RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Long List Options - Briefing Report

May 2016

Prepared for Bristol City Council

Issue	Date	Details	Prepared by	Checked by	Approved by
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EXECUTIVE SUMMARY

This briefing report sets out the long list of options for the River Avon Tidal Flood Risk Management Strategy and outlines the next steps to be undertaken in the options appraisal process.

Forming the long list of strategic options is the first stage of the options appraisal process. Each strategic option outlines a sequence of measures to be implemented in each time epoch of the Strategy (short, medium and long term). For example, a Strategic Option may be to implement property protection and temporary defence measures in the short term (2015-2030), construct low flood walls in the medium term (2030-2065) and finally construct a tidal barrier in the long term (2065-2115).

The objectives for the flood risk management options have been agreed with the project team. These 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, with consideration of reactive emergency response.
5. To ensure navigation of the River Avon and marine activities can continue.
6. Ensure the Strategy is fundable and deliverable over its duration.

Long List Measures

Before assembling the strategic options a range of 'feasible' measures to manage tidal flood risk were developed. These included:

- Low defences or crest raising
- Narrow tidal barrier solution
- Property protection and temporary defences
- Do minimum
- High defences or crest raising
- Wide tidal barrier solution
- Secondary measures to manage the consequences / response to flooding (such as flood forecasting and warnings)

A number of other measures were also considered, but were deemed 'unfeasible' solutions in the context of managing the tidal flood risk in Bristol. The unfeasible measures included:

- Fluvial flood storage areas
- Pumping against the tide at the Floating Harbour
- River Avon tidal barrage
- Wholesale land raising in the floodplain
- River Avon channel deepening / widening
- Severn Estuary tidal barrage
- Property / city relocation
- Fluvial flood diversion channels

More details of the long list measures are provided in section 3 of this briefing note.

Long List Strategic Options

Having identified the 'feasible' measures, the measures were then assembled into a range of different strategic options. This process is described in section 4 of this briefing note.

To ensure that this stage of the appraisal was robust, and that each potential combination of measures was considered, an 'options tree' was created which mapped each potential sequence of measures for the long list strategic options. Impractical combinations were discounted from the tree and scoped out from further assessment. In total 39 long list options have been developed; the 'tree' of long list options is presented in section 4 of the Briefing Report, and the accompanying figure.

Next Steps

The next step in the appraisal process involves reducing the long list of Strategic Options down to a short list. This will be informed by a multi-criteria assessment which will establish the impact of the long list options against each of the seven strategy option objectives (presented above in the executive summary and also in section 1.5 of the Briefing Report).

Following the development of the short-list, the options will be appraised to identify the preferred strategic approach to manage tidal flood risk in Bristol. A number of tasks will be undertaken to support this process, including:

- Numerical modelling to establish the 'Do Nothing' flood risk and economic damages. Scenario runs of the short-list options will also be undertaken to determine the economic benefits of implementing the options.
- A benefit:cost economic assessment and affordability check
- The development and definition of the range of 'Futures' (i.e. development, climate change and funding) ; considering different likely scenarios for development, funding and climate change which will be used to sensitivity check the short-list options.
- Environmental screening to establish the likely environmental impacts and opportunities of the short-list options and to identify suitable mitigation measures (if necessary)
- Barrier solution costing and technical feasibility assessment, including numerical modelling to establish the preferred barrier location
- Key stakeholder input

More details of the next steps in the option appraisal process are provided in sections 5 & 6 of this briefing note.

1. INTRODUCTION AND OBJECTIVES

1.1 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 on 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. Consideration of downstream and upstream impacts is to be given, including Pill and Portbury.

Figure 1 presents the project area alongside an estimate of the area potentially at risk from tidal flooding. The tidal flood risk area for this Figure was determined using predicted extreme water levels and land elevation (i.e. a bathtub approach) and no consideration was made of existing defences. A more accurate depiction of the area at risk will be available following the undertaking of baseline numerical modelling.

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 'strategic 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.

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 in reality sea level rise occurs slower than expected and the exceedance of the risk threshold does not occur, there is built in flexibility so that the scheme can be delayed until a later stage.

1.2 Overview of tidal flood risk in Bristol

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 via inundation or overtopping. 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.

Existing modelling has shown a strong relationship between tidal / surge return period events and peak water levels in the Floating Harbour. However, there is only a weak relationship between Floating Harbour peak water levels and fluvial return period events of the Rivers Avon and Frome.

At present (i.e. with no allowance for climate change considered), CAFRA modelling predicts that there are approximately 300 residential and commercial properties in the city centre that have a greater than 1 in 20 chance of flooding in any given year. CAFRA Workstream 3 identifies that large parts of the city centre have a 1 in 20 chance of flooding in any given year, with low-lying areas of St Philips Marsh, the Cumberland Basin and Netham at even greater risk during the tidally dominated and intermediate events with a joint probability of occurrence of 1 in 20 in any year. Properties in Mina Road and Ashton Gate are predicted to be at risk during the corresponding fluvially-dominated events.

1.3 Previous studies and recommended options

A number of studies investigating the flood risk in Bristol have recently been undertaken. In 2010 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 appropriate 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. These comprise:

- Improved flood forecasting, warning and planning;
- Early raised defences at low spots along the riverside to reduce to 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 appropriately high level strategic scales. This introduces a number of limitations and constraints into the studies. For example, the CAFRA modelling has constraints as to the representation of detailed flood sources and pathways, and the First Phase Feasibility Study excluded option costs from its high level economic assessment. Further details of the limitations are provided in the Baseline Review Briefing Note.

1.4 Strategy objectives

The objectives of the Strategy are:

a) to develop an agreed understanding of flood risk from now until 2115. The impact of this risk on existing development and infrastructure, and future proposals needs to be quantified. This should be proportionate and build on the best available information (the CAFRA and River Avon Strategic Flood Defences First Phase Feasibility Study) to improve the evidence base and confidence in predictions, reflecting opportunistic synergies realised from infrastructure proposals such as Metrobus.

b) Intervention options should be confirmed, to 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). The delivery cost and risk of these options needs to be determined, proportionate to the likelihood of progression, and when the options would be needed. Efficiencies from opportunistic synergies with other infrastructure proposals should be identified.

c) The justification for investment needs to be evaluated. We recognise the different drivers and priorities of BCC and the Environment Agency. However both organisations commit to actively work together and exploit mutually-beneficial synergies. The Environment Agency will evaluate against objectives to manage flood risk to people and property. BCC will also evaluate the impact on broader, strategic regeneration objectives. The consequence of inaction should be clarified.

1.5 This report and option appraisal objectives

This briefing report sets out the long list of strategic options for the TFRMS, and the next steps to be undertaken in developing the short list of options. This stage of the Strategy follows the initial baseline review, in which an understanding of flood risk in Bristol and the work already undertaken was developed.

Forming the long list of strategic options is the first stage of the options appraisal process. The flow chart shown in Figure 2 outlines the key stages of the option development and appraisal process.

To facilitate the option appraisal process, the objectives for the flood risk management options were 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 alleviate flood risk and the restrictions it brings 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, with consideration of reactive emergency response.
5. To ensure navigation of the River Avon and marine activities can continue.
6. Ensure the Strategy is fundable and deliverable over its duration.

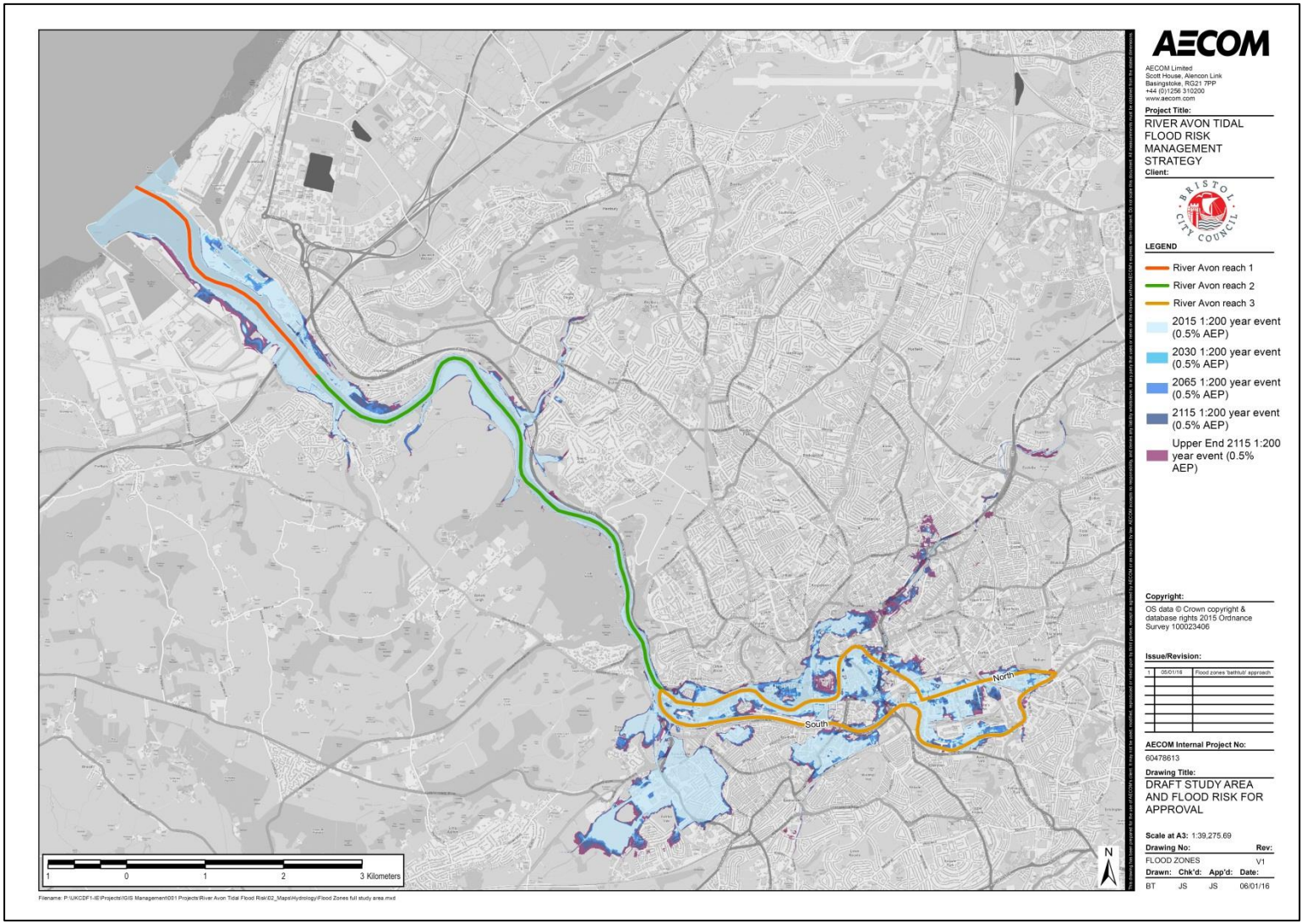

Figure 1. Strategy project boundaries, reaches and tidal flood risk.

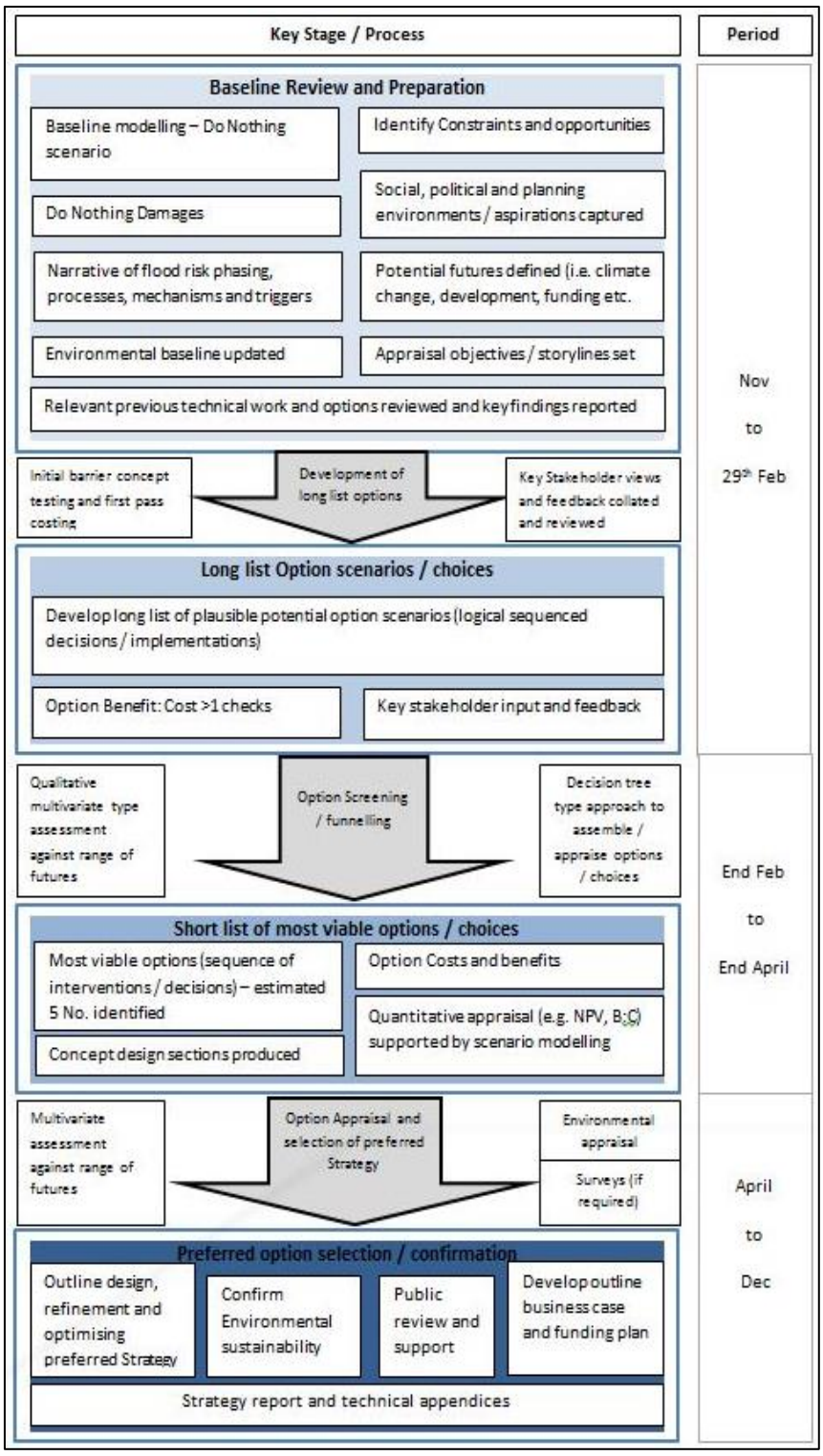

Figure 2. Flow diagram showing overview of the process of option development, appraisal and selection of the preferred option.

2. DEVELOPMENT OF THE LONG LIST OF OPTIONS

2.1 Aim

The aim of this stage is to develop a long list of potentially viable strategic management choices and interventions which will then be subject to appraisal in order to 'funnel down' to a short list of strategic alternatives for more detailed assessment and evaluation.

Developing the long list of options is the first part of the Strategy development process following the baseline review and is necessary for developing robust and adaptable solutions to manage tidal flood risk in Bristol over the next 100 years.

It is intended that the 'net is cast sufficiently wide' at this early stage to ensure potential options which may be worthy of detailed appraisal are not overlooked or removed prematurely. Only options which are by inspection clearly not relevant, technically flawed or are unacceptable (i.e. affordability, political, social or risk terms) are excluded at this stage. This process was informed by a detailed review of the previous studies which have been undertaken in the study area.

Given the large number of options and alternatives at this stage the detail surrounding each option has been kept at a necessarily high level. The appraisal of long list options is about considering strategic choices and concepts rather than specific details. Once a reduced number short list of options is developed the details and specifics of each option will be worked up accordingly to allow for a more detailed evaluation and appraisal.

2.2 Approach

The long list option appraisal was undertaken in liaison with Bristol City Council and the Environment Agency and builds upon the option appraisal work that has previously been undertaken during the Bristol City Council CAFRA (2012-2015) and First Phase Feasibility (2014) studies. These studies provide significant thinking and testing of potential options and these findings have been reviewed and built upon in the development of long list options for the Strategy.

The period over which the options are to be developed and appraised spans the 100 year duration of the Strategy, from 2015 to 2115, but this period is comprised of three time epochs; the short term (2015-2030), the medium term (2030-2065) and the long term (2065-2115). These epochs provide three decision periods over which to consider options.

The long list development process comprised the following key steps:

1. Identify all potential **measures** to manage tidal flood risk in Bristol.
2. Scope out any **measures** which are not considered by inspection to be relevant, deliverable, or are not legally compliant (informed by a high level review and the work undertaken in previous option appraisals – CAFRA (2012-2015) and the First Phase Feasibility study (2014)), leaving a long list of feasible measures.
3. Assemble the feasible **measures** into a sequences or packages of practical **Strategic Options (alternatives)**, providing a range of approaches to manage tidal flood risk over the next century.
4. Hold a BCC and Key stakeholder workshop to discuss and agree long list options (held at AECOM Crescent Centre, 13 January 2016).
5. Delivery of the long list options briefing report (this report).
6. Confirmation and approval of long list options by the project board

Following confirmation and agreement of the long list options, an appraisal of long list options will be undertaken through a multivariate criteria analysis and conceptual appraisal. This will 'funnel down' the options to the short list of options most worthy of detailing appraisal and further evaluation. As well as the 'Do Something options' the short list will also include the hypothetical 'Do Nothing baseline option 'for comparison terms. Further details on the appraisal approach are shown in the flow diagram in Figure 2.

2.3 Terminology

Clarification of the terminology used in the long list development process is provided in the definitions below:

- **Measure** - an intervention to manage or reduce the probability of occurrence of a tidal flood event or to reduce the consequences of flooding. For example, a flood wall or a flood embankment are measures that could reduce the probability of flooding whilst a flood warning system may help to reduce the consequences of flooding.
- **Strategic Option** – an assemblage or package of phased measures spanning the duration of the Strategy appraisal period (2015-2115). For each time epoch (short, medium or long term), a Strategic Option comprises a **measure** or **measures** which are to be implemented during that time epoch. For example, a Strategic Option could be to implement property protection and temporary defence measures in the short term (2015-2030), construct low flood walls in the medium term (2030-2065) and finally construct a tidal barrier in the long term (2065-2115).

3. LONG LIST OF POTENTIAL MEASURES

3.1 Potential measures

The process of identifying measures for consideration in the long list was based on interpretation of available evidence such as the BCC CAFRA (2012-2015) and First Phase Feasibility (2014) studies alongside the extensive project team experience in developing flood risk management plans and strategies. Potential measures were identified for Bristol that achieve the following;

- measures that change the source of flood risk;
- measures that modify the pathway or change the probability of flood risk;
- measures that manage receptors to reduce the consequences of flooding;
- temporary measures as well as permanent measures;
- measures that work with natural processes;
- measures that are adaptable to future changes in risk;
- measures that require actions to be taken to deliver the predicted benefits (i.e. closing flood gates or deploying demountable defences); and
- measures that can deliver opportunities and wider benefits.

The measures identified (in no particular order) are shown in the list below:

- Low flood defences (e.g. Walls, embankments, gates etc.) or crest raising (to reduce the immediate significant tidal flood risk)
- Property level protection (flood resilience measures)
- Flood storage areas
- River Avon channel deepening (dredging) / channel widening
- Severn estuary tidal barrage
- Wholesale land raising in the flood plain
- Flood forecasting and warning systems
- Raising flood awareness / education
- Maintenance of existing flood defence assets
- Use of floating harbour as flood storage area
- Compartmentalisation of the floodplain
- High flood defences (e.g. walls, embankments, land raising etc.) to reduce the long term risk associated with sea level rise)
- Optimising Floating Harbour operations and operational infrastructure
- Demountable / temporary flood defences
- Pumping against the tide at the Floating Harbour / Northern Storm Water Interceptor (NSWI)
- River Avon tidal barrier
- River Avon tidal barrage
- Local land raising in the flood plain
- Property / City relocation
- Flood emergency and evacuation plans
- Fluvial flood diversion channels
- Development planning and urban renewal

A high level review was carried out to remove from further consideration any measures which were deemed not feasible to manage the flood risk in Bristol. A brief discussion of which measures were scoped out, and the reasons for this, is provided in section 3.2 below.

3.2 Scoped out measures

- **Fluvial flood storage areas** – Fluvial flood storage areas work by attenuating flood waters upstream of the area at risk during periods of high fluvial flows. Fluvial flood storage areas are typically created in rural, low lying land adjacent to the river channel by constructing a low height embankment dam and river control structures.

  A major reason why this option has been discounted is because that in the study area there is unlikely to be sufficient space for fluvial flood storage areas to be located. The River Avon catchment is very large, draining parts of Gloucestershire, Wiltshire and Somerset and is approximately 2,221 square kilometres in size (Environment Agency, 2012). Consequently, in order to form an effective solution to managing flood risk and to accommodate potentially very large fluvial flow volumes, it is likely that the storage areas will need to be extremely large. This is problematic given that the nature of the catchment within the study site is largely developed and also includes the major urban areas of Bristol, Pill and Shirehampton. In addition there are also a number of environmentally sensitive areas within it, including a number of SSSI designations, the Severn Estuary SPA and SAC. The developed nature of the catchment and the environmental designations are likely to significantly constrain the possibilities for locating large fluvial flood storage areas within the study area.

  Comparisons can be made with the city of Bath, which is located upstream of Bristol on the River Avon, and has also recently investigated the potential for upstream storage areas to alleviate fluvial flood risk. The Bath flood risk management project was undertaken by Bath and North East Somerset Council in 2013. In this project it was found that in order to provide flood storage that would reduce peak flows of the River Avon, storage areas in excess of 10million cubic metres would be needed in locations upstream of Bath, on land which currently does not flood. Due to the sheer magnitude of the storage areas that would be required no suitable sites could be found and therefore upstream flood storage areas were discounted from the investigation.

  In addition to the lack of suitable sites for upstream storage within the study site, if fluvial flood storage areas were to be used in isolation (i.e. without another flood risk intervention alongside this measure) evidence from previous studies (i.e. the First Phase Feasibility Study) suggests that upstream storage areas are unlikely to change the tidally dominated flood risk in the city. Therefore, with the major flood risk to the city being tidally dominated, this measure is not considered a feasible solution to managing the tidal flood risk.

  For these reasons this measure has been discounted from further consideration in this study. However, should opportunities for smaller scale attenuation areas arise, these should be investigated in future studies as they could potentially provide some local flood risk benefit to some areas during flooding events.

- **River Avon channel deepening / channel widening** – By increasing the width and/or depth of the River Avon Channel this measure could increase the flow conveyance which, theoretically, could reduce the chance of fluvial flooding to adjacent areas during periods of high fluvial flows. However, due to a number of technical concerns, this option has been ruled out from further consideration.

  A major concern with this measure relates to the impact which it could have on the tidal prism of the Avon estuary. The tidal prism is the volume of water exchanged through a coastal or transitional system typically measured between Mean Low Water Spring and Mean High Water Spring tides. By widening / deepening the channel, the tidal prism could increase which could result in a higher volume of tidal water entering and advancing up the channel on a given tide. Based on engineering judgement and the understanding of tidal flood risk in the area, this could have the potential to actually increase the tidal flood risk in the study area and the measure has therefore been ruled out on this basis. In addition, changes to the tidal prism of an estuary can lead to fundamental alterations to the habitats that the water body can support. This is also likely to be of significant concern in the Avon estuary which supports various habitats and designated environmental sites, such as the Severn SPA and SAC.

  A number of significant technical challenges are also likely to arise with this measure, such as managing and mitigating the geomorphological, environmental and local flood risk issues which may arise from changing the River flows and hydrology. Social and political issues could also arise alongside temporary environmental concerns (i.e. water quality) and ecological impacts associated with dredging activities (to widen / deepen the channel).

  For these reasons this measure has been discounted from further consideration within this study.

- **Severn Estuary tidal barrage and/or widespread tidal lagoons** – There is a range of ideas for building a barrage from the English coast to the Welsh coast over the Severn tidal estuary. A barrage structure would act to impound water levels which could then be used to derive tidal

energy. Depending on the location and operating regime, it could also help to control tide water levels in the Severn estuary and provide a significant flood risk benefit to Bristol. Recently, a barrage has been the focus for development plans due the tidal power generating capacity of the structure and the Government's aim to increase renewable energy production in the UK. There are however a wide range of drawbacks to a Severn Estuary barrage, including a number of significant challenges, with environmental, technical and socio-political challenges associated with the project.

Ideas for damming or barraging the Severn estuary have existed since the 19th century and there is considerable uncertainty as to whether the project will ever go ahead. Between 2008 and 2010 the UK Government undertook the Severn Tidal Power Feasibility study. This study investigated the feasibility of constructing a tidal power project which would use the large tidal range in the Severn Estuary and Bristol Channel to generate electricity. The investigation concluded there was no strategic case for building a barrage, but it was recommended that emerging technologies should continue to be investigated. More recently, in June 2013, the Energy and Climate Change Select Committee published its findings after an 8-month study of the arguments for and against the Barrage. Members of Parliament stated that the case for the Barrage was unproven and were not convinced that the economic case was strong enough, stating that the developer, Hafren Power, had failed to answer serious environmental and economic concerns.

Due to the significant uncertainty and risk surrounding the project and whether it will ever be delivered, a Severn Estuary Barrage has been ruled out from further consideration as a feasible measure to reduce flood risk in Bristol. This measure is a hugely ambitious scheme and is likely to cost multiple billions of pounds and could take several decades to deliver. In the interim, the residual flood risk in Bristol would be unacceptable and it is not viable to plan a long term flood risk management strategy on the assumption that the barrage scheme will be delivered in the future. However, the potential impacts of a future Severn estuary barrage will be qualitatively considered during the Strategy.

As an alternative to a Severn estuary barrage, tidal lagoons represent a different means of generating tidal energy in the area. A potential scheme has been developed for Swansea Bay. However, the impact of lagoons on the water levels away from the site are expected to be marginal (Tidal Lagoon Swansea Bay Plc, Environmental Statement) and therefore Lagoons are not expected to influence the tidal flood risk within the study area. For this reason, tidal lagoons have also been discounted as a feasible measure to manage tidal flood risk in the study area.

- **River Avon tidal barrage** –a tidal barrage could be constructed across the River Avon. The benefits of an Avon barrage would include the control of tidally-dominated water levels within the River Avon to manage tidal flood risk in Bristol, the potential to harness tidal energy to produce electricity, the potential to create a new transport link across the barrage and also the possibility to create an area of permanently raised water levels which may be beneficial for development and aesthetic/recreational purposes.

  Despite the benefits, a barrage across the River Avon is likely to have a number of significant drawbacks.

  To predict the impact of a tidal barrage, it first requires an understanding of the factors (for example, water currents and sediment load) that influence estuary characteristics. Currently there are no studies investigating the potential impacts of a barrage specifically across the River Avon and therefore it is necessary to use studies and evidence from barrages constructed elsewhere to indicate generic barrage impacts. Potential impacts from a barrage construction include:

  - Physical changes; by impounding water behind a barrage for part of the tidal cycle there are typically changes to the estuary basin and channels. Wolf et al. (2008) describe the generic physical changes resulting from a tidal barrage, however, the extent of the impacts depend on the mode of operation and are site specific:

    "The tidal and residual flows will be modified, possibly leading to some local scouring around the structure, specifically in the outflow regions of the turbines and sluices, and siltation in the basin. The amount of vertical mixing will be reduced where the tidal flows are reduced and with less re-suspension the levels of suspended particulate matter will drop, leading to increased light penetration. A reduction in mixing will also lead to an increase in density stratification. There may be a build-up of contaminants both physical and chemical due to reduced flushing rates and in areas of increased flows there may be potential re-suspension of contaminated sediments. This may result in net reduction in water quality. An abundance of nutrients combined with increased light availability may lead to increased primary production, potentially

leading to eutrophication. An increase in average water level inside the basin would lead to a decrease in ground water flows which may have impacts on land drainage."

- Changes to habitat structure; a range of habitats are likely to be affected by a tidal barrage including saltmarsh (an important habitat for birds, fish and plants which depends on sediment transported and deposited for growth at a rate that exceeds sea level rise) and mudflats (an intertidal habitat that is vitally important for migratory birds, and species of invertebrates and fish). A barrage structure, by impounding water and potentially reducing the tidal range in parts of the Avon estuary could lead to an initial loss of intertidal habitat (both mudflat and saltmarsh). When investigating potential habitat impacts for a barrage across the Severn Estuary, a number of conceptual models were developed to try to explain long term change in Habitat structure (e.g. Pethick et al. 2009 and Kirby,R and Shaw, 2005). Parallels can be drawn to these conceptual studies due to the close proximity of the Severn barrage study area to the River Avon. The conceptual model results vary; it is predicted that new habitat would be established almost immediately and also that there will be no gain in habitat because of increased erosion pressure (The Parliamentary Office of Science and Technology (POST), 2013). A 2010 Department of Energy and Climate Change (DECC) study included computer modelling of an ebb-only barrage across the Severn Estuary and predicted a number of impacts including a loss of more than 36-63% of intertidal habitat (POST, 2013). In order for a barrage across the River Avon to be granted permissions, under WFD legislation, compensatory habitats within the River Avon waterbody would need to be secured. It is likely that space for compensation habitats would be limited in the developed River Avon catchment.
- Changes to water quality; a barrage across the River Avon is likely to change the hydrodynamics and levels of suspended sediment which have important implications for water quality. The amount of time which water spends in an estuary and the existing level of nutrients, pathogens and metals are the key factors which determine the potential water quality impacts of a barrage. Currently there are a number of Wessex Water Combined Sewer Overflows (CSOs) that currently discharge to the River Avon and help to maintain serviceability of the largely combined sewer network of Bristol. The water quality impacts of a barrage are important for both the recreational use of the River Avon (navigation routes and potential recreational uses of the impounded reservoir) and for environmental reasons (pollution, dissolved oxygen levels and debris management). Conceptual models of a barrage across the River Avon would be required to establish the potential water quality impacts, to both the environment and recreational purposes.
- Changes to biodiversity; No studies of existing barrages have assessed the overall change in species diversity and abundance. The impact on biodiversity is likely to depend upon the extent and type of habitat loss / creation following barrage construction. With SAC, Ramsar and SPA designations close to potential barrage locations across the River Avon, the impact that a barrage may have on bird populations is likely to be of high concern. In 1999, a barrage was constructed in Cardiff Bay and studies have revealed a displacement of a number of bird species to neighbouring sites, with displaced birds showing reduced survival rates compared to non-displaced birds (Burton, 2006). In both the Eastern Scheldt storm surge barrier (Netherlands) and Cardiff Bay scheme there have been declines or local extinctions of wader bird species (Van Zanten and Adriaanse, 2008; Burton , 2006).
- Fish Mortality; there are two categories of threats to fish from a tidal barrage, direct and indirect. Direct threat is the potential injury and mortality due to blade strike and water conditions (i.e. water pressure) from a barrage and indirect threat is the loss and degradation of habitat which may be important for feeding and spawning, and disruption to movement and migration routes (POST, 2013). Each of these threats would be expected to increase with a tidal barrage across the River Avon which could detriment the fish species found in the Avon. In addition to the threats already outlined, fish commonly suffer disorientation during turbine passage which increases predation risk, this has been observed at the La Rance tidal barrage (France).
- Landscape impacts; the character of an area and the landscape may be drastically changed if a tidal barrage is constructed (Wolf et al. 2008). To provide a flood risk benefit to Bristol a barrage would need to be located downstream of the city. As outlined in the Environmental baseline report, the landscape of the area downstream is characterised by natural river valleys, wetlands and grasslands. As a tidal barrage would significantly alter the landscape, objections to the project may be raised on this basis. However there are likely to be pros and cons as some people may find the intrusion objectionable but others may find that it adds interest (Wolf et al. 2008).

Concerns could to be raised from residential properties at Pill and Ham Green which currently overlook the natural landscape and river channel.

- One may expect the raised / impounded water levels in the reservoir behind a barrage to potentially provide opportunities for a variety of recreational and development activities. However, depending on the barrier location, the benefit is likely to be very limited given that the water level in central Bristol (where the majority of the opportunities are likely to arise) is already controlled and effectively managed by the Floating Harbour water level control system. As such, within the study site a barrage will only have an impact on water levels in the new cut river channel which may be of little benefit to recreational and development opportunities in central Bristol.
- During periods of high fluvial / pluvial flows the water level of the impounded reservoir would need to be lowered to increase the storage capacity and to prevent increases in fluvial flood risk. Numerical modelling should be undertaken to determine the frequency that this is likely to be required. The lowering of impounded water levels prior to high fluvial flows is likely to limit the use and amenity potential of the impounded upstream 'reservoir', thus reducing the significance of one of the key benefits of the barrage. There is also potentially a risk that if impounded water levels were not lowered (i.e. due operational failure of the barrage, forecasting error etc.) during high fluvial flows then tidal locking of the barrage sluices / gates could occur, increasing the residual risk of flooding to Bristol city centre and the wider area. Depending on the location of a barrage there are also a number of fluvial / surface water outflows including Mylne's Culvert, Malago Interceptor, Old Course culvert and the Colliter Brook Culvert which could also be at risk of tide locking, increasing the residual risk of flooding upstream. Numerical modelling would be required to substantiate the tide locking risk during joint-probability events.
- The construction of a barrage may lead to increased build-up of sediment in the storage reservoir and could block the flow of sediment downstream. Depending on the sediment availability and pathways in the vicinity of the barrage location (i.e. whether the sediment is primarily supplied by the fluvial or marine environment), a build-up of sediment behind the barrage could lead to a 'sediment starved' system. This could potentially lead to erosion of downstream sedimentary deposits, increasing the erosion risk in the area and having knock-on impacts to the slope stability of the channel banks. In addition, given the importance of the sediment supply and saltmarsh / mudflat habitats to the Severn SAC / SPA / Ramsar designations, any potential impacts on sediment dynamics arising from the barrage are likely to be highly significant.

  At the present time, no studies have been undertaken to assess the impact of a barrage on the River Avon on sediment dynamics perspective and there is scope for further studies to undertake sediment transport modelling to better understand this risk.
- A barrage could have a significant impact on the navigation within the estuary / river channel. The River Avon is a busy navigation route with approximately 1300 boat licences/registrations for the 12 month period in 2015 (Association of Inland Navigation Authorities, 2015). To maintain the navigation facility of the River Avon (a key option objective of the Strategy) it would be essential for a barrage structure to include a lock-gate system (which would disrupt traffic flows if the barrage has a road crossing). Whilst this would allow navigation to continue, it could lead to delays in navigation to an already busy traffic route and would require operational maintenance and upkeep. Objections to a barrage may be raised by various stakeholders who may value the existing navigation capacity of the river.
- No studies have been carried out to estimate the cost of a tidal barrage across the River Avon. However, based upon the additional structural, operational, maintenance and infrastructure requirements of a tidal barrage compared to a barrier, one can assume that the cost of a barrage is likely to be considerably greater than that of a barrier (estimated cost of the Severn Barrage approximately £15-25 billion). For instance, the tidal power infrastructure and connectivity and the potential inclusion of a lock-gate system to maintain navigation routes are likely to increase the cost of a barrage. Alongside this are the potential costs of mitigating a range of environmental impacts, such as habitat replacement and safe fish passing routes which are also likely to significantly increase capital and maintenance costs.

In summary, evidence has been collected from barrage projects elsewhere which suggest that there are likely to be significant adverse impacts associated with a barrage and it is also likely to be very high cost.

A tidal barrage for flood risk and water level management would seem not to provide much greater benefit when compared to a tidal barrier to warrant a greater impact on the environment and restrictions on navigation that would arise. It also seems likely, based on assessments at other sites, that the cost would be significantly higher. Therefore from a flood risk perspective it does not warrant being taken forward to the options shortlist.

However, a tidal power barrage at a downstream location could be combined with a second road crossing of the Avon, to create a project with multiple benefits and revenue streams, with flood risk being a secondary benefit (rather than the primary benefit that a tidal barrier would provide).

Although the technical challenges and environmental impacts (e.g. sediments, water quality) should not be underestimated, potential energy revenues could make a barrage project financially viable, where a barrier (without a revenue stream) may not be affordable.

There are a number of tidal power projects currently being proposed or studied in the UK, including the Swansea Lagoon, and their economic viability is ultimately determined by energy pricing policy. Viable projects will receive attention from project promoters wishing to take them forward, but non-viable projects will stall. Reliance on a tidal power project to provide flood risk management therefore has a risk of a long planning/financing period and the project not being implemented. Reliable information on viability is crucial if such an option is to be taken forward.

Given the scope of the current study, and the lack of any existing studies of tidal power on the Avon with current information on costs and revenues, it isn't possible for the current study to take this option forward.

It is therefore recommended that an Avon tidal barrage option is scoped out at this stage, and not taken forward to shortlisting. However, BCC may consider it would be prudent to commission a high-level tidal power and second Avon crossing study as parallel, additional activities to the current study, and if the results were positive the barrage option could potentially be reintroduced during the short list appraisal phase of the current study.

- **Property / City relocation** – Relocating properties in Bristol from areas currently at risk of tidal flooding could help to reduce the impacts and consequences of flooding. However this approach is considered to be socially, economically and politically impractical and unacceptable. In addition, on a city wide scale, this measure conflicts with the Joint Spatial Plan, Bristol Local Plan, and also a number of the Strategy option appraisal objectives.

  There are likely to be widespread objections by property owners and the general public to relocation, as it could influence property value and local commercial markets (amongst other impacts). Strong and numerous local objections have the potential to make this option technically impractical and very difficult to implement. Recreational and amenity access to the waterfront areas within Bristol is an important aspect of the local economy and indirect impacts should be expected to occur should waterfront access be limited.

- **Reducing water levels to increase the storage capacity of the Floating Harbour** – This option has been scoped out due to technical concerns surrounding the structural integrity of the harbour walls, quayside walls and retaining walls.

  To increase the storage capacity of the Floating Harbour the water level in the harbour would have to be reduced prior to a flood event. This water level drawdown could lead to the collapse of the harbour walls which would pose a significant health and safety risk to people in and around central Bristol, as well as potentially damaging properties and infrastructure in the area. Under an extreme tidal event this option would also not provide sufficient storage volume to prevent widespread damage.

  Structural surveys are required to provide more information and a greater understanding of the structural concerns, but based upon the liaison with the project team which has highlighted the concerns, this measure has been scoped out from further assessment.

- **Wholesale land raising in the flood plain** – On a city-wide scale this measure would be impractical due to the size of the area that would need raising, land ownership issues and the potential impact on existing infrastructure, heritage, environmental and archaeological assets. In addition, wholesale raising could to lead to a fluvial and surface water detriment to adjacent areas due to insufficient space for compensatory storage.

  However, future developments should consider including land raising and integrating this with flood protection measures of adjacent sites to form a robust local defence against likely sea level rise. This localised land raising approach is considered in section 3.3 below.

- **Fluvial flood diversion channels** – A number of fluvial diversion channels are already in place along key watercourses in the study area, such as the Frome, Malago and Brislington Brook. As a result the flood risk benefits of these diversion channels have already been realised.

Constructing additional fluvial flood diversion channels upstream of Bristol, on the River Avon for instance, may serve to reduce the fluvial flood risk to some areas but are unlikely to provide significant flood risk benefits to tidal flood risk (the primary objective of the Strategy). In addition, this diversion channels are expected to be very costly and it will be difficult to justify a business case for the approach.

Finally, diversion channels typically span a large spatial area and significant disruption is likely to be caused to the environment and land-owners which may present a number of challenges towards implementation. For these reasons fluvial flood diversion channels have been scoped out of the assessment as a measure to address tidal flood risk.

3.3 Feasible measures

Following the scoping exercise, the measures remaining in the appraisal process are considered feasible and form the basis of potential solutions to manage the tidal flood risk in Bristol. The remaining measures are categorised as 'primary' and 'secondary' measures. 'Primary' measures provide the greatest reductions in flood risk and form the basis of the option selection process. On the other hand it is envisaged that the 'secondary' measures are used in support of the primary measures to reduce the consequences and improve the response to flooding as the Strategy is implemented. A combination of both primary and secondary measures will help to ensure a strategic approach to flood risk management is realised.

Some of the feasible measures are very similar, for example 'property level protection' has a similar ethos to 'demountable / temporary flood defences'. In cases such as this, similar measures have been grouped together and it is assumed that grouped measures will be undertaken simultaneously as part of an integrated approach to flood risk management.

Do Minimum and Do Nothing approaches to flood risk management have also been considered in the assessment and are included in the descriptions below. The Do Nothing approach is not considered viable but is included to provide a hypothetical solution from which to compare the relative merits of the Do Minimum and Do Something measures.

The Do Minimum approach is based on the assumption that two of the key secondary measures are undertaken for the duration of the Strategy; the continued maintenance of the existing flood defences and the operation of the Floating Harbour operations and infrastructure.

With the exception of the Do Minimum scenario, the extent to which the secondary measures may or may not be utilised has not been considered in detail at this stage of the appraisal. Any of the secondary measures, such as local land raising or development planning may be undertaken alongside each of the primary Do Something measures or the Do Minimum approach.

However, given the large number of total option combinations that may arise from incorporating different primary and secondary measures, the appraisal has instead focussed on sequences of primary measures, on the basis that secondary measures can be utilised freely alongside the preferred strategic approach as the Strategy is implemented in the future.

More details of the approach and sequences of primary measures are provided in Chapter 4.

A brief description of the 'primary' feasible management measures is provided below:

- **Low defences or crest raising (e.g. low walls, flood gates, embankments etc.)** – these measure involves identifying 'low' spots in the existing defences and constructing new 'low' floodwalls or similar defences or raising existing defence crest levels.

  In terms of defining a 'low' wall, this can be viewed as a wall that is intended to provide a required Standard of Protection (SoP) for the short to medium term period but does not account for longer term sea level rise i.e. an interim solution that could be adapted in the future to mitigate future sea level rise.

  The new defences or crest raising will be constructed to a height to protect against significant tidal risk, with the optimal standard of protection to be determined through the options appraisal process. The work already undertaken in CAFRA Workstream 4 and the First Phase Feasibility study has identified potential 'low' spots in existing defences at Avon Crescent, Bathurst Basin and Totterdown Lock / Victor Street.

- **High defences or crest raising (e.g. low walls, flood gates, embankments etc.)** – this measure involves raising existing defence crest levels or constructing new 'high' floodwalls or similar defences to protect areas against future tidal flood risk by considering climate change and potential sea level rise.

In terms of defining a 'high' wall, this type of wall would provide the required SoP for most of or all of the duration of the Strategy period and account for longer term sea level rise i.e. this solution is intended to not require future adaptation / modification to mitigate long term sea level rise predictions. Compared to the 'low defences' approach, this measure will require new defences on a larger scale, in both length and height with the optimal SoP to be determined through the options appraisal process.

- **Local scale measures, property protection and temporary defences** – this approach groups property level protection measures and demountable / temporary defences. These interventions are similar in ethos and it is considered practical to implement these measures simultaneously as part of an integrated approach at various locations across Bristol. Potential locations for property level protection and demountable / temporary flood defences will be assessed during the option appraisal process.
- **Wide tidal barrier (and associated defences)** – a tidal barrier across the River Avon is considered a potentially effective measure to manage predicted tidally dominated flood risk in Bristol. Two high level approaches have been identified for the long list, a 'wide' barrier solution and a 'narrow' barrier solution. Compared to a tidal barrage across the River Avon, a barrier is likely to be a cheaper solution as it will not include the turbines and connectivity infrastructure to produce tidal energy (additional studies would be necessary to confirm this judgement), is expected to have reduced operational and maintenance costs and will likely require less mitigation of impacts. The cost of a barrier relates to its position within the River Avon (with a narrower barrier expected to be lower cost), and at this stage of the assessment there is insufficient evidence to identify the preferred barrier location and therefore both a wide and narrow barrier are taken forward for further assessment.

  The 'wide' barrier concept is based on the preferred position identified in the Pre-Feasibility Study, far downstream from Bristol (potentially close to the M5 road bridge i.e. in Section 1 of the river or the western end of Section 2 shown on Figure 1) and may allow for a maximum fluvial attenuation storage capacity. In terms of defining 'wide', this type of barrier should be considered for the wider sections of the river (not just near Avonmouth). Based on the variation in river width, this is likely to result in the barrier spanning, approximately, over 100m, and potentially increasing up to the order of 200-300m. The exact position of the wide barrier solution will be assessed during the options appraisal process.

  As part of a wide barrier solution, additional defences (such as walls or embankments) are likely to be required to tie into higher ground levels to ensure protection against both fluvial and tidal flood risk. These defences are included as part of this measure.
- **Narrow tidal barrier (and associated defences)** – a 'narrow' barrier would be located in a position downstream of Bristol but upstream of the 'wide' barrier solution where the River Avon is narrower. A narrow barrier is expected to be cheaper than the wide barrier solution. For the purposes of definition, this type of barrier is more applicable to Section 2 of the river shown in Figure 1, as opposed to Section 1. In terms of defining 'narrow', the river dimensions result in this barrier being less than, approximately, 100m in width. The optimal position of a narrow barrier will be assessed during the short-listing phase of the options appraisal process.

  As part of a narrow barrier solution, additional defences (such as walls or embankments) are likely to be required to tie into higher ground levels to ensure protection against both fluvial and tidal flood risk. These defences are included as part of this measure.
- **Do Minimum** – Do minimum represents what happens if the 'status quo' is maintained. This involves a continuation of maintenance both the existing Floating Harbour water level control structures and raised defences throughout the duration of the Strategy period (a combination of two separate 'secondary' measures described below).

  It is assumed that under this approach 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).

  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) will be maintained to ensure their flood defence function continues; however, the defences will not be raised and consequently the standard of flood protection will fall over time in response to sea level rise.
- **Do Nothing** – 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). Doing nothing is not considered a viable long term approach in Bristol but has been included as it provides a hypothetical baseline against which all other measures and strategic options can be compared.

Under this approach, all maintenance, repair and renewal work of existing flood defences, together with assets whose function influences flood risk (e.g. lock gates) would cease immediately. There would be no investment in asset maintenance from the present day onwards. If this option 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 fail and 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.

As sea levels rise and the defence condition deteriorates, flood risk would increase significantly from both failure of the defences and through inundation over areas of low-lying topography. 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 this approach would be politically unacceptable.

This approach would 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.

For a detailed breakdown of the assumed time periods in which specific defences are likely to fail under the Do Nothing scenario please refer to the Baseline scenarios technical note.

The 'secondary' feasible measures, which can be used to supplement the 'primary' measures include:

- the continued **maintenance** of the existing flood defences within Bristol to maintain the structural integrity and condition of defences that provide a flood risk benefit (it is assumed that maintenance will be carried out alongside the primary Do Something measures and that maintenance is also undertaken as part of the Do Minimum approach). Further appraisal work is required to prioritise maintenance efforts and expenditure;
- the **continued operation of the Floating Harbour operations and infrastructure** to help reduce the chance of flooding during periods of high fluvial and/or tidal water levels (it is assumed that this will be carried out alongside the primary Do Something measures and that it is also undertaken as part of the Do Minimum approach);
- the **optimisation of the Floating Harbour operations and infrastructure** to minimise the chance of flooding during periods of high fluvial and/or tidal water levels. Optimal operation of the Harbour water level control structures may vary according to the magnitude of flood event and therefore further studies specifically investigating optimal operational procedures are required;
- **development planning and urban renewal,** could be carried out alongside a primary Do Something option or the Do Minimum approach to minimise flood risk to new developments and ensure optimal funding avenues for future flood defences;
- **localised land raising** carried out as part of development in flood risk areas. This process should be supported by planning regulations and consider the potential impacts on flood risk in adjacent areas. Potential for this to be carried out alongside a primary Do Something option or the Do Minimum approach, although it may not be required if a barrier is constructed as a barrier would reduce flood risk on a city wide scale and land raising of local developments may not necessarily be required;
- **compartmentalisation of the floodplain** through selective land raising to provide preferential flood routes across the floodplain to storage areas;
- **flood forecasting and warning systems**, essential for some primary Do Something options (e.g. necessary to successfully operate a tidal barrier and also the access gates which are likely to be installed as part of raised defences) and could also be added to the Do Minimum approach to improve community response to flood events;
- the development of **flood emergency and evacuation plans** to limit the consequences of flooding should it occur, should be carried out alongside a primary Do Something option or the Do Minimum approach; and
- flooding **awareness and education**

4. LONG LIST STRATEGIC OPTIONS

The next stage of the process was to develop a range of Strategic Options. A Strategic Option lays out a sequence of feasible, coherent and logical primary measures to be implemented over the duration of the Strategy appraisal period (2015-2115).

For each Strategic option a primary measure was assigned to each time epoch, so for instance a Strategic option may suggest maintenance and resilience in the short term (2015-2030), the construction of low flood walls in the medium term (2030-2065) and finally the construction of a narrow tidal barrier in the long term (2065-2115). Note that whilst the Do Nothing measure is not considered a feasible long term approach in Bristol, it is included in this assessment to provide a baseline against which to compare the relative merits of the other options.

To ensure that this stage of the appraisal was robust, and that each potential combination of measures was considered, an 'options tree' was created which mapped each potential sequence of measures. From here, the impractical combinations were discounted and scoped out from further consideration. Figure 3 presents the final 'options tree' with the impractical sequences removed. In total 39 different sequences remain on the tree in Figure 3, 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 3.

At this stage of the options appraisal process, the Strategic Options represent logical sequences of measures to manage tidal flood risk in the study area. However, as the Strategy progresses, and the list of options is scoped down to the shortlist, more detail such as potential locations, thresholds and trigger levels applicable to the implementation of each option will be developed.

Some examples of illogical, undeliverable or nonsensical options that have been removed from the 'options tree' (Figure 3) 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 walls 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 walls after this in the long term (2065-2115).
- Example of an illogical option (2) – construct high walls 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 walls 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 3) 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.

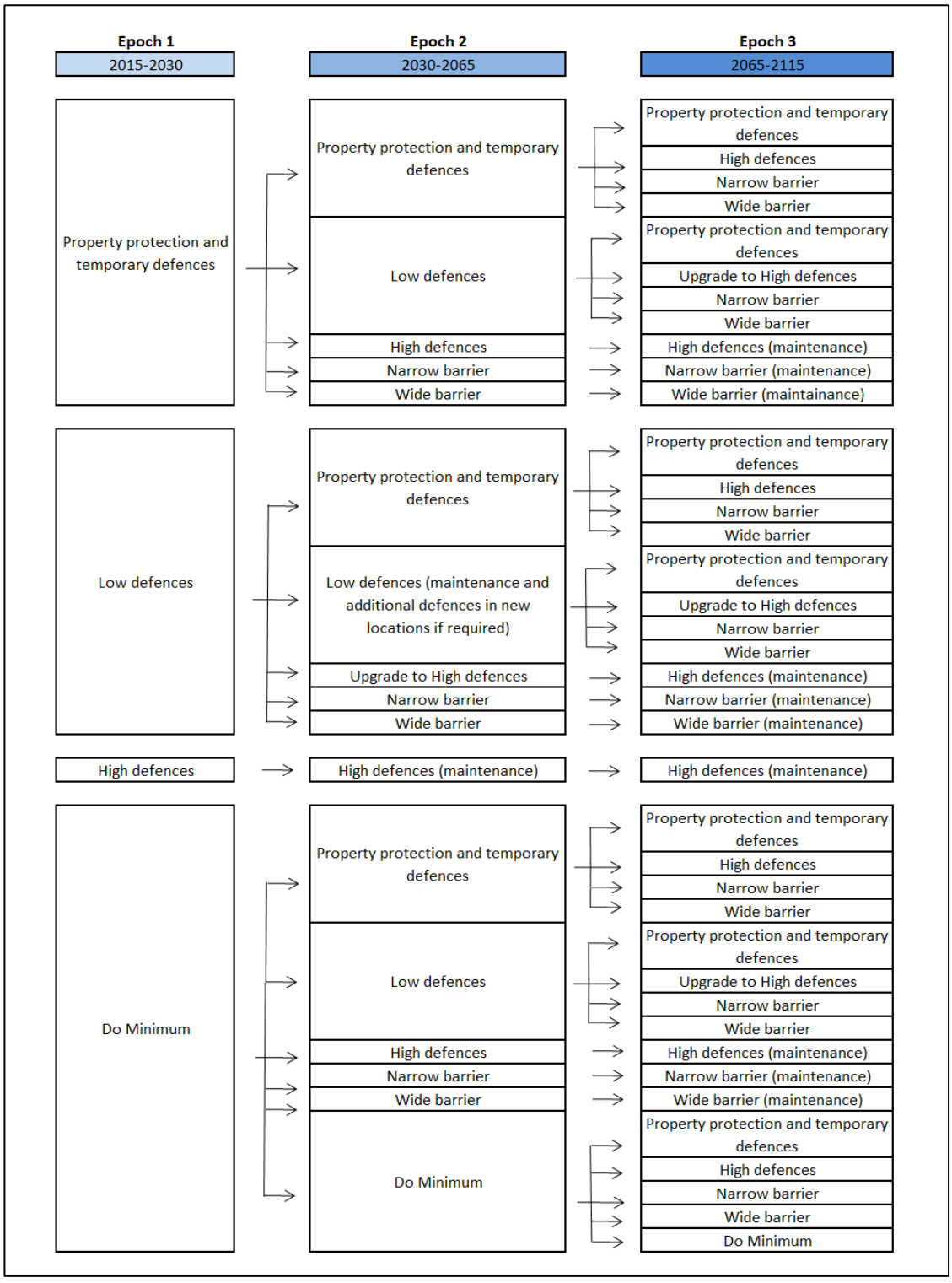

Figure 3. Tree of feasible measures and sequences leading to the long list of Strategic Options - *Figure 3 presents the feasible sequences of measures leading to the long list of Strategic Options. In total 39 different sequences or Strategic Options have been identified for the long list (each of which is shown in Figure 3).*

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 are 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).

5. LONG LIST APPRAISAL

5.1 Appraisal methodology

In total 39 long list options have been developed and are presented in Figure 3. The next step in the appraisal process involves appraisal of the long list of Strategic Options down to a short list. It is anticipated that a short list of strategic options will be identified and then worked up in more detail (in terms of potential standards, indicative route alignment, indicative locations, spatial variation and applicability etc.). These will then be subjected to a more detailed qualitative and quantitative multivariate assessment in the later stages of the Strategy development process.

A multi-criteria assessment utilising the option objectives will be used to appraise the long list options in order to reduce them down to a shortlist worthy of more detailed appraisal.

This will involve assessing the impact of the long list options against each of the six strategy option objectives (presented in section 1.5 of this report). A scoring system will be applied to score the options relative to the Do Nothing scenario and this will allow for the relative merits and drawbacks of the long list options to be compared. Supporting narrative and commentary will be used to capture the rationale and explain nuances or where there are exceptions to an overall rating. Typically a numerical scoring system between -+2 to -2 will be used to score each option against the option objectives, however, for objective 1, which relates to flood risk, a scoring system between +3 to -3 will be used to better discriminate between the flood risk benefits of the options.

An overview of the scoring system is outlined in Table 1 below.

Table 1. Assessment 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 significantly decreases the standard of flood protection and the safety of people in and around central Bristol compared to the Do Nothing scenario.
		- -	Moderate negative impact	Option moderately decreases the standard of flood protection and the safety of people in and around central Bristol compared to the Do Nothing scenario.
		-	Minor negative impact	Option marginally decreases in the standard of flood protection and the safety of people in and around central Bristol compared to the Do Nothing scenario.
		0	No impact	No impact on the standard of flood protection or the safety of people in and around central Bristol compared to the Do Nothing scenario.
		+	Minor positive impact	Option provides a minor improvement to the standard of flood protection and increases the safety of people in and around central Bristol compared to the Do Nothing scenario.
		+ +	Moderate positive impact	Option provides a moderate improvement to the standard of flood protection and increases the safety of people in and around central Bristol compared to the Do Nothing scenario.
		+ + +	Significant positive impact	Option provides a significant improvement to the standard of flood protection and significantly increases the safety of people in and around central Bristol compared to the Do Nothing scenario.

Objective	Criteria	Score	Impact	Description
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 growth and fully supports the sustainable growth of Bristol and the wider West of England economy compared to the Do Nothing scenario.
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 enhances 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.

Objective	Criteria	Score	Impact	Description
4. To reduce whole life costs, with consideration of reactive emergency response, and to ensure the strategy is fundable	Whole life cost and funding	- -	Significant negative impact	Option is very high cost and significantly increases the whole life costs of the Strategy. The option is likely to require a very large amount of private funding which is not likely to be attained.
		-	Minor negative impact	Option is high cost and increases the whole the life costs of the Strategy. The option is likely to require a significant level of private funding but this is potentially achievable.
		0	No impact	NA – cost of options cannot be compared to that of Do Nothing and therefore the options are ranked on a relative scale.
		+	Minor positive impact	Option is low cost and provides some reductions to the whole life cost of the Strategy. The option is likely to require only a moderate level of funding to be implemented or is likely to receive the partnership funding or the required contribution in the timescale it is required.
		+ +	Significant positive impact	Option is very low cost and significantly reduces the whole life costs of the Strategy. Option is likely to only require a minimal level of funding to be implemented or is very likely to receive partnership funding or the required contribution in the timescale required.
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 does not impact navigation and marine activities along the River Avon compared to the Do Nothing scenario
		+	Minor positive impact	Option enhances marine activities and navigation routes along the River Avon compared to the Do Nothing scenario.
		+ +	Significant positive impact	Option significantly enhances navigation routes and marine activities 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. 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.

Objective	Criteria	Score	Impact	Description
		0	No impact	NA – deliverability of options cannot be compared to that of Do Nothing and therefore the options are ranked on a relative scale.
		+	Minor positive impact	Option is technically feasible. Potential that achieving funding / consenting / construction which could impact delivery of option, although the likelihood is small.
		+ +	Significant positive impact	Technically most feasible options. Very low risk of extended timescales to achieve funding / consenting / construction that may impact the delivery of the option.

The multi-criteria assessment will be carried out by the project team, minimising the risk of subjectivity when scoring the options. The assessment will be used to 'funnel down' to the 5-6 options with the highest total score across the eight option objectives. These options will be taken forward to the short list. AECOM will undertake the initial scoring of options, but will seek wider project team and key stakeholder support before confirming the short-list options.

Once the short list of options has been identified, the short list options will be developed further by considering more comprehensive details including the:

- Spatial scale of the option (i.e. Strategy wide approach to manage risk or an individual or a series of local interventions e.g. by flood cell)
- Option location and potential alignments
- Optimal standards of protection
- Economic cost and benefit of the options
- Funding and deliverability
- Environmental and social impacts of the options

6. NEXT STEPS

Once the short-list has been confirmed a number of supporting studies and tasks will be undertaken to inform the detailed appraisal of the short list options. These include:

- Numerical modelling to establish the 'Do Nothing' flood risk and economic damages. Scenario runs of the short-list options will also be undertaken to determine the economic benefits of implementing the options.
- A benefit: cost economic assessment and affordability check.
- The development and definition of the range of 'Futures' (i.e. development, climate change and funding); considering different likely scenarios for development, funding and climate change which will be used to sensitivity check the short-list options.
- Environmental screening to establish the likely environmental impacts and opportunities of the short-list options and to identify suitable mitigation measures (if necessary).
- Intervention / measure technical feasibility assessment, including numerical modelling to establish the preferred locations.
- Facilitated key stakeholder input via workshops and meetings.

7. REFERENCES

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