RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Baseline Review – Briefing Report

April 2016

Prepared for Bristol City Council

Issue	Date	Details	Prepared by	Checked by	Approved by
1	11/01/16	Initial draft for client review	**Ben Taylor** Graduate Coastal Engineer **Jonathan Short** Senior Coastal Specialist	**Jason Drummond** Principal Flood and Coastal Specialist	**David Dales** Director
2	29/01/16	Updated issue following client review	**Ben Taylor** Assistant Coastal Engineer **Jonathan Short** Senior Coastal Specialist	**Jason Drummond** Principal Flood and Coastal Specialist	**David Dales** Director
3	18/04/16	Updated, final issue following client review	**Ben Taylor** Assistant Coastal Engineer **Jonathan Short** Senior Coastal Specialist	**Jason Drummond** Principal Flood and Coastal Specialist	**David Dales** Director

Scott House
Alencon Link
Basingstoke
Hampshire
RG21 7PP

Limitations

AECOM Infrastructure & Environment UK Limited ("AECOM") has prepared this Report for the sole use of **Bristol City Council** in accordance with the Agreement under which our services were performed **[River Avon Tidal Flood Risk Management Strategy RESP1007626 (23/10/15) and Response to Tender Submission Clarifications (03/11/15)]**. No other warranty, expressed or implied, is made as to the professional advice included in this Report or any other services provided by AECOM. The report takes into account the particular instructions and requirements of Bristol City Council. It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

The conclusions and recommendations contained in this Report are based upon information provided by others and upon the assumption that all relevant information has been provided by those parties from whom it has been requested and that such information is accurate. Information obtained by AECOM has not been independently verified by AECOM, unless otherwise stated in the Report.

The methodology adopted and the sources of information used by AECOM in providing its services are outlined in this Report. The work described in this Report was undertaken between December 2015 and April 2016 and is based on the conditions encountered and the information available during the said period of time. The scope of this Report and the services are accordingly factually limited by these circumstances.

Where assessments of works or costs identified in this Report are made, such assessments are based upon the information available at the time and where appropriate are subject to further investigations or information which may become available.

AECOM disclaim any undertaking or obligation to advise any person of any change in any matter affecting the Report, which may come or be brought to AECOM's attention after the date of the Report.

Certain statements made in the Report that are not historical facts may constitute estimates, projections or other forward-looking statements and even though they are based on reasonable assumptions as of the date of the Report, such forward-looking statements by their nature involve risks and uncertainties that could cause actual results to differ materially from the results predicted. AECOM specifically does not guarantee or warrant any estimate or projections contained in this Report, but does take into account the particular instructions and requirements of Bristol City Council.

Copyright

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Project background

A tidal risk management strategy for Bristol is vitally important for the city, 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 performance.

This project will deliver a Tidal Flood Risk Management Strategy (the 'Strategy'). This will recommend an adaptive programme; identify when FRM interventions are needed and how they will be funded.

The Strategy, once adopted by BCC's Cabinet following a Key Decision, will provide evidence to support the future review of Bristol's Local Plan. The Strategy may conclude that no strategic intervention is justified for some time if, for instance, another possible form of intervention(s) can achieve the objectives.

1.2 Scope of baseline review

The purpose of this briefing report is to set out and discuss the key findings from an initial review of previous work. Given the wealth of previous work and existing data this report is not intended to provide a verbatim account of the baseline or project background; rather it is focussed on signposting key information and providing 'highlights' with concise and proportionate commentary and on the problem, themes and issues to be addressed. It also sets out the project and option appraisal objectives and highlights the key baseline information required. Setting and agreeing these parameters is a key step in prior to the development and appraisal of Strategy options.

Key aspects of the report include:

- Confirmation of the project objectives
- Confirmation of the study area and project boundaries
- Confirmation of the Strategy appraisal period and epochs being used
- Key findings and a review of suitability of existing data including:
    - Extreme water levels
    - Climate Change and Sea Level Rise
    - Approach to joint probability
    - Hydraulic modelling
    - Condition of key defences
    - Flood risk mechanisms
    - Previous economic appraisal work
- Environmental baseline / objectives
- Review of previous option appraisal assessments
- High level appraisal of barrier solution
- Social, Political and planning issues and opportunities
- Potential Futures
- Uncertainties and data gaps
- A summary of recent Key Stakeholder Feedback
- Confirmation of option objectives (to be used in the appraisal)
- Next Steps

1.3 Project Objectives

The project objectives 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.

1.4 Project Boundaries

- The project focus is 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. Therefore, the study area has been split into three reaches to reflect the change in geomorphological, nature conservation designation and landscape characteristics, and particularly the significance of flood risk i.e. Reach 3 relates to the principal area of risk, the city of Bristol. These are shown as coloured sections on the centreline of the river.
- Figure 1 presents the project area alongside an estimate of the area potentially at risk from tidal flooding. This figure shows the maximum theoretical flood extent without defences (determined using predicted extreme water levels and land elevation - i.e. a 'bathtub' approach) to identify the maximum spatial extent for the Strategy to consider. This extent, shown as the 'Upper End 2115 1:200 year event' effectively shows the Environment Agency's Flood Zone 3 of the future, incorporating sea level rise allowance that is appropriate for planning purposes i.e. precautionary. A more accurate depiction of the areas at risk will be available following the completion of the updated baseline numerical flood modelling.
- Flood risk is dominated by tidal events (approx. downstream of Avon Bridge) and this will be the focus of options and economic appraisal; however consideration for residual pluvial and fluvial flood risk is to be given and options addressing tidal flood risk must be demonstrated not to detrimentally increase flood risk from other sources.
- The tidally dominated flood extent within the study area can be split into a number of distinct flood cells. These include the city centre area to the north of the Floating Harbour, the area south of the New Cut, St Phillips, and the area downstream of Bristol at Shirehampton/Sea Mills and Pill towards the mouth of the River Avon.

1.5 Epochs

The Strategy is to appraise options and outline a preferred strategic approach to managing tidal flood risk over the next 100 years (2015 – 2115). To facilitate this, the 100 year appraisal period has been split into a 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 'trigger thresholds' or '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. To assist with the presentation of this the Strategy interventions will be mapped out in time but also against a timeless axis (using water levels showing the various trigger thresholds). The trigger thresholds will be determined by identifying the existing standard of protection of defences and the resultant magnitude of sea level rise which can occur before the standard of protection drops below the target standard. Once the magnitude of sea level rise surpasses this threshold a defence upgrade will be required to increase the standard of protection back to target levels. A sensitivity test of climate change projections will be considered in the timeline axis to give

indicative time periods in which the trigger thresholds are most likely to be exceeded under a range of different climate change scenarios.

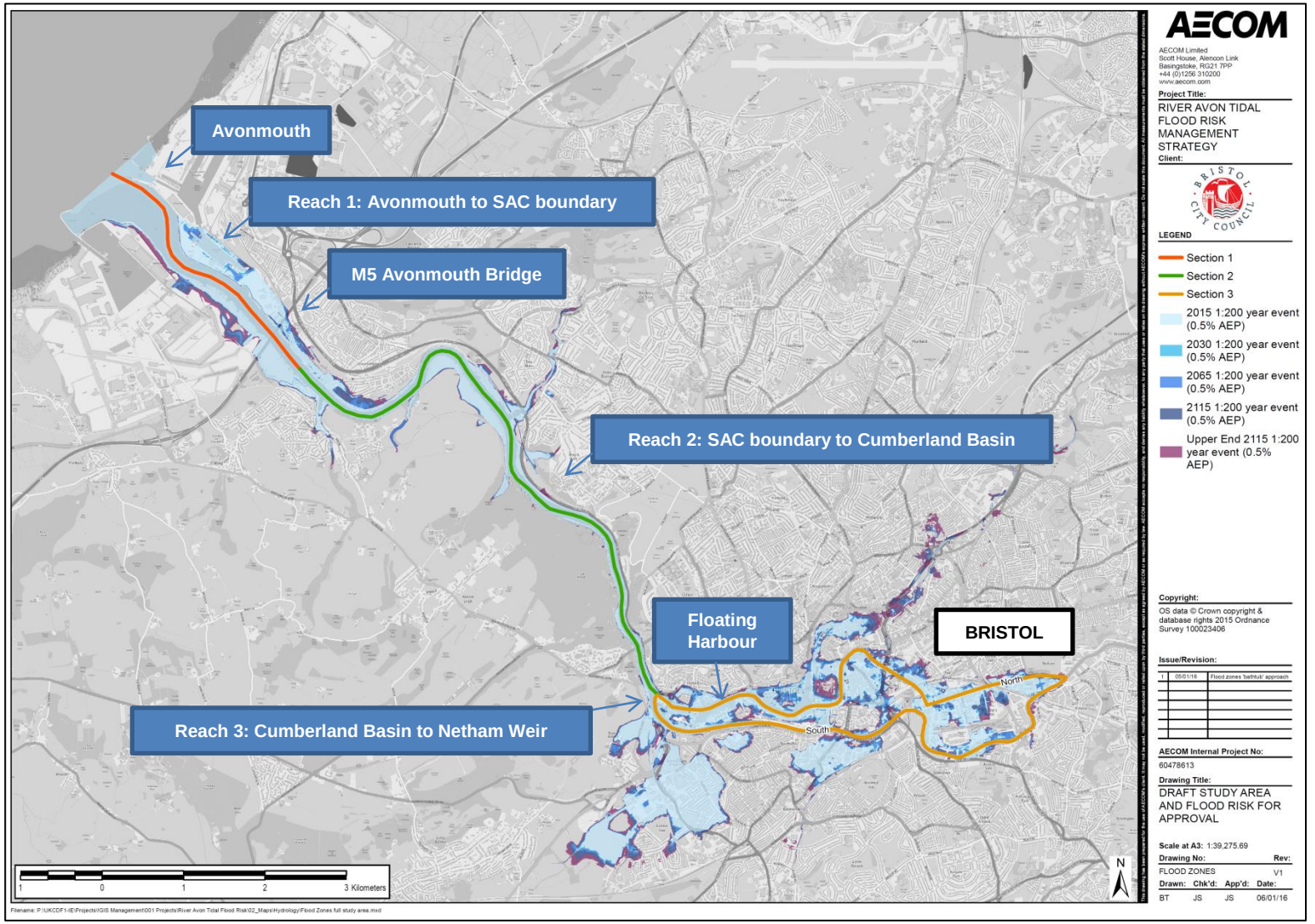


Figure 1. Project boundaries, reaches and tidal flood risk

1.6 Key references and previous work

1.6.1 *Bristol Central Area Flood Risk Assessment (CAFRA)*

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. The scope of each CAFRA workstream is outlined below:

- *Workstream 1* – collection and review of existing hydraulic models, studies and survey data
- *Workstream 2* – hydrological statistical analysis of key sub-catchments to derive peak flows, which were combined with upper end tidal levels to inform the hydraulic model boundary conditions for the remaining workstreams. The workstream also considered the joint probability of high river flows coinciding with tidal surges and assessed climate change impacts for future time periods (2060 and 2110).
- *Workstream 3 (2012)* – the 1D-2D hydrodynamic model build of the study area. Combined predictions of flood water peak depth and extent were prepared for present day and with climate change allowances. The predicted flood with was assessed as the maximum of a composite range of tidal and fluvial events with the same probability of occurrence.
- *Workstream 4 (2012)* – a review of the fluvially-dominated flood risk was carried out and fluvial flood risk management interventions were scoped alongside an assessment of the North Storm Water Interceptor (NSWI) operational procedure. A parallel Harbour Study was also included in Workstream 4 which focussed on the tidally dominated central Bristol area with separate modelling. The Harbour study built on the work of the Floating Harbour Asset Management Strategy, scoped tidal flood risk interventions and reviewed the operational resilience and impact of key structures associated with the Floating Harbour. A pre-feasibility study of a River Avon tidal barrier solution was also undertaken.

Following on from the 2010-2012 CAFRA modelling, Hyder undertook a number of updates to the CAFRA model. Of particular relevance to the Bristol TFRMS is the:

- 2014 assessment of the St Philips Marsh Flood Defences and lower return period events; and
- 2015 update work for climate change scenarios on tidally dominated events

By definition, the existing CAFRA model covers a large area and therefore the CAFRA studies have been undertaken at an appropriately high level strategic scale. This introduces a number of limitations and constraints into the study such as the modelling representation of detailed flood sources, pathways and receptors as well as modelled management interventions such as the Cumberland Road Wall and walls at Bathurst Basin and St Philips Marsh. In addition the joint probability nature of the model creates uncertainty when examining flood risk in upstream fluvial reaches (CAFRA additional model climate change runs report, 2015). Limitations such as this will need to be considered during the development of the Bristol TFRMS.

1.6.2 *First Phase Feasibility Study*

In 2013 Arup was commissioned by Bristol City Council to conduct the first phase high-level feasibility study 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. A prioritised programme for further work was also developed. The flood risk predictions used to inform the study were based on the findings of the CAFRA modelling.

There are a number of limitations associated with the First Phase Feasibility study which should be considered during the development of the Bristol TFRMS. These include the high level nature of the economic damages that were developed, the absence of cost considerations when developing and recommending management options and pre-dating the construction of the Cumberland Road Wall.

1.6.3 *Severn Estuary Shoreline Management Plan 2 (SMP2) (2009)*

The Severn Estuary study area encompasses the shoreline from Lavernock Point (Wales) to Anchor Head, just north of Western Bay (England). The document proposes how the shoreline around the

Severn Estuary (including the Bristol TFRMS study area) should be managed over the next 100 years. The plan provides high level management policies for each policy unit (198 units in total); Hold the Line, No Active Intervention, Managed Realignment, or Advance the Line.

1.6.4 *Bristol Strategic Flood Risk Assessment (SFRA)*

The Level 1 SFRA (Bristol City Council, 2009) mapped all sources of flood risk and provided the evidence base to inform a risk based sequential approach to flood risk. The Level 2 SFRA (Bristol City Council, 2009) then focussed on assessing whether flood risk to, or from, development in flood risk areas will be 'acceptably safe' throughout the lifetime of the proposed developments. The SFRA considered climate change impacts and potential sea level rise and identified that the predicted extent of flooding will increase in the future. A number of flood risk management interventions were proposed.

1.6.5 *Bristol Surface Water Management Plan (SWMP)*

The SWMP (Bristol City Council, 2012) assessed the surface water flood risk in Bristol using integrated urban drainage modelling. Thirteen priority areas at particular risk from surface water flooding were identified.

1.6.6 *Bristol City Core Strategy (adopted 2011)*

The Bristol City Core Strategy forms the primary document in the Bristol Development Framework, which, alongside the Development Management Policies Local Plan and Bristol Central Area Plan will replace the Bristol Local Plan (adopted in 1997). The Core Strategy considers how the city of Bristol will develop over the next 15 to 20 years and will help direct a range of implementation plans and decisions on planning applications. In summary, the Core Strategy sets out the city's main social, physical and economic characteristics, sets a vision of city development, and outlines the means of delivering the vision and objectives.

1.6.7 *Bristol Temple Quarter Enterprise Zone (TQEZ)*

The TQEZ is one of the UK's largest urban regeneration projects. Opened in 2012, the zone aims to attract 4000 jobs by 2017 and 17,000 in the 25 year lifespan of the project. A number of key projects and supporting studies related to the TQEZ are relevant to the Bristol TFRMS.

2. DISCUSSION OF KEY FINDINGS

2.1 Hydrodynamic modelling summary

A review of the updated CAFRA model build setup, results and modelling approaches has been undertaken by an AECOM principal modeller and the suitability of using this model to support the development of options in the TFRMS was assessed. The findings and recommendations of this review are provided in a forthcoming Baseline Modelling Review Briefing Report.

Since project inception an alternative hydraulic model has been available from the Bristol City Council Phase 3 City Docks Study (Edenvale Young, 2013). This model has a greatly reduced run time compared to the CAFRA model due to less onerous computational requirements. This model has been used previously to test a large number of options scenarios and this data may be used as supporting information for the assessment of options. However, a review and testing of the EVY model to assess its relative merits and drawbacks and potential suitability for use in this study is not currently covered within the existing scope of work; therefore, unless instructed to undertake this additional task through a compensation event it is proposed that the updated CAFRA model (or a simplified version thereof) is adopted for use in this study. –see separate Baseline Modelling Review Report for more detail on the approach.

2.2 Joint probability approach

Workstream 2 of the original 2010-2012 CAFRA modelling study was concerned with deriving boundary conditions for the hydraulic modelling in Workstream 4. The derivation of boundary conditions consisted of two elements; tidal/fluvial joint probability analysis and hydrological analysis of the fluvial catchment. This section of the report provides a brief summary of the joint probability analysis that was undertaken in workstream 2.

The joint probability analysis undertaken was based on the most recent guidance available at the time, the FD2308 Defra and Environment Agency reports (2005 – 2006) to determine the individual return periods for the tidal and fluvial extreme events which combine to give the required joint probability events. This guidance is still relevant for use in fluvial/tidal joint probability analysis and therefore as the derived values and results have been previously approved and adopted there is no apparent requirement to update the joint probability analysis for the Bristol TFRMS.

The joint probability analysis undertaken in Workstream 2 is based on an assumption about the level of dependence between peak river flow in the Avon and maximum surge at Avonmouth. The analysis is based on a dependence (X) of 0.11 between the Bathford flow gauge and the Avonmouth tide gauge. This is a high value of dependence and reflects a strong correlation between daily river flow in the Avon at Bathford and surge at the Avonmouth tide gauge.

Based on the high dependence value, X=0.11, for each of the five joint probability scenarios assessed in CAFRA (and required for the Bristol TFRMS), five fluvial / tidal combinations were derived, see example in Table 1 for a 1 in 200 year joint probability scenario.

Table 1. Example of fluvial / tidal event combinations making up the 1:200 year joint probability scenario

Combined return period (years)	Tidal event return period (years)	Fluvial event return period (years)
200	200	2
	100	5
	20	24
	5	97
	2	200

For the purposes of the Bristol TFRMS it is not proposed to make any refinements or modifications to the previous joint probability analysis undertaken during Workstream 2 of the CAFRA study. In the original modelling, five different fluvial / tidal event combinations were tested for each joint probability scenario. Through this modelling it was established that the tidally dominated combination represented the highest risk for each joint probability scenario. Therefore, for the Bristol TFRMS it is proposed that for each joint probability event to be assessed (i.e. 1:20 year, 1:75 year, 1:100 year, 1:200 year and 1:1000 year) one single tidally dominated event is to be used, as shown in Table 2.

Whilst the tidally dominated flood risk forms the focus of the Strategy, the impact (and potential mitigation) of the proposed management options on the residual fluvial and pluvial flood risk will also be considered. Impact assessment and mitigation measures will vary by option; for a tidal barrier, numerical modelling will be undertaken to determine the impact that the barrier and barrier closure may have on

residual fluvial flood risk. The modelling will be used to help optimise the indicative barrier location and identify the required storage capacity of the system. It will also aid in the design of supporting mitigation measures such as flood walls or embankments which may be required to contain raised fluvial water levels during the closure of the barrier. For high or low defences, consideration will be made in the design to provide adequate drainage and a design allowance for combined fluvial and tidal extreme water level events (i.e. by using a joint combination of events to determine the design water level of the structures).

2.3 Extreme water levels and climate change

This section provides an overview of the water levels and climate changes scenarios adopted in previous modelling studies and outlines the approach to be used in the Bristol TFRMS.

2.3.1 *Original CAFRA modelling*

The original 2010-2012 CAFRA modelling adopted the 'Upper End' estimates for sea level rise, as defined by the Environment Agencies guidance on *Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities* (Environment Agency, 2011). The 'Upper End' estimate is based on the UKCP09 high emissions scenario and equates to sea level rise of +1.01m over the 100 year appraisal period. This precautionary approach was adopted because of the potentially very high consequences of tidal flooding to Bristol. The tidal boundaries used in the original modelling related to a 2008 baseline which were updated to a 2010 epoch using the 'Upper End' estimates for sea level rise.

2.3.2 *Harbour Study modelling*

The Harbour Study, running parallel to the CAFRA Workstream 4, used a different sea level rise allowance based on the "95%ile medium emissions scenario" which is the change factor typically recommended in the 2011 Environment Agency climate change guidance. The allowance for increase in surge varies with return period such that the allowance for sea level rise and storm surge is +0.74m for a 1 in 100 annual chance event and +0.82m for a 1 in 200 annual chance event.

2.3.3 *CAFRA modelling update 2015*

The 2015 climate change update used the predicted Severn Estuary (Environment Agency, 2011) climate change allowance of 2.4mm/yr to derive sea level rise allowances from 2008 to 2015. The present day (2015) extreme water levels were updated in the latest CAFRA modelling to account for recent isostatic and eustatic adjustment. These estimates have been checked and provide the best available information and will be adopted in the TFRMS. The 2015 tide levels used in the climate change update study are in the top block of data in Table 2 below.

For the 2015 updated climate change scenarios. UKCP09 Medium Emissions 95%ile and UKCP09 High Emissions 95%ile allowances (Environment Agency, 2011) were investigated in order to support the assessment and management of flood risk in Bristol including allowances for vertical land movement. The tide levels for the 2030, 2065 and 2115 epochs used in the climate change update study are in the lower data blocks of Table 2.

To reduce the number of runs required, the proposed tidal levels for each scenario were examined and simulations were only generated for events which could not be assigned equivalent results (generally +/- 50mm) from previously run design events or climate change scenarios. The 2015 climate change update includes an equivalency table summarising where it was possible to use from previously run design events or climate change scenarios and where new events were run for the update.

2.3.4 *Proposed approach and equivalencies for the Bristol TFRMS*

The depth/damage assessment work carried out for the economic appraisal within the Bristol TFRMS will adopt the climate change tide levels from the Medium emissions 95%tile scenario, as shown in the middle column of Table 2. It is proposed to adopt the same equivalency approach as taken in the 2015 CAFRA climate change update to manage the number of simulations for the Bristol TFRMS modelling work.

Where appropriate during the option development phases of the Strategy the upper and lower end climate change allowances will also be considered in sensitivity testing the robustness of options to different rates of sea level rise.

To take into account climate change impact on peak fluvial flows, a 10% fluvial flow increase is to be adopted for the 2030 epoch (short term), a 20% increase for the 2065 epoch (medium term) and a 25% increase for the 2115 epoch (long term).

Table 2. Summary of extreme tide levels used in the 2015 CAFRA climate change update

Epoch	Joint probability	Fluvial / Tidal combination	Tide Level (m AOD)		
			Upper end SLR	Medium emissions 95%tile SLR	High emissions 95%tile SLR
2015	1:20 year	FBASE T020	8.69	8.69	8.69
	1:75 year	FBASE T075	8.94	8.94	8.94
	1:100 year	FBASE T100	9.00	9.00	9.00
	1:200 year	F002 T200	9.13	9.13	9.13
	1:1000 year	F012 T1000	9.45	9.45	9.45
2030	1:20 year	FBASE T020	8.78	8.77	Not considered
	1:75 year	FBASE T075	9.03	9.02	Not considered
	1:100 year	TBASE T100	9.09	9.08	Not considered
	1:200 year	F002 T200	9.22	9.21	Not considered
	1:1000 year	F012 T1000	9.54	9.53	Not considered
2065	1:20 year	FBASE T020	9.11	9.01	9.08
	1:75 year	FBASE T075	9.36	9.26	9.33
	1:100 year	FBASE T100	9.42	9.32	9.39
	1:200 year	F002 T200	9.55	9.45	9.52
	1:1000 year	F012 T1000	9.87	9.77	9.84
2115	1:20 year	FBASE T020	9.84	9.43	9.59
	1:75 year	FBASE T075	10.09	9.68	9.84
	1:100 year	FBASE T100	10.15	9.74	9.90
	1:200 year	F002 T200	10.28	9.87	10.03
	1:1000 year	F012 T1000	10.60	10.19	10.35

It is proposed that the Bristol TFRMS baseline includes the new Cumberland Road wall defence (crest level 9.2m AOD) as this structure will be in place for the duration of the Strategy period. Table 3 below shows the modelling scenarios that are to be used, based on equivalencies tables from the 2015 CAFRA climate change update. Figure 2 shows the extreme water levels used in the modelling scenarios.

Table 3. Summary of model runs used to define the baseline for the Bristol TFRMS

Epoch	Joint probability	Fluvial / Tidal combination	Tide Level (m AOD)	Equivalencies – with Cumberland Road wall (9.2mOD modelled crest)
			Medium emissions 95% SLR	
2015	1:20 year	FBASE T020	8.69	CAFRA_132_20yr_Fbase_T020_2015
	1:75 year	FBASE T075	8.94	CAFRA_132_75yr_Fbase_T075_2015
	1:100 year	FBASE T100	9.00	CAFRA_132_100yr_Fbase_T100_2015
	1:200 year	F002 T200	9.13	CAFRA_132_200yr_F002_T200_2015
	1:1000 year	F012 T1000	9.45	CAFRA_132_1000yr_F012_T1000_2015_0.65a
2030	1:20 year	FBASE T020	8.77	CAFRA_132_20yr_FBase_T020_2030Med
	1:75 year	FBASE T075	9.02	Medium Emissions 95%ile SLR 2015 1 in 100 FBASE T100
	1:100 year	TBASE T100	9.08	Medium Emissions 95%ile SLR 2015 1 in 200 F002 T200
	1:200 year	F002 T200	9.21	CAFRA_132_200yr_F002_T200_2030Med
	1:1000 year	F012 T1000	9.53	CAFRA_132_1000yr_F012_T1000_2030Med
2065	1:20 year	FBASE T020	9.01	Medium Emissions 95%ile SLR 2015 1 in 100 FBASE T100
	1:75 year	FBASE T075	9.26	CAFRA_132_75yr_FBase_T075_2065Med_0.65a
	1:100 year	FBASE T100	9.32	CAFRA_132_100yr_FBase_T100_2065Med
	1:200 year	F002 T200	9.45	Medium Emissions 95%ile SLR 2015 1 in 1000 F012 T1000
	1:1000 year	F012 T1000	9.77	Medium Emissions 95%ile SLR 2115 1 in 100 FBASE T100
2115	1:20 year	FBASE T020	9.43	CAFRA_132_20yr_FBase_T020_2115Med
	1:75 year	FBASE T075	9.68	CAFRA_132_75yr_FBase_T075_2115Med_0.65a
	1:100 year	FBASE T100	9.74	CAFRA_132_100yr_FBase_T100_2115Med
	1:200 year	F002 T200	9.87	CAFRA_132_200yr_F002_T200_2115Med
	1:1000 year	F012 T1000	10.19	CAFRA_132_1000yr_F012_T1000_2115Med

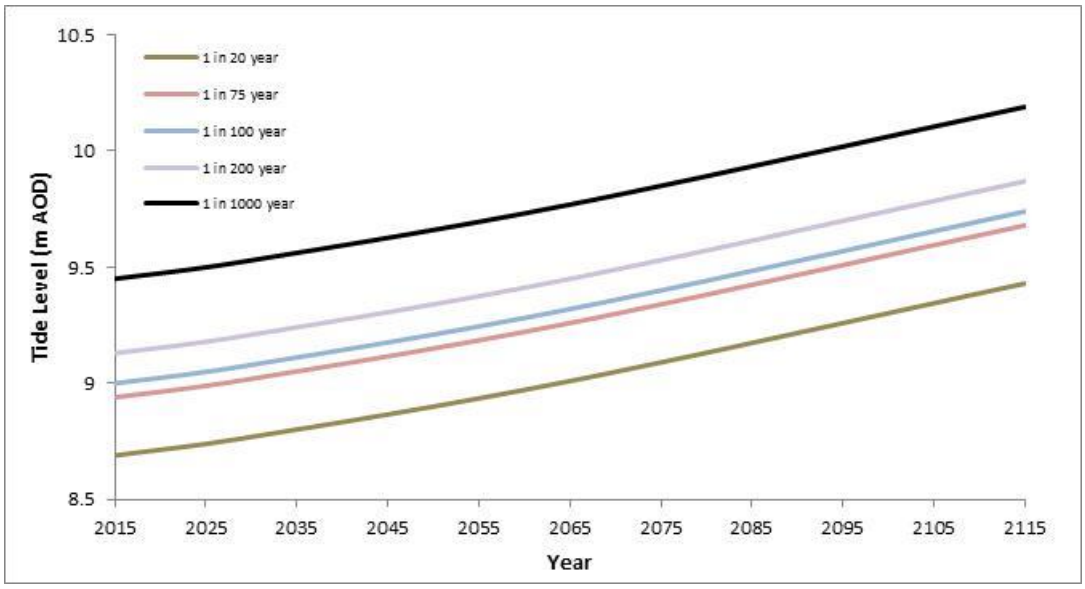


Figure 2. Extreme tide levels used to define the baseline for the Bristol TFRMS

2.4 Overview of tidal flood risk in Bristol

Bristol has a long history of flooding with the worst floods in the last 125 years occurring in 1882, 1960 and 1968 (First Phase Feasibility Study, 2014). Recent tidal flooding has been recorded in 1981, 1990, 1999 and 2014 at locations including Cumberland Basin Road, Avon Crescent and Cattle Market Road.

Low spots along the banks of the River Avon are the first pathways for flood water to inundate a significant number of properties in central Bristol, either directly, or because water levels become raised in the Floating Harbour and overtop low spots at Avon Crescent, Junction Lock and Bathurst Basin. Other areas at risk include St. Phillips Marsh , Redcliffe (risk significantly increasing in the future) and Temple Gate / Clarence Road (risk significantly increasing in the future).

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. The predicted flood risk to central Bristol is therefore considered to be tidally dominated.

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.

If climate change continues as expected it will result in the continuation / acceleration of rising sea levels. This is expected to increase the depth and extent of flooding in Bristol with the CAFRA modelling suggesting that by 2110 over 400 hectares of the city centre will be either directly inundated or isolated during a 1:200 year tidal event coinciding with a 1:10year fluvial flow. This magnitude event would flood approximately 3500 ground floor properties and lead to widespread disruption.

Baseline risk for the area within the Strategy boundaries, and the numbers of properties considered at risk during different time periods and magnitude events will be refined in the next stages of the Strategy development.

2.5 Impact of flooding on potential development within Bristol

The Bristol Local Plan (running to 2026) sets out the development objectives for Bristol. The plans include the council's approach to minimising the risk and impact of flooding in the context of new development. The risk of flooding has informed the spatial strategy for the city, which proposes to locate development predominantly in areas with the lowest risk of flooding. However under rising sea levels the tidal flood risk within the city centre is projected to increase in the future. The forthcoming review of the Local Plan in 2016 to extend its duration to 2036 and bring it in line with the Joint Spatial Plan, which will apply to the 2036 time horizon, will be informed by the results of the Strategy. Climate change predictions have the potential to constrain the scale and form of development of central Bristol today. Sites allocated within the existing Local Plan have been allocated through the sequential approach and determined to meet the first part of the Exception Test, however, each site-specific flood risk assessment must demonstrate that the development will be safe for its lifetime taking account of the vulnerability of its users (Project Initiation document, S1.8.3).

Within the city centre the areas of focus for development and regeneration include Harbourside (around Harbour Road and Canons Way), Redcliffe (including the area around Victoria Street) and Broadmead. The assumed working life of new commercial properties is approximately 50 years, and for residential properties 100 years. There is a varying degree of present and future flood risk in each of the areas focussed for development and therefore the importance of managing flood risk through mitigation measures and the potential constraints to development will be investigated in more detail at later stages during the Strategy.

2.6 Condition of existing defences

A diverse range of flood defence structures and assets are currently in place within Bristol, including harbour walls, embankments, weirs, dams, culverts, sluice gates, flood defence walls and lock and gate systems. The defences provide an interconnected system to manage both the tidal and fluvial flood risk to the centre of Bristol. The condition of the flood risk management structures varies considerably and in many cases the condition of the defences is currently unknown.

At the Floating Harbour, as part of the operational protocol to manage water levels within the harbour, Bristol City Council (BCC) manually close the Junction Lock and Netham flood gates in advance of tides forecast to exceed the harbour water level. In addition, if sufficient warning is provided, BCC will pre-

lower the water levels within the harbour to provide a greater storage capacity for fluvial water attenuation.

Mott MacDonald, as part of CAFRA Workstream 4 investigations, undertook a Floating Harbour Resilience Study (2013) in which the condition of the Floating Harbour defences and operational infrastructure was visually assessed. The visual condition survey was undertaken using the Environment Agency's Asset condition methodology. The condition of the vitally important Floating Harbour structures and operational infrastructure is summarised below:

- Netham Weir - The condition of the Netham Weir sub-structure and concrete weir crest is considered to be in a 'fair' condition whilst the condition of the rock apron is considered to be 'poor'. Sheet piling alongside Netham Weir on the right bank of the River Avon is considered to be in a 'good' condition.
- The Netham lock and sluice system comprises reinforced concrete structures, sluices and mechanical systems. The concrete structures are considered to be in a 'fair' condition, but the sluice paddles and operating mechanisms are considered to be in a 'poor' condition.
- Forgotten Lock – comprising the abutments and gabion wall structure. Both the abutments, comprised of masonry walls, and gabion baskets are considered to be in a fair condition.
- Totterdam Dam and Lock - The form of construction of the lock and dam is largely unknown, with the structure having been infilled and covered. It was therefore not possible to assess the condition of these assets.
- Bathurst Basin Dam – the dam, constructed from precast concrete facing blocks which have been backfilled with mass concrete is considered to be in a 'good' condition. The CAFRA Workstream 4 assessment recognised that the Bathurst Basin Dam is the structure most vulnerable to overtopping within the Floating Harbour, and recommendations were made to assess the structures condition and integrity in more detail.
- Mylne's Culvert – the culvert beneath the Floating Harbour is comprised of a circular cast iron culvert whilst the upstream and downstream sections are brick egg shaped sewers. The condition the culvert is unknown. The culvert outfall and tidal flap, which consists of a timber flame with a bolted steel flap is considered to be 'poor'.
- Nova Dam and Sluices – the Nova Dam, constructed of masonry, is considered to be in a 'fair' condition whilst the sluices mechanical and electrical systems are considered to be in a 'very good' condition.
- Junction Lock - The Junction Lock upper gates and the 2010 stop gates comprise welded steel plates with protective paint coating. The condition of the gates is deemed to be 'very good'. The upper gates utilise a hydraulic system installed in 2010 which is deemed to be in a 'very good' condition. The lower gates use the original 1981 hydraulic system which is considered to be in a 'fair' condition. The backup stop gates, which were constructed in 1992, are considered to be in a 'poor' condition, but the hydraulic system used to operate these gates is considered to be in a 'good' condition. The lock barrel is comprised of close jointed masonry and is in a 'good' condition.
- Underfall Yard – Underfall Yard is comprised of culverts, masonry outfall headwalls, sluices and embankments. There is considerable uncertainty as to the composition of the embankment structures and the overall condition of the embankments is considered to be 'poor'. The culverts of Underfall Yard are masonry arch structures, constructed in approximately 1890. They were last inspected 10 to 20 years ago and the condition of culvert pointing and masonry was considered to be good to fair. It was not possible to visually inspect the condition of the culverts in the most recent study and therefore their present condition is unknown. The walls and headwalls of Underfall Yard and the main sluice gates are in a 'fair' condition. The condition of the inlet or emergency back-up sluice gates is unknown. The instrumentation and control systems for the Underfall Yard main and back up sluice gates is operated by a computer system that relies on mains electricity, with no emergency generator fitted. The system was installed in 1985, and its age suggests that the condition of the computer system is 'poor'.

Following on from the recommendations of CAFRA (2012), Arup undertook a study to further investigate the condition of the Bathurst Basin Dam. The condition of the dam was tested against various factors including water and soil loading, impact loading, flood defence properties and resistance to erosion. For the purpose of the Strategy, the condition of dam in relation to flood defence is most relevant; the dam is frequently overtopped (numerous times a year) with the crest elevation falling approximately 0.6m below 1:20 year water levels (5% AEP). In terms of soil loading the dam is considered to be compliant, and it was also concluded that an impact strike against the dam is unlikely to lead to catastrophic dam failure (although it is possible that the coping layer at the crest of the dam could be removed by an impact). Erosion is very unlikely to present a risk to the structural integrity of dam in the immediate future.

Cumberland Road is a low spot within Bristol that is particularly vulnerable to overtopping. During high spring tides there is 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 but cannot be relied upon to provide a robust defence against flooding. The onset of property flooding at Avon Crescent occurs from as little as a 1:20 year tidal water level event. As part of the Ashton Vale to Temple Meads (AVTM) Metrobus project a new wall is currently under construction along Cumberland Road. The crest height of the new wall will be 9.2mOD and will reduce service disruption to the Metrobus link.

During future phases of the Strategy and follow on studies consideration of the BCC and EA asset condition information is planned.

2.7 Overview of flood risk mechanisms

The First Phase Feasibility Study (Arup, 2014), provided a useful summary of 'how Bristol gets flooded', through reference to previous work undertaken during CAFRA. The most important points to highlight from this to be considered further in the option appraisal are:

- Tidal inundation dominates over fluvial flooding from the Avon or Frome rivers
- Ingress of tidal water occurs at Avon Crescent, Junction Lock and Bathurst Basin low spots (as noted in Section 2.4)
- Floating Harbour water level raised by overtopping, tide locking and Frome inflow
- St Philips and Netham area are flooded because of the tidal river overtopping river banks in these locations e.g. the Whitchurch Railway Path, in the area bounded by Feeder Road and Albert Road.
- The duration of a tidal flood event may be very limited i.e. only around the peak of the tide, whilst a high tide combined with a fluvial event and a tidal surge may extend the duration to several hour or more than one day (several tidal cycles).
- Today, a 1:20 year return period tidal flood event can cause flooding of large parts of central Bristol. Modelling undertaken during CAFRA indicates that lower frequency events, e.g. 1:2 and 1:5 year return periods are capable of causing flooding in the St Philip's Marsh area.
- Buildings or walls situated close to the River Avon may act as informal or defacto flood defences and contribute to present day flood risk mitigation.

Hydraulic modelling will be undertaken during the Strategy to improve confidence in lower order return period events and the areas affected, through further development of the modelling work undertaken during CAFRA. The modelling will also include investigation of the role of previously unmodelled defacto defences in reducing flood extents.

2.8 Environmental issues and opportunities

Environmental assessment forms one of several workstreams informing the development of this strategy. Inputs are programmed to ensure that environmental constraints and opportunities are integrated throughout the project, with reporting due at three key points:

- Baseline mapping (Task 9A);
- Options appraisal, including long-listing and short-listing considerations (Task 9B); and
- Pre-scoping report, containing a framework for future environmental assessment of the preferred option (Task 9C).

The findings and recommendations of the environmental baseline review are provided in a separate accompanying Environmental Baseline Report. The methodology for environmental appraisal will be provided and an overview of the approach and deliverables is shown in the flow chart in Chapter 8.4 of this report.

The purpose of the Environmental Baseline Report, prepared for activity 9A, is to provide the findings of a desk based review of secondary data for the River Avon and immediate surrounds between the Severn Estuary and Netham Weir, to identify potential "show stoppers" and key constraints or opportunities relevant to a future flood defence scheme. This has involved:

- An examination of relevant work undertaken to date, such as the Arup Pre-Feasibility Report;
- Baseline constraints mapping using open-source and other publicly available data, mapping into Geographical Information Systems (GIS);
- Initial consultation with data providers such as BCC's in-house GIS team, Ecological Officer, and the Archaeological Officer; Natural England; the Environment Agency; and Historic England;

- Illustration of constraints data overlaid on base mapping to inform to inform the future tasks within the TFRMS programme; and
- Presenting recommendations for the next steps and how environmental considerations could be integrated within the wider TFRMS' evolution.

The Environmental Baseline Report provides further information on data collected, any limitations, the findings, and the constraints mapping, in particular Figures 4-1 to 4-6. The report provides a high level overview of the data within Tables 4-2 to 4-4, to which the reader is referred. Commentary is provided on issues such as protected/designated sites, land use, notable and invasive species such as Japanese Knotweed, archaeology and air quality. Limitations with the environmental baseline collected during task 9A have been highlighted in the Environmental Baseline Review. Aspects such as age of data, and spatial coverage of various sources, are discussed further.

Some particularly sensitive constraints are highlighted here.

The whole of Reach 1 is designated as the Severn Estuary Site of Special Scientific Interest (SSSI), the condition of which is described as 'unfavourable declining'. Reach 1 is also designated as the Severn Estuary Special Area of Conservation (SAC) and Special Protection Area (SPA). The SAC incorporates the River Avon whilst the SPA incorporates the River Avon mudflats. Additionally, the whole of Reach 1 is also a Ramsar site and an Important Bird Area (IBA) according to RSPB data. As to be expected from its designations, numerous sensitive bird species were recorded in this area. Potential visual elements associated with the residential area of Pill, together with the land uses at the Docks and transportation links, should be borne in mind for potential TFRMS solutions in this area.

Reach 2 features four SSSIs: Ham Green SSSI, Horseshoe Bend SSSI, Avon Gorge SSSI and Ashton Court SSSI. Avon Gorge SSSI is also designated as an Avon Gorge Woodlands SAC and therefore is of international importance. Various European Protected Species have been recorded, including otter and bats. A number of sensitive bird species are also mapped. From an archaeological perspective, three Scheduled Monuments are near to Reach 2, of which the Abonae roman settlement is particularly close. Numerous listed buildings would require consideration, including the Grade I listed Clifton Suspension Bridge and Grade II listed Harbour Walls at various locations.

Whilst there are no internationally designated ecological sites in Reach 3, there are mobile records of European Protected Species such as otter and of bats, and assorted sensitive bird recordings which require further consideration. Various Scheduled Monuments are close by, including Underfall Yard within Bristol Docks, and assorted listed buildings which are particularly sensitive if located close to the Floating Harbour.

3. OPTIONS IDENTIFIED IN PREVIOUS WORK

3.1 CAFRA and First Phase Feasibility Study

A key aspect of the CAFRA (2010-2015) and First Phase Feasibility (2014) Studies was to develop strategic approaches to the management of the flood risk in Bristol. Each study undertook an options appraisal which are summarised briefly below.

3.1.1 *CAFRA*

As part of the Harbour Study which ran parallel to the Workstream 4 CAFRA studies, a high level scoping and screening of tidal flood risk management options was undertaken. A number of locations were initially identified for potential land raising / construction of new defences and following a project workshop and liaison with Bristol City Council a list of potential locations was established which included; Avon Crescent, Bathurst Basin and Totterdown Lock/Victor Street. To provide an indication of potential changes to the baseline flood risk the peak water levels in the Floating Harbour were modelled in CAFRA for eight combinations of defences in these locations. Based upon the modelling results, three combinations of defences were taken forward for further consideration, these were;

- Scenario C: Defences at Avon Crescent (plus an additional variation of scenario C, known as scenario R)
- Scenario F: Defences at Avon Crescent, Bathurst Basin and Totterdown Dam / Victor Street
- Scenario D: Defences at Avon Crescent and Bathurst Basin

An economic assessment was then undertaken, assuming a 1:200 year SoP for each option.

Following on from the findings of the Workstream 4 option appraisal, Mott MacDonald undertook a high level appraisal of a tidal barrier solution, which included additional modelling runs to incorporate a barrier structure with fluvial and tidal surge flows. The results of the high level assessment were as follows

- The introduction of a barrier would have significant flooding benefits for central Bristol.
- The location, operation and timing of a barrier would be critical factors in its effectiveness.

- A barrier located near the M5 would reduce tidal flood risk in Bristol such that water levels in the Floating Harbour would remain within acceptable fluctuations.

Following this initial high level study of barrier feasibility, Mott MacDonald then undertook Phase 2 and 3 studies to investigate in more detail potential barrier locations. Several barrier locations were initially considered but following discussions with Bristol City Council, it was agreed to test in detail two barrier locations:

- Just upstream of the M5 road crossing
- Just downstream of the North Storm Water Interceptor (NSWI) outfall

The modelling undertaken in the study indicated that flood levels in Bristol are highly sensitive to the location of the barrier with the most significant flood risk benefits likely to be produced if the barrier is located just upstream of the M5 road crossing. The benefits of locating the barrier downstream of the NSWI outfall are limited in comparison. The study recommended that in future appraisals intermediate positions between these two locations are also investigated.

3.1.2 *First Phase Feasibility Study*

Building upon the work of CAFRA and other flood risk management studies in Bristol, the First Phase Feasibility study reviewed the options to manage flood risk and recommended a strategic approach to flood risk management. The approach used in the study was to group options into 'strategic families' depending on the type and scope of the option. The options were then grouped further into various spatial scales; study wide (15 options), central harbour area (8 options), central Frome area (5 options), central south Bristol area (8 options), lower Avon (4 options) and the upper Avon (2 options). Each option was appraised at a high level on engineering and environmental grounds and a short list of options which could be included as part of an adaptive approach to manage flood risk was developed. The short list of options comprised

- Better flood forecasting, warning and planning
- Raised defences to address low spots, or as a strategic solution taking into account the impacts of climate change. Three principal locations were identified at Avon Crescent, Bathurst Basin and St Philips Marsh (Totterdown) based on low spots in existing defences. Two approaches for raising defences were suggested; a 'low walls' approach to tackle the immediate flood risk and a 'high walls' approach to allow for the predicted impacts of climate change.

  As part of the 'low walls' approach to achieve a present day 1:200 year standard of protection approximately 600m of wall 1.0m (or less) above the bank level would be required at Avon Crescent, approximately 370m of wall 0.5m (or less) above the bank level at Bathurst Basin, and 1.6km of wall 1.2m (or less) above the bank level at St. Phillips Marsh would be required. Raising defences at these locations could be included as an initial component of a 'no regrets' adaptive approach to flood risk management.

  For the 'high walls' approach, the length of flood defences required would be approximately twice that of the 'low walls' approach and the walls would need to be constructed to 'above head height' to account for higher water levels in the future. The initial appraisal concluded that the 'high walls' approach is likely to be impractical given the required height and extent of defences, and their likely detrimental impact to the city centre.
- Tidal barrier or barrage would be effective measures to manage predicted tidally dominated flood risk. However, the initial appraisal concluded that a barrier would be the favoured structure as it would not have such substantial impacts compared to a barrage which is likely to lead to widespread habitat loss, landscape and ecology impacts, changes to the flow, siltation regime and water quality of the River Avon. A barrage could also increase the likelihood of flooding compared to a barrier due to tidal locking during major flood events.

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 which comprise:

- Improved flood forecasting, warning and planning;
- Early raised defences at low sports 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.

Similar to the latter CAFRA studies, the First Phase Feasibility study also investigated potential tidal barrier locations. The study found that a barrier located close to the M5 could protect the floating harbour from tidal overtopping with an allowance for 100 years of sea level rise. However, a barrier located immediately upstream or downstream of the NSWI outfall at Black Rock would only provide marginal improvements to flood risk due to insufficient upstream attenuation volume.

3.2 Economic appraisal

As part of the options appraisals carried out in the CAFRA (2010-2015) and First Phase Feasibility (2014) studies, economic assessments of the shortlisted options were undertaken. In addition, in support of the Tidal Avon Study, Hyder (2015) completed an initial economic assessment of flood damages to Bristol City Centre. A brief summary of the economic assessments for each study is provided below.

3.2.1 *CAFRA Workstream 4*

An initial assessment was carried out to test the economic cases of the constructing flood defences in the shortlisted locations at Avon Crescent, Bathurst Basin and Totterdown Dam / Victor Street. The various combinations of defences tested is summarised in section 3.1.1 above. The economic damages / benefits were derived for the option areas within the Floating Harbour using the DEFRA and EA approved approach outlined in the Multi-coloured Manual (MCM). Costs of the flood defence options were estimated from SPON's civil engineering and highways price book. For costing purposes the options were designed to provide a present day standard of protection of 1:200 years. A summary of the economic case for each shortlist option is provided in the tables below:

Table 4 CAFRA Workstream 4 options economic analysis summary. Table adopted from CAFRA Workstream 4 main report (2012), pg. 68. Economic analysis for the options within the Floating Harbour based upon 100 years discounting

	No Scheme	Option C	Option R	Option D	Option F
Estimated PV cost	NA	£25,000	£20,000	£30,000	£75,000
Optimism bias adjustment	NA	£196,500	£180,409	£314,400	£750,000
Total PV Costs from appraisal PVc	NA	£574,000	£531,091	£888,400	£2,050,000
PV damage Pvd*	£29,865,996	£4,632,985	£4,778,489	£5,059,144	£568,587
PV damage avoided	NA	£25,233,010	£25,087,507	£24,806,851	£29,297,408
Total PV benefits PVb	NA	£25,233,010	£25,087,507	£24,806,851	£29,297,408
Net Present Value NPV	NA	£24,659,010	£24,556,416	£23,918,451	£27,247,408
Average Benefit : Cost ratio	NA	43.96	47.24	27.92	14.29

Table 5 CAFRA Workstream 4 options economic analysis summary. Table adopted from CAFRA Workstream 4 main report (2012), pg. 68. Economic analysis for the options within the Floating Harbour based upon 25 years discounting

	No Scheme	Option C	Option R	Option D	Option F
Estimated PV cost	NA	£25,000	£20,000	£30,000	£75,000
Optimism bias adjustment	NA	£196,500	£180,409	£314,400	£750,000
Total PV Costs from appraisal PVc	NA	£574,000	£531,091	£888,400	£2,050,000
PV damage Pvd*	£17,460,120	£2,708,514	£2,793,578	£2,957,653	£332,405
PV damage avoided	NA	£14,751,606	£14,666,542	£14,502,467	£17,127,716
Total PV benefits PVb	NA	£14,751,606	£14,666,542	£14,502,467	£17,127,716
Net Present Value NPV	NA	£14,177,606	£14,135,451	£13,614,067	£15,077,716
Average Benefit : Cost ratio	NA	25.70	27.62	16.32	8.35

3.2.2 *First Phase Feasibility Study*

A high level appraisal of the business for flood risk management intervention options was carried out as part of this study. The appraisal followed the Flood and Coastal Erosion Risk Management (FCERM) appraisal guidance (EA, 2010) and Treasury Green Book (HM Treasury, 2013). Flood risk management options with an initial range in standards of protection and timings were considered, and grouped as follows:

- Options 1a and 1b: 'Do Minimum' and 'Do Nothing' options
- Options 2a and 2b: 'Raise low spots' to present day 1:75 year SoP in the city centre in 2015. Raising to a present day 1:100 year SoP was also considered although the complexity is likely to be disproportionately greater than the 1:75 SoP.

Options 3 to 7 below were assumed likely to include a tidal barrier.

- Options 3a and 3b: Interventions in 2030 to raise citywide SoP to 1:100 or 1:200 year standard.
- Options 4a and 4b: Interventions in 2030 to raise citywide SoP to 1:100 or 1:200 year standard for the duration of the appraisal period to account for climate change.
- Options 5a and 5b: As options 4a and 4b but implemented in 2050.
- Options 6a and 6b: An adaptive approach whereby an early intervention raises local low spots in 2015 (as option 2) and then a strategic intervention to provide long term protection in 2030 (as option 4a or 4b).
- Options 7a and 7b: As options 6a and 6b but with the strategic intervention delayed until 2050.

At the preliminary stage of undertaking the assessment there were significant uncertainties associated with the options and interventions including their arrangement/location, risks and opportunities. As such, option costs were not developed in great detail and the options were therefore appraised on the basis of benefit alone. A summary of the option benefits is presented in the table below. Note that the study area in which the economic benefits and damages were derived differs to that of the CAFRA studies.

Table 6. First Phase Feasibility study (2013) high level estimate of present value damages and benefits of the various options within the Study Area (between Hanham weir and the M5 road bridge). Table adopted from First Phase Feasibility Study report, pg 87.

Scenario	Definition	PV damage to Property Fabric and Contents (£m)	PV Residential Risk to Life (£m)	PV Critical Infrastructure nominal allowance (£m)	Total PV damage (£m)	Benefit (£m)
Option 1a	Do Nothing	229	3	75	307	0
Option 1b	Do Minimum	204	3	67	275	33
Option 2a	Low spot intervention 2015, 1:75, deteriorating	197	3	65	264	43
Option 2b	Low spot intervention 2015, 1:100, deteriorating	193	3	64	260	47
Option 3a	Strategic intervention in 2030, 1:100, deteriorating to <1:1 by 2110	168	2	56	226	81
Option 3b	Strategic intervention in 2030, 1:200, deteriorating to <1:1 by 2110	158	2	52	213	95
Option 5a	Strategic intervention in 2050, 1:100 precautionary, (1:1000 deteriorating to 1:100 by 2110	133	2	44	179	128
Option 5b	Strategic intervention in 2050, 1:200 precautionary, (1:1000 deteriorating to 1:200 by 2110	128	2	42	172	135
Option 7a	Low spot intervention 2015 (1:75 deteriorating) followed by strategic intervention in 2050 (1:100 precautionary)	116	1	38	158	151
Option 7b	Low spot intervention 2015 (1:75 deteriorating) followed by strategic intervention in 2050 (1:200 precautionary)	114	1	37	151	156
Option 4a	Strategic intervention 2030, 1:100 precautionary	94	1	31	126	181
Option 4b	Strategic intervention 2030, 1:200 precautionary	89	1	29	120	188
Option 6a	Low spot intervention 2015 (1:75 deteriorating), followed by strategic intervention in 2030 (1:100 precautionary)	83	1	27	112	196
Option 6b	Low spot intervention 2015 (1:75 deteriorating), followed by strategic intervention in 2030 (1:200 precautionary)	78	1	26	105	202

3.2.3 *Tidal Avon Study (Hyder, 2015)*

The Tidal Avon Study investigated potential mitigation measures to reduce tidal flooding in central Bristol, including the MetroBus wall on Cumberland Road and a strategic city wide scheme. The economic assessment undertaken by Hyder (2015) built upon the findings of this study, which had concluded that there was significant benefit associated with the construction of the Metro Bus wall at Cumberland Road.

The updated economic assessment concluded that a wall at Cumberland Road with a crest elevation 9.2m AOD is beneficial when compared to the Do Nothing and Do Minimum scenarios. Increasing the wall elevation to 9.6m AOD increases the flood risk benefit by approximately £635k. The results also indicate that that post-2065 a more strategic solution could be required to mitigate tidal flooding in the Cumberland Road area.

As part of a strategic city wide approach, the economic analysis indicated that increasing the standard of protection (SoP) from a 1:100 year SoP to 1:200 year SoP increases the benefit by £34M when compared to the Cumberland Road wall (9.2m AOD) scheme alone.

3.3 Discussion

The previous preliminary economic appraisals carried out in CAFRA and the First Phase Feasibility study have been, by intention, undertaken at a high level and include notable limitations such as scope of in-direct damage valuation and restricted spatial extent. However these assessments, alongside the Tidal Avon Study Economic Assessment (Hyder, 2015), provide useful data for initial screening of options in the TFRMS and provide an indication of potential returns on investment.

It is proposed that the economic appraisal for the Strategy will be undertaken with new spreadsheets but will draw upon the previous work in this area. Damage and benefit estimation will be undertaken in accordance with best practice guidance (e.g. FCERM-AG) principles. Damage assessments will adopt the valuations and guidance provided by the MCM manual (2015) for residential and commercial properties and indirect damages will also be explored such as emergency service and evacuation costs, transport and disruption costs, vehicle damages, intangible damages and environmental damages. Strategic level option costs will be built up from first principles (e.g. Spon's 2015). Present value CBA will be carried out on the shortlist options (strategic alternatives) as part of the wider option appraisal process to support selection of the preferred options.

In addition, a high level Gross Value Added (GVA) assessment will be undertaken to assess the local economic consequences on Doing Nothing.' As part of considering the potential opportunity lost, estimates of local economic benefits of the various storylines and scenarios will also be developed. For further information regarding the approach to future storylines and scenarios please refer to the option appraisal Short List and Preferred Option Briefing Reports.

4. HIGH LEVEL REVIEW OF TIDAL BARRIER SOLUTION

As part of the baseline review AECOM has carried out a high level assessment of a tidal barrier solution to manage tidal flood risk in Bristol. This assessment has been informed by reviewing details from a number of barriers constructed in the UK over the last 40 years, such as the iconic Thames Barrier and Hull barrier, as well as those barriers still in the planning or construction phase such as the Ipswich and Boston Barriers. During the appraisal of management options, consideration is also given to a tidal barrage, or tidal exclusion gate solution. For more details of the option appraisal process please refer to the Long List Briefing Report.

4.1.1 *Barrier costs*

The costs of barriers vary considerably and it is difficult to standardise on a "unit cost" for a barrier. A comment from the Ipswich FDM Strategy in 2005 states that "the cost of a barrier relates mainly to its span and the hydraulic head difference it operates under". The review has confirmed the veracity of this statement. This was validated at a meeting with barrier specialists KGAL who advised that the costs of the "moving parts" of a barrier are generally small in comparison to the civil components.

The total project costs are also very dependent on the works required in addition to the barrier structure itself such as raised defences and mitigation for environmental or navigational issues. For example, the total Boston Barrier project estimate (including design and other upfront costs) is £90.3m with the construction cost of the barrier itself only £15.3m of that.

4.1.2 *Barrier design considerations*

At the current recommended barrier location on the Avon (upstream of the M5 Bridge) the total width is 450m wide at the approximate level of the top of a tidal barrier (assumed to be 10.45m). This includes around 150m of channel and 300m of grassed marshland and banks. This compares to a total width of 520m for the Thames Barrier (construction cost £534m in 1984) and 25m for the Boston Barrier.

The River Avon is heavily influenced by the tidal flows in the Severn Estuary which has the second largest tidal range in the world. At the proposed barrier location the bed level is estimated to be at minus 7m AOD and with a top gate level of 10.45m AOD gives a gate height of 17.5m. This is second only to the Thames barrier which has a gate height of 20m. All the other gates were in the range of 5-10m.

The type of barrier (mitre, rising sector etc.) did not feature significantly in the decision making process of the barriers reviewed once the primary function of the barrier was determined.

A key aspect in the final decision about location, form and size of a barrier was consideration of the navigation issues. Each barrier had different issues to consider; a fishing fleet was relocated at Boston while leisure craft are still able to pass, at Ipswich the location was chosen specifically to avoid impacts on the operation of the commercial craft and the Port and in Colne the Sailing Club was relocated downstream of the barrier. On the Avon, upstream of the ports at Portbury and Avonmouth the constraint on navigation is the Cumberland Lock which can take vessels with a maximum 14m beam and 4.5m draught. The Shirehampton Sailing Club has its club house on the right bank at the proposed barrier location and will therefore need to be incorporated into future decision making.

All the barriers reviewed were predominantly tidal surge barriers which were operated only when forecast tide levels exceeded a designated threshold, although some, notably the Thames Barrier, have also been operated to provide additional storage capacity in times of high fluvial flow. Some barriers such as the Foss included overpumping so that flood flows could be conveyed over the closed barrier. The Bristol Avon Flood Barrier Phase 2 and 3 Report described modelling that demonstrated that the further downstream the barrier was located, the better the impact on fluvial flooding was likely to be. It did not appear to show that fluvial flood levels would be made worse by the operation of a barrier so further modelling is required.

4.1.3 *Environmental considerations*

As with all infrastructure developments, the environment also has a major influence on the choice of location and barrier type. The area likely to be affected by the construction and operation of an Avon barrier is located close to, or contains, a number of statutorily designated sites. Environmental advisors have therefore been embedded as part of the TFRMS delivery team for the River Avon. The most sensitive designations are the Severn Estuary Special Area of Conservation (SAC) and Special Protection Area (SPA), and Ramsar site. There is potential that statutory Environmental Impact Assessment (EIA) will be required to support any future planning application, which will inform design and influence programme and cost. Furthermore, any proposals close to or within the SAC/SPA will require consideration of the need for Habitat Regulations Assessment in parallel with the EIA.

Compliance with the Water Framework Directive's objectives for the water body should also be borne in mind.

In addition to the ecological aspects above, there are also likely to be landscape and visual impact issues to be considered as well as potential impacts upon archaeology and built heritage. Other tidal barrier projects that have been reviewed all had similar issues to overcome and specific project budgets were allocated for enhancement and mitigation measures over and above those designed into the main works e.g. £0.9m for Boston. Early engagement with environmental consultees such as Natural England, the Environment Agency, Historic England, and the various advisors within Bristol City Council is required to inform the environmental scope of the TFRMS, consultation and the subsequent decision-making process.

4.1.4 *Summary and recommendations*

Based on this initial review the current 'first pass' cost estimate range for the design and construction of a tidal Barrier on the Avon, including gaining all approvals and legislation required, is £70m-200m (if a suitable narrow location can be found) or £150m-450m at the proposed or similarly wide location. By comparison the maximum present value benefits stated in CAFRA was £202m. It is recommended that:

- The recommended barrier location (upstream of the M5 Bridge) is on arguably the widest part of the Avon's channel which will significantly increase construction costs. Alternative locations should be considered;
- Modelling should be carried out to assess the impacts of the location of the barrier on fluvial flood levels in the centre of Bristol;
- Modelling should be carried out to support the assessment of barrier impacts with regard to joint probability tidal / fluvial events, confirm barrier locations and investigate flood storage capacity and impacts.
- The economic viability of the barrier should be established by identifying funding partners and ensuring the economic justifications (benefit cost analysis or other method) that underpin decisions are sound.

5. UNCERTAINTIES AND DATA GAPS

5.1 Uncertainties

A wealth of existing information and data already exist relating to tidal flooding Bristol. These studies contain information on the types and scale of residual uncertainties which could present sources of error and could influence flood risk management decisions going forward.

The uncertainties relate to physical system parameters defences, such as defences, water levels and operation of the harbour assets. They also relate to data and modelling, such as the boundaries, computation, spatial data quality etc. Significant uncertainties relating to futures with climate change, asset deterioration, land use and development being foremost.

A log of residual uncertainties, relating mainly to data and modelling aspects, was produced by the previous CAFRA study and has been reviewed (2015-08-12 Bristol River Avon – Sources of uncertainty and design response_draft). The sources and significance of uncertainties will be considered and kept under continual review moving forward, with sensitivity testing being used to assess the significance of these where relevant.

Moving forward, in conjunction with BCC and the EA, efforts to manage or reduce these risks will be sought, and the relevance of each will need to be considered depending on the situation (e.g. depending on options being put forward and the importance of the impacts to the decisions which are being made) and these will be documented in a log through the project. Risk reduction workshops will be held as required as a forum to achieve this.

A summary of the key uncertainties and the initial proposals to manage the uncertainty is provided in Table 8 below. The resolution of uncertainty will improve as the Strategy progresses through the option appraisal phases.

Table 7 Key uncertainties in existing information

Uncertainty	Proposals to manage/address uncertainty
Defence condition, deterioration and residual life	Consider BCC and EA asset condition information in option appraisal , particularly the role of defences failing, and agree approach to incorporation of information in economic assessment with BCC and EA i.e. define Do Nothing (‘Walk Away’) and Do Minimum (‘Status Quo’)
Defacto defences	Survey work has been undertaken. Potential to undertake modelling of defacto defences in the future to better understand role in flood risk mitigation and / or feed findings into option development / design.
Operation of harbour assets	Consider the magnitude of influence of BCC harbour assets in option appraisal, and agree approach to incorporation in economic assessment with BCC and EA as part of the definition of the Do Nothing (‘Walk Away’) and Do Minimum (‘Status Quo’) scenarios
Modelling – quality of boundary data	Review adequacy of previously used CAFRA boundary data in hydraulic modelling task
Climate change and sea level rise projections	Adopt the latest national guidelines for climate change and sea level rise. Strategy options will be created with built in flexibility and will be adaptable to varying levels of climate change as and when it develops in the future.
Future land uses and development	Different plausible ‘future scenarios’ will be developed during the option appraisal to project future development and against which the consequence of flood defence investment and implementation decisions can be assessed.

5.2 Data

Defence condition

A review of available records and information shows a notable apparent lack of formal up to date asset condition data. There is historic asset condition survey data and also more recent condition ratings for the assets around the harbour (Mott MacDonald, 2010). However residual life estimates have not currently been provided. Further data providing this information may be required in some locations, depending on the short listed options.

Defacto defence survey data is due to be delivered in March 2016 and this will be reviewed and the findings incorporated as required.

Stakeholder views

Further stakeholder feedback and data will also be obtained in accordance with the methods set out in the Stakeholder Engagement Strategy for the project.

Overall

The review of available data and information demonstrates that there is currently sufficient information to move forward with the next stage of the project (Option Development and long list option appraisal).

Further data collection maybe required (e.g. environmental surveys, ground investigations, condition surveys, topographic survey data etc.) and this will be determined through the development of the Strategy and undertaken as required on the agreement of BCC.

6. STAKEHOLDER ENGAGEMENT

6.1 Stakeholder Engagement Plan

Based on our initial review of previous documents and attendance at engagement events, we have produced and issued a Draft Stakeholder Engagement Plan that sets out our approach to consultation over the next year with statutory stakeholders, technical stakeholders and the public. This sets out the intended stakeholder groups to be engaged with throughout each part of the project, along with the mediums to be used and the objectives of each stage. It is intended that this document is a live document and will be updated and adjusted throughout the delivery of the project to provide flexibility for effective engagement as well as to respond to specific issues or opportunities as they arise.

The programme for engagement is split into 5 stages. These are, in summary:

- *Stage 1a: Initial strategy development (December 2015):* The objective of the first phase is to raise stakeholder awareness and gather relevant information to advance the development of the Strategy. The first Stakeholder Engagement Workshop was the key event of this stage.
- *Stage 1b: Pre-shortlist strategy development (January to March 2016)*: We will seek input from stakeholders to help move from the long list of options to a short list. Discussion of funding opportunities will be a key element of this stage. Based on engagement so far, further conversations with those attendees at the meetings/workshops outlined above e.g. the Bristol Port Company and TQEZ representatives will be necessary for this phase, particularly to discuss and identify funding contributions in more detail.
- *Stage 2: Shortlisted options to Preferred Option (March to May 2016)*: In this stage, we will seek views on the proposed preferred option and our consideration of the short listed options. This stage will involve a second Stakeholder Engagement Workshop with statutory and other technical stakeholders, together with community representatives. Our objective will be to secure buy-in from non-public stakeholders before consulting with public.
- *Stage 3: Public consultation on Draft Strategy (October/November 2016)*: We will present the preferred option/s to the public in this stage, and collect their views to finalise the Strategy. Two public meetings are proposed as the key face to face mechanism for taking on board public opinion before finalising the Strategy.
- *Stage 4: Finalise Strategy (December 2016*): The final stage of engagement will see us obtaining the approval / endorsement of the BCC / EA to the final Strategy.

6.2 Initial Key Stakeholder feedback – Stage 1a

A process of awareness raise and engagement with key stakeholders has already begun through a dedicated sessions to open (or re-open) dialogue channels with internal stakeholders within BCC and the EA, and wider external stakeholders. These followed and built on the successful consultations completed for the Pre-Feasibility Study and provided information, views and aspirations in order to update the social, political and planning baselines.

To date, we have facilitated or participated in the following events:

- 2 December 2015 – Development and Flood Risk meeting: this workshop involved members of the BCC and EA Project team discussing the issue of flood risk and its effect on the development of the city with BCC staff from Economy and Enterprise, Economic Development, Strategic Planning and the Urban Design Group, some of which are involved with the Temple Quay Enterprise Zone.

- 8 December 2015 – Stakeholder Engagement Workshop no.1: This workshop represented the first key meeting of the Stakeholder Engagement Plan, which introduced the AECOM team to key technical stakeholders including The Bristol Port Company, Wessex Water and the LEP. The purpose of the workshop was to gather information from stakeholders via group discussions around 4 themes that will influence the outcome of the Strategy (Strategic Development and Planning, Funding, Engineering and Infrastructure, Environment and Amenity). Further details on the workshop findings are provided in Section 6.4.

6.3 Key messages from Development and Flood Risk workshop

The BCC workshop on Development and Flood Risk highlighted three key issues that will affect the future development patterns and growth of the city:

1) *The need to implement the Joint Spatial Plan to deliver a housing shortage*: The JSP will establish the need and strategic locations for 85,000 new homes by 2036 within the West of England (BCC, BANES, SGC, NSC) boundary. There are currently 56,000 new homes already planned for; this leaves a shortfall of 29,000 new homes to be allocated. The JSP is out to consultation until the end of January 2016 and the feedback on the proposed spatial scenarios can feed into the development 'scenarios/storylines' used by the Strategy.

2) *The challenges and missed opportunities for delivering strategic development planning targets*: Currently, BCC Strategic Planning does not consider any area identified as Flood Zone 3 (present day) for new homes; areas that are predicted to be in Flood Zone 3 in the future (incorporating climate change) are, however, being considered for siting future allocations. The reliance on site-specific FRAs to deliver allocated sites presents opportunities that will help shape the Strategy. The potential missed opportunities of mitigating flood risk in existing flood zones to enable these sites should also be considered; the Strategy will consider how strategic flood risk mitigation can improve this situation over the status Quo. A high level GVA assessment will be undertaken as part of the Strategy to explore and help quantify the 'opportunity lost' impacts.

3) *How flood risk mitigation in the city can support the implementation of Temple Quay Enterprise Zone (TQEZ) and vice versa*: The objective of the TQEZ is to create 17,000 jobs in 25 years. In return, the zone is allowed to capture business rate uplift, which can help fund the development of the zone. There is currently £10m in the LEP's Growth Fund to support development. It is estimated by BCC economic developers that, currently, around £30m could be secured from developers interested in the EZ. The realisation potential of these funding pots will be identified and reviewed as part of the Strategy.

6.4 Stakeholder feedback from Stakeholder Engagement Workshop 1

During the workshop the key messages from the Stakeholders were collected. For the purpose of this report, the messages have been summarised into the following key bullet points. The points give clues as to the significant constraints to resolve, but also the opportunities and aspirations that the Strategy can influence and hopefully realise:

- *Strategic Development and Planning:*
    - The area in the vicinity of the M5 bridge and the Port of Bristol was identified as a favourable location to develop a tidal barrier, and the port is the main landowner downstream of the M5 bridge.
    - Difficulty of making decisions now for implementing engineering solutions a long time into the future.
    - Flood risk constraints should be addressed to improve development potential.
- *Funding:*
    - This is the number one risk to the whole project and is pivotal to finding an affordable and deliverable solution.
    - LEP and CIL are likely to be key avenues for funding; in contrast, Defra funding via GiA is expected to be minimal.
    - The implementation of the Temple Quay Enterprise Zone offers a potential funding stream from developers. The mechanism of a 'roof tax' (as promoted for the proposed Bridgwater Tidal Barrier) or alternative charge on developers should be investigated.
    - The LEP funding criteria stipulate that the creation of jobs and increasing the value of goods and services in the city i.e. GVA, would be key to exploring the LEP funding opportunity
    - Funding pots may need to be built up over time before drawing down monies to implement solutions.
- *Engineering and Infrastructure:*

- The condition of existing dockside structures and ground conditions in the Floating Harbour will have a significant influence on the cost and implementation of raised defences (flood walls)
- The effect of a tidal barrier on the hydrodynamic regime of the River Avon, particularly the balance between upstream flood storage and preventing tidal ingress.
- The need to maintain navigational rights on the River Avon.
- The sedimentation regime in the Avon, which results in the Port of Bristol dredging at the mouth of the Avon every 6 weeks.
- The relative importance/impact of constructing flood walls in key areas of the city (Cumberland Road, Bathurst Basin, Cattlemarket Road, Totterdown frontage).

- *Environment and Amenity:*
  - Effect of a tidal barrier on the existing discharge of Combined Sewer Overflows (CSOs) into the Floating Harbour
  - Visual impact, nature conservation and heritage are likely to be key environmental subjects influencing siting and form of proposals.
  - The Temple Quay Enterprise Zone is not just about business; strategic flood defences could help deliver amenity benefit and 'a sense of place' to positively influence development potential.

6.5 Social, political and planning issues and opportunities

From a review of previous studies, project objectives, discussion with BCC and feedback from key stakeholders it is clear that the Strategy must dovetail, support and enable development, regeneration and economic prosperity through promoting sustainable, adaptive and affordable tidal flood risk management options. Growth and attracting future development are key aspirations for the City, but measures to achieve this must be environmentally sustainable, visually in keeping and affordable. The Strategy must respect the heritage and culture of Bristol and where possible enhance not detriment the public realm.

Affordability of options is likely to form one of the most significant challenges for the Strategy and demonstrating the benefits for the local economy, housing targets, public realm and for the future prosperity of the City will be key to attracting and leveraging the large contributions that will inevitably required to deliver the Strategy. By continuing dialogue and liaison with Bristol City Council Strategic Planning teams we will continue to seek opportunities to enable these broader outcomes through future proofing via strategic flood risk management.

6.6 Potential Futures

In order to ensure that a managed adaptive Strategy is delivered, the future flood risk management choices must be appraised against the range of future uncertainty (range of possible futures). Some future uncertainties (e.g. climate change) are to a large degree independent variables and cannot be controlled or linked to actions in Bristol. Other future variables such as investment, funding and development are more controllable and are more likely to be influenced by management choices. When these variables interact overtime there is a wider envelope of future uncertainty and whilst this cannot be accurately predicted, it is necessary to ensure that the choices made are appropriate and adaptive. This will minimise regrettable actions or abortive investment and will ensure appropriate and suitable management of risks.

It is proposed that a series of storylines comprising a range of possible futures (comprising Development, Climate Change and Funding variables) will be developed and agreed with the Project Team and Project Board. These will then be used in the screening and more detailed appraisal of options to ensure the final Strategy is robust, adaptive sustainable and appropriate.

7. OBJECTIVES / CRITERIA TO SUPPORT APPRAISAL OF OPTIONS

7.1 Option objectives

Given the findings of the baseline review of information, key stakeholder feedback and project objectives as set of option objectives reflecting the specific requirements of the Strategy have been developed to support the appraisal of options. These objectives will be used in the funnelling down of options and also to measure the performance of the final Strategy. More detailed information on how these will be used in the appraisal process will be provided in subsequent option appraisal reports.

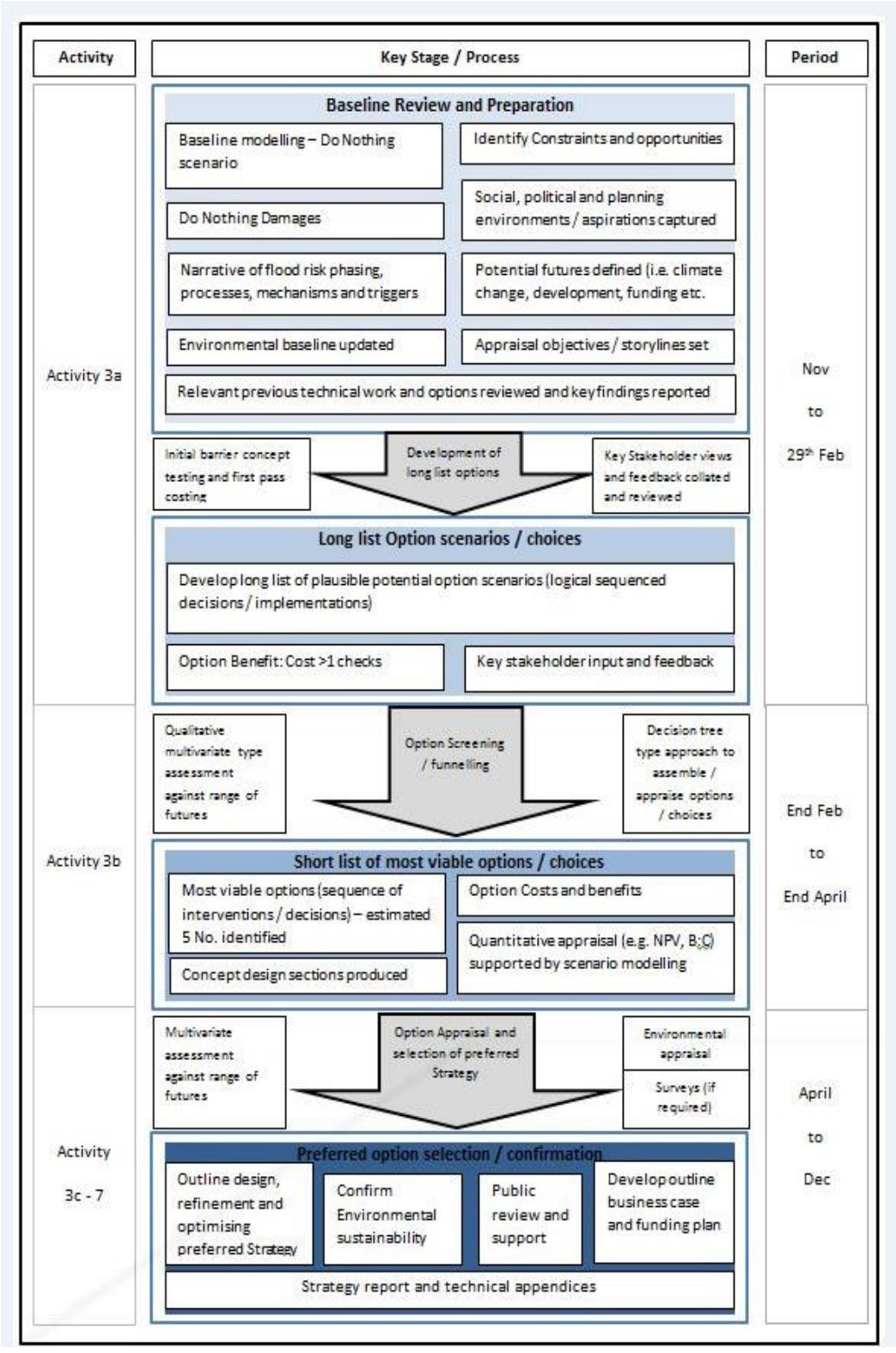
The following form a set of criteria against which options can be screened and tested in order to ensure that the final Strategy achieves the overarching objectives and vision:

- 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
- 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
- To maintain, and where possible enhance, natural, historic, visual and built environments.
- To reduce whole life costs, with consideration of reactive emergency response, and to ensure the Strategy is fundable
- To ensure navigation of the River Avon and marine activities can continue.
- Ensure the Strategy is technically feasible and deliverable over its duration

8. NEXT STEPS

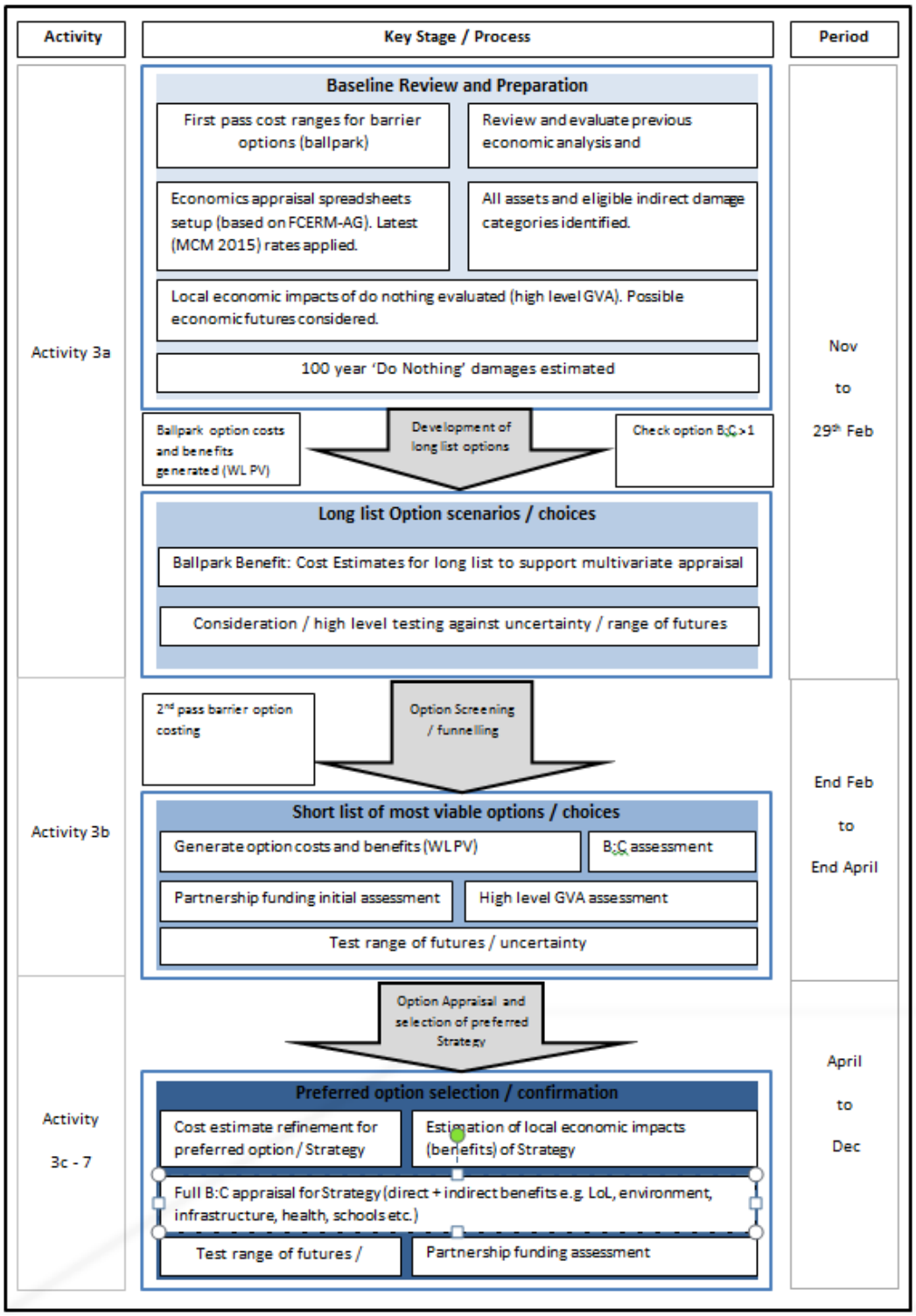
8.1 Option Development, appraisal and selection of the preferred option

Following approval of the baseline reports, option development and appraisal will be undertaken in accordance with the brief and project requirements. The flow chart below outlines the key stages of option development going forward, which was communicated to BCC on 17 December 2015. The forthcoming long list options report provides further details on this activity and the process of option appraisal.



8.2 Economic appraisal

Economic appraisal will form an integral part of the strategy development and assessment of options. The flow chart below summarises the key parts of the economic appraisal and how it aligns with the overall process of Strategy development and the timescales.



8.3 Supporting modelling activities

Hydraulic modelling will form a key support role in the development of the Strategy through providing flood depths to support damage and benefit assessments and through testing and confirming options. A summary of the key modelling stages and methodology is provided in Table 8; this was communicated to BCC on 17 December 2015.

Table 8.Summary of modelling methodology, tasks and outputs for the Strategy.

Task	Description	Deliverable / Objectives	Number of runs	Task period
1a	**Technical Review of CAFRA model - Key questions to explore / points to clarify / testing** Does it work? How long does it take to run? (baseline) How many tidal cycles does the current setup include? How has surge been applied (on top of the astronomical tidal curve) What does the model include? Purely tidal boundary? What about fluvial inputs? What is the resolution? How are the ponding areas created on the land? Are they 'real' or modelling artifacts? How long does it take to run the model for just the storm tide (i.e. lw to hw to lw)? How is the barrier represented in the model? What impact do structures have on run time? What water levels / scenarios have been run? What Joint Probability events have been used and simulated? Have any breach scenarios been run? Has 'good modelling practice' been adopted? Roughness values etc? Are there any areas which need increased resolution / extension / updates? How are the tidal boundaries applied? How are fluvial discharges represented? How stable is the model? Patches etc.?	Produce Technical Review Certificate Needs to set out clearly if it is suitable for use in the study (or if not why not) Scope of any required changes / updates Update model report (if required)	**TEST RUNS AS REQ**	10/12/2015 to 14/01/2016
1b	**Initial model test runs** Barrier - 100% blockage and 50% blockage at M5 crossing location Include 1:10 yr fluvial with 1:200 yr tidal (2115), 1:10 yr tidal with 1:200 year fluvial (2115) & 200 yr comined event	Test model stability / capability in relation to a barrier. GIS layers of depth, extent and hazard	**6 runs**	
**2	**Model updates / changes / amendments (if required - CE needed)** If model needs tuning / updating following review to be suitable for purpose intended If new defacto defence information needs incorporating	**Updated model suitable for production runs**		tbc
3	**Production Runs**			
3a	**Baseline Tidal Runs (present day extremes, joint fluvial / tidal events and SLR with existing defences in place)** Model a range of water levels (combined tidal / fluvial) to cover 1:1yr present day up to 1:1000yr with climate change (2115) 8.6mODN up to 10.5mODN in 10cm increments. Apart from lower end (8.6 and 8.7m) these events are all covered by existing CAFRA runs (check this)	Run log GIS layers of depth, extent and hazard for full range of water levels / scenarios. Flood data for Do-Nothing Damages	**IF ALL OK USE CAFRA RUNS (+ 2 new ones required) If new needed - 20 runs**	18/01/2016 to 31/01/2016
3b	**Option scenario testing** Test packages of measures against a range of futures 5 packages of measures against range of extreme water levels (1:20, 1:75, 1:200, 1:1000) at each time period - 2015, 2030, 2065, 2115) e.g. low walls, full height walls, barrier, walls then barrier etc.. Propose to use only 1 tidal cycle to keep run times down.	Run log GIS layers of depth, extent and hazard - residual flooding with packages of measure in place Data for into high level economic screening of packages of measures	**TBC ~** **Upto 40 runs** **(some may not be needed - GIS method instead)**	20/01/2016 to 24/03/2016
3c	**Optimise and refine preferred option** Optimise barrier location Run full range of extreme events for preferred option (assemblages of measures) Testing to ensure suitable redundancy for worst case design event (i.e. high return fluvial event with low return tide or visa versa) Full runs (3 tidal cycles?)	Confirmatrion of preferred option Run log GIS layers of depth, extent and hazard - residual flooding with preferred package of measures in place Data for residual damage assessment and preferred option benefits. Outputs to produce before and after comparison plots / animation.	**26 runs (if barrier included)**	29/03/2016 to 24/05/2016

8.4 Environmental Appraisal

Environmental Appraisal will form key role in the development of the Strategy to ensure options are environmentally sustainable, compliant with legislation and meet the objectives. A summary of the key stages, methodology and timetable is provided below; this was communicated to BCC on 17 December 2015.