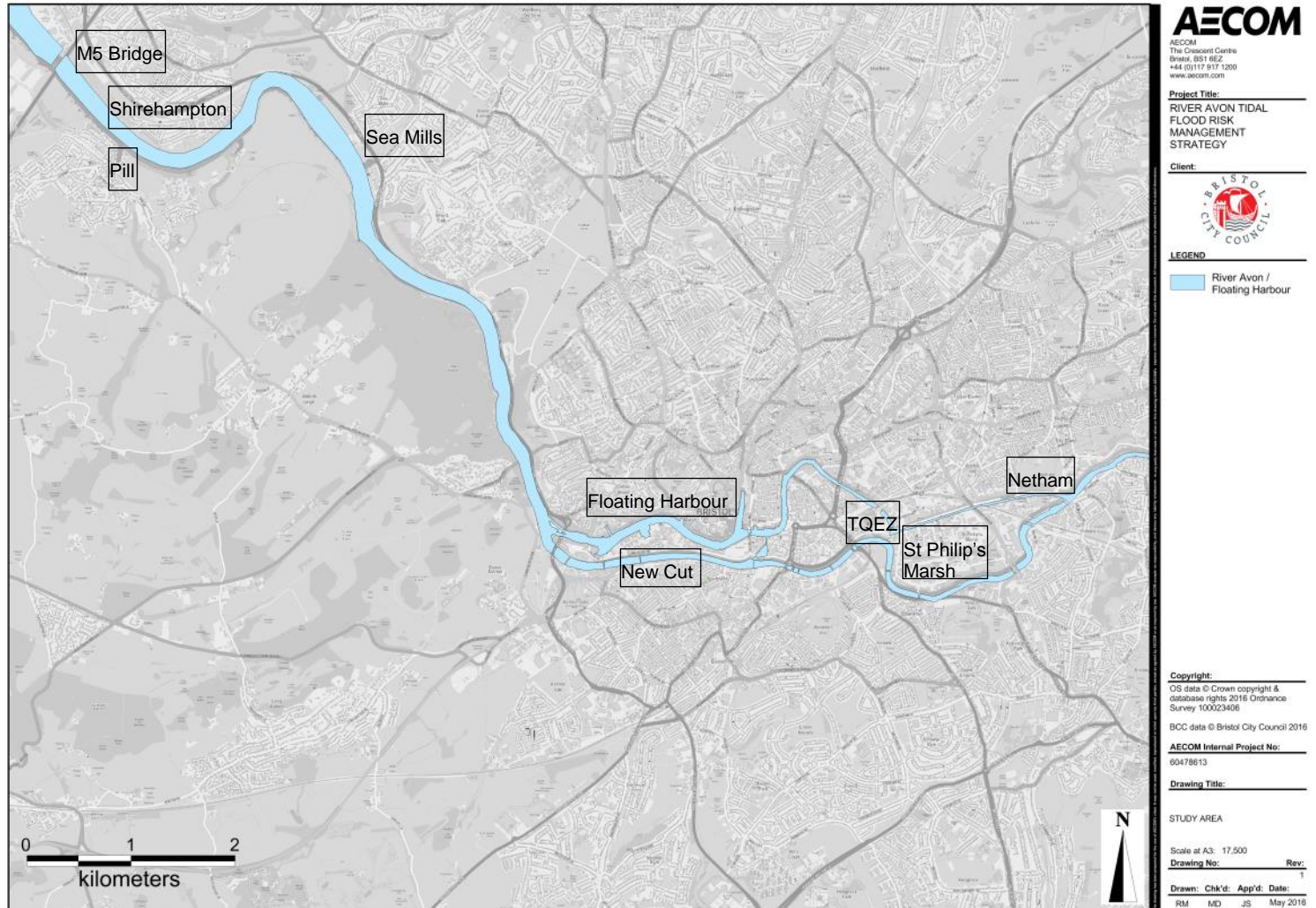


Figure 1 Map of the study area

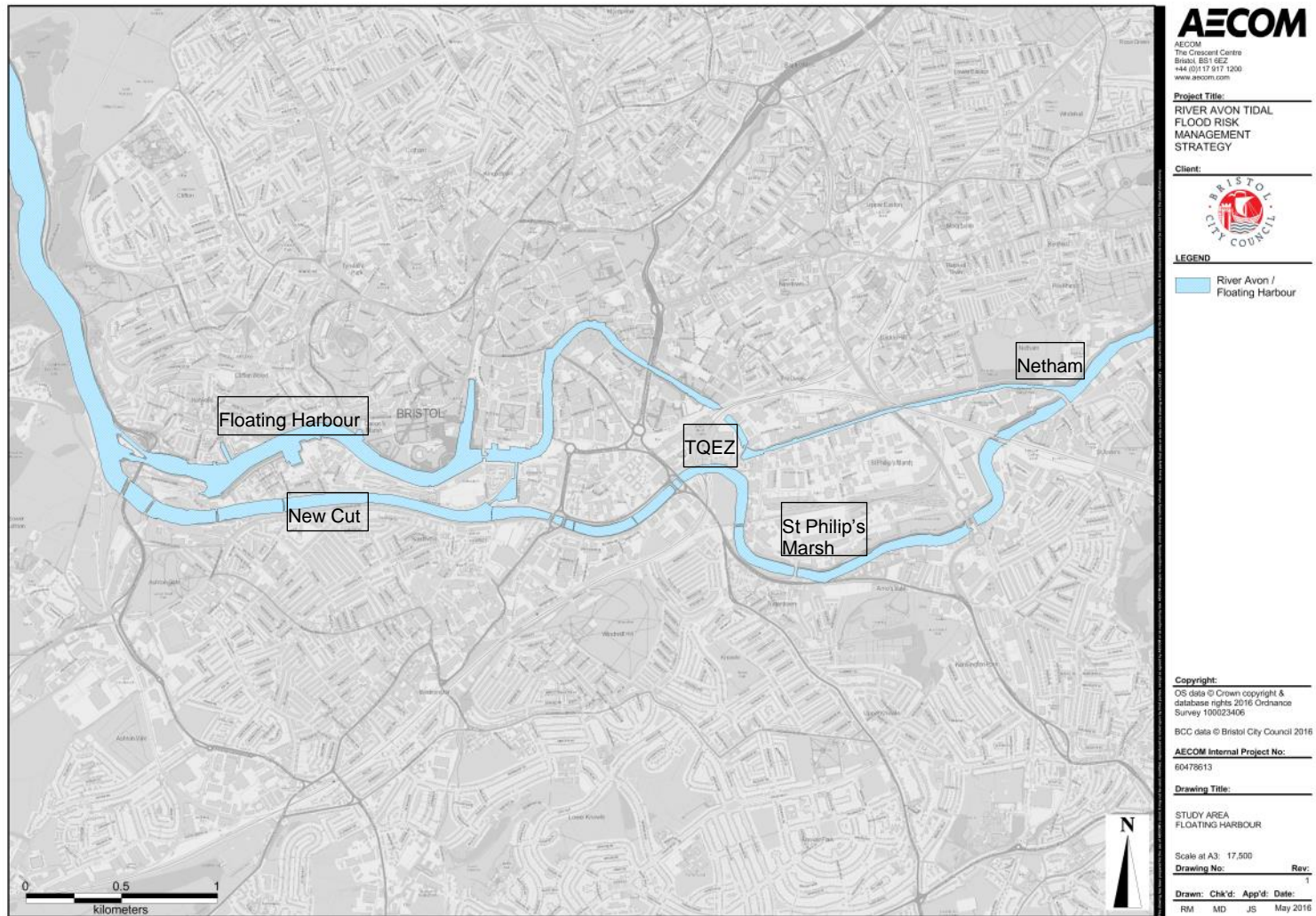


Figure 2 Map of central Bristol and the Floating Harbour

2.3

Structure of this report

Chapter 3 sets out the flood risk baseline for the study area, describing the results of the numerical modelling which has been undertaken to underpin the option appraisal process.

Chapter 4 provides an overview of the option appraisal process, defining 'measures' and 'strategic options'.

Chapter 5 provides an in-depth description of each of the potentially feasible measures identified in the long list report. The economic cost, technical feasibility and potential environmental impacts of each measure is assessed, as well as the potential stakeholder aspirations / concerns that may arise when implementing each measure. Chapter 5 provides a detailed evidence base for each of the measures.

In Chapter 6, the evidence for each measure is combined and used to appraise the 39 different strategic options. The appraisal uses a multi-criteria assessment to evaluate the strategic options. This involves assessing the impact of each of the long list options against the six strategy option objectives. A scoring system is applied to score the options relative to the Do Nothing scenario. This allows for the relative merits and drawbacks of the long list strategic options to be compared.

Chapter 7 summarises the results of the appraisal and presents the recommended short list of strategic options in more detail.

Chapter 8 outlines the next steps to be taken in the Strategy.

This report should be read in conjunction with the following technical reports:

- Environmental Assessment Report
- Economic Assessment Report
- Hydraulic Modelling Report

3. FLOOD RISK

3.1 Overview of tidal flood risk in Bristol

Hydraulic modelling has been undertaken for the Do Nothing scenario and Do Minimum scenarios. The model results show current flood risk and how risk is expected to evolve over time, identifying the number of properties that are at risk.

An overview of the tidal flood risk in the Strategy study area is provided in the Hydraulic Modelling Report. Further work will be required to refine these results during the next stage of the project.

Low spots along the banks of the River Avon, notably at Avon Crescent, Junction Lock and Bathurst Basin are the first pathways for flood water to inundate a significant number of properties in central Bristol. Other areas, such as Baltic Wharf are also at risk as water levels become raised in the Floating Harbour and overtop low spots in the defences. At present (i.e. with no allowance for climate change considered), a number of low lying areas at St. Phillips Marsh, the Cumberland Basin and Netham are at risk of flooding. This flood risk is expected to evolve in the future due to rising sea level and increased magnitudes of extreme tidal water levels. More details of the flood risk are provided in sections 3.3 and 3.4 below.

Based upon the results of the Hydraulic modelling it is estimated that the Do Nothing damages will reach approximately £1.87 billion over the appraisal period (2015-2115). A breakdown of the Do Nothing damages is presented in Table 1 below.

Table 1 PV Flood Damages for the appraisal period (2015-2115)

PV Flood Damages –(£k)		PV Flood Damages – Write Off and Capping (£k)		PV Other (£k)	PV Total (£k)
Residential	Commercial	Residential	Commercial		
330,000	1,130,000	191,000	144,000	79,000	1,873,000

3.2 Extreme water levels adopted by the Strategy

It has been agreed with the project team to adopt the Medium Emissions 95th percentile scenario as the change factor for future tide levels. This has been decided to ensure that the options and economic appraisal is consistent with other Flood and Coastal Erosion Risk Management (FCERM) projects and therefore potential grant-in-aid eligibility of the options can be assessed in accordance with FCERM appraisal guidance. Therefore, unless otherwise stated, the extreme water levels referred to in this report have been determined using the Medium Emissions scenario.

Table 2 below presents the extreme water levels for the Strategy under a range of climate change emission scenarios; the Medium Emissions scenario, the High Emissions scenario and the Upper End emissions scenario. Water levels for a range of return period events across the different Strategy time epochs are shown. More details of the combined fluvial and tidal sources to determine the joint probability events are presented in the Hydraulic Modelling Report. Note that the Local Planning Authority uses a different set of climate change allowances for planning purposes; the allowances were updated by the Environment Agency in February 2016; these allowances approximate to the High Emissions 95% scenario in Table 2.

Table 2 Extreme Tide Levels (Medium Emissions 95%tile scenario adopted by the Strategy). Levels provided are for the downstream boundary of the numerical model.

Epoch	Return Period	Tide Level (m AOD)		
		Upper End SLR	Medium Emissions 95%ile SLR	High Emissions 95%ile SLR
2015	20yr	8.69	8.69	8.69
	75yr	8.94	8.94	8.94
	200yr	9.13	9.13	9.13
	1000yr	9.45	9.45	9.45
2030	20yr	8.78	8.77	<i>Not considered</i>
	75yr	9.03	9.02	<i>Not considered</i>
	200yr	9.22	9.21	<i>Not considered</i>
	1000yr	9.54	9.53	<i>Not considered</i>
2065	20yr	9.11	9.01	9.08
	75yr	9.36	9.26	9.33
	200yr	9.55	9.45	9.52
	1000yr	9.87	9.77	9.84
2115	20yr	9.84	9.43	9.59
	75yr	10.09	9.68	9.84
	200yr	10.28	9.87	10.03
	1000yr	10.60	10.19	10.35

3.3

What is at risk in Do Nothing?

Do Nothing represents a hypothetical baseline against which all other measures and strategic options can be compared. Under the Do Nothing approach, all maintenance, repair and renewal work of existing flood defences, together with assets whose function influences flood risk (i.e. lock gates) would cease immediately. There would be no investment in asset maintenance from the present day onwards. If this approach were adopted, existing flood defences would deteriorate, and any damage would not be repaired. It is assumed that all water level management assets (e.g. lock gates, sluices and lock systems) would be left in an open position, or fail and then remain in an open position throughout the duration of the appraisal period. This would result in the defence system being in a poor condition immediately and this would further deteriorate over time.

Table 3 below presents the agreed timeline of asset failure under the Do Nothing scenario. This timeline was developed for the purpose of the numerical hydraulic modelling exercise and has been used as a basis for the Do Nothing model simulations. Agreed approach was captured in *River Avon TFRMS – Baseline Scenarios Note*, 10 March 2016

Table 3 Do Nothing scenario: Asset representation

Time Period	Asset Location and Description	Comments/Assumptions	Failure Representation / Model Commentary
2015 to 2065	Albert Road, Totterdown – Mid Section	Poor condition, failing. Local issues/gaps in defences. EA FRM asset.	Modelling to assume failure across all epochs.
	Pill and Shirehampton; Raised Flood Gates	Manually operated. EA FRM asset.	Location of defence within 1D domain. As such, this defence is represented as 'left open' within both the Do Nothing and Do Minimum model setup for all epochs.
	Netham Lock Gates and Sluices	Lock gates retain Floating Harbour water level and provide safe haven for mariners New lock gate – Good condition. Sluice paddles and operating system – Poor condition. Resilience of operation system believed to be poor.	Modelling to assume failure in 'open' position across all epochs.
	Totterdown Dam	No available info. Construction form unknown having been infilled and covered. Assume condition is fair.	Assume solid structure with minimal chance of failure. This structure has been represented as 'not failed' for all epochs.
	Nova Dam and Sluices	Nova Dam – Fair condition. Sluices and electrical system – very good condition. Standby generator may be vulnerable to flooding.	Modelling to assume failure to sluices only in 'open' position across all epochs.
	Junction Lock Gate and Sluices	New stop gates, upper gates and sluices – Very good condition. Old backup gates – Poor condition (inundated during spring tides).	Modelling to assume failure in 'open' position across all epochs.
	Entrance Lock Gates	Resilient against flooding. Lock gates stowed at times of surge tide and are unable to hold back high river levels.	Modelled as 'open' in both Do Nothing and Do Minimum scenario.
	Underfall Yard: Culverts, Sluices and Gates	High vulnerability to flooding –Poor condition.	Modelling to assume failure in 'open' position across all epochs.
			Modelling to assume failure in 'open' position across all

	Brunel Dam Sluices / Gates	High vulnerability to flooding –Poor condition.	epochs.
2065 to 2115	1 - Marine Parade (Pill); Masonry Flood Wall 2 - Marine Parade (Pill); Embankment 3 - Shirehampton Sailing Club; Embankment 4 - Shirehampton Sailing Club; Flood Wall	EA FRM asset. 1 - Good condition. 2 - Fair condition. 3 - Good condition. 4 - Good condition.	1-4: Location of defences within 1D domain. As such, this defence is represented as 'failed' within both the Do Nothing and Do Minimum model setup for all epochs.
	Albert Road, Totterdown – North Section	Fair condition. EA FRM asset.	Modelling to assume failure for this epoch only.
	Totterdown – Defences adjacent Bristol RSPCA (concrete wall)	Fair condition. Current failure experienced through breaching. EA FRM asset.	Modelling to assume failure for this epoch only.
	Totterdown – Defences downstream of Bristol RSPCA (embankment)	Constructed in 2003. Good condition. EA FRM asset.	Modelling to assume failure for this epoch only.
	Cumberland Road Wall Defence	New structure with less than 50 year design life without maintenance.	Modelling to assume failure for this epoch only.
	New Cut: Retaining Wall and Drainage (900m).	Risk to Cumberland Road Wall.	Modelling to assume failure for this epoch only (by breach).
	Netham Weir masonry sub-structure, concrete crest and rock apron.	Netham Weir helps retain Floating Harbour water level. Netham Weir is retained due to legal navigation duty and enables a safe haven for mariners. Sub-structure and concrete crest currently in fair condition. Rock apron in poor condition. Consequence of rock apron failure likely to lead to undermining and failure of weir.	Assumed that the rock apron will fail in 2065, which will undermine and lead to failure of the weir itself. However in the Do Nothing model simulations the weir structure will not be breached as the flood risk arising from failure of the structure will be represented by the failure of Netham gates and sluices.

Do Nothing is not considered a feasible approach to flood risk management and is not incorporated into any of the long list options. It is understood from BCC that Do Nothing would probably not conflict with any legal duty that the Port or BCC has and it is important to understand what would happen if no further work was undertaken to address flood risk in Bristol (i.e. the walk away option).

As sea levels rise and defence condition deteriorates, flood risk would increase significantly from both failure of the defences and through inundation over areas of low lying topography. Defence failure would increase as the severity and frequency of overflowing increased.

Eventually many of the existing residential and commercial assets within Bristol would be written off. Economic prosperity, opportunities for growth and community viability in Bristol would significantly decrease, and therefore a Do Nothing approach would be politically unacceptable. Doing Nothing would

likely result in the escalation of uncertainty and this, with the loss of investor confidence, and lack of policy or infrastructure solution would result in the whole city and environs being prejudiced, and investment blocked or withdrawn.

Table 4 and Table 5 below present the numbers of properties within the study that are expected to be at risk of inundation under the Do Nothing scenario. For the present day approximately 2721 properties are at risk from a 1 in 200 year joint probability event. Approximately 64% of these properties are residential properties, with the remainder being non-residential or commercial. By 2115 the total number of properties at risk from a 1 in 200 year event is expected to have risen to 4345. Approximately 63% of these properties are residential.

The evolution of flood risk in the study area under the Do Nothing scenario is presented below in Figure 3 and Figure 4. The flood risk for a 1 in 200 year event for the present day (2015) and 2115 is shown. Within Bristol city centre the areas exposed to the greatest level of flood risk are located at Cumberland Basin, Cumberland Road, St. Phillips marsh, Totterdown (Victor Street), Albert Road and downstream of Netham.

Table 4 Properties at risk under the Do Nothing scenario; Residential and Commercial

Epoch	1:2yr (50%)		1:20yr (5%)		1:75yr (1.33%)		1:200yr (0.5%)		1:1000yr (0.1%)	
	Residential	Commercial	Residential	Commercial	Residential	Commercial	Residential	Commercial	Residential	Commercial
2015	486	225	883	476	1245	679	1743	978	2290	1316
2030	625	264	992	577	1308	713	1874	1064	2447	1382
2065	777	421	1706	910	1308	714	2092	1233	2291	1324
2115	1318	738	1876	1002	2061	1199	2724	1621	3740	2011

Table 5 Properties at risk under the Do Nothing scenario; Total

Epoch	1:2yr (50%)	1:20yr (5%)	1:75yr (1.33%)	1:200yr (0.5%)	1:1000yr (0.1%)
	Total	Total	Total	Total	Total
2015	711	1359	1924	2721	3606
2030	889	1569	2021	2938	3829
2065	1198	2616	2022	3325	3615
2115	2056	2878	3260	4345	5751

It should be noted that these figures do not include any properties built in the city since 2011 (as these are not eligible for Defra Grant in Aid flood defence funding) nor any of the 9052 homes planned to be built in the city between 2015-2026 in the housing trajectory assessment as set out in the current Local Plan document entitled *Bristol City Council Five Year Housing Land Supply 2015 – 2020*.

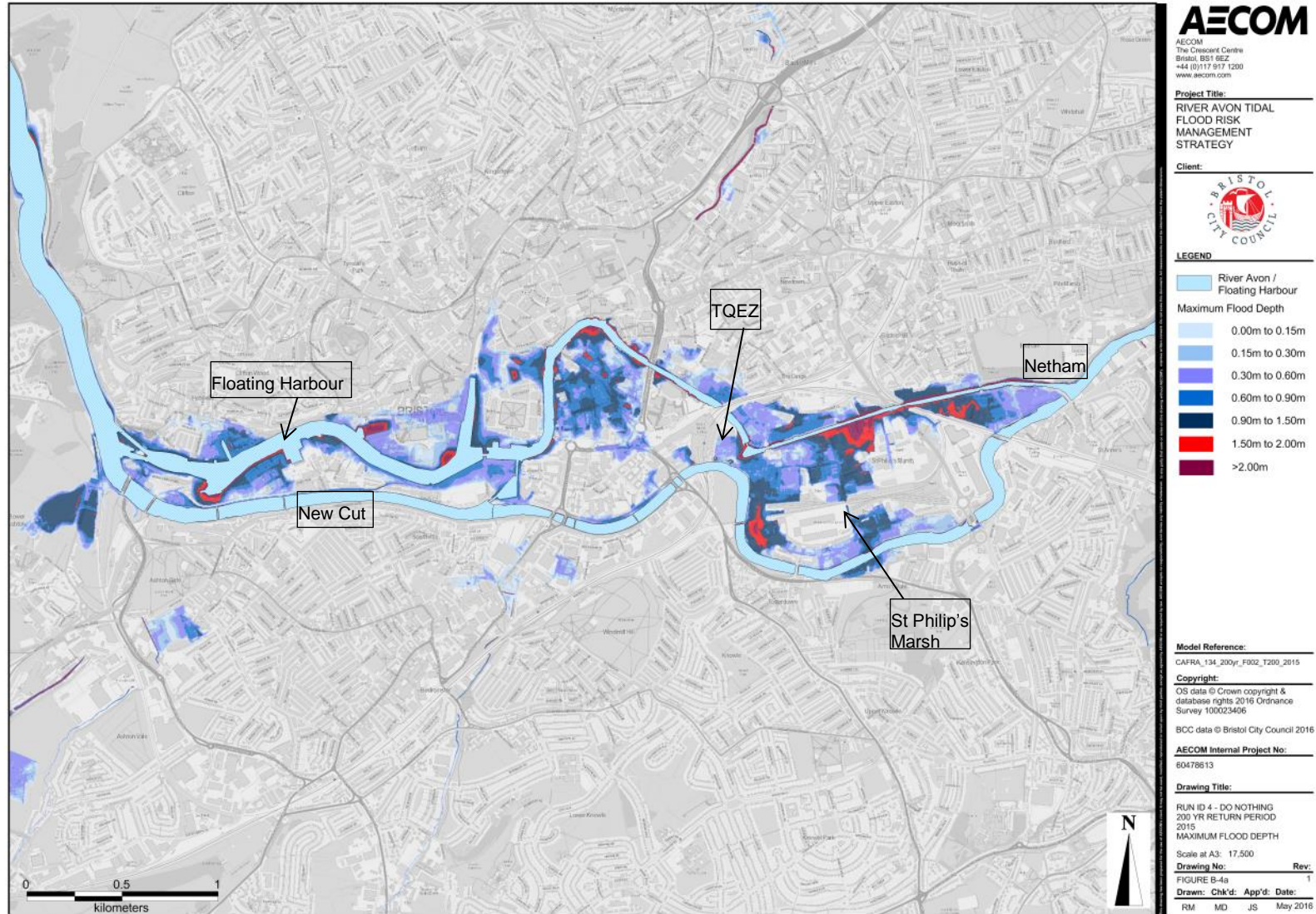


Figure 3 Flood Mapping for the Do Nothing scenario 1 in 200 year event 2015

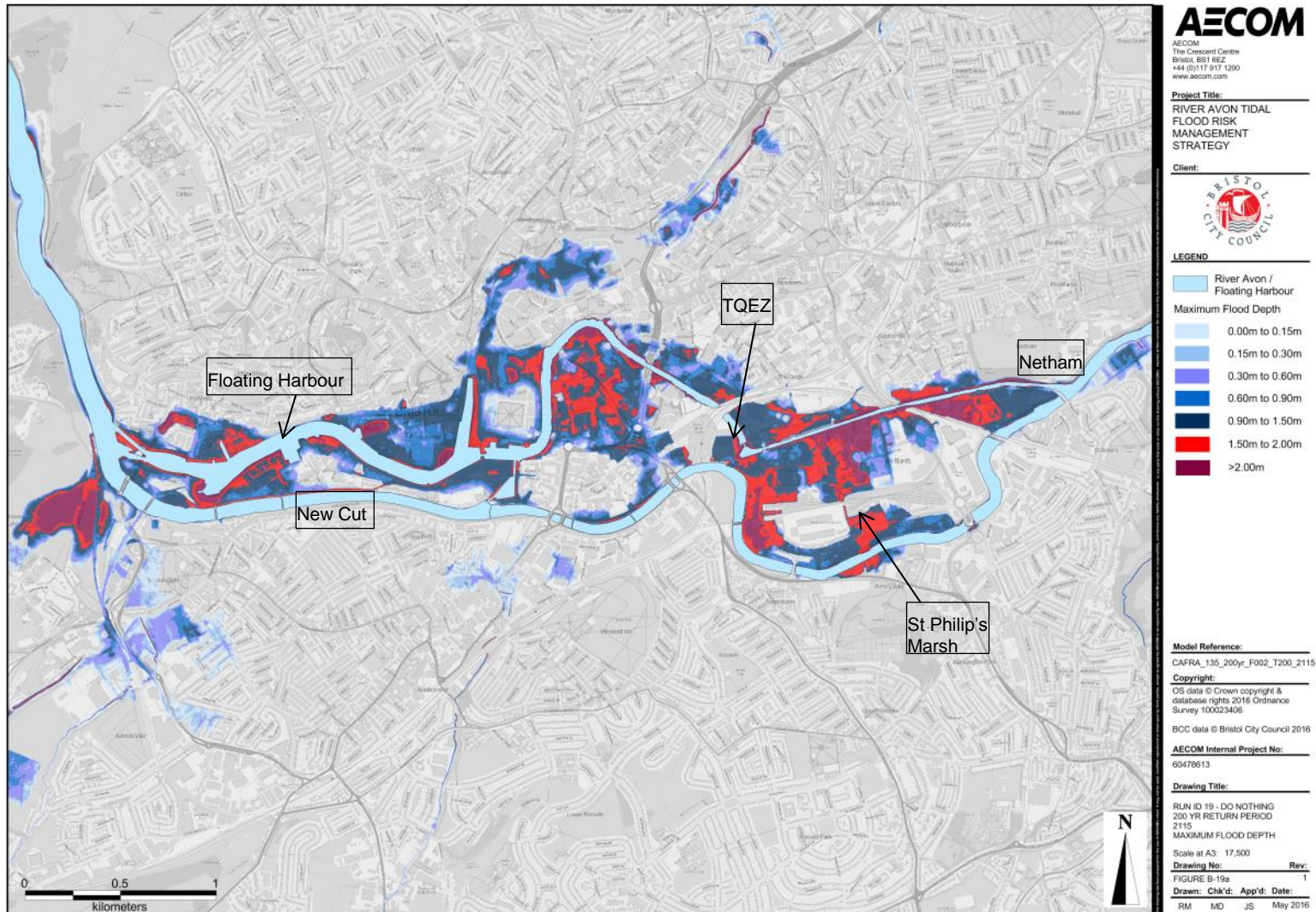


Figure 4 Flood Mapping for the Do Nothing scenario 1 in 200 year event 2115

3.4

What is at risk in Do Minimum?

Do Minimum represents what happens if the 'status quo' is maintained. This involves a continuation of maintenance to both the existing Floating Harbour water level control structures and raised defences throughout the duration of the Strategy period.

It is assumed that under the Do Minimum scenario the functioning of the Floating Harbour water level control structures would be sustained until 2115, and maintenance would incorporate improvements to the resilience of MEICA control and electrical systems to flooding (i.e. by raising the elevation of controls to reduce vulnerability to flooding). Do Minimum is considered a feasible approach to managing tidal flood risk.

Under Do Minimum it is assumed that like-for-like replacement of mechanical infrastructure e.g. lock gates would be undertaken but with no improvements in performance to account for sea level rise. The raised defences within the city and at Avonmouth (including Pill and Shirehampton) would be maintained to ensure their flood defence function continues; however, the defences would not be raised and consequently the standard of flood protection would be expected fall over time in response to sea level rise.

Table 6 and Table 7 below present the numbers of properties at risk under the Do Minimum scenario. For the present day approximately 1009 properties are at risk from a 1 in 200 year joint probability event. Approximately 54% of these properties are residential properties, with the remainder being non-residential or commercial. By 2115 the total number of properties at risk from a 1 in 200 year event is expected to have risen to 3718. Approximately 63% of these properties are residential.

The evolution of flood risk in the study area under the Do Minimum scenario is presented in Figure 5 and Figure 6. The flood risk for a 1 in 200 year event for the present day (2015) and 2115 is shown. The areas exposed to the greatest level of flood risk are located at Cumberland Basin, Cumberland Road, St. Phillips marsh, Totterdown (Victor Street), Albert Road and downstream of Netham.

Table 6 Properties at risk under the Do Minimum scenario; Residential and Commercial

Epoch	1:2yr (50%)		1:20yr (5%)		1:75yr (1.33%)		1:200yr (0.5%)		1:1000yr (0.1%)	
	Residential	Commercial	Residential	Commercial	Residential	Commercial	Residential	Commercial	Residential	Commercial
2015	171	60	236	158	319	257	547	462	1686	971
2030	186	84	267	189	339	278	758	522	2118	1090
2065	222	129	339	129	531	383	1686	971	1684	900
2115	331	273	795	474	1686	826	2365	1353	3506	1903

Table 7 Properties at risk under the Do Minimum scenario; Total

Epoch	1:2yr (50%)	1:20yr (5%)	1:75yr (1.33%)	1:200yr (0.5%)	1:1000yr (0.1%)
	Total	Total	Total	Total	Total
2015	231	391	576	1009	2657
2030	270	456	617	1280	3208
2065	351	468	914	2657	2584
2115	604	1269	2512	3718	5409

It should be noted that these figures do not include any properties built in the city since 2011 (as these are not eligible for Defra Grant in Aid flood defence funding) nor any of the 9052 homes planned to be built in the city between 2015-2026 in the housing trajectory assessment as set out in the current Local Plan document entitled *Bristol City Council Five Year Housing Land Supply 2015 – 2020*.

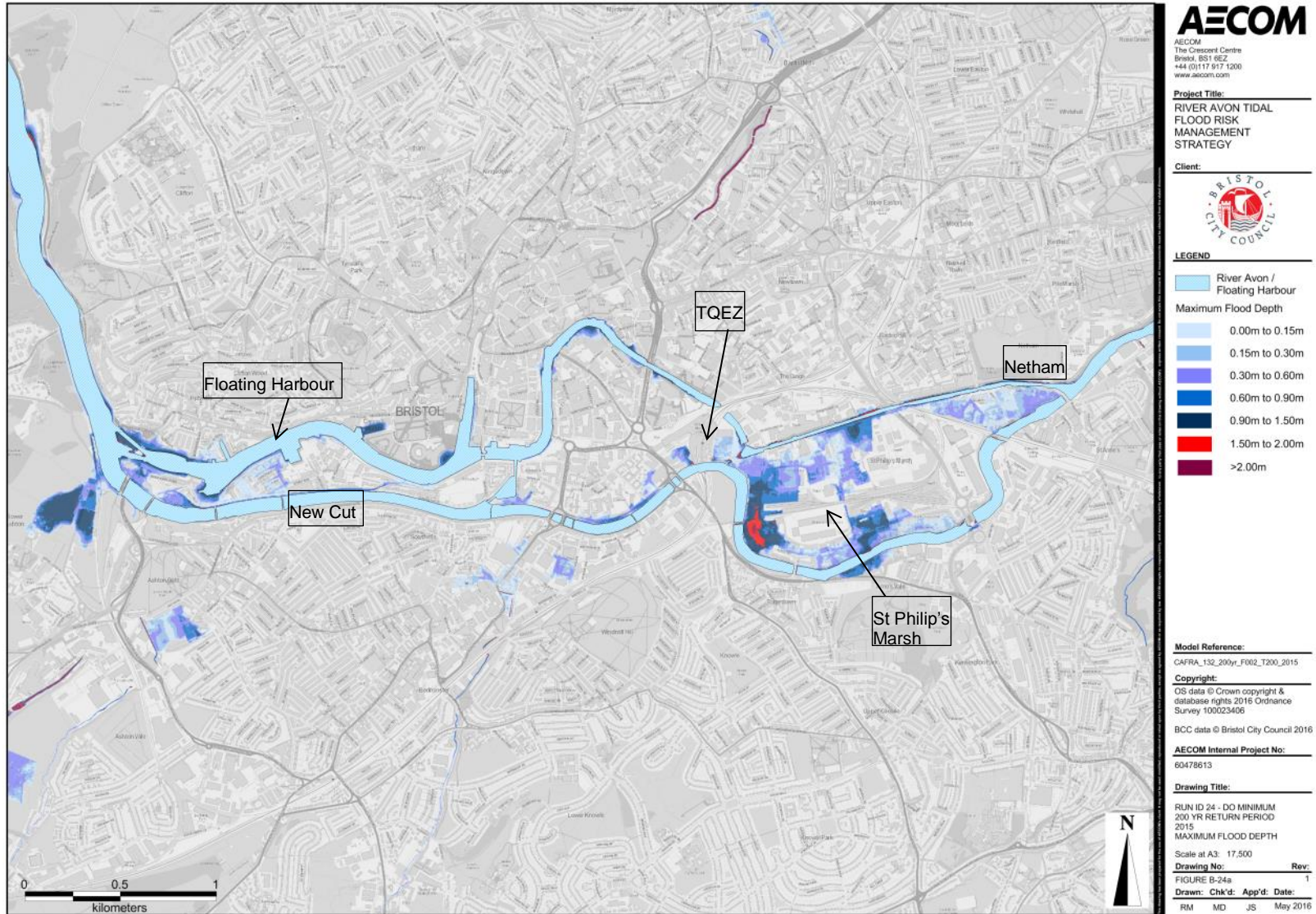


Figure 5 Flood Mapping for the Do Minimum scenario 1 in 200 year event 2015

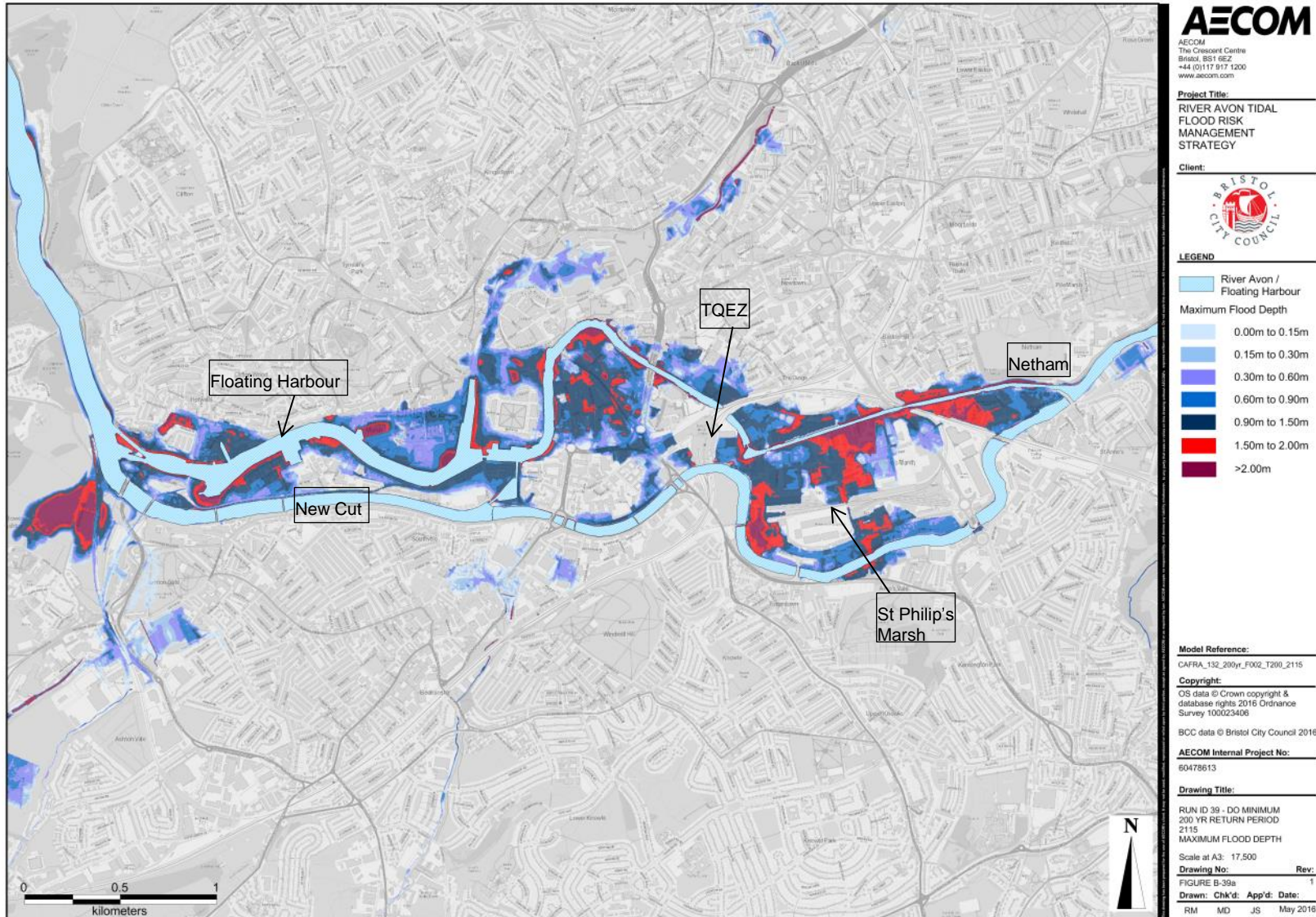


Figure 6 Flood Mapping for the Do Minimum scenario 1 in 200 year event 2115

4. OPTION APPRAISAL OVERVIEW

4.1 Purpose of this report

To date, option appraisal has developed a long list of 39 strategic options. This report describes the process by which the 39 options have been narrowed down to a short list. The short list of options will be used during future appraisal work to develop the preferred strategy.

4.2 Option objectives

To facilitate the option appraisal process, the objectives for the flood risk management options have been agreed with the project team. The options provide a means of considering multiple factors for the options to achieve a balanced Strategy and outcome. However, it is recognised that the principal aim for the Strategy is to reduce flood risk and the restrictions it may bring to future development. The option objectives are as follows:

1. To support the safe living, working and travelling of people in and around central Bristol by ensuring that the flood threat is reduced and that measures are in place to address residual risks.
2. To facilitate the sustainable growth of Bristol and the wider West of England economy by supporting development opportunities for employment and residential land, and associated infrastructure.
3. To maintain, and where possible enhance, natural, historic, visual and built environments.
4. To reduce whole life costs
5. To ensure navigation of the River Avon and marine activities can continue.
6. Ensure the Strategy is technically feasible and deliverable over its duration.

4.3 Strategy time epochs

To facilitate the development of the Strategy and appraisal of options the 100 year appraisal period (2015-2115) has been split into three time epochs:

- 2015 to 2030 (short term);
- 2030 to 2065 (medium term); and
- 2065 to 2115 (long term)

By developing management options in accordance with these time epochs it will allow for an adaptive approach to management to be developed that keeps pace with climate change and potential sea level rise. In addition, the approach has sufficient flexibility to address uncertainty thereby ensuring the most appropriate strategic choices are taken now and in the future. As the Strategy is implemented, to help inform the best time to implement the recommended management interventions, various risk 'thresholds' and 'tipping points' will be outlined. For instance, the Strategy may initially recommend that a scheme is implemented at the start of epoch 2, but, if sea level rise occurs more slowly than expected and the exceedance of the risk threshold does not occur, the scheme could be delayed until a later stage.

4.4 Potentially feasible measures

In previous work (see Long List options briefing note), 39 long list strategic options were established, each of which comprises a sequence of feasible, coherent and logical measures to be implemented over the duration of the Strategy appraisal period (2015-2115).

For each long list strategic option, a 'measure' was assigned to each time epoch, so for instance a long list strategic option may suggest maintenance and resilience in the short term (2015-2030), the construction of low flood defences in the medium term (2030-2065) and finally the construction of a narrow barrier in the long term (2065-2115). For the purpose of the appraisal it has been assumed that the measure for each time epoch will be constructed / implemented at the start of each time epoch.

The measures from which the long list of strategic options were developed included:

- Do Minimum
- Property Level Protection and Temporary Defences
- Low Defences
- High Defences
- Narrow Tidal Barrier

- Wide Tidal Barrier

These measures were identified in the Long Listing phase of the options appraisal process as potentially feasible solutions to manage flood risk. They are defined in the Strategy as 'primary' measures and justification for their selection is provided in the Long List Briefing Note.

In addition to the 'primary' measures, a number of secondary measures were also identified. Compared to the primary measures, the secondary measures provide a reduced flood risk benefit and therefore are only expected to be used in support of the primary measures to reduce the consequences and improve the response to flooding.

Using the secondary measures as the principal solutions to manage flood risk is not considered appropriate on a city wide scale (i.e. if the secondary measures were to be implemented alongside the Do Nothing scenario only, with no primary measure in place). Given the large number of strategic option combinations that would arise from incorporating different primary and secondary measures, the option appraisal process has focussed on sequences of primary measures only, on the basis that the secondary measures can be utilised alongside the preferred strategic approach as the Strategy.

To facilitate the process of combining the primary measures into logical and coherent strategic options, an 'options tree' was created which mapped each potential sequence of measures. The impractical combinations were discounted and scoped out from further consideration.

Figure 7 presents the final 'options tree' with the impractical sequences removed. In total 39 different sequences remain on the tree in Figure 7, with each of these sequences considered a practical Strategic Option. The final long list of Strategic Options is made up of the 39 different sequences presented in Figure 7.

Some examples of illogical, undeliverable or nonsensical options that have been removed from the 'options tree' (Figure 7) are provided below:

- Example of a nonsensical option (1) - undertaking maintenance and resilience measures in the short term (2015-2030), constructing a narrow (or wide) barrier (and associated defences) in the medium term (2030-2065) then following this with the construction of high defences in the long term (2065-2115). This approach is nonsensical because the long term tidal flood risk would be effectively managed by constructing a barrier in the medium term (2030-2065), negating the need to construct high defences after this in the long term (2065-2115).
- Example of an illogical option (2) – construct high defences in the short term (2015-2030) then construct a narrow (or wide) barrier (and associated defences) in the medium term (2030-2065), maintaining this structure in the long term (2065-2115). This approach is not appropriate because the construction of high defences prior to a barrier solution (and the additional defences associated with a barrier solution) would represent a wasted investment, as either of these solutions in isolation could protect against long term flood risk throughout the duration of the Strategy period.
- Example of an undeliverable option (3) – construct a narrow (or wide) barrier in the short term (2015-2030). A tidal barrier is a large scale construction and it is unlikely that a barrier could be completed prior to the year 2030. For this reason this approach is not considered feasible at this time. It is assumed that the earliest time epoch in which a barrier could be implemented is in the medium term, from 2030 to 2065.

With the impractical or nonsensical options screened out, the feasible and logical strategic options that remained on the 'options tree' (Figure 7) were assembled for the long list. Examples of feasible Strategic Options, included in the long list, are presented below:

- Strategic Option example 1 – implement property protection and temporary defence measures in the short term (2015-2030) before constructing a narrow (or wide) tidal barrier in epoch 2 (2030-2065). Following construction, maintain the barrier infrastructure and operations throughout the remaining duration of the Strategy (2065-2115).
- Strategic Option example 2 – Construct low walls in the low spots in existing defences in the short term (2015-2030). Maintain / raise these new defences in response to increasing risk and sea level rise and construct additional low walls in other vulnerable areas in the medium term (2030-2065). In the long term upgrade the low walls to high walls to keep pace with continued sea level rise.

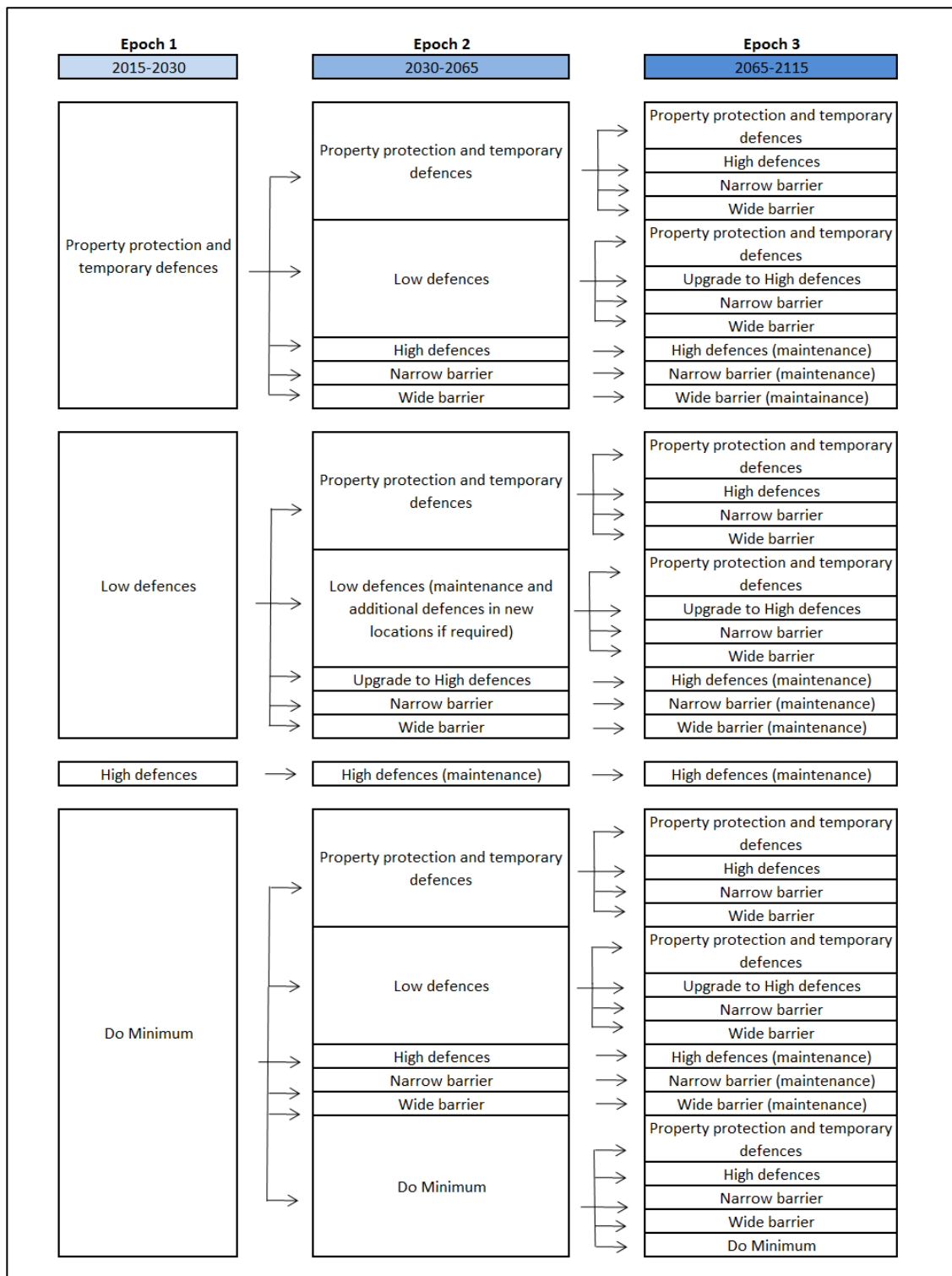


Figure 7 Tree of feasible measures and sequences leading to the long list of strategic options

Figure 7 presents the feasible sequences of measures leading to the long list of Strategic Options. In total 39 different sequences or Strategic Options have been identified for the long list (each of which is shown in Figure 7).

A number of assumptions were made during the development of the long list of Strategic Options. These include:

1. It is anticipated that a large construction project such as a tidal barrier will require a long lead in time (e.g. at least 10 years) to account for technical studies, TWAO, attaining planning and funding and construction. It is therefore only considered possible to implement a barrier solution from 2030 onwards.

2. It is assumed that the construction of flood walls can occur with shorter lead in times and therefore walls can be implemented within the early years of epoch 1 of the Strategy.
3. It is assumed that maintenance of existing defences within Bristol will be continued alongside the implementation of the Do Something and Do Minimum options. The structural integrity of the defence structures should be maintained to ensure that the flood defence benefits that Do Something structures may provide are continued into the future.
4. It is assumed that continued operation of the Floating Harbour operations and infrastructure will be carried out alongside the implementation of the Do Something and Do Minimum options. In the short term this will help to minimise the chance of flooding in the Floating Harbour during periods of moderately high fluvial and/or tidal water levels. However, in the medium and long term, due to climate change, the magnitude and frequency of large flood events (in today's terms) are expected to increase. As a result, the effectiveness of the Floating Harbour in controlling water levels will decrease in the future.
5. It is assumed that existing flood forecasting and warning systems remain in place, or new systems developed and these will assist in the operation of 'Do Something' options such as low or high defences (operation of flood gates), a wide or narrow tidal barrier (closing of the barrier) and demountable defences (set-up and placement of demountable defences).

4.5 Assessment of feasible measures

The next part of this report, Chapter 5, provides an in-depth description of each of the potentially feasible measures identified in the long list report. The economic cost, technical feasibility and potential environmental impacts of each measure is assessed, as well as the potential stakeholder aspirations / concerns that may arise when implementing each measure. Chapter 5 provides a detailed evidence base for each of the measures.

In Chapter 6, the evidence for each measure is combined and used to appraise the 39 different strategic options. The appraisal uses a multi-criteria assessment to evaluate the strategic options. This involves assessing the impact of each of the long list options against the six strategy option objectives. A scoring system is applied to score the options relative to the Do Nothing scenario. This allows for the relative merits and drawbacks of the long list strategic options to be compared.

5. DESCRIPTION OF MEASURES

This chapter provides an in-depth description of each of the six measures which comprise the strategic options. These measures include:

- Do Minimum
- Local scale property level protection & temporary / demountable defences
- High Defences
- Low Defences
- Narrow Tidal Barrier
- Wide Tidal Barrier

Details are provided on the costs of the different measures, the technical feasibility of implementing the measures, potential environmental impacts which may arise, and a wider interpretation of the key risks and issues of each measure, including potential stakeholder aspirations and concerns.

5.1 Do Minimum

5.1.1 Description

The Do Minimum measure involves maintaining the existing defence assets, the floating harbour water level control infrastructure and ensuring that the operation of the floating harbour is continued. In essence, the Do Minimum measure represents what happens if the current 'status quo' is maintained.

Under the Do Minimum measure, the existing defences would be maintained but would not be raised or lengthened, nor the standard of protection increased. As a result, with sea level rise, the standard of protection of the existing defences would be expected to decrease over the duration of the Strategy. Under the Do Minimum measure there is therefore an increased risk in the future that the existing defences will be inundated / overtopped during tidal flood events.

Despite the fall in the standard of protection under the Do Minimum measure, the maintenance works that would be carried out are assumed to preserve the structural integrity of the existing defences. In this respect the Do Minimum measure provides a flood risk benefit compared to the Do Nothing scenario, in which it is assumed that many of the defences breach or are operationally abandoned.

A summary of the defence assets that will be maintained under the Do Minimum measure is provided in Table 8 below. Table 8 also outlines the time epoch in which these defences are expected to fail under the Do Nothing scenario.

Table 8 The Defence assets which will be maintained under the Do Minimum approach

Asset	Comments	Assumed epoch of failure under Do Nothing
Netham Weir masonry sub-structure, concrete crest and rock apron	Sub-structure and concrete crest currently are in fair condition. Rock apron in poor condition.	Epoch 3
Netham Lock Gates and Sluices	New lock gate are in a good condition. The sluice paddles and operating system are in a poor condition	Epoch 1
Totterdown defences, Albert Road east section	Poor condition of defences. Currently failing in places	Epoch 1
Totterdown defences, downstream of Bristol RSPCA site	Constructed in 2003. Good condition	Epoch 3
Totterdown defences, adjacent Bristol RSPCA site	Fair condition. Current failure experienced through breaching	Epoch 3
Totterdown defences, Albert Road north Section	Fair condition	Epoch 3
New Cut retaining wall and drainage	Risk to Cumberland Road Wall	Epoch 3
Cumberland Road wall defence	New structure, expected <50 year design life without maintenance	Epoch 3
Underfall Yard culverts, sluices and gates	High vulnerability to flooding –Poor condition.	Epoch 1
Junction Lock gate and sluices	New stop gates, upper gates and sluices in a very good condition. Old backup gates in a poor condition (inundated during spring tides)	Epoch 1
Nova Dam and Sluices	Dam in a fair condition. Sluices and electrical system in a very good condition.	Epoch 1
Entrance Lock gates	Resilient against flooding.	Epoch 1
Brunel Dam	Poor condition and a high vulnerability to flooding	Epoch 1
Pill, Marine Parade defences	Fair to good condition.	Epoch 1
Shirehampton, Marine Parade defences	Good condition.	Epoch 1
Pill and Shirehampton, raised flood gates	Manually operated.	Epoch 1

In the development of the strategic options it has been assumed that the Do Minimum measure can act as a 'stand-alone' measure and also as a measure which will be carried out in support of the other 'Do Something' measures (i.e. Property Level Protection, High and Low Defences, Narrow and Wide Tidal

Barriers). For example, if a strategic option outlines the construction of High Defences in epoch 1, it is assumed that the components of the Do Minimum measure (e.g. lock gate maintenance and operation) would also be undertaken during this epoch. This would ensure that the maintenance of the existing defences in the study area and the ongoing operation of the floating harbour would be continued.

5.1.2 **Technical Feasibility**

The Do Minimum measure involves continuing the ongoing operation and maintenance of the Floating Harbour water level control assets and infrastructure and maintaining the existing defence assets. It assumes EA continue to provide flood/surge forecast and warning. Given that this is already occurring, the measure is considered to be technically feasible, especially so in the short to medium term.

In the future, due to sea level rise, the frequency and magnitude of extreme tidal water level events is expected to increase. As a result, it is expected that the water level control assets will need to be operated more frequently to prevent and/or minimise tidal flooding within the Harbour. Currently, tidal stop gates at Netham and Junction Lock are deployed for predicted tides greater than 6.1m AOD.

It is also expected that flood barriers and flood gates for the existing defences will need to be deployed more frequently in the future due to sea level rise. In 2014 the barriers and gates were deployed on four separate occasions. Due to the recent construction of Cumberland Road wall, the barriers and gates now only require deployment for tides greater than 9.2m AOD.

During epoch 3 of the Strategy there is potential for some technical challenges to arise with regards to the maintenance of existing defence assets. By this time (2065 and onwards), the existing defences will have aged considerably and the feasibility of maintaining these structures to a high condition will be reduced.

5.1.3 **Costs**

High level costs for the Do Minimum measure have yet to be estimated and will be developed at a later stage of the Strategy appraisal. For the purpose of developing the shortlist of options, the cost for the Do Minimum scenario is not critical as the Do Minimum measure is included as part of each 'Do Something' measure. Therefore the Do Minimum cost will not influence the comparative scoring of options in the multi-criteria appraisal.

At a later stage of the Strategy appraisal, the Do Minimum cost estimate will be incorporated:

- Costs to maintain the existing defence assets at Totterdown, the New Cut, Cumberland Road, Pill and Shirehampton (the defence assets outlined in Table 8).
- Costs to inspect and maintain the water level control infrastructure at Netham, Underfall Yard, Junction Lock, Nova Dam, Entrance Lock and Brunel Dam (the water level control assets outlined in Table 8)
- Costs to operate the water level control infrastructure at Netham, Underfall Yard, Junction Lock and Entrance Lock (the operable water level control assets outlined in Table 8). Including the deployment of stop gates at Junction Lock and Netham Lock for tide levels greater than 6.1m AOD.
- Costs to inspect and maintain the sluice gates which support the water level control infrastructure, 38 gates in total.
- Deployment of existing flood barriers, typically for tide levels greater than 9.2m AOD.

5.1.4 **Environmental impacts**

Overall, this flood defence measure is likely to have a limited environmental impact as 'Do Minimum' represents what happens if the 'status quo' is maintained, and therefore this flood defence measure is likely to have a negligible impact on the environment, compared with baseline conditions.

Within the environmental assessment report the only (minor) impact identified within 'Do Minimum' is for socio-economics, as flood defences will not be raised, and as a result of sea level rise the standard of flood protection is expected to fall over time. This may deter developers and individuals from investing in the city in the future.

In summary, for the environmental assessment the Do Minimum flood defence measure has been assessed as follows:

- No 'significant' impacts have been identified for this flood defence measure;
- There are few negative impacts due to the increasing likelihood of saline flood inundation (e.g. heritage receptor damage) and no positive impacts.
- On balance the negative impacts outweigh the positives.

5.1.5

Wider issues and opportunities

In the short term the Do Minimum measure provides some flood risk benefit compared to the Do Nothing scenario. In 2015 for Do Minimum approximately 1712 fewer properties are at risk of flooding from a 1 in 200 year event compared to the Do Nothing approach. Despite this the present day Do Minimum flood risk remains significant with 1009 properties at risk from a 1 in 200 year 2015 event.

Over the long term, as a result of rising sea levels, the benefit of the Do Minimum measure, compared to the Do Nothing scenario, is expected to reduce. By 2115, under a 1 in 200 year event, approximately 4345 properties are at risk under Do Nothing and 3718 at risk under Do Minimum. With such a large number of properties still at risk under Do Minimum this approach is unlikely to be favoured as a long term solution by the general public and stakeholders. The Do Minimum measure is therefore unlikely to form the basis of a long-term strategic approach to flood risk management in the Strategy.

Whilst not a favourable long-term approach, the Do Minimum measure can provide an effective 'stop-gap' solution until a 'Do Something' measure can be delivered in the long term. For instance, Do Minimum may form the basis of an approach to epoch 1 (and possibly epoch 2) while funding is secured for a long term solution.

If the preferred strategic option includes Do Minimum, it will be essential to effectively communicate and explain the approach to the general public and stakeholders in order to build support for the strategy. It will also be essential to continue flood forecasting and warnings to ensure that water level control structures, such as lock gates and flood gates, are operated correctly.

The Do Minimum approach would require that a monitoring programme be established for the existing defence assets, and carried out over the duration of the measure. This would involve periodic asset surveys rather than an 'ad-hoc' approach. For the key defence assets a detailed condition assessment would be required as part of the monitoring programme. The monitoring programme would inform the maintenance requirements needed to successfully deliver this measure, and a programme of annual maintenance works would be required, based upon the findings of the monitoring programme.

In order to successfully implement the Do Minimum measure it would be important to liaise with stakeholders and private land owners to ensure that private defences are maintained to an acceptable standard (i.e. at Totterdown).

5.2 Property Level Protection

5.2.1 Description

This measure groups together Property Level Protection approaches and use of temporary / demountable flood defences.

5.2.1.1 Property Level Protection

Property Level Protection (PLP) is a generic term for permanent flood defences such as individual property barriers (fitted to any property openings such as front doors, windows and garden gates), non-return valves (fitted to drains to prevent floodwater backing up into a home) and airbrick/vent covers (placed over existing airbricks and vents to prevent the ingress of water).

PLP can also take the form of community flood defences – low walls built to protect blocks of flats or close housing groups.

PLP is typically retro-filled to existing building stock, but the same measures can be designed into new developments.

Typically, PLP can provide protection from flooding to individual properties up to about 600mm depth of water (though greater depths can be accommodated through use of customised flood barriers). For flood depths greater than 600mm PLP is unlikely to form an effective defence. PLP can provide only a relatively low standard of protection.

5.2.1.2 Temporary / demountable defences

The Environment Agency issued guidance for the design and management of temporary / demountable flood defence products and systems in 2011 and information from this guidance is provided below.

A temporary flood defence is defined as (Environment Agency, 2011):

“A temporary flood protection system is formed by removable flood protection products that are wholly installed during a flood event and removed completely when levels have receded, its connection with the underlying surface, and its end connections.”

Four categories of temporary flood protection products have been identified (based upon the form of the material) and include; tubes (air filled or water filled), filled containers (permeable and impermeable), freestanding barriers (flexible and rigid) and frame barriers (flexible and rigid).

A demountable flood defence is defined as (Environment Agency, 2011):

“A demountable flood protection system is a moveable flood protection system that is fully pre-installed and requires operation during a flood event, or a system that requires part-installation into pre-installation guides or sockets within a pre-constructed foundation.”

Four categories of demountable flood protection barriers have been identified and include; freestanding barriers (flexible and rigid), frame barriers, sectional barriers (automatic and manual) and flood gates (automatic and manual). Demountable defences can also be categorised according to a) whether they are fully erected barriers requiring only a closure operation as compared to those requiring part erection into pre-existing permanent parts, and b) the operational aspect to reflect their requirement for automatic or manual or intervention for closure.

Temporary or demountable flood defences can be used in a variety of situations and to perform different tasks including; raising the level of protection, strengthening existing defences, containing flood water from either overtopping or breaching of permanent defences, and diverting or directing water elsewhere on the floodplain. BCC currently have the facility to deploy a temporary barrier on receipt of a flood warning, such as the one that has been mobilised on several occasions at Avon Crescent, prior to the construction of the new wall along Cumberland Road.

5.2.2 Technical Feasibility

The general areas in which this measure could be implemented have been established and are presented in Figure 8 to Figure 10 below. Consideration has yet to be made to potential alignments of temporary / demountable defences or to the individual properties which may require property level protection. Therefore these areas have been outlined by identifying the groups of properties which are at risk from a 1 in 20 year event (or greater) in each time epoch. This flood event has been used to identify the properties because it represents the flood risk threshold for which properties are expected to be eligible to attract grant in aid funding to implement property level protection measures. It would be possible to apply temporary/demountables and property level defences in other areas if funding was available beyond GiA.

As shown in Figure 8 to Figure 10, the areas identified for the PLP and temporary / demountable defences are:

- Totterdown, in the area to the east of Victor Street, to the south-east of Bristol Temple Meads rail station;
- Albert Road, in the area to the east of the Albert Road to Bath Road bridge crossing, to the east of the Albert Crescent roundabout; and
- St. Phillips Marsh, in the area south of Feeder Road

PLP is a technically feasible solution to manage the tidal flood risk in these areas, but it should be recognised that PLP will not be suitable for each and every property located in these areas. As shown in Figure 8 to Figure 10, in some locations within the allocated PLP areas, the flood depths for a 1 in 20 year event exceeds 1m (i.e. at Totterdown) and it is unlikely that PLP will be suitable to mitigate against this level of flooding. Alternative approaches to manage the flood risk to these properties, such as temporary barriers will need to be investigated in future appraisal work.

Property Level protection and temporary / demountable defences offers a technically feasible solution in the short term. However, in the future, due to rising sea levels, there is the possibility that this measure may not be technically feasible in all areas as flood depths may exceed the typical depths which PLP and temporary / demountable defences can protect against.

5.2.3

Costs

A high level cost estimate for the PLP and temporary / demountable defence measure has been estimated based on the number of properties which are likely to require protection. The number of properties have been determined in GIS by carrying out a count of the properties which are at risk from a 1 in 20 year event for each time epoch. This is the typical event magnitude in which PLP measures are effective at reducing flood risk. The areas are outlined in Figure 8 to Figure 10. The property locations have been obtained from the National Receptor Database and the numbers of properties earmarked for PLP in each time epoch are provided in Table 9 below.

Indicative alignments haven't been made for temporary / demountable defences and therefore cost estimates for these structures have not been included in the estimated costs for this measure. Estimates will be included in future appraisal work based upon unit rates (per metre) of temporary barrier. These have been made available from quotations by suppliers and it is estimated that the cash cost per metre of a temporary barrier of 0.9m in height is approximately £320.

More details on the costing methodology for this measure can be found in Appendix 1 of this report.

Table 9 Numbers of properties outlined for PLP in each time epoch

Epoch	Number of properties for PLP (residential)	Number of properties for PLP (commercial)	Number of properties for PLP (total)
Epoch 1 (2015-2030)	7	100	107
Epoch 2 (2030-2065)	12	124	136
Epoch 3 (2065-2115)	26	192	218

The costs of PLP have been estimated to be £5,000 per property. This is the typical amount which is that is available to residential properties eligible for PLP under the government grant-in-aid funding guidelines (i.e. those properties considered to be at very significant flood risk). Additional costs which may arise in excess of the funding allowance will need to be provided from other sources.

Estimated cash costs to implement the PLP measure in each epoch are provided in Table 10 below.

Table 10 Estimated cash costs for the PLP & temporary / demountable defences measure

Epoch	Estimated cash cost of PLP & temporary / demountable defences measure (£)	Estimated amount of funding available for residential properties (£)
Epoch 1 (2015-2030)	£535,000	£35,000
Epoch 2 (2030-2065)	£680,000	£60,000
Epoch 3 (2065-2115)	£1,090,000	£130,000

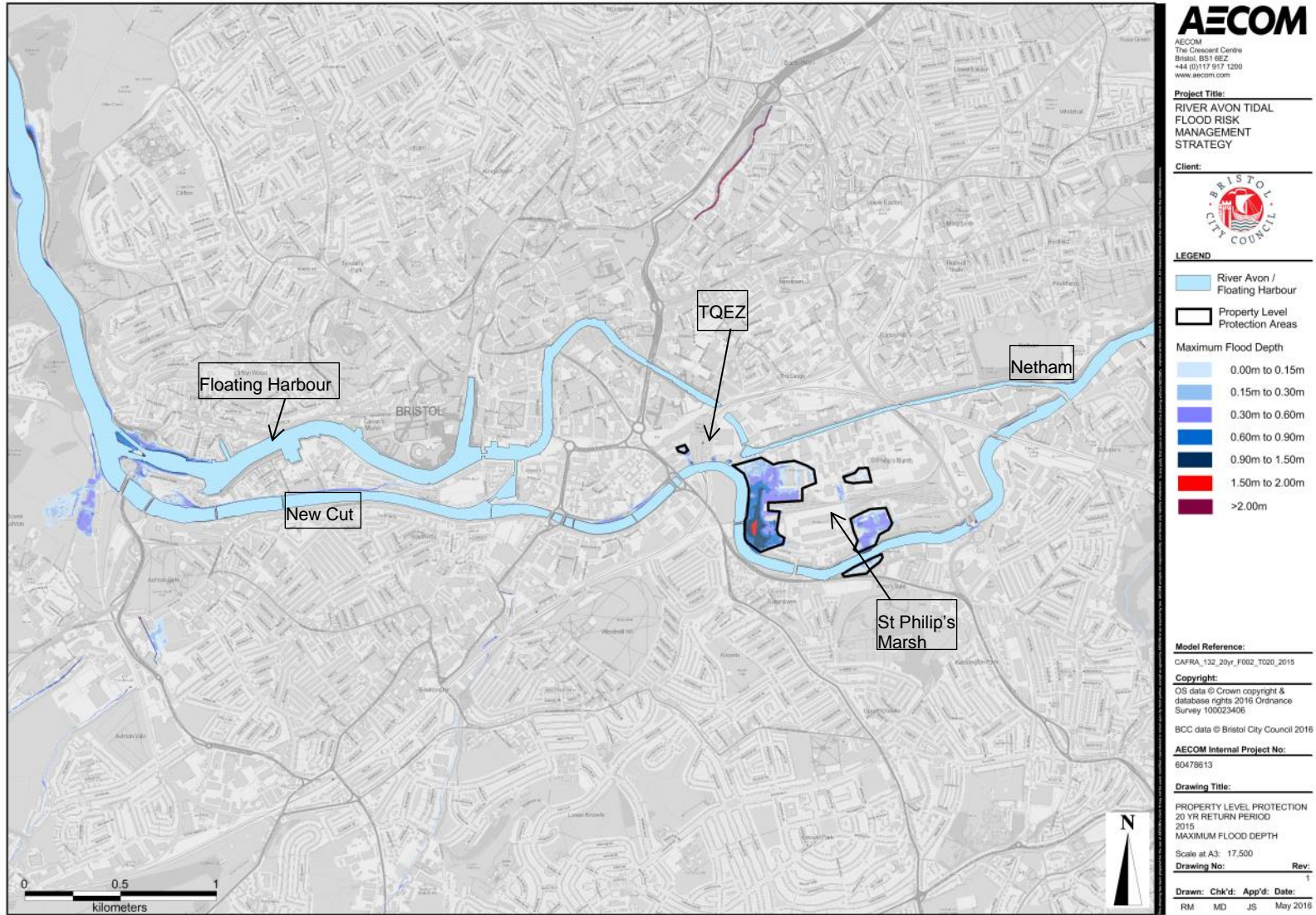


Figure 8 Indicative PLP areas for epoch 1, 2015. Flood modelling shown for a 1:20 year event in 2015 under the Do Minimum scenario (prior to PLP implementation)

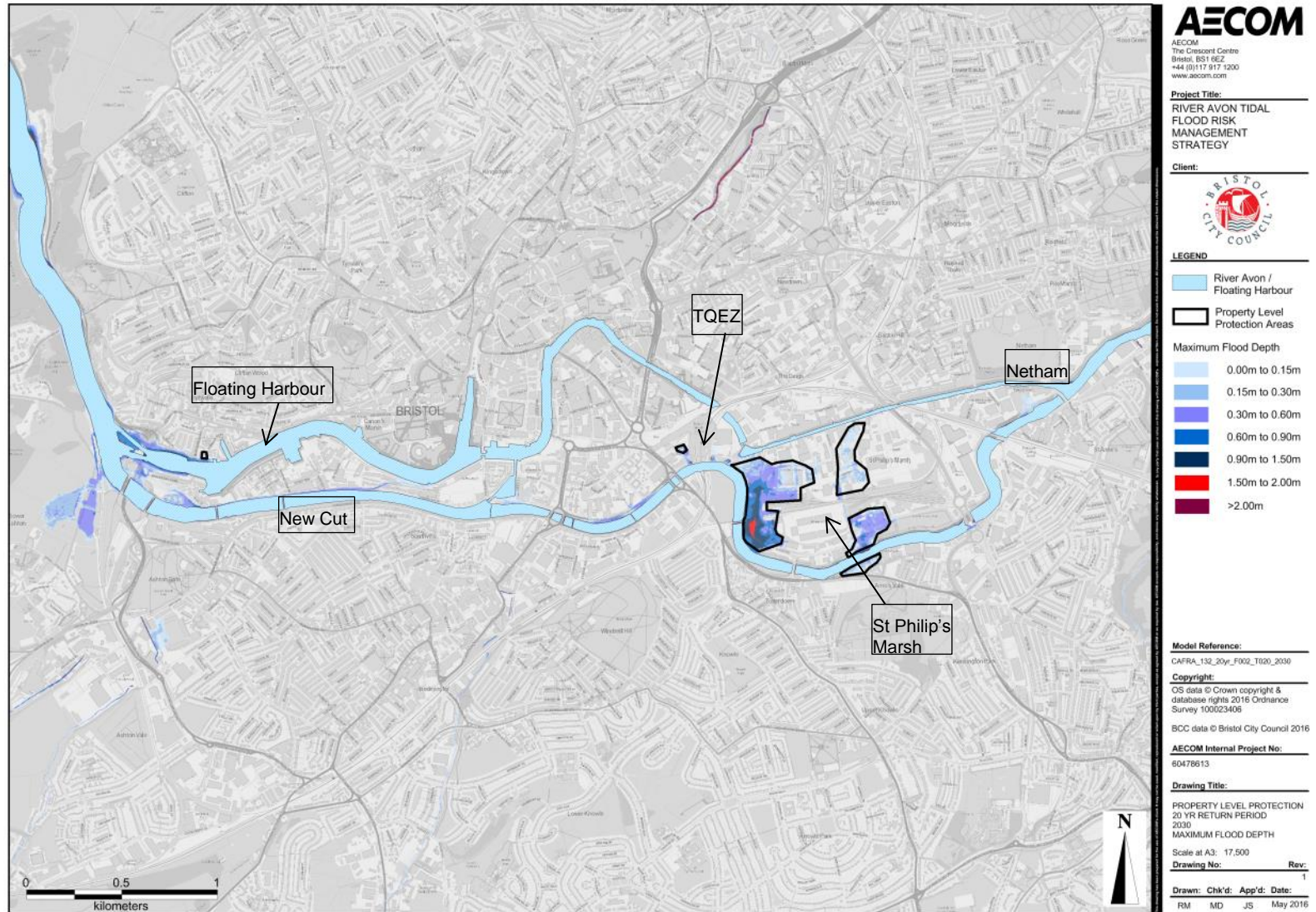


Figure 9 Indicative PLP areas for epoch 1, 2030. Flood modelling shown for a 1:20 year event in 2015 under the Do Minimum scenario (prior to PLP implementation)

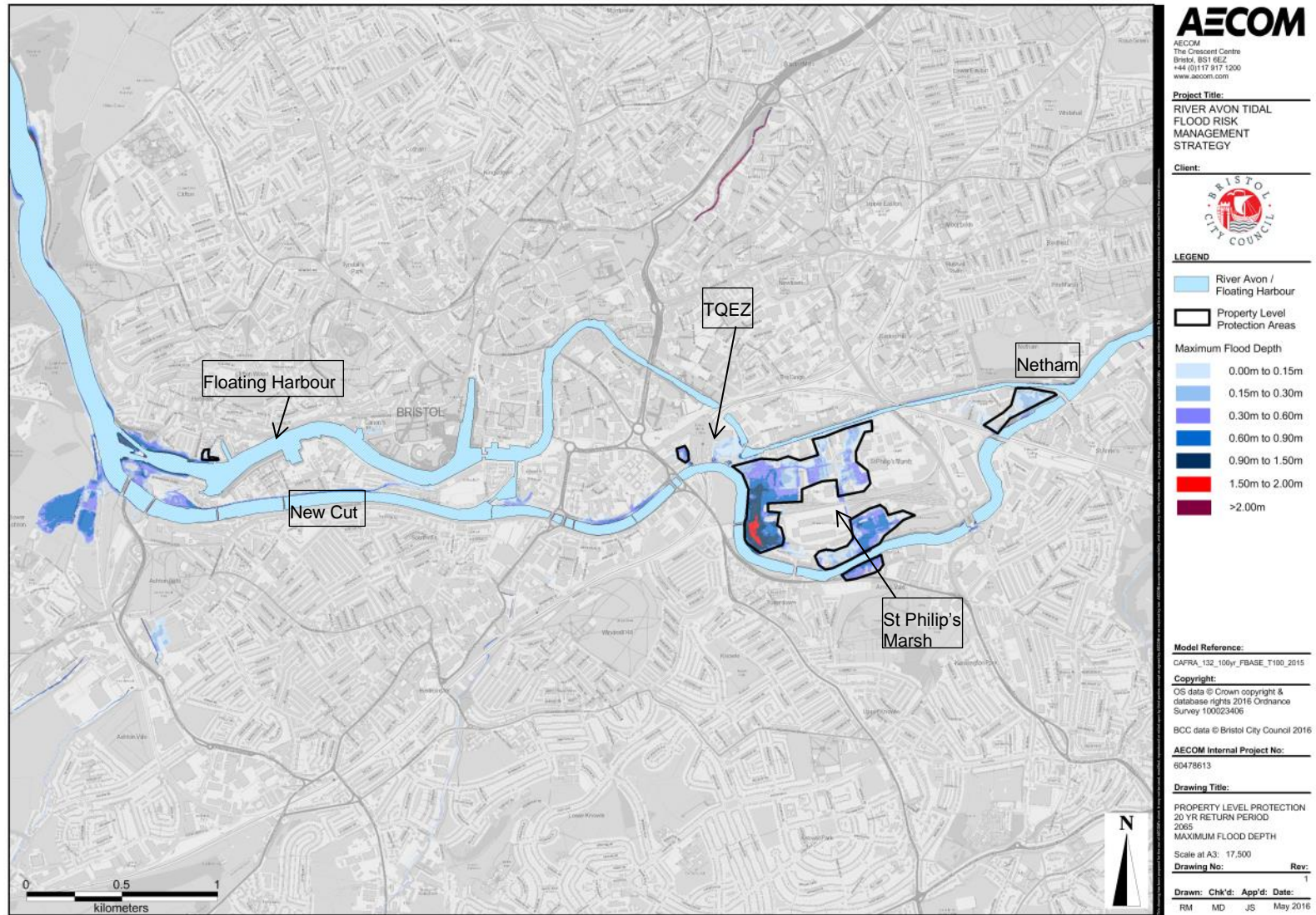


Figure 10 Indicative PLP areas for epoch 1, 2065. Flood modelling shown for a 1:200 year event in 2015 under the Do Minimum scenario (prior to PLP implementation)

5.2.4 **Environmental impacts**

This flood defence measure is considered to have a relatively limited environmental impact as the measures are local to the façade of buildings or roads, and/or erected temporarily; and therefore unlikely to interact with most aspects of the environment.

As these measures are temporary and/or small in scale, the landscape and visual impact is expected to be negligible. Likewise, a negligible impact on traffic and transport would be expected due to the limited and highly dispersed trip generation which the delivery of these defences would necessitate.

A minor adverse impact is expected on archaeology and heritage as this flood defence measure may temporarily change the appearance of any listed buildings which they are used to protect. The impact is short term (during the period of flood risk) and reversible, however.

A negligible impact is expected on terrestrial and riverine ecology as this flood defence measure is local to the façade of buildings or roads, where ecology is generally absent or of low interest. As these defence measures are local to structures and infrastructure they are also expected to result in a negligible impact to geomorphology and water quality and soil and groundwater.

This measure is unlikely to have a noticeable impact on air quality and noise. There will be some very minor and localised noise and dust generation during initial installation (and possibly the removal), but no more severe than that caused by general building maintenance and the impacts should be adequately managed through appropriate control measures.

Finally, this measure was considered to have no overall impact on socio-economics, as although the defences will provide a benefit to the communities through provision of flood protection, local communities are likely to still feel vulnerable and stressed during periods of prolonged or heavy rainfall. People may also be discouraged from investing in property or business by the continued high risk flood status, particularly in residential, ground floor dwellings.

In summary, the Property Protection and Local Defences measure has been assessed in the environmental assessment as follows:

- No 'significant' impacts have been identified for this flood defence measure;
- There are few negatives impacts but there are no positive impacts.
- On balance the negative impacts outweigh the positives.

5.2.5 **Wider issues and opportunities**

Property level protection and temporary / demountable defences provides only a low standard of protection compared to other 'Do Something' measures such as low and high defences, and the tidal barrier solutions. As such, this approach is unlikely to be considered an acceptable long term solution to manage tidal flood risk in the long term, both politically and for the general population and stakeholders.

Residual risk is high, due to possibility of inadequate warning period or failed mobilisation/deployment. On their own plp/temporary defences will not provide a sufficiently high SoP to sustain new development.

However, compared to the Do Nothing scenario, PLP and temporary / demountable defences will provide a flood risk benefit, especially in the short term and therefore can be considered an effective 'stop-gap' measure to manage the short term tidal flood risk whilst the funding for a long term approach is secured. For instance PLP and temporary / demountable defences could be implemented in epoch 1 (and possibly 2) while funding is secured for a tidal barrier or high defences in the long term.

PLP is a measure which is likely to attract an amount of government Grant-in-Aid (GiA) funding which could help facilitate the successful delivery of this measure. Under GiA guidelines, residential properties that are at risk from a present day 1:20 year flood event are considered to be at very significant risk and eligible for a £5k funding grant to implement property protection measures. Additional costs which may arise in excess of the funding allowance will need to be sourced privately from other sources.

In addition to the structural components of PLP and temporary / demountable defences, there are a number of additional aspects which would be essential to the successful deployment of this measure. These include:

- Forecasting systems and methods;
- Flood alert systems and monitoring;
- Mobilisation of equipment and manpower and materials;
- Closure of temporary defence systems / PLP gates

These aspects would need to be considered as part of more detailed scheme development and for the purpose of this option appraisal in the Strategy it is assumed that these aspects would be delivered as part of the PLP and temporary / demountable defences measure.

5.3 High Defences

5.3.1 *Description*

The 'High Defences' measure comprises linear defences – walls or embankments – to provide a high standard of protection in a single implementation phase.

The implementation of High Defences involves identifying low spots or gaps in the existing defences and then raising the defence crest levels or constructing new floodwalls or similar defences (i.e. embankments) in these locations. High defences are a precautionary approach and would provide long term protection from tidal flood risk by considering sea level rise and climate change projections up until 2115.

For the purpose of the short list appraisal, it is assumed that the defences would be constructed to a 1:200 year standard of protection (2115 standard). This would meet the requirements of national planning policy in regard to flood risk for new development. However, at the time of undertaking the long to short list appraisal, a detailed economic appraisal has yet to be carried out and therefore the optimal standard of protection for High Defences has not yet been explored in detail. The 1:200 standard of protection is therefore only preliminary and testing and potential refinements to this standard will be made during later stages of the Strategy appraisal.

Based upon the Do Minimum modelling outputs, a first pass assessment was carried out to identify the areas where raised high defences would be required to prevent tidal flooding during the 2115 1:200 year event. The assessment was based upon a visual analysis in GIS, whereby the areas of tidal flooding were identified and indicative route alignments needed to block the path of flooding were established.

Initially it appeared that much of the flooding which occurred was as a result of high water levels in the Floating Harbour, exceeding adjacent defence levels. However, a root-cause approach identified that the principal cause of the flooding was water entering the Floating Harbour through two main types of route: overland after spilling out of the Avon and overflowing defences; and directly into the Floating Harbour by overflowing the locks/defences at the entrances at either end.

Therefore the defences within this measure consist of a combination of walls/embankments along the Avon and improvements to crest levels at either end of the Floating Harbour

5.3.2 *Technical Feasibility*

During normal operation, water levels within the floating harbour are controlled by lock gates and sluice systems, most notably at Junction Lock, at the tidal entrance to the harbour, and at Netham, the upstream entrance to the harbour. During large magnitude flood events, a major pathway for flood water inundating the harbour is at these locations, by either inundating the lock gates themselves, or by flowing up and over the land adjacent to the gate systems. A photograph showing the inundation of the land either side of Junction Lock during a tidal flood event is shown below.



Figure 11 Photograph showing Cumberland Basin overflowing into the Floating Harbour at Junction Lock (photo adopted from the Avon First Phase Feasibility Study)

Rather than constructing long sections of high defences within the Floating Harbour around the areas at risk, a more cost effective and feasible solution is proposed that includes raising the lock gates or constructing a permanent flood gate at the downstream entrance to the Harbour (either at Entrance Lock gates or Junction Lock gates) and at the upstream entrance to the Harbour at the Netham gates. New defences around the lock gate systems (or permanent flood gate) to prevent water from inundating either side would also be required.

The benefits of effectively 'sealing-off' both entrances to the Harbour are:

- Prevents water entering the floating harbour at either entrance, allowing water levels within the Harbour to be effectively controlled during flood events.
- Removes the need for new high defences to be constructed within the floating harbour itself
- Reduces visual impact on the landscape of the city centre by removing the need for high defences around the harbour
- Reduces costs compared to constructing long lengths of high defences around the floating harbour
- Reduces the potential technical complications which may arise when constructing new defences on top or adjacent to the existing harbour walls which are generally in an ageing / poor condition. The Clarence Road wall collapse on the New Cut, and in other locations such as Bridgwater (River Parrett) demonstrate the challenges of working with old walls with a history of interaction with a tidal watercourse.

At the downstream entrance to the harbour, two locations have been identified for the lock gate upgrades:

- Cumberland Basin lock gates (Entrance Lock) - In this location a narrow a lock gate upgrade (or permanent flood gate) would be constructed and would be raised / closed during periods of high tide levels to prevent water inundating at the entrance to the Floating Harbour. Raised defences either side of this location would be required to tie-in to higher ground and to ensure the barrier / lock gates are not outflanked.
- Junction Lock - In this location the existing lock gates would be replaced and raised so that high tide levels could be kept out of the Floating Harbour. Raised defences either side of the lock gates would be required alongside a possible upgrade to the existing lock gate infrastructure to ensure the larger gates can be operated.

At the upstream entrance to the harbour, an alignment for upgraded lock gates and tie in walls has been identified at Netham Lock gates.

To ensure the successful operation and deployment of a upgraded lock gates at the entrances to the Harbour it is essential to have a flood forecasting and warning system. This would be needed to ensure the gates are closed prior to a high tidal magnitude event and to minimise the residual risk associated with barrier / lock gate closure. It is assumed that a forecasting system would be developed alongside this approach to ensure the successful delivery of this option.

'Sealing-off' the entrances to the harbour would effectively prevent tidal inundation at these locations. However, a number of alternative flood pathways into the Floating Harbour exist along the New Cut and high defences would be required at these locations. The main areas where new defences are required are at Cumberland Road, Bathurst Basin Dam, Totterdown, Temple Meads and Clarence Road. A defence at Bath Road may also been needed to prevent water inundating an industrial / commercial area south of the New Cut.

Figure 12 shows indicative defence alignments in central Bristol for the High Defences. Figure 13 and Figure 14 show potential alignments at Entrance lock and Junction Lock for the tie-in defences at the downstream entrance to the floating harbour. Either of these locations is suitable for a lock gate upgrade. Figure 15 shows the potential alignments at Netham, the upstream entrance to the floating harbour. All the indicative defence alignments for the High defences assume a 1:200 year standard of protection to the year 2115.

Downstream of the floating harbour area, high defences would also be required at sites in Pill and Shirehampton. In these locations the numerical modelling is limited and has simulated flood risk in a one-dimensional format. Based on the information available at this stage of the appraisal the indicative defence lengths and heights have been estimated for these locations and are presented in Table 11.

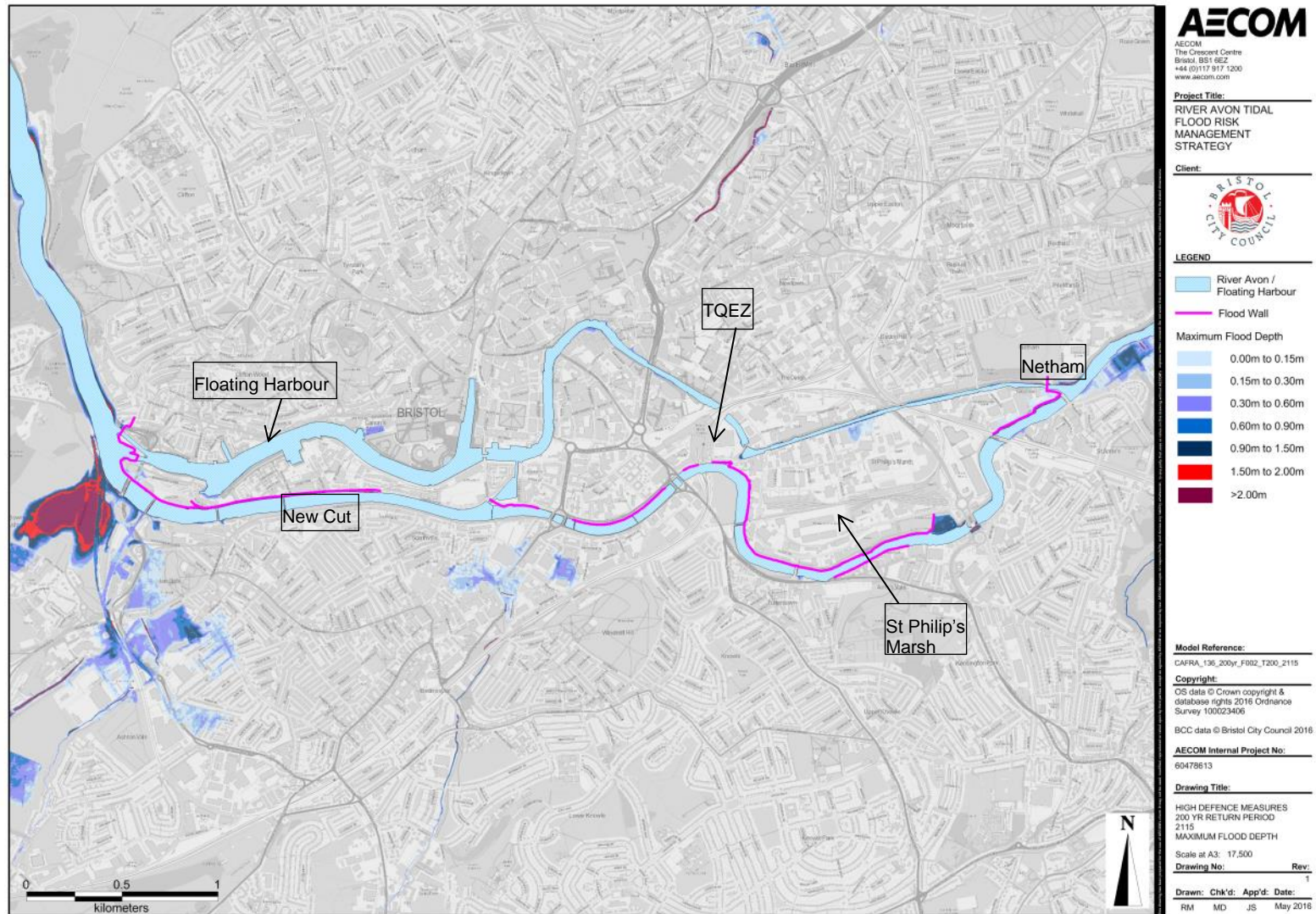


Figure 12 Indicative alignments for potential High Defences along the New Cut (1:200 year SoP, 2115). Flood modelling shown following the implementation of the High Defences alignments for a 1:200 year event in 2115, Do Minimum scenario.

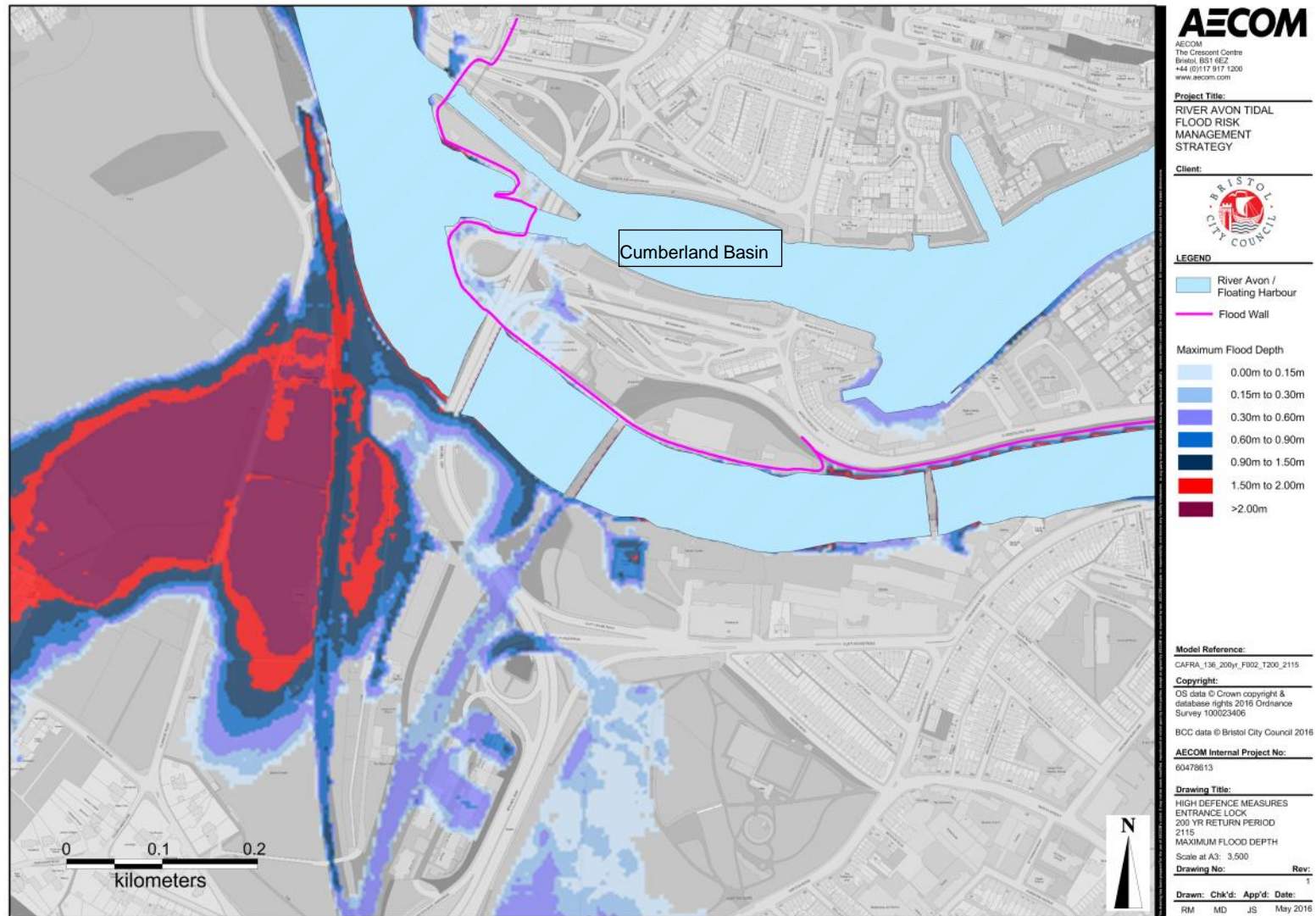


Figure 13 An indicative alignment for potential defences at Entrance Lock to tie in with higher ground. Flood modelling shown following the implementation of the High Defences alignments for a 1:200 year event in 2115, Do Minimum scenario

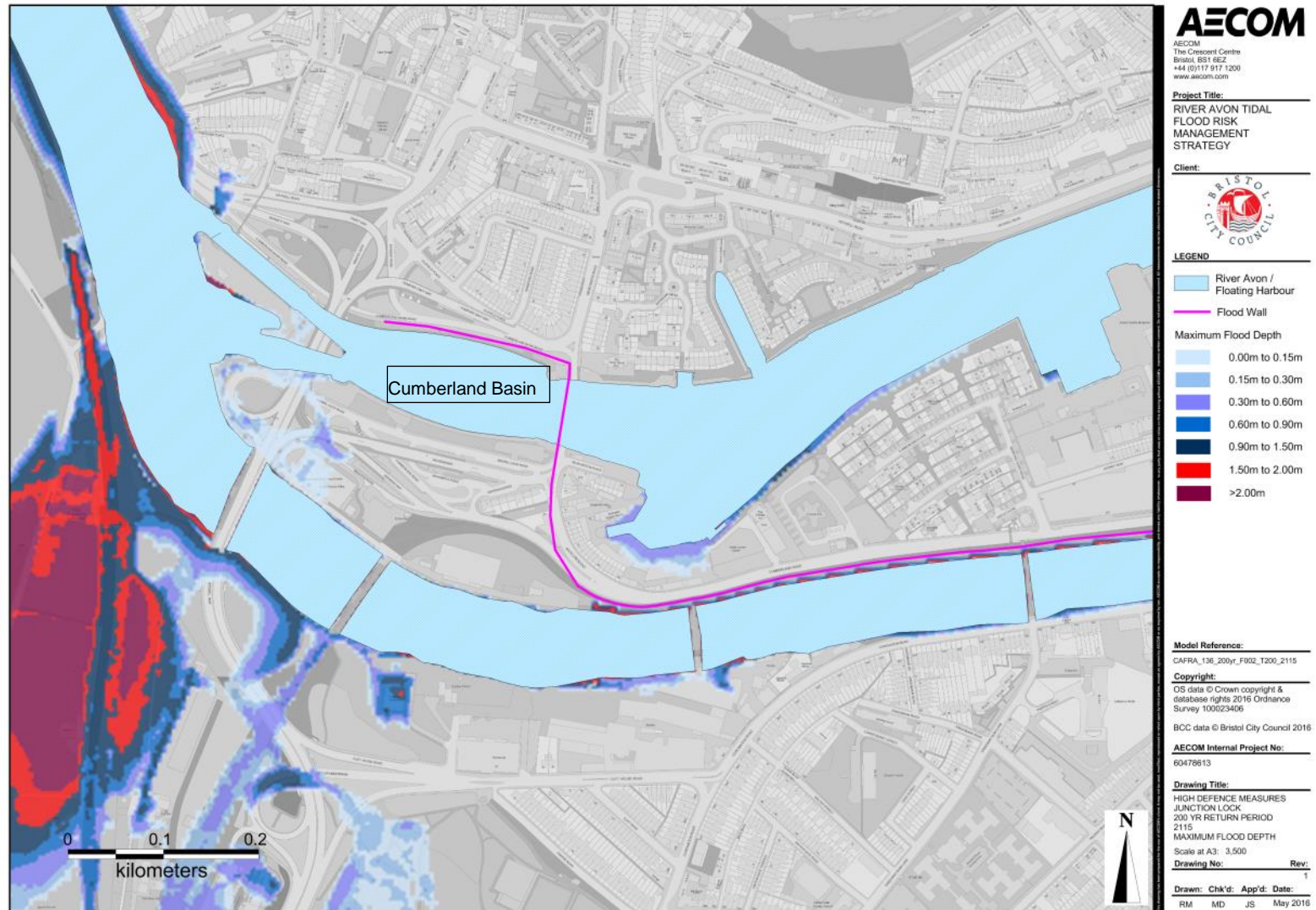


Figure 14 An indicative alignment for potential defences at Junction Lock to tie in with higher ground. Flood modelling shown following the implementation of the High Defences alignments for a 1:200 year event in 2115, Do Minimum scenario

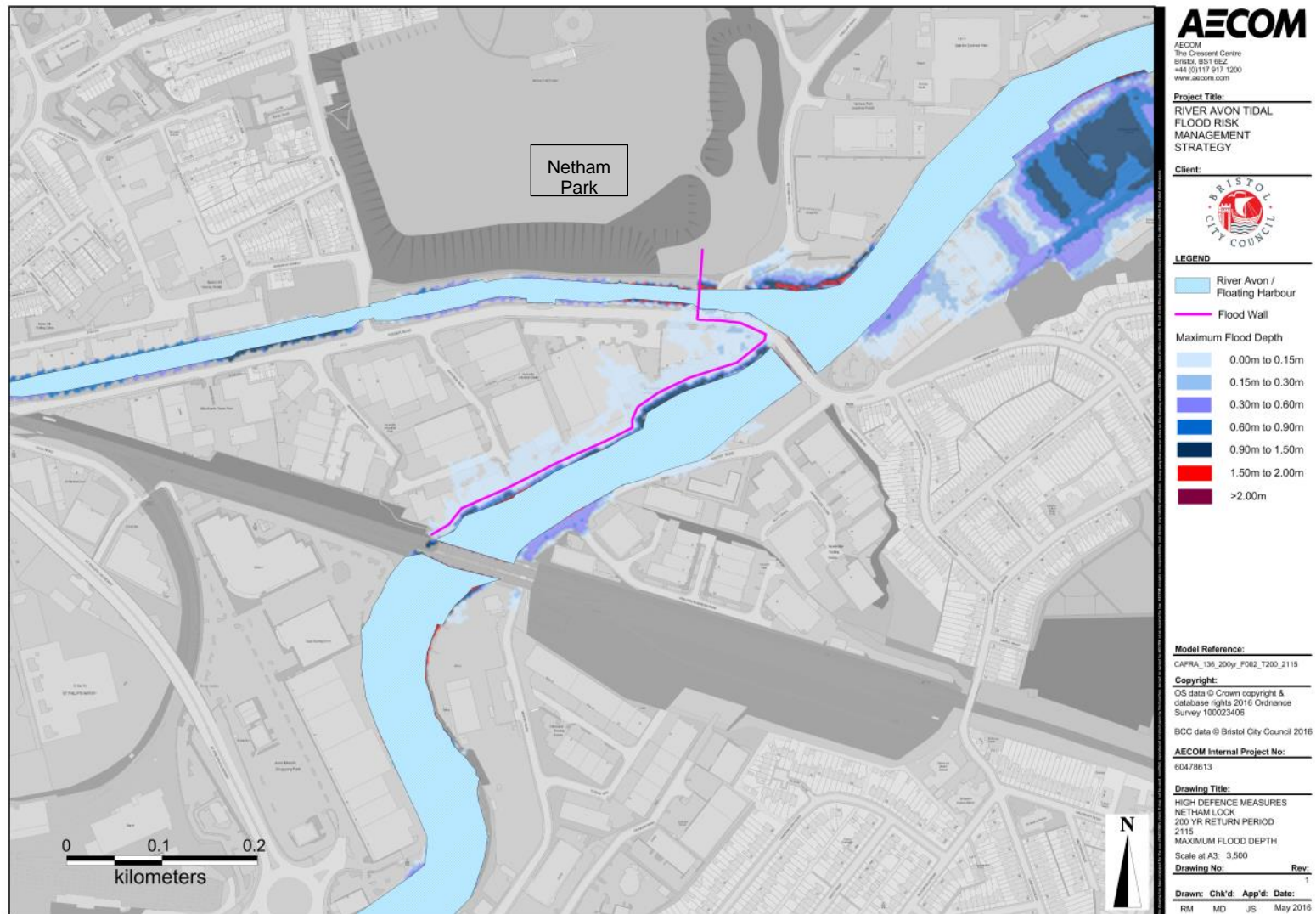


Figure 15 An indicative alignment for potential defences at Netham Lock to tie in with higher ground. Flood modelling shown following the implementation of the High Defences alignments for a 1:200 year event in 2115, Do Minimum scenario

The alignments assume a 1:200 year standard of protection (2115) and it is assumed that a 0.3m freeboard allowance is required. The design water level for a 1:200 year event in 2115 is 9.87m AOD (under the medium emissions 95thtile climate change scenario) and therefore when including a 0.3m freeboard the design crest level of the defences is 10.17m AOD. In addition to lengths and heights of the defences, the typical space restrictions/availability has also been considered and is presented in Table 11. This has helped to determine the technical feasibility of implementing high defences in these locations.

The mean ground level along the new defence alignments has been obtained using recent LiDAR data of the study area. In a GIS, a line inspection has been carried out to determine the mean ground elevation beneath the defence alignments. This mean value has also been cross-checked against a visual interpretation of the LiDAR elevation to provide an elevation range for the ground beneath the defence alignments. To provide a conservative estimate of the defence height required, the lower end of the ground elevation range has been used to determine indicative mean defence heights for each alignment.

A number of limitations exist when using LiDAR data to obtain ground levels, such as potential data uncertainties. Therefore the ground levels and indicative mean defence heights which have been obtained from these levels should only be considered as preliminary estimates (as presented in Table 11). In addition, the new defence alignments may not necessarily follow the alignments of existing defences. Therefore, in some of the locations, there may be either existing defences or spots of higher ground landward of the indicative alignments that may be preventing flooding from occurring (under current conditions). For example at Totterdown, the indicative alignment which was drawn at the front of the public footpath and in some locations there are defences landward of this alignment which help to prevent flooding in the areas of low ground.

More detailed studies to more accurately determine indicative defence heights and how to incorporate existing defences into potential alignments (if feasible) will be undertaken once the short-list of options has been confirmed. This could include the use of topographic survey data.

Also, robustness of solution is a factor given the historical nature and poor condition of many of the existing river walls. New flood walls will need to be designed so that they are not reliant on existing structures with an inadequate residual life.

For each wall alignment a number of potential routes have been considered at ground level using photographs collected during field visits to the key sites at Cumberland Road, Totterdown and Bathurst Basin. This exercise has helped to scope the technical feasibility of implementing high defences in the outlined locations. More details of the alignments at each of these key locations are provided below.

Table 11 Indicative mean defence heights and lengths for high defences along the New Cut, Shirehampton and Pill. Assumed standard of protection is 1:200 year (2115)

Area	Design crest level (including 0.3m freeboard allowance)	Length (m)	Mean ground level (mOD) obtained from LiDAR data	Indicative mean defence height (m)	Space availability
Totterdown – New Cut, north Bank	10.17	1675	8.3-9.0	1.9	Restricted
Bath Road – New Cut, south bank	10.17	454	8.5	1.7	Available
Temple Meads – New Cut, north Bank	10.17	76	9.0-9.7	1.2	Available
Bathurst Basin Dam – New Cut, north bank	10.17	285	8.9-9.5	1.3	Available
Clarence Road – New Cut, north Bank	10.17	213	9.3-9.4	1.0	Available
Cumberland Road - New Cut, north Bank	10.17	752	8.6-9.1	1.2	Available
Hotwells Road (near Clifton Suspension Bridge), River Avon, north bank	10.17	242	9.2	1.0	Available
Hadrian Close (Stoke Bishop), River Avon, north bank	10.17	523	8.2-8.3	2.0	Available
Nibley Road (Shirehampton), River Avon, north bank	10.17	245	7.5	2.7	Available
Station Road (Shirehampton), River Avon, north bank	10.17	768	8.6-8.7	1.6	Available
Pill, River Avon, south bank	10.17	1143	7.8-8.0	2.2	Restricted

Table 12 Indicative mean defence heights and lengths for high defence tie-ins at the entrances to the floating harbour. Assumed standard of protection is 1:200 year (2115)

Area	Design crest level (including 0.3m freeboard allowance)	Length (m)	Mean ground level (mOD) obtained from LiDAR data	Indicative mean defence height (m)	Space availability
Entrance Lock tie in defences for improvements to Entrance Lock gates	10.17	972	8.7	1.5	Available
(or) Junction Lock tie in defences for improvements to Junction Lock gates	10.17	568	9.1	1.1	Available
Netham Lock tie in defences for improvements to Netham Lock gates	10.17	556	9.0	1.2	Available (although some restrictions)

5.3.2.1

Cumberland Road

Cumberland Road is situated along the New Cut to the south of Cumberland Basin. The area is a transport corridor for Bristol with a public footpath, rail line and main road situated within 20m of the water's edge. The frontage is a low spot within Bristol that is particularly vulnerable to flooding. During high spring tides there is a considerable flood risk in this area and to the area behind at Avon Crescent. There are a number of 'defacto' defences in this location which may act to constrain flood waters to some extent but cannot be relied upon to provide a robust defence against flooding.

As part of the Ashton Vale to Temple Meads (AVTM) Metrobus project a new wall is currently under construction along Cumberland Road. The construction can be seen in the recent photograph in Figure 16. The crest elevation of the new wall is 9.2m AOD and will reduce service disruption to the Metrobus link. This wall elevation equates to a 1:200 year present day standard of protection, but by 2065 with anticipated sea level rise the standard is expected to have dropped to below a 1:75 year standard, and by 2115 to below a 1:20 year standard. The new wall has been included in the numerical modelling model runs which show a propagation of flood risk in this area in the future.

Despite the transport links in the area there appears to be available space for a range of different option alignments; a frontline alignment at the public footpath in front of the rail line, a setback alignment at the back of the rail line along the alignment of the Metrobus wall under construction, and finally a setback alignment at the back of Cumberland Basin Road. The potential alignments are shown in Figure 16 and Figure 17, looking west and east along the New Cut respectively.

In order to provide a 1 in 200 year standard of protection to the year 2115, the new defence would need to be approximately 752m in length and approximately 1.2m in height (average) relative to the existing ground levels. This estimated height has been obtained by extracting ground levels from LiDAR data, but not necessarily along the alignment of the Metrobus wall that is currently under construction. In reality, the average defence height required could be considerably less, but for costing purposes a conservative approach has been followed and a maximum mean defence height has been assumed.

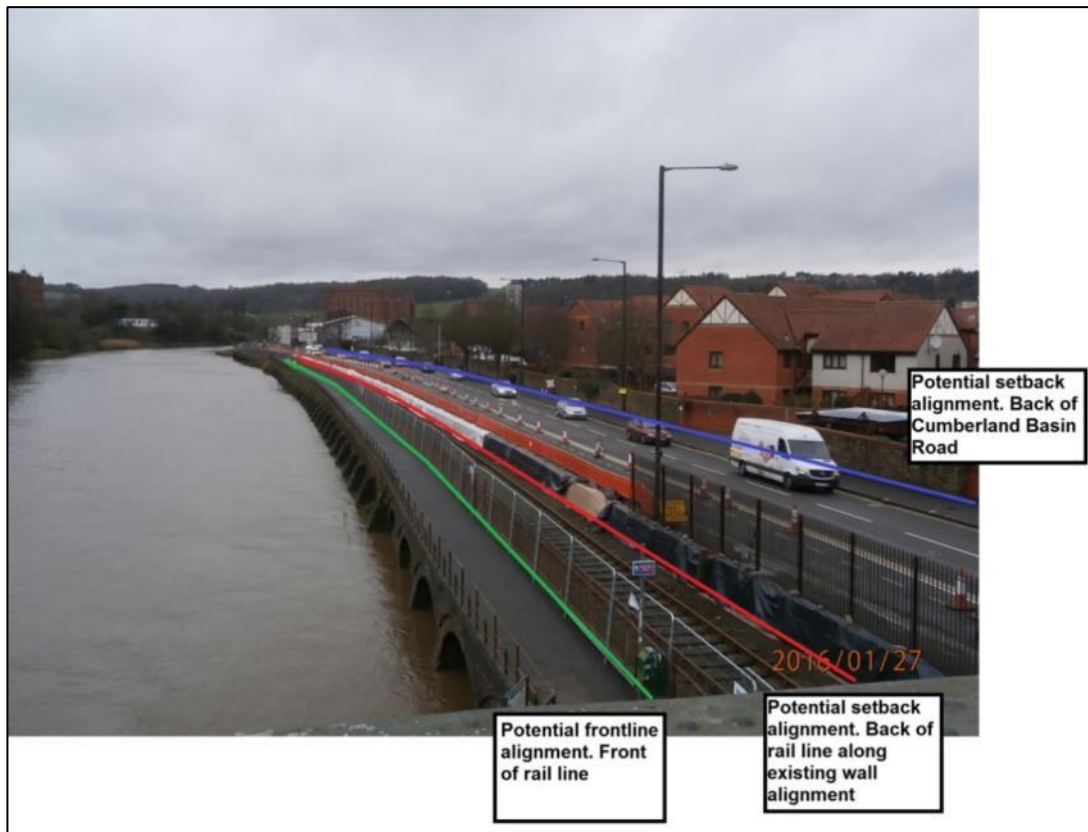


Figure 16 Potential defence alignments at Cumberland Road. Photo looking west along the New Cut)

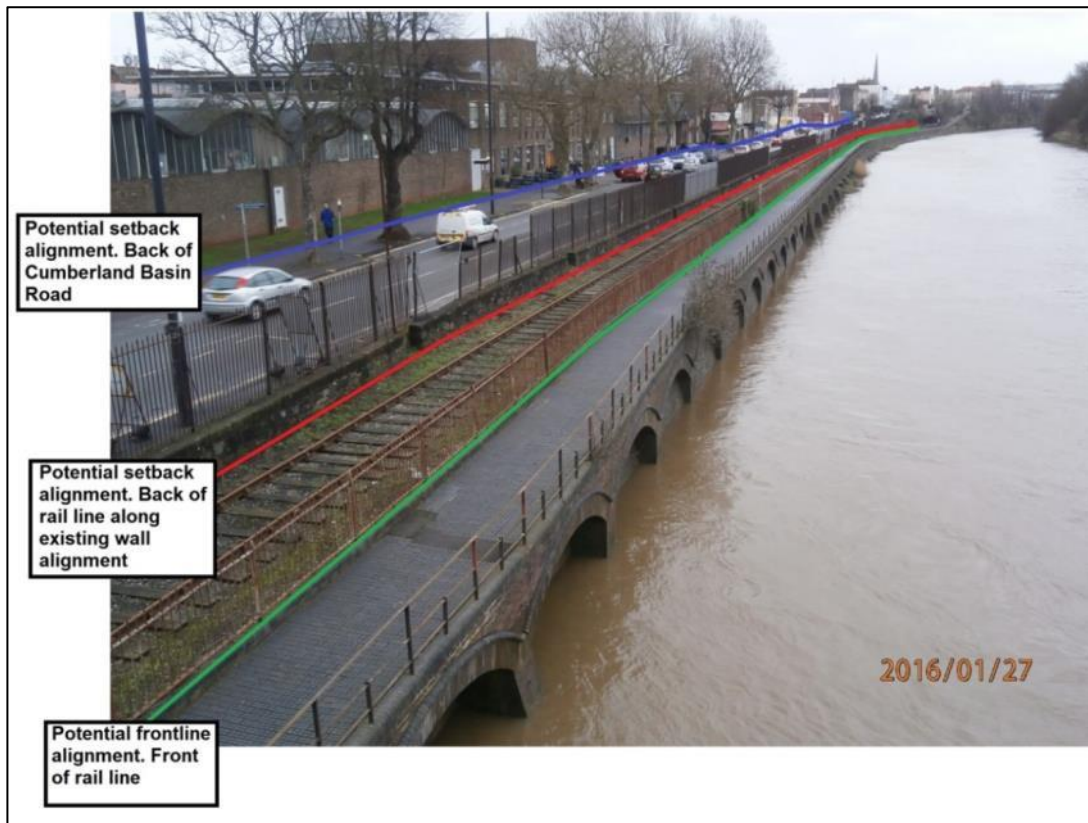


Figure 17 Potential defence alignments at Cumberland Road. Photo looking east along the New Cut

There are advantages and disadvantages of each potential route, such as which transport assets are protected (i.e. all the transport links or just the rail line or road etc.). Table 13 below describes the relative merits of each defence route and for costing purposes at this stage of the appraisal a preliminary preferred route has been identified. Further investigations are required at later stages of the Strategy and in subsequent studies to expand on this assessment, identify the preferred route alignment in more detail and to consider aspects such as structural stability and ground conditions which may impact the feasibility of implementing an alignment in certain locations.

Table 13 Advantages and disadvantages of potential defence routes at Cumberland Road

Route	Advantages	Disadvantages	Indicative structure type	Preferred route for costing purposes?
Frontline at front of rail line	- Protects rail line and main road from flooding	- Potentially obstructs and limits access to footpath along waterfront - Footpath not protected - Potential footpath and rail line disruption during construction & maintenance	Seepage Pile or retention pile	x
Setback at rear of rail line	- Protects main road from flooding - Tie in with MetroBus wall under construction	- Footpath and rail line not protected - Potential rail line disruption during construction	Seepage Pile	✓
Setback at rear of Cumberland Basin Road	- Space widely available	- May have to tie-in / incorporate existing boundary walls for private properties - No transport routes protected	Seepage Pile or Concrete Floodwall	x

5.3.2.2

Bathurst Basin Dam

Bathurst Basin Dam is situated along the New Cut at the intersection between Cumberland Road and Commercial Road. The area is a notable low spot in the land adjacent to the New cut and flood water has historically inundated into the Floating Harbour over the Dam structure during flood events. The CAFRA Workstream 4 assessment identified the Dam as the structure most vulnerable to inundation within the Floating Harbour.

In order to completely block the flood pathway to the land adjacent to the New Cut and into the floating harbour a new defence is required at both Bathurst Basin Dam and along the adjoining Commercial Road to the east. At the Dam structure itself, a feasible solution would be to raise the existing crest level (as shown in Figure 18).

To provide a 1:200 year standard of protection to the year 2115, the new defence would need to be approximately 285m in length and constructed to an average height of 1.3m relative to the existing ground levels.

For the purpose of the short listing phase of the Strategy it is assumed that this is feasible given that the structure is in a 'good' condition and is constructed from precast concrete facing blocks and backfilled mass concrete. At Commercial Road to the east, there appears to be space available for either a frontline or setback alignment (shown in Figure 19). The frontline alignment could follow the front of the public footpath along the water's edge whilst the setback alignment would follow the back of the footpath at the edge of the road.

To provide a 1:200 year standard of protection to the year 2115, the new defence would need to be approximately 285m in length and constructed to an average height of 1.3m relative to the existing ground levels.



Figure 18 Potential defence alignments at Bathurst Basin Dam

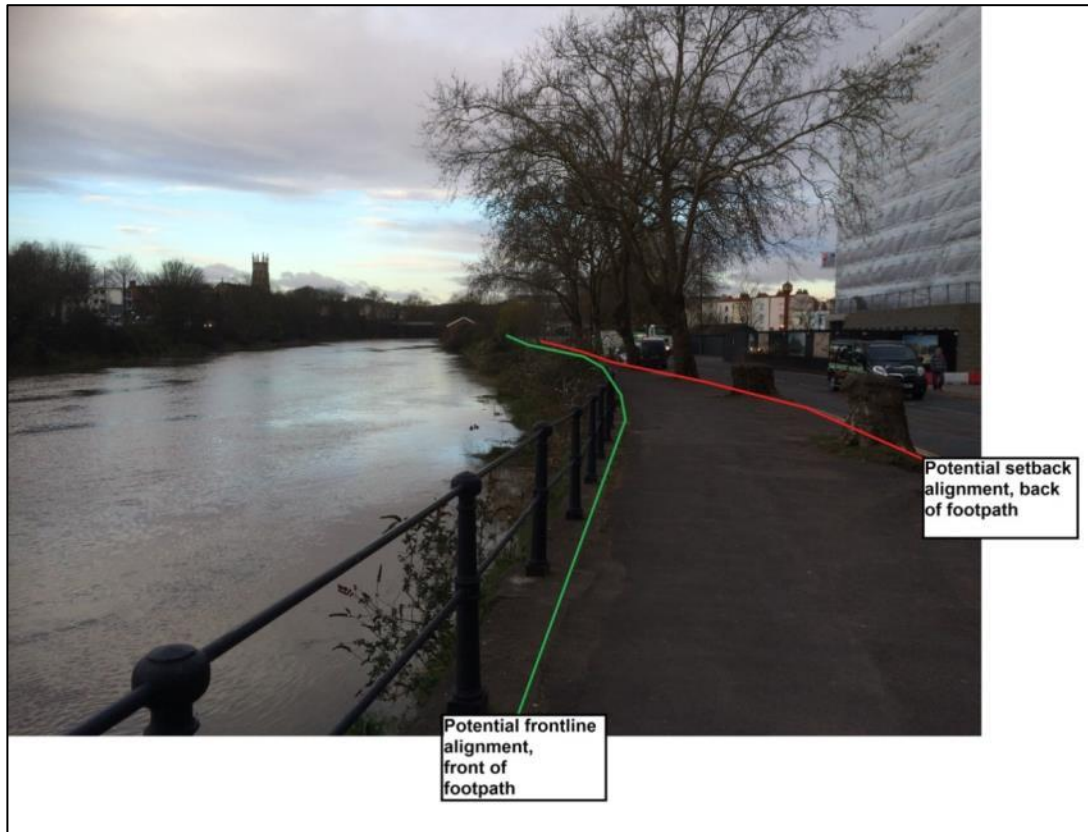


Figure 19 Potential defence alignments at Commercial Road, looking east (photo taken immediately to the east of Bathurst Basin Dam)

There are advantages and disadvantages to both the frontline and setback alignments such as which transport assets are protected (i.e. all the transport links or just the rail line or road etc.). Table 14 below describes the relative merits of each defence route and for costing purposes at this stage of the appraisal a preliminary preferred route has been identified. Further investigations are required at later stages of the Strategy and in subsequent studies to expand on this assessment, identify the preferred route alignment in more detail and to consider aspects such as structural stability and ground conditions which may impact the feasibility of implementing an alignment in certain locations.

Table 14 Advantages and disadvantages of potential defence routes at Bathurst Basin and adjoining Commercial Road

Route	Advantages	Disadvantages	Indicative structure type	Preferred route for costing purposes?
Frontline at front of public footpath	- Protects public footpath and Commercial Road from flooding	- Potentially obstructs and limits access to footpath along waterfront - Potentially impacts visual landscape, and views of the waterfront from the footpath	Retainment Pile	x
Setback along the side of Commercial Road	- Protects Commercial road from flooding	- Footpath not protected - Potential traffic disruption during construction	Seepage Pile	✓

5.3.2.3

Totterdown

The area known as Totterdown refers to a length of proposed defences from Cattle Market Road, just south of Bristol Temple Meads Rail Station, along the area in front of Albert Road to its intersection near the A4320. The area includes the area of St. Philips Marsh which is a low point along the New Cut and is particularly vulnerable to flooding.

The properties which would benefit from a scheme along this frontage are mainly commercial and industrial. In the area to the west of Victoria Road a number of the commercial properties currently act as 'defacto' defences and are likely to provide some, yet unreliable, flood risk benefit to the area behind. A scheme in this area was undertaken in 1984 by Wessex Water Authority which consisted of raising bank levels, walls and waterproof rendering of boundary walls. These works provided protection up to 9.00m AOD but the condition of the defences is now very poor in some locations and the numerical flood modelling has shown that this area is at very high risk of flooding.

To protect the entire area at risk within this flood cell it would be necessary to construct approximately 1.7km of new / raised defences to an average height of 1.9m above the existing ground levels. This length and height of defence would protect to a 1:200 year standard in 2115.

A public footpath runs along the edge of the New Cut for the length of the frontage. However a number of commercial properties are situated in close proximity or immediately adjacent to the footpath and restrict the routes for potential setback defence alignments. A frontline alignment towards the front of the footpath is technically feasible along the length of the frontage. Annotated figures showing the potential alignments and constraints to a setback alignment are shown in Figure 20 to Figure 24.



Figure 20 Potential defence alignments to the west of Victoria Road, looking south with the railway bridge across the River Avon shown in the distance



Figure 21 Potential defence alignments to the west of Victoria Road, looking south. Industrial / commercial buildings are shown which act as defacto defences and potentially restrict a setback alignment



Figure 22 Potential defence alignments at St. Phillips Marsh Industrial area, looking north west



Figure 23 Potential defence alignments immediately east of the road bridge (between Albert Road and Bath Road), looking west. Industrial / commercial buildings are shown which act as defacto defences and potentially restrict a setback alignment



Figure 24 Potential defence alignments at the area adjacent to the Albert Road / Albert Crescent intersection roundabout. Industrial / commercial buildings are shown which act as defacto defences and potentially restrict a setback alignment

There are advantages and disadvantages to both the frontline and setback alignments at Totterdown. Table 15 below describes the relative merits of each defence route and for costing purposes at this stage of the appraisal a preliminary preferred route has been identified. Further investigations are required at later stages of the Strategy and in subsequent studies to expand on this assessment, identify the preferred route alignment in more detail and to consider aspects such as structural stability and ground conditions which may impact the feasibility of implementing an alignment in certain locations.

Table 15 Advantages and disadvantages of potential defence routes at Totterdown

Route	Advantages	Disadvantages	Indicative structure type	Preferred route for costing purposes?
Frontline at front of public footpath	<ul style="list-style-type: none"> - Robust defence against flooding with no significant space constraints - Does not rely on defacto defences to provide a flood defence function 	<ul style="list-style-type: none"> - Potentially obstructs and limits access to footpath along waterfront - Limits waterfront access - Potential impacts on visual landscape, and views of the waterfront from the footpath 	Retainment Pile	✓
Setback along the side of Commercial Road	<ul style="list-style-type: none"> - Shorter defence route alignment - Lesser potential visual impact 	<ul style="list-style-type: none"> - Reliance on defacto defences for protection (i.e. property walls) where route cannot pass - Space and access constraints (i.e. buildings) make it a technically challenging route 	Seepage Pile	✗

5.3.2.4

Bath Road

Bath Road is situated on the south side of the New Cut, approximately half a kilometre downstream from Netham, and opposite the Totterdown defences at Albert Road that are outlined above. To protect to a 1:200 year standard of protection in 2115, approximately 454m of defence raising / new defences, with a mean height of 1.7m, are required. This would prevent flooding to a number of industrial / commercial properties in the area. Existing defences in this location are private; the issue of 3rd party beneficiaries and contributions will be developed by the Strategy in the preferred option phase and in preparing a Funding Strategy.

There are not thought to be any major space restrictions in the area and therefore either a setback or frontline defence alignment is considered feasible. Potential alignments are shown in Figure 25.



Figure 25 Potential defence alignments at Bath Road, photograph looking south east towards the frontage from the North bank of the New Cut

Table 16 Advantages and disadvantages of potential defence routes at Bath Road

Route	Advantages	Disadvantages	Indicative structure type	Preferred route for costing purposes?
Frontline at waterfront	<ul style="list-style-type: none"> - Potential to tie into existing alignment - Minimal impact on visual character of the area 	<ul style="list-style-type: none"> - Potentially more challenging construction – retainment pile likely to be needed - Potential encroachment into intertidal area 	Retainment Pile	✗
Setback along the side of access road	<ul style="list-style-type: none"> - Protects all assets from flooding 	<ul style="list-style-type: none"> - Potential traffic disruption during construction - Potential visual impact to landscape behind existing frontage 	Seepage Pile	✓

5.3.2.5

Entrance Lock gates

As discussed in section 5.3.2, the high defences measure includes works at either Entrance Lock or Junction Lock to upgrade and raise the lock gates (or construct a permanent flood barrier) to prevent water from inundating into the harbour at its downstream entrance. This section discusses the feasibility of upgrading the gates at Entrance Lock and potential route alignments for the tie-in defences either side of the lock gate system.

Entrance Lock provides entry to Cumberland Basin from the River Avon. It is situated immediately to the west of the Brunel Way Road Bridge, to the north of the bridge abutment. To the south of the abutment is Brunel Dam, which would likely also have to be raised to prevent water from inundating over this structure. Entrance Lock is approximately 20m wide and lock gates control the flow of water into the Basin.

To effectively reduce the flood risk and to stop water inundating into Cumberland Basin (and then subsequently into the Floating Harbour), the existing lock gates could be upgraded and raised in size to ensure they are robust against sea level rise. If this were the case it is likely that the infrastructure supporting the existing lock gates would need to be upgraded to accommodate the larger gate replacements (i.e. controls and operational infrastructure). An alternative to lock gate raising would be to construct a permanent flood gate across the channel.

In addition to the lock gates, approximately 972m of new defences would be required to tie in to higher ground and to stop tidal flood waters from outflanking the barrier / gates. In general there are few spatial constraints along the proposed alignments for the new defences. However, in some locations, the defences may have to pass transport infrastructure, such as the A4 road, and therefore demountable flood gates / road raising may be necessary. Indicative alignments for the new defences and potential positions for the barrier / lock gate upgrades are shown on Figure 13.

The indicative spatial alignments have also been considered at ground level using photographs collected during field visits to the site. This has helped to scope the technical feasibility of implementing defences.

In general there is sufficient space along the frontage to implement either a frontline or setback alignment. Figure 26 and Figure 27 show the potential alignments along the north bank of the New Cut, just to the west of the Brunel Way road bridge crossing of the New Cut. In this location there is a large amount of space available for either alignment and a high defence is unlikely to cause significant impacts on the landscape or access routes. To the south of the Brunel Bridge abutment is Brunel Dam, Figure 28 shows the potential to raise the height of the Dam to prevent inundation. The figure also demonstrates that there is space available for either a frontline or setback alignment to tie into this structure. Potential defence alignments at Entrance Lock are shown in Figure 29. Defence tie-ins to higher ground will also be needed north of this channel and it is likely that either demountable flood gates or passive defences such as road raising will be required for a defence to pass Cumberland Basin Road and the Hotwells Road (A4).



Figure 26 Potential defence alignments along the north bank of the New Cut, immediately to the west of Brunel Way road bridge. Photograph looking west towards Clifton Suspension Bridge.



Figure 27 Potential defence alignments at the headland between the north bank of the New Cut and the southern entrance to Cumberland Basin. Photograph looking west towards Clifton Suspension Bridge



Figure 28 Potential defence alignments at Brunel Dam. Photograph looking east



Figure 29 Potential defence alignments at Entrance Lock at entrance to Cumberland Basin. A potential lock gate position is also shown. Photograph looking west towards Clifton Suspension Bridge



Figure 30 Potential defence alignments at Entrance Lock at the entrance to Cumberland Basin. The existing lock gates are shown in a closed position. Photograph looking east.

There are advantages and disadvantages to both the frontline or setback route alignments for the tie-in defences either side of Entrance Lock. Table 17 below describes the relative merits of each defence route and for costing purposes at this stage of the appraisal a preliminary preferred route has been identified. Further investigations are required at later stages of the Strategy and in subsequent studies to expand on this assessment, identify the preferred route alignment in more detail and to consider aspects such as structural stability and ground conditions which may impact the feasibility of implementing an alignment in certain locations.

Table 17 Advantages and disadvantages of potential tie-in defence routes at Entrance Lock

Route	Advantages	Disadvantages	Indicative structure type	Preferred route for costing purposes?
Frontline at waterfront	<ul style="list-style-type: none"> - Protects public footpath and assets located on Brunel Bridge abutment from flooding - Provides protected area for new lock gate / barrier supporting infrastructure to be protected from flooding - Can incorporate existing quay side walls into defences 	<ul style="list-style-type: none"> - Potentially more challenging construction – retainment pile likely to be needed - Potential encroachment into intertidal area 	Retainment Pile	x
Setback along the edge of the public footpath	<ul style="list-style-type: none"> - Protects footpath from flooding - Likely a cheaper / more straightforward design 	<ul style="list-style-type: none"> - Land-in front of defences still at risk of flooding - Potential visual impact to landscape behind existing frontage 	Seepage Pile	✓

5.3.2.6

Junction Lock Upgrades

An alternative location to stop the entry of water into the Floating Harbour during tidal flood events is at the eastern end of Cumberland Basin, at the Harbour entry point at Junction Lock. The width of Junction Lock is approximately 14m. The Lock and the surrounding land levels are a low point in the defences of the Floating Harbour and on previous occasions flood water has inundated this location (see Figure 11).

To stop flood water passing into the Floating Harbour during future flood events it is proposed that the Junction lock gates are replaced and raised. Improvements to the operational infrastructure of the lock may also be required to ensure operation of the larger gates, but this needs further consideration as the gates currently utilise a relatively new hydraulic system that was installed in 2010 which is deemed to be in a 'very good' condition (please refer to Baseline Review report) and could potentially be capable of operating larger gate structures.

Approximately 568m of additional defences would be required to ensure that the upgraded Junction Lock gates are not outflanked by tidal flood waters. However, in some locations, the defences may have to pass transport infrastructure and therefore demountable flood gates / road raising may be necessary. Indicative alignments for the new defences and potential positions for the barrier / lock gate upgrades are shown on Figure 14.



Figure 31 Potential defence tie-ins to higher ground at Junction Lock. The existing lock gates are shown in an open position. Photograph looking north across the Junction Lock.

At Junction Lock constructing defences to tie in with higher ground could prove to be technically challenging, largely due to constraints such as space availability and the presence and positions of the existing infrastructure that is used to operate the swing bridge and lock gates. However, indicative alignments have been annotated onto Figure 31, although further more detailed studies will be required to confirm the feasibility of these alignments.

To the south of Junction Lock, a potential defence alignment exists to the rear of Merchants Road which passes over the Nova Dam. It is likely that the Dam will require raising to stop water from inundating into the Floating Harbour. The defence alignment identified in Figure 14 follows the pathway of Avon Crescent and would tie into the defences along Cumberland Road that are proposed as part of the High Defence options.

To the north of Junction Lock, in order to tie into higher ground the defence could feed past the Pump House public house and cross the A4 road. This could be achieved by either installing demountable defences across the road or by using passive defences, such as road raising.

Raising of the lock gates themselves could also provide a technical challenge as the lock gates lie beneath the road bridge which would likely need to be raised to accommodate the increased lock gate height.

5.3.3

Costs

Based upon the indicative heights, lengths and preferred structure types for each alignment a high level cost estimate for each defence alignment has been made. The cost estimate has been made in cash terms, and includes a 60% optimism bias, appropriate for a strategic level study. For more details of the costing methodology, please refer to Appendix 1 towards the back of this report.

The preferred structure types at the key flood risk locations are outlined in sections 5.3.2.1 to 5.3.2.6. For the remaining alignments, where site photographs have not been collected, appropriate structure types have been established by examining aerial photographs, maps and engineering judgement. This process has been suitably high level for a strategic study and was informed by considering aspects such as space availability, the placement of existing infrastructure, potential risks to other sources of flooding and environmental impacts including the visual environment and encroachment impacts.

It should be noted that the preferred structure types have been identified for high level costing purposes only, and therefore represent a preliminary decision. Going forward, once the short list options have been confirmed, more detailed assessments in the Strategy and in subsequent studies are required to confirm or to change the preferred structure types.

Table 18 and Table 19 below present the estimated cash costs (including a 60% optimism bias) for the various defence alignments that form the basis of the High Defences measure. Table 19 also shows the estimated costs of upgrading the lock gates at Entrance Lock, Junction Lock and Netham Locks. Note that an upgrade to the gates will be required at only one location at the downstream entrance to the floating harbour (i.e. at either Entrance Lock or Junction Lock, not at both). The ground level used to identify the indicative mean defence height is highlighted (either the mean level obtained from a GIS line inspection or by visual inspection).

Table 18 Estimated cash costs of each defence alignment for the High Defences measure.

Defence alignment	Design crest elevation (m ODN)	Mean ground level obtained from LIDAR (m ODN)	Mean ground level obtained from visual check (m ODN)	Indicative mean defence height (m)	Length (m)	Space availability	Route and type of defence	Cost (inc. 60% OB)	Cost per m (incl. 60% Optimism Bias)
Totterdown, New Cut, north bank, full length	10.17	8.3	9.0	1.9	1675	×	Frontline, retainment Pile	£19,726,300	£11,800
Bath Road, New Cut, south bank	10.17	8.5	8.5	1.7	454	✓	Setback, seepage Pile	£2,078,800	£4,600
Temple Meads, New Cut, north bank	10.17	9.7	9.0	1.2	76	✓	Setback, seepage Pile	£343,400	£4,520
Bathurst Dam, New Cut, north bank	10.17	9.5	8.9	1.3	285	✓	Setback, seepage Pile	£1,256,600	£4,410
Clarence Road, New Cut, north bank	10.17	9.4	9.3	0.9	213	✓	Setback, seepage Pile	£903,400	£4,240
Cumberland, New Cut, north bank	10.17	9.1	8.6	1.6	752	✓	Setback, seepage pile	£3,408,000	£4,530
Hotwells Road (near Clifton Suspension Bridge), River Avon, north bank	10.17	9.2	9.2	1	242	✓	Setback, seepage pile	£1,037,500	£4,290
Hadrian Close (Stoke Bishop), River Avon, north Bank	10.17	8.2	8.3	2	523	✓	Setback, seepage pile	£2,462,800	£4,710
Nibley Road (Shirehampton), River Avon, north bank	10.17	7.5	7.5	2.7	245	✓	Setback, embankment	£548,800	£2,240
Station Road (Shirehampton), River Avon, north bank	10.17	8.6	8.7	1.6	768	✓	Setback, embankment	£1,228,000	£1,600
Pill, River Avon, south bank	10.17	7.8	8.0	2.4	1143	✓	Frontline, retainment pile	£13,308,100	£11,640
Total	/	/	/	/	6376	/	/	£46,301,700	/

Table 19 Estimated cash costs of the tie-in defence alignments for lock gate upgrades under the high defence measure.

Defence alignment	Design crest elevation (m ODN)	Mean ground level obtained from LIDAR (m ODN)	Mean ground level obtained from visual check (m ODN)	Mean defence height (m)	Length (m)	Space availability	Route and type of defence	Cost (incl. 60% Optimism Bias)	Cost per m (incl. 60% Optimism Bias)
Entrance Lock defence tie-ins	10.17	8.7	8.7	1.5	972	✓	Setback, seepage pile	£4,364,300	£4,490
(or) Junction Lock defence tie-ins	10.17	9.1	9.1	1.1	568	✓	Seepage pile	£2,451,700	£4,320
Netham Lock defence tie-ins	10.17	9.0	9.0	1.2	556	✓	Setback, seepage pile	£2,423,400	£4,360
Lock gate upgrades	10.17	NA	NA	NA	NA	✓	Lock gate raising	£6,500,000	NA
Permanent Flood Gate at Entrance Lock (only)	10.17	NA	NA	NA	19	✓	Small scale barrier	£11,600,000	£610,530
Total	/	/	/	/	/	/	/	£13,287,700*	/

* Total cost assumes that lock gate upgrades are carried out at entrance lock and at Netham Lock (i.e. the costs highlighted in bold)

Based upon the values presented in Table 18 and Table 19, the overall cash costs for implementing the high defences measure has been estimated. This value represents the cash costs required to construct the defences only, and does not consider maintenance costs for a) maintaining the structural integrity, functionality and H&S requirements of the structures and b) the operation of the water control structures (i.e. the lock gates / small scale barrier).

To provide a conservative cost estimate (i.e. the most costly combination), it has been assumed that the 'sealing-off' of the floating harbour downstream entrance is carried out at Entrance Lock, rather than at Junction Lock. The Entrance Lock defence tie-ins are estimated to be of a considerably higher cost than those needed at Junction Lock.

The high defence measure is precautionary and designed to protect to a 1 in 200 year standard of protection in 2115. Therefore the specification of the high defences does not change, irrespective of when it is implemented across time epochs (i.e. high defences constructed in epoch 1 will be to the same specification as high defences constructed in epoch 3). As such, the cash cost of constructing high defences can be estimated by one cost estimate.

The estimated cash costs for the capital works required to implement the High Defences measure is £59.6 million. This assumes that the lock gate upgrades are carried out at Entrance Lock and Netham Lock. The breakdown for this cost is provided in Table 20 below.

Table 20 Estimated cash costs for the High Defences Measure

Feature	Estimated cash cost (£)
High Defences along the New Cut, Pill and Shirehampton	£46,301,700
Lock gate upgrades	£6,500,000
Entrance Lock gate tie-ins	£4,364,300
Netham Lock gate tie-ins	£2,423,400
Total	£59,589,400

5.3.4

Environmental Impacts

The implementation of High Defences involves identifying low spots in the existing defences and then raising the defence crest levels or constructing new floodwalls or similar defences (i.e. embankments) in these locations.

A negligible impact is predicted for air quality and noise as these impacts are likely to be temporary and can be adequately managed through measures contained within a Construction Environmental Management Plan (CEMP). There are also unlikely to be impacts on geomorphology and water quality. There will be temporary entrainment of sediment during riverbed disturbance, but this is unlikely to affect the overall quality of the water and therefore the impact is expected to be negligible.

This flood defence measure is likely to have a minor negative impact on terrestrial ecology and estuarine/riverine ecology during the construction stage, particularly if the works take place within an ecologically sensitive area such as the Severn Estuary which is designated as an SPA and SAC, SSSI and Ramsar site. However, the construction phase is temporary and once constructed this measure is unlikely to have a noticeable impact on terrestrial ecology and estuarine/riverine ecology.

There is the potential for significant adverse impacts on archaeological and heritage receptors, especially if there are high value receptors in close proximity to the high defences, such as the SS Great Britain.

The High Defences measure is likely to have a minor impact on Traffic & Transport as there will be some additional trips associated with bringing the materials used for the defences to site but these will be over a relatively short period of time and distributed across large parts of the transport network. A Transport Management Plan should be able to adequately address any negative impacts. Negligible impacts are predicted for soil and groundwater as the High Defences may generate pollutant pathways but these will be managed through an appropriate risk assessment and Ground Investigations, as well as any remediation measures.

There is the potential for significant landscape and visual impacts as the high defences will be visually prominent and therefore likely to have a substantial impact on key views and on the Landscape Character of the area.

The level of protection that the High Defences measure will provide is likely to have a significant positive impact on socio-economics as this flood defence measure represents a long term, precautionary approach to managing the impacts of sea level rise which will encourage individuals and developers to invest in the city in the future.

In summary, the High Defences measure has been assessed as follows:

- Negative 'significant' impacts may occur on Landscape and Visual as well as Heritage and Archaeology;
- Positive 'significant' impacts may occur on Socio-economics;
- On balance the negative impacts outweigh the positives.

5.3.5

Wider issues and opportunities

High defences provide a high standard of protection against flooding over the full design life and are likely to be supported by the general public and stakeholders as a long term approach to manage the tidally dominated flood risk. Despite this there are number of issues, and associated opportunities which may arise with High Defences which are discussed below.

The provision of High Defences and their accommodation in areas of existing structures, e.g. bridges, will be considered in the preferred option phase. Walkover inspections will be undertaken to consider the importance of such structural constraints.

An issue which may arise relates to the potential visual impact of high defences on the city's landscape and architecture which is a highly valued aspect of the city's culture and tourism value. Bristol's architecture includes many examples of medieval, gothic, modern industrial and post-war architecture. The visual appeal and continued access to the waterfront along the floating harbour is also important to businesses and tourism for the city and considered an integral part of the city's development. Introduction of High Defences along the waterfront in some locations may therefore be seen to compromise the visual character of the city and mitigation may be necessary to reduce this potential impact.

A potential approach to mitigation is to include 'softer' structure types as part of the High Defences measure, such as earth embankments (where space allows) or reinforced glass walls. Landscaping of new High Defences could also be carried out. Mitigation techniques such as these could help to preserve views along the waterfront and even enhance the character and visual appeal of some areas. Some examples of these mitigation techniques are provided below.



Figure 32 Example of landscaping that could be used as part of the High Defences measure



Figure 33 Example of a reinforced glass floodwall (image courtesy of Flood Control International. Available at www.floodcontrolinternational.com)

High Defences is a measure which is in line with the long term aspirations for the Strategy; to provide a high standard of flood protection and to help facilitate regeneration and development objectives of the city. With this in mind, High Defences are compatible with a long term strategic approach to the management of tidal flood risk in the study area. By providing a physical barrier to flood waters in the areas most at risk, the High Defences measure also helps to address the residual risk which may arise from other sources of flooding, such as fluvial flood risk. A more detailed discussion of residual flood risk is provided in section 7.5 of this report.

As part of the High Defences measure it would be essential to continue, flood forecasting and warning systems. This is paramount to ensure the successful operation of the tidal lock gates at either Entrance Lock or Junction Lock, and at Netham. In addition, due to access requirements it is likely that a number of demountable or manually operated flood gates will need to be included in the High Defence alignments. An operating regime / programme for these gates will need to be developed to ensure that the gates are closed during flood events and to minimise the residual risk of these gates being left open.

5.4 Low Defences

5.4.1 *Description*

The 'Low Defences' measure comprises linear defences – walls or embankments – to provide a high standard of protection, but for a limited period after which the defence would be raised further or an alternative measure implemented. Low Defences are an adaptable solution to manage tidal flood risk and sea level rise whereas High Defences are precautionary.

The implementation of Low Defences involves identifying low spots or gaps in the existing defences and then raising the existing defence levels or constructing new floodwalls or similar defences (e.g. embankments) in these locations.

Low Defences will be required in similar locations to High Defences but the defences will generally be shorter and lower. Low defences will be constructed to a specified standard in 2015, 2030 or 2065 and are intended to provide a standard of protection that is robust against short to medium term levels of sea level rise before a defence upgrade is needed. On the other hand, High Defences are constructed to a standard of protection for 2115 and therefore represent a long term, precautionary approach to managing the impacts of sea level rise.

For the purpose of the short list appraisal, it has been assumed that Low Defences would be constructed to a 1:200 year standard of protection. However, at the time of undertaking the long to short list appraisal, a detailed economic appraisal has yet to be carried out and therefore the optimal standard of protection for Low Defences has not yet been explored in detail. The 1:200 standard of protection is therefore only preliminary and testing and potential refinements to this standard will be made during later stages of the Strategy appraisal.

A 1:200 SoP for the lifetime of a development would meet the requirements of national planning policy in regard to flood risk for new development. A lesser standard would constrain development.

5.4.2 *Technical feasibility*

Based upon the Do Minimum modelling outputs, a first pass assessment was carried out to identify the areas where raised Low Defences would be required to prevent tidal flooding during the following design standard events:

- 2015 1:200 year event
- 2030 1:200 year event
- 2065 1:200 year event

The assessment was based upon a visual analysis in GIS, whereby the areas of tidal flooding were identified and indicative route alignments needed to block the path of flooding were established.

It is proposed that the same lock gate / permanent flood gate 'sealing-off' approach that is proposed alongside the High Defences is also undertaken with Low Defences. This will prevent tidal flood water from entering the Harbour at the entrance and would allow for water levels within the Harbour to be controlled during flood events. The benefits of effectively 'sealing-off' both entrances to the Harbour are:

- Prevents water from entering the floating harbour at both entrances, allowing water levels within the Harbour to be controlled effectively during flood events.
- Removes the need for new high defences to be constructed within the floating harbour itself
- Potentially a reduced visual impact on the landscape of the city centre by removing the need for high defences around the harbour
- Reduces costs compared to constructing long lengths of high defences around the floating harbour
- Reduces the potential technical complications which may arise when constructing new defences on top or adjacent to the existing harbour walls which are generally in an ageing / poor condition.

Further details of the 'sealing-off' approach can be found in section 5.3. As discussed in section 5.3, a lock gate upgrade / permanent flood gate will need to be constructed at either Entrance Lock or Junction lock (at the downstream entrance to the Harbour) and at Netham Lock gates (the upstream entrance to the harbour). Tie-in defences either side of the lock gates will be required to ensure tidal flood waters do not outflank the gates and inundate the harbour behind.

Whilst 'sealing-off' the floating harbour at its entrances removes the need to construct long lengths of defence around the harbour, a number of flood pathways from the New Cut into the harbour exist in 2015, 2030 and 2065. Therefore, as part of the Low Defences measure, new raised defences are required at these locations. The main areas where new defences are required are at Cumberland Road, Bathurst Basin Dam, Totterdown, Temple Meads and Clarence Road. A defence at Bath Road may also be needed to prevent water inundating an industrial / commercial area south of the New Cut.

Figure 34 to Figure 36 show the indicative defence alignments for Low Defences in each time epoch. Indicative alignments and descriptions of routes for the defence tie-ins at Entrance Lock, Junction Lock and Netham Lock gates are provided Figure 13 and Figure 14 located in the previous section, section 5.3.

Downstream of the floating harbour area, high defences would also be required at sites in Pill and Shirehampton. In these locations the numerical modelling is limited and has simulated flood risk in a one-dimensional format. Based on the information available at this stage of the appraisal the indicative defence lengths and heights have been estimated for these locations and are presented in Table 21, Table 23 and Table 25.

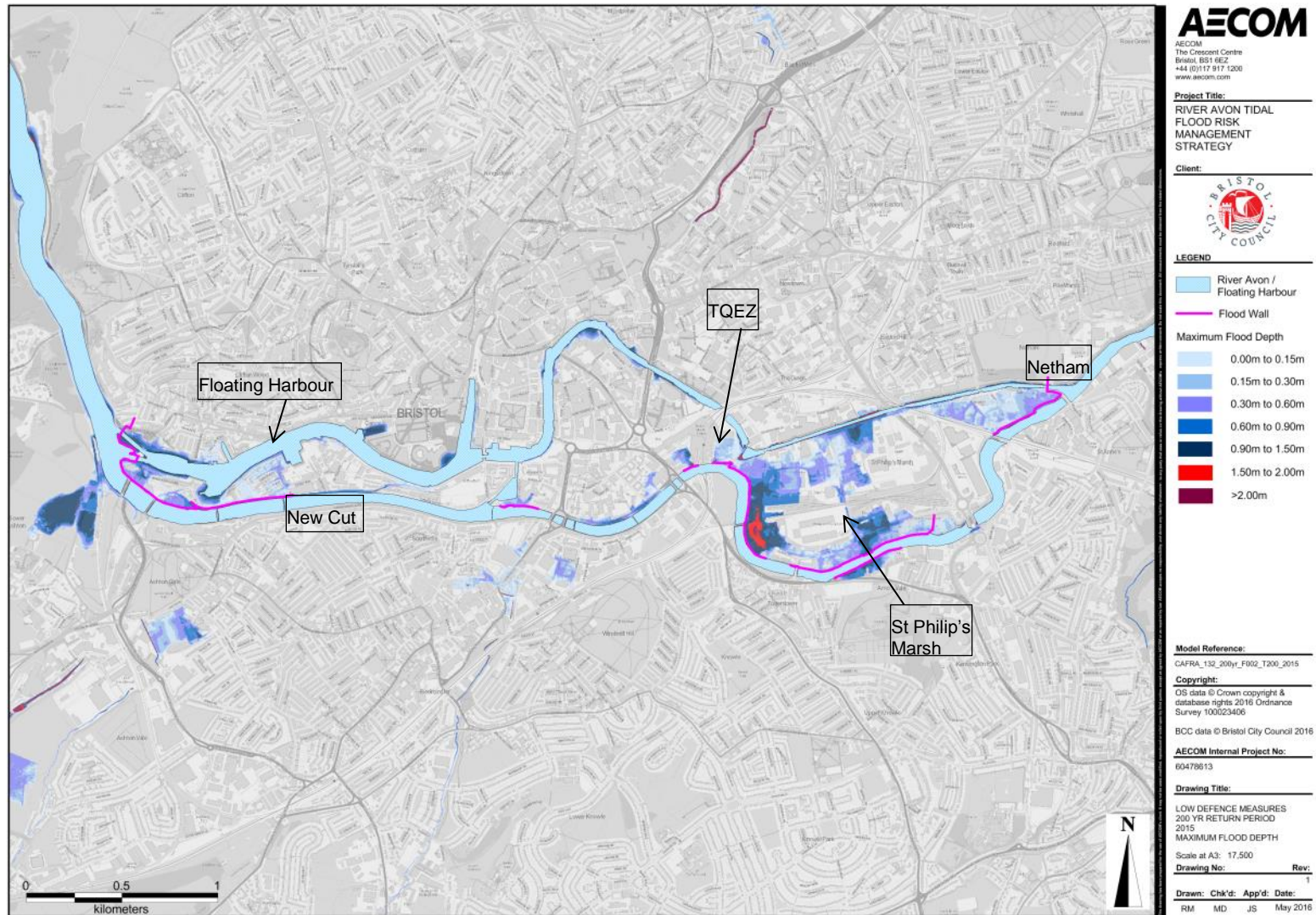


Figure 34 Indicative alignments for potential low defences along the New Cut (1:200 year SoP, 2015). Flood modelling shown for a 1:200 year event in 2015 under the Do Minimum scenario (prior to wall implementation).

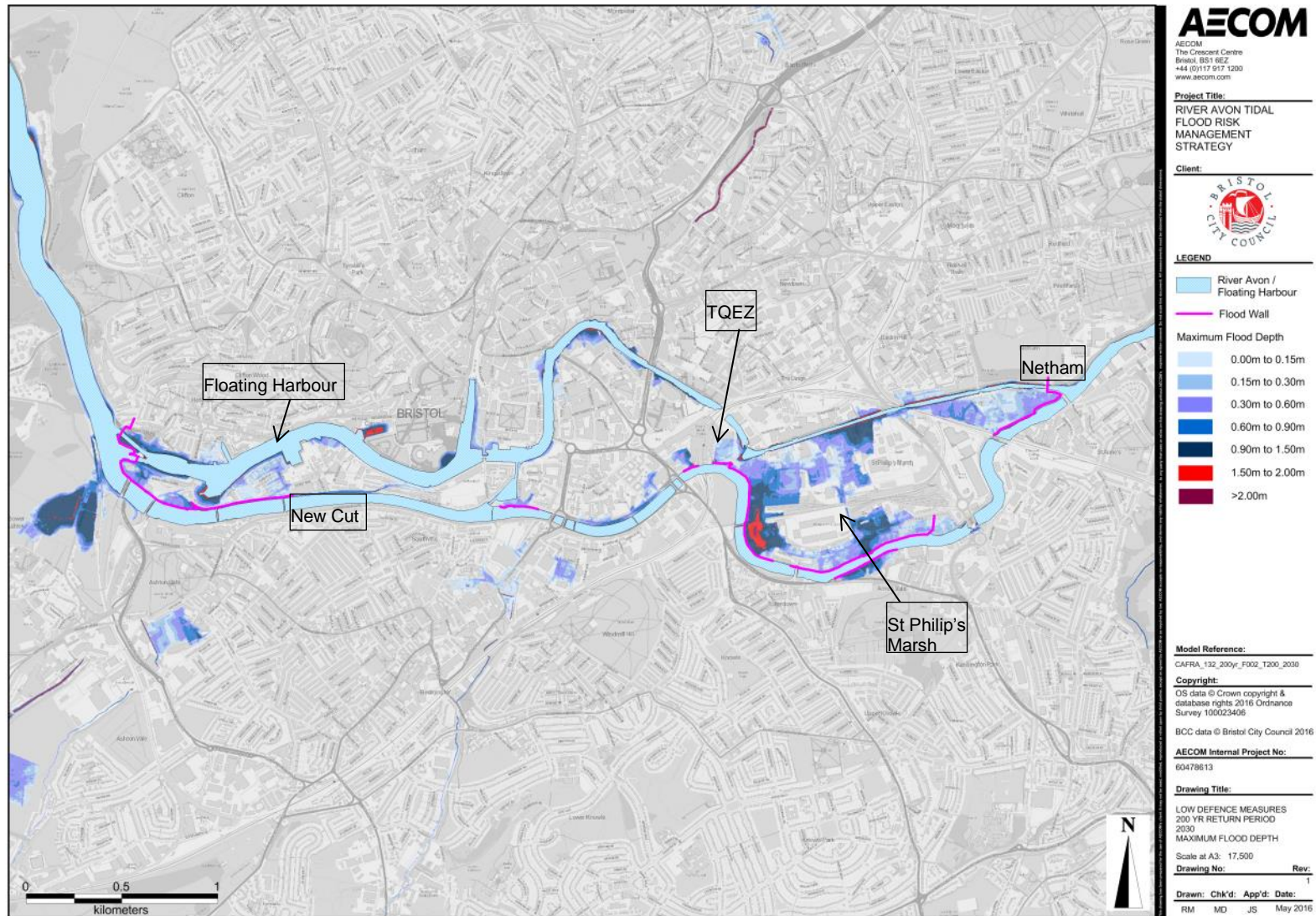


Figure 35 Indicative alignments for potential low defences along the New Cut (1:200 year SoP, 2030). Flood modelling shown for a 1:200 year event in 2030 under the Do Minimum scenario (prior to wall implementation).

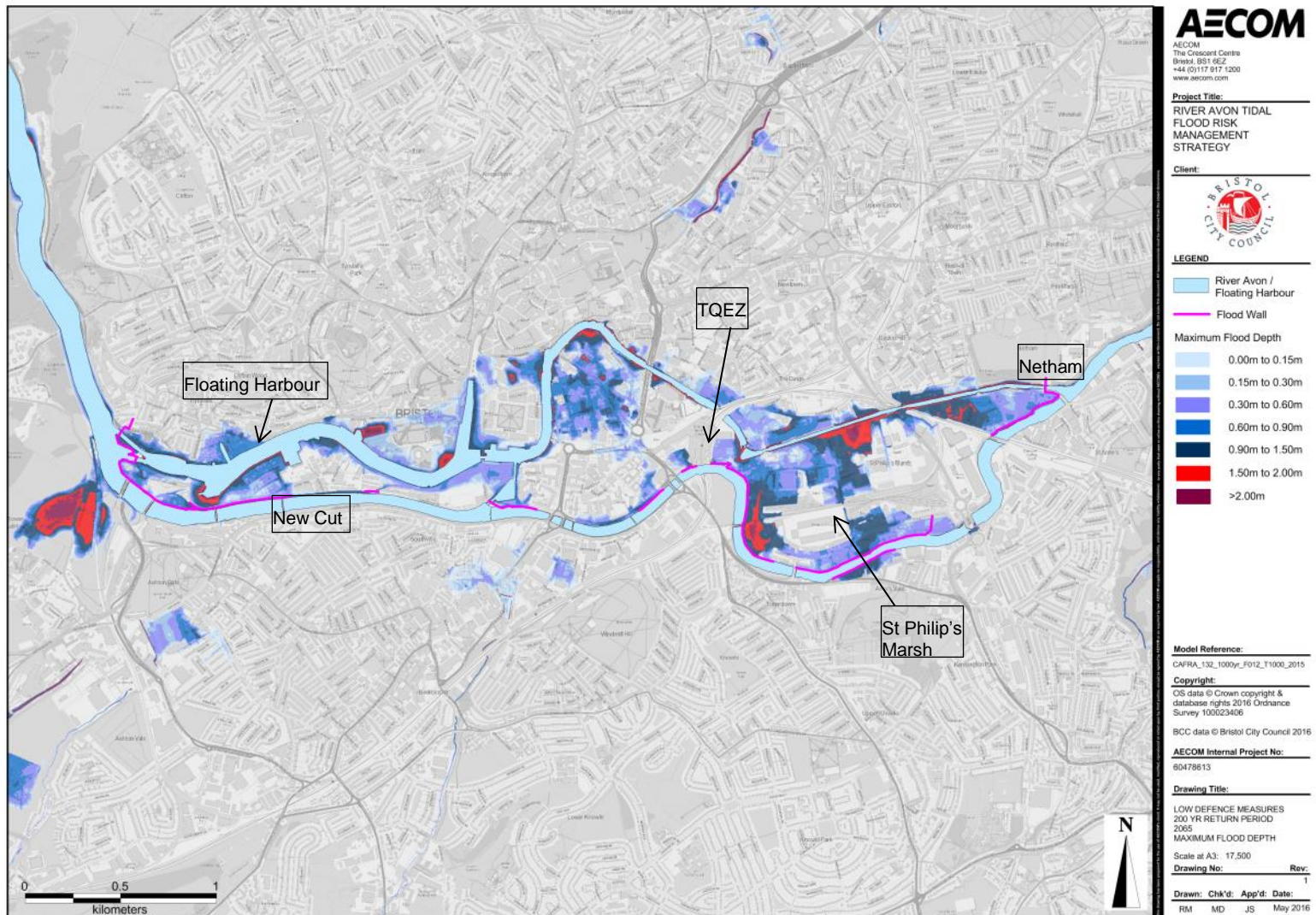


Figure 36 Indicative alignments for potential low defences along the New Cut (1:200 year SoP, 2065). Flood modelling shown for a 1:200 year event in 2065 under the Do Minimum scenario (prior to wall implementation).

Outlined in Table 21, Table 23 and Table 25 are the indicative defence heights and lengths that are likely to be required at each of the defence alignments for low defences in the years 2015, 2030 and 2065. Table 22, Table 24 and Table 26 show the indicative defence heights and lengths for the defence tie-in alignments at the downstream and upstream barrier / lock gate improvements at Entrance / Junction Lock and Netham Lock gates for Low Defences.

The alignments for Low Defences have been established assuming a 1:200 year standard of protection for the year of implementation (i.e. 2015, 2030 and 2065). The design water levels for a 1:200 year event are 9.13m AOD, 9.21m AOD and 9.45m AOD for the years 2015, 2030 and 2065 respectively (under the medium emissions 95thtile climate change scenario). Therefore, when including a 0.3m freeboard the design crest levels of the defences are 9.43m AOD, 9.51m AOD and 9.75m AOD for 2015, 2030 and 2065 respectively. In addition to lengths and heights of the defences, the typical space restrictions/availability has also been considered and is presented in Table 21 to Table 26. This has helped to determine the technical feasibility of implementing high defences in these locations.

The mean ground level along the defence alignments has been obtained using recent LiDAR data of the study area. In a GIS, a line inspection has been carried out to determine the mean ground elevation beneath the defence alignments. This mean value has also been cross-checked against a visual interpretation of the LiDAR elevation to provide an elevation range for the ground beneath the defence alignments. To provide a conservative estimate of the defence height required, the lower end of the ground elevation range has been used to determine indicative mean defence heights for each alignment.

A number of limitations exist when using LiDAR data to obtain ground levels, such as potential data uncertainties. Therefore the ground levels and indicative mean defence heights which have been obtained from these levels should only be considered as preliminary estimates. In addition, the new defence alignments may not necessarily follow the alignments of existing defences. Therefore, in some of the locations, there may be either existing defences or spots of higher ground landward of the indicative alignments that may be preventing flooding from occurring (under current conditions). For example at Totterdown, the indicative alignment which was drawn at the front of the public footpath and in some locations there are defences landward of this alignment which help to prevent flooding in the areas of low ground.

More detailed studies to more accurately determine indicative defence heights and how to incorporate existing defences into potential alignments (if feasible) will be undertaken once the short-list of options has been confirmed. This could include the use of topographic survey data.

Table 21 Indicative mean defence heights and lengths for low defences along the New Cut, Shirehampton and Pill in the year 2015. Assumed standard of protection is 1:200 year (2015)

Area	Design crest level (including 0.3m freeboard allowance)	Length (m)	Mean ground level (mOD) obtained from LiDAR data	Indicative mean defence height (m)	Space availability
Totterdown – New Cut, north bank, Albert Road	9.43	831	9.0-9.5	0.5	Restricted
Totterdown – New Cut, north bank, Victoria Road	9.43	664	8.0	1.4	Restricted
Bath Road – New Cut, south bank	9.43	381	8.5	1.0	Available
Temple Meads – New Cut, north bank	9.43	69	9.0-9.7	0.5	Available
Bathurst Basin Dam – New Cut, north bank	9.43	174	8.9-9.1	0.6	Available
Cumberland Road - New Cut, north bank	9.43	516	8.6-8.9	0.6	Available
Hadrian Close (Stoke Bishop), River Avon, north bank	9.43	502	8.2-8.7	1.3	Available
Nibley Road (Shirehampton), River Avon, north bank	9.43	235	7.5	2.0	Available
Station Road (Shirehampton), River Avon, north bank	9.43	350	8.2	1.3	Available
Pill, River Avon, south bank	9.43	1085	7.7-8.0	1.5	Restricted

Table 22 Indicative mean defence heights and lengths for low defence tie-ins at the entrances to the floating harbour. Assumed standard of protection 1:200 year (2015)

Area	Design crest level (including 0.3m freeboard allowance)	Length (m)	Mean ground level (mOD) obtained from LiDAR data	Indicative mean defence height (m)	Space availability
Entrance Lock tie in defences for improvements to Entrance Lock gates / permanent flood gate	9.43	972	8.7	0.8	Available
(or) Junction Lock tie in defences for improvements to Junction Lock gates	9.43	568	9.1	0.4	Available
Netham Lock tie in defences for improvements to Netham Lock gates	9.43	556	9.0	0.5	Available (although some restrictions)

Table 23 Indicative mean defence heights and lengths for low defences along the New Cut, Shirehampton and Pill in the year 2030. Assumed standard of protection is 1:200 year (2030)

Area	Design crest level (including 0.3m freeboard allowance)	Length (m)	Mean ground level (mOD) obtained from LiDAR data	Indicative mean defence height (m)	Space availability
Totterdown – New Cut, north bank, Albert Road	9.51	853	9.0-9.5	0.5	Restricted
Totterdown – New Cut, north bank, Victoria Road	9.51	724	8.0	1.5	Restricted
Bath Road – New Cut, south bank	9.51	382	8.5	1.0	Available
Temple Meads – New Cut, north bank	9.51	76	9.0-9.7	0.5	Available
Bathurst Basin Dam – New Cut, north bank	9.51	174	8.9-9.1	0.6	Available
Cumberland Road - New Cut, north bank	9.51	524	8.6-8.9	0.7	Available
Hadrian Close (Stoke Bishop), River Avon, north bank	9.51	525	8.2-8.3	1.4	Available
Nibley Road (Shirehampton), River Avon, north bank	9.51	235	7.5	2.1	Available
Station Road (Shirehampton), River Avon, north bank	9.51	371	8.2	1.4	Available
Pill, River Avon, south bank	9.51	1085	7.6-8.0	1.6	Restricted

Table 24 Indicative mean defence heights and lengths for low defence tie-ins at the entrances to the floating harbour. Assumed standard of protection 1:200 year (2030)

Area	Design crest level (including 0.3m freeboard allowance)	Length (m)	Mean ground level (mOD) obtained from LiDAR data	Indicative mean defence height (m)	Space availability
Entrance Lock tie in defences for improvements to Entrance Lock gates / permanent flood gate	9.51	972	8.7	0.9	Available
(or) Junction Lock tie in defences for improvements to Junction Lock gates	9.51	568	9.1	0.5	Available
Netham Lock tie in defences for improvements to Netham Lock gates	9.51	556	9.0	0.6	Available (although some restrictions)

Table 25 Indicative mean defence heights and lengths for low defences along the New Cut, Shirehampton and Pill in the year 2030. Assumed standard of protection is 1:200 year (2065)

Area	Design crest level (including 0.3m freeboard allowance)	Length (m)	Mean ground level (mOD) obtained from LiDAR data	Indicative mean defence height (m)	Space availability
Totterdown – New Cut, north bank, Albert Road	9.75	853	9.0-9.5	0.8	Restricted
Totterdown – New Cut, north bank, Victoria Road	9.75	724	8.0	1.8	Restricted
Bath Road – New Cut, south bank	9.75	382	8.5	1.3	Available
Temple Meads – New Cut, north bank	9.75	76	9.0-9.7	0.8	Available
Bathurst Basin Dam – New Cut, north bank	9.75	263	8.9-9.4	0.9	Available
Clarence Road, New Cut, north bank	9.75	179	9.3	0.5	Available
Cumberland Road - New Cut, north bank, short section	9.75	67	9.0-12.2	0.8	Available
Cumberland Road - New Cut, north bank	9.75	524	8.6-8.9	0.9	Available
Hadrian Close (Stoke Bishop), River Avon, north bank	9.75	524	8.2-8.3	1.6	Available
Nibley Road (Shirehampton), River Avon, north bank	9.75	236	7.5	2.3	Available
Station Road (Shirehampton), River Avon, north bank	9.75	423	8.3	1.5	Available
Pill, River Avon, south bank	9.75	1170	7.6-8.0	1.8	Restricted

Table 26 Indicative mean defence heights and lengths for low defence tie-ins at the entrances to the floating harbour. Assumed standard of protection 1:200 year (2065)

Area	Design crest level (including 0.3m freeboard allowance)	Length (m)	Mean ground level (mOD) obtained from LiDAR data	Indicative mean defence height (m)	Space availability
Entrance Lock tie in defences for improvements to Entrance Lock gates / permanent flood gate	9.75	972	8.7	2.4	Available
(or) Junction Lock tie in defences for improvements to Junction Lock gates	9.75	568	9.1	0.7	Available
Netham Lock tie in defences for improvements to Netham Lock gates	9.75	556	9.0	0.8	Available (although some restrictions)

The areas along the New Cut, Pill, Shirehampton and the entrances to the floating harbour that have been identified for Low Defence alignments are very similar to those required for High Defences. The technical feasibility of implementing defences in these locations has been considered in section 5.3.2, where potential route alignments (i.e. setback or frontline) have been annotated on photographs collected during site visits.

In section 5.3.2 the preferred structure types for the High Defence route alignments have also been considered. It is assumed that these structure types are also the preferred solution for Low Defences. It should be noted that the structure types identified are for high level costing purposes only at this stage of the options appraisal, and more detailed studies to confirm or change the structure types will be undertaken during later appraisal work and subsequent studies.

5.4.3

Costs

Based upon the indicative heights, lengths and preferred structure types for each alignment a high level cost estimate for each defence alignment has been made. The cost estimate has been made in cash terms, and includes a 60% optimism bias, appropriate for a strategic level study. More details of the costing methodology are given in Appendix 1.

The preferred structure types and details of how these have been chosen for the defence alignments are described in section 5.3.2. It should be noted that the preferred structure types have been identified for high level costing purposes only, and therefore represent a preliminary decision. Once the short list options have been confirmed, more detailed assessments in the Strategy and in subsequent studies are required to confirm or to change the preferred structure types.

Table 27, Table 29 and Table 31 below present the estimated cash costs (including a 60% optimism bias) for the various defence alignments that form the basis of the Low Defences measure. A cost estimate has been made for the alignments in each time epoch for Low Defences. This is because the measure represents an 'adaptive' approach and therefore the lengths and heights increase over the duration of the Strategy due to sea level rise and the increase in tidal flood risk.

Table 28, Table 30 and Table 32 also show the estimated costs of upgrading the lock gates at Entrance Lock, Junction Lock and Netham Locks. Note that an upgrade to the gates will be required at only one location at the downstream entrance to the floating harbour (i.e. at either Entrance Lock or Junction Lock, not at both). The ground level used to identify the indicative mean defence height is highlighted (either the mean level obtained from a GIS line inspection or by visual inspection).

Table 27 Estimated cash costs of each defence alignment for the Low Defences measure in 2015. The ground level used to identify the indicative mean defence height is highlighted (either the mean level obtained from a GIS line inspection or by visual inspection)

Defence alignment	Design crest elevation (m ODN)	Mean ground level obtained from LIDAR (m ODN)	Mean ground level obtained from visual check (m ODN)	Indicative mean defence height (m)	Length (m)	Space availability	Route and type of defence	Cost (inc. 60% OB)	Cost per m (inc. 60% OB)
Totterdown, New Cut, north bank, Albert Road	9.43	9.5	9.0	0.5	831	*	Frontline, retainment pile	£10,474,100	£12,600
Totterdown, New Cut, north bank, Victoria Road	9.43	8.0	8.0	1.5	664	*	Frontline, retainment pile	£8,030,400	£12,090
Bath Road, New Cut, south bank	9.43	8.5	8.5	1.0	381	✓	Setback, seepage pile	£1,629,500	£4,280
Temple Meads, New Cut, north bank	9.43	9.7	9.0	0.5	69	✓	Setback, seepage pile	£291,700	£4,230
Bathurst Basin Dam , New Cut, north bank	9.43	9.1	8.9	0.6	174	✓	Setback, seepage pile	£717,500	£4,120
Cumberland, New Cut, north bank	9.43	8.9	8.6	0.9	516	✓	Setback, seepage pile	£2,183,400	£4,230
Hadrian Close (Stoke Bishop), River Avon, north Bank	9.43	8.7	8.2	1.3	502	✓	Setback, seepage pile	£2,211,700	£4,410
Nibley Road (Shirehampton), River Avon, north bank	9.43	7.5	7.5	2.0	235	✓	Setback, embankment	£376,000	£1,600
Station Road (Shirehampton), River Avon, north bank	9.43	8.2	8.2	1.3	350	✓	Setback, embankment	£448,000	£1,280
Pill, River Avon, south bank	9.43	7.7	8	1.5	1085	*	Frontline, retainment pile	£13,067,400	£12,040
Total	/	/	/	/	4807	/	/	£39,429,700	/

Table 28 Estimated cash costs of the tie-in defence alignments for lock gate upgrades under the low defence measure in 2015. The ground level used to identify the indicative mean defence height is highlighted (either the mean level obtained from a GIS line inspection or by visual inspection)

Defence alignment	Design crest elevation (m ODN)	Mean ground level obtained from LIDAR (m ODN)	Mean ground level obtained from visual check (m ODN)	Indicative mean defence height (m)	Length (m)	Space availability	Route and type of defence	Cost (inc. 60% OB)	Cost per m (inc. 60% OB)
Entrance Lock defence tie-ins	9.43	8.7	8.7	0.8	972	✓	Setback, seepage pile	£4,064,000	£4,180
(or) Junction Lock defence tie-ins	9.43	9.1	9.1	0.5	568	✓	Seepage pile	£2,286,900	£4,010
Netham Lock defence tie-ins	9.43	9.0	9.0	0.5	556	✓	Setback, seepage pile	£2,253,500	£4,050
Lock gate upgrades	10.2	NA	NA	NA	NA	✓	Lock gate raising	£6,500,000	NA
Permanent Flood Gate at Entrance Lock (only)	10.2	NA	NA	NA	19	✓	Small scale barrier	£11,600,000	£610,530
Total	/	/	/	/	/	/	/	£12,817,500*	/

* Total cost assumes that lock gate upgrades are carried out at entrance lock and at Netham Lock (i.e. the costs highlighted in bold)

Table 29 Estimated cash costs of each defence alignment for the Low Defences measure in 2030. The ground level used to identify the indicative mean defence height is highlighted (either the mean level obtained from a GIS line inspection or by visual inspection)

Defence alignment	Design crest elevation (m ODN)	Mean ground level obtained from LIDAR (m ODN)	Mean ground level obtained from visual check (m ODN)	Indicative mean defence height (m)	Length (m)	Space availability	Route and type of defence	Cost (inc. 60% OB)	Cost per m (inc. 60% OB)
Totterdown, New Cut, north bank, Albert Road	9.51	9.5	9.0	0.6	853	×	Frontline, Retainment pile	£10,711,800	£12,560
Totterdown, New Cut, north bank, Victoria Road	9.51	8.0	8.0	1.6	724	×	Frontline, retainment pile	£8,718,600	£12,040
Bath Road, New Cut, south bank	9.51	8.5	8.5	1.1	382	✓	Setback, seepage pile	£1,651,700	£4,320
Temple Meads, New Cut, north bank	9.51	9.7	9.0	0.6	76	✓	Setback, seepage pile	£323,700	£4,260
Bathurst Basin Dam , New Cut, north bank	9.51	9.1	8.9	0.7	174	✓	Setback, seepage pile	£724,900	£4,170
Cumberland, New Cut, north bank	9.51	8.9	8.6	1.0	524	✓	Setback, seepage pile	£2,238,800	£4,270
Hadrian Close (Stoke Bishop), River Avon, north Bank	9.51	8.3	8.2	1.4	525	✓	Setback, seepage pile	£2,334,800	£4,450
Nibley Road (Shirehampton), River Avon, north bank	9.51	7.5	7.5	2.1	235	✓	Setback, embankment	£451,200	£1,920
Station Road (Shirehampton), River Avon, north bank	9.51	8.2	8.2	1.4	371	✓	Setback, embankment	£474,900	£1,280
Pill, River Avon, south bank	9.51	7.6	8.0	1.6	1085	×	Frontline, retainment pile	£13,020,400	£12,000
Total	/	/	/	/	4949	/	/	£40,650,800	/

Table 30 Estimated cash costs of the tie-in defence alignments for lock gate upgrades under the low defence measure in 2030. The ground level used to identify the indicative mean defence height is highlighted (either the mean level obtained from a GIS line inspection or by visual inspection)

Defence alignment	Design crest elevation (m ODN)	Mean ground level obtained from LIDAR (m ODN)	Mean ground level obtained from visual check (m ODN)	Indicative mean defence height (m)	Length (m)	Space availability	Route and type of defence	Cost (inc. 60% OB)	Cost per m (inc. 60% OB)
Entrance Lock defence tie-ins	9.51	8.7	8.7	0.9	972	✓	Setback, seepage pile	£4,109,500	£4,230
(or) Junction Lock defence tie-ins	9.51	9.1	9.1	0.5	568	✓	Seepage Pile	£2,301,500	£4,050
Netham Lock defence tie-ins	9.51	9.0	9.0	0.6	556	✓	Setback, seepage pile	£2,276,900	£4,100
Lock gate upgrades	9.51	NA	NA	NA	NA	✓	Lock gate raising	£6,500,000	NA
Permanent Flood Gate at Entrance Lock (only)	9.51	NA	NA	NA	19	✓	Small scale barrier	£11,600,000	£610,530
Total	/	/	/	/	/	/	/	£12,886,400*	/

* Total cost assumes that lock gate upgrades are carried out at entrance lock and at Netham Lock (i.e. the costs highlighted in bold)

Table 31 Estimated cash costs of each defence alignment for the Low Defences measure in 2065. The ground level used to identify the indicative mean defence height is highlighted (either the mean level obtained from a GIS line inspection or by visual inspection)

Defence alignment	Design crest elevation (m ODN)	Mean ground level obtained from LIDAR (m ODN)	Mean ground level obtained from visual check (m ODN)	Indicative mean defence height (m)	Length (m)	Space availability	Route and type of defence	Cost (inc. 60% OB)	Cost per m (inc. 60% OB)
Totterdown, New Cut, north bank, Albert Road	9.75	9.5	9.0	0.8	853	✘	Frontline, retainment pile	£10,603,000	£12,430
Totterdown, New Cut, north bank, Victoria Road	9.75	8.0	8.0	1.8	724	✘	Frontline, retainment pile	£8,627,600	£11,920
Bath Road, New Cut, south bank	9.75	8.5	8.5	1.3	375	✓	Setback, seepage pile	£1,652,900	£4,410
Temple Meads, New Cut, north bank	9.75	9.7	9.0	0.8	76	✓	Setback, seepage pile	£328,600	£4,320
Bathurst Basin Dam , New Cut, north bank	9.75	9.4	8.9	0.9	263	✓	Setback, seepage pile	£1,112,600	£4,230
Clarence Road, New Cut, north bank	9.75	9.3	9.3	0.5	179	✓	Setback, seepage pile	£728,600	£4,070
Cumberland, New Cut, north bank, short section	9.75	12.2	9.0	0.8	67	✓	Setback, seepage pile	£291,700	£4,350
Cumberland, New Cut, north bank	9.75	8.9	8.6	1.2	545	✓	Setback, seepage pile	£2,376,600	£4,360
Hadrian Close (Stoke Bishop), River Avon, north Bank	9.75	8.3	8.2	1.6	524	✓	Setback, seepage pile	£2,375,400	£4,530
Nibley Road (Shirehampton), River Avon, north bank	9.75	7.5	7.5	2.3	236	✓	Setback, embankment	£453,100	£1,920
Station Road (Shirehampton), River Avon, north bank	9.75	8.3	8.3	1.5	423	✓	Setback, embankment	£541,400	£1,280
Pill, River Avon, south bank	9.75	7.6	8.0	1.8	1170	✘	Frontline, retainment pile	£13,883,000	£11,870
Total	/	/	/	/	5435	/	/	£42,556,710	/

Table 32 Estimated cash costs of the tie-in defence alignments for lock gate upgrades under the low defence measure in 2065. The ground level used to identify the indicative mean defence height is highlighted (either the mean level obtained from a GIS line inspection or by visual inspection)

Defence alignment	Design crest elevation (m ODN)	Mean ground level obtained from LIDAR (m ODN)	Mean ground level obtained from visual check (m ODN)	Indicative mean defence height (m)	Length (m)	Space availability	Route and type of defence	Cost (inc. 60% OB)	Cost per m (inc. 60% OB)
Entrance Lock defence tie-ins	9.75	8.7	8.7	1.1	972	✓	Seepage Pile	£4,192,000	£4,310
(or) Junction Lock defence tie-ins	9.75	9.1	9.1	0.7	568	✓	Seepage Pile	£2,350,800	£4,140
Netham Lock defence tie-ins	9.75	9.0	9.0	0.8	556	✓	Setback, seepage pile	£2,327,400	£4,190
Lock gate upgrades	9.75	NA	NA	NA	NA	✓	Lock gate raising	£6,500,000	NA
Permanent Flood Gate at Entrance Lock (only)	9.75	NA	NA	NA	19	✓	Small scale barrier	£11,600,000	£610,530
Total	/	/	/	/	/	/	/	£13,019,400*	/

* Total cost assumes that lock gate upgrades are carried out at entrance lock and at Netham Lock (i.e. the costs highlighted in bold)

Based upon the values presented in Table 27 to Table 32, the overall cash costs for implementing the Low Defences measure has been estimated for each time epoch for the years 2015, 2030 and 2065. The cost estimate represents the cash costs required to construct the Low Defences only, and does not consider maintenance costs for a) maintaining the structural integrity, functionality and H&S requirements of the structures and b) the operation of the water control structures (i.e. the lock gates / small scale barrier).

To provide a conservative cost estimate (i.e. the most costly combination), it has been assumed that the 'sealing-off' of the floating harbour downstream entrance is carried out at Entrance Lock, rather than at Junction Lock. The Entrance Lock defence tie-ins are estimated to be of a considerably higher cost than those needed at Junction Lock.

The cost estimate for implementing the Low Defences measure across the various time epochs is provided in Table 33 below. This cost estimate assumes the Low Defences will be constructed from scratch in each time epoch, so for instance, the cost associated with Low Defences in epoch 2 assumes that no Low Defences are in place from the previous time epoch. For details of the costing methodology in instances when Low Defences have been constructed in previous time epochs and only an upgrade is needed, please refer to Appendix 1.

Table 33 Cash costs for implementing Low Defences

Measure	Epoch / year	Cost (cash terms, including 60% optimism bias)
Low Defences	Epoch 1 / 2015	£52,247,200
Low Defences	Epoch 2 / 2030	£53,537,200
Low Defences	Epoch 3 / 2065	£55,576,110

5.4.4

Environmental Impacts

Low Defences will be required in similar locations to High Defences but the length and height of the defences will vary (they will be shorter and smaller); therefore Low Defences are likely to have less of an environmental impact compared to the High Defence measure due to the scale and footprint of the defence involved.

A negligible impact is predicted for air quality and noise as any noise impacts are likely to be temporary and will be managed through measures contained within a construction management plan. There are also unlikely to be noticeable long-term or detrimental short-term impacts on geomorphology and water quality. There will be temporary and localised entrainment of sediment during riverbed disturbance, but this is unlikely to affect the overall quality of the water.

This flood defence measure is likely to have minor landscape and visual impacts. The majority of the defences will be less than a metre in height and therefore less visually intrusive compared to the High Defence measure.

This measure is expected to have a minor impact on terrestrial ecology and estuarine/riverine ecology during the construction stage, particularly if the works take place within an ecologically sensitive area such as the Severn Estuary which is designated as an SPA and SAC, SSSI and Ramsar site. However, the construction phase is temporary in nature and once constructed this flood defence measure is unlikely to have a discernible impact on terrestrial ecology and estuarine/riverine ecology. Negligible impacts are predicted for soil and groundwater as the Low Defences may generate pollutant pathways but these will be managed through an appropriate risk assessment and Ground Investigations, as well as any remediation measures.

There are likely to be some small and noticeable impacts on archaeology and heritage receptors, especially if there are high value receptors in close proximity to the low defences. When considering the setting of archaeology and heritage receptors this may also result in a minor impact, particularly if the defence is built in close proximity to high value receptors such as the SS Great Britain.

The Low Defences measure is likely to have a minor impact on traffic & transport as there will be some additional trips associated with bringing in the materials used for the defences to site but these will be over a relatively short period of time and distributed across large parts of the transport network. A Transport Management Plan should be able to adequately address any negative impacts.

This flood defence measure will reduce the risk of flooding and promote investment in the city centre and therefore a minor positive impact would be expected for socio-economics.

In summary, the Low Defence measure was assessed as follows:

- No 'significant' impacts have been identified for this defence measure;
- On balance the negative impacts outweigh the positive impacts.

5.4.5

Wider issues and opportunities

At the time of construction the Low Defences measure provides a high standard of protection against flooding. However, over time, as sea levels rise, the standard of protection provided by the Low Defences measure will fall and an upgrade / raising of the defences will be required during the next time epoch to sustain the standard of protection. As a long term approach to manage tidally dominated flood risk, Low Defences represent a proactive approach and are likely to be acceptable to the general public and stakeholders. The measure is adaptive to climate change and therefore if the rate of sea level rise differs from projections then the measure can be adjusted, in terms of defence heights and timings, to account for this.

Similarly to the High Defences measure, Low Defences would have a potential visual impact on the city's landscape and architecture which is a highly valued aspect of the city's culture and tourism value. The visual appeal and continued access to the waterfront along the floating harbour is also important to businesses and tourism for the city and considered an integral part of the city's development. Introduction of Low Defences along the waterfront in some locations may therefore be seen to compromise the visual character of the city and mitigation may be necessary to reduce this impact.

The potential mitigation techniques outlined for High Defences could also be applied to Low Defences. To reduce the impact of the Low Defences 'softer' structures and landscaping could be carried out. Examples of landscaping and reinforced glass walls, which would help preserve the visual appeal of the waterfront areas, have previously been provided in section 5.3.5.

As part of the High Defences measure it would be essential to continue and improve flood forecasting and warning systems. This is paramount to ensure the successful operation of the tidal lock gates at either Entrance Lock or Junction Lock, and at Netham. In addition, due to access requirements it is likely that a number of demountable or manually operated flood gates would be included in the Low Defences alignments. An operating regime / programme for these gates would need to be developed to ensure that the gates are closed during flood events and to minimise the residual risk of these gates being left open.

By providing a physical barrier to flood waters in the areas most at risk, the Low Defences measure also helps to address the residual risk which may arise from other sources of flooding, such as fluvial flood risk. A more detailed discussion of residual flood risk is provided in section 7.5 in this report.

5.5 Tidal Flood Barrier - Overview

A tidal flood barrier, constructed on the River Avon downstream of Bristol, would, in principle, provide an effective flood defence against high tidal levels. For the purposes of this report, a tidal flood barrier is defined as a barrier with movable gates which would normally be in the open position, allowing free movement of fluvial flows and tides, but capable of being moved to the closed position on receipt of a warning of an extreme high tide.

5.5.1 Background

Tidal barriers are not commonly used for flood defence in the UK, due to their high cost. However, a number of recent flood risk management studies – Boston, Ipswich and Bridgwater - have identified a tidal flood barrier as the optimum solution. The prime attraction of a barrier is its ability to provide a single strategic solution to flood risk by cutting off ingress of flood waters which would otherwise propagate upstream on a river or inlet. Where the alternative is long lengths of linear defences, the barrier solution can be more cost effective and cause less adverse impact than alternatives.

A tidal barrier was considered as part of CAFRA but only at a very high level. In the work that was previously undertaken, a range of barrier locations were investigated. In the Hyder CAFRA report in 2012 a barrier location just upstream of the M5 road bridge, between the communities of Shirehampton and Pill was recommended. This was based on the numerical modelling undertaken by Mott MacDonald and Edenvale Young. In the Arup report, a barrier solution was estimated to have an indicative cost of £50 million to £100 million.

As part of this Strategy, a tidal barrier solution has been investigated in more detail. The key elements of the work have been:

- Reviewing possible configurations
- Reviewing possible locations
- Cost estimation
- High level assessment of environmental issues
- Modelling of effectiveness in passing fluvial flows

The following text describes the assessment criteria considered in this study for a tidal barrier solution.

5.5.2 Research

The initial activity involved researching existing and planned tidal barriers around the UK to assist with assessing the potential gate type, costs (both capital and whole life) as well as other factors which may influence the choice of a barrier solution.

A key conclusion is, not surprisingly, that the single most important parameter for determining barrier cost is the width of the barrier. Other factors, such as configuration/gate type, are less important for costing and there are a number of different technical solutions to achieve the required objectives for any particular barrier project.

5.5.3 Barrier Design

- Tide levels: In order to determine an appropriate barrier structure it was necessary to identify the tide level that the barrier should protect against. This has been identified as the 1:1000 tide level for the upper end SLR scenario for 2115. This tide water level equates to 10.6mAOD at Shirehampton. A review of the initial model runs for the Do Nothing and Do Minimum scenarios has been carried out to assess how the tidal prism moves up the gorge and what impact this has on water levels around the Cumberland Basin. It was evaluated that for extreme tides there was only a 100mm increase giving a tide level of 10.7mAOD.

Further justification for choosing a 1000 year return period event for the design standard of the barrier is provided when comparing the 100 year and 1000 year return period tide levels (for the same scenario and epoch). These tide levels are typically only 450mm apart so it is not considered excessive to aim for the higher return period tide level (1:1000), particularly when considering that the marginal cost difference between the two will be small compared to the capital cost of a barrier.

- Freeboard allowance: For the gate and barrier structure height a freeboard allowance of 300mm has been included to take account of uncertainties with the modelling of tide levels, wave action and other risks associated with the data available. The design levels for the barrier solutions located at Shirehampton and Cumberland Basin are therefore 10.9m AOD and 11.0mAOD respectively.

- Ground conditions: It has been assumed that ground conditions and foundation requirements are as stated in the Arup Outline Geotechnical Assessment Note 2013. This note concluded that the solid geology throughout the gorge was suitable to found a barrier on but that the depth of this solid geology may vary. When developing costs for a barrier they have included for piled foundations to approximately -30mAOD beneath any concrete structures.
- Width occupied by Gates: For the development of the barrier solution it has been assumed that flows are tidally dominated. The fluvial flood risk has not been considered in detail. Gate sizes have been developed on the basis that fluvial flows should remain as close as possible to the existing flows in the wet channel below a designated design level. The design level chosen for Shirehampton was 9.6mAOD (based on 9.3m AOD water level for 2110 F200 T2 CAFRA run plus 0.3m freeboard). Further modelling to assess the impact of the barrier on fluvial flood risk and ensure that there is no increase in the risk is required during later stages of the Strategy. Mitigation measures such as additional sluice gates through tie in embankments or upstream defences may be required.

The barrier and gate heights and extents have been developed based on available Lidar data or previously modelled cross sections. Discrepancies have been noted between the two sources of information particularly in the built up areas and further detailed topographical data will need to be collected for a design phase.

- Gate Configuration: Based upon the information available at this stage of the Strategy it is proposed that the gates of the barrier are rising sector gates, similar to those used at the Ipswich and Thames Barriers, and proposed for Boston and Bridgwater. Rising sector gates are commonly used for flood defence, and in principle the technology is well-proven.

However, it should be noted that there has been some concern raised about the suitability of this type of gates to retain the heights of water proposed: the tidal range on the Avon is greater than at any of these locations and this leads to a need for gates of greater height than any recently considered. Also, gate widths may need to be significantly wider than the Ipswich/Boston/Bridgwater barriers – and similar to the Thames Barrier. Further investigations will need to be undertaken following the shortlisting phase to confirm the feasibility of using rising sector gates and if necessary to scope potential alternatives. For the purpose of the shortlisting exercise at this stage of the appraisal, all cost estimates have been based on rising sector gates. Additional information to support costing of barrier is provided in Appendix 1.

The Severn carries a heavy silt load and it is acknowledged that this will present a design challenge for gate operation.

5.5.4 **Location and Configuration**

The following aspects have been considered:

- Width of channel: The tidal barrier will need to form a defence to the full height of the tidal defence level to prevent outflanking. In addition to the movable structures required across the “wet” channel it is necessary to assess the need for embankments or other structures to tie the barrier into high ground. At this stage no modelling has been carried out to assess the minimum cross section required to pass fluvial flows so therefore any obstructions to the flow (piers and abutments) below the fluvial flood design level have been kept to a minimum.
- Location: While the Shirehampton-Pill location offers the greatest benefit in terms of fluvial storage capacity and the communities protected, it has a significant negative in being located at a relatively wide point of the channel. It would be expected to have the highest capital costs. As a result, other locations have also been investigated as part of this study.
- Adjacent infrastructure: When considering locations the impact on adjacent infrastructure such as roads, railways, property, outfalls etc. has been taken into account.

The Severn Beach Branch line (rail line) runs along the north (right) bank of the River Avon. Carrying out works to Network Rail property is difficult and expensive and therefore when considering barrier locations efforts have been made to avoid the need to work within the curtilage of this line while reducing the flood risk to it. It is also understood that the existing Portishead line (currently run as a freight line to Portbury Dock only) on the south (left) bank of the Avon is due to be upgraded in the near future as part of the MetroWest scheme.

Avoiding construction impacts on the road network while trying to improve its protection or reliance has also been a consideration but, as is noted later in this document, major impacts could not always be avoided.

There are known to be a number of watercourse, surface water and sewage outfalls along the river Avon between the city and the estuary mouth. The hydraulic impacts on each should be considered in more detail at a later stage. Efforts have been made to identify locations where

these outfalls will not be directly affected, but works to mitigate impacts may nonetheless be necessary.

- Bank types: When determining potential locations the type of river bank is an important aspect that has been considered (i.e. cliffs, tidal marsh, embankments).
- Navigation: Generally navigation on the River Avon upstream of the docks at Avonmouth and Portbury tends to consist of small leisure craft making their way to the city docks or the sailing club at Shirehampton, coupled with relatively few movements of larger vessels such as the Balmoral or Tall Ships. Potential barrier locations have been sought in positions away from bends in the river to maximise the lines of sight for tight manoeuvres and to assist craft in passing through barrier gates.
- Environmental restrictions: There are a number of SSSI's and other designated sights (Leigh Woods National Nature Reserve (NNR)) along the Avon Gorge. Many of the designations are located on top of cliffs and therefore works within the river channel are unlikely to cause detrimental impacts (although a formal assessment is still required). However, at the downstream extent of the gorge the Severn Estuary SAC, SPA, Ramsar, and SSSI site covers the channel and tidal marshes from the River Avon's confluence with the estuary as far upstream as Pill. A barrier located in a downstream position close to Shirehampton may therefore have an impact on these designated sites and appropriate mitigation measures would need to be incorporated if a barrier in this location was to proceed.

There are no heritage, landscape or built environment designations in the lower sections of the Avon gorge but closer to the city centre there are a number of listed buildings which will need to be considered. The visual impact of a barrier on the docks area will also need to be taken into account when considering form and materials.

- Fluvial flood storage: The further downstream the barrier is located, the greater the storage capacity for fluvial events. In recent years the Thames Barrier has been closed more frequently to reduce the risk of fluvial flooding compared to tidal flooding (the barrier is raised in advance of the high tide to prevent it backing up the river and impeding flood flows). The CAFRA Phase 2 and 3 Flood Barrier Report identified that the benefits within the Floating Harbour (from the potential reduction in flood risk) are sensitive to both to the location of the barrier and its operation.
- Access: When investigating potential locations the provision of sufficient access to operate and maintain the structure as well as to construct it was considered. Sufficient space is available for access from the north (right) bank at the A4 Portway although upstream of Sea Mills there is limited space between the road edge and tidal mud flats. On the north (left) bank the topography is more challenging. There are steep wooded cliffs for most of the length between the Clifton Suspension Bridge and Ham Green. There are no highways and the Portishead freight line and River Avon Trail run along the south (left) bank between Pill and the city centre.

5.5.5 *Wider Issues and Opportunities*

The Barrier will need to gain a parliamentary assent via a Transport and Works Act Order (TWAO). It is likely that as part of this process a public inquiry will be undertaken to hear evidence for and against the proposals prior to any approval being given. A robust business case which can be fully defended will be required in advance of the TWAO application. It is expected that a TWAO could take two years to obtain once a decision to proceed with a barrier solution is made, and feasibility studies completed. Overall it is unlikely that a barrier would be under construction within 10 years.

To produce a robust case in support of the TWAO, in addition to all the aspects considered in terms of barrier location and gate design, it will be necessary to consider the following aspects in detail and demonstrate that there is no adverse impact or include mitigation measures. This list is not exhaustive and further issues may arise as the design develops:

- Fluvial flood risk upstream of the barrier. Investigations are required to optimise the barrier operational procedures to maximise flood storage during fluvial flood events and ensure no adverse impacts from the barrier.
- Local and regional changes to flows and velocities, assessed via detailed modelling.
- Impacts on services, in particular the potential impacts on surface water and sewer networks including operation of the Northern Stormwater interceptor.
- Impacts on other watercourses: The impacts on other watercourses, for example the River Trym, will need to be assessed.

- Geomorphology: The potential impacts on geomorphology of the estuary, river channel and surrounding areas should be investigated. In particular the potential impacts to the silt bed and the requirements for regular dredging to be undertaken should be assessed.
- Navigation: Barrier abutments and structures within the existing water channel have the potential to change the flow regime of the Avon. This may affect the smaller craft and the viability of a number of the riparian clubs (e.g. Shirehampton Sailing Club, Sea Cadets etc.)
- Relocation of affected businesses, clubs, societies or amenities
- Transport infrastructure during and post construction
- Potential visual impact and landscaping
- Water level management of the North Somerset Levels Internal Drainage Board
- Temporary impacts during construction, which would require the partial closures of the Avon

Other consents or approvals required may include:

- Environmental Permits or exemptions (flood risk activities, pollution, waste management)
- Marine Management Organisation Marine Licence
- Crown Estates consent
- Natural England Assent
- Planning permission

5.5.6 ***Barrier Options for Further Assessment***

As discussed above, there are a number of possible locations for a tidal flood barrier, and various possible configurations and gate designs. All will have significant technical challenges and potential for significant environmental impact. From an initial assessment and research of solutions adopted elsewhere it was concluded that the key parameters which would drive decision making on suitability of barrier are: width of barrier – fundamentally drives cost; and distance downstream of Cumberland Basin – fundamentally affects fluvial storage capacity and tolerance of impact on fluvial flows.

To facilitate assessment of these parameters three possible locations for the barrier have been identified as suitable for more detailed consideration: Shirehampton-Pill – the ‘Wide’ barrier, a location further upstream at Ham Green/Nibley Road where the channel is significantly narrower, and a third location just downstream of the Cumberland Basin where the channel is narrower still. A fourth site, at Black Rock, at the Northern Stormwater Interceptor outfall has been briefly investigated following the recommendations of the Mott MacDonald / Edenvale Young CAFRA study. However, due to the access difficulties with this location and the minimal perceived advantages compared to the other sites that have been considered this was not investigated further.

Indicative barrier solutions have been developed at each of these sites and are described in sections 5.6 and 5.7. An overview map showing the different locations is shown in Figure 37.

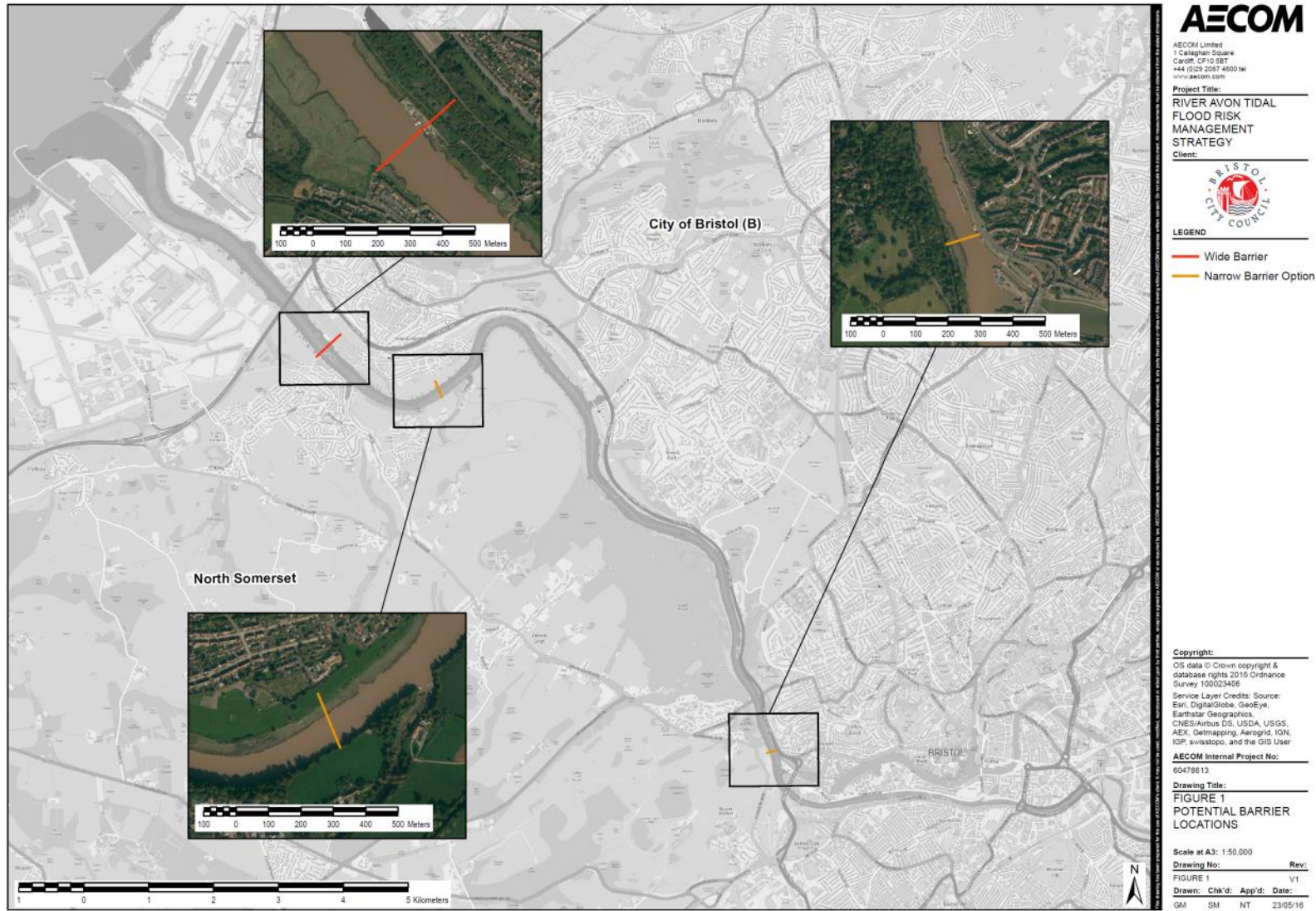


Figure 37 Barrier locations taken forward for consideration in the appraisal

5.6 'Wide' Tidal Barrier

5.6.1 Location

The location of the 'Wide' barrier is 500m upstream of the M5 road bridge, extending from the downstream extent of Pill to the railway line near Shirehampton. The location has been selected taking into account a number of considerations, including:

- Channel depth
- Channel width
- Bank ground levels
- Space availability for defence tie-ins either side of the tidal barrier
- Presence of transport links and services in the immediate vicinity of the barrier

This is a nominal location, for option assessment purposes, which may be revised as further appraisal work is undertaken later in Strategy development, and would ultimately need to be confirmed as optimal through ground investigation and studies of hydraulics, navigation and environmental impact.

Advantages of the wide barrier location are that:

- it enables a substantial length of the Avon to be used as fluvial flood storage during high fluvial flow events, thereby minimising any adverse impacts of the barrier itself and also potentially reducing current fluvial risk; and
- it provides the most comprehensive reduction in flood risk to the communities including and upstream of Pill and Shirehampton, the full length of the A4 Portway as well as Bristol city centre. This is subject to the coastal defences at Avonmouth being upgraded and tying into the barrier to prevent outflanking.
- It provides the best location from a navigation perspective

A disadvantage of the wide barrier location is that the footprint of the barrier on the south (left) bank is likely to extend into the Severn Estuary designated sites. The environmental impacts of the barrier will therefore need to be taken into account and appropriate environmental mitigation implemented. In addition, the wide barrier location sits very close to the club house of the Shirehampton Sailing Club. The club house and access may therefore need to be relocated, particularly if the barrier gates cause changes to the flow regimes within the channel which could impact the manoeuvrability of the vessels which normally used by the club.

A Wessex Water pumping station is located immediately adjacent to the barrier location and it is likely that it and any associated outfalls will need to be relocated. The impacts on the sewer and surface water networks in Pill behind the raised defences will need to be assessed to ensure that there is no impact on their operation.

5.6.2 Description

The design tide level of the barrier at this location is 10.9m AOD and the bed level, taken from the Arup geotechnical report is assumed to be -7m AOD giving a gate height of 17.9m AOD. The bed levels taken from the modelled cross sections range from -5.6m AOD and -5.2m AOD but this discrepancy with the Arup value may be due to the accumulation of soft bed material and the inherent inaccuracies of measuring silt.

A concept design has been developed for the Wide Barrier, and is shown in **Figure 38**. The barrier comprises 4 gates ranging in width from 25m to 40m wide and in height from 3.4m to 17.9m. On the south (left bank) side the barrier will tie into the existing Pill flood defence embankments which will need to be raised by up to 2m. On the north (right) bank the main structure will tie into high ground via an earth embankment across a grassed field and the access to the Sailing Club. Additional topographic survey data is required to assess the extent of the tie in. With this barrier position it may be necessary to carry out works across or alongside the Severn Beach railway to provide the full flood risk benefits up to 2115. The overall length of the barrier would be 355m and there would need to be additional raising of the existing Pill flood defence embankments to prevent outflanking.

More detailed hydraulic studies would be necessary to predict flows during construction of a barrier, potential high flow velocities (caused by impedance) as well as any flow increase in the event a navigation bypass being required to allow the centre of the channel to be closed for installation of a gate and sill.

Access to the barrier is available from both banks although walkways or other access arrangements will be required to reach the central piers and gates.

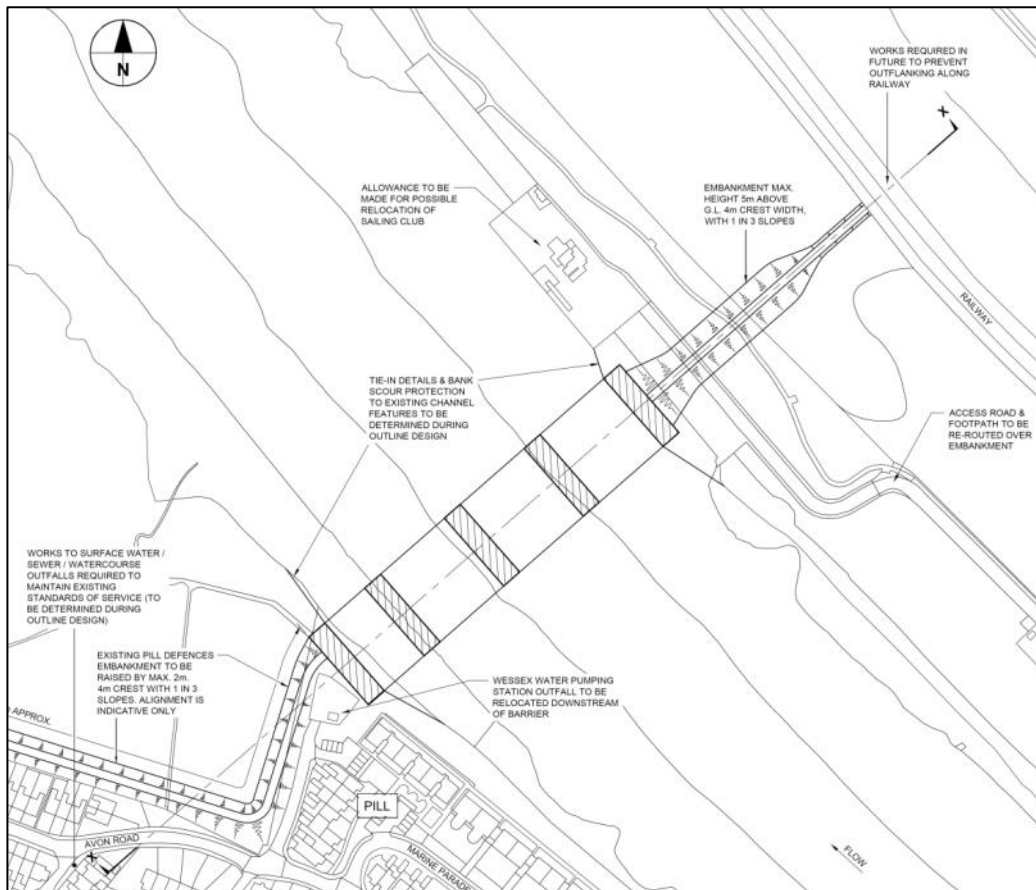


Figure 38 Potential location of the Wide Tidal Barrier at Shirehampton

Layout of gates and piers should be considered notional at this point, but has been selected to achieve the following:

- A compromise between multiple gates and large opening widths
- A central navigable channel, avoiding a central pier which might pose a problem for navigation
- Provision of openable gates across the full width of the fluvial flood plain, with lower-cost embankments used to extend the barrier to connect into high ground

5.6.3

Technical Feasibility

Gate Design

The solution identified in the concept design is comprised of gates significantly wider and higher than proposed for recent projects such as Ipswich and Boston. The largest openings are 40m, compared to Boston's 25m, and the height is 17.9m compared to Boston's approx. 14m. Unlike Boston or Ipswich the solution has multiple openings, requiring use of a number of piers within the river. The overall width of the barrier is many times more than these other projects.

Therefore this barrier concept is an order of magnitude bigger, and more complex, than Boston, Ipswich or Bridgwater. In overall scale it is much closer to the Thames Barrier.

Therefore it must be acknowledged that there is considerable uncertainty about the technical feasibility of the solution as shown, which can only be resolved by extensive investigation and study. In particular cost estimation is difficult as the solutions from projects such as Boston cannot be simply scaled up, and there has been no flood barrier project of a similar scale in the UK for the last 40 years.

Feedback from a brief workshop with BCC and CH2M captured the following key points:

- The scale might exceed what can be achieved by rising sector gates
- A horizontal sector gate might be required instead
- Costs could be of the order £500 million - £1000 million

If the Wide Barrier is taken forward to the shortlist, alternative solutions will be considered further.

Operation

The barrier would be closed for forecast high tidal water levels, typically at low tide. By closing the barrier at low tide, storage capacity can be provided to accommodate fluvial flows. Operating procedures have not been considered in detail, and would need to be considered as part of design development.

Hydraulic Performance

A barrier at this location would not be feasible from a hydraulic performance perspective if either of the following were found to be the case:

- The impact of the barrier in its open position would cause a severe increase in upstream flood levels during a high fluvial flow event. This is unlikely for the Wide Barrier as the piers are relatively small compared to the overall channel width.
- The impact of the barrier when closed during a high tidal level event in coincidence with a high flow fluvial event would cause a significant increase in upstream flood levels. This combination is a highly infrequent one during early epoch 1, but projected sea level rise make this a realistic possibility by epoch 3.

A limited modelling programme has been undertaken for the Wide Barrier. Results are not conclusive, but indicate that there would be sufficient storage capacity to accommodate high fluvial flows.

Therefore it has been concluded that in principle this location is suitable for a tidal flood barrier, subject to further design development and validation.

5.6.4

Costs

A high level cost assessment has been undertaken. As noted above, the concept solution is sufficiently larger and/or more complex than any recent UK barrier scheme, so that cost estimation is problematic.

The following approach has been adopted:

- A basic construction cost estimate for the concept solution was obtained from Volker Stevin, who are framework contractors to the Environment Agency and the contractor delivering the Ipswich Barrier project.
- Risk allowances were added in accordance with practices adopted on the Boston Barrier project
- Allowances for non-construction costs were added in accordance with practices adopted on the Boston Barrier project
- Inputs from CH2M's barrier expert given in a workshop between AECOM/BCC/BCC were taken into account

The results are summarised in

Table 34 below:

Table 34 Estimated cash costs for the Wide Barrier measure

Study, Design, Construction Phase	Cost (£m)
Construction cost, including temporary and accommodation works, equipment, buildings and tie-ins to adjacent banks.	322
Raised linear defences	Excluded
Pre-PAR/Feasibility	15
EA and Council staff	3
Consultants costs (TWA0, Design, Contract Management, Supervision, Cost Management, ECI)	31
Environmental Mitigation and Enhancement, Compensation, Licences	12
Risk	193
Total Study, Design, Construction Phase	577
Operation Phase - Operation, Maintenance and Refurbishment	184

The estimated capital cost for a wide barrier is £577 million. These cost estimates are high-level, developed only to provide a basis for comparison of Options and for initial screening for affordability by BCC.

Operation phase costs are estimated at £184 million for 100 years of operation.

5.6.5

Environmental Impacts

The environmental appraisal shows that the Wide Barrier is the flood defence measure which has the highest negative score of all the flood defence measures. It also has the highest score for positive impacts alongside the Narrow Barrier and High Defences measure.

The Wide Barrier will be visually prominent and is likely to have a substantial impact on local key viewpoints and the Landscape Character of the area, although impacts will be fairly localised. This was scored as a significant negative impact in the environmental appraisal as the assessment was based on a precautionary approach and assumed the barrier would be adjacent to or very visible from a sensitive receptor.

The Wide Barrier has the potential to result in significant impacts on terrestrial ecology and estuarine/riverine ecology particularly during the construction phase; however these impacts will be temporary and be managed through measures contained within a Construction Environmental Management Plan. Once the barrier is constructed this flood defence measure is unlikely to have any impact on terrestrial or estuarine/riverine ecology. However, the significant negative score reflects the potential for some habitat loss which may affect sensitive habitats such as the Severn Estuary SPA, SAC, Ramsar and SSSI sites. This would be especially likely as the current potential location for the Wide Barrier would see it placed on the edge of the Severn Estuary, with part of the footprint inside the designation.

The Wide Barrier may involve a greater impact on ecology as more habitat loss is likely to be involved, due to the larger barrier footprint, compared to the Narrow Barrier.

The Wide Barrier is likely to be visually prominent and impact on archaeology and heritage. It was scored as a significant negative impact due to the potential for the Wide Barrier to have a significant impact on the setting of heritage receptors, particularly where there are high value receptors in close proximity to the barrier.

There will be some additional trips associated with bringing in the defences to site, likely to be more than for the Narrow Barrier, but these will be over a relatively short period of time and focussed on specific roads. A Transport Management Plan should be able to adequately address any negative impacts related to road trips. Further impacts to transport infrastructure could result from works which may be required across or alongside the Severn Beach railway, which would cause disruption impacts to those using this line. A significant impact is therefore expected in relation to traffic and transport.

A significant impact on geomorphology and water quality would be expected as the Wide Barrier could alter the water flow and disturb sediment and mudbanks in the area where it is to be located.

Negligible impacts are predicted for air quality and noise as these impacts are only likely during the construction phase but they will be temporary in nature and will be managed adequately through measures contained within a CEMP. Once constructed, this flood defence measure is unlikely to have any impact on air quality and noise. Negligible impacts are predicted for soil and groundwater as the Wide Barrier may generate pollutant pathways but these will be managed through an appropriate risk assessment and Ground Investigations, as well as any remediation measures.

This measure will reduce flood risk to a Standard of Protection until 2115. This reassurance is likely to have a significant positive impact on socio-economics as individuals and developers are not discouraged from investing in the city centre due to flood risk.

In summary, the Wide Barrier was assessed as follows:

- Negative 'significant' impacts would be expected for Landscape and Visual; Heritage and Archaeology; Terrestrial Ecology; and Estuarine/Riverine Ecology; Geomorphology and Water Quality; and Traffic and Transport;
- Positive 'significant' impacts would be expected for Socio-economics;
- On balance the negative impacts greatly outweigh the positive impacts.

5.6.6

Wider Issues and Opportunities

The wider issues and opportunities that are likely to be associated with a tidal barrier solution are discussed in section 5.5. Issues and opportunities specific to the Wide Barrier solution are:

- Land take – adoption of a horizontal sector gate would require land take of around 200m on each side of the channel to accommodate the gate when in the open position
- Geomorphology – significant changes to the river bed would be needed to accommodate any of the solutions
- Transport crossing – the issue of combining a barrier with a transport link across the Avon has been considered, but no synergy has been identified.
- Responsibility for operation and maintenance – whether this would sit with BCC or with the Environment Agency

5.7 'Narrow' Tidal Barrier

5.7.1 *Location*

Two locations have been considered for a 'narrow' barrier. The first of these, designated 'Ham Green/Nibley Road' is located 1500m upstream of the wide barrier position and extends between Ham Green on the south (left) bank and the Nibley Road allotments on the north (right) bank. This location provides a potential for flood storage between the barrier and the city centre. The second 'narrow' barrier location, designated 'Cumberland Basin', is located close to the city centre, 150m downstream of the Junction Lock entrance to Cumberland Basin. It provides much less flood storage upstream of the barrier. By considering these two options the trade-off between barrier width and storage has been investigated. In doing this, other factors have been considered, in terms of navigation, environmental sensitivities and engineering constraints.

5.7.2 *Description - Ham Green / Nibley Road Barrier*

The concept design for the barrier located between Ham Green and Nibley Road consists of 4 gates ranging in width from 10m to 25m wide and in height from 9.9m to 17.9m. The design tide level of the barrier at this location is 10.9m AOD. On the south (left) bank the barrier will tie into the cliffs whilst on the north (right) bank the barrier ties into high ground across the playing field / allotments. The cliffs on the south bank prohibit access so therefore the only access route to the barrier is from the north bank.

Compared to the 'wide' barrier solution outlined above, a 'narrow' barrier in this position requires no works that will affect highways or the railway. The overall length of the barrier would be approximately 180m, compared to the 355m required for the 'wide' barrier, a reduction of almost 50%.

A major disadvantage of this barrier position (compared to the wide barrier location) is that the barrier would not reduce the flood risk to Pill, the Severn Beach railway line further downstream and parts of Shirehampton. Although the barrier is outside to the Severn Estuary environmentally designated sites, it is still close-by so the impacts of the barrier on these designations would need to be taken into account.

5.7.3 *Technical Feasibility - Ham Green / Nibley Road Barrier*

A high level assessment has been carried out to identify potential alignments for a barrier at Ham Green/Nibley Road and at Cumberland Basin. A number of considerations have been made when making this assessment including:

- Channel depth
- Channel width
- Bank ground levels
- Space availability for defence tie-ins either side of the tidal barrier
- Impact on transport links and services in the immediate vicinity of the barrier

Figure 39 shows the potential alignment that has been taken forward. It should be noted that this barrier alignment is not considered final and further revisions to the alignment may be undertaken during further appraisal work as the Strategy is developed.

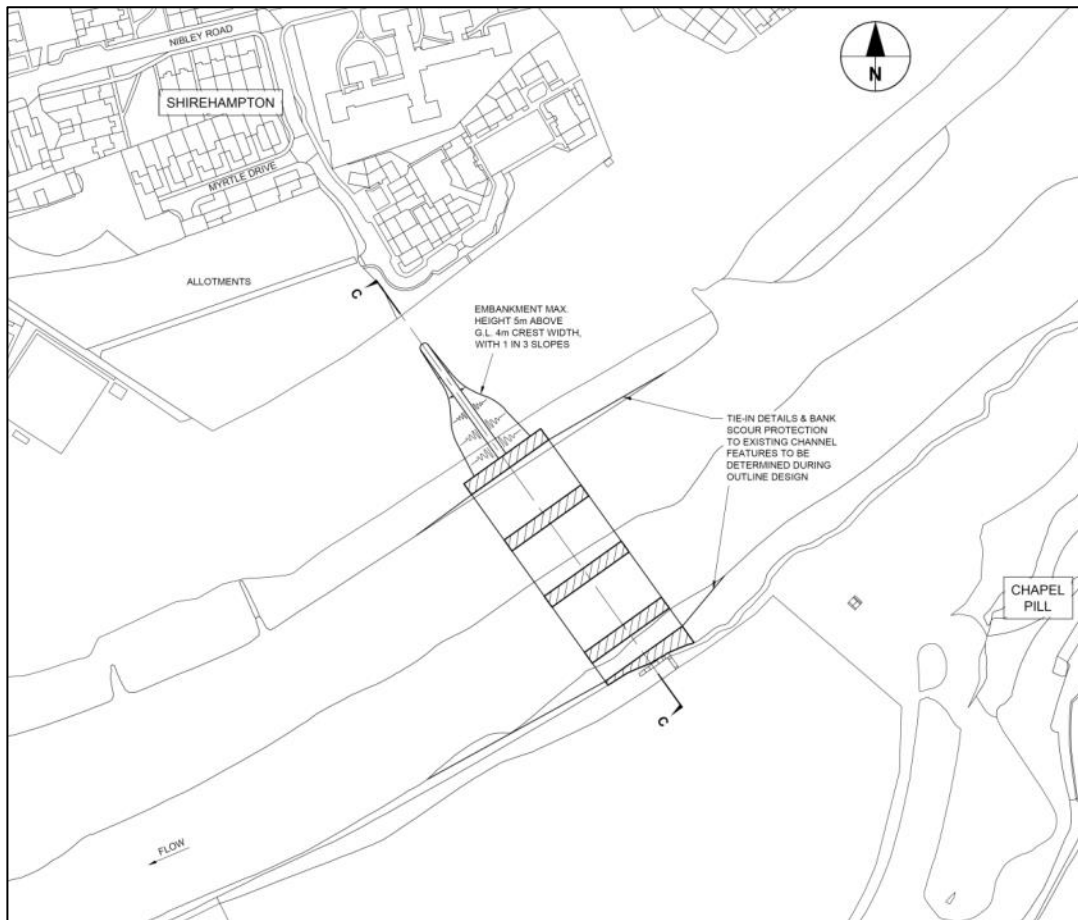


Figure 39 Potential location of the Narrow Tidal Barrier at Ham Green / Nibley Road

Gate Design and Operation

The solution identified in the concept design is comprised of gates of a similar width to those that will be used in the Boston and Ipswich Barriers, but significantly higher. The use of multiple gates, with central piers, adds much more complexity. Therefore this barrier is a substantial 'step-up' from those solutions, several times wider and much more complex, arguably closer to the Thames Barrier in scale and complexity.

Significant design development would be needed to ensure that the concept solution is optimal. It is possible, for example, that an alternative arrangement, such as a horizontal sector gate, might be preferable to the rising sector gate approach shown. However, it is considered that the overall scale of the gates is sufficiently similar to Boston that it can be concluded that a barrier of broadly similar configuration would, in principle, be feasible.

Hydraulic Performance

A barrier at this location would not be feasible from a hydraulic performance perspective if either of the following were found to be the case:

- The impact of the barrier in its open position would cause a severe increase in upstream flood levels during a high fluvial flow event.
- The impact of the barrier when closed during a high tidal level event in coincidence with a high flow fluvial event would cause a severe increase in upstream flood levels.

The feasibility of this location has not been directly assessed through hydraulic modelling, however in terms of storage it is quite similar to the Wide Barrier location, for which modelling results were positive, albeit only of a preliminary nature.

It has been concluded that in principle this location is suitable for a tidal flood barrier subject to further design development and validation.

5.7.4 **Description - Cumberland Basin Barrier**

The position at Cumberland Basin is located much closer to the city centre and avoids the need for additional linear defences. The bed level in this location is approximately -3.5m AOD and the design tide level is 11.0m AOD. The barrier in this location would comprise 2 gates; one 20m wide and 10m high, the other 30m wide and 14.5m high. On the south (left) bank, the Portishead railway, an unclassified access road the Avon trail would need to be raised on embankments up to 4m high. On the north (right) bank, the A4 Hotwells Road would need to be raised by up to 2.5m. Alternatives to raising the transport infrastructure would be to allow temporary or demountable defences or flood gates to be used for all or part of the tie in but this would increase the residual flood risk if there were to be any operational failures.

The barrier solution at Cumberland Basin is the shortest of the three barrier options considered.

A barrier in this location could provide significant improvement to flood risk within the city centre. However, downstream communities and critical infrastructure such as the Severn Beach and Portishead railway lines and the A4 Portway road would remain undefended unless significant lengths of new linear defences were constructed.

The barrier at Cumberland Basin is also close to a Wessex Water Pumping Station alongside the A4. This would require further consideration and possible relocation. There are also a number of dilapidated wooden moorings downstream of the pumping station which may need to be relocated if they are still in use.

Navigation issues may arise due to the barrier being located so close to the city centre and the entrance to Cumberland Basin, and mitigation would need to be provided accordingly.

5.7.5 **Technical Feasibility - Cumberland Basin Barrier**

Figure 39 shows the potential alignment that has been taken forward for the remainder of the options appraisal process. It should be noted that this barrier alignment is not considered final and further revisions to the alignment may be undertaken during further appraisal work as the Strategy is developed.

Gate Design and Operation

The solution identified in the concept design is comprised of gates of a similar scale and type to those that will be used in the Boston Barrier. Therefore, although design development would be required to validate that the concept is optimal, and to develop the concept to design, it is concluded that the concept is inherently feasible.

Hydraulic Performance

A barrier at this location would not be feasible from a hydraulic performance perspective if either of the following were found to be the case:

- The impact of the barrier in its open position would cause a severe increase in upstream flood levels during a high fluvial flow event.
- The impact of the barrier when closed during a high tidal level event in coincidence with a high flow fluvial event would cause a severe increase in upstream flood levels.

The feasibility of this location in respect of ability to pass fluvial flows has been assessed through limited hydraulic modelling, using the EVY 1-D model. Although the modelling work should not be regarded as definitive in terms of design validation, indications are that the barrier would cause a significant increase in flood levels upstream. Therefore the barrier would need to be coupled with flood walls on the Avon, thereby negating the advantage of a barrier.

It has been concluded from this work that in principle this location is not suitable for a tidal flood barrier.

5.7.6 **Costs**

A high level cost assessment has been undertaken for both the narrow barrier options. As noted above, the concept solutions are sufficiently larger and/or more complex than any recent UK barrier scheme, so that cost estimation is problematic.

The following approach has been adopted:

- A basic construction cost estimate for the concept solution at Ham Green/Nibley Road was obtained from Volker Stevin, who are framework contractors to the Environment Agency and the contractor delivering the Ipswich Barrier project.
- Taking the Ham Green/Nibley Road cost and using a pro rata approach to arrive at a construction cost estimate for the Cumberland Basin Barrier
- Risk allowances were added in accordance with practices adopted on the Boston Barrier project
- Allowances for non-construction costs were added in accordance with practices adopted on the Boston Barrier project

The results are summarised in Table 35 below:

Table 35 Estimated cash costs for the Narrow Barrier measure

	Ham Green/Nibley Road	Cumberland Basin
Study, Design, Construction Phase	Cost (£m)	Cost (£m)
Construction cost, including temporary and accommodation works, equipment, buildings and tie-ins to adjacent banks.	236	177
Raised linear defences	Excluded	Excluded
Pre-PAR/Feasibility	11	8
EA and Council staff	2	2
Consultants costs (TWAO, Design, Contract Management, Supervision, Cost Management, ECI)	23	17
Environmental Mitigation and Enhancement, Compensation, Licences	9	7
Risk	141	106
Total Study, Design, Construction Phase	422	317
Operation Phase - Operation, Maintenance and Refurbishment	135	101

The estimated capital cost for a narrow barrier is £317 million to £422 million. These cost estimates are high-level, developed only to provide a basis for comparison of Options and for initial screening for affordability by BCC.

They include a 60% risk allowance.

Operation phase costs are estimated at £100 million to £135 million for 100 years of operation.

As the result of the hydraulic assessment is that the Cumberland Basin location is unsuitable, the higher band costs have been used in Option appraisal.

5.7.7

Environmental Impacts

The environmental appraisal illustrates that in general the Narrow Barrier measure is likely to have more negative impacts than the other flood defence measures, with the exception of the Wide Barrier. It also has the highest score for positive impacts alongside the Wide Barrier and High Defences measure.

The Narrow Barrier measure will be visually prominent and is likely to have a substantial impact on local key viewpoints and the Landscape Character of the area, although it will be fairly localised. This was scored as significant negative impact in the environmental appraisal as the assessment was based on a precautionary approach and assumed the barrier would be adjacent to or very visible from a sensitive receptor.

The Narrow Barrier measure has the potential to result in significant impacts on terrestrial ecology and estuarine/riverine ecology, particularly during the construction phase; however these impacts will be temporary and be managed through measures contained within a CEMP. Once the barrier is constructed this flood defence measure is unlikely to have any impact on terrestrial or estuarine/riverine ecology. However, the significant negative impact scoring reflects the potential for some habitat loss which may affect sensitive habitats such as the Severn Estuary SPA, SAC, Ramsar and SSSI sites even if the barrier sits outside of these.

The impact on archaeology and heritage was scored as a significant negative impact due to the potential for the barrier to have a significant impact on the setting of archaeology and heritage receptors, particularly where there are high value receptors in close proximity to the barrier.

Minor impacts are expected on geomorphology and water quality as the narrow barrier could alter the water flow and introduce sediment during riverbed disturbance in the construction phase. Minor impacts would also be likely for Traffic & Transport as there will be some additional trips associated with bringing in the defences to site, but these will be over a relatively short period of time and distributed across large parts of the transport network. A Transport Management Plan should be able to adequately avoid any significant impacts.

Negligible impacts are predicted for air quality and noise as these impacts are only likely during the construction phase but they will be temporary in nature and will be managed adequately through

measures contained within a CEMP. Once constructed, this measure is unlikely to have any impact on air quality and noise. Negligible impacts are predicted for soil and groundwater as the barrier measures may generate pollutant pathways but these will be managed through an appropriate risk assessment and Ground Investigations, as well as any remediation measures.

In terms of flood risk the Narrow Barrier will reduce flood risk to a Standard of Protection until 2115. This reassurance is likely to have a significant positive impact on socio-economics as individuals and developers are not discouraged from investing in the city centre because of flood risk.

In summary, the Narrow Barrier was assessed as follows:

- Negative 'significant' impacts are expected for Landscape and Visual; Heritage and Archaeology; Terrestrial Ecology; and Estuarine/Riverine Ecology;
- Positive 'significant' impacts are expected for Socio-economics;
- On balance the negative impacts greatly outweigh the positive impacts.

5.7.8

Wider Issues and Opportunities

The wider issues and opportunities that are likely to be associated with a tidal barrier solution are discussed in Section 5.5. This section presents issues and opportunities specific to the Narrow Barrier solution:

- Exclusion of protection to properties at Pill and Shirehampton
- Need to maintain navigation and potential for sedimentation, maintenance dredging
- Visual impact close to city centre and within Avon Gorge
- Responsibility for operation and maintenance – whether this would sit with BCC or with the Environment Agency

6. OPTION APPRAISAL - LONG LIST TO SHORT LIST

This chapter presents the long list to short list appraisal. The previous chapter of this report has described the various measures being considered; Do Minimum, Property Level Protection (PLP), High Defences, Low Defences, Narrow Tidal Barrier and a Wide Tidal Barrier.

Each of the 39 strategic options within the long list comprises a different package and sequence of measures over the duration of the Strategy appraisal period. For instance one strategic option is to 'Do Minimum' in epoch 1, to construct 'Low Defences' in epoch 2 and then construct a 'Narrow Barrier' in epoch 3. Another strategic option is to implement PLP in epoch 1, then construct and maintain 'High Defences' in epochs 2 and 3. The full list of the long list of strategic options is provided in Chapter 4 (Figure 7).

In this chapter each option comprising a package of measures is appraised over the full Strategy appraisal period. This has reduced and rationalised the number of potential choices to a short list of most feasible options. The short listed options will then be further explored and worked up in more detail to and these will then be subjected to more detailed technical, environmental and economic appraisal in order to develop and select the preferred options or 'Strategy'.

An overview of the appraisal methodology used to assess the long list of options is provided in section 6.1 and the results of the appraisal with commentary and summary scoring for each of the long list options is provided in section 6.2.

6.1 Methodology

6.1.1 Multi-criteria appraisal

To ensure that the appraisal was technically robust and as objective as possible, a multi-criteria assessment and scoring system was utilised and each option was considered against six option appraisal objectives in equal measure (i.e. there was no ranking or weighting in the assessment). The six option appraisal objectives were developed and agreed by the project team and Project Board and are:

1. To support the safe living, working and travelling of people in and around central Bristol by ensuring that the flood threat is reduced and that measures are in place to address residual risks.
2. To facilitate the sustainable growth of Bristol and the wider West of England economy by supporting development opportunities for employment and residential land, and associated infrastructure.
3. To maintain, and where possible enhance, natural, historic, visual and built environments.
4. To reduce whole life costs.
5. To ensure navigation of the River Avon and Marine activities can continue.
6. Ensure the Strategy is technically feasible and deliverable over its duration.

Each long listed option was developed sufficiently in terms of concept and spatial influence and potential form to ensure an adequate understanding of potential option impacts was achieved in order to carry out a robust appraisal with sound decision making.

Supporting evidence and technical studies

The appraisal process was supported and informed by a wide range of supporting evidence, technical assessments and engineering experience with key facets including:

- The project team's detailed understanding of the Strategy frontage, including the evolution of flood risk, the technical issues and flood risk management opportunities in central Bristol;
- Numerical flood modelling to understand and simulate flood risk under and Do Nothing and Do Minimum Scenario, along with initial testing of options;
- Initial high level costing of measures and options and indicative measure alignments;
- Initial environmental assessment of options, considering the indicative option alignments;
- Collaboration with the wider project team to ensure that the extensive local knowledge of flood risk and the wider management constraints and opportunities are captured in the appraisal; and
- Engagement with key stakeholders via a short list appraisal workshop.

Scoring

For each option appraised, the predicted impacts were assessed in relation to six different option objectives. The assessment was then used to provide a representative impact score using a numerical scale between +2 to -2. The scoring was based on the potential option impacts relative to the Do Nothing scenario. This methodology ensures that the relative merits and drawbacks of each of the strategic options is robustly captured with an audit trail of decision making.

The general rule of scoring the options follows that a +2 score represents a significant positive impact whilst a -2 score represents a significant negative impact compared to the Do Nothing scenario (see Table 36).

Each long list option comprises a sequence or package of measures, with a measure for each time epoch of the Strategy (i.e. a measure in each of the short term, medium and long term time epochs). In order to capture and compare the potential impacts of these different options both over time, and over the whole duration of the appraisal period, the assessment was carried out on an epoch by epoch basis i.e. for a given option the measure in epoch 1 was scored, the measure in epoch 2 was scored, and the measure in epoch 3 was scored. The total score across all three time epochs gives the overall summary of potential impacts over the full appraisal period.

A number of exceptions to the general scoring rules have been made in order to tailor the scoring system to specific option objectives. The exceptions include:

- For option objective 1, which describes the impact on Flood risk and H&S, a -3 to +3 numerical scoring scale has been used. A larger scale has been used for this objective because it is necessary to better differentiate between the flood risk benefits that an option may provide.
- For option objectives 4 and 6, which describe the cost and the deliverability of the options respectively, the scoring of options is not comparable to the Do Nothing scenario. The option scoring for these objectives is therefore made on a relative scale, with the options cost and deliverability compared against other options, rather than to the Do Nothing scenario.
- Option objective 4, which describes the cost of the option has been considered in whole life terms, across the full duration of the Strategy. For this reason, a total cost score has been applied to the option in epoch 3 to represent the whole life cost across all three epochs. The score has been developed by ranking the options in descending order by their whole life costs and applying a score to each option on this basis.
- Option objective 6, deliverability, has been assessed from the perspective of risk - i.e. uncertainty in cost has been seen as a negative, as has the likelihood of encountering showstoppers whether technical, legal or environmental

The environmental category in the multi-criteria analysis has been informed by a separate criteria analysis carried out in the environmental assessment. Using a similar approach (i.e. -2 to +2 scoring system), the environmental assessment scored each measure against a variety of environmental categories; landscape and visual, terrestrial ecology, estuarine/riverine ecology, archaeology and heritage, air quality and noise, geomorphology and water quality, traffic and transport, soil and groundwater and socio-economics. The overall score for each measure in the environmental assessment has been used to inform the score of the environmental impact in the multi-criteria assessment. All scores should be considered as 'with reasonable mitigation measures' but nonetheless many options have negative impacts. At this point of the project, the intention is to take forward a balanced scorecard of options, some of which do not meet all objectives e.g. environmental requirements. At the preferred option stage some options may be rejected for that reason, whereas some might be acceptable with more wide ranging mitigation or compensation.

The total score of each option across the six option objectives will be used to select the short list of options.

Table 36. Appraisal criteria and scoring system to be used in the multi-criteria analysis of long list options

Objective	Criteria	Score	Impact	Description
1. To support the safe living, working and travelling of people in and around central Bristol by ensuring that the flood threat is reduced and that measures are in place to address residual risks.	Flood risk and H&S	---	Significant negative impact	Option leads to standard of flood protection reducing significantly and severely compromises the safety of people compared to the Do Nothing scenario.
		--	Moderate negative impact	Option leads to the standard to flood protection reducing and compromises the safety of people compared to the Do Nothing scenario.
		-	Minor negative impact	Option leads to the standard to flood protection reducing marginally and slightly compromises the safety of people compared to the Do Nothing scenario.
		0	No impact	No impact on the standard of flood protection or the safety of people compared to the Do Nothing scenario.
		+	Minor positive impact	Option provides a minor improvement to the standard of flood protection and improves the safety of people compared to the Do Nothing scenario.
		++	Moderate positive impact	Option provides a moderate improvement to the standard of flood protection and improves the safety of people compared to the Do Nothing scenario.
		+++	Significant positive impact	Option provides a significant improvement to the standard of flood protection and significantly improves the safety of people compared to the Do Nothing scenario.
2. To facilitate the sustainable growth of Bristol and the wider West of England economy by supporting development opportunities for employment and residential land, and associated infrastructure.	Sustainability	--	Significant negative impact	Option significantly decreases the standard of flood protection to potential development sites for employment and residential land and associated infrastructure. Option significantly decreases opportunities for the sustainable growth of Bristol and the wider West of England economy compared to the Do Nothing scenario.
		-	Minor negative impact	Option marginally decreases the standard of flood protection to potential development sites for employment and residential land and associated infrastructure. Option decreases opportunities for the sustainable growth of Bristol and the wider West of England economy compared to the Do Nothing scenario.
		0	No impact	No impact on standard of protection to potential development sites for employment and residential land and associated infrastructure or the potential for sustainable growth in Bristol and the wider West of England economy compared to the Do Nothing scenario.
		+	Minor positive impact	Option provides a minor improvement to the standard of flood protection to potential development sites for employment and residential land and associated infrastructure. Option increases opportunities for growth helping to support the sustainable growth of Bristol and the wider West of England economy compared to the Do Nothing scenario.
		++	Significant positive impact	Option provides a significant improvement to the standard of flood protection to potential development sites for employment and residential land and associated infrastructure. Option significantly increases opportunities for enabling growth and fully supports the sustainable growth of Bristol and the wider West of England economy compared to the Do Nothing scenario.

Objective	Criteria	Score	Impact	Description
3. To maintain, and where possible enhance, natural, historic, visual and built environments	Environment	--	Significant negative impact	Option leads to significant detrimental impacts on the natural, historic, visual and built environments compared to the Do Nothing scenario.
		-	Minor negative impact	Option leads to detrimental impacts on the natural, historic, visual and built environments compared to the Do Nothing scenario.
		0	No impact	Option does not impact the natural, historic, visual and built environment compared to the Do Nothing scenario.
		+	Minor positive impact	Option helps preserve or enhance the natural, historic, visual and built environment compared to the Do Nothing scenario.
		++	Significant positive impact	Option significantly enhances the natural, historic, visual and built environments compared to the Do Nothing scenario.
4. To reduce whole life costs (this objective is scored as a total score across all three epochs to account for cost discounting)	Whole life cost	-2	Significant negative impact	Option has a very high whole life cost relative to the other options. Options have been ranked in order of cost. This score applies to the 8 options with the highest whole life costs.
		-1	Minor negative impact	Option has a high whole life cost relative to the other options. Options have been ranked in order of cost. This score applies to options ranked 9-16 in terms of whole life cost (descending order).
		0	No impact	Options have an average whole life cost relative to the other options. Options have been ranked in order of cost. This score applies to options ranked 17-24 in terms of whole life cost (descending order).
		+1	Minor positive impact	Option has a relatively low whole life cost relative to the other options. Options have been ranked in order of cost. This score applies to options ranked 25-32 in terms of whole life cost (descending order).
		+2	Significant positive impact	Option has a very low whole life cost relative to the other options. Options have been ranked in order of cost. This score applies to options ranked 33-39 in terms of whole life cost (descending order).

Objective	Criteria	Score	Impact	Description
5. To ensure navigation of the River Avon and Marine activities can continue	Navigation and marine activities	--	Significant negative impact	Option significantly or permanently disrupts and stops marine activities and blocks the navigation routes along the River Avon compared to the Do Nothing scenario.
		-	Minor negative impact	Option disrupts marine activities and hinders the navigation routes along the River Avon compared to the Do Nothing scenario.
		0	No impact	Option has neutral impact on marine activities and navigation and along the River Avon compared to the Do Nothing scenario.
		+	Minor positive impact	Option enhances potential for marine activities and navigation routes along the River Avon compared to the Do Nothing scenario.
		++	Significant positive impact	Option significantly enhances potential for marine activities navigation routes and along the River Avon compared to the Do Nothing scenario.
6. Ensure the Strategy is technically feasible and deliverable over its duration	Deliverability	--	Significant negative impact	Option is very technically challenging to implement. A significant risk that the option may not be delivered within the allotted timeframe due to the extended timescales required to achieve potential funding / consenting / construction.
		-	Minor negative impact	Option is technically challenging. A minor risk that achieving funding / consenting / construction may increase the delivery timescales of the option.
		0	No impact	Option represents an average level of technical challenges and deliverability risks relative to the other options.
		+	Minor positive impact	Option is technically feasible. Potential that achieving funding / consenting / construction which could impact delivery of option, although the likelihood is low.
		++	Significant positive impact	Option is technically feasible. Very low risk of extended timescales to achieve funding / consenting / construction that may impact the delivery of the option.

6.2 Description of long list options and scoring

A brief description of each strategic option, on an epoch-by-epoch basis, together a breakdown of the scoring for each epoch, supporting commentary on each score, and a present value (PV) cost for each option is given in Appendix 2. Information on how this PV was formulated is given in Appendix 1.

6.3 Summary of Results

A summary table showing the total scores for each of the 39 strategic options on the long list is provided in Table 37.

There are three options scoring higher than the others, and separated by a clear gap of 2 points (scores of +14, +12 and +12). These were proposed for the short list of strategic options. There are a further five options grouped in the next tier of scoring (+10) and these were also proposed for the short list.

Table 37 Summary of the strategic option multi-criteria scoring

Strategic Option	Epoch 1 measure	Epoch 2 measure	Epoch 3 measure	Whole life costs PV(£)	Scores						
					Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
1	PLP	PLP	PLP	£785,000	+2	0	0	+2	0	+2	+6
2	PLP	PLP	High Defences	£6,986,000	+4	+1	-1	+2	0	+3	+9
3	PLP	PLP	Narrow Barrier	£45,401,000	+5	+2	-2	0	0	+2	+7
4	PLP	PLP	Wide Barrier	£61,831,000	+5	+2	-2	-1	0	+1	+5
5	PLP	Low Defences	PLP	£19,761,000	+3	+1	-1	+1	0	+2	+6
6	PLP	Low Defences	High Defences	£20,895,000	+5	+2	-2	+1	0	+3	+9
7	PLP	Low Defences	Narrow Barrier	£64,377,000	+6	+3	-3	-1	0	+2	+7
8	PLP	Low Defences	Wide Barrier	£80,807,000	+6	+3	-3	-1	0	+1	+6
9	PLP	High Defences	High Defences	£21,818,000	+6	+2	-1	+1	0	+4	+12
10	PLP	Narrow Barrier	Narrow Barrier	£166,233,000	+7	+4	-2	-2	0	+3	+10
11	PLP	Wide Barrier	Wide Barrier	£227,072,000	+7	+4	-2	-2	0	+2	+9
12	Low Defences	PLP	PLP	£41,896,000	+3	+1	-1	+1	0	+1	+5
13	Low Defences	PLP	High Defences	£48,097,000	+5	+2	-2	0	0	+2	+7
14	Low Defences	PLP	Narrow Barrier	£86,512,000	+6	+3	-3	-1	0	+1	+6
15	Low Defences	PLP	Wide Barrier	£102,942,000	+6	+3	-3	-2	0	0	+4
16	Low Defences	Low Defences	PLP	£42,072,000	+4	+2	-1	+1	0	+2	+8
17	Low Defences	Low Defences	High Defences	£43,207,000	+6	+3	-2	0	0	+3	+10
18	Low Defences	Low Defences	Narrow Barrier	£86,689,000	+7	+4	-3	-1	0	+2	+9
19	Low Defences	Low Defences	Wide Barrier	£103,119,000	+7	+4	-3	-2	0	+1	+7
20	Low Defences	High Defences	High Defences	£46,182,000	+7	+3	-2	0	0	+1	+9

Strategic Option	Epoch 1 measure	Epoch 2 measure	Epoch 3 measure	Whole life costs PV (£)	Scores						
					Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
21	Low Defences	Narrow Barrier	Narrow Barrier	£237,766,000	+8	+5	-3	-2	0	+2	+10
22	Low Defences	Wide Barrier	Wide Barrier	£309,841,000	+8	+5	-3	-2	0	+1	+9
23	High Defences	High Defences	High Defences	£47,373,000	+8	+3	-1	0	0	+4	+14
24	Do Minimum	PLP	PLP	£360,000	+2	0	0	+2	0	+2	+6
25	Do Minimum	PLP	High Defences	£6,561,000	+4	+1	-1	+2	0	+3	+9
26	Do Minimum	PLP	Narrow Barrier	£44,976,000	+5	+2	-2	0	0	+2	+7
27	Do Minimum	PLP	Wide Barrier	£61,406,000	+5	+2	-2	-1	0	+1	+5
28	Do Minimum	Low Defences	PLP	£19,335,000	+3	+1	-1	+1	0	+2	+6
29	Do Minimum	Low Defences	High Defences	£20,470,000	+5	+2	-2	+1	0	+3	+9
30	Do Minimum	Low Defences	Narrow Barrier	£63,952,000	+6	+3	-3	-1	0	+2	+7
31	Do Minimum	Low Defences	Wide Barrier	£80,382,000	+6	+3	-3	-1	0	+1	+6
32	Do Minimum	High Defences	High Defences	£21,392,000	+6	+2	-1	+1	0	+4	+12
33	Do Minimum	Narrow Barrier	Narrow Barrier	£165,808,000	+7	+4	-2	-2	0	+3	+10
34	Do Minimum	Wide Barrier	Wide Barrier	£226,647,000	+7	+4	-2	-2	0	+2	+9
35	Do Minimum	Do Minimum	PLP	£116,000	+2	0	0	+2	0	+3	+7
36	Do Minimum	Do Minimum	High Defences	£6,316,000	+4	+1	-1	+2	0	+4	+10
37	Do Minimum	Do Minimum	Narrow Barrier	£44,732,000	+5	+2	-2	0	0	+3	+8
38	Do Minimum	Do Minimum	Wide Barrier	£61,162,000	+5	+2	-2	0	0	+2	+7
39	Do Minimum	Do Minimum	Do Minimum	£0	+2	0	0	+2	0	+5	+9

7. SELECTED SHORT LIST OPTIONS

7.1 Overview of short list options

Based upon the results of the multi-criteria appraisal, the options with the highest total score across the six option objectives were initially selected. In total eight options were identified, these include (highest total score first, in descending order):

- Option 23: High Defences in epoch 1 and then maintenance of the High Defences in epochs 2 and 3. The total score for this option is +14.
- Option 9: PLP in epoch 1, construction of High Defences in epoch 2 and then maintenance of the High Defences in epoch 3. The total score for this option is +12.
- Option 32: Do Minimum in epoch 1, construction of High Defences in epoch 2 and then maintenance of the High Defences in epoch 3. The total score for this option is +12.
- Option 10: PLP in epoch 1, construction of a Narrow Barrier in epoch 2 and then maintenance of the Narrow Barrier in epoch 3. The total score for this option is +10.
- Option 17: The construction of Low Defences in epoch 1, the raising, lengthening and maintenance of these Low Defences in epoch 2 before an upgrade to High Defences in epoch 3. The total score for this option is +10.
- Option 21: The construction of Low Defences in epoch 1 before the construction of a Narrow Barrier in epoch 2. In epoch 3 the barrier would be maintained. The total score for this option is +10.
- Option 33: Do Minimum in epoch 1 before a Narrow Barrier is constructed in epoch 2. Barrier to be maintained in epoch 3. The total score for this option is +10.
- Option 36: Do Minimum in epochs 1 and 2 before the construction of High Defences in epoch 3. The total score for this option is +10.

7.2 Moderation and Rationalisation

Following presentation of the 8 initially selected options a moderation/rationalisation process was undertaken by the technical team (AECOM with BCC, Paul Sayers (adviser to BCC) and the Environment Agency. The list was reviewed, practical duplications removed and one 'near miss' added back in. This consensus-based approach gave a more rounded short list of 7 options, covering both precautionary and adaptive approaches:

Most precautionary

- Option 21: Low Defences in epoch 1 before the construction of a Narrow Barrier in epoch 2. In epoch 3 the barrier would be maintained
- Option 23: High Defences in epoch 1 and then maintenance of the High Defences in epochs 2 and 3

Precautionary

- Option 9: PLP in epoch 1, construction of High Defences in epoch 2 and then maintenance of the High Defences in epoch 3
- Option 10: PLP in epoch 1, construction of a Narrow Barrier in epoch 2 and then maintenance of the Narrow Barrier in epoch 3

Adaptive

- Option 17: Low Defences in epoch 1, the raising, lengthening and maintenance of these Low Defences in epoch 2 before an upgrade to High Defences in epoch 3.
- Option 36: Do Minimum in epochs 1 and 2 before the construction of High Defences in epoch 3

Most Adaptive

- Option 6: PLP in epoch 1, construction of Low Defences in epoch 2 and then upgrade to High Defences in epoch 3

Strategic Option	Epoch 1 measure	Epoch 2 measure	Epoch 3 measure	Whole life costs PV(£)	Scores						
					Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
23	High Defences	High Defences	High Defences	£47,373,000	+8	+3	-1	0	0	+4	+14
9	PLP	High Defences	High Defences	£21,818,000	+6	+2	-1	+1	0	+4	+12
10	PLP	Narrow Barrier	Narrow Barrier	£166,233,000	+7	+4	-2	-2	0	+3	+10
17	Low Defences	Low Defences	High Defences	£43,207,000	+6	+3	-2	0	0	+3	+10
21	Low Defences	Narrow Barrier	Narrow Barrier	£237,766,000	+8	+5	-3	-2	0	+2	+10
36	Do Minimum	Do Minimum	High Defences	£6,316,000	+4	+1	-1	+2	0	+4	+10
6	PLP	Low Defences	High Defences	£20,895,000	+5	+2	-2	+1	0	+3	+9

For more details of what each of these shortlist options involves, please refer to Appendix 2 where a full description of each is provided. The following text provides an overview of the appraisal results for each of the short list options.

Option 23 (score +14) - High Defences (Epoch 1), High Defences (Epoch 2), High Defences (Epoch 3)

This option involves constructing High Defences in epoch 1 and then maintaining these defences for the remainder of the Strategy appraisal period. As part of the option, lock gate upgrades at both Netham and Junction / Entrance Lock will be required to stop water inundating the Floating Harbour during tidal flood events. This option scores the highest in the multi-criteria analysis with a total score of +14.

The option can be considered a precautionary approach to flood risk management; High Defences are constructed in epoch 1 of the Strategy to a 1:200 year standard of protection in 2115. Therefore for a large part of the strategy duration, the defence standard of protection will greatly exceed the 1 in 200 year standard, offering a very high level of protection to the areas which would otherwise be at risk of flooding. As a result of this the option scores highly for flood risk benefits (+8 out of a possible +9) in the multi criteria assessment.

The option also scores highly in deliverability as the option is technically feasible to implement and once constructed no further capital works will be required (i.e. maintenance only). Due to the long term flood risk benefit which this measure provides, it also scores highly for sustainability as it will help to facilitate development in the areas benefiting from the defences.

The option scores a -1 (out of a maximum potential negative score of -6) in the environmental category. This is largely because the option will be visually prominent and may have an impact on the landscape character of the area and heritage and archaeology. The option may also have an impact on terrestrial ecology and estuarine / riverine ecology. The option would however provide socio-economic benefits to the environment.

Option 9 (score +12) - PLP (Epoch 1), High Defences (Epoch 2), High Defences (Epoch 3)

This option involves undertaking PLP in epoch 1 before constructing High Defences in epoch 2. The new defences will be maintained in epoch 3. As part of the High Defences in epoch 2, lock gate upgrades at both Netham and Junction / Entrance Lock will be required to stop water inundating the Floating Harbour during tidal flood events. The option scores a total of +12 in the multi-criteria assessment.

The option will provide a high standard of flood protection from epoch 2 onwards, i.e. when the High Defences are constructed. In the interim, during epoch 1, the flood risk will be expected to increase across the study site. PLP and temporary / demountable defences will be used in some areas during epoch 1 to help manage the flood risk in the areas with the most significant risk.

Across the entire appraisal period this options scores highly for flood risk benefits (+6 out of a possible +9). This is because from epoch 2 onwards this option provides in excess of a 1in200 year standard of protection due to the High Defences being a precautionary measure. The option also scores highly in deliverability as the option is technically feasible to implement and once the High Defences are constructed in epoch 2, no further capital works will be required (i.e. maintenance only).

Compared to Option 23 (described above), this option scores more highly for whole life option cost. This is because the capital investment for High Defences is delayed until epoch 2, and therefore the cost of this measure is discounted. In epoch 1 only a relatively small costs (relative to other options) is required to implement the PLP and temporary / demountable defences measure.

The option scores a -1 (out of a maximum potential negative score of -6) in the environmental category. The negative impacts mainly arise from the High Defences measure from epoch 2 onwards with minimal impact arising from PLP in epoch 1. High Defences will be visually prominent and may have an impact on the landscape character of the area and heritage and archaeology. The option may also have an impact on terrestrial ecology and estuarine / riverine ecology.

Option 10 (score +10) – PLP (epoch 1), Narrow Barrier (epoch 2), Narrow Barrier (epoch 3)

This option involves undertaking PLP in epoch 1 before constructing a Narrow Barrier in epoch 2. The barrier will continue to be maintained in epoch 3.

The barrier, constructed in epoch 2 will provide a very high standard of flood protection from this point onwards . In the interim, during epoch 1, the flood risk will be expected to increase across the study site. PLP and temporary / demountable defences will be used in some areas during epoch 1 to help manage the flood risk in the areas with the most significant risk. The overall score for flood risk benefits for this option is +7 (out of a possible +9).

Due to the high cost of the narrow barrier relative to the other measures (it is the second most costly measure), the score for the whole life cost category is -2. The option also scores a -2 in the environmental category. The negative environmental impacts arise mainly from the Narrow Barrier in epoch 2 onwards with minimal impacts arising from PLP in epoch 1. The Narrow Barrier is likely to be visually prominent and impact the landscape character of the area as well as potentially having an impact on terrestrial ecology, estuarine / riverine ecology and archaeology and heritage. Minor negative environmental impacts could arise to geomorphology and water quality and traffic and transport.

The impact of the option on sustainability in the study area is very positive, with the option having a +4 score (out of a maximum potential score of +6). This positive benefit arises largely due to the Narrow Barrier, from epoch 2 onwards, which would protect the entire city centre from flooding to a high standard and help facilitate development in the future. The residual risk of flooding arising from fluvial and other sources of flooding would still need to be considered by future developments, even if a Narrow Barrier was constructed.

Option 17 (score +10) – Low Defences (epoch 1), Low Defences (epoch 2), High Defences (epoch 3)

This option involves constructing Low Defences in epoch 1 and then raising and lengthening these Low defences in epoch 2 to the same standard of protection. In epoch 1 the defences would be constructed to a 1 in 200 year standard for 2015 and then in epoch 2 they would be raised / lengthened to a 1 in 200 year standard for 2030. In epoch 3, the measure will be upgraded to High Defences, which will involve upgrading, raising and lengthening the defences to the 1 in 200 year standard for 2115.

The sequence of using Low Defences in the first two epochs and then High Defences in epoch 3 represents an adaptive approach to managing the flood risk in the study area. An advantage of an adaptive approach is that the required heights and lengths of the defences can be adjusted in the future according to the magnitude of sea level rise and increase in flood risk that is observed. Overall this option provides a large flood risk benefits and is scored as +6 in this category within the multi-criteria appraisal.

This option also scores highly in the sustainability and deliverability categories. The positive benefit for sustainability arises as the new Defences will provide a flood risk benefit to areas within the study site which will help facilitate growth and development in these areas. In terms of deliverability, this option is technically feasible and after the initial defences have been constructed in epoch 1, the option largely involves a series of upgrades to these assets rather than widespread construction in new areas.

The option achieves an average score for whole life cost (relative to the other options) and is expected to be one of the most cost effective options on the short list.

The overall environmental impact of the option comes to a -2 score in the multi-criteria appraisal. The negative environmental impacts largely arise as the new defences could have an impact visually on the existing landscape of the area and could also negatively impact terrestrial ecology and estuarine and

riverine ecology. The option could also have a negative impact on traffic and on archaeology and heritage.

Option 21 (score +10) – Low Defences (epoch 1), Narrow Barrier (epoch 2), Narrow Barrier (epoch 3)

This option involves constructing Low Defences in epoch 1 before the construction of a Narrow Barrier in epoch 2. In epoch 3 the Narrow Barrier will continue to be maintained to sustain its flood defence function. The total score for this option is +10 in the multi-criteria appraisal.

This option scores very highly in the flood risk category of the multi-criteria assessment due to its flood risk benefits (scored as +8 out of a possible +9 for this category). The flood risk benefits arise from epoch 1 onwards with the construction of Low Defences. These defences will be constructed to a 2015 standard and will provide a vast improvement in flood protection standard to a number of areas throughout the study area. From epoch 2, a Narrow Barrier will be constructed to a standard of protection designed for 2115.

The impact of the option on sustainability in the study area is also very positive, with the option having a +5 score (out of a maximum potential score of +6). This is the joint highest scoring option for this category and the positive benefit arises largely due to the Narrow Barrier, from epoch 2 onwards, which would protect the entire city centre from flooding to a high standard and help facilitate development in the future. The residual risk of flooding arising from fluvial and other sources of flooding would still need to be considered by future developments, even if a Narrow Barrier was constructed.

Due to the high cost of the Narrow Barrier measure, the overall whole life cost for this option is scored negatively, as -2. The option also scores a -3 in the environmental category. The negative environmental impacts arise mainly from both the Low Defences and the Narrow Barrier. The Narrow Barrier is likely to produce most of these impact as it is likely to be visually prominent and impact the landscape character of the area as well as potentially having an impact on terrestrial ecology, estuarine / riverine ecology and archaeology and heritage. Minor negative environmental impacts could arise to geomorphology and water quality and traffic and transport.

Option 36 (score +10) – Do Minimum (epoch 1), Do Minimum (epoch 2), High Defences (epoch 3)

This option is similar to Option 32, but it involves constructing High Defences later, in epoch 3, rather than in epoch 2. The option therefore comprises Doing Minimum in epochs 1&2 before constructing High Defences in epoch 3. The total score for the option in the multi-criteria appraisal is +10.

Due to the delay in implementing a 'Do Something' measure for this option (i.e. High Defences not until epoch 3), the flood risk benefits of this option are reduced (compared to the other options to make the shortlist). The score for the flood risk category for this option is +4 (out of a maximum possible score of +9). However, the delay in implementing the High Defences for this option is reflected in the whole life cost for this option, with the category scored highly, with a +2 score. This is because the investment required for High Defences will not be needed until epoch 3 and it is discounted in the whole life costs accordingly.

This option also scores highly in the deliverability criteria (+4 score out of a maximum potential score of +6). This is because the Do Minimum measure is expected to be deliverable (effectively maintaining the 'status quo') and High Defences is also a technically feasible measure.

In terms of environmental impact, this option is scored as -1. The negative impacts for this option are associated with the High Defences measure in epoch 3 which could impact the visual environment, alongside potential impacts to terrestrial, riverine and estuarine ecology. The option could also have a negative impact on traffic and on archaeology and heritage.

Option 6 (score +9): PLP (epoch 1), Low Defences (epoch 2), High Defences (epoch 3)

This strategic option is regarded as the most adaptive approach from the shortlist of strategic options. It involves undertaking Property Level Protection (PLP) in epoch 1, constructing Low Defences in epoch 2 and then upgrading these defences to High Defences in epoch 3. The total score for the option in the multi-criteria appraisal is +9.

The option scores marginally less than Option 9 in terms of flood risk mitigation by virtue of the epoch 2 measure of Low Defences scoring less than High Defences. The environmental score is lower for Option 6 compared to Option 9 because whilst there are benefits in the adaptive approach in epoch 2, the negative impact of two sets of construction work (low defences in epoch 2 and then raising defences in epoch 3) is scored as having a greater negative impact.

This option scores relatively well on deliverability compared to other options, e.g. Option 10 and Option 17. The change from epoch 2 is largely involves a series of upgrades to these assets rather than widespread construction in new areas.

For other criteria, this Option has comparable scores with Option 9, in terms of sustainability (+2 score), and whole life costing and funding (+1).

7.3 Discussion of the appraisal results

This section provides a discussion of some of the key points that have been considered during the long to short list appraisal process.

7.3.1 Exclusion of Wide Barrier in the short list options

The Wide Barrier measure failed to make it onto any of the short list options. This is down to a number of reasons which include:

- **Highest cost:** The Wide Barrier measure has the highest capital costs of any measure, with estimated cash costs expected to be in the range of £550-600million (capital cash costs). This is picked up in the multi-criteria appraisal with options that include a Wide Barrier generally being ranked amongst the lowest for this category.
- **Environmental Impacts:** The Wide Barrier, being located adjacent to key environmental designations, is likely to produce the most significant environmental impacts of any measure. The environmental assessment has identified that the Wide Barrier is likely to significantly impact Landscape and Visual, Terrestrial Ecology, Estuarine and Riverine Ecology, Archaeology and Heritage, Geomorphology and Water Quality and Traffic and Transport.
- **Deliverability Risk:** The Wide Barrier poses significant deliverability risk with challenges expected to arise in acquiring the necessary consents, especially those which may relate to environmental impacts with the Barrier being located so close to the environmental designations. The Barrier will also need to acquire a TWAO which could pose a significant deliverability risk.

When compared to the other measures which comprise the short-list options, the benefits of the Wide Barrier can be achieved through the implementation of a Narrow Barrier, and to some extent, via the High Defences measure (as this also provides a high standard of protection to central Bristol). As these alternative measures have less negative impacts than the Wide Barrier, yet provide a similar level of benefits, it is considered appropriate to exclude the Wide Barrier measure from the short list of options.

7.3.2 Use of PLP and temporary / demountable defences and Do Minimum as a short term solution

A large number of the short list options include property level protection and demountable / temporary defences as a viable measure in epoch 1 of the appraisal period. Doing Minimum for this epoch is also included as a feasible approach for a number of the short list options. These measures can be considered as an 'interim' solution until a more substantial 'Do Something' measure is implemented, such as Low Defences, High Defences or a Narrow Barrier.

7.3.3 Impact of measures on navigation

Each measure has been scored as having a negligible impact (i.e. impact of 0) on navigation and marine activities in the River Avon. The measures that would perhaps be expected to have an impact on this category are the Wide and Narrow Barriers. However, it has been assumed that a barrier would be designed to ensure navigation impacts and impacts on marine activities are fully mitigated. During engagement with Port of Bristol it became clear that they are of the view that navigation and marine safety presents greater negative impacts than captured in the scoring. Rather than re-visit the entire scoring, it was agreed to take this issue on board in the next stage of the study.

7.3.4 Timescales for decision making

Five of the eight short list strategic options involve the construction of either High Walls or a Narrow Barrier in epoch 2. For these options to be successfully implemented, it will be necessary to commit and to start planning these measures in epoch 1 of the Strategy. Two options (option 23 and 17) involve the construction of either High Defences or Low Defences in epoch 1. Therefore for most of the short-listed Strategic options a decision on the Strategy and how it will be implemented is required in epoch 1. Only one of the seven short-list options (option 36) allow the decision making on major investment (i.e. an investment for Low Defences, High Defences and Narrow Barrier) to be deferred until later in the appraisal period, in epoch 3.

7.3.5 **Compatibility of options with development needs**

Not all of the options selected for the shortlist will support new development in the city. A key part of the next phase of the study will be assessing to what extent each option meets development needs (or provides additional development potential) and therefore provides additional value over a lower-cost but lower-standard approach.

7.4 **Preliminary assessment of potential Partnership Funding**

In order to understand potential funding requirements and the likely scale of contributions which may be required for options, preliminary partnership funding assessments were carried out.

At the shortlisting stage the partnership funding assessment was carried out at a high level in order to inform the maximum theoretical potential Grant in Aid that can be expected. This is intended to inform affordability and deliverability consideration at this stage. Further refinement of options and associated benefits will be carried out on the shortlist to allow a partnership funding score to be calculated for each option.

The Do Nothing and Do Minimum Damages were calculated using the flood modelling outputs for these scenarios. The damages assessment was carried out in accordance with FCERM-AG. For full details of the methodology and results see the Economic Assessment Report.

Do Nothing is represented by a hypothetical walk away scenario with no further management or maintenance of assets. Operation of water level control structures is assumed to cease under this scenario and lock gates, sluices and flood gates are assumed to fail open. This scenario results in very significant levels of additional damage compared to the Do Minimum case.

Do Minimum effectively represents the 'status quo' with reactive maintenance of assets and continued operation of the water level control structures (e.g. in the Floating Harbour). No raising or improvement of defences occurs under this scenario and significant damage still occurs, particularly in the future as a result of asset failure and as a result of sea level rise.

The Outcome Measure 1 part of the PF calculator counts the overall monetary whole life PV benefits of a scheme. However, a high proportion of the Do Nothing damage can be avoided by continuing with the current status quo of operation and maintenance and these activities are not eligible for GiA funding. Therefore the more realistic representation of the maximum potential benefit which could be achieved by 'Do Something' options to improve (e.g. a barrier, high defences, low defences etc.) is indicated by the Do Minimum damage.

The preliminary partnership funding assessment was therefore carried out on the following basis and assumptions:

- 80% of the whole life (100 years) damages (under Do Nothing and Do Minimum) was used as a proxy for a maximum theoretical benefits for options such as the barriers and high and low defences. This percentage was adopted to account in a high level way for potential residual damage; the fact that not all areas may benefit; further reduction of potential damage likely as a result of accounting for defacto defences; and modelling limitations at Pill and Shirehampton (to be assessed in next phase of the project).
- The numbers of properties at risk in the different risk bands were all in the mid deprived category.
- The assumption that the required contributions will be attained in order to obtain a 100% PF score

Utilising the above assumptions / methodology the indicative maximum theoretical GiA contribution was estimated.

Table 38 Preliminary partnership funding assessment

Scenario	~ 80% PV damage (100 years) used as a proxy for theoretical maximum potential benefit	Potential Maximum GiA (assuming required contributions obtained)
Do Nothing	£1.5bn	£93m*
Do Minimum	£400m	£22m

*Note this level of GiA is not likely to be obtainable as a Do Minimum option removes much of the potential damage (and therefore benefit for improve options) and this is achieved through non-capital activities (e.g. maintenance) which is not eligible for GiA .

This preliminary assessment indicates that if the improve options being considered in the short list can achieve 80% of the baseline damages as a benefit it is indicated that there is the potential for approx. £22m of GiA towards the capital costs of schemes, if the required contributions can be found to achieve a 100% PF score. This value is likely to vary considerably depending on the timing of options, and specific outcomes achieved and the PF scores for each of the schemes of the short listed options will be provided in the next stage of appraisal once further details have been developed and refined (e.g. costs, benefits, outcomes etc.) However, with this order of magnitude of potential GiA it is clear that considerable external contributions will need to be obtained in order to implement many of the 'improve' options within the short list given the initial cost estimates provided.

7.5 Residual Flood Risk

7.5.1 Context and Objective

A key objective for the Strategy is to:

“mitigate the climate change flood threat scenario to satisfy relevant Risk Management Authorities that regeneration can occur, provided site specific consideration of residual risk. This will support fostering a prosperous and resilient City by addressing the existing blight that flooding risks posing on development in Central Bristol.”

Within the short list of options a range of potential measures are available which will reduce (to greater or lesser extents) the risk of flooding to central Bristol. Flood risk in Central Bristol is tidally dominated, with greatest risk from tidal surge events. This risk is set to increase over time due to predicted climate change and sea level rise.

Some of the options will provide shorter term, more geographically limited protection (such as PLP or low walls), and others such as the barrier options provide a more precautionary, robust, wider strategic protection delivering a higher standard of protection to a wider geographical area. Whichever options or package of measures comprise the final Strategy, residual risk will remain in some form. The sources and significance of residual risk will depend upon the preferred options recommended.

7.5.2 Types of Residual Risk

Residual risk can materialise in several different ways, the significance and relevance of each aspect varying depending on the option in question. Residual flood risk includes:

1. **Interim risk**- the risk of flooding between the present day and the time until a 'do something' option is implemented to reduce this risk.
2. **Remaining risk** - the risk of flooding which remains to those properties benefiting from a defence once the option / measure is implemented. This can arise from:
 - above design standard events e.g. overtopping, outflanking inundating defences etc.
 - collapse or failure of the defence, e.g. breaching, failure to close floodgates etc.
 - mechanical failure e.g. control structures, gates etc.
3. **Other sources of risk** – the risk of flooding from other sources (e.g. the remaining risk from fluvial, groundwater, surface water, pluvial flooding). The Strategy will put forward suitable measures to address and reduce the primary flood risk from tidal surge events. These may also have an additional benefit in reducing flood risk from other sources (e.g. new raised floodwalls may address both fluvial and tidal flood risk.) If options do not reduce flooding from other sources it will at least need to be ensured that they do not exacerbate the risks posed from other sources.

7.5.3 Dealing with Residual Risk

Some of the aspects of residual risk can be controlled and reduced at this strategic stage. For example, the Strategy will recommend the preferred Standard of Protection and this will help frame the appropriate level of residual risk. Uncertainties can be sensitivity tested to help inform future more detailed appraisal, decision making and aspects such as planning policy. The strategy will also recommend the suitable contingency or 'redundancy' allowances within systems or defences. For example, suitable freeboard allowances can be recommended based on the uncertainties faced (e.g. settlement of defences, wave overtopping) as another mechanism to address residual risk.

Proportionate consideration and simulation of residual risk will be made to understand the significance and potential sources of risk for the preferred options. Proportionate estimates of residual flood risk will also be carried out in order to capture the economic impacts of residual risk (i.e. the value of potential residual damage).

The outputs of this strategic level assessment will be used to signpost potential remaining residual risks. These risks will need to be further considered and quantified during more detailed appraisals, such as in the detailed design of schemes with intent to eliminate (e.g. design out), reduce (increase contingency in design) or manage these as required (put procedures and strategies in place to reduce impacts). Aspects such as breach analysis should also be considered in the detailed appraisal of development plans.

The reduction in the dominant source of risk (tidal flooding) which the Strategy will provide will help enable and facilitate housing allocations, regeneration and redevelopment aspirations; however, (although less onerous) there will still be a requirement for suitable site specific measures to mitigate residual risks. For example the following types of measure may need to be implemented:

- innovative non-residential street scape solutions to flood routeing and storage
- floor level and threshold raising
- sustainable drainage
- on-site defences
- safe access and egress provisions
- emergency warning and evacuation procedures.

Planning policy and development control procedures will then need to update as appropriate to ensure that the suitable mechanisms are in place to manage and reduce these on a site-by-site basis.

8. NEXT STEPS

8.1 Appraisal of short list options to select preferred options

In the next stage of the project a more detailed appraisal of the short-listed options will be carried out to select the draft preferred Strategy option.

This will include the following key activities:

- Further development of options, including spatial requirements and alignments, typical details and engineering concepts.
- Further technical appraisal of option feasibility, risks and uncertainty. This will be informed by site walkovers, desktop review and engineering appraisal.
- Modelling of option scenarios to establish benefits.
- Consideration of different futures (e.g. sensitivity testing difference climate change scenarios, development and funding cases) and their impact on outcomes.
- Further refinement and valuation of whole life costing and benefits of options.
- More detailed economic appraisal of options including CBA, IBCR, PF scores and High level estimation of GVA (local economic impact of shortlist options).
- Consideration of broader outcomes and compatibility with Strategy objectives.
- Establishment of trigger levels (precautionary or managed adaptive) for option intervention. Timing of intervention will be recommended based on current change factors for climate change, but, where there is the potential for deferred strategic choices, will also be presented on a timeless axis with water levels thresholds identified as a mechanism to show potential range uncertainty in the recommendations and to show the future flexibility required.
- Assessment of funding requirements, deliverability, and a potential funding strategy to obtain required contributions.
- More detailed environmental assessment of options including Strategic Environmental Assessment.
- Further engagement with key stakeholders (e.g. Port of Bristol on navigation) and potential beneficiaries to gain feedback, build consensus and support for preferred options.

The culmination of the above activities will lead to the selection and recommendation of the draft preferred option/s. The following criteria will need to be met in the selection of the preferred option/s:

- It can be demonstrated that the Strategy is technically robust, economically viable and environmentally sustainable and decision making has been made in accordance with good practice guidance (i.e. FCERM-AG).
- The Strategy will have a reasonable prospect of delivery (i.e. required partnership funding has a realistic prospect of being attained in the required timeframe).
- Preferred options adequately satisfy the key objectives of the Strategy.
- The Strategy is supported by the BCC, the Environment Agency and key stakeholders.

APPENDIX 1: COSTING METHODOLOGY

Approach to option costing

This appendix outlines the process by which high level cost estimates have been made for each of the strategic options.

Each Strategic option is comprised of a sequence of different measures over the duration of the Strategy. Costs for the various strategic options have been developed by following a 'bottom-up' approach, whereby costs for the separate measures in each epoch have been estimated and then summed to derive the total costs for the Strategic Option. At this stage of the appraisal process, costs have been considered in cash terms only. Whole life discounted costs for the short list of strategic options will be investigated in future appraisal work within the Strategy.

The measures for which costs have been estimated comprise Do Minimum, PLP, Low Defences and High Defences (including lock gate upgrades), Narrow Barrier and the Wide Barrier.

For the PLP, Low Defences and High Defences measure indicative alignments and heights for each time epoch have been established and are presented in sections 5.2.3, 5.3.3 and 5.4.3 of the report. For the Low Defences and High Defences measures, a range of structure types are potentially feasible, including; reinforced concrete flood walls, embankments, seepage piles and retention piles. For each site the most suitable structure type was chosen and alongside the height and length information, this was used as the basis to cost each of the measures.

An overview of the approach to costing the various measures is provided in Table 39 below. Also included in this table are a number of key assumptions, such as the indicative standard of protection (and therefore the resultant defence height) used as the basis for the high level costing exercise.

Table 39 Overview of the costing approach of the different measures

Measure	Epochs costed	SoP information and costing assumptions
Do Minimum	Epochs 1, 2 & 3	Costing for the maintenance of existing structures and water level control infrastructure within the floating harbor.
PLP / Temporary Defences	Epochs 1, 2 & 3	Properties at risk from a 1:20 year event eligible for Property Level Protection under Grant in Aid funding. Typical grant available is approximately £5k. Costs built up by assuming £5k costs per property at risk from a 1:20 year event.
Low Defences	Epochs 1, 2 & 3	Epoch 1: assumed that Low Defences are constructed to the present day 1:200 year standard of protection. Due to sea level rise the standard of protection will fall from the 1:200 year standard between the years 2015 and 2030. Epoch 2: assumed that Low Defences are constructed to provide a 1:200 year standard of protection for 2030. Due to sea level rise the standard of protection will fall from the 1:200 year standard between the years 2030 and 2065. It is assumed that any upgrades to Low Defences in epoch 3 would come under the High Defences measure (i.e. would be constructed to the 1:200 year standard of protection for 2115).
High Defences	Epoch 3	Assumed that High Defences will be constructed to the same standard of protection, irrespective of timing. The standard of protection that is assumed is a 1:200 year standard of protection for 2115. This represents a precautionary approach whereby, due to sea level rise, the protection standard will only drop to this level by 2115 and will therefore be in excess of this for the duration of the Strategy.
Narrow Barrier	Epoch 3	Assumed that barrier would be constructed to same standard or protection, irrespective of timing.
Wide Barrier	Epoch 3	Assumed that barrier would be constructed to same standard or protection, irrespective of timing.

Optimism Bias

In line with Environment Agency Flood and Coastal Erosion Risk Management Appraisal Guidance (FCERM-AG), an optimism bias of 60% has been applied to the costs of each strategic option. Optimism bias:

“is included to account for the tendency for appraisers to be overly optimistic in early assessment of project costs, timescales and benefits in comparison to the final values. This ‘optimism’ is a result of uncertainty in the final design detail and implementation as a result of the high level strategic approach required at this stage. To counter this, the HM Treasury issued guidance in the form of a percentage to increase the present value costs depending on the uncertainty surrounding the estimates. This

guidance has been adopted with FCERM-AG. With regard to coastal Strategies, the FCERM-AG recommends an optimism bias level of 60% as these projects are typically at an early stage and adopt a higher level approach to design and costing” (FCERM-AG, Environment Agency, 2010).

Unit capital costs for different defence structures

The cost estimations for the new defence structures, or capital works, was undertaken using a variety of sources, using the best available information and to a level of detail suitable for a high level strategic study. In the first instance, where actual defence costs were available from previous projects or published data, these costs have been used as a basis for relevant options in this study.

In the absence of ‘real’ costs, values have been estimated from rates provided in civil engineering price books (e.g. SPONS, 2016) coupled with experience of costs from similar projects.

The following sections summarise the costing basis and assumptions for different management structures which comprise the various measures and strategic options. Costs of the structures typically vary with height and length. A detailed breakdown of the lengths and heights of each structure that are required is provided in sections 5.3 and 5.4 of the main report.

Reinforced Concrete Walls

Unit rates per metre for reinforced concrete flood defence walls were estimated using civil engineering price books (e.g. SPONS, 2016) coupled with experience of costs from similar projects. A standard indicative cross section was adopted to cost the structures. The typical setback flood wall cross section assumed for costing is provided below in Figure 40. The estimated costs per metre of reinforced concrete flood wall range from £690 to £3,100 for walls of heights 0.5m to 2.5m respectively.

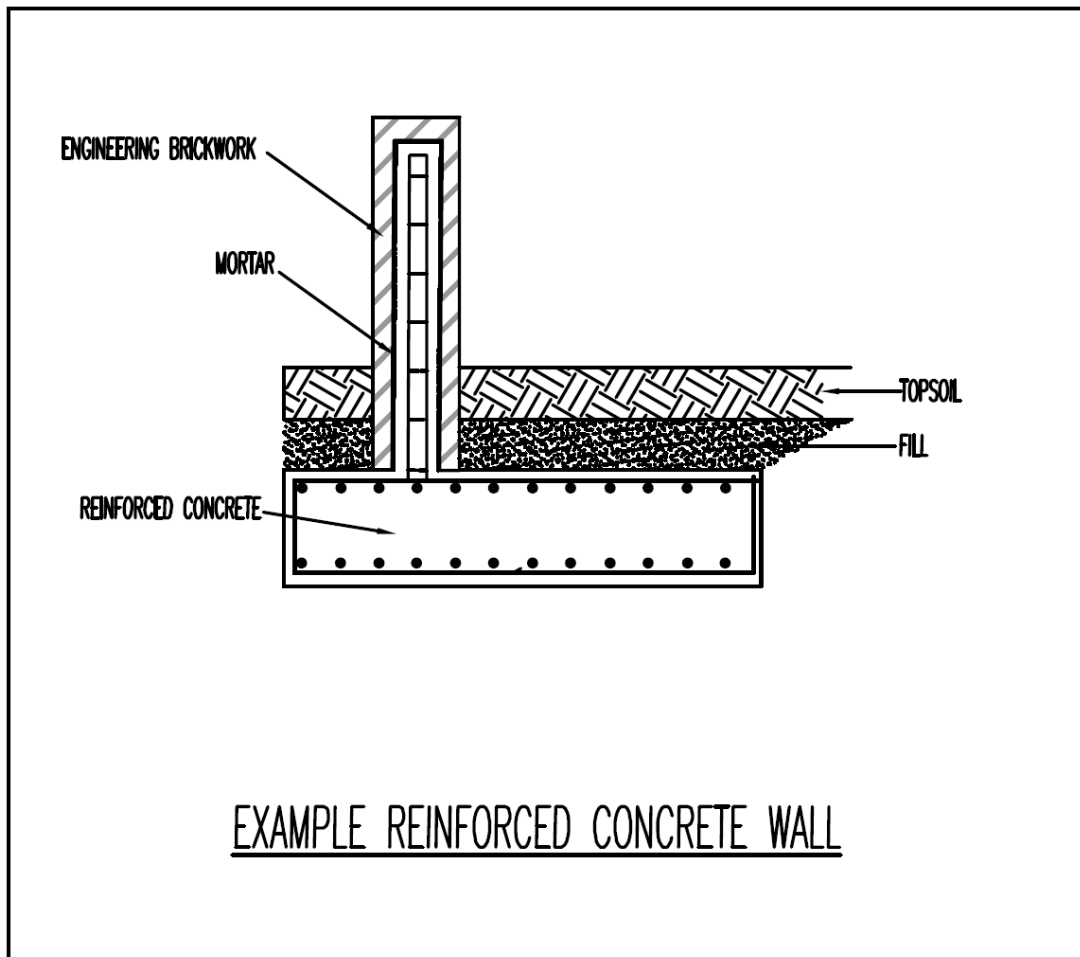


Figure 40 Indicative flood wall cross section

The costing of the walls includes an allowance for the following aspects and materials:

- Excavation and disposal
- Trimming of excavation
- Topsoil
- Fill
- Facing brickwork
- Engineering brickwork
- Concrete top - Design mix
- Placing of concrete
- Reinforcement of concrete
- Formwork
- Trimming of filled surfaces
- Drainage
- Seeding
- Preliminaries and scaling of works
- Overhead / profit

By multiplying the relevant unit costs of the required height of floodwalls by the defence lengths the capital construction costs were estimated for floodwalls.

Seepage Piles

Costs per specified defence length for seepage piles and capping walls were estimated using civil engineering price books (e.g. SPONS, 2016) coupled with experience of costs from similar projects. The average cost per metre of the seepage Piles was determined by dividing the worked up cost of the defence by the total length.

A typical seepage pile cross section was developed as a basis for the cost estimates. Sheet piles are available in a range of standard lengths and therefore it was necessary to select a suitable length of pile for the indicative cross section for the Strategy costing. Seepage piles are intended to be used as part of a setback solution and the typical height above ground level for seepage piles in the study area is between 0.5 – 2m. Based on these dimensions a seepage pile length of 6.4 was identified as the most appropriate and has been used in the indicative cross sections. For more detailed studies, for example as part of individual scheme development, the indicative pile length should be revisited and adjustments made to ensure that a suitable pile length is selected for the specific location.

The typical cost per metre of the Seepage Piles worked up in the Strategy ranges from £4,000 to £5,000. The typical seepage pile cross section used in the Strategy for costing purposes is shown in Figure 41.

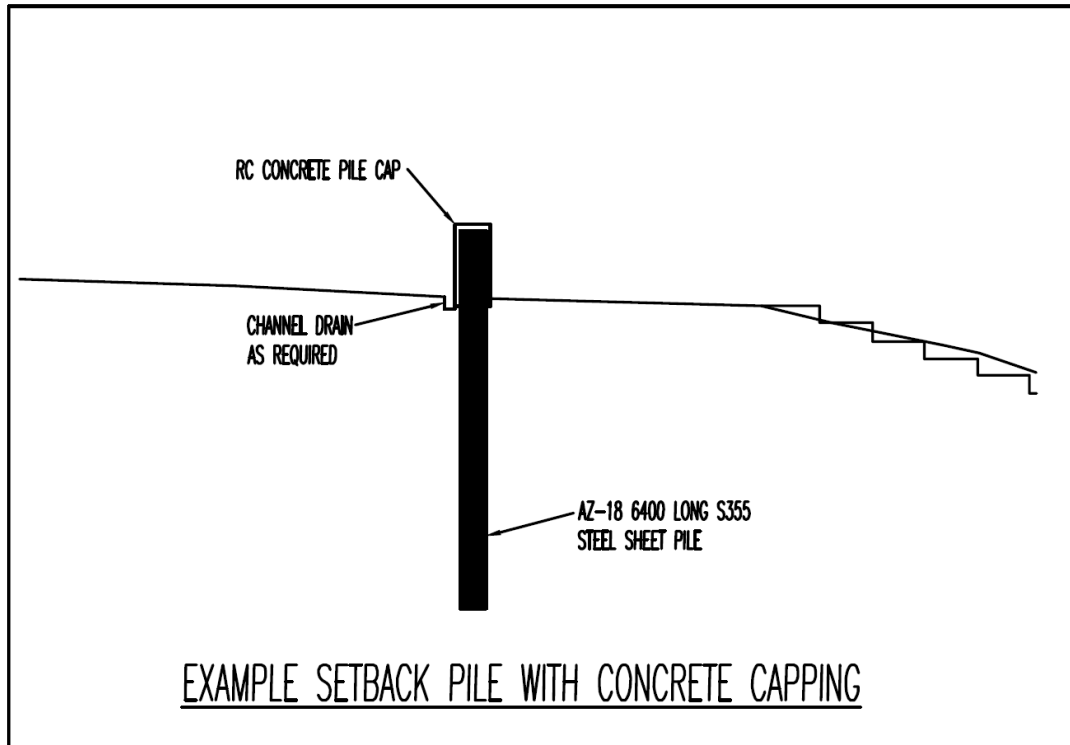


Figure 41 Indicative seepage pile cross section

The costing of the seepage pile includes an allowance for the following aspects and materials:

- Piling Rig
- Sheet Piles
- Pile Driving
- Reinforcement
- Formwork
- Concrete
- Placing of concrete
- Backfill
- Masonry cladding
- Preliminaries and scaling of works
- Overhead / profit

Retention Piles

Costs per specified defence length for retention piles and capping walls were estimated using civil engineering price books (e.g. SPONS, 2016) coupled with experience of costs from similar projects. The average cost per metre of the retention Piles was determined by dividing the working up cost of the defence by the total length.

A typical retention pile cross section was developed as a basis for the cost estimates. As discussed in the previous section, sheet piles are available in a range of standard lengths and therefore it was necessary to select a suitable length of pile for the indicative cross section for the Strategy costing. Retention piles are intended to be used as part of a frontline solution and the typical height above ground level for retention piles in the study area is between 0.5 – 2.0m. However, this height is derived from ground levels extracted from LiDAR data and it is possible that the true channel bed level may fall beneath this point. Therefore to ensure an adequate pile length for the indicative retention pile cross section a pile length of 13.5m was adopted. For more detailed studies, for example as part of individual scheme development, the indicative pile length should be revisited and adjustments made to ensure that a suitable pile length is selected for the specific location.

The typical cost per metre of the retention piles worked up in the Strategy ranges from £11,800 to £12,600. The typical retention pile cross section used in the Strategy for costing purposes is shown in Figure 42.

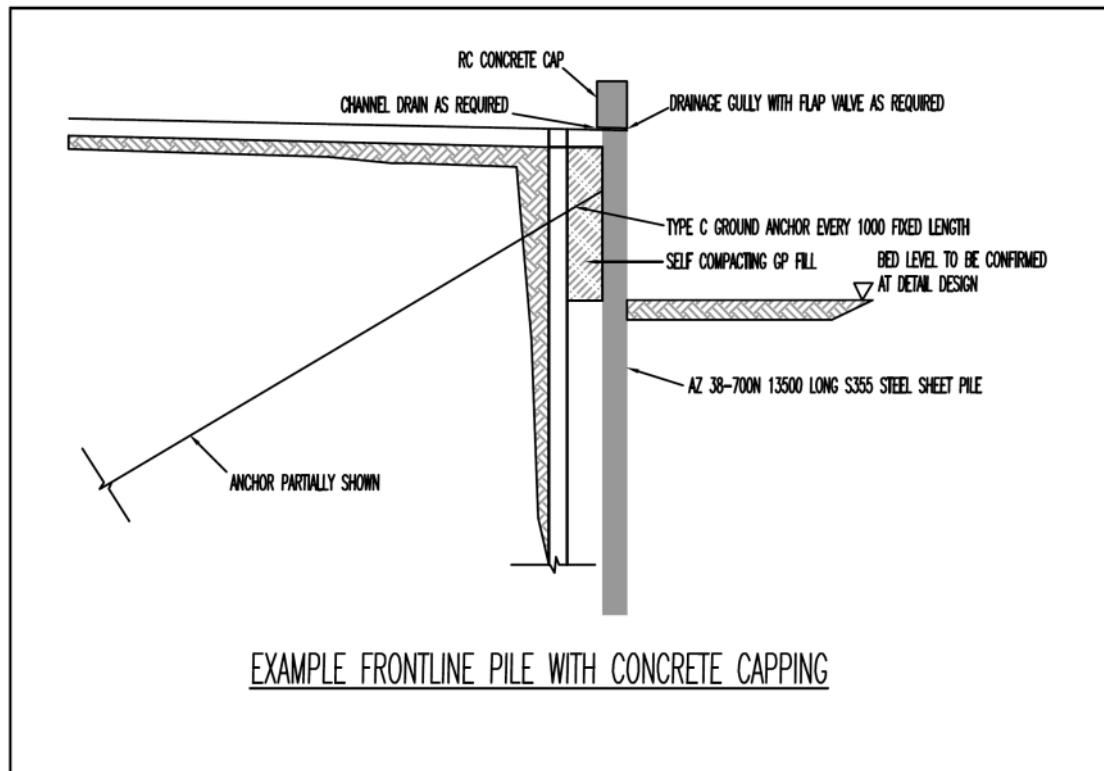


Figure 42 Indicative retention pile cross section

The costing of the retainment pile includes an allowance for the following aspects and materials:

- Piling Rig
- Pile Driving
- Formwork
- Wailing beam
- Anchor plant
- Placing of concrete
- Bollards
- Ladders
- Sheet pile coating protection
- Sheet Piles
- Reinforcement
- Concrete
- Wailing beam installation
- Anchor ties
- Backfill
- Preliminaries and scaling of works
- Overhead / profit

Tidal Lock Gates

As discussed in sections 5.3 and 5.4, lock gate raising and replacement at Entrance Lock or Junction Lock is an approach being considered to supplement either the High defences or Low defence options. The costs of a Lock gate replacement have been estimated based upon the Environment Agency guidance document 'Cost estimation for control assets – summary of evidence, Report SC080039/R5'. The report provides a summary of indicative costs and guidance on a number of channel, flow and level control assets typical of those used by operating authorities for watercourses in England and Wales. The cost estimates for MEICA systems provided in the report are based on the experience of regional Environment Agency MEICA teams drawing on typical costs experienced for similar types of work. In reality the possible range of actual costs is high and the costs provided are therefore only suitable for use in high level initial assessments (such as a Strategy). Further, more detailed cost estimations of lock gate replacement will be required if this approach is pursued in the future.

The cost build-up below is for one replacement of the lock gates and associated infrastructure. The design life of the replacement is approximately 20-40 years and therefore further refurbishments will be required over the duration of the Strategy.

No specific structural dimensions for Entrance Lock or Junction Lock have been used in the costing exercise. Rather, standard unit rates for maximum size gates >10m² and the associated infrastructure have been utilised.

The costing of the lock gate raising and replacement includes an allowance for the following aspects and materials:

Building services

- Electrical systems

Controls

- Common MCC controls

Mechanical

- Actuation
- Engines (over 250 horsepower)
- Gates (over 10m²)
- Gearbox (over 250 horsepower)

Pumps

- Screw pumps

Electrical

- Auto-transformers
- Electronic power components
- High voltage control equipment
- High voltage and power correction capacitors
- Three-phase motors

Lifting and winching

- Cranes over 5 tonnes

Other

- Powered weed screen
- Hydraulic systems

In addition, allowances have also been made for Preliminaries and scaling of works, as well as overheads/profit.

Based on this approach, the capital costs of raising the lock gates at Netham Lock and Entrance Lock / Junction Lock are estimated to be approximately £6.5million.

Permanent Flood Gate (i.e. at Entrance Lock)

As discussed in sections 5.3 and 5.4 , a permanent flood gate at Entrance Lock is an approach being considered to supplement either the High defences or Low defence options. The width of Entrance Lock is 19m and costs for a permanent flood gate in this location have been estimated based on the construction costs of a similar sized tidal barrier project at Boston, UK. The width of the Boston Barrier is approximately 25m and its construction costs reached approximately £15.3million.

By scaling the dimensions and costs of the Boston Barrier to the width of permanent flood gate required at Entrance Lock, the construction costs of a permanent flood gate at Entrance Lock are estimated to be £11.6million.

It is considered suitable to use this high level approach to costing a permanent flood gate at Entrance Lock for the costing of a strategic study. However, for further, more detailed studies that will undoubtedly be needed in the future to take this option forward, it is recommended that a more detailed cost estimate is undertaken. In addition to the construction costs of a permanent flood gate, the total project costs are very dependent on the works required in addition to the structure itself, such as raised defence tie-ins or mitigation measures to deal with environmental or navigation impacts.

Embankments

Unit rates per metre for earth embankments were estimated using civil engineering price books (e.g. SPONS, 2016) coupled with experience of costs from similar projects and benchmarking against information obtained from the Environment Agency. The typical embankment cross section assumed for costing is provided below in Figure 43.

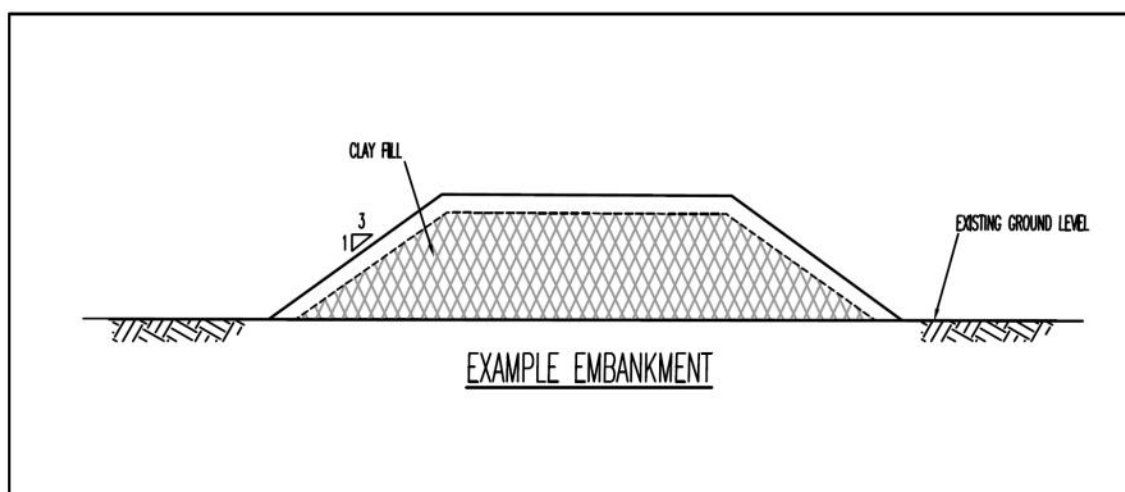


Figure 43 Indicative earth embankment cross section

The costing of the earth embankment included allowance for the following aspects and materials:

- Excavation and disposal
- Fill
- Trimming of filled surfaces
- Seeding
- Overhead / profit
- Topsoil
- Erosion control
- Drainage
- Preliminaries and scaling of works

By multiplying the relevant unit costs of the required height of earth embankment by the defence lengths the capital construction costs were estimated for the earth embankments.

Demountables

Unit rates for demountable flood gates were estimated using civil engineering price books (e.g. SPONS, 2016). A total cost for two 3m wide flood gates of 0.9m height that protected both sides of a typical road cross section was estimated as £70,000. The costing of a flood gate over a road included allowance for the following aspects and materials:

- Excavation and disposal
- Concrete top – design mix
- Reinforcement of concrete
- Gate
- Overhead / profit
- Trimming of excavation
- Placing of concrete
- Formwork
- Preliminaries and scaling of works

Property Level Protection – flood resilience

Cost estimates for property level protection have been based on real costs from a 49 property resistance scheme at Wallingford (Fareham) on the south coast of the UK. Additional information from Environment Agency published literature, Defra Pilot studies and quotations for commercially available defences from direct contractor discussion (UK Flood Barriers) has also been used. The worked up estimates of the costs are £4,250 per property. This sum also covers the material and fitting costs estimated per property and any liaison/engagement costs that may be associated with installing the protection. However, the engineer fee for undertaking a pre-installation property survey is not included. It should be acknowledged that additional costs associated with the protection works are likely to have to come from alternative sources, such as the Coastal Flood Levy or homeowners.

Tidal Barrier

Indicative cross sections of the barrier solutions at Pill-Shirehampton and at Ham Green-Nibley Road have been used to inform a high level cost estimate for the Wide and Narrow Barriers respectively. In addition to this, comparisons have been made with cost information from the Boston Barrier and cost estimates provided by Volker Stevin. The indicative cross sections for potential barriers at Pill-Shirehampton and at Ham Green-Nibley Road are shown below.

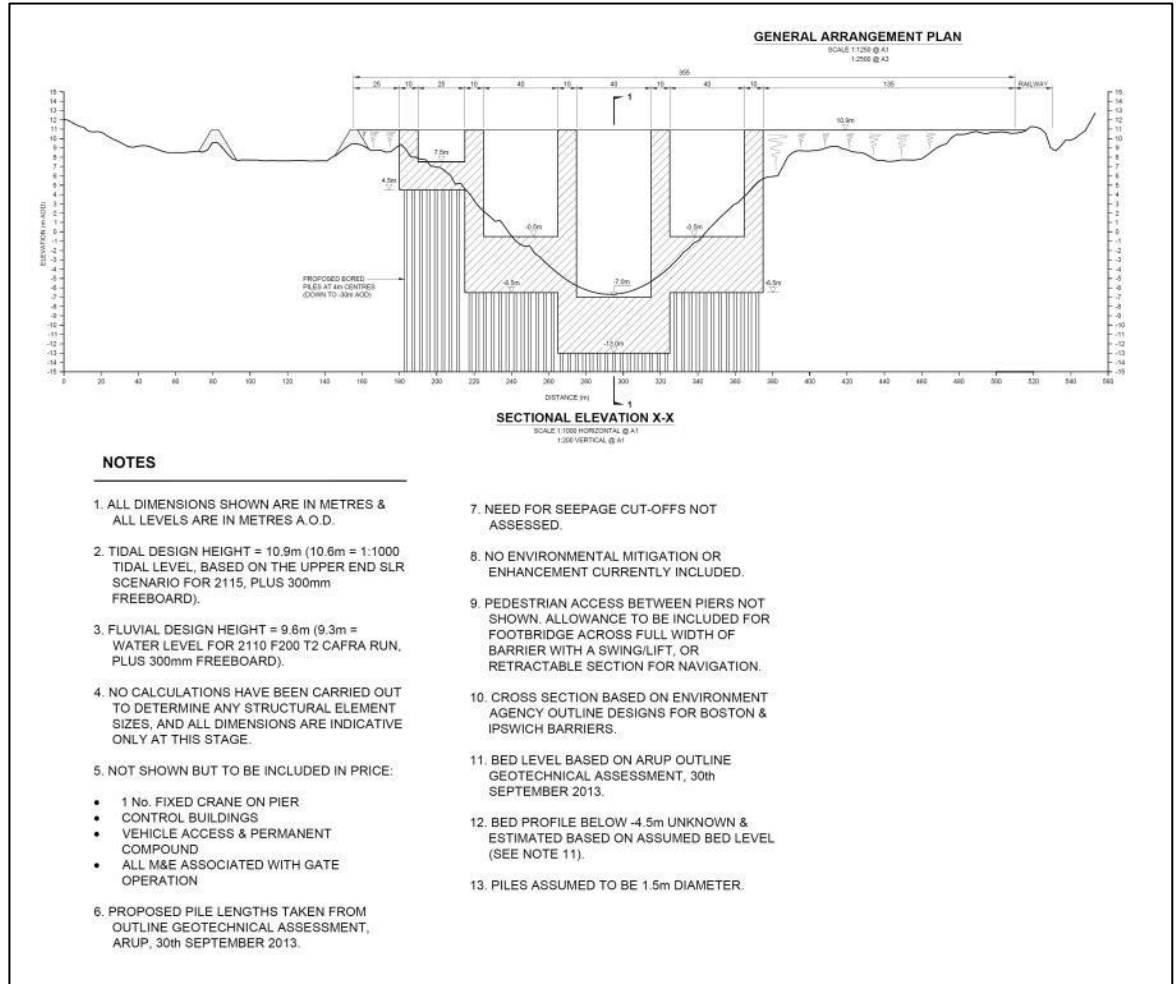


Figure 44 Indicative cross section for a Wide Barrier at Pill-Shirehampton

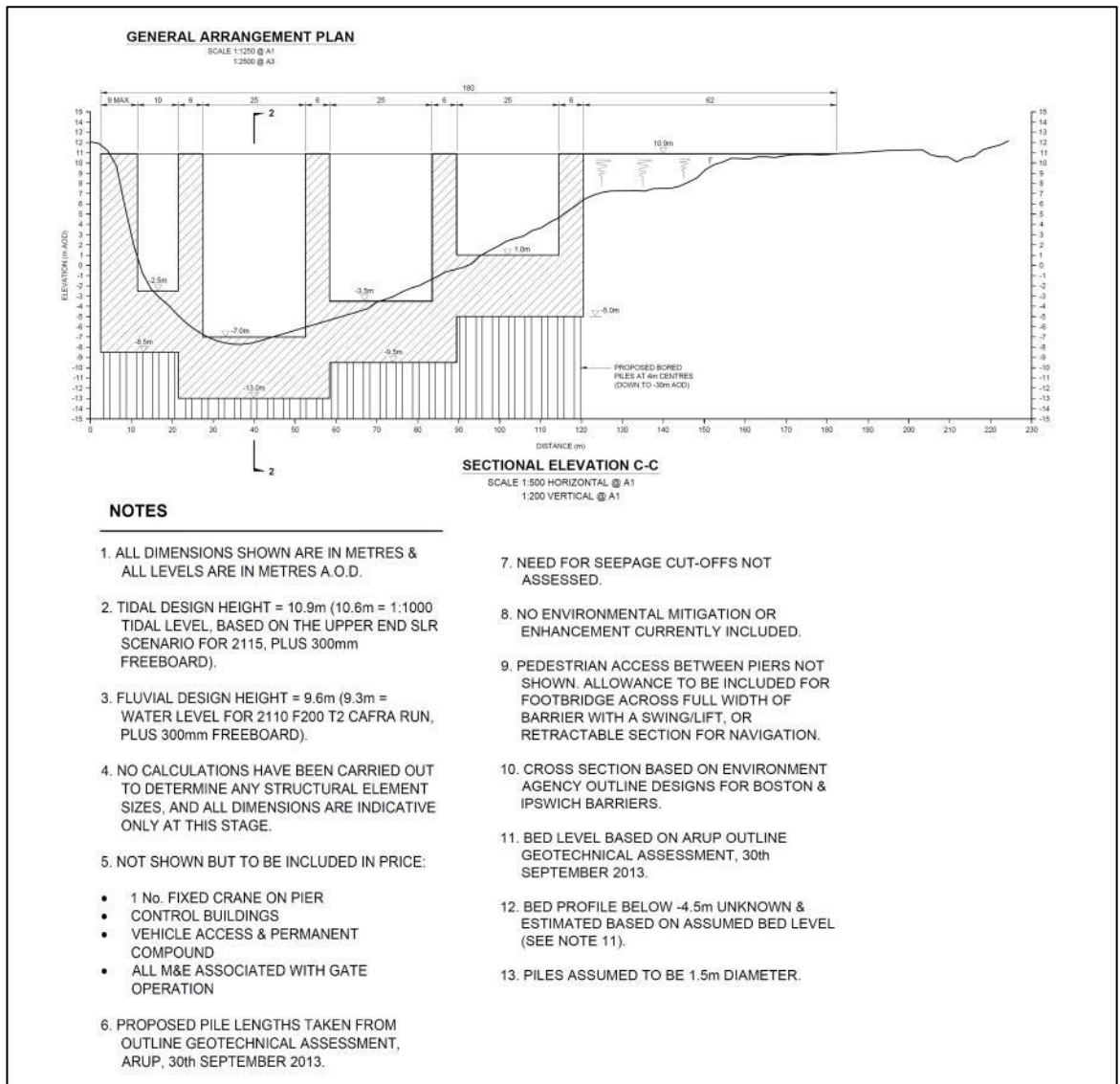


Figure 45 Indicative cross section for a Narrow Barrier at Ham Green-Nibley Road

Present Value Costs and Defence Upgrades

Discounting

Discounting is a technique used to compare costs that occur at different points in time over the appraisal period (i.e. the next 100 years). Standard discount rates have been used to convert all cash costs to 'present values' (PV). This enables the whole life costs of the various strategic options to be compared and also leads to a realistic assessment of the cost implications of the options in today's cost terms. According to FCERM-AG, the following variable discounts rates have been used within the economic appraisal; 3.5% for the years 0 to 30, 2.5% for the years 31 to 75 and 2.5% for the years 76 to 99. This results in a PV factor over the 100 years at 29.9.

At this stage of the assessment, costs have been estimated at a suitably high level and an average discount factor for each time epoch has been applied to each strategic option to produce an estimated whole life cost for each option.

Costs for defence upgrades

The cost estimates for High Defences and Low Defences assume that no new defences are in place from the previous time epochs. For some of the options, upgrading Low Defences or upgrading from Low to High Defences is recommended as the sequence of measures from one time epoch to the next. In these instances the costs for the defence upgrades have been estimated by scaling the cost of the measure by the increased length required in the following time epoch. This avoids the double counting of the large initial construction costs and ensures that only the new length of defence has been costed for the upgrade. This approach has limitations but at this stage of the appraisal where only a high level cost estimate has been made this is considered appropriate. A more detailed cost estimate for upgrading defences will be needed in later stages of appraisal.

APPENDIX 2: SHORT LIST APPRAISAL

Description of the Long List Strategic Options and Multi-criteria Scoring

Strategic Option 1: PLP (epoch 1); PLP (epoch 2); PLP (epoch 3)

This strategic option involves undertaking Property Level Protection (PLP) in each of the three time epochs.

In epoch 1 PLP is required in locations at Totterdown (Victoria Road), Albert Road and Bath Road. In epoch 2, an additional area of PLP will be required in the St. Phillips Marsh area to the east of Victoria Road. In epoch 3, a greater number of properties at Totterdown, St. Phillips Marsh and Albert Road will need protecting and a new area of PLP at Netham will also be required.

In addition to undertaking PLP, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 40 Summary of strategic option 1 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: PLP Epoch 2: PLP Epoch 3: PLP	£785,000	+2	0	0	+2	0	+2	+6

Strategic Option 2: PLP (epoch 1); PLP (epoch 2); High Defences (epoch 3)

This strategic option involves undertaking Property Level Protection (PLP) in epochs 1 and 2 and then constructing High Defences in epoch 3.

In epoch 1 PLP is required in locations at Totterdown (Victoria Road), Albert Road and Bath Road. In epoch 2, an additional area of PLP will be required in the St. Phillips Marsh area to the east of Victoria Road. In epoch 3, High Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Clarence Road, Bathurst Basin and Cumberland Road. Along the River Avon High Defences are required at Hotwells Road, Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock.

In addition to undertaking PLP and constructing High defences, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the High Defences would also be required post construction.

Table 41 Summary of strategic option 2 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: PLP Epoch 2: PLP Epoch 3: High Defences	£6,986,000	+4	+1	-1	+2	0	+3	+9

Strategic Option 3: PLP (epoch 1); PLP (epoch 2); Narrow Barrier (epoch 3)

This strategic option involves undertaking Property Level Protection (PLP) in epochs 1 and 2 and then constructing a narrow tidal barrier in epoch 3.

In epoch 1 PLP is required in locations at Totterdown (Victoria Road), Albert Road and Bath Road. In epoch 2, an additional area of PLP will be required in the St. Phillips Marsh area to the east of Victoria Road. In epoch 3, a narrow tidal barrier would be constructed at one of two locations; Shirehampton (between Ham Green and Nibley Road) or at Cumberland Basin.

In addition to undertaking PLP and constructing the narrow barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the Narrow Barrier would also be required post construction.

Table 42 Summary of strategic option 3 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: PLP Epoch 2: PLP Epoch 3: Narrow Barrier	£45,401,000	+5	+2	-2	0	0	+2	+7

Strategic Option 4: PLP (epoch 1); PLP (epoch 2); Wide Barrier (epoch 3)

This strategic option involves undertaking Property Level Protection (PLP) in epochs 1 and 2 and then constructing a wide tidal barrier in epoch 3.

In epoch 1 PLP is required in locations at Totterdown (Victoria Road), Albert Road and Bath Road. In epoch 2, an additional area of PLP will be required in the St. Phillips Marsh area to the east of Victoria Road. In epoch 3, a wide tidal barrier would be constructed 500m upstream of the M5 road bridge between the downstream extent of Pill to the railway line near Shirehampton.

In addition to undertaking PLP and constructing High defences, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the Wide Barrier would also be required post construction.

Table 43 Summary of strategic option 4 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: PLP Epoch 2: PLP Epoch 3: Wide Barrier	£61,831,000	+5	+2	-2	-1	0	+1	+5

Strategic Option 5: PLP (epoch 1); Low Defences (epoch 2); PLP (epoch 3)

This strategic option involves undertaking Property Level Protection (PLP) in epoch 1, constructing Low Defences in epoch 2 and then more PLP in epoch 3.

In epoch 1 PLP is required in locations at Totterdown (Victoria Road), Albert Road and Bath Road. In epoch 2, Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon High Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 3, PLP is required in additional locations at Totterdown, St. Phillips Marsh, Albert Road and Netham.

In addition to undertaking PLP and constructing Low defences, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the Low Defences would also be required post construction.

Table 44 Summary of strategic option 5 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: PLP Epoch 2: Low Defences Epoch 3: PLP	£19,761,000	+3	+1	-1	+1	0	+2	+6

Strategic Option 6: PLP (epoch 1); Low Defences (epoch 2); High Defences (epoch 3)

This strategic option involves undertaking Property Level Protection (PLP) in epoch 1, constructing Low Defences in epoch 2 and then upgrading these defences to High Defences in epoch 3.

In epoch 1 PLP is required in locations at Totterdown (Victoria Road), Albert Road and Bath Road. In epoch 2, Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 3, the Low Defences and lock gate tie-ins will be upgraded to High Defences by raising / lengthening the existing Low Defences or by constructing new defences in their place. The approach will be determined at the time depending on the condition of the existing defences. In addition, High defences will be required at new locations including Clarence Road (New Cut) and Hotwells Road (River Avon).

In addition to undertaking PLP and constructing Low/High defences, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the Low and High Defences would also be required post construction.

Table 45 Summary of strategic option 6 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: PLP Epoch 2: Low Defences Epoch 3: High Defences	£20,895,000	+5	+2	-2	+1	0	+3	+9

Strategic Option 7: PLP (epoch 1); Low Defences (epoch 2); Narrow Barrier (epoch 3)

This strategic option involves undertaking Property Level Protection (PLP) in epoch 1, constructing Low Defences in epoch 2 and then constructing a Narrow Barrier in epoch 3.

In epoch 1 PLP is required in locations at Totterdown (Victoria Road), Albert Road and Bath Road. In epoch 2, Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 3, a narrow tidal barrier would be constructed at one of two locations; Shirehampton (between Ham Green and Nibley Road) or at Cumberland Basin.

In addition to undertaking PLP and constructing Low Defences and a Narrow Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the Low Defences and the Narrow Barrier would also be required post construction.

Table 46 Summary of strategic option 7 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: PLP Epoch 2: Low Defences Epoch 3: Narrow Barrier	£64,377,000	+6	+3	-3	-1	0	+2	+7

Strategic Option 8: PLP (epoch 1); Low Defences (epoch 2); Wide Barrier (epoch 3)

This strategic option involves undertaking Property Level Protection (PLP) in epoch 1, constructing Low Defences in epoch 2 and then constructing a Wide Barrier in epoch 3.

In epoch 1 PLP is required in locations at Totterdown (Victoria Road), Albert Road and Bath Road. In epoch 2, Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 3, a wide tidal barrier would be constructed 500m upstream of the M5 road bridge between the downstream extent of Pill to the railway line near Shirehampton.

In addition to undertaking PLP and constructing Low Defences and a Wide Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the Low Defences and the Narrow Barrier would also be required post construction.

Table 47 Summary of strategic option 8 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: PLP Epoch 2: Low Defences Epoch 3: Wide Barrier	£80,807,000	+6	+3	-3	-1	0	+1	+6

Strategic Option 9: PLP (epoch 1); High Defences (epoch 2); High Defences (epoch 3)

This strategic option involves undertaking Property Level Protection (PLP) in epoch 1, constructing High Defences in epoch 2 and then maintaining these High Defences in epoch 3.

In epoch 1 PLP is required in locations at Totterdown (Victoria Road), Albert Road and Bath Road. In epoch 2, High Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Clarence Road, Bathurst Basin and Cumberland Road. Along the River Avon High Defences are required at Hotwells Road, Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 3, the High Defences will require maintenance, alongside the maintenance of existing defence assets and water level control infrastructure & operations (scope of maintenance for these assets in line with the Do Minimum measure).

Table 48 Summary of strategic option 9 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: PLP Epoch 2: High Defences Epoch 3: High Defences	£21,818,000	+6	+2	-1	+1	0	+4	+12

Strategic Option 10: PLP (epoch 1); Narrow Barrier (epoch 2); Narrow Barrier (epoch 3)

This strategic option involves undertaking Property Level Protection (PLP) in epoch 1, constructing a Narrow Barrier in epoch 2 and then maintaining the Barrier in epoch 3.

In epoch 1 PLP is required in locations at Totterdown (Victoria Road), Albert Road and Bath Road. In epoch 2, a narrow tidal barrier would be constructed at one of two locations; Shirehampton (between Ham Green and Nibley Road) or at Cumberland Basin. In epoch 3 this barrier would require maintenance to sustain its flood risk protection function.

In addition to maintenance of the Narrow Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 49 Summary of strategic option 10 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: PLP Epoch 2: Narrow Barrier Epoch 3: Narrow Barrier	£166,233,000	+7	+4	-2	-2	0	+3	+10

Strategic Option 11: PLP (epoch 1); Wide Barrier (epoch 2); Wide Barrier (epoch 3)

This strategic option involves undertaking Property Level Protection (PLP) in epoch 1, constructing a Wide Barrier in epoch 2 and then maintaining the Barrier in epoch 3.

In epoch 1 PLP is required in locations at Totterdown (Victoria Road), Albert Road and Bath Road. In epoch 2, a wide tidal barrier would be constructed 500m upstream of the M5 road bridge between the downstream extent of Pill to the railway line near Shirehampton. In epoch 3 this barrier would require maintenance to sustain its flood risk protection function.

In addition to maintenance of the Wide Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 50 Summary of strategic option 11 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: PLP Epoch 2: Wide Barrier Epoch 3: Wide Barrier	£227,072,000	+7	+4	-2	-2	0	+2	+9

Strategic Option 12: Low Defences (epoch 1); PLP (epoch 2); PLP (epoch 3)

This strategic option involves constructing Low Defences in epoch 1, then undertaking Property Level Protection (PLP) in epochs 2 and 3.

In epoch 1 Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 2 PLP is required in locations at Totterdown (Victoria Road), Albert Road, Bath Road and in the St. Phillips Marsh area to the east of Victoria Road. In epoch 3 a greater number of properties at Totterdown, St. Phillips Marsh and Bath Albert Road will need protecting and a new area of PLP at Netham will also be required.

In addition to constructing Low Defences and undertaking PLP, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 51 Summary of strategic option 12 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Low Defences Epoch 2: PLP Epoch 3: PLP	£41,896,000	+3	+1	-1	+1	0	+1	+5

Strategic Option 13: Low Defences (epoch 1); PLP (epoch 2); High Defences (epoch 3)

This strategic option involves constructing Low Defences in epoch 1, undertaking Property Level Protection (PLP) in epoch 2 and then constructing High Defences in epoch 3.

In epoch 1 Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 2 PLP is required in locations at Totterdown (Victoria Road), Albert Road, Bath Road and in the St. Phillips Marsh area to the east of Victoria Road. In epoch 3 the Low Defences and lock gate tie-ins (constructed in epoch 1) will be upgraded to High Defences by raising / lengthening the existing Low Defences or by constructing new defences in their place. The approach will be determined at the time depending on the condition of the existing defences. In addition, High defences will be required at new locations including Clarence Road (New Cut) and Hotwells Road (River Avon).

In addition to the maintenance of the Low Defences (epochs 1&2) and High Defences (epoch 3), for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 52 Summary of strategic option 13 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Low Defences Epoch 2: PLP Epoch 3: High Defences	£48,097,000	+5	+2	-2	0	0	+2	+7

Strategic Option 14: Low Defences (epoch 1); PLP (epoch 2); Narrow Barrier (epoch 3)

This strategic option involves constructing Low Defences in epoch 1, undertaking Property Level Protection (PLP) in epoch 2 and then constructing a Narrow Barrier in epoch 3.

In epoch 1 Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 2 PLP is required in locations at Totterdown (Victoria Road), Albert Road, Bath Road and in the St. Phillips Marsh area to the east of Victoria Road. In epoch 3 a narrow tidal barrier would be constructed at one of two locations; Shirehampton (between Ham Green and Nibley Road) or at Cumberland Basin.

In addition to the maintenance of the Low Defences and Narrow Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 53 Summary of strategic option 14 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Low Defences Epoch 2: PLP Epoch 3: Narrow Barrier	£86,512,000	+6	+3	-3	-1	0	+1	+6

Strategic Option 15: Low Defences (epoch 1); PLP (epoch 2); Wide Barrier (epoch 3)

This strategic option involves constructing Low Defences in epoch 1, undertaking Property Level Protection (PLP) in epoch 2 and then constructing a Wide Barrier in epoch 3.

In epoch 1 Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 2 PLP is required in locations at Totterdown (Victoria Road), Albert Road, Bath Road and in the St. Phillips Marsh area to the east of Victoria Road. In epoch 3 a Wide tidal barrier would be constructed 500m upstream of the M5 road bridge between the downstream extent of Pill to the railway line near Shirehampton.

In addition to the maintenance of the Low Defences and Wide Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 54 Summary of strategic option 15 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Low Defences Epoch 2: PLP Epoch 3: Wide Barrier	£102,942,000	+6	+3	-3	-2	0	0	+4

Strategic Option 16: Low Defences (epoch 1); Low Defences (epoch 2); PLP (epoch 3)

This strategic option involves constructing Low Defences in epochs 1 & 2, then undertaking Property Level Protection (PLP) in epoch 3.

In epoch 1 Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 2 the Low Defences and lock gate tie-ins will be raised / lengthened to the 1:200 year standard of protection for 2030 or new Low Defences will be constructed in their place. In epoch 3, PLP will be required at Totterdown, St. Phillips Marsh, Bath Road, Albert Road and Netham.

In addition to constructing Low Defences and undertaking PLP, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 55 Summary of strategic option 16 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Low Defences Epoch 2: Low Defences Epoch 3: PLP	£42,072,000	+4	+2	-1	+1	0	+2	+8

Strategic Option 17: Low Defences (epoch 1); Low Defences (epoch 2); High Defences (epoch 3)

This strategic option involves constructing Low Defences in epochs 1 & 2, then upgrading to High Defences in epoch 3.

In epoch 1 Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 2 the Low Defences and lock gate tie-ins will be raised / lengthened to the 1:200 year standard of protection for 2030 or new Low Defences will be constructed in their place. In epoch 3, the Low Defences and lock gate tie-ins will be upgraded to High Defences by raising / lengthening the existing Low Defences or by constructing new defences in their place. The approach will be determined at the time depending on the condition of the existing defences. In addition, High defences will be required at new locations including Clarence Road (New Cut) and Hotwells Road (River Avon).

In addition to the maintenance of the Low and High Defences, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 56 Summary of strategic option 17 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Low Defences Epoch 2: Low Defences Epoch 3: High Defences	£43,207,000	+6	+3	-2	0	0	+3	+10

Strategic Option 18: Low Defences (epoch 1); Low Defences (epoch 2); Narrow Barrier (epoch 3)

This strategic option involves constructing Low Defences in epochs 1 & 2, then constructing a Narrow Barrier in epoch 3.

In epoch 1 Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 2 the Low Defences and lock gate tie-ins will be raised / lengthened to the 1:200 year standard of protection for 2030 or new Low Defences will be constructed in their place. In epoch 3 a narrow tidal barrier would be constructed at one of two locations; Shirehampton (between Ham Green and Nibley Road) or at Cumberland Basin.

In addition to the maintenance of the Low Defences and Narrow Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 57 Summary of strategic option 18 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Low Defences Epoch 2: Low Defences Epoch 3: Narrow Barrier	£86,689,000	+7	+4	-3	-1	0	+2	+9

Strategic Option 19: Low Defences (epoch 1); Low Defences (epoch 2); Wide Barrier (epoch 3)

This strategic option involves constructing Low Defences in epochs 1 & 2, then constructing a Wide Barrier in epoch 3.

In epoch 1 Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 2 the Low Defences and lock gate tie-ins will be raised / lengthened to the 1:200 year standard of protection for 2030 or new Low Defences will be constructed in their place. In epoch 3 a Wide tidal barrier would be constructed 500m upstream of the M5 road bridge between the downstream extent of Pill to the railway line near Shirehampton.

In addition to the maintenance of the Low Defences and Wide Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 58 Summary of strategic option 19 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Low Defences Epoch 2: Low Defences Epoch 3: Wide Barrier	£103,119,000	+7	+4	-3	-2	0	+1	+7

Strategic Option 20: Low Defences (epoch 1); High Defences (epoch 2); High Defences (epoch 3)

This strategic option involves constructing Low Defences in epoch 1, then upgrading to High Defences in epoch 2. Maintenance of the High Defences will be required in epoch 3.

In epoch 1 Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 2 the Low Defences and lock gate tie-ins will be upgraded to High Defences by raising / lengthening the existing Low Defences or by constructing new defences in their place. The approach will be determined at the time depending on the condition of the existing defences. In addition, High defences will be required at new locations including Clarence Road (New Cut) and Hotwells Road (River Avon).

Throughout the Strategy duration the Low and High Defences will require maintenance to sustain their flood defence function. In addition to this, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 59 Summary of strategic option 20 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Low Defences Epoch 2: High Defences Epoch 3: High Defences	£46,182,000	+7	+3	-2	0	0	+1	+9

Strategic Option 21: Low Defences (epoch 1); Narrow Barrier (epoch 2); Narrow Barrier (epoch 3)

This strategic option involves constructing Low Defences in epoch 1, then constructing a Narrow Barrier in epoch 2. Maintenance of the barrier will be required in epoch 3.

In epoch 1 Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 2 a narrow tidal barrier would be constructed at one of two locations; Shirehampton (between Ham Green and Nibley Road) or at Cumberland Basin. The barrier would need to be maintained throughout epoch 3.

The Low Defences and Barrier will require maintenance to sustain their flood defence function. In addition to this, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 60 Summary of strategic option 21 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Low Defences Epoch 2: Narrow Barrier Epoch 3: Narrow Barrier	£237,766,000	+8	+5	-3	-2	0	+2	+10

Strategic Option 22: Low Defences (epoch 1); Wide Barrier (epoch 2); Wide Barrier (epoch 3)

This strategic option involves constructing Low Defences in epoch 1, then constructing a Wide Barrier in epoch 2. Maintenance of the barrier will be required in epoch 3.

In epoch 1 Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon Low Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 2 a Wide tidal barrier would be constructed 500m upstream of the M5 road bridge between the downstream extent of Pill to the railway line near Shirehampton. The barrier would need to be maintained throughout epoch 3.

The Low Defences and Barrier will require maintenance to sustain their flood defence function. In addition to this, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 61 Summary of strategic option 22 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Low Defences Epoch 2: Wide Barrier Epoch 3: Wide Barrier	£309,841,000	+8	+5	-3	-2	0	+1	+9

Strategic Option 23: High Defences (epoch 1); High Defences (epoch 2); High Defences (epoch 3)

This strategic option involves constructing High Defences in epoch 1, then maintaining the High Defences in epochs 2 and 3.

In epoch 1 High Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Clarence Road, Bathurst Basin and Cumberland Road. Along the River Avon High Defences are required at Hotwells Road, Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epochs 2 and 3, the High Defences will require maintenance, alongside the maintenance of existing defence assets and water level control infrastructure & operations (scope of maintenance for these assets in line with the Do Minimum measure).

Table 62 Summary of strategic option 23 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: High Defences Epoch 2: High Defences Epoch 3: High Defences	£47,373,000	+8	+3	-1	0	0	+4	+14

Strategic Option 24: Do Minimum (epoch 1); PLP (epoch 2); PLP (epoch 3)

This strategic option involves Doing Minimum in epoch 1, then undertaking Property Level Protection (PLP) in epochs 2 and 3.

In epoch 1 Do Minimum involves maintaining the existing defence assets and water level control infrastructure and operations. In epoch 2 PLP is required in locations at Totterdown (Victoria Road), Albert Road, Bath Road and in the St. Phillips Marsh area to the east of Victoria Road. In epoch 3, a greater number of properties at Totterdown, St. Phillips Marsh and Albert Road will need protecting and a new area of PLP at Netham will also be required.

For epochs 2 and 3, In addition to undertaking PLP the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 63 Summary of strategic option 24 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: PLP Epoch 3: PLP	£360,000	+2	0	0	+2	0	+2	+6

Strategic Option 25: Do Minimum (epoch 1); PLP (epoch 2); High Defences (epoch 3)

This strategic option involves Doing Minimum in epoch 1, then undertaking Property Level Protection (PLP) in epoch 2 and constructing High Defences in epoch 3.

In epoch 1 Do Minimum involves maintaining the existing defence assets and water level control infrastructure and operations. In epoch 2 PLP is required in locations at Totterdown (Victoria Road), Albert Road, Bath Road and in the St. Phillips Marsh area to the east of Victoria Road. In epoch 3, High Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Clarence Road, Bathurst Basin and Cumberland Road. Along the River Avon High Defences are required at Hotwells Road, Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock.

In addition to undertaking PLP and constructing High defences, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the High Defences would also be required post construction.

Table 64 Summary of strategic option 25 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: PLP Epoch 3: High Defences	£6,561,000	+4	+1	-1	+2	0	+3	+9

Strategic Option 26: Do Minimum (epoch 1); PLP (epoch 2); Narrow Barrier (epoch 3)

This strategic option involves Doing Minimum in epoch 1, then undertaking Property Level Protection (PLP) in epoch 2 and constructing High Defences in epoch 3.

In epoch 1 Do Minimum involves maintaining the existing defence assets and water level control infrastructure and operations. In epoch 2 PLP is required in locations at Totterdown (Victoria Road), Albert Road, Bath Road and in the St. Phillips Marsh area to the east of Victoria Road. In epoch 3, a narrow tidal barrier would be constructed at one of two locations; Shirehampton (between Ham Green and Nibley Road) or at Cumberland Basin.

In addition to undertaking PLP and constructing the Narrow Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the Narrow Barrier would also be required post construction.

Table 65 Summary of strategic option 26 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: PLP Epoch 3: Narrow Barrier	£44,976,000	+5	+2	-2	0	0	+2	+7

Strategic Option 27: Do Minimum (epoch 1); PLP (epoch 2); Wide Barrier (epoch 3)

This strategic option involves Doing Minimum in epoch 1, then undertaking Property Level Protection (PLP) in epoch 2 and constructing High Defences in epoch 3.

In epoch 1 Do Minimum involves maintaining the existing defence assets and water level control infrastructure and operations. In epoch 2 PLP is required in locations at Totterdown (Victoria Road), Albert Road, Bath Road and in the St. Phillips Marsh area to the east of Victoria Road. In epoch 3, a wide tidal barrier would be constructed 500m upstream of the M5 road bridge between the downstream extent of Pill to the railway line near Shirehampton.

In addition to undertaking PLP and constructing the Wide Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the Wide Barrier would also be required post construction.

Table 66 Summary of strategic option 27 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: PLP Epoch 3: Wide Barrier	£61,406,000	+5	+2	-2	-1	0	+1	+5

Strategic Option 28: Do Minimum (epoch 1); Low Defences (epoch 2); PLP (epoch 3)

This strategic option involves Doing Minimum in epoch 1, constructing Low Defences in epoch 2 and then undertaking PLP in epoch 3.

In epoch 1 Do Minimum involves maintaining the existing defences assets and water level control infrastructure and operations. In epoch 2, Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon High Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 3, PLP is required in locations at Totterdown, St. Phillips Marsh, Albert Road and Netham.

In addition to constructing Low defences and undertaking PLP, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the Low Defences would also be required post construction.

Table 67 Summary of strategic option 28 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: Low Defences Epoch 3: PLP	£19,335,000	+3	+1	-1	+1	0	+2	+6

Strategic Option 29: Do Minimum (epoch 1); Low Defences (epoch 2); High Defences (epoch 3)

This strategic option involves Doing Minimum in epoch 1, constructing Low Defences in epoch 2 and then upgrading to High Defences in epoch 3.

In epoch 1 Do Minimum involves maintaining the existing defences assets and water level control infrastructure and operations. In epoch 2, Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon High Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 3, the Low Defences and lock gate tie-ins will be upgraded to High Defences by raising / lengthening the existing Low Defences or by constructing new defences in their place. The approach will be determined at the time depending on the condition of the existing defences. In addition, High defences will be required at new locations including Clarence Road (New Cut) and Hotwells Road (River Avon).

In addition to the Low and High defences, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the Low and High Defences would also be required post construction.

Table 68 Summary of strategic option 29 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: Low Defences Epoch 3: High Defences	£20,470,000	+5	+2	-2	+1	0	+3	+7

Strategic Option 30: Do Minimum (epoch 1); Low Defences (epoch 2); Narrow Barrier (epoch 3)

This strategic option involves Doing Minimum in epoch 1, constructing Low Defences in epoch 2 and then constructing a Narrow Barrier in epoch 3.

In epoch 1 Do Minimum involves maintaining the existing defences assets and water level control infrastructure and operations. In epoch 2, Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon High Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 3, a narrow tidal barrier would be constructed at one of two locations; Shirehampton (between Ham Green and Nibley Road) or at Cumberland Basin.

In addition to constructing Low Defences and a Narrow Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the Low Defences and Barrier would also be required post construction.

Table 69 Summary of strategic option 30 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: Low Defences Epoch 3: Narrow Barrier	£63,952,000	+6	+3	-3	-1	0	+2	+7

Strategic Option 31: Do Minimum (epoch 1); Low Defences (epoch 2); Wide Barrier (epoch 3)

This strategic option involves Doing Minimum in epoch 1, constructing Low Defences in epoch 2 and then constructing a Wide Barrier in epoch 3.

In epoch 1 Do Minimum involves maintaining the existing defences assets and water level control infrastructure and operations. In epoch 2, Low Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Bathurst Basin and Cumberland Road. Along the River Avon High Defences are required at Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 3, a wide tidal barrier would be constructed 500m upstream of the M5 road bridge between the downstream extent of Pill to the railway line near Shirehampton.

In addition to constructing Low Defences and a Wide Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure). Maintenance of the Low Defences and Barrier would also be required post construction.

Table 70 Summary of strategic option 31 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: Low Defences Epoch 3: Wide Barrier	£80,382,000	+6	+3	-3	-1	0	+1	+6

Strategic Option 32: Do Minimum (epoch 1); High Defences (epoch 2); High Defences (epoch 3)

This strategic option involves Doing Minimum in epoch 1, constructing High Defences in epoch 2 and then maintaining these High Defences in epoch 3.

In epoch 1 Do Minimum involves maintaining the existing defences assets and water level control infrastructure and operations. In epoch 2, High Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Clarence Road, Bathurst Basin and Cumberland Road. Along the River Avon High Defences are required at Hotwells Road, Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock. In epoch 3, the High Defences will require maintenance, alongside the maintenance of existing defence assets and water level control infrastructure & operations (scope of maintenance for these assets in line with the Do Minimum measure).

Table 71 Summary of strategic option 32 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: High Defences Epoch 3: High Defences	£21,392,000	+6	+2	-1	+1	0	+4	+12

Strategic Option 33: Do Minimum (epoch 1); Narrow Barrier (epoch 2); Narrow Barrier (epoch 3)

This strategic option involves Doing Minimum in epoch 1, constructing a Narrow Barrier in epoch 2 and then maintaining the Barrier in epoch 3.

In epoch 1 Do Minimum involves maintaining the existing defences assets and water level control infrastructure and operations. In epoch 2, a narrow tidal barrier would be constructed at one of two locations; Shirehampton (between Ham Green and Nibley Road) or at Cumberland Basin. In epoch 3 this barrier would require maintenance to sustain its flood risk protection function.

In addition to maintenance of the Narrow Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 72 Summary of strategic option 33 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: Narrow Barrier Epoch 3: Narrow Barrier	£165,808,000	+7	+4	-2	-2	0	+3	+10

Strategic Option 34: Do Minimum (epoch 1); Wide Barrier (epoch 2); Wide Barrier (epoch 3)

This strategic option involves Doing Minimum in epoch 1, constructing a Wide Barrier in epoch 2 and then maintaining the Barrier in epoch 3.

In epoch 1 Do Minimum involves maintaining the existing defences assets and water level control infrastructure and operations. In epoch 2, a wide tidal barrier would be constructed 500m upstream of the M5 road bridge between the downstream extent of Pill to the railway line near Shirehampton. In epoch 3 this barrier would require maintenance to sustain its flood risk protection function.

In addition to maintenance of the Wide Barrier, for each time epoch the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 73 Summary of strategic option 34 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: Wide Barrier Epoch 3: Wide Barrier	£226,647,000	+7	+4	-2	-2	0	+2	+9

Strategic Option 35: Do Minimum (epoch 1); Do Minimum (epoch 2); PLP (epoch 3)

This strategic option involves Doing Minimum in epochs 1 and 2, then undertaking Property Level Protection (PLP) in epoch 3.

In epochs 1 and 2 Do Minimum involves maintaining the existing defence assets and water level control infrastructure and operations. In epoch 3 PLP is required in locations at Totterdown (Victoria Road), Albert Road, Bath Road, Netham and in the St. Phillips Marsh area to the east of Victoria Road.

In epoch 3, in addition to undertaking PLP the maintenance of existing defence assets and water level control infrastructure & operations will be required (scope of maintenance in line with the Do Minimum measure).

Table 74 Summary of strategic option 35 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: Do Minimum Epoch 3: PLP	£116,000	+2	0	0	+2	0	+3	+7

Strategic Option 36: Do Minimum (epoch 1); Do Minimum (epoch 2); High Defences (epoch 3)

This strategic option involves Doing Minimum in epochs 1 and 2, then constructing High Defences in epoch 3.

In epochs 1 and 2 Do Minimum involves maintaining the existing defence assets and water level control infrastructure and operations. In epoch 3 High Defences are required along the New Cut at Netham, Bath Road, Totterdown, Temple Meads, Clarence Road, Bathurst Basin and Cumberland Road. Along the River Avon High Defences are required at Hotwells Road, Pill and Shirehampton. In addition, lock gate raising / upgrades and new defence tie-ins are required at either Entrance Lock or Junction Lock, and at Netham Lock.

In epoch 3, in addition to constructing and maintaining the new High Defences, the maintenance of existing defence assets and water level control infrastructure & operations will also be required (scope of maintenance in line with the Do Minimum measure).

Table 75 Summary of strategic option 36 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: Do Minimum Epoch 3: High Defences	£6,316,000	+4	+1	-1	+2	0	+4	+10

Strategic Option 37: Do Minimum (epoch 1); Do Minimum (epoch 2); Narrow Barrier (epoch 3)

This strategic option involves Doing Minimum in epochs 1 and 2, then constructing a Narrow Barrier in epoch 3.

In epochs 1 and 2 Do Minimum involves maintaining the existing defence assets and water level control infrastructure and operations. In epoch 3 a narrow tidal barrier would be constructed at one of two locations; Shirehampton (between Ham Green and Nibley Road) or at Cumberland Basin.

In epoch 3, in addition to constructing and maintaining a Narrow Barrier, the maintenance of existing defence assets and water level control infrastructure & operations will also be required (scope of maintenance in line with the Do Minimum measure).

Table 76 Summary of strategic option 37 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: Do Minimum Epoch 3: Narrow Barrier	£44,732,000	+5	+2	-2	0	0	+3	+8

Strategic Option 38: Do Minimum (epoch 1); Do Minimum (epoch 2); Wide Barrier (epoch 3)

This strategic option involves Doing Minimum in epochs 1 and 2, then constructing a Wide Barrier in epoch 3.

In epochs 1 and 2 Do Minimum involves maintaining the existing defence assets and water level control infrastructure and operations. In epoch 3 a wide tidal barrier would be constructed 500m upstream of the M5 road bridge between the downstream extent of Pill to the railway line near Shirehampton.

In epoch 3, in addition to constructing and maintaining a Wide Barrier, the maintenance of existing defence assets and water level control infrastructure & operations will also be required (scope of maintenance in line with the Do Minimum measure).

Table 77 Summary of strategic option 38 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: Do Minimum Epoch 3: Wide Barrier	£61,162,000	+5	+2	-2	0	0	+2	+7

Strategic Option 39: Do Minimum (epoch 1); Do Minimum (epoch 2); Do Minimum (epoch 3)

This strategic option involves Doing Minimum in epochs 1, 2 and 3.

Do Minimum involves maintaining the existing defence assets and water level control infrastructure and operations.

Table 78 Summary of strategic option 39 scoring in multi-criteria appraisal

Sequence of measures	Estimated PV Cost (including 60% optimism bias)	Scores						
		Flood risk H&S	Sustainability	Environment	Whole life cost & funding	Navigation	Deliverability	Total
Epoch 1: Do Minimum Epoch 2: Do Minimum Epoch 3: Do Minimum	£0	+2	0	0	+2	0	+5	+9

8.1.1 Multi-criteria scoring Assessment

Epoch 1		Epoch 2		Epoch 3		Option objectives						SUM								
2015-2030		2030-2065		2065-2115		1 - Flood Risk H&S		2 - Sustainability / development		3 - Environment		4 - Whole Life Cost		5 - Navigation + Marine Activities		6 - Deliverability		SUM	No. +	No. -
Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary					
Property protection and temporary defences	Property protection and temporary defences	Property protection and temporary defences	Property protection and temporary defences	Property protection and temporary defences	Property protection and temporary defences	1	Assumed that PLP / demountables are provided to all properties in areas which are presently at the greatest risk of flooding. However, on a CTRWIDE scale, improvements to flood risk in only select locations is likely to only provide a very minor improvement	0	(PLP / demountables would not typically provide any flood protection to development sites, and as flood risk increases over this period, the SoP provided to these sites likely to decrease in line with the DN scenario)	0	Measure scored as -1 (range 1 to -10) in environmental assessment.	0	Scored as a total whole life cost in epoch 3	0	In epoch 1 PLP / temporary flood barriers unlikely to have any impact at all on navigation and marine activities	2	Implemented on a property by property basis. Assumed that property owners would be in support of scheme and it should therefore be easily deliverable within the allotted timeframe. If properties are not at very significant risk of flooding and eligible for GIA funding then funding may need to be privately sourced.	3	3	0
Low defences	Property protection and temporary defences	Property protection and temporary defences	Property protection and temporary defences	Property protection and temporary defences	Property protection and temporary defences	2	Assumed that the low defences would be constructed to a present day 1:200 year SoP creating a moderate improvement to the standard of flood protection	1	Low Defences expected to protect some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored as -4 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	In epoch 1 low defences are unlikely to have any impact on navigation and marine activities	1	A technically feasible option that is likely to be delivered within allotted timeframe. Potentially a risk associated with achieving consents due to possible landscape, access and visual impacts, but expected that this could be mitigated and therefore the risk level is considered low.	3	4	-1
High defences	High defences (maintenance)	High defences (maintenance)	High defences (maintenance)	High defences (maintenance)	High defences (maintenance)	3	Defences constructed to given standard for 2115 (i.e. 1:200) so precautionary for epoch 1 (i.e. 1:1000), creating a significant improvement to the standard of flood protection throughout compared to the Do Nothing scenario	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored as -5 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	In epoch 1, high defences unlikely to have any impact on navigation and marine activities	0	Similar level of technical challenge to low defences. Associated impacts may need to be mitigated (i.e. visual / landscape / access). Achieving the necessary consents may extend timescales of the options.	3	4	-1
Do minimum	Property protection and temporary defences	Property protection and temporary defences	Property protection and temporary defences	Property protection and temporary defences	Property protection and temporary defences	1	Continued operation of the floating harbour water control systems during epoch 1 likely to reduce flood risk compared to the DN scenario	0	Do Minimum unlikely to provide any additional flood protection to development sites, and as flood risk increases over this period, the SoP provided to these sites likely to decrease in line with the DN scenario	0	Measure scored as -1 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	In epoch 1 Do Minimum unlikely to have any impact at all on navigation and marine activities	2	Technically a very feasible option. Water control measures already in place within floating harbour and continued operation and maintenance unlikely to lead to any delays in implementing this option.	3	3	0

Epoch 1 2015-2030		Epoch 2 2030-2065		Epoch 3 2065-2115		Option objectives						SUM								
						1 - Flood Risk H&S		2 - Sustainability / Development		3 - Environment		4 - Whole Life Cost		5 - Navigation + Marine Activities		6 - Deliverability		SUM	No. +	No. -
Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary			
Property protection and temporary defences	Property protection and temporary defences	High defences	Narrow barrier	Wide barrier	1	Assume that higher temporary barriers are provided compared to epoch 1 to keep pace with sea level rise and that more properties are provided PLP. However, on a CITYWIDE scale the improvement in flood risk from PLP+Demountables is likely to be minor	0	Not envisaged that PLP / demountables would be provided to development areas and therefore, with rising sea levels, the flood risk at these sites is likely to increase during epoch 2	0	Option is not likely to enhance the environment or to cause any disruption compared to the DN scenario. Option scored as -1 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	In epoch 2, PLP / temporary barriers unlikely to have any impact on marine activities and navigation	1	In epoch 2 PLP will be more technically challenging as flood waters become deeper	2	2	0	
	Low defences	Upgrade to High defences	Narrow barrier	Wide barrier	2	Assumed that low defences constructed to a 2030 1:200 year SoP therefore this option is likely to provide a moderate increase in the SoP	1	Low Defences expected to protect some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored as -4 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	In epoch 2, low walls unlikely to have any impact on navigation and marine activities	1	A technically feasible option that is likely to be delivered within allotted timeframe. Potentially a risk associated with achieving consents due to possible landscape, access and visual impacts, but expected that this could be mitigated and therefore the risk level is considered low.	3	4	-1	
	High defences	High defences (maintenance)	High defences (maintenance)	High defences (maintenance)	3	Option constructed to a given SoP in 2115 i.e. 1:200 and would therefore be precautionary in 2030, i.e. a 1:500 year SoP. Likely to produce a significant increase in SoP compared to the Do Nothing scenario	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored as -5 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	High defences unlikely to have any impact on navigation and marine activities	0	Similar level of technical challenge to low defences. Associated impacts may need to be mitigated (i.e. visual / landscape / access). Achieving the necessary consents may extend timescales of the options.	3	4	-1	
	Narrow barrier	Narrow barrier (maintenance)	Narrow barrier (maintenance)	Narrow barrier (maintenance)	3	Option would be constructed to a given SoP in 2115 and therefore precautionary during epoch 2. Compared to DN, significantly increasing SoP	2	Option likely to protect entire at risk area within city centre so the SoP to development sites within this area likely to increase, potentially increasing opportunities for development	-2	Measure scored -8 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-1	Option likely to be technically challenging and to hold risks associated with achieving funding and consents. Construction also poses significant risks of delay and it is possible that the option may not be implemented within the allotted timeframe. However, compared to the Wide Barrier, the narrow barrier is to be located further from environmental designations and there is potentially a reduced scope for consenting / planning issues to arise because of this.	2	5	-3	
	Wide barrier	Wide barrier (maintenance)	Wide barrier (maintenance)	Wide barrier (maintenance)	3	Option would be constructed to a given SoP in 2115 and therefore precautionary during epoch 2. Compared to DN, likely to be significant increase in the SoP	2	Option likely to protect entire at risk area within city centre so the SoP to development sites within this area likely to increase, potentially increasing opportunities for development	-2	Measure scored -10 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-2	Option likely to be technically challenging and hold risks associated with achieving funding and consents. Construction also poses significant risks of delay and it is possible that the option may not be implemented within the allotted timeframe.	1	5	-4	
Low defences	Property protection and temporary defences	High defences	Narrow barrier	Wide barrier	1	Assume that SoP of low walls would reduce to approx. 1:50 by end of epoch 2. Addition of PLP+Demountables in certain areas is likely to create a minor improvement in flood risk on a CITYWIDE scale	0	Assumed that PLP / demountables would not be provided to development sites, therefore the flood risk to these areas likely to increase as sea levels rise during epoch 2 in line with DN scenario	0	Measure scored as -1 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	In epoch 2, PLP / temporary barriers unlikely to have any impact on marine activities and navigation	1	In epoch 2 PLP will be more technically challenging as flood waters become deeper	2	2	0	
	Low defences (maintenance and raising of defences constructed initially in epoch 1)	Upgrade to High defences	Narrow barrier	Wide barrier	2	Assumed that low defences constructed in epoch 1 would be raised to a 2:200 SoP for 2030. Additional defences in previously undefended areas also likely to boost overall SoP to the city.	1	Low Defences expected to protect some areas of potential development, potentially increasing opportunities for growth and sustainable development	0	Measure scored 1 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	In epoch 2, low walls unlikely to have a significant effect on navigation and marine activities	2	Maintenance / raising is technically feasible and is unlikely to present any significant technical challenges / risks associated with achieving the necessary consents / funding etc.	5	5	0	
	Upgrade to High defences	High defences (maintenance)	High defences (maintenance)	High defences (maintenance)	3	High defences would be constructed to a given standard for 2115, i.e. 1:200 and would therefore still be over-precautionary in epoch 2 (i.e. 1:500), providing a very high SoP against flooding	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored -5 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	High defences unlikely to have any impact on navigation and marine activities	0	Similar level of technical challenge to low defences. Associated impacts may need to be mitigated (i.e. visual / landscape / access). Achieving the necessary consents may extend timescales of the options.	3	4	-1	
	Narrow barrier	Narrow barrier (maintenance)	Narrow barrier (maintenance)	Narrow barrier (maintenance)	3	Option would be constructed to a given SoP in 2115 and therefore precautionary during epoch 2. Compared to DN likely to provide a significant increase in the SoP	2	Option likely to protect entire at risk area within city centre so the SoP to development sites within this area likely to increase, potentially increasing opportunities for development	-2	Measure scored -8 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-1	Option likely to be technically challenging and to hold risks associated with achieving funding and consents. Construction also poses significant risks of delay and it is possible that the option may not be implemented within the allotted timeframe. However, compared to the Wide Barrier, the narrow barrier is to be located further from environmental designations and there is potentially a reduced scope for consenting / planning issues to arise because of this.	2	5	-3	
	Wide barrier	Wide barrier (maintenance)	Wide barrier (maintenance)	Wide barrier (maintenance)	3	Option would be constructed to a given SoP in 2115 (i.e. 1:200) so precautionary for epoch 1 (i.e. 1:1000), creating a significant improvement to the standard of flood protection throughout compared to the Do Nothing scenario	2	Option likely to protect entire at risk area within city centre so the SoP to development sites within this area likely to increase, potentially increasing opportunities for development	-2	Measure scored -10 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-2	Option likely to be very technically challenging and hold significant risks associated with achieving funding and consents. Construction also poses significant risks of delay and it is possible that the option may not be implemented within the allotted timeframe.	1	5	-4	
High defences	High defences (maintenance)	High defences (maintenance)	High defences (maintenance)	3	Defences constructed to given standard for 2115 (i.e. 1:200) so precautionary for epoch 1 (i.e. 1:1000), creating a significant improvement to the standard of flood protection throughout compared to the Do Nothing scenario	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	0	Measure scored 1 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	In epoch 2, high walls unlikely to have significant effect on navigation and marine activities	2	Maintenance is likely to be technically feasible and unlikely to present any significant technical challenges / risks associated with achieving the necessary consents / funding etc.	6	6	0		

Do minimum

Property protection and temporary defences
Low defences
High defences
Narrow barrier
Wide barrier
Do minimum

Property protection and temporary defences
High defences
Narrow barrier
Wide barrier
Property protection and temporary defences
Upgrade to High defences
Narrow barrier
Wide barrier
Property protection and temporary defences
High defences
Narrow barrier
Wide barrier
Property protection and temporary defences
High defences
Narrow barrier
Wide barrier
Do minimum

1	Higher temporary barriers and more PLP provided compared to if this option was implemented initially in epoch 1. Option likely to provide a benefit in SoP compared to DN in the locations in which it is implemented but on a CITYWIDE scale the benefits are likely to be minor	0	Not envisaged that PLP / demountables would be provided to development areas and therefore, with rising sea levels, the flood risk at these sites are likely to increase during epoch 2	0	Measure scored -1 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	In epoch 2, PLP / temporary barriers unlikely to have any impact on marine activities and navigation	1	In epoch 2 PLP will be more technically challenging as flood waters become deeper	2	2	0
2	Assumed that low defences constructed to a 1:200 year SoP for 2030. Compared to the Do Nothing scenario, where the SoP of existing frontline defences would fall over epoch 2, this option is likely to provide a moderate increase in the SoP	1	Low Defences expected to protect some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored -4 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	In epoch 2, low walls unlikely to have any impact on navigation and marine activities	1	A technically feasible option that is likely to be delivered within allotted timeframe. Potentially a risk associated with achieving consents due to possible landscape, access and visual impacts, but expected that this could be mitigated and therefore the risk level is considered low.	3	4	-1
3	Defences constructed to given standard for 2115 (i.e. 1:200) so precautionary for epoch 1 (i.e. 1:1000), creating a potentially significant improvement to the standard of flood protection compared to the Do Nothing scenario	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored -4 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	In epoch 2, high walls unlikely to have significant effect on navigation and marine activities	0	Similar level of technical challenge to low defences. Associated impacts may need to be mitigated (i.e. visual / landscape / access). Achieving the necessary consents may extend timescales of the options.	3	4	-1
3	Option would be constructed to a given SoP in 2115 and therefore precautionary during epoch 2. Compared to DN this option is likely to significantly increase the SoP	2	Option likely to protect entire at risk area within city centre so the SoP to development sites within this area likely to increase, potentially increasing opportunities for development	-2	Measure scored -8 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-1	Option likely to be technically challenging and to hold risks associated with achieving funding and consents. Construction also poses significant risks of delay and it is possible that the option may not be implemented within the allotted timeframe. However, compared to the Wide Barrier, the narrow barrier is to be located further from environmental designations and there is potentially a reduced scope for consenting / planning issues to arise because of this.	2	5	-3
3	Option would be constructed to a given SoP in 2115 and therefore precautionary during epoch 2. Compared to DN this option is likely to significantly increase the SoP	2	Option likely to protect entire at risk area within city centre so the SoP to development sites within this area likely to increase, potentially increasing opportunities for development	-2	Measure scored -10 (range 1 to -10) in environmental assessment	0	Scored as a total whole life cost in epoch 3	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-2	*Option likely to be very technically challenging and hold significant risks associated with achieving funding and consents. Construction also potentially poses significant risks of delay and it is possible that the option may not be implemented within the allotted timeframe.	1	5	-4
1	Continued operation of the floating harbour water control systems during epoch 2 likely to reduce flood risk compared to the DN scenario	0	Do Minimum unlikely to provide any additional flood protection to development sites, and as flood risk increases over this period, the SoP provided to these sites is likely to decrease in line with the DN scenario	0	Measure scored -1 (range 1 to -10) in environmental assessment.	0	Scored as a total whole life cost in epoch 3	0	In epoch 2 Do Minimum unlikely to have any impact at all on navigation and marine activities	2	Technically a very feasible option. Water control measures already in place within floating harbour and continued operation and maintenance unlikely to lead to any delays in implementing this option.	3	3	0

2	2	0
3	4	-1
3	4	-1
2	5	-3
1	5	-4
3	3	0

Epoch 1		Epoch 2		Epoch 3		Option objectives												SUM		
2015-2030		2030-2050		2065-2105		1. Flood Risk M&S		2. Sustainability / Development		3. Environment		4. Whole Life Cost		5. Disruption / Marine Activities		6. Defensibility		SUM	No. 4	No. 5
Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary	Score	Commentary			
0	As flood risk increases during epoch 3 it is unlikely that this option would be able to maintain a sustainable S&P, risk and residual risk likely to be high and comparable to the DR scenario	0	Not envisaged that P&P / demountables would be provided to development areas and therefore, with rising sea levels, the flood risk at these sites likely to increase during epoch 3	0	Measure scored as -1 (range 1 to -10) in environmental assessment	2	Rank 36	0	In epoch 3, P&P / temporary barriers unlikely to have any impact on marine activities and navigation	-1	In epoch 3 P&P will be more technically challenging as flood waters become deeper	1	2	-1						
2	Option protects to given S&P for 2115 (i.e. 1,200) which is a high S&P and is likely to provide significant flood risk benefits compared to the DR scenario. However, given that this is a precautionary approach for epochs 1&2, in S&P greatly in excess of 1,200, the relative flood risk benefits would reduce in this epoch.	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored as -5 (range 1 to -10) in environmental assessment	2	Rank 19	0	High defences unlikely to have any impact on navigation and marine activities	0	Similar level of technical challenge to low defences. Associated impacts may need to be mitigated (i.e. visual / landscape / access). Achieving the necessary consents may extend timescale of the option.	4	5	-1						
3	Option would be constructed to a given S&P in 2115 and therefore a precautionary approach for epochs 1&2. Compared to DR this option is likely to significantly increase the S&P	2	Option likely to protect entire at risk area within city centre so the S&P to development sites within this area is likely to be improved, potentially increasing opportunities for development	-2	Measure scored as -4 (range 1 to -10) in environmental assessment	0	Rank 21	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-1	Option likely to be technically challenging and to hold risks associated with achieving funding and consents. Construction also poses significant risks of delay and it is possible that the option may not be implemented within the allowed timeframe. However compared to the Wide Barrier, the narrow barrier is to be located further from environmental designations and there is potentially a reduced scope for consenting / planning issues to arise because of this.	2	5	-3						
3	Option would be constructed to a given S&P in 2115 and therefore a precautionary approach for epochs 1&2. Compared to DR this option is likely to significantly increase the S&P	2	Option likely to protect entire at risk area within city centre so the S&P to development sites within this area is likely to be improved, potentially increasing opportunities for development	-2	Measure scored as -10 (range 1 to -10) in environmental assessment	-1	Rank 15	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-2	Option likely to be very technically challenging and hold significant risks associated with achieving funding and consents. Construction also poses significant risks of delay and it is possible that the option may not be implemented within the allowed timeframe.	0	5	-5						
0	Changing management approach from low defences to P&P and demountables is likely to reduce standard of protection, bringing the S&P closer to that of the DR scenario during epoch 3	0	Not envisaged that P&P / demountables would be provided to potential development sites. Even so, unlikely that this option would improve protection significantly even if it was provided	0	Measure scored as -1 (range 1 to -10) in environmental assessment	1	Rank 31	0	In epoch 3, P&P / temporary barriers unlikely to have any impact on marine activities and navigation	-1	In epoch 3 P&P will be more technically challenging as flood waters become deeper	0	1	-1						
2	Option protects to given S&P for 2115 (i.e. 1,200) which is a high S&P and is likely to provide significant flood risk benefits compared to the DR scenario. However, given that this is a precautionary approach for epochs 1&2, in S&P greatly in excess of 1,200, the relative flood risk benefits would reduce in this epoch.	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored as -4 (range 1 to -10) in environmental assessment	1	Rank 29	0	High defences unlikely to have any impact on navigation and marine activities	0	Similar level of technical challenge to low defences. Associated impacts may need to be mitigated (i.e. visual / landscape / access). Achieving the necessary consents may extend timescale of the option.	3	4	-1						
3	Option would be constructed to a given S&P in 2115 and therefore a precautionary approach for epochs 1&2. Compared to DR this option is likely to significantly increase the S&P	2	Option likely to protect entire at risk area within city centre so the S&P to development sites within this area is likely to be improved, potentially increasing opportunities for development	-2	Measure scored as -4 (range 1 to -10) in environmental assessment	-1	Rank 13	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-1	Option likely to be technically challenging and to hold risks associated with achieving funding and consents. Construction also poses significant risks of delay and it is possible that the option may not be implemented within the allowed timeframe. However compared to the Wide Barrier, the narrow barrier is to be located further from environmental designations and there is potentially a reduced scope for consenting / planning issues to arise because of this.	1	5	-4						
3	Option would be constructed to a given S&P in 2115 and therefore a precautionary approach for epochs 1&2. Compared to DR this option is likely to significantly increase the S&P	2	Option likely to protect entire at risk area within city centre so the S&P to development sites within this area is likely to be improved, potentially increasing opportunities for development	-2	Measure scored as -10 (range 1 to -10) in environmental assessment	-1	Rank 11	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-1	Option likely to be very technically challenging and hold significant risks associated with achieving funding and consents. Construction also poses significant risks of delay and it is possible that the option may not be implemented within the allowed timeframe.	0	5	-5						
2	Option protects to given S&P for 2115 (i.e. 1,200) which is a high S&P and is likely to provide significant flood risk benefits compared to the DR scenario. However, given that this is a precautionary approach for epochs 1&2, in S&P greatly in excess of 1,200, the relative flood risk benefits would reduce in this epoch.	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	0	Measure scored as 1 (range 1 to -10) in environmental assessment	1	Rank 27	0	In epoch 2, high walls unlikely to have significant effect on navigation and marine activities	2	Maintenance likely to be technically feasible and unlikely to present any significant technical challenges / risks associated with achieving the necessary consents / funding etc.	6	6	0						
3	Option would be constructed to a given S&P in 2115 and therefore a precautionary approach for epochs 1&2. Compared to DR this option is likely to significantly increase the S&P	2	Option likely to protect entire at risk area within city centre so the S&P to development sites within this area is likely to be improved, potentially increasing opportunities for development	0	Measured scored as 1 (range 1 to -10) in environmental assessment	-2	Rank 5	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	2	Maintenance is likely to be technically feasible and unlikely to present any significant technical challenges / risks associated with achieving the necessary consents etc.	5	7	-2						
3	Option would be constructed to a given S&P in 2115 and therefore a precautionary approach for epochs 1&2. Compared to DR this option is likely to significantly increase the S&P	2	Option likely to protect entire at risk area within city centre so the S&P to development sites within this area is likely to be improved, potentially increasing opportunities for development	0	Measured scored as 1 (range 1 to -10) in environmental assessment	-2	Rank 1	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	2	Maintenance is likely to be technically feasible and unlikely to present any significant technical challenges / risks associated with achieving the necessary consents etc.	5	7	-2						

Property protection and temporary defences	Property protection and temporary defences	0	As flood risk increases during epoch 2 it is unlikely that this option would be able to maintain a suitable SuP, risk and residual risk is likely to be very high, comparable to the DR scenario	0	Not envisaged that PUF / demountables would be provided to development areas and therefore, with rising sea levels, the flood risk of these areas is likely to increase during epoch 3	0	Measure scored as -1 (range 1 to 10) in environmental assessment	1	Rank 26	0	In epoch 3, PUF / temporary barriers unlikely to have any impact on marine activities and navigation	-1	In epoch 3 PUF will be more technically challenging as flood waters become deeper	0	1	-1
		2	Option protects to given SuP for 215 (i.e. 1.200) which is a high SuP and is likely to provide significant flood risk benefits compared to the DR scenario. However, given that this is a precautionary approach for epochs 1&2 i.e. SuP greatly in excess of 1.200, the relative flood risk benefits would reduce in this epoch.	1	Assumed that high defences, being more widespread and constructed to a higher SuP than low defences, are likely to protect some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored as -5 (range 1 to 10) in environmental assessment	0	Rank 18	0	High defences unlikely to have any impact on navigation and marine activities	0	More technically challenging than low defences due to increased heights/lengths required and the associated risks which may need to be mitigated (i.e. visual / secondary / farmed). Achieving the necessary consent may extend timescale of the option.	2	3	-1
		3	Option would be constructed to a given SuP in 215 and therefore precautionary during epoch 2. Compared to DR this option is likely to significantly increase the SuP	2	Option likely to protect entire at risk area within city centre so the SuP to development sites within this area likely to increase, potentially increasing opportunities for development	-2	Measure scored as -8 (range 1 to 10) in environmental assessment	-1	Rank 10	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-1	Option likely to be technically challenging and to hold risks associated with achieving funding and consent. Construction also poses significant risk of delay and it is possible that the option may not be implemented within the allowed timeframe. However, the narrow barrier is to be located further from environmental obligations and there is potentially a reduced scope for consenting / planning issues to arise because of this.	1	5	-4
		3	Option would be constructed to a given SuP in 215 and therefore precautionary during epoch 2. Compared to DR this option is likely to significantly increase the SuP	2	Option likely to protect entire at risk area within city centre so the SuP to development sites within this area likely to increase, potentially increasing opportunities for growth and sustainable development	-2	Measure scored as -10 (range 1 to 10) in environmental assessment	-2	Rank 8	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-2	Option likely to be very technically challenging and hold significant risks associated with achieving funding and consent. Construction also potentially poses significant risk of delay and it is possible that the option may not be implemented within the allowed timeframe.	-1	5	-6
Low defences	Low defences (maintenance and additional defences in new locations if required)	0	Changing management approach from low defences to PUF and demountables is likely to reduce standard of protection, bringing the SuP closer to that of the DR scenario during epoch 3	0	Not envisaged that PUF / demountables would be provided to potential development sites. Even so, unlikely that this option would increase protection significantly even if it was provided	0	Measure scored as -1 (range 1 to 10) in environmental assessment	1	Rank 25	0	In epoch 3, PUF / temporary barriers unlikely to have any impact on marine activities and navigation	-1	In epoch 3 PUF will be more technically challenging as flood waters become deeper	0	1	-1
		2	Option protects to given SuP for 215 (i.e. 1.200) which is a high SuP and is likely to provide significant flood risk benefits compared to the DR scenario. However, given that this is a precautionary approach for epochs 1&2 i.e. SuP greatly in excess of 1.200, the relative flood risk benefits would reduce in this epoch.	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored as -5 (range 1 to 10) in environmental assessment	0	Rank 24	0	High defences unlikely to have any impact on navigation and marine activities	0	Similar level of technical challenge to low defences. Associated risks may need to be mitigated (i.e. visual / landscape / access). Achieving the necessary consent may extend timescale of the option.	2	3	-1
		3	Option would be constructed to a given SuP in 215 and therefore precautionary during epoch 2. Compared to DR this option is likely to significantly increase the SuP	2	Option likely to protect entire at risk area within city centre so the SuP to development sites within this area likely to increase, potentially increasing opportunities for development	-2	Measure scored as -8 (range 1 to 10) in environmental assessment	-1	Rank 9	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-1	Option likely to be technically challenging and to hold risks associated with achieving funding and consent. Construction also poses significant risk of delay and it is possible that the option may not be implemented within the allowed timeframe. However, the narrow barrier is to be located further from environmental obligations and there is potentially a reduced scope for consenting / planning issues to arise because of this.	1	5	-4
		3	Option would be constructed to a given SuP in 215 and therefore precautionary during epoch 2. Compared to DR this option is likely to significantly increase the SuP	2	Option likely to protect entire at risk area within city centre so the SuP to development sites within this area likely to increase, potentially increasing opportunities for development	-2	Measure scored as -10 (range 1 to 10) in environmental assessment	-2	Rank 7	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-2	Option likely to be very technically challenging and hold significant risks associated with achieving funding and consent. Construction also potentially poses significant risk of delay and it is possible that the option may not be implemented within the allowed timeframe.	-1	5	-6
Upgrade to high defences	Upgrade to high defences (maintenance)	2	Option protects to given SuP for 215 (i.e. 1.200) which is a high SuP and is likely to provide significant flood risk benefits compared to the DR scenario. However, given that this is a precautionary approach for epochs 1&2 i.e. SuP greatly in excess of 1.200, the relative flood risk benefits would reduce in this epoch.	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	0	Measure scored as 1 (range 1 to 10) in environmental assessment	0	Rank 20	0	In epoch 2, high walls unlikely to have significant effect on navigation and marine activities	0	Maintenance likely to be technically feasible and unlikely to present any significant technical challenges / risks associated with achieving the necessary consent / funding etc.	3	3	0
		3	Option would be constructed to a given SuP in 215 and therefore precautionary during epoch 2. Compared to DR this option is likely to significantly increase the SuP	2	Option likely to protect entire at risk area within city centre so the SuP to development sites within this area likely to increase, potentially increasing opportunities for development	0	Measure scored as 1 (range 1 to 10) in environmental assessment	-2	Rank 2	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	2	Maintenance likely to be technically feasible and unlikely to present any significant technical challenges / risks associated with achieving the necessary consent etc.	5	7	-2
		3	Option would be constructed to a given SuP in 215 and therefore precautionary during epoch 2. Compared to DR this option is likely to significantly increase the SuP	2	Option likely to protect entire at risk area within city centre so the SuP to development sites within this area likely to increase, potentially increasing opportunities for development	0	Measure scored as 1 (range 1 to 10) in environmental assessment	-2	Rank 2	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	2	Maintenance likely to be technically feasible and unlikely to present any significant technical challenges / risks associated with achieving the necessary consent etc.	5	7	-2
		2	Option protects to given SuP for 215 (i.e. 1.200) which is a high SuP and is likely to provide significant flood risk benefits compared to the DR scenario. However, given that this is a precautionary approach for epochs 1&2 i.e. SuP greatly in excess of 1.200, the relative flood risk benefits would reduce in this epoch.	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	0	Measure scored as 1 (range 1 to 10) in environmental assessment	0	Rank 19	0	In epoch 2, high walls unlikely to have significant effect on navigation and marine activities	2	Maintenance likely to be technically feasible and unlikely to present any significant technical challenges / risks associated with achieving the necessary consent etc.	5	5	0

Do Minimum	Property protection and temporary defences	0	As flood risk increases during epoch 3 it is unlikely that this option would be able to maintain / sustain a respectable SuF, risk and residual risk is likely to be very high, compatible to the DR scenario	0	Not envisaged that PFP / defences would be provided to development sites and therefore, with rising sea levels, the flood risk at these sites is likely to increase during epoch 3	0	Measure scored as: 1 (range 1 to 10) in environmental assessment	2	Rank 17	0	In epoch 3, PFP / temporary barriers unlikely to have any impact on marine activities and navigation	-1	In epoch 3 PFP will be most technically challenging as flood waters become deeper	1	2	-1	
		High defences	2	Option protects to given SuF for 2115 (i.e. 1:200) which is a high SuF and is likely to provide significant flood risk benefits compared to the DR scenario. However, given that this is a precautionary approach for epochs 1&2 (i.e. SuF greatly in excess of 1:200), the relative flood risk benefits would reduce in this epoch.	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored as: 5 (range 1 to 10) in environmental assessment	2	Rank 14	0	High defences unlikely to have any impact on navigation and marine activities	0	Similar level of technical challenge to low defences. Associated impacts may need to be mitigated (i.e. visual / landscape / access). Achieving the necessary consents may extend timescale of the options.	4	5	-1
		Narrow barrier	3	Option would be constructed to a given SuF in 2115 and therefore a precautionary approach for epochs 1, 2 compared to DR this option is likely to significantly increase the SuF	2	Option likely to protect entire at risk area within city centre so the SuF to development sites within this area would likely increase, potentially increasing opportunities for development	-2	Measure scored as: 8 (range 1 to 10) in environmental assessment	0	Rank 22	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-1	Option likely to be technically challenging and to hold risks associated with achieving funding and consents. Construction also poses significant risks of delay and it is possible that the option may not be implemented within the allowed timeframe. However, compared to the Wide Barrier, the narrow barrier is to be located further from environmental obligations and there is potentially a reduced scope for consenting / planning issues to arise because of this.	2	5	-3
		Wide barrier	3	Option would be constructed to a given SuF in 2115 and therefore a precautionary approach for epochs 1, 2 compared to DR this option is likely to significantly increase the SuF	2	Option likely to protect entire at risk area within city centre so the SuF to development sites within this area would likely increase, potentially increasing opportunities for development	-2	Measure scored as: 10 (range 1 to 10) in environmental assessment	-1	Rank 16	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-2	Option likely to be very technically challenging and hold significant risks associated with achieving funding and consents. Construction also potentially poses significant risks of delay and it is possible that the option may not be implemented within the allowed timeframe.	0	5	-6
	Upgrade to High defences	Property protection and temporary defences	0	Engineering management approach from low defences to PFP and defences is likely to reduce standard of protection, bringing the SuF closer to that of the DR scenario during epoch 3	0	Not envisaged that PFP / defences would be provided to potential development sites. Even so, unlikely that this option would improve protection significantly even if was provided	0	Measure scored as: 1 (range 1 to 10) in environmental assessment	1	Rank 12	0	In epoch 3, PFP / temporary barriers unlikely to have any impact on marine activities and navigation	-1	In epoch 3 PFP will be most technically challenging as flood waters become deeper	0	1	-1
		High defences	2	Option protects to given SuF for 2115 (i.e. 1:200) which is a high SuF and is likely to provide significant flood risk benefits compared to the DR scenario. However, given that this is a precautionary approach for epochs 1&2 (i.e. SuF greatly in excess of 1:200), the relative flood risk benefits would reduce in this epoch.	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored as: 5 (range 1 to 10) in environmental assessment	1	Rank 10	0	High defences unlikely to have any impact on navigation and marine activities	0	Similar level of technical challenge to low defences. Associated impacts may need to be mitigated (i.e. visual / landscape / access). Achieving the necessary consents may extend timescale of the options.	3	4	-1
		Narrow barrier	3	Option would be constructed to a given SuF in 2115 and therefore a precautionary approach for epochs 1, 2 compared to DR this option is likely to significantly increase the SuF	2	Option likely to protect entire at risk area within city centre so the SuF to development sites within this area would likely increase, potentially increasing opportunities for development	-2	Measure scored as: 8 (range 1 to 10) in environmental assessment	-1	Rank 14	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-1	Option likely to be technically challenging and to hold risks associated with achieving funding and consents. Construction also poses significant risks of delay and it is possible that the option may not be implemented within the allowed timeframe. However, compared to the Wide Barrier, the narrow barrier is to be located further from environmental obligations and there is potentially a reduced scope for consenting / planning issues to arise because of this.	1	5	-4
		Wide barrier	3	Option would be constructed to a given SuF in 2115 and therefore a precautionary approach for epochs 1, 2 compared to DR this option is likely to significantly increase the SuF	2	Option likely to protect entire at risk area within city centre so the SuF to development sites within this area would likely increase, potentially increasing opportunities for development	-2	Measure scored as: 10 (range 1 to 10) in environmental assessment	-1	Rank 12	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-2	Option likely to be very technically challenging and hold significant risks associated with achieving funding and consents. Construction also potentially poses significant risks of delay and it is possible that the option may not be implemented within the allowed timeframe.	0	5	-6
	Low defences	High defences (maintenance)	2	Option protects to given SuF for 2115 (i.e. 1:200) which is a high SuF and is likely to provide significant flood risk benefits compared to the DR scenario. However, given that this is a precautionary approach for epochs 1&2 (i.e. SuF greatly in excess of 1:200), the relative flood risk benefits would reduce in this epoch.	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored as: 3 (range 1 to 10) in environmental assessment	1	Rank 28	0	In epoch 2, high walls unlikely to have significant effect on navigation and marine activities	2	Maintenance is technically feasible and unlikely to present any significant technical challenges / risks associated with achieving the necessary consents / funding etc.	6	6	0
		Narrow barrier	3	Option would be constructed to a given SuF in 2115 and therefore a precautionary approach for epochs 1, 2 compared to DR this option is likely to significantly increase the SuF	2	Option likely to protect entire at risk area within city centre so the SuF to development sites within this area would likely increase, potentially increasing opportunities for development	-2	Measure scored as: 1 (range 1 to 10) in environmental assessment	-2	Rank 6	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	2	Maintenance is likely to be technically feasible and unlikely to present any significant technical challenges / risks associated with achieving the necessary consents etc.	5	7	-2
		Wide barrier	3	Option would be constructed to a given SuF in 2115 and therefore a precautionary approach for epochs 1, 2 compared to DR this option is likely to significantly increase the SuF	2	Option likely to protect entire at risk area within city centre so the SuF to development sites within this area would likely increase, potentially increasing opportunities for development	-2	Measure scored as: 1 (range 1 to 10) in environmental assessment	-2	Rank 4	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	2	Maintenance is likely to be technically feasible and unlikely to present any significant technical challenges / risks associated with achieving the necessary consents etc.	5	7	-2
		Property protection and temporary defences	0	As flood risk increases during epoch 3 it is unlikely that this option would be able to maintain / sustain a respectable SuF, risk and residual risk is likely to be very high, compatible to the DR scenario	0	Not envisaged that PFP / defences would be provided to development sites and therefore, with rising sea levels, the flood risk at these sites is likely to increase during epoch 3	0	Measure scored as: 1 (range 1 to 10) in environmental assessment	2	Rank 18	0	In epoch 3, PFP / temporary barriers unlikely to have any impact on marine activities and navigation	-1	In epoch 3 PFP will be most technically challenging as flood waters become deeper	1	2	-1
	Do Minimum	High defences	2	Option protects to given SuF for 2115 (i.e. 1:200) which is a high SuF and is likely to provide significant flood risk benefits compared to the DR scenario. However, given that this is a precautionary approach for epochs 1&2 (i.e. SuF greatly in excess of 1:200), the relative flood risk benefits would reduce in this epoch.	1	High Defences are likely to incorporate some areas of potential development, potentially increasing opportunities for growth and sustainable development	-1	Measure scored as: 5 (range 1 to 10) in environmental assessment	2	Rank 15	0	High defences unlikely to have any impact on navigation and marine activities	0	Similar level of technical challenge to low defences. Associated impacts may need to be mitigated (i.e. visual / landscape / access). Achieving the necessary consents may extend timescale of the options.	4	5	-1
		Narrow barrier	3	Option would be constructed to a given SuF in 2115 and therefore a precautionary approach for epochs 1, 2 compared to DR this option is likely to significantly increase the SuF	2	Option likely to protect entire at risk area within city centre so the SuF to development sites within this area would likely increase, potentially increasing opportunities for development	-2	Measure scored as: 8 (range 1 to 10) in environmental assessment	0	Rank 23	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-1	Option likely to be technically challenging and to hold risks associated with achieving funding and consents. Construction also poses significant risks of delay and it is possible that the option may not be implemented within the allowed timeframe. However, compared to the Wide Barrier, the narrow barrier is to be located further from environmental obligations and there is potentially a reduced scope for consenting / planning issues to arise because of this.	2	5	-3
		Wide barrier	3	Option would be constructed to a given SuF in 2115 and therefore a precautionary approach for epochs 1, 2 compared to DR this option is likely to significantly increase the SuF	2	Option likely to protect entire at risk area within city centre so the SuF to development sites within this area would likely increase, potentially increasing opportunities for development	-2	Measure scored as: 10 (range 1 to 10) in environmental assessment	0	Rank 17	0	Barrier to be designed to mitigate navigation impacts and impacts on marine activities	-2	Option likely to be very technically challenging and hold significant risks associated with achieving funding and consents. Construction also potentially poses significant risks of delay and it is possible that the option may not be implemented within the allowed timeframe.	1	5	-4
		Do Minimum	0	Failure of various water control structures in existing barrier and raised defences in epoch 3 means that defences lose flood-risk benefit compared to DR	0	No protection to development sites and rising flood risk has the potential to severely constrain potential development in Bristol	0	Measure scored as: 1 (range 1 to 10) in environmental assessment	2	Rank 19	0	In epoch 3 Do Minimum unlikely to have any impact at all on navigation and marine activities	1	Technically feasible option, however, becoming more difficult to implement during epoch 3 due to ageing of structures which may need to be replaced / replaced to ensure continued flood defence function.	3	3	0

Pathway scoring - by epoch

Epoch 1				Epoch 2				Epoch 3				Totals		
2015-2030	Sum	No. +	No. -	2030-2065	Sum	No. +	No. -	2065-2115	Sum	No. +	No. -	Sum	No. +	No. -
Property protection and temporary defences	3	3	0	Property protection and temporary defences	2	2	0	Property protection and temporary defences	1	2	-1	6	7	-1
				Low defences	3	4	-1	High defences	4	5	-1	9	10	-1
				High defences	3	4	-1	Narrow barrier	2	5	-3	7	10	-3
				Narrow barrier	2	5	-3	Wide barrier	0	5	-5	5	10	-5
				Wide barrier	1	5	-4	Property protection and temporary defences	0	1	-1	6	8	-2
								Upgrade to High defences	3	4	-1	9	11	-2
								Narrow barrier	1	5	-4	7	12	-5
								Wide barrier	0	5	-5	6	12	-6
								High defences (maintenance)	6	6	0	12	13	-1
								Narrow barrier (maintenance)	5	7	-2	10	15	-5
								Wide barrier (maintenance)	5	7	-2	9	15	-6
Low defences	3	4	-1	Property protection and temporary defences	2	2	0	Property protection and temporary defences	0	1	-1	5	7	-2
				Low defences (maintenance and additional defences in new locations if required)	5	5	0	High defences	2	3	-1	7	9	-2
				Upgrade to High defences	3	4	-1	Narrow barrier	1	5	-4	6	11	-5
				Narrow barrier	2	5	-3	Wide barrier	-1	5	-6	4	11	-7
				Wide barrier	1	5	-4	Property protection and temporary defences	0	1	-1	8	10	-2
								Upgrade to High defences						
								Narrow barrier	2	3	-1	10	12	-2
								Wide barrier	1	5	-4	9	14	-5
								High defences (maintenance)	3	3	0	7	14	-7
								Narrow barrier (maintenance)	5	7	-2	9	11	-2
								Wide barrier (maintenance)	5	7	-2	10	16	-6
												9	16	-7
High defences	3	4	-1	High defences (maintenance)	6	6	0	High defences (maintenance)	5	5	0	14	15	-1
Do minimum	3	3	0	Property protection and temporary defences	2	2	0	Property protection and temporary defences	1	2	-1	6	7	-1
				Low defences	3	4	-1	High defences	4	5	-1	9	10	-1
				High defences	3	4	-1	Narrow barrier	2	5	-3	7	10	-3
				Narrow barrier	2	5	-3	Wide barrier	0	5	-5	5	10	-5
				Wide barrier	1	5	-4	Property protection and temporary defences	0	1	-1	6	8	-2
								Upgrade to High defences	3	4	-1	9	11	-2
								Narrow barrier	1	5	-4	7	12	-5
								Wide barrier	0	5	-5	6	12	-6
								High defences (maintenance)	6	6	0	12	13	-1
								Narrow barrier (maintenance)	5	7	-2	10	15	-5
								Wide barrier (maintenance)	5	7	-2	9	15	-6
								Property protection and temporary defences	1	2	-1	7	8	-1
								High defences	4	5	-1	10	11	-1
								Narrow barrier	2	5	-3	8	11	-3
								Wide barrier	1	5	-4	7	11	-4
								Do minimum	3	3	0	9	9	0