RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Preferred Option Development Report

November 2017

Prepared for Bristol City Council

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0. EXECUTIVE SUMMARY

0.1 Background

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

The flood risk in the study area is dominated by tidal events and this is the focus of the study. The development of the Strategy has been underpinned by an appraisal of management options to address present and future tidal flood risk. During the last stage of work a preferred strategic option was recommended and agreed by the project team.

Following the selection of the preferred option AECOM Infrastructure and Environment UK Limited (AECOM) were commissioned to undertake an additional phase of works to assist with the development of the preferred option to support the Strategy. In summary, the objectives of this phase of work include:

- Identification of a phased delivery plan which will allow Bristol City Council (BCC) to implement the Strategy in a series of schemes;
- Confirmation of defence alignment for each scheme;
- Identification of the standard of protection (SoP) for each scheme / phase of work;
- Refinement of cost estimates and further development of the outline design works;
- Updating the economic benefits of the preferred option accounting for the phased delivery of schemes;
- Updating FCERM decision rule adopting new phasing plan;
- Identification of Partnership Funding scores for the Strategy schemes and funding gaps; and
- Production of reports associated with funding strategies, modelling, economic and environmental issues

This report brings together the findings of the numerical modelling, design and economic assessments to summarise this phase of work. Separate reports for each of these assessments are available and have been issued during this phase of work. The reports include:

- 9C Pre-scoping Environmental report
- Preferred Options Development Phase: Economics report
- Preferred Options Development Phase: Additional Hydraulic Modelling report
- Preferred Options Development Phase: Outline Design Briefing report

There are two main audiences for this report; the risk management authority and the local planning authority. There is a discrepancy between the climate change allowances used by these audiences and the definition of defence standards of protection;

- Risk management authorities – sea level rise based on the 95th%tile medium emissions climate change scenario. A freeboard is required on all proposed defences, although the benefit of the freeboard is not considered in the appraisal when defining the standard of protection of strategic defences.
- Local planning authorities – sea level rise based on the more precautionary Defra 2006 upper end climate change scenario. If a proposed defence includes a freeboard it is included in the appraisal when defining the standard of protection.

The discrepancy in the approach is an ongoing unresolved national issue. For the purpose of this report, the defence standards are described in terms of the flood risk management authorities (in FRM terms). The standard of protection in planning terms is discussed specifically in section 2.2.1.

0.2 Preferred strategic option

The preferred strategic option recommended by the Strategy involves constructing low defences along the New Cut in epochs 1 & 2 (2015-2030 and 2030-2065) and then raising the defences to high defences in epoch 3 (2065-2115). Low defences will be constructed to a 2030 1:200 year standard of protection whilst high defences will be constructed to a 2115 1:200 year standard of protection taking account of sea level rise (see Figure 1).

The defences are required in numerous locations within the study area; central Bristol, Pill and Shirehampton. During this phase of work the attention has been on the optimising the defences in central Bristol. The defences at Pill and Shirehampton are standalone schemes and have not been investigated further.

Within central Bristol new defences are required at Entrance Lock, Cumberland Road underpass, Bathurst Basin Dam and Netham. These defences will stop the flow of water into the Floating Harbour during flood events. More defences will also be required along the New Cut to protect against separate flood cells in these locations. The New Cut defence areas are at Cumberland Road, Commercial Road, Clarence Road and Cattle Market Road. Defences are also required at Totterdown / St. Phillips.

0.3 Defence phasing

Based upon the project team's understanding of the onset of flood risk, the numbers of properties at risk in each flood cell, economic damages, costs and benefits and deliverability the team devised a phasing plan for the preferred strategic option.

The Floating Harbour flood cell has the greatest number of properties at risk within epoch 1 and therefore defences for this cell are a priority. Defences will ensure that the major routes for flood water into the harbour are blocked and the harbour would be 'sealed' off during potential flood events.

Defences are also a priority at Totterdown / St. Phillips. The initial flood risk in this area is not as prominent as in the Floating Harbour (in terms of property numbers), but during larger magnitude events the flood modelling suggests that water flows from the Totterdown sub-cell into the Floating Harbour. Therefore in order to fully realise the benefits of the Floating Harbour schemes it will be necessary to construct the Totterdown defences in epoch 1. In addition, the Totterdown / St.Phillips area is currently being redeveloped as part of the Arena development and there are works planned to raise the path either side of the new footbridge. This offers an excellent opportunity to utilise these improvements as part of a low defence scheme during epoch 1 of the Strategy.

During epoch 1 the flood risk is relatively low at Cumberland Road, Commercial Road, Clarence Road and Cattle Market Road (i.e. the New Cut areas) and there are relatively fewer properties at risk and economic damages compared to the Floating Harbour. The capital costs for the New Cut defences are also of a similar scale to the Floating Harbour and therefore the New Cut defences provide a lower return on investment. For these reasons the New Cut defences are less of a priority and could feasibly be delayed until epoch 2 of the Strategy.

0.4 Economic assessment

The preferred option costs and benefits have been refined during this stage of work. Present value whole life costs for the option have reduced mainly due to the phased delivery of the defences (i.e. by delaying the New Cut defences until epoch 2), refinement of the design assumptions and updated costing. PV costs have reduced from £166.3m in the last phase of work to £67.7m. The benefits of the preferred option also reduce if the defences are phased, falling from £1,575.9m to £1,531m.

Table 1 presents the PV costs and the updated Average Benefit: Cost ratio (ABCR) of the preferred option and also that from the last phase of work prior to the updates.

Table 1 **Updated preferred option whole life costs and benefits, compared to in the previous phase of work**

Option	Notes	PV costs (£m)	PV benefits (£m)	ABCR
Preferred option prior to updates (last phase of work)*	Original cost estimates and phasing (all low defences in epoch 1)	166.3	1,575.9	9:1
Preferred option following updates	Updated cost estimates and phasing (New Cut low defences delayed until epoch 2)	67.7	1,531	23:1

*includes costs for Pill and Shirehampton schemes (capital non-discounted cash cost of £30million)

The main purpose of the new tidal flood defences outlined in the preferred option is to prevent tidal flooding. However, the defences will have an additional benefit of protecting against fluvial flood risk along the New Cut and in the Floating Harbour. Further studies and modelling runs will be required to monetise this benefit.

0.5 Partnership funding

Partnership funding scores for the schemes which comprise the Strategy preferred option have been undertaken.

The baseline for the Partnership funding calculations is the Do Nothing scenario. This is in line with FCERM guidance (Flood and Coastal Erosion Risk Management appraisal Guidance, Environment Agency, 2010) and the approach was agreed by the project team during previous stages of the Strategy. Use of this baseline is also in accordance with a steer from the Environment Agency during the last phase of work. The partnership funding scores using a Do Minimum baseline are less favourable which highlights the importance of the continued operation of the Floating Harbour to the total flood damages within the study area and the reliance on human intervention and continued management to operate the water level control structures within the harbour.

To derive the Partnership Funding scores the defences have been grouped into schemes according to the phasing plan; a scheme for the Floating Harbour and Totterdown defences and a scheme for the New Cut defences.

The Floating Harbour and Totterdown / St.Phillips scheme has a PF score of 135%. The New Cut defences, whilst having a similar cost profile to the Floating Harbour and Totterdown scheme, protect significantly fewer properties and have a PF score of only 13%. The funding gap to achieve a PF score of 100% for the New Cut defences is approximately £15.9m (see Table 2).

The phased approach to scheme delivery has been endorsed by the project board in February 2017. There is a strong case for funding the schemes in epoch 1 and the approach is favourable in terms of deliverability and maximising returns on investment.

The PF score for the epoch 1 schemes is in excess of 100% which suggests that the defences could be fully funded by GiA. However, the latest DEFRA target is for schemes to deliver a minimum 10-15% external contribution, even if the score is in excess of 100%.

Table 2 Summary of Partnership funding calculations

Scheme	Base date for calculation	Raw Partnership Funding Score	Estimated funding shortfall to achieve 100% score	Estimated level of GiA funding available should score reach 100%
Floating Harbour and Totterdown / St.Phillips defences	Present day	135%	£0	£43.3m
Net Cut defences	2030	13%	£15.9m	£2.5m

0.6 Residual Risk

Additional modelling runs have been undertaken to better understand the residual risk associated with defence failure / breaching and sea level rise.

The level of residual risk from above design standard events varies across the city.

When the preferred option is in place, the level of risk associated with breaching at the entry points to the Harbour (i.e. at Netham or Entrance Lock) is very similar to the baseline Do Minimum scenario.

By constructing new flood / lock gates at Entrance Lock and at Netham the chance of failure by breaching/failing open will be considerably reduced compared to the present day with the existing lock gates in place.

At the downstream entry to the harbour there will now be two sets of gates; new gates and Entrance Lock and the existing gates at Junction Lock which will reduce the chance of failure. Even if the new Entrance Lock flood gates were to breach / fail open then the existing gates at Junction Lock would be closed to block the most direct pathway for water to flow into the Floating Harbour. Some overtopping / outflanking of the Junction Lock gates would occur during significant flood events but the volume of water entering the harbour would be considerably reduced compared to an open channel.

In addition to the above, the new flood/lock gates at Entrance Lock and Netham will be constructed with multiple levels of redundancy to the power supply and operation to reduce the chance of failure. There are also last resort means of protection which could be implemented in order to reduce the time period of exposure should a failure occur. For example, at Entrance Lock and Netham a stop-log type system could be deployed or sand-filled bags could be stored on site and placed in the channel during a failure.

0.7 Detriment

Additional modelling has been undertaken during this phase of work to improve the understanding of detriment as a result of the Strategy. Two main areas of detriment have been identified; at Bower Ashton / Ashton Gate and at Netham / St. Anne's.

If mitigation is not undertaken the Strategy would lead to an increased flood risk and detriment to 189 properties. However, works to mitigate the risk have been identified, costed and are included in the preferred strategic option. These mitigation works will ensure that any detrimental impacts of the Strategy are mitigated before they can arise.

0.8 Delivery risk

A Monte Carlo assessment has been undertaken and based on the results it is concluded that applying the standard 60% optimism bias is a reasonable approach and this has been adopted throughout the economic assessment. As the project goes forward, it is recommended that best practice risk management continues to be applied to deliver risk mitigation with extra focus on higher risk items discussed at the delivery workshop.

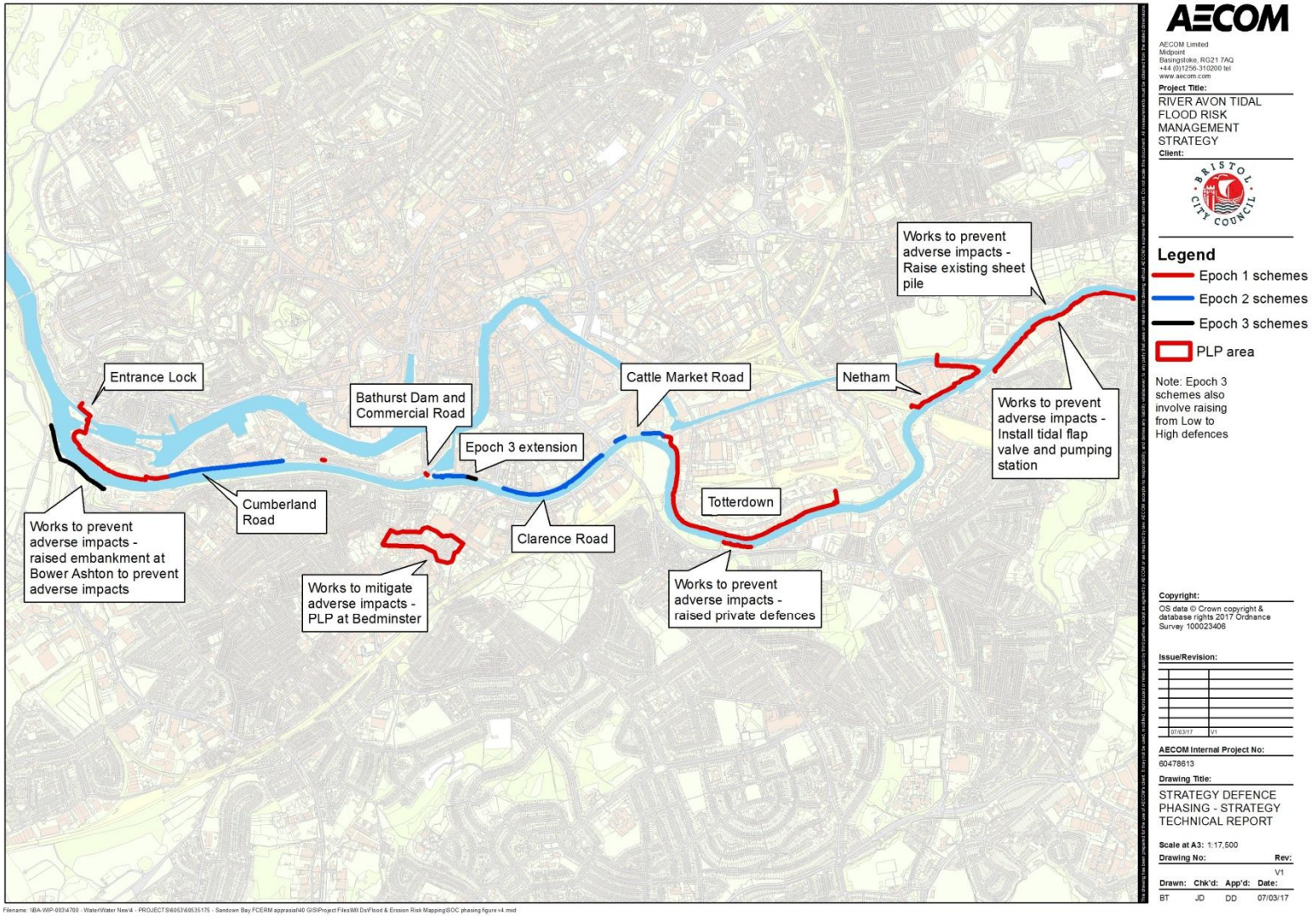


Figure 1 **Overview of Strategy schemes**

1. INTRODUCTION

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

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

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

1.1 Strategy objectives

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

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

1.2 Previous studies

Prior to the Strategy a number of studies investigating the flood risk in Bristol have been undertaken. In 2010 Bristol City Council commissioned the Bristol Central Area Flood Risk Assessment (CAFRA) to develop an understanding of flood risk on tidally-influenced watercourses within the Bristol City boundary. CAFRA was divided into four workstreams, and also included a parallel harbour study.

- Workstream 1 collected and reviewed existing hydraulic models, studies and survey data.
- Workstream 2 considered joint probability to derive boundary conditions for the CAFRA numerical modelling.
- Workstream 3 detailed the hydrodynamic model build and assessment of the predicted flood risk.
- Workstream 4, alongside the harbour study, scoped fluvial and tidal flood risk management options. Recent updates to the CAFRA study have been carried out in 2014 and 2015.

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

Based upon the shortlist of options, a series of interventions were recommended by the First Phase Feasibility study:

- Improved flood forecasting, warning and planning;
- Early raised defences at low spots along the riverside to reduce the risk of inundation and 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 city wide solution involving a tidal barrier.

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

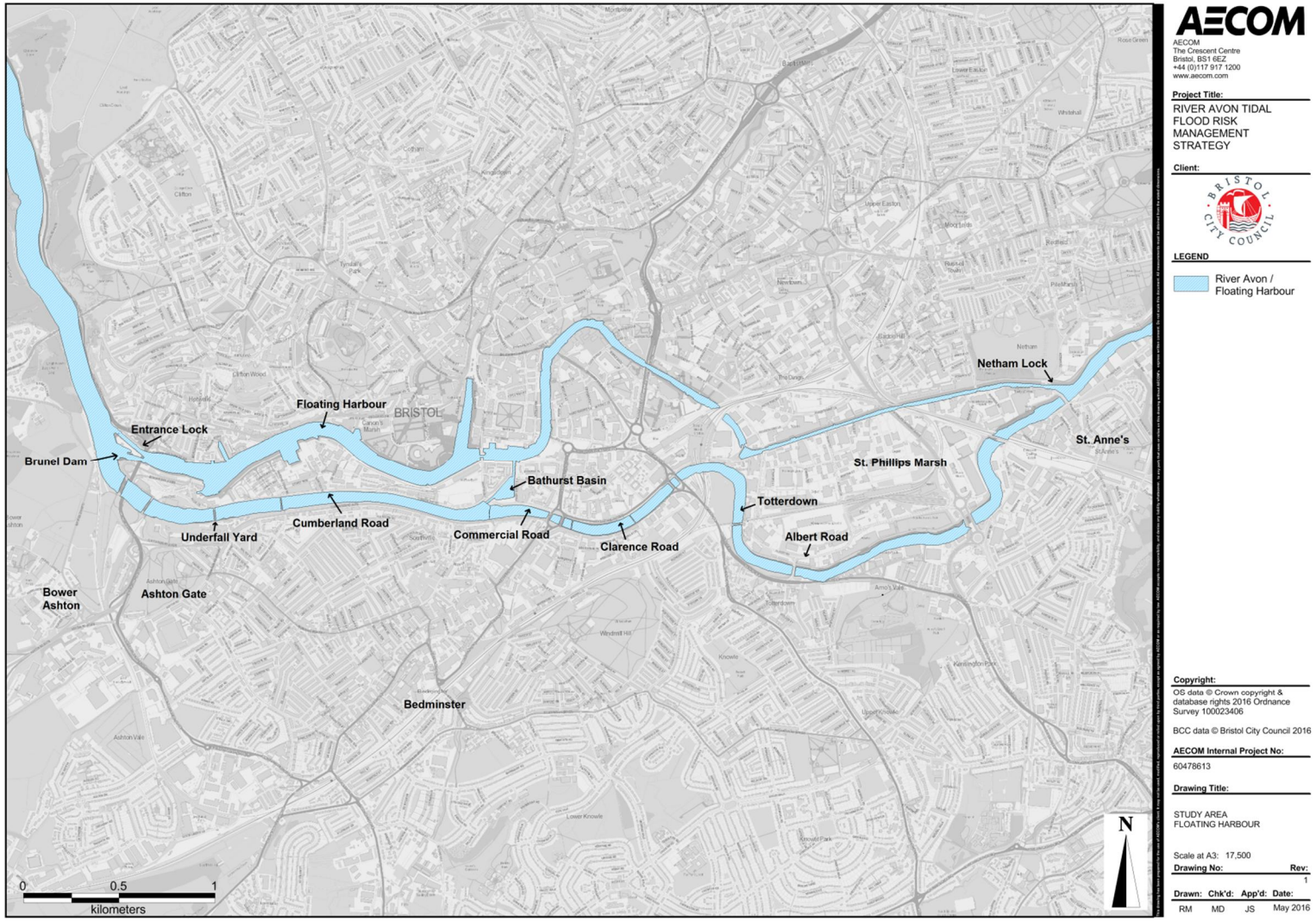


Figure 2 Central Bristol Floating Harbour area (OS data © Crown Copyright and database rights 2016 Ordnance Survey 100023406)

1.3 Strategy Development to date

Completed phases of the Strategy include; baselining, longlisting, shortlisting, and the selection of the preferred Strategic option.

During the long listing phase of the project a total of 39 options were developed. During short listing, the total number of options was reduced to seven and finally during the most recent phase a preferred option was selected.

To facilitate the option appraisal, the 100 year strategy appraisal period (2015-2115) was divided into three time epochs:

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

By developing management options in accordance with these time epochs it has allowed adaptive options to be developed that keep pace with climate change and sea level rise.

The options considered included a range of flood risk intervention measures including; a Do Minimum approach, property level protection / temporary defences, low defences, high defences and a tidal barrier. The preferred strategic option which has been identified encompasses the construction of low defences during epochs 1&2 and then raising these defences in epoch 3:

- Epoch 1 (2015 - 2030) : Low Defences
- Epoch 2 (2030 – 2065): Low Defences
- Epoch 3 (2065 – 2115): High Defences

For more details of the preferred strategic option, refer to chapter 2 below. For further information regarding why this option was selected as the preferred option, refer to the preferred option report.

1.4 Purpose and structure of this report

Following the selection of the preferred option, AECOM Infrastructure and Environment UK Limited (AECOM) was commissioned to undertake an additional phase of works to assist with the development and refinement of the preferred option. In summary, the objectives of this phase of work include:

- Identification of a phased delivery plan which will allow BCC to implement the preferred option in a series of schemes;
- Confirmation of defence alignment for each intervention;
- Identification of the standard of protection (SoP) for each scheme / phase of work;
- Refinement of cost estimates and further development of the outline design works;
- Identification of scheme benefits, both FCERM and broader outcome opportunities (e.g. facilitation, potential synergies with asset replacement etc.);
- Updating FCERM decision rule adopting new phasing plan;
- Calculation of Partnership Funding scores for schemes and funding gaps; and
- Production of reports associated with funding strategies, modelling, economic and environmental issues

This report draws together the findings of the numerical modelling, design, and economic assessments to summarise this phase of work. Separate reports for each of these assessments are available and have been issued during this phase of work. The reports include:

- 9C Environmental report
- Economics report
- Additional Hydraulic Modelling report
- Outline Design Briefing report

Chapter 2 of this report describes the preferred option which was selected during the previous phase of work. This chapter includes details on the adaptive approach to flood risk management and the key drivers behind reducing flood risk in the city.

Chapter 3 summarises the outline design and assumptions. It includes details on the base data, freeboard, defence crest levels, and methodology for the outline design.

Chapter 4 presents the defence alignments which have been refined since the preferred option was identified.

Chapter 5 discusses the option phasing that has been agreed by the project team. It discusses the onset of flood risk and how the defences have been grouped in separate schemes to benefit their delivery. It also includes details on the updated economic assessment, considering revised capital cost estimates and defence phasing.

Chapter 6 outlines the Strategy trigger points for implementing the preferred option schemes.

Chapter 7 outlines the partnership funding assessment which has been undertaken for the schemes. Calculations have been carried out for both a Do Nothing and Do Minimum baseline.

Chapter 8 discusses residual risk and detriment. These were key themes for the Strategy which were identified during previous work.

Chapter 9 discusses delivery risk and presents the results of a Monte Carlo assessment.

Chapter 10 summarises the findings from this stage of work.

At the back of this report there are three appendices; the landscape visualisations, output results from the preferred option beneficiary mapping exercise which was undertaken and the delivery risk register.

1.5 Report audience

There are two main audiences for this report; the risk management authority and the local planning authority. There is a discrepancy between the climate change allowances used by these audiences and the definition of defence standards of protection;

- Risk management authorities – sea level rise based on the 95th%tile medium emissions climate change scenario. A freeboard is required on all proposed defences, although the benefit of the freeboard is not considered in the appraisal when defining the standard of protection of strategic defences.

- Local planning authorities – sea level rise based on the more precautionary Defra 2006 upper end climate change scenario. If a proposed defence includes a freeboard it is included in the appraisal when defining the standard of protection.

The discrepancy in the approach is an ongoing unresolved national issue. For the purpose of this report, the defence standards are described in terms of the risk management authorities (in FRM terms). The standard of protection in planning terms is discussed specifically in section 2.2.1.

2. PREFERRED STRATEGIC OPTION

2.1 Overview

Within central Bristol the propagation of tidal flood risk is complex. Anecdotal evidence and model simulations show that tidal flooding occurs locally in a number of areas along the New Cut; Cumberland Road, Clarence Road, Commercial Road, Cattle Market Road and Totterdown / St. Phillips. In these locations, water from the New Cut flows over low spots in the existing defences and directly floods properties and assets behind. Elsewhere within the city centre, an 'indirect' pathway of flooding exists, whereby water from the New Cut flows over low spots in the defences and into the Floating Harbour. Gradually the Floating Harbour fills up with water and once the storage capacity of the harbour has been exceeded the water spills into adjacent areas within central Bristol, flooding additional properties and assets.

The preferred strategic option recommended by the Strategy involves constructing new low defences along the New Cut in epochs 1 & 2 (2015-2065) and then raising the defences to form high defences in epoch 3 (2065-2115) to mitigate predicted climate change. Low defences will be constructed to provide a 2030 1:200 year standard of protection, whilst high defences will be constructed to provide a 2115 1:200 year standard of protection. Figure 3 later in the report shows the locations of the proposed defences.

To deliver this option, approximately 5km of new raised defences will be required within central Bristol. New raised defences will be required at Cumberland Road, Commercial Road, Clarence Road, Cattle Market Road, Totterdown and St. Phillips. Defences in these locations will prevent local flooding to the properties and assets situated behind.

New defences at Entrance Lock, Netham, Bathurst Basin and Cumberland Road underpass will also be required. These defences will prevent water from flowing into the Floating Harbour and flooding properties in central Bristol once the harbour capacity is exceeded. Part of the new defences at Entrance Lock and Netham will be the installation of new tidal stop gates and operating infrastructure.

The defences in central Bristol are located on the north bank of the New Cut and the Floating Harbour. On the south bank of the New Cut the flood risk is more localised and is generally multi-sourced, for example, from tide locking of fluvial watercourses. As a result the preferred option does not outline any primary defences on the south bank of the New Cut and it is recommended that more site specific flood risk assessments are undertaken in the at-risk locations to identify appropriate management interventions.

Outside of central Bristol the preferred option outlines new defences for Pill and Shirehampton, towards the mouth of Avon. These areas are within separate flood cells to central Bristol and going forward the defences at Pill and Shirehampton will be treated as standalone schemes. This approach with Pill and Shirehampton has been approved by the project board and no further consideration of the Pill and Shirehampton schemes is provided in this report.

Throughout this report each defence area is described by a 'reach' number. These are presented in Table 3 below.

Table 3 Defence sections and reaches

Reach	Defence section	Primary area protected from flooding
1	Entrance Lock	Floating Harbour
2	Cumberland Road	Cumberland Road flood cell
3	Cumberland Road underpass (East)	Floating Harbour
4	Bathurst Basin Dam	Floating Harbour
4	Commercial Road	Commercial Road flood cell
5	Clarence Road	Clarence Road flood cell
6	Cattle Market Road	Cattle Market Road flood cell
7	Totterdown / St. Phillips	Totterdown / St, Phillips marsh flood cell
8	Netham	Floating Harbour and Netham

2.2 Adaptive approach and standard of protection

For the preferred strategic option new raised defences across the city are required from epoch 1 onwards. The defences will be constructed in two separate phases; low defences during epochs 1 & 2 and then high defences during epoch 3.

The low defences will be constructed to a 1:200 year standard of protection for 2030. The upgraded high defences will provide a 1:200 year standard of protection for 2115. Between 2030 and 2065, due to sea level rise the standard of protection provided by the defences will gradually fall from the 1:200 year standard. However, if sea levels rise as projected, by 2065 the standard will remain above the 1:75 year standard of protection. **Table 4** presents the standard of protection provided by the preferred option through the appraisal period.

Table 4 Standard of protection provided by the preferred option

Time period	Defences	Standard of protection provided
Epoch 1 (2015 – 2030)	Low Defences	≥ 1:200 year SoP
Epoch 2 (2030 – 2065)	Low Defences	> 1:75 year SoP (falling from a 1:200 year SoP in 2030)
Epoch 3 (2065 – 2115)	High Defences	≥ 1:200 year SoP

The exact time within epoch 3 when the defences are upgraded is flexible and the upgrade will involve crest raising of the low defences rather than starting the construction of high defences from scratch. Trigger levels for the implementation of the high defences have been established and are discussed in chapter 6.

The preferred strategic option represents a more adaptive approach than building defences to the full high defence height from the outset. Upgrading the defences from 2065 onwards (from the start of epoch 3) allows for potential sea level rise and flood risk to be monitored and the most appropriate time to undertake the upgrade to be identified. If sea levels rise slower than expected then the upgrade can be delayed. On the other hand, if sea levels rise faster than expected then the high defences upgrade can be moved forward in time.

Such an approach has a number of benefits compared to a more precautionary approach (in which all construction work would be undertaken in epoch 1, i.e. constructing high defences in 2015, to a 1:200 year standard for 2115). For instance, the adaptive approach helps to prevent constructing defences which may end up being too high, or too low if sea levels rise at a different rate to current projections. Importantly investment is carried out when it is required and spreads the financial burden involved in implementing in new flood risk management infrastructure.

2.2.1 *Planning context*

As discussed in section 1.5, there is a discrepancy between the climate change allowances used by Flood Risk Management Authorities, who consider sea level rise based on the 95%tile medium emissions climate change scenario, and local planning authorities who consider the more precautionary Defra 2006 upper end estimate.

There is also a difference in how FRM and planning authorities consider freeboard when defining the standard of protection provided by a proposed defence. In FRM terms, if a proposed defence includes a freeboard it is not considered in the appraisal and does not contribute to the defence standard. However, in planning terms the freeboard is considered and it is the actual defence crest level is used to define the standard. Individual site thresholds (typically 300mm) are then applied at a site specific level to account for uncertainties.

Table 6 presents the standard of protection provided by the preferred option through the appraisal period in a planning context. In this table the standard of protection includes the defence freeboard (200mm) and is based on the Defra 2006 upper end scenario sea level rise projection. Bearing in mind the discrepancies between FRM and planning, Table 6 shows that in planning terms the standard of protection provided by the proposed defences is equal to or greater than a 1:200 year standard for the duration of epochs 1 and 2.

Table 5 Standard of protection provided by the preferred option (planning context)

Time period	Defences	Standard of protection provided
Epoch 1 (2015 – 2030)	Low Defences	> 1:200 year SoP
Epoch 2 (2030 – 2065)	Low Defences	≥ 1:200 year SoP (falling to the 1:200 year SoP in 2065)
Epoch 3 (2065 – 2115)	High Defences	≥ 1:200 year SoP

The Strategy preferred option will increase the standard of protection in the areas behind the defences but it is still recommended that developers undertake site specific flood risk assessments and identify any additional measures to reduce the consequences of flooding to developments. For example, developers may need to consider site specific threshold levels / raise floor levels of buildings / provide safe access and egress.

Note that for the remainder of this report, the defence standard of protection is described in FRM terms (i.e. based on the 95%tile medium emissions scenario and not including the proposed freeboard in the standard of protection definition).

2.3 Drivers

2.3.1 *Risk to existing property and assets*

A primary driver for constructing new raised defences in central Bristol is to reduce the tidal flood risk to the existing properties and assets. Under a 'Do Nothing' scenario a 1:200 year event during epoch 1 result in the flooding of around 2700 properties. By 2115 a 1:200 year event would result in the flooding of over 4300 properties. Under this scenario, large areas of the city would have flood depths greater than 1m. The projected increase in risk over time is a result of climate change and sea level rise.

2.3.2 *Development and planning*

Another driver for new defences is to reduce flood risk for potential development and redevelopment areas in the city. Currently the flood risk presents a significant challenge for development and constructing flood defences could help to 'unlock' development potential and lead to the economic growth of Bristol and the wider region.

A development planning workshop was held with key project team members and representatives from Bristol City Council during this phase of the Strategy. During the workshop a number of 'dummy' site applications were considered which provided clarification on the process of determination of planning applications and a mutual agreement on processes and principles surrounding development was reached.

Some key planning parameters / National Planning Policy Framework (NPPF) guidance was clarified during the workshop. Including:

- Site specific Flood Risk Assessment needs to demonstrate safe and appropriate for lifetime in respect to flood risk as per NPPF.
- For residential development there is a development lifetime of 100 years (a minimum). For commercial development this is 60 years.
- For development the design flood event is the 1:200 yr for tidal and the 1:100 yr for fluvial.
- Planning practice guidance notes that access considerations should include the voluntary and free movement of people during a 'design flood', as well as the potential for evacuation before a more extreme event.
- Residual risk (e.g. from above design events, breaching of defences, or other sources of flooding) needs to be robustly assessed and adequately mitigated for each site
- It is a requirement to ensure development does not adversely detriment flood risk to third party sites.

- Planning Practice Guidance provides guidance on appropriate land use vulnerability types acceptable within difference flood risk zones.

It was agreed during the development planning workshop that further assessment of residual risk under the preferred strategic option was required to provide more clarity on site specific impacts and betterment (in terms of flood risk mitigation).

2.3.3 *Synergies with ongoing development*

There are a number of ongoing developments which are incorporated into the Strategy proposals, for example, as part of the Bristol Arena construction a section of the frontage at Totterdown is currently being developed between Brock's Bridge and Victor Street. This development will raise existing crest levels and has been integrated into the scheme for the location.

3. ENGINEERING METHODOLOGY AND ASSUMPTIONS

In the previous stage of work when the preferred option was identified a high level cost estimate was provided. Since that time the engineering designs for high and low defences have been developed further to improve deliverability confidence and to enable a more robust cost estimate to be prepared.

The Strategy has developed engineering designs to an outline design stage as far as possible consistent with the available information; however some key information (e.g. detailed location specific ground condition information) was unavailable at this stage, limiting the level of detail. Additional development and refinement of the designs will be required when developing an Outline Business Case for any schemes that follow on from the Strategy, and to bring them to a state suitable for a planning application.

The designs consider the defence alignment (discussed in detail in the next chapter), level (the defence level to be achieved) and the form (the type of the defence to be implemented). Additional details of the design are found in the Outline Design Briefing Report.

3.1 Base data

3.1.1 *Background*

Three reaches were identified where it was considered that the proposed solutions would have a significant impact on the total costs of the Strategy. These reaches were Cumberland Road (high defences), Clarence Road (low and high defences) and Netham (high defences). For these reaches worst case cross sections were identified and analysis was carried using available information to identify the key dimensions of structures which would be required. A single 'design concept' was identified and applied across the whole reach and no optimisation was carried out to refine the design in any way. This approach is suitable for the current stage of the project and has allowed a more robust cost estimate to be produced but one which still presents opportunities for value engineering / efficiencies to be realised during subsequent design phases.

3.1.2 *Topographic survey and LiDAR*

LiDAR data at 2m resolution was used to assess ground levels across the whole study site. Whilst the LiDAR data provided full spatial coverage, the resolution and filtering meant that it was not always possible to pick up all relevant structures and ground levels to support design.

The LiDAR data was supplemented with existing topographic survey data, which covered the following areas:

- Bathymetric cross sections of the New Cut channel approximately every 200-400m (January 2010)
- Topographic survey of Cattle Market Road pre and post MetroBus works (2016)
- Topographic survey of Entrance Lock area
- Topographic survey of Cumberland Road
- Topographic survey of Netham Lock area
- Cross sections and topographic survey of Totterdown, north of Victor Street

Additional data was requested from the BCC surveyor to supplement the data at key locations including:

- Netham (Feeder Road)
- Entrance Lock (Hotwell Road tie-in)

Where topographic survey data was available it was compared to the underlying LiDAR data. In some areas discrepancies were found, mainly close to buildings, the edge of the river channels close to

riparian walls and where there was significant tree or vegetation cover. In instances where differences were found the topographic data was used in the analysis as this is considered to be more accurate.

3.1.3 *Ground investigation*

A geotechnical desk review study was carried out pulling together all available information from previous site investigation reports provided by BCC along with freely available borehole records from the British Geological Society.

Typical design ground parameters to be used for the sizing of elements in the key areas were estimated based on the boreholes available which were assumed to be representative. The parameters were in some cases based on soil descriptions only or extracted from test results detailed in third party reports so their reliability would need to be confirmed prior to further design work.

It is recommended that site specific site investigation is carried out prior to further design.

3.1.4 *Existing structures*

There are numerous existing riparian walls in the city centre of varying construction types and condition. Information relating to these walls was extremely limited and in most cases was anecdotal.

Determining whether these walls could provide the necessary foundation for the required raised tidal defences is a key factor in the out turn cost of the Strategy. In most cases it has been difficult to demonstrate that historic walls will have an adequate residual life and factor of safety against failure to current design standards. However, the fact that many are standing without evidence of any movement or stress indicate that they are capable of carrying out the function for which they were constructed and are therefore not necessarily unsafe.

No assessments were carried out as part of the outline design to assess the capacity of existing structures to be raised or support new tidal defences. AECOM were not made aware on any structural investigations having been carried out to identify construction type, durability or residual life of any existing structures.

A design assumptions workshop was held on the 29th September 2016 by the project team and the approach outlined in Table 6 below was agreed:

Table 6 Summary of existing structures and assumptions

Reach	Description	Exiting Riparian Structure	Assumption for outline design
1	Entrance Lock	Masonry walls – assumed to be gravity retaining walls but no construction details available	Can be relied upon to support raised defences
1	Brunel Dam	Partially silted up sluice gate structure with concrete sub and superstructure	Replace structure in its entirety. No need to incorporate sluices
2	Cumberland Road	Retaining wall at edge of highway of unknown construction, raised in some locations as part of MetroBus scheme. Secondary retaining wall supporting heritage railway and footpath (Chocolate Path) understood to be vaulted masonry structure. Recent and ongoing issues with settlement of the footpath suggest inadequate or deteriorating condition.	Design structure to retain and protect the highway but not the heritage railway or footpath if this is too onerous. Do not rely on structural support from either of the two lines of retaining structure.
3	Cumberland Road East	Heritage Railway Line in tunnel	Cannot apply additional loading to tunnel
4	Bathurst Basin Dam	Mass concrete dam reinforced with steel railway tracks constructed in 1940's	Condition assessment showed unlikely to be able to be raised in current form without additional support.
4	Commercial Road	Masonry walls – assumed to be gravity retaining walls but no construction details available. In fair / poor condition with signs of movement behind the wall.	New wall to replace the retaining structure as well as provide raised tidal defence
5	Clarence Road	Masonry walls – assumed to be gravity retaining walls but no construction details available. Recent failure of part of wall repaired using mass concrete backfill.	New wall to replace the retaining structure as well as provide raised tidal defence
6	Cattle Market Road	Wing walls associated with Network Rail bridge extend only partway along proposed defence line before tying in to natural bank	No additional loading to be put on Network Rail bridge or wing walls.
7	Totterdown / St Phillips	No riparian structures - natural banks with any structures set back from bank crest.	
8	Netham	Sheet pile wall with concrete capping beam. Unknown lengths or pile size.	Do not use*
8	Netham Lock	Masonry walls – assumed to be gravity retaining walls but no construction details available	Can be relied upon to support raised defences

**The initial decision at Netham was to not rely on existing sheet piling but during the design phase this was reconsidered.*

In all locations where natural river banks exist in front of the riparian walls it was agreed that it could be assumed that the profile of the bank would remain unaltered in the future and that erosion or accretion would not be considered at this stage.

3.1.5 *Services*

Services and utility information was made available for consideration during the outline design. As expected in a city centre a large number of cables, pipes and ducts are to be found close to, or intersect with, the proposed alignment. It has been assumed that in the majority of cases services will be temporarily or permanently diverted away from the working area and an allowance has been included in the costs for this.

Where services were shown to cross the proposed defence alignment further investigations were undertaken. Specifically this related to Wessex Water sewers which are siphoned across the river corridor. Meetings with Wessex Water (culminating on 15 September), and consideration of as built drawings provided by them, confirmed that the locations and levels of the siphons did not impact on our proposed works.

3.2 Freeboard

FRM authorities require a freeboard to be included on all proposed defences to account for some degree of uncertainty and therefore a freeboard has been included. However, the benefit of the freeboard is not considered in the appraisal, and in FRM terms the standard of protection provided by the defences is described by excluding the freeboard allowance.

Derivation of the Freeboard allowance was based on the Quick Method within the Environment Agency's Fluvial Freeboard Guidance Note. This is not directly applicable to a tidal scheme but provides a methodology which can be applied to the varying uncertainties inherent in estimating the defence crest levels. The approach is described in the Outline Design Report for this phase of work.

Based on this approach a freeboard value of 0.2m was applied to the water levels to obtain defence levels for low and high defences.

Since undertaking the freeboard assessment, the Environment Agency has released new freeboard guidance '*Accounting for residual uncertainty: an update to the fluvial freeboard guide*' (February 2017). The new guidance should be considered in the future development of the schemes.

3.3 Defence crest levels

The crest defence levels to achieve a 1:200 year standard of protection for low defences (2030) and for high defences (2115), plus a 0.2m freeboard are presented in Table 7 below. These levels have been used in the outline design and costing of defences in this phase of work. The levels change as you move upstream along the New Cut and are presented for each defence alignment.

Table 7 Defence crest levels (including a 0.2m freeboard). Levels presented to m AOD.

Reach	Defence section	Predicted peak water level (2030)	Predicted peak water level (2115)	Low Defence crest level (2030 1:200 year standard)	High Defence crest level (2115 1:200 year standard)
1	Entrance Lock	9.45	10.10	9.65	10.30
2	Cumberland Road	9.45	10.10	9.65	10.30
3	Cumberland Road underpass	9.45	10.10	9.65	10.30
4	Commercial Road & Bathurst Basin Dam	9.45	10.10	9.65	10.30
5	Clarence Road	9.45	10.10	9.65	10.30
6	Cattle Market Road	9.60	10.20	9.80	10.40
7	Totterdown / St.Phillps	9.60	10.20	9.80	10.40
8	Netham	9.60	10.20	9.80	10.40

3.4 Methodology and design assumptions

3.4.1 *Methodology*

Designs have been prepared for all lengths of the proposed works but to varying levels of detail depending on the likely impact on the cost estimate.

Three reaches were deemed to have a major impact on cost due to their length and the proposed solution:

- Cumberland Road (high defences)
- Clarence Road (low and high defences)
- Netham (high defences)

These reaches were chosen on the basis that they will be structures which retain the land behind as well as act as a tidal defence. As the ground behind the defences is up to 10m above the river bed level the structures will need to be fully engineered structures with the worst design case being the retention of the land behind rather than the tidal load case.

Proportionate geotechnical and structural analyses were applied to these structures to identify the likely sizes of the key elements. The results of these analyses can be found in appendices to the Outline Design Briefing Report.

All other defences were chosen using engineering judgement and rules of thumb. Reinforced concrete cantilever walls have been proposed where defence heights above ground level are less than 2m. Sheet piled walls have been proposed for defences over 2m or where topography meant that a cantilever wall may not be able to be constructed.

Ramps have been proposed wherever possible to minimise the use of moveable gates and hence reduce operational requirements. It is acknowledged that this will create some potentially unwieldy structures within the public realm and landscaping considerations will need to be fully incorporated into the next design phases to ensure that the impacts are minimised.

Ramps and road raising will be fully DDA (Disability Discrimination Act 1995) compliant and are assumed to have a maximum gradient of 1 in 20 or a steeper gradient with appropriate landings.

3.4.2 *Assumptions*

The following design assumptions have been applied to all reaches:

- Design life to be 100 years (assume where raising existing structures that residual life can be achieved through maintenance (up to 100 years).
- Maximum water level to be at the top of the wall, no overtopping allowed for (but deemed to be covered by factors of safety incorporated into the design)
- Defences to be provided where the ground level is below the modelled water level. Freeboard only to be applied to the crest level of required defences not when considering the extent of the defences.
- Where defence types are the same for the low and high levels the low defences will be constructed with foundations suitably designed to allow for raising in the future to the high defence level.
- Brick or stone cladding will be applied where deemed appropriate or a fair faced concrete finish elsewhere.
- Services and utilities are assumed to be able to be temporarily or permanently diverted.
- Glass walls and demountable defences have not been explicitly considered in any of the reaches but remain as options particularly when raising from low to high defence levels. Foundations for either would be the same as for a standard wall raising but other issues such as maintenance (cleaning the windows), acceptability and operation (in the case of demountable panels) would

need to be considered on a site by site basis. Should glass walls be included in future designs, there will be an impact on the construction and maintenance costs.

3.4.3 *Assumptions relating to analysed reaches*

In addition to the assumptions listed above in section 3.4.2, the following design assumptions have been applied to the analysed reaches at Cumberland Road, Clarence Road and Netham:

- Assume river channel shape does not alter significantly during the design life (no active erosion or deposition of soft material)
- Ground water level on landside to be appropriate to land use and ground conditions behind. Assume that back of wall drainage will be installed if required.
- Design to Eurocodes as far as practicable (GI is not appropriate for a fully Eurocode compliant design).
- Where appropriate (e.g. Clarence Road) landscaping features (e.g. raised ground levels) may be used to assist with optimising the design.
- Services and utilities do not need to be considered.
- Below ground details (extent and condition) of existing structures are unknown and any assumptions relating to them are clearly stated in the calculation reports.
- Construction methods to be considered taking adjacent land use into account (e.g. minimal access at Netham).

3.4.4 *Assumptions relating to non-analysed reaches*

In addition to the assumptions listed in section 3.4.2, the following design assumptions have been applied to the non-analysed reaches:

- Base widths of cantilever walls to be approximately 0.7 times the retained height
- Sheet pile lengths to be approximately 3 times the retained height (twice the retained height below ground)
- Embankments to have a 4m crest width and minimum 1 in 3 slopes

3.5 Capital cost estimate

Capital costs have been estimated for all of the engineering elements of the designs. More details on the approach to capital costs are found in the Outline Design Briefing Report and associated appendices.

Unit rates were generated for linear and surface features such as walls and cladding based on Environment Agency Cost Estimation Guidance supplemented as appropriate with build ups using SPONS price book (2016).

Lump sums were also estimated for discrete elements of work (such as flood/lock gate replacements) based on previous similar works either planned or constructed.

3.6 Health, safety and environment considerations

3.6.1 *Construction Design and Management Regulations*

In accordance with the Construction Design and Management Regulations (CDM, 2015), hazards during construction, operation, maintenance and demolition have been considered while developing the designs. Due to the early stage of the design process only high level assessments have been carried out to date and mitigation measures will need to be continued throughout the design phase. All of the designs shown on various drawings contained within this report and the accompanying Outline Design Briefing report must be regarded as 'Preliminary – not for construction'.

AECOM are the Principal Designer and have undertaken an independent internal review to confirm that the approach is acceptable.

3.6.2 *Construction*

Constructability of the proposals has been a key consideration when identifying the defence type. In addition to the general construction hazards associated with the tidal and river engineering works, specific hazards relating to the Strategy are:

- Unknown condition and construction of existing riparian walls
- Contained working, particularly in Totterdown / St. Philips and Netham. Considered that working from the river may partially overcome this problem but brings additional hazards associated with tidal working.
- Proximity of buildings and infrastructure
- Unknown ground conditions

3.6.3 *Operation*

Whilst every effort has been made to incorporate passive defences wherever possible, in some locations this has not been possible. Hazards associated with the operation of the Strategy are:

- Flood and lock gates will require operation in advance of high tides. Most are located within or close to Entrance Lock and are assumed to be able to be operated by the Harbour Master. Elsewhere it may be necessary to identify local flood wardens to close gates in the event that Council or EA staff cannot reach the sites in time. Alternatively the gates could be remotely operated.
- The Strategy aims primarily to protect people and property from tidal flooding and consequently there will continue to be flooding to roads, footpath and other public areas. This hazard can be mitigated with the use of appropriate signage, public awareness and where necessary barriers or gates to prevent access.
- The collection of overland flow behind the defences which cannot be discharged due to the high tide levels could still cause areas of floodwater behind the defences. Further work is required during the detailed design phase to mitigate this either through storage, overpumping or educating the public to accept residual flooding and the associated hazards.

3.6.4 *Maintenance*

Regular maintenance activities associated with the Strategy would be similar to tasks already undertaken by BCC and the Environment Agency and would include:

- Regular inspections and monitoring

- Small scale remedial works to defences including joint replacement, repointing, seal replacement etc.

Hazards associated with these tasks would need to be assessed on a case by case basis but would be exacerbated by tidal working. Further consideration should be given to these aspects during the outline and detailed design.

Larger scale capital maintenance such as replacement of elements of the lock gates or associated M&E infrastructure would have similar and comparable hazards to the construction phase described above.

3.6.5 *Environment*

The environmental impacts of the proposals are covered in detail in the Options Identification and Environment Appraisal Addendum Report (December 2016). The items which have an effect on the proposals and have been included in the costs are:

- Cladding

Additional mitigation measures which have a percentage allowance included in the costs but should be considered in more detail at the outline and detailed design stages are:

- Landscaping
- Incorporation of defences into the public realm improvements
- As detailed defence design takes place, every opportunity will be taken to minimise net loss of intertidal mudflat to reduce the losses identified. Ultimately, measures will be developed and presented as part of the detail to support a planning application to ensure no net loss of intertidal habitat. If any losses are incurred this would need to be addressed through the Environment Agency's Regional Habitat Creation Programme.

4. DEFENCE ALIGNMENTS

4.1 Approach to Alignment decisions

The alignment identified in the preferred option report was generally a frontline sheet piled defence, encroaching into the river channel by approximately 2m. This alignment was identified for costing purposes as it was considered as a worst case scenario both in terms of cost and physical impact. During the outline design phase further evaluation and refinement of the alignments and construction types was made with the intention of improving upon the general assumptions behind the high level proposals.

The alignment selection and confirmation process was informed by a project team site visit on 5th October with the key representatives from the City Council, Environment Agency, Harbour Authority, Network Rail and other key stakeholders in attendance. The preferred alignment was chosen based on the discussions and the evidence that was collected on that day and subsequently verified through survey and analyses.

The proposed alignments have been selected with the intention to maximise benefits to property and transport infrastructure as well as amenity assets, whilst also providing as minimal impact as possible on the flood storage and flow capacity in the river. However, there are areas where this was not possible due to topography or other constraints meaning that protecting a feature would lead to a defence becoming prohibitively expensive. For example where a riparian footpath is on the edge of the river bank a raised defence would require the bank to be supported as well leading to a larger more expensive engineered structure compared to a setback defence where only the tidal loading needs to be considered. When developing the alignments the following aspects were considered:

- Defence heights above ground level;
- Defence type;
- Construction access and buildability;
- Encroachment into the river channel; and
- Existing and future land use

Passive defences have been preferred wherever possible. This has included ramps or ground raising to maintain access across defence alignments rather than installing floodgates. In some locations identified below, floodgates have been identified as the only feasible way of maintaining access. This increases the residual risk of defence failure as there is a chance that the gates could be left open during flood events. It is recommended that operational procedures are put in place to ensure that BCC have a team to operate and close the flood gates during events. Effective operation will rely on the continued forecasting and warning of flooding prior to events. Instructions to close the gates should be provided with sufficient time to reduce the risk of the gates being left open.

4.1.1 *Further considerations and additional work*

The proposed alignments are indicative and in order to confirm that the alignments are feasible a number of additional studies should be undertaken during the development of the design including the following:

- Ground investigation bespoke to the locations of the defences (following Eurocode guidelines) in order to provide more detailed and accurate ground condition parameters.
- Structural assessment of MetroBus wall and sheet piles at Netham to investigate whether raising is feasible.
- Investigations into location, type and condition of existing structures particularly at Cumberland Road, Clarence Road and the Network Rail Bridge to improve confidence in most suitable solutions here.
- Liaison with heritage bodies particularly in relation to Entrance lock and raising the bridge level across Brunel Dam in order to mitigate impacts to this heritage asset.
- Consideration of the use of glass walls in key locations (to reduce visual / landscape impacts)

- Consultation on visual impact and materials choice.
- Land ownership liaison particularly at Bathurst Basin where the alignment crosses private land
- Liaison with Network Rail to discuss bridge tie ins at Cattle Market Road.
- Surveys of properties proposed for property level protection to ensure that they are suitable and identify the works required
- Consideration of the operation of raised flood/lock gates at Netham and Entrance lock to reduce residual risk.
- Consideration of operation rules and requirements of flood gates to reduce residual risk.
- Consideration of how defences may incorporate construction works undertaken between now and the time that the defences are constructed (i.e. at Bathurst Basin Dam where there is a MetroBus bridge proposed).
- Phase 1 habitat surveys to inform the alignment. Liaison with the Environment Agency and Natural England regarding HRA and WFD assessments.

4.1.2 *Summary of defence alignments*

Sections 4.2 to 4.10 describe each defence area alignment in more detail. A summary is provided in Table 8 below, including information of the alignment length in each area, average defence height above ground level, maximum defence height and structure type(s). Figure 3 shows the location of the defences.

Table 8 Summary of defence alignments

Reach	Defence section	Structure type(s)	Defence length for low defences (m)	Defence length for high defences (m)	Average height for low defences (m)	Max height for low defences (m)	Average height for high defences (m)	Max height for high defences (m)
1	Entrance Lock	Floodwalls, flood/lock gate replacement, highway / bridge abutments, ramps, road raising	900	910	1.1	1.9	1.8	2.6
2	Cumberland Road	Floodwalls	610	640	0.8	1.2	1.5	1.8
3	Cumberland Road underpass	Floodgate, ramp and floodwall tie-ins	20	20	1.1	1.3	1.7	2.0
4	Bathurst Basin Dam	Raising of existing structure, floodwall tie-ins	60	60	0.7	2.6	1.4	3.3
4	Commercial Road	Floodwalls, retaining structure, ramp	190	240	0.7	1.2	1.4	1.8
5	Clarence Road	Floodwalls, retaining structure, bridge abutment	620	620	1.0	2.0	1.6	2.7
6	Cattle Market Road	Floodwalls, retaining structure	180	190	0.8	2.1	1.4	2.7
7	Totterdown / St. Phillips	Floodwalls, ramps, resilience structures to existing buildings, bridge abutment	1,500	1,500	0.9	2.1	1.4	2.7
8	Netham	Floodwalls, flood/lock gate replacement, road raising	740	740	1.0	3.3	1.6	3.9
Total			4800	4900	0.9	3.3	1.5	3.9

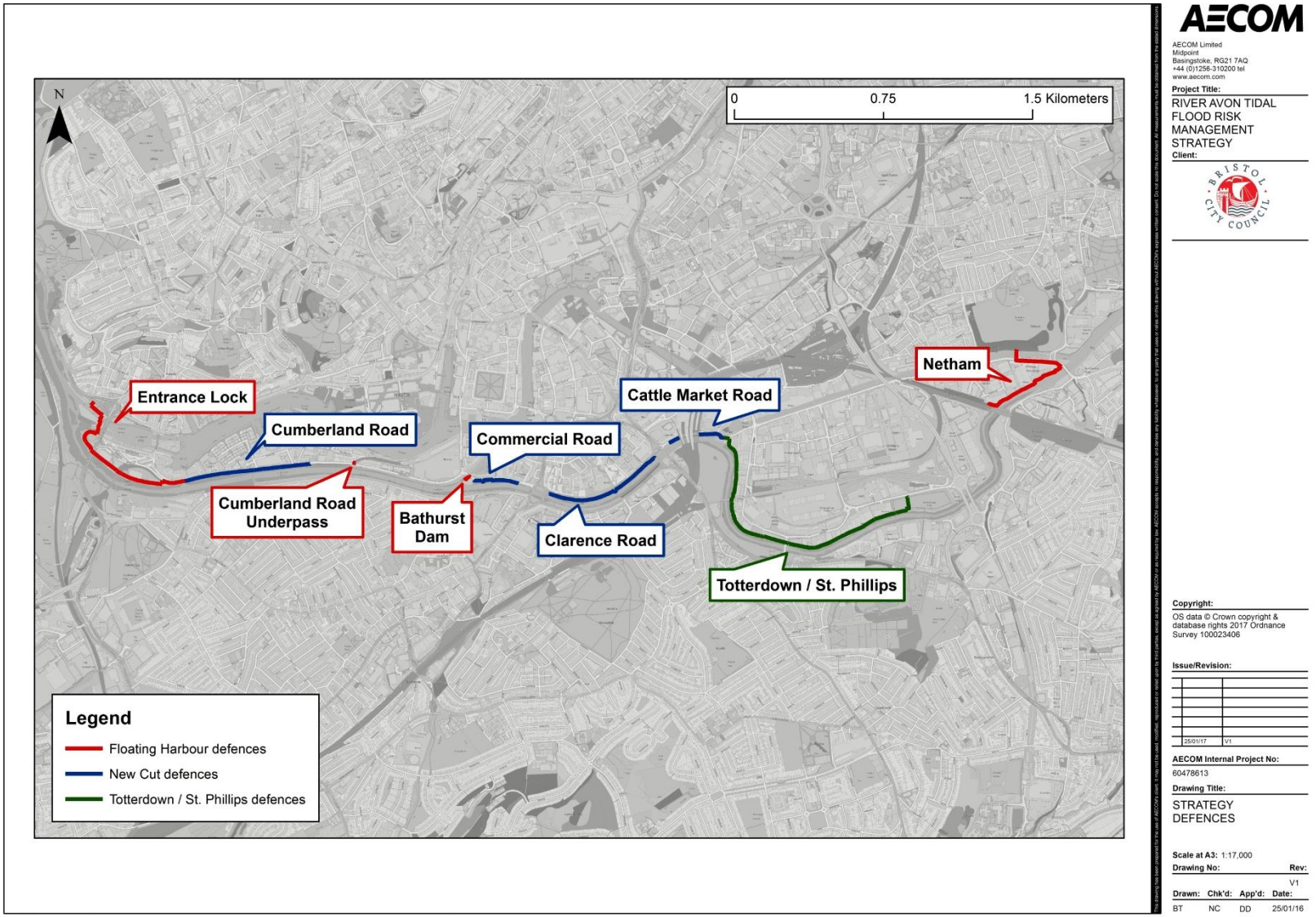


Figure 3 Defence locations (high defence alignments shown)

4.2 Entrance Lock

4.2.1 *Background*

The Entrance Lock defence corridor is between Hotwell Road and the Underfall Yard sluices on Cumberland Road as shown in Figure 4.

The main purpose of the defences at Entrance Lock is to prevent flood water from flowing from the New Cut into the Floating Harbour. Once water enters the Floating Harbour during flood events the harbour can gradually fill to capacity, before spilling into central Bristol and flooding properties and assets in the city.

The defence corridor at Entrance Lock is characterised by a mix of land uses and there are a number of constraints which limit the choice of the preferred route alignment in this location. The Harbour Authority own land at the 'Knuckle' which is used for operation of the Entrance Lock gates and is important for the visibility of approaching vessels. East of Brunel Way bridge there are a number of commercial properties located in renovated industrial buildings behind the defence corridor.

The waterfront is comprised of vertical masonry harbour walls at Entrance Lock and around the 'Knuckle'. There is a natural river bank upstream of Brunel Way dam comprising intertidal mud flats and lower levels with a sloped and vegetated upper section. A footpath is located on the bank top for most of the length and highways run behind. A Heritage Railway runs between the footpath and highway from Cumberland Road upstream connecting to the MShed in the city centre.

At the east end of the alignment, a flood wall is currently under construction as part of the MetroBus scheme. The wall is positioned between Cumberland Road and the heritage railway and has a crest level of 9.2m AOD which equates to a present day 1:200 year standard of protection. The wall is approximately 0.7m high (relative to ground levels) at its western end and extends into the adjacent defence area to the east. The wall has not been explicitly designed to accommodate future raising but is expected to have some redundancy which can be exploited in the short term.

4.2.2 *Alignment*

The tie in at the downstream extent of the strategy study area is at the piazza adjacent to Hotwell Road. A defence up to 0.8m for low defences and 1.4m for high comprising a small kerb or reinforced concrete wall will need to link to a section of road and footpath raising across Cumberland Basin Road. The piazza defence can be landscaped into the area to minimise the visual impact. The location of the road raising has been chosen to avoid the need for a flood gate and benefit from the rising road levels in this area.

A masonry clad reinforced concrete wall will need to run along the line of the existing railings adjacent to Cumberland Road and the defence then crosses the lock side footpath with ramps and steps to maintain access.

The preferred alignment at Entrance Lock was proposed following discussions between the project team and the Harbour Authority to minimise the impact on the operation of the lock and take the heritage issues relating to the numerous listed structures into account.

To maintain visibility down the River Avon and minimise the lengths of harbourside wall raised it was agreed that the defences would need to follow a line as close to Cumberland Basin as feasible.

The upper lock gates (i.e. the gates closest to Cumberland Basin) and accompanying infrastructure will need to be replaced with dedicated flood gates on the existing alignment to prevent water flowing into Cumberland Basin. The gates will be designed to resist water head from both sides at entrance lock and will need to have a dual flood/lock gate function. The gates will also need to have multiple layers of redundancy in power supply and controls to ensure that the risk of failure is minimised and is lower than with the existing lock gates. For instance, the gates will need to be powered from both sides of the channel (so that electrical supply failure on one side does not compromise closure), have a backup independent power source and will also need to be fitted to enable manual operation (in case of complete electrical failure). To maximise benefits, it is proposed that the high defence flood/lock gates are installed early in the strategy to provide long term cost savings and avoid the need for an upgrade during the Strategy period. The new gates will need to have a crest level of 10.3m AOD, which corresponds to a 1:200 year standard of protection for 2115.

Other areas within the lock were considered for the raised lock gates, for instance approximately half way down the lock, but there are a large number of service lines / cables beneath the surface of the

‘Knuckle’ which restrict the space available for operating infrastructure in these locations. In addition, the lock is also used to moor vessels during busy periods and a new set of gates half way down the lock would prevent this from occurring. An advantage of placing the new gates in this position is that there will be space available to house the new operating infrastructure for the gates (i.e. the hydraulic pistons).

Connecting into the lock gates a new raised reinforced concrete defence wall will need to be constructed across the Knuckle on an alignment avoiding the underground chambers associated with Brunel’s Bridge and other hydraulic and electrical equipment. Further studies will be needed to confirm an exact route alignment or to develop plans to mitigate / re-route the utility lines.

The change from a frontline option to the proposed alignment means that the Harbour Master’s building (a listed structure) and the new HPU buildings would remain at flood risk and allowance has been included for flood proofing.

A flood gate will be required through this defence to maintain vehicle access, including for heavy plant associated with the operation of the harbour, to the undefended side. Due to a lack of space it has not been possible to identify a defence arrangement which would incorporate a ramp but the floodgate could be kept closed at all times unless access was required to minimise the risk of failure.

The defence line continues across Brunel Dam which it is proposed to be raised with mass concrete. The sluice gates through the dam (which are currently not operated) will need to be formally decommissioned and there will also be associated works to raise the bridge deck (above the dam) and parapets. The approach for doing this will need to be agreed with the relevant heritage bodies.

From Brunel Dam the defence alignment crosses the footpath and follows it along the river bank using the existing highway abutments as a defence wherever possible. Short sections of infill defences will also be required before the defence reaches The Create Centre. The defence continues as a reinforced concrete wall on the riverside edge of the road crossing with the MetroBus bridge with a ramp (low defences) and a floodgate (high defences) before crossing the heritage railway at the eastern end of Cumberland Road with another flood gate. A ramp will also need to be installed to maintain access along the Chocolate path.

At its eastern end the alignment will need to connect to the new MetroBus flood wall which is currently under construction. The alignment follows the MetroBus flood wall until Underfall Yard and for low defences it is proposed that the MetroBus wall is used as part of the defence. To achieve the low defence standard of protection (1:200, 2030) the crest of the MetroBus wall will need to be raised by approximately 0.45m. Without further assessment this is assumed to be feasible but further studies to investigate the loading capacity of the wall are required.

For high defences when crest levels increase to 10.3m AOD it will be necessary to fully replace the MetroBus wall with a contiguous piled wall located beneath the heritage railway supporting a reinforced concrete pile cap and wall to provide the defence. This solution provides support to the highway without relying on any existing retaining walls or structures.

The total length of the Entrance Lock defence alignment is approximately 910m. Ground levels vary considerably along the alignment. Relative to existing ground levels immediately behind the defence the average height of low defences along the alignment is approximately 1.1m and the maximum height is 1.9m. The average height of high defences is approximately 1.8m and the maximum height is 2.6m.

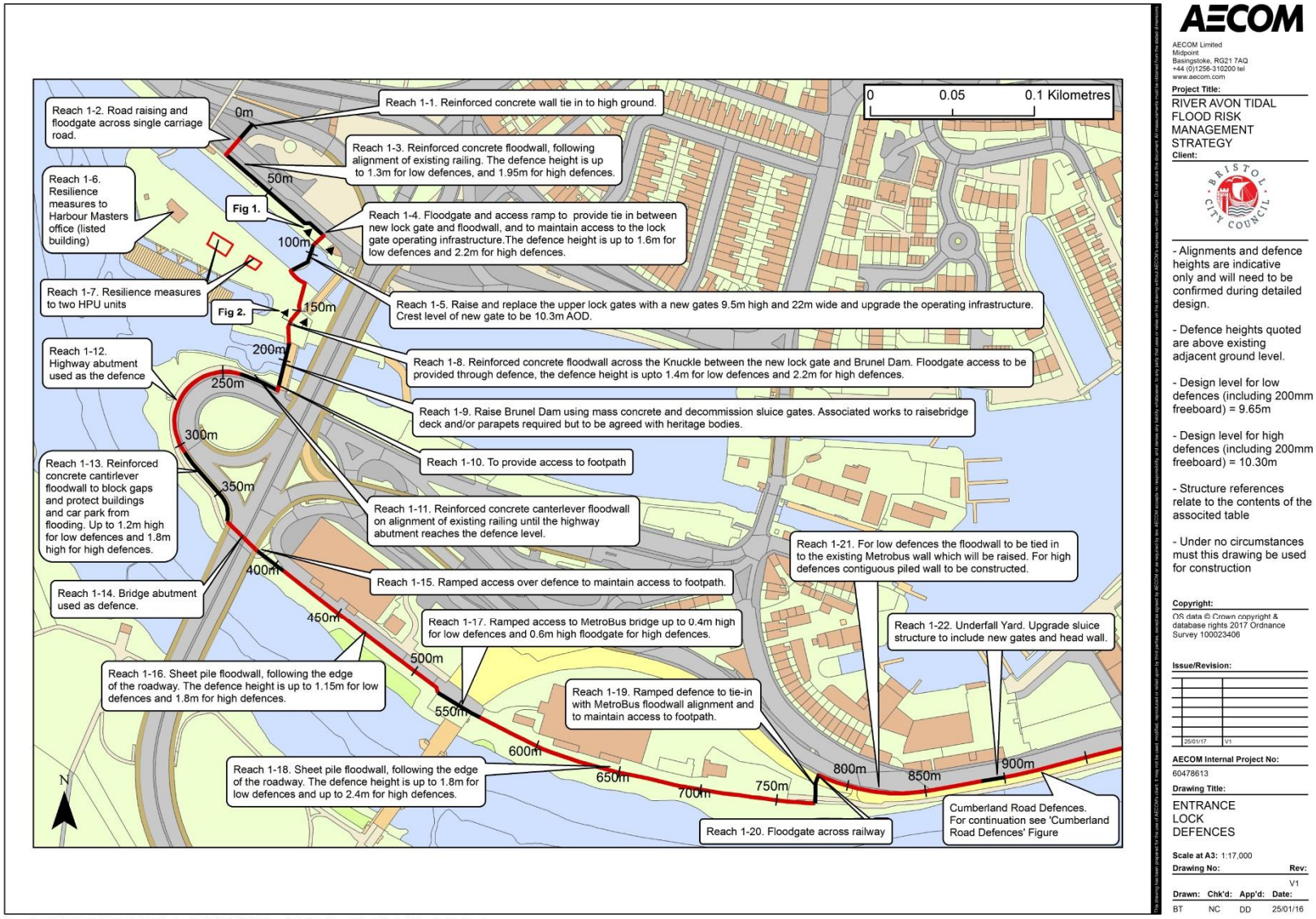


Figure 4 Defence alignment at Entrance Lock

4.2.3 *Landscape visualisations*

Figure 5 and Figure 6 below show landscape visualisations of the proposed defence. The viewpoint of Figure 5 is from Cumberland Basin Road, looking south east across Entrance Lock to the 'Knuckle'. In this location the road will be raised and new lock gates will be installed at the end of Entrance Lock. Figure 6 shows the access road in-front of the commercial buildings on Spike Island, immediately east of Brunel Way bridge. The New Cut river channel is to the right of the image. In this location a defence has been constructed at the crest of the natural river bank.

Figure 5 Landscape visualisation of the proposed defence at Entrance Lock (low defences shown in red, high defences in pink)

Figure 6 Landscape visualisation of the proposed defence at Entrance Lock (low defences shown in red, high defences in pink)

4.3 Cumberland Road

4.3.1 *Background*

The Cumberland Road defence joins to the Entrance Lock defence at Underfall Yard and ties into high ground at its eastern end. The proposed defence will prevent water from entering the area behind the defences which contains a mixture of residential and commercial properties. Cumberland Road, which is a key transport link within the city, is situated immediately behind the proposed defence alignment and will also be protected.

The defences at Cumberland Road will protect properties immediately behind them. It is unclear from the modelling whether there is a flow route from Cumberland Road into the Floating Harbour. If a flow route does exist it will only be during high magnitude events and further modelling is required to investigate this further. For the purpose of the flood risk economics, it has been assumed that Cumberland Road protects the immediate flood cell behind the defences and the area does not act as a pathway to the Floating Harbour.

The defence alignment corridor at Cumberland Road is characterised by a mix of land uses including residential, commercial and industrial. Cumberland Road itself is a major transport pathway through the city.

The river bank along this reach comprises a small area of mud / intertidal environment adjacent to a vertical brick arch structures supporting the Chocolate Path, a foot and cycle path of heritage and landscape importance to Bristol. The chocolate path and supporting structures are in a poor condition in some locations.

Between the Chocolate Path and Cumberland Road there is a heritage railway line which is of importance to the local area. Both the highway and railway are supported by separate retaining structures. The highway retaining structure is the original and once represented the edge of the New Cut channel. The railway retaining structure was constructed at a later date and extended the land boundary into the New Cut channel.

On the landward side of Cumberland Road the pavement is backed by a 2m high wall and a number of tall buildings in some locations.

The MetroBus flood wall discussed in section 4.1 is currently under construction in the western section of the defence corridor.

4.3.2 *Alignment*

The wall alignment for the full length of this reach follows the existing wall between Cumberland Road and the Heritage Railway. For low defences the MetroBus wall will need to be raised and extended (subject to structural assessments). For high defences when crest levels increase to 10.3m AOD it will be necessary to fully replace the MetroBus wall with a contiguous piled wall located beneath the heritage railway supporting a reinforced concrete pile cap and wall to provide the defence. This solution provides support to the highway without relying on any existing retaining walls or structures.

A number of alignments were considered and rejected prior to deciding on this alignment including:

- The landward side of Cumberland Road either along on the boundary wall at the back of the footpath or between the road and the footpath. This was rejected due to the number of driveways and accesses that would require floodgates (insufficient space for ramps) and the landscape impacts. Also the use of flood gates across this road to connect to the Entrance lock defence due to the traffic impacts makes this alignment unviable.
- Riverside edge of the Chocolate Path. Being a frontline alignment the wall would need to provide flood defence but also offer structural support to the existing structures (footpath, railway and roadway). It would be essential for the wall to be able to take the rail and road loads which would be imposed upon it. This was rejected due to the anticipated costs, the encroachment into the channel, the minimal additional benefits of protecting the railway and Chocolate Path and the loss of the heritage value of the brick arch structure.
- Riverside edge of Heritage Railway (Protecting the railway but not the Chocolate Path). The wall would need to provide flood defence but also offer structural support to the existing structures (railway and roadway).This option was rejected due to the anticipated costs, the likely impact on the brick arch structure and the minimal additional benefits of protecting the railway. The current proposal could be amended to protect the Heritage Railway from tidal flooding but has not been designed to do so and may increase costs and would impact on the brick structure.

The proposed defence is approximately 650m in length. The defence height relative to ground levels varies along the alignment. West of Vauxhall Bridge the defence that follows the MetroBus flood wall alignment will need to be up to 1.8m above existing ground levels for high defences (including freeboard). East of Vauxhall Bridge, the defence will need to be up to 1.5m above existing ground levels for high defences, although for low defences the defence height will only need to be up to 0.9m. The land levels gradually increase moving east and the defence will tie-in to higher ground just east of Gas Ferry Road.

A drawback of the preferred alignment is that it doesn't protect the degrading brick walls in front of the alignment. However, the solution does offer a degree of highway stabilisation so the urgency to repair or stabilise the frontline brick structures from retainment loading is reduced. With the preferred alignment in place the frontline brick walls could be repaired / stabilised according to the availability of BCC resources and heritage requirements / preferences without impacting on flood risk.

4.3.3 *Landscape visualisation*

Figure 7 below shows a landscape visualisation of the proposed defence at Cumberland Road. The viewpoint is from the back of Cumberland Road, looking south west across the New Cut river channel.

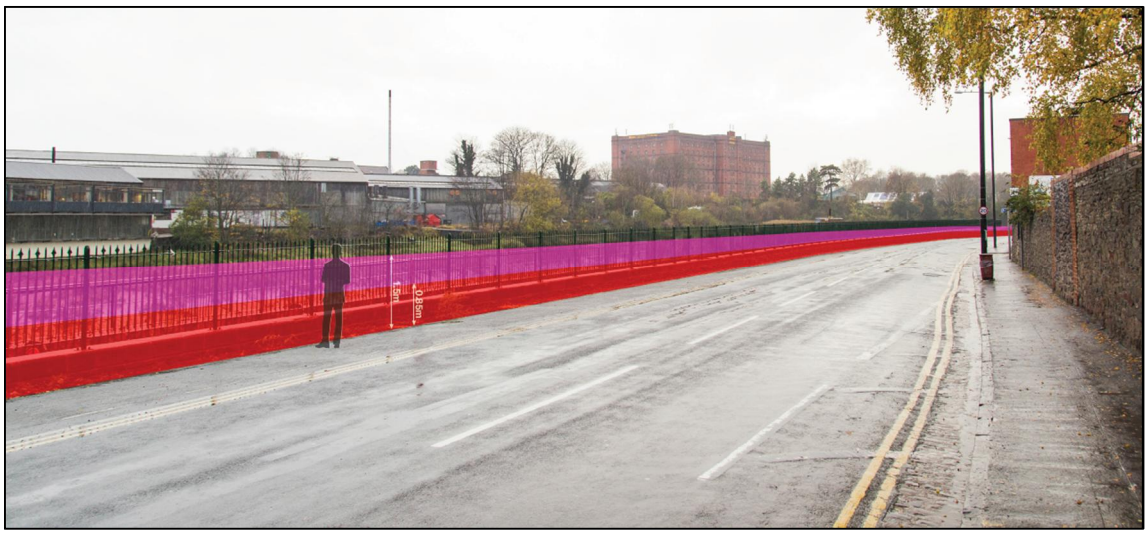


Figure 7 Landscape visualisation of the proposed defence at Cumberland Road (low defence in red, high defence in pink)

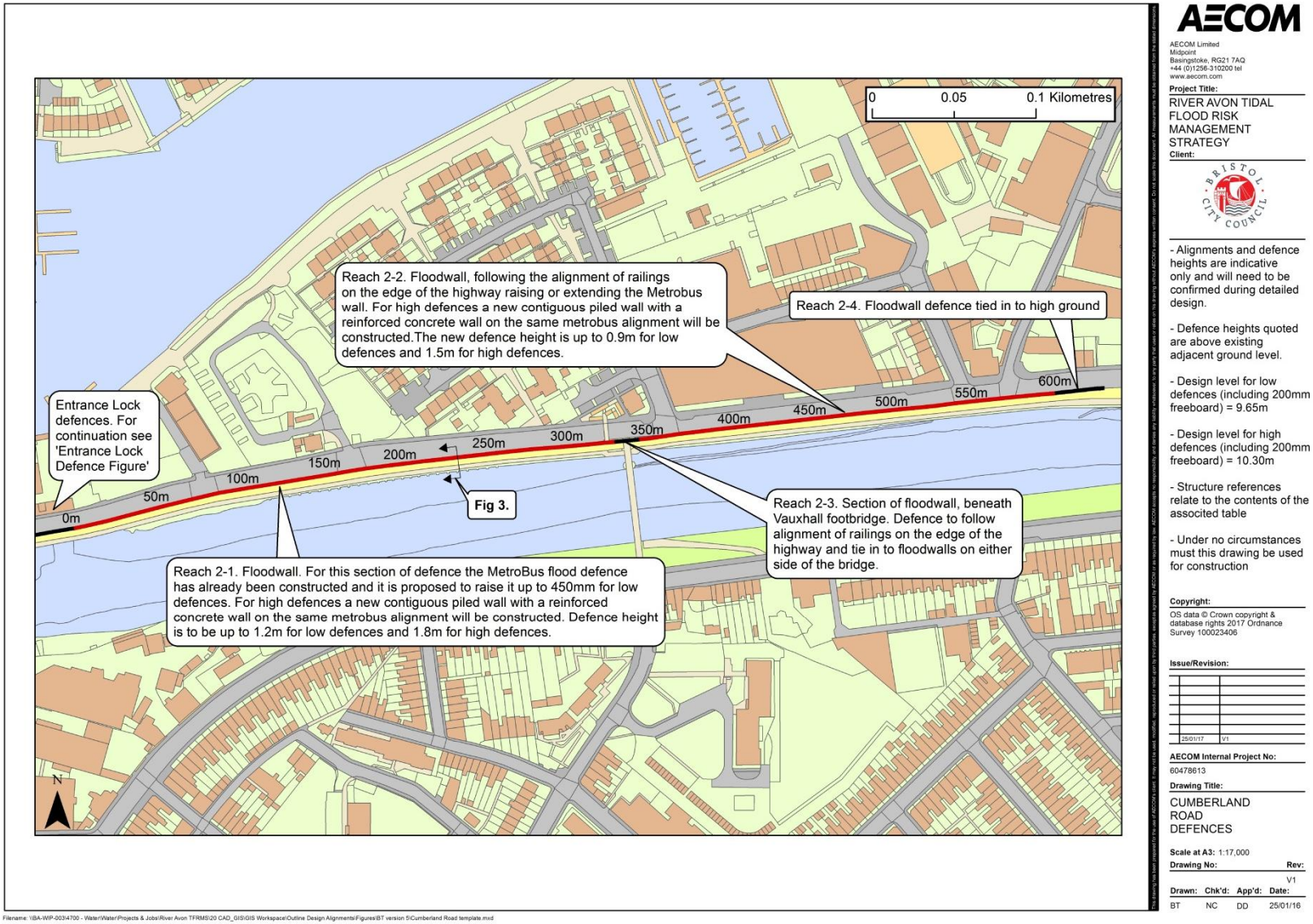


Figure 8 Defence alignment at Cumberland Road

4.4 Cumberland Road Underpass

4.4.1 *Background*

Cumberland Road underpass refers to a low lying area of land which carries the heritage railway and a public footpath beneath Cumberland Road.

The underpass currently provides a flow route for flood water into the Floating Harbour.

The area is setback from the New Cut river channel and does not adjoin to any other defence areas. The underpass is used entirely for access purposes and maintaining the access route for both the railway and footpath is an essential aspect of a defence in this area. The underpass runs beneath a road bridge with a clearance height of approximately 5m.

4.4.2 *Alignment*

The land uses and space constraints in the underpass limit the choice of defence alignments in this location.

The proposed defence comprises a large flood gate across the railway line. Adjacent to this, the footpath will need to be raised via a ramp. The defence will prevent water from flowing through the underpass and into the Floating Harbour but will also maintain the access requirements of the railway and footpath during normal conditions when flood risk is low. The alignment is presented in Figure 9.

Twin gates 6m wide and 2.0m high (high defence level) and associated supporting structures are proposed across the railway. The ramp along the footpath will need to be designed to be fully accessible for all users.

Given the space constraints and access requirements at this location the scope for different defence alignments is limited and therefore no alternative alignments were considered. Liaison with the Office of Rail Regulation and Heritage Railway will be required regarding the installation of the flood gate across the existing railway.

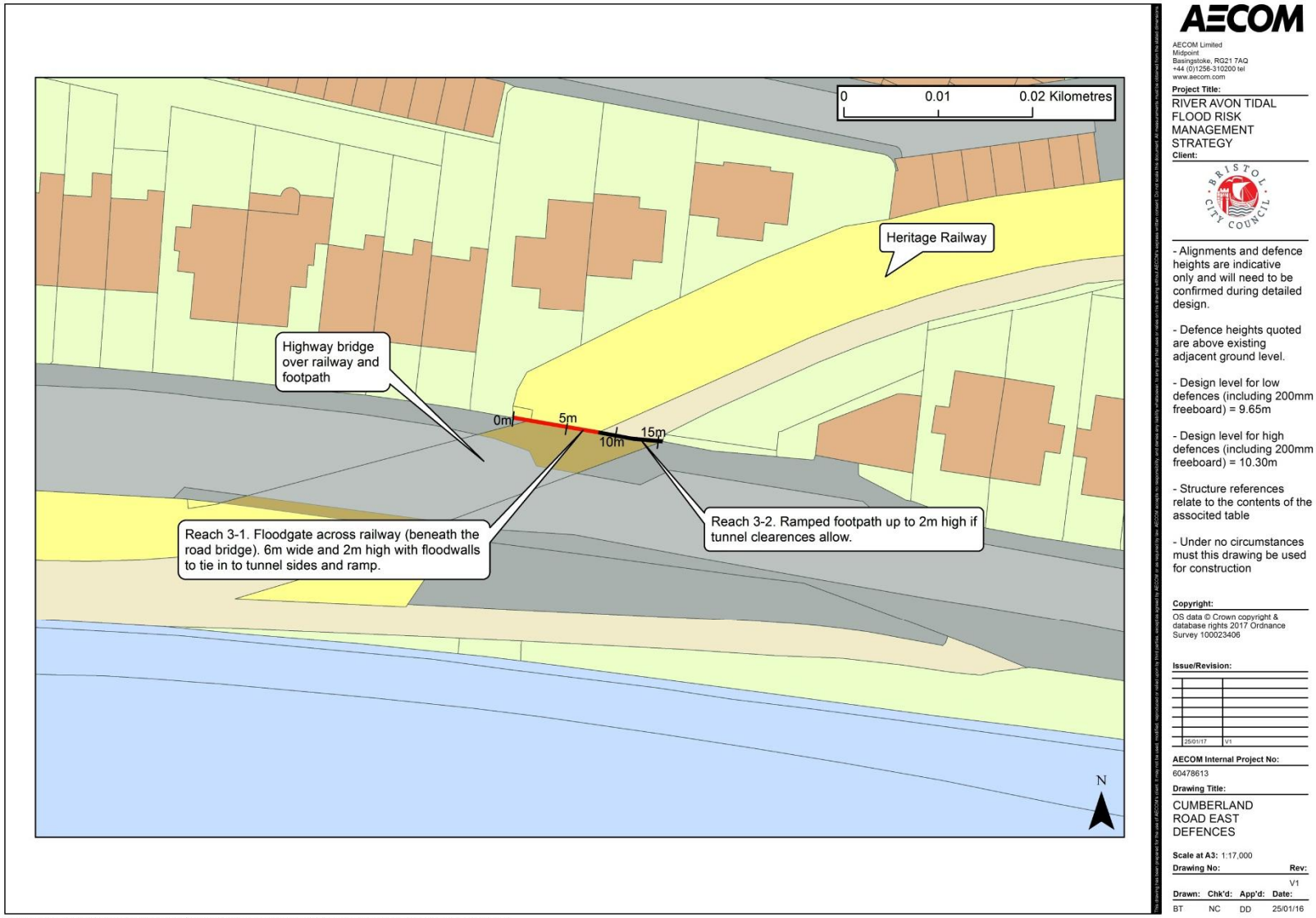


Figure 9 Defence alignment at Cumberland Road underpass

4.5 Bathurst Basin Dam

4.5.1 *Background*

Bathurst Basin Dam is situated along the New Cut at the intersection between Cumberland Road and Commercial Road. It blocks a historic navigation route into Bathurst Basin. The dam was constructed in the 1940's and comprises a mass concrete structure with railway track reinforcement. The dam has been previously assessed as being in a 'good' condition with existing crest level of the dam is approximately 8.3m AOD and the dam is approximately 12m long.

The proposed defence is required to prevent flood waters entering onto the Floating Harbour.

It was agreed by the project team to make best use of the existing Bathurst Basin dam structure for future defences as it provides cost savings and is likely to minimise the environmental, visual and landscape impact to the area.

4.5.2 *Alignment*

At the time of writing this report a new bridge in close proximity to the Dam is under construction. Therefore, at this stage the proposed defence alignment is indicative only to enable costing to be undertaken and the final route of the defences should be determined in the next phase after the Strategy, taking into account the final layout and tie in details of the new bridge and an assessment of the quay walls (via the proposed BCC Harbour Asset Management Strategy).

Full details of the alignment considered at this stage are available in the Bathurst Basin Design Review Technical Note. A summary is provided below:

4-0 God's Garden – tying into the access steps to God's Garden from Cumberland Road, a 6m long wall would cut across the quay. The typical ground level on the quay is 8.4m AOD requiring a 1.9m high wall (for high defences). Above ground this is assumed to be a reinforced stem. Foundations of the new wall will need to be determined but are expected to be piled, either sheet piles, bored piles or screw piles depending on the ground condition and construction of the quay wall.

4-1 Bathurst Basin Dam – the dam crest will be raised with a reinforced concrete stem which will be supported by a mass concrete gravity base, extending the existing gravity structure.

4-2 Quayside – an 8m long wall will tie the raised dam crest into the bridge alignment. The exact route of this wall will need to be determined once further details on the quay walls are known and details of the wall foundations are determined. Foundations of the wall will need to be determine but are expected to be piled, either sheet piles, bored piles or screw piles depending on the ground condition and condition and construction of the quay wall.

4-2a Tie in to Commercial Road – The new bridge wing wall on the eastern approach will need to be raised by up to 200mm or a new L shaped (cantilevered) reinforced concrete gravity wall built in front. The proposed tie in between the new MetroBus lanes and the existing ground levels is unclear and further analysis will need to be undertaken once as built details are available. It appears that ground levels are such that defences will be required along the full length from the bridge wing wall to the start of the Commercial Road defences. It has been assumed for the purposes of costing that the existing retaining wall separating the highway from the access road to the boatyard will not be adequate for flood defence purposes and therefore that a new L shaped reinforced concrete retaining wall shall be required along the full length of this section rather than simply raising the existing. This sub-reach in particular will need a thorough review once the MetroBus as built information becomes available to determine opportunities for cost savings.

4.6 Commercial Road

4.6.1 *Background*

The proposed defence at Commercial Road lies extends from Bathurst Basin Dam defences to tie in to high ground close to Bedminster bridge.

A defence is needed here primarily to prevent the flow of floodwater over the land immediately behind the defence and, to a lesser extent, into the Floating Harbour.

The area through which the proposed alignment goes at Commercial Road is characterised by a mix of land uses including commercial, residential as well as critical infrastructure such as Bristol General Hospital. Commercial Road is a key transport pathway through the city.

From Bathurst Basin Dam ground levels initially rise to enable access to the road bridge over the dam but then fall again moving upstream. The mud banks forming the edge of the river channel are steep and there are signs of instability both of the banks and the land behind. Further upstream the banks reduce in extent and the vertical masonry wall retaining the highway becomes more prominent.

Immediately behind the retaining wall is a footpath alongside Commercial Road. At the downstream extent a ramped access crosses the footpath providing access to the building and swing mechanism for the road bridge over adjacent to Bathurst Basin Dam.

4.6.2 *Alignment*

The proposed defence alignment is shown in Figure 10. The defence ties into high ground at the western end and then comprises a reinforced concrete wall along the edge of the road up to the access road. A ramp will be needed to maintain the defence across the access and the alignment will then need to switch to a frontline defence to tie into high ground at the upstream extent. It is proposed that the defence here will comprise a contiguous piled wall set 1-2m into the channel and backfilled with a masonry clad reinforced concrete wall above. This wall will need to be able to support the road behind as well as act as a tidal defence.

The frontline alignment was chosen as it will be immediately in-front of and will stabilise the existing retaining structure which is degrading in condition. Therefore the defence will provide synergies with otherwise separate work that may be required in the future to support the highway. According to the availability of BCC resources the flood defence work could be tied into work to stabilise the retaining structure which would offer overall cost savings.

Setting the defence alignment on the landward side Commercial Road was not feasible as the road is backed by a number of buildings which have ground floor windows. Locating a defence in close proximity to the windows is not considered viable. East of New Guinea Street there are a number of large trees located along the pavement in-front of Commercial Road. A slightly setback defence alignment through the middle of this pavement has been considered but the trees would constrain this alignment and lead to additional landscape impacts.

The total length of the defence is approximately 240m, of which 180m is the frontline section. The height of the defences relative to existing ground levels varies along the alignment. For the frontline section the height relative to ground levels behind the defences (i.e. from the roadside) is up to 1.2m for low defences and up to 1.8m for high defences. For the setback section of the defence the defence height is generally lower being up to 0.8m for low defences and 1.5m for high defences.

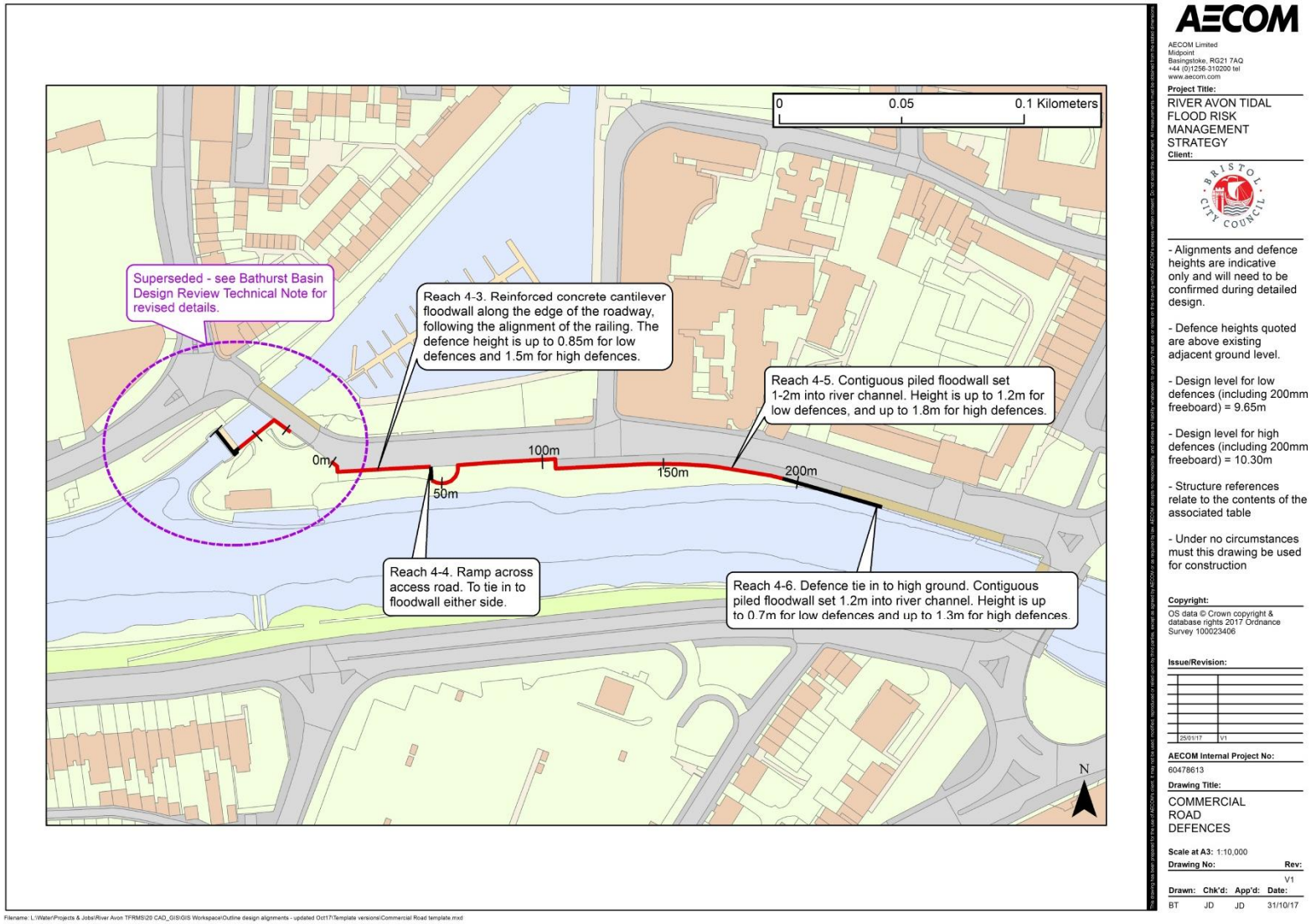


Figure 10 Defence alignment at Bathurst Basin Dam and Commercial Road

4.7 Clarence Road

4.7.1 *Background*

A defence is proposed at Clarence Road between Ship Lane and Bath Road Bridge to prevent the flow of floodwater into the land immediately behind the defence. There is no direct flow path from Clarence Road into the Floating Harbour.

Clarence Road runs along the edge of the New Cut River channel linking Commercial Road to the west and Cattle Market Road to the east. The road is a key transport pathway through the city and includes a footpath cycle and road immediately behind the riparian wall. The land uses immediately behind include a secondary school, a number of commercial properties and also residential areas.

The highway is supported by a vertical masonry retaining structure which forms the interface with the New Cut river bank. The bank comprises a muddy intertidal environment.

4.7.2 *Alignment*

The proposed defence at this location is shown in Figure 11 and is a frontline alignment which follows the front edge of Clarence Road (and footpath). It is proposed that the defence is a joint floodwall and retaining structure which will need to be constructed immediately in front of the retaining structure which is currently in place.

The total length of the defence is approximately 620m and will need to tie into high ground at the western end and into Bath Road Bridge abutment at the eastern end. The height of the defence relative to existing ground levels varies along the alignment from zero at the tie ins up to a maximum of 2.0m for low defences and 2.7m for high defences.

A key reason why a frontline alignment has been chosen is to provide synergies by stabilising the existing retaining structure for Clarence Road. The condition of the retaining structure is deteriorating and in January 2014 a 40-50m long section failed and the wall moved riverwards by approximately 100mm into the channel. Elevated ground water levels following a high tide event was believed to be the cause and repairs were carried out to prevent further deterioration to this section of wall[1].

Alternative alignments setback from the river were considered but rejected due to the practicalities of dealing with the multiple accesses to the north of Clarence Road (private and public highway). These would all require ramps, for which there would be insufficient space, or floodgates, which would increase operational complexity. Raising the height of the existing retaining wall on the same line was not considered as an option due to the stability and asset condition issues discussed above.

In addition the impact on the existing landscape and character could be significant. There are areas along the frontage which have a clear view across Clarence Road and the New Cut channel and a setback defence would disrupt this. For example, a defence alignment along the rear pavement would block the view from buildings with ground floor windows immediately behind.

[1] Craddy Pitchers Davidson, 2014

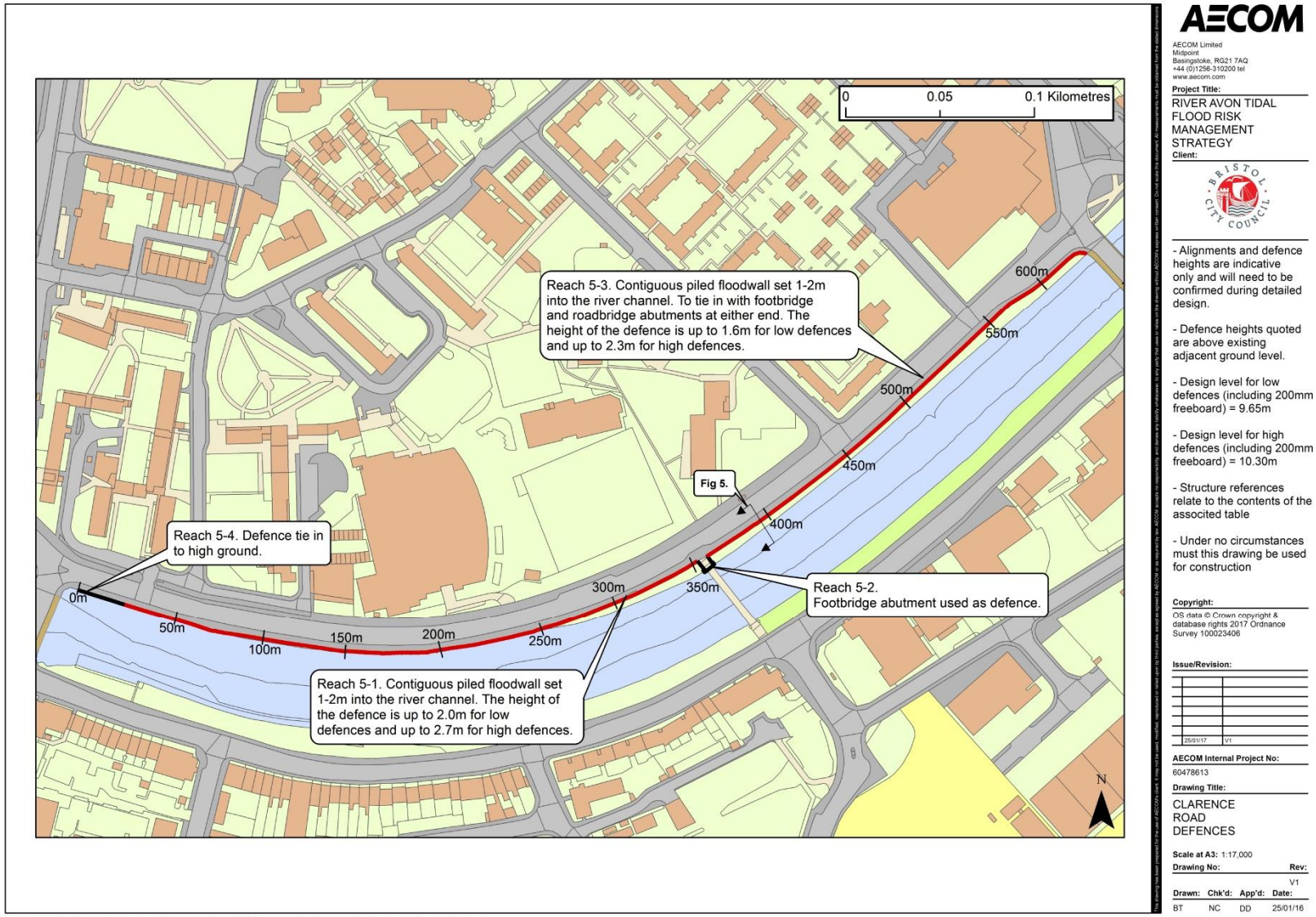


Figure 11 Defence alignment at Clarence Road

4.7.3 *Landscape visualisation*

Figure 12 below shows a landscape visualisation of the proposed defence at Clarence Road. The viewpoint is from the edge of the cycle path, looking south west across the New Cut river channel.

Figure 12 **Landscape visualisation of the proposed defence at Clarence Road (low defence in red, high defence in pink)**

4.8 Cattle Market Road

4.8.1 *Background*

The Cattle Market Road reach extends from just upstream of Bath Road Bridge to the tie into to the new Arena access bridge known as Brock's bridge. This reach extends under the Network Rail Bridge carrying the mainline into Temple Meads station.

There is not a direct flow pathway from Cattle Market Road into the Floating Harbour and the defences protect properties immediately behind. There is also a potential flow route to the east of the Cattle Market Road defences whereby water could flow beneath the rail bridge and outflank the defences which are proposed to the east ((the Totterdown / St. Phillips defences, see section 4.9). Additional modelling is required to confirm this flow pathway but the defence at Cattle Market Road will also prevent this if it is confirmed.

The protected area includes Network Rail assets, commercial properties and development sites. The area is currently undergoing a period of change with the University of Bristol identifying the derelict sorting office site for their new campus and transport improvements incorporating a new foot/cycle path and bus lane to enable access to the new Arena.

The land in front of Cattle Market Road comprises the natural river bank of the New Cut channel. The bank is steep yet vegetated. There are short wing walls adjacent to the rail bridge abutment which helps to stabilise the bank and there is evidence of the historic Totterdown lock structure upstream of the railway bridge.

4.8.2 *Alignment*

A map of the proposed alignment is shown in Figure 13 and follows the bank top between the road and the river. It ties into high ground at the western extent and into Brock's Bridge in the east. There will be a need for the defence to tie in to the Network Rail Bridge abutment to maintain the defence line. The total length of the defence is approximately 190m.

The defence will be at its highest (relative to existing ground levels) adjacent to the rail bridge at 2.1m for low defences and 2.7m for high defences.

An important benefit of a frontline defence is that it will protect the highway and footpath routes from flooding and stabilise the bank against future erosion (although the potential for erosion is limited given the sheltered environment).

In 2015 BCC developed plans to develop a frontline flood defence along the front edge of Cattle Market Road to protect the road from significant high tides. However, when developing the design the estimated cost of construction was considered to be high and due to funding constraints the defence was never constructed. The structure of the proposed defence was a reinforced concrete wall with brick facing and piled foundations and a revised version of this is proposed for this reach.

Alternative alignments were considered including:

- setting the defence between the bus lane and cycle path,
- setting it alongside the buildings at the landward side of the footpath
- allowing the area beneath the railway bridge to flood but maintaining pedestrian access via a raised walkway.

A key consideration at this location was maintaining pedestrian access between the station and the Arena site due to the reliance of the Arena on public transport. The setback alignments were all rejected on grounds of technical feasibility despite offering a lower cost option. The issues that could not be overcome were:

- access to the development land and properties to the north could only be maintained via numerous large flood gates (up to 2.5m high) as there was insufficient space for ramps, or vehicles would need to drive along the foot / cycle path to access these locations.
- Clearance to the railway bridge soffit was inadequate to provide a raised walkway for pedestrians and cyclists.

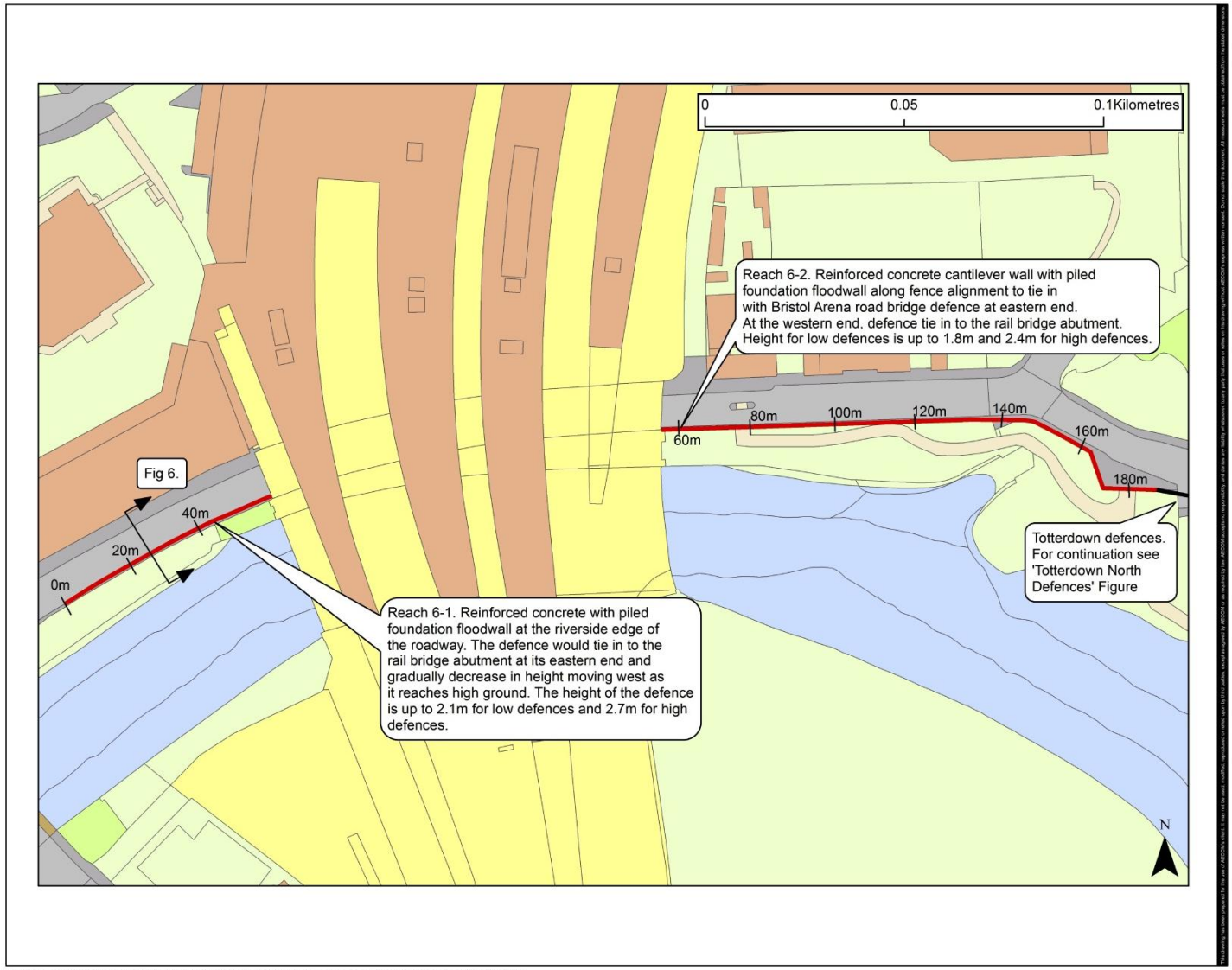


Figure 13 Defence alignment at Cattle Market Road

4.9 Totterdown / St. Phillips

4.9.1 *Background*

The Totterdown and St. Phillips defence corridor is on the north bank of the New Cut channel between the new Arena access bridge known as Brock's Bridge and Sparke Evans Park near St Phillip's Causeway.

The defence at Totterdown / St/ Phillips will prevent the flow of water into the commercial areas behind the defence and at St.Phillps Marsh. There is no direct flow pathway from Totterdown / St. Phillips into the Floating Harbour except for during extreme magnitude events.

Land use behind the defence comprises commercial and industrial properties. A public footpath / cycle path runs along the full length between the river and buildings. In some locations there is only 3-5m between the bank top and the building behind. The natural river bank varies in steepness along the reach, is vegetated and appears to be in a stable condition.

The proposed defence at Totterdown / St. Phillips is a setback alignment along the back edge of the footpath / cycle path. The most significant challenge associated with a setback defence alignment is ensuring that there is sufficient space for a formal flood defence at the back of the path. The amount of space varies considerably along the frontage; in some locations there is 1-2m of space available behind the path where a defence could be located whilst in other areas the path is bordered by a building wall and space is much more limited.

For the majority of the frontage there are no formal flood defences currently in place and if water levels exceed the crest level of the natural river bank then flood water can flow into the land behind. In some areas the building and boundary walls at the rear of the footpath act as 'defacto' defences for shallow flooding. However, in the long term these cannot be relied upon. In 1984 a formal flood defence scheme was undertaken (by the Environment Agency) on the river bank between extending 300m downstream of the RSPCA Dogs and Cats home (approx. chainage 80-380m) but this will not provide adequate defence height in the future.

As part of the Bristol Arena construction a section of the frontage at Totterdown is currently being developed between Brock's Bridge and Victor Street:

- A footbridge will be constructed across the New Cut from the Arena to the north bank,
- A new riparian concrete retaining wall will be constructed,
- The footpath and cyclepath will be raised to 9.5m AOD.

This redevelopment will provide a standard of protection to the area that is close to (but just below) the low defences 2030 1:200 year standard. However, this will only be provided to the area immediately behind the section of frontage between Brock's bridge and Victor Street and the land either side of this redevelopment area will remain low with outflanking a possible issue.

Commercial areas along Albert Road to the south are located within the proposed Enterprise Zone and may be developed in the future. In cases where development is likely to occur it may be possible to reclaim areas of land behind the existing footpath or the re-route the footpath alignment to increase the amount of space available for the proposed defence.

4.9.2 *Alignment*

The total length of the Totterdown / St. Phillips defence alignment is approximately 1,500m.

Between Brock's Bridge and Victor Street low defences will need to be provided using existing alignments and works associated with the Arena development generally on the landward side of the existing footpath or with land raising.

Upstream of Victor Street, low defences can be provided via a combination of methods but aligned on the landward side of the footpath. Where space is restricted it is proposed that the defence will make use of the existing buildings and boundary walls with additional resilience measures being provided to ensure that they can be relied upon to provide a robust defence. Infill reinforced concrete walls will be constructed between buildings to provide continuity of defence.

Liaison with the existing property owners will be essential to ensure that the low defence scheme can be delivered. There is limited space for new construction in this location and therefore making best use of the existing boundary walls is important.

High defences are expected to be constructed around 2065. It is expected that by this time period many of the existing buildings / properties along this reach will have / will be redeveloping. BCC will be able to work alongside the developers to ensure that defences are incorporated into redevelopment proposals. It is likely that this will need to be undertaken on a piecemeal basis, as and when areas are proposed for redevelopment. For the purposes of costing it has been assumed that a sheet piled defence can be installed along the full length from Brock's Bridge to Sparke Evans Park.

For the low and high defence tie-in at the eastern end of the frontage the defence alignment passes through Sparke Evans Park. In this location the proposed defence transitions to a raised earth embankment as plenty of space is available in this location and an embankment is more suited to the open-space environment in this location.

There are a number of access points onto the riverside footpath which will be intersected by the proposed defence alignment. Ramps are proposed to maintain the access and provide a passive defence. At Victor Street and the RSPCA there may be a need to reassess access requirements to avoid the need for floodgates for the high defence as there is insufficient space for the ramps.

Figure 14 to Figure 16 show the different sections of the defence alignment. The length of the Totterdown / St. Phillips proposed defence is approximately 1.5km and the height of the defence varies considerably along this frontage. The maximum height of the low defences along the frontage reaches 2.1m (relative to existing ground levels). The maximum height of the high defences along the alignment is approximately 2.7m.

An alignment on the riverside of the footpath was rejected on cost, environmental and visual impact grounds. This alignment would consist of piling along the river bank some 1-2 m from the edge of the footpath and capping the pile with a reinforced concrete wall. The benefits of this option were:

- Protecting the footpath from flooding,
- Less risk to existing properties during construction
- Construction access from the riverside using a barge
- Would be designed to ensure footpath and buildings protected from bank erosion.

This option was rejected for the following reasons:

- It would be significantly more expensive that the current proposals
- Larger piles would be required to retain the land behind
- Encroachment of the defence into the channel increased modelled water levels
- Encroachment causing loss of intertidal habitat
- Loss of visual amenity (lack of river views from the footpath)

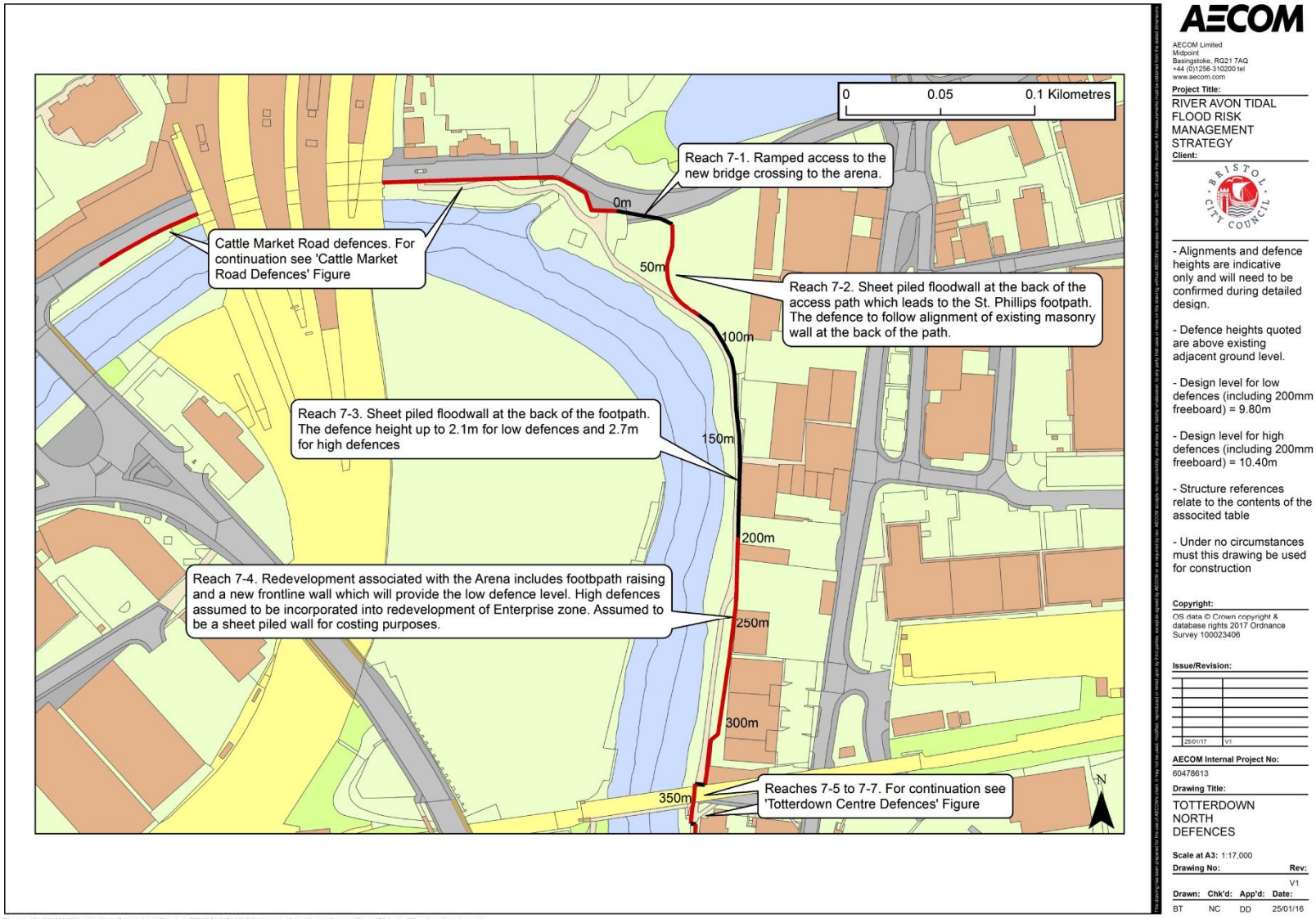


Figure 14 Defence alignment at Totterdown / St.Phillips (north section)

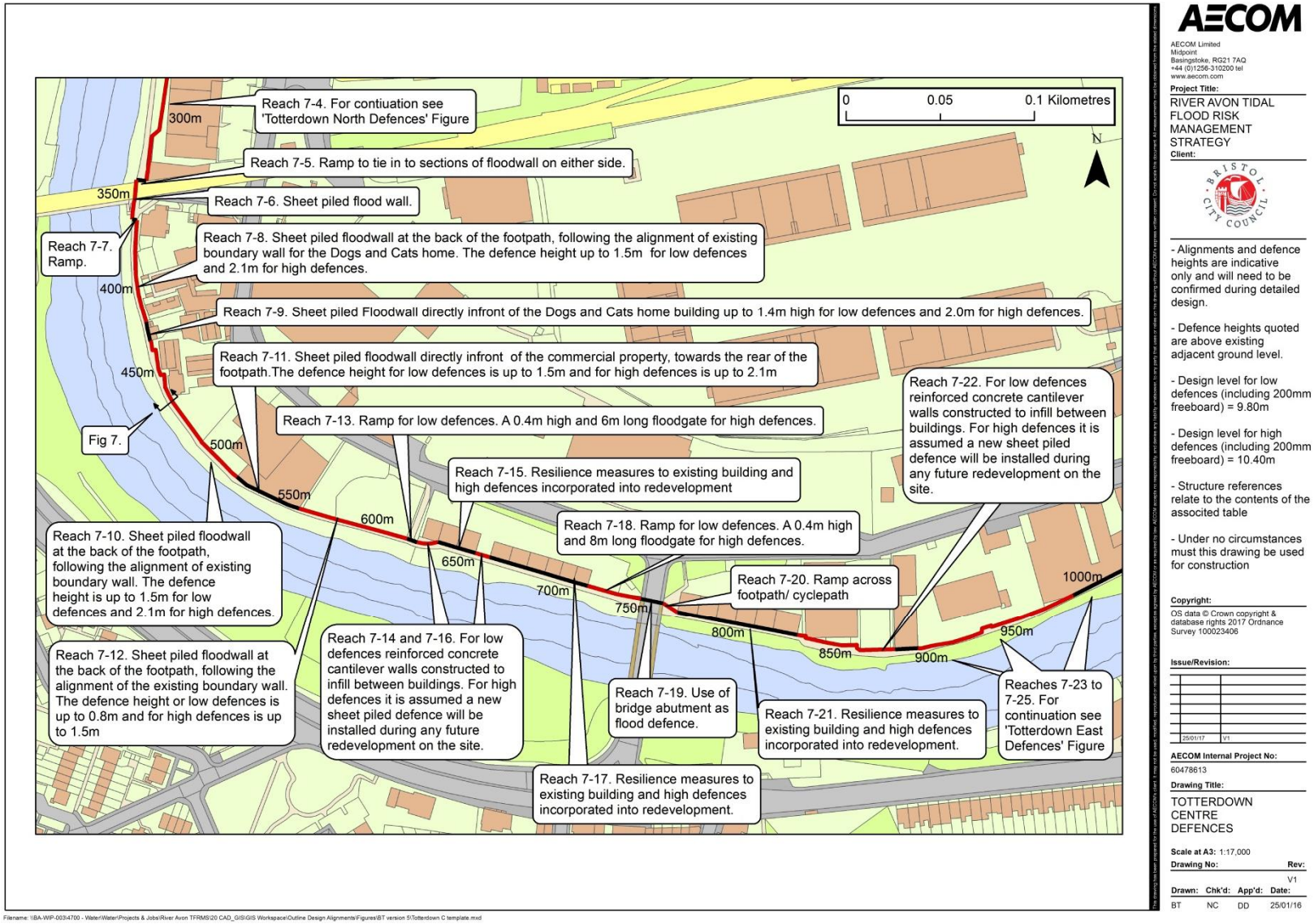


Figure 15 Defence alignment at Totterdown / St.Phillips (central section)

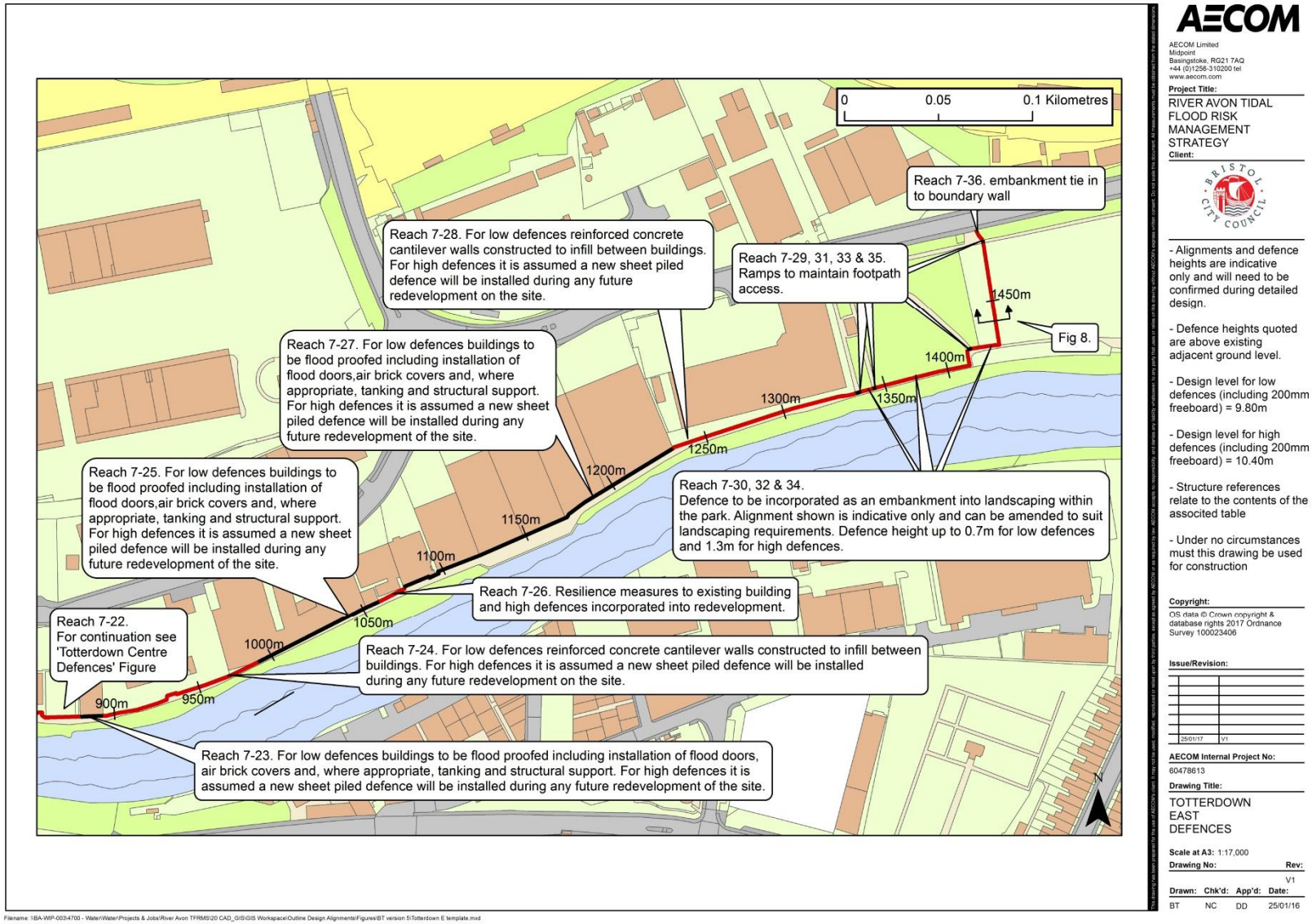


Figure 16 Defence alignment at Totterdown / St.Phillips (east section)

4.10 Netham

4.10.1 *Background*

The Netham defence corridor extends from the derelict rail bridge across the New Cut downstream of Netham Weir, approximately 160m upstream to the Netham lock gates which provide access to from the New Cut into the Floating Harbour.

Primarily the new defences and lock gates proposed at Netham will prevent water from flowing into the Floating Harbour and will help protect properties in central Bristol from flooding. It will also help protect commercial properties immediately behind the defence.

The area directly protected includes Feeder Road, commercial properties and access roads.

There is a mixture of defences currently in place, with sheet piling between the derelict rail bridge and Netham Weir, an undefended natural bank from Netham Weir to the intersection of the New Cut and Floating Harbour channels and piling / masonry walls between the intersection and Netham lock gates. The piling at the intersection is in a poor state of repair and there is visual evidence of significant amounts of displacement indicating that the loading is exceeding the design capacity of this structure.

There are varying amounts of intertidal mudflats between the defences and the river and higher up the bank the slopes are vegetated in some areas.

4.10.2 *Alignment*

The proposed defence at Netham is shown in Figure 17. When considering the alignment in this location the following issues were critical:

- Little or no encroachment into the channel as water levels in this area are fluvially dominated and reductions in channel cross section have a bigger impact than elsewhere
- Operation of Netham Lock

Between the derelict rail bridge and Feeder Road bridge the defence line will need to follow the existing sheet piled defence line. For low defences it is proposed to raise the existing pile cap with a new concrete cap dowelled in to the existing. For high defences the existing sheet piles will not have an adequate residual life and are unlikely to be structurally capable of being raised further. It is proposed that a contiguous bored pile wall is constructed with a concrete capping beam. The initial design calculations have determined that 1.5m diameter piles would be required and to avoid encroachment into the channel existing buildings would need to be reconfigured to enable these to be installed. This can either be dealt with through any future redevelopment of the site, relaxation of the encroachment constraint or further design analyses and consideration of alternative construction methods.

To the north-west of Feeder Road bridge, the defence follows the southern edge of the pavement, along the alignment of the existing boundary wall and is proposed to be a reinforced concrete wall. The height of the defence varies along this section. For low defences the maximum height of the defences relative to the existing ground levels is approximately 0.8m. For high defences the maximum height of the defences relative to existing ground levels is 1.4m.

There is an access road which crosses the proposed alignment and leads into an industrial estate behind the defence. To avoid the need for a flood gate across this road and to accommodate the road raising on Feeder Road described below it is proposed that the access road is moved to the west.

For high defences it will be necessary for the alignment to cross Feeder Road. To avoid the need for a demountable floodgate, road raising is proposed. Due to the traffic light controlled junction with Netham Road it was necessary to consider the highways implications of the works (sight lines, braking, cambers etc.). The location of the road raising was chosen as the crown of the road to the west of junction to limit the amount of raising that would be required to only 400mm. It is assumed that ramps up to it would need to have a minimum slope of 1 in 20 (as the footpath would also need to be raised) and this location also enabled the ramp to be sufficiently far away from the junction to avoid any traffic issues.

The proposed defence alignment continues across the entrance to the Floating Harbour immediately adjacent to the road raising to tie in to high ground to the north. There is a significant fall in ground level from Feeder Road to the canal and defences will comprise walls and a new lock gate over 3m high above the towpath level. An embankment will need to tie into the landscaped high ground to the north

and the footpath will be diverted northwards around the defence line to avoid the need for ramps or floodgates.

The Floating Harbour channel in this location is wider than the lock (22m) and will require new flood/lock gates approximately 7m high (above estimated cill level). To operate gates of this size it will be necessary to provide additional mechanical and electrical (M&E) infrastructure. The towpath to the south of the lock terminates at approximately this location so the defences between Feeder Road and the gate will not be severing access and will not require a flood gate or ramp.

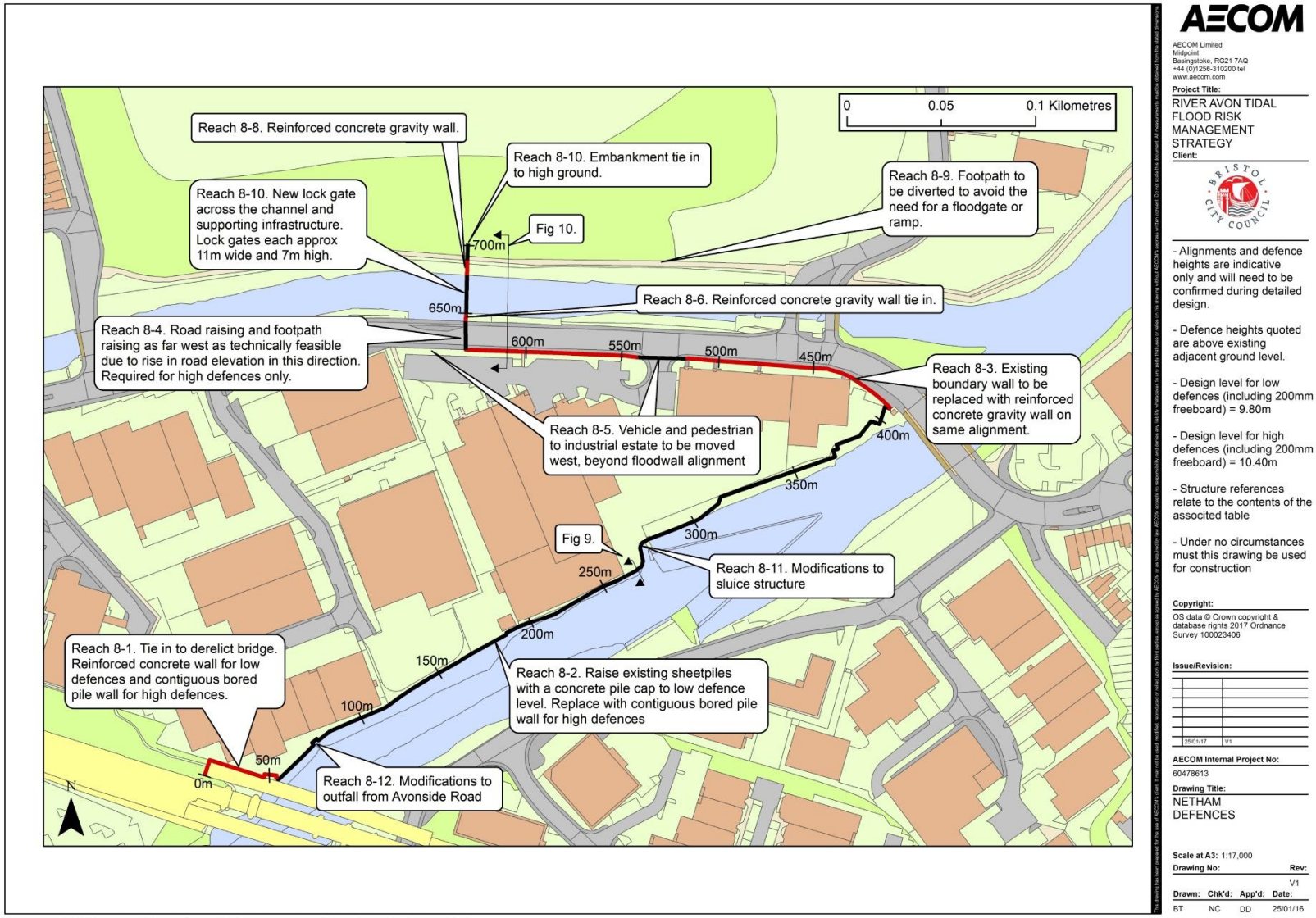
The new flood/lock gates will be designed to prevent water flowing into the Floating Harbour. The gates will need to be designed to resist water head from both sides at Netham Lock and will have a dual flood/lock gate function. The gates will also need to have multiple layers of redundancy in power supply and controls to ensure that the risk of failure is minimised and is lower than with the existing lock gates. For instance, the gates will need to be powered from both sides of the channel (so that electrical supply failure on one side does not compromise closure), have a backup independent power source and will also need to be fitted to enable manual operation (in case of complete electrical failure). To maximise benefits, the high defence flood/lock gates will be installed early in the strategy to provide long term cost savings and avoid the need for an upgrade during the Strategy period (i.e. construction to a 1:200 year standard of protection for 2115).

The location of the new flood/lock gate works is approximately 150m away from the listed structures associated with the existing lock. Although significant works would be required to support the gates this would be new build infrastructure and would have only minor effect on the existing channel walls. The impact on the heritage and visual amenity of the lock would be the least of all the options considered.

The preferred location of the new flood/lock gates and the defences to tie into them was the culmination of numerous iterations of defence line. Rejected locations for the lock gates included:

- Raising and replacing the existing gate closest to the New Cut. This gate is already larger than the others and so would require less infrastructure change. However, this was offset against the difficulties with tying the defence into the sheet piles downstream of Feeder Road. Crossing Feeder road so close to the junction with Netham Road was not feasible. Crossing Feeder Road at the currently proposed location away from the junction would still require the defence line to cross Netham Road which was also not technically feasible.
- Raising and replacing the westerly lock gate. This option is technically feasible and could tie in to the road raising in its proposed location. This would require a raised defence on the northern side of feeder road between the footpath and towpath. The required defence across the towpath and operational area containing the Harbour Officers Building would sever access westwards and require a ramp or floodgate to get over the 3m high wall. This option was rejected due to the visual and heritage impact on the listed structures and their setting and the additional lengths of defence that would be required on the north side.
- Installing a new set of flood/lock gates approximately 15m west of the existing lock gates. This option is similar to raising the westerly gate but would involve a new bespoke set of flood gates and associated operating infrastructure westwards of the existing lock. The channel here is wider so the gates would be wider than the existing ones and would require substantial works to the historic masonry channel walls to enable them to support the loads applied. The access, visual and heritage impacts would be the same as for raising the westerly lock gate and so this option was rejected in favour of moving the new gate further west.

The frontline defence alignment between the derelict rail bridge and Feeder Road bridge passes next to Netham Weir. There are currently a system of sluices on the north side the weir and modifications may be required with a new defence in this area. In addition, changes to the outfall at Avonside Road may also be required.



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Project Title:
RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:
BRISTOL CITY COUNCIL

- Alignments and defence heights are indicative only and will need to be confirmed during detailed design.

- Defence heights quoted are above existing adjacent ground level.

- Design level for low defences (including 200mm freeboard) = 9.80m

- Design level for high defences (including 200mm freeboard) = 10.40m

- Structure references relate to the contents of the associted table

- Under no circumstances must this drawing be used for construction

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BT	NC	DD	25/01/16

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Figure 17 Defence alignment at Netham

4.10.3 *Landscape visualisation*

Figure 18 below shows a landscape visualisation of the proposed defence at Netham. The viewpoint is from the top of Netham Road bridge, immediately above the existing lock gates, looking downstream into the Floating Harbour. The visualisation shows the new lock gates, road raising and defences on the far side of the road.

Figure 18 Landscape visualisation of the proposed defence at Netham

5. DEFENCE PHASING AND ECONOMIC ASSESSMENT

5.1 Background

The preferred strategic option which was identified in the previous phase of work was to construct low defences in the first epoch of the Strategy (present day to 2030) and then raise the defences to high defences in the final epoch of the Strategy (from 2065 to 2115). In the interim between these time periods the low defences would be maintained.

Additional work has been carried out to investigate how the low defences could be more optimally phased over the course of the first two time epochs. The onset of flood risk varies along the Strategy frontage and there could be merit in delaying the construction of some low defence schemes until the second epoch (between 2030 and 2065). The onset of risk in some areas may not be fully established until epoch 2 and constructing defences in these areas prior to this may not be an optimal approach. In addition, delaying certain schemes may provide opportunities to align the defences with other works to structures and assets in the study area.

Another key benefit of phasing the implementation of low defences is that it helps spread the capital investment over a longer time period meaning reduced present value costs for the Strategy. Delaying certain low defence schemes until epoch 2 also provides BCC with greater time to make up potential funding shortfalls, acquire contributions or to redirect funds to flood defence schemes. In addition, phasing also helps to reduce delivery risks by reducing the size of design and construction contracts.

Investigating and improving the phasing of low defences also ensures that investment is made on a risk based approach (only implementing defences as required) and that the Strategy is more adaptive to climate change. Delayed low defence schemes which are not required immediately can be implemented as and when required in the future depending on the rate of climate change and sea level rise.

The project team held a prioritisation and phasing workshop (5th October 2016) and discussed the onset of flood risk across the Strategy frontage. From this meeting initial ideas were gathered as to which low defence schemes could be delayed until epoch 2. Follow up work was then undertaken to split the flooding across the Strategy area into flood sub-cells. This allowed the economic flood damages and benefits of schemes in each sub-cell to be estimated and the phasing of low defences to be investigated.

5.2 Onset of flood risk

During larger return period events the flood extent in central Bristol comprises a large flood cell surrounding the Floating Harbour and the areas adjacent to the New Cut. By examining animations of modelled flood events and inspecting how the flood cell propagates it has been possible to sub-divide the flood cell. The following sub-cells were identified:

- Floating Harbour;
- Cumberland Road;
- Commercial Road;
- Clarence Road;
- Cattle Market Road; and
- Totterdown / St. Phillips

The sub-cells are separate from each other during smaller magnitude events, but as the flood risk develops the cells appear to merge in various locations. Based upon the existing modelling it is not possible to determine the volumes of water that flow between sub-cells. As such, the sub-cell boundaries are arbitrary and are limited by the modelling capabilities. Further modelling would be required to identify the volume of water that passes between flood cells and to verify the boundaries.

The boundaries of the sub-cells that are protected by the high defences during a 2115 200yr tidal event are shown in Figure 19. During this magnitude event the sub-cells have merged in various locations, for example between Cumberland Road and the Floating Harbour, and between Totterdown and the Floating Harbour. For events of even larger magnitude the extent of the flood cells will increase in size and depth.

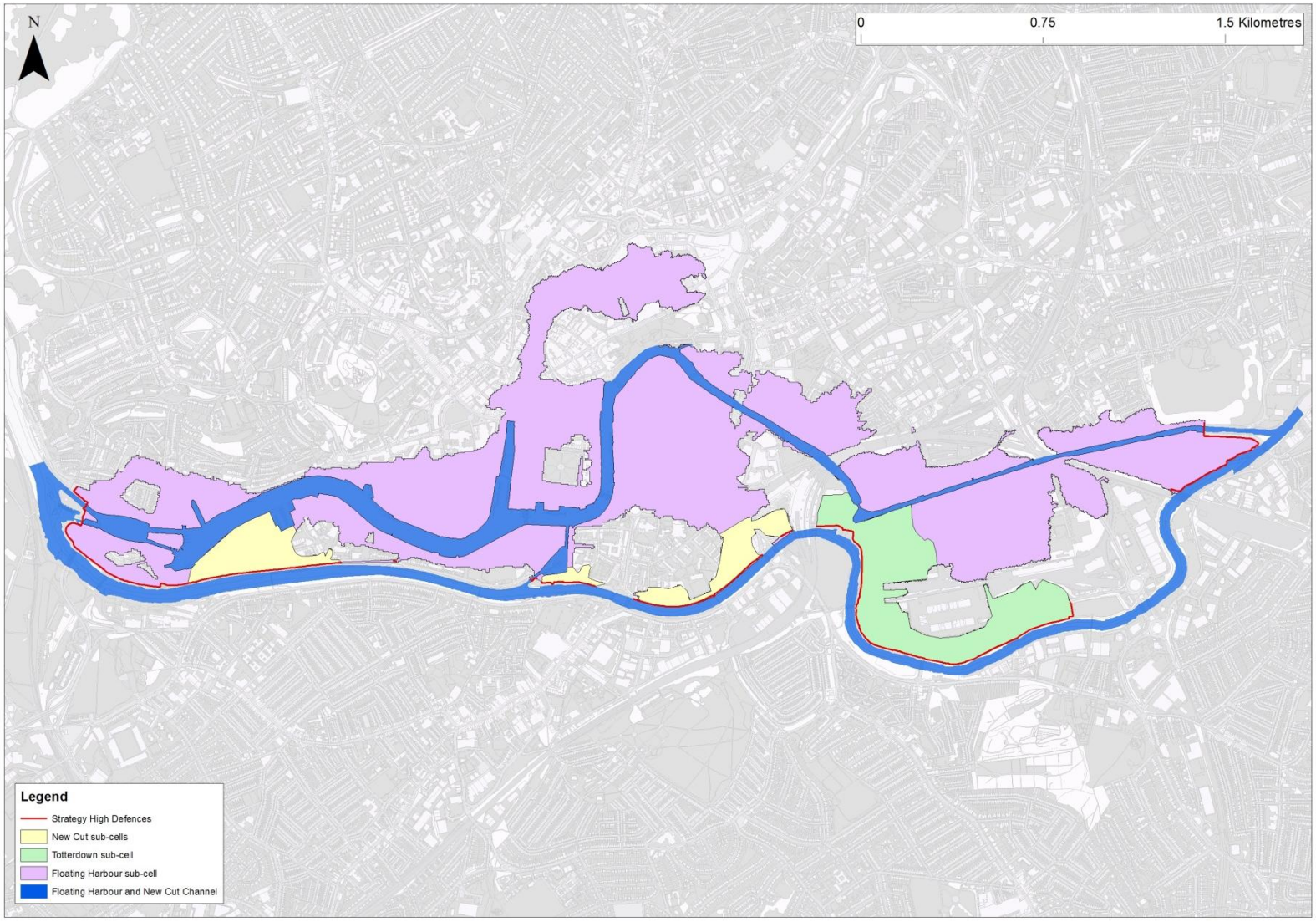


Figure 19 **Sub-cells (benefit areas) within the flood cell for a 1:200 year 2115 event.. The benefit areas are indicative based on the areas behind the proposed defences which will be protected)** **(OS data © Crown Copyright and database rights 2016 Ordnance Survey 100023406)**

The Floating Harbour sub-cell is complex in that there are a number of entry points at different locations for flood water to enter the harbour and flooding does not necessarily occur adjacent to the entry point. Instead water enters the harbour which causes it to gradually fill to its capacity. Once it exceeds its storage capacity the flood water spills into land surrounding the harbour, which could be in an entirely different location to where the water was entering. The main entry points for the Floating Harbour sub-cell are at Entrance Lock (and then Junction Lock), Cumberland Road underpass, Bathurst Basin Dam and Netham.

The timing and onset of significant flood risk for each sub-cell varies. Under the Do Nothing scenario flooding in the Floating Harbour sub-cell starts to occur from a present day 1:20 year event (or greater). The sub-cell covers large parts of central Bristol and includes a large number of properties and assets. With the existing flood modelling it is difficult to ascertain where the majority of the flood water entering the harbour is coming from (i.e. Entrance Lock, Cumberland Road underpass, Bathurst Basin Dam or Netham). To investigate this in more detail further model runs are required in which all but one of the entry points are sealed off and the resultant water volume in the Floating Harbour is measured. This is beyond the scope of this assessment but further studies to investigate this may be beneficial in the future.

Flooding in the Cumberland Road flood sub-cell occurs from the present day, but the MetroBus flood wall (currently under construction) protects to a present day 1:200 year standard and therefore flooding only occurs for events greater than this magnitude. From 2030 the standard of the MetroBus flood wall is predicted to reduce due to climate change and flooding is expected to occur during lower magnitude events.

Flooding at Commercial Road occurs from epoch 1 onwards, although the depth and extent of flooding is limited. The modelling suggests that there are two potential routes for flood water to enter the sub-cell; directly from the New Cut over the crest of Commercial Road, or indirectly from Bathurst Basin (which is within the Floating Harbour sub-cell). The model animations suggest that the initial flow pathway into the sub-cell is overland from Commercial Road.

At Clarence Road flooding starts to occur from a present day 1:20 year event, although the extent is largely limited to the highway and footpath. It is only during events of greater magnitude (i.e. 1:200 years or greater) that the flood extent starts to surround properties and assets behind the highway. At Cattle Market Road flooding is expected to occur from a present day 1:200 year event although the sub-cell and number of properties at risk are small relative to other cells in the Strategy area. For lower return period events, such as the present day 1:2, 1:20 and 1:75 year, the industrial buildings at the back of the highway provide a defacto defence against flooding.

Flooding at Totterdown (between the RSPCA dogs and Cats home and Albert Road) starts to occur from a present day 1:20 year event. The sub-cell is large relative to other cells in the city and a significant number of commercial properties are expected to be at risk. During a present day 1:20 year event (or greater) the Totterdown sub-cell connects with the Floating Harbour sub-cell in the area to the east of Bristol Temple Meads station. Additional modelling is required to determine the volume of water passing from the Totterdown sub-cell into the harbour but a visual inspection of the flood mapping suggests that the volume could be significant during larger return period events. For this reason it is important that the Totterdown flood defences are implemented in combination with the Floating Harbour defences to ensure that the benefits of each sub-cell are realised.

Table 9 below shows the numbers of properties at risk from 1:20, 1:75 and 1:200 year flood events within each sub-cell for the Do Nothing scenario. The cells at Cumberland Road, Commercial Road, Clarence Road and Cattle Market Road have been grouped in the ‘New Cut’ sub-cell. The equivalent data showing the percentage of properties at risk by sub-cell is shown in Table 10. The tables demonstrate how flood risk propagates across the city in relation to the number of properties at risk.

Table 9 Numbers of properties at risk in each sub-cell (Do Nothing scenario), by year and return period event

Flood sub-cell	2015			2030			2065			2115		
	20yr	75yr	200 yr	20yr	75yr	200yr	20yr	75yr	200yr	20yr	75yr	200 yr
Floating Harbour	913	1317	1891	1064	1375	2056	1376	1870	2540	2074	2364	2970
New Cut	97	116	155	111	145	173	148	159	200	176	199	229
Totterdown / St. Phillips	88	103	173	112	145	178	145	171	192	177	190	194

Table 10 Percentage of total properties at risk by sub-cell location (Do Nothing scenario), by year and return period event

Flood sub-cell	2015			2030			2065			2115		
	20yr	75yr	200 yr	20yr	20yr	75yr	200 yr	20yr	20yr	75yr	200 yr	20yr
Floating Harbour	83%	86%	85%	82%	82%	86%	82%	85%	87%	86%	86%	88%
New Cut	9%	8%	7%	9%	9%	7%	9%	7%	7%	7%	7%	6%
Totterdown / St. Phillips	8%	6%	8%	9%	9%	7%	9%	8%	6%	7%	7%	6%

Table 10 shows that the majority of properties at risk within the first time epoch are found within the Floating Harbour (83-86%). The sub-cells at the New Cut and Totterdown / St. Phillips have comparatively fewer properties at risk within the first time epoch, with 7-9% and 6-8% respectively.

In the second time epoch (from 2030 to 2065) the sub-cells at the New Cut and Totterdown / St. Phillips have an increased number of properties at risk, but as a percentage these cells occupy a similar proportion of risk as in epoch 1, given that the number of properties at risk has also increased in the Floating Harbour sub- cell.

5.3 Phasing

5.3.1 *Phasing plan*

The project team devised a phasing plan for the preferred strategic option based upon the team's understanding of the onset of flood risk, the numbers of properties at risk in each flood cell, deliverability and securing the maximal return on investment (see Figure 20).

The Floating Harbour sub-cell has the greatest number of properties at risk within epoch 1 and therefore defences for this cell are a priority. The defences for the Floating Harbour include the defences at Entrance Lock, Cumberland Road underpass, Bathurst Basin Dam and Netham. For the Floating Harbour defences to be at their most effective it requires defences to be constructed at all four locations. This will ensure that the major routes for flood water into the harbour are blocked during potential flood events. If defences are not constructed in one or more of the locations then flood water will still be able to flow into the harbour, albeit at a reduced rate. The Floating Harbour has some storage capacity for flood water but it is limited and if one or more of the defences are not constructed then there is a chance that the storage capacity will be exceeded and flooding could occur within central Bristol.

Defences are also a priority at Totterdown / St. Phillips. The initial flood risk in this area is not as prominent as in the Floating Harbour (in terms of property numbers), but during larger magnitude events

the flood modelling suggests that water flows from the Totterdown sub-cell into the Floating Harbour (see section 5.2). Therefore in order to fully realise the benefits of the Floating Harbour schemes it will be necessary to construct the Totterdown defences. In addition, the Totterdown / St.Phillips area is currently being redeveloped as part of the Arena development and there are works planned to raise the path either side of the new footbridge. This offers an excellent opportunity to utilise these improvements as part of a low defence scheme during epoch 1 of the Strategy.

During epoch 1 the flood risk is relatively low at Cumberland Road, Commercial Road, Clarence Road and Cattle Market Road (i.e. the New Cut areas) and there are relatively fewer properties at risk and economic damages compared to the Floating Harbour. The capital costs for the New Cut defences are also of a similar scale to the Floating Harbour and therefore the New Cut defences provide a lower return on investment. For these reasons the New Cut defences are less of a priority and could feasibly be delayed until epoch 2 of the Strategy.

Similar to the example at Totterdown, during large magnitude events the New Cut sub-cells appear to merge with the Floating Harbour in various locations. However, inspection of the modelling results suggests that the extent to which the flood cells merge is less than at Totterdown and it only occurs from larger magnitude events (for example Totterdown merging occurs from a present day 1:20 year event, whilst Commercial Road merging occurs from a present day 1:75yr event). After this commission during further design development it is recommended that additional modelling is undertaken to investigate the extent and volumes of water flowing between the New Cut and Floating Harbour sub-cells during larger return period events. This will help to verify the phasing plan and will also provide a better indication of the flooding potential in the interim period after the epoch 1 defences have been constructed but before the construction of epoch 2 defences along the New Cut.

The phasing plan for the preferred option is as follows:

Epoch 1 (from present day to 2030)

- Construct low defences to the Floating Harbour flood cell at Entrance Lock, Cumberland Road underpass, Bathurst Basin Dam and Netham (Floating Harbour defence group).
- As an exception, the new lock gates at Entrance Lock and Netham will have a crest level for high defences (to avoid having to go back in 2065 and providing a new set of gates). For the rest of the scheme's length the defences will be constructed to the low defence height.
- Low defences at Totterdown / St. Phillips.

Epoch 2 (from 2030 to 2065)

- Construct low defences at Cumberland Road, Commercial Road, Clarence Road and Cattle Market Road (New Cut defences).
- Maintain the low defences of the Floating Harbour defence group at Entrance Lock, Cumberland Road underpass, Bathurst Basin Dam and Netham and also at Totterdown / St. Phillips.

Epoch 3 (from 2065 to 2115)

- Raise all low defences to high defences. This will be undertaken for all the schemes; at Entrance Lock, Cumberland Road, Cumberland Road underpass, Bathurst Basin Dam, Commercial Road, Clarence Road, Cattle Market Road, Totterdown / St. Phillips and Netham.

5.3.2 *Assumptions for the economic assessment and the derivation of benefit areas*

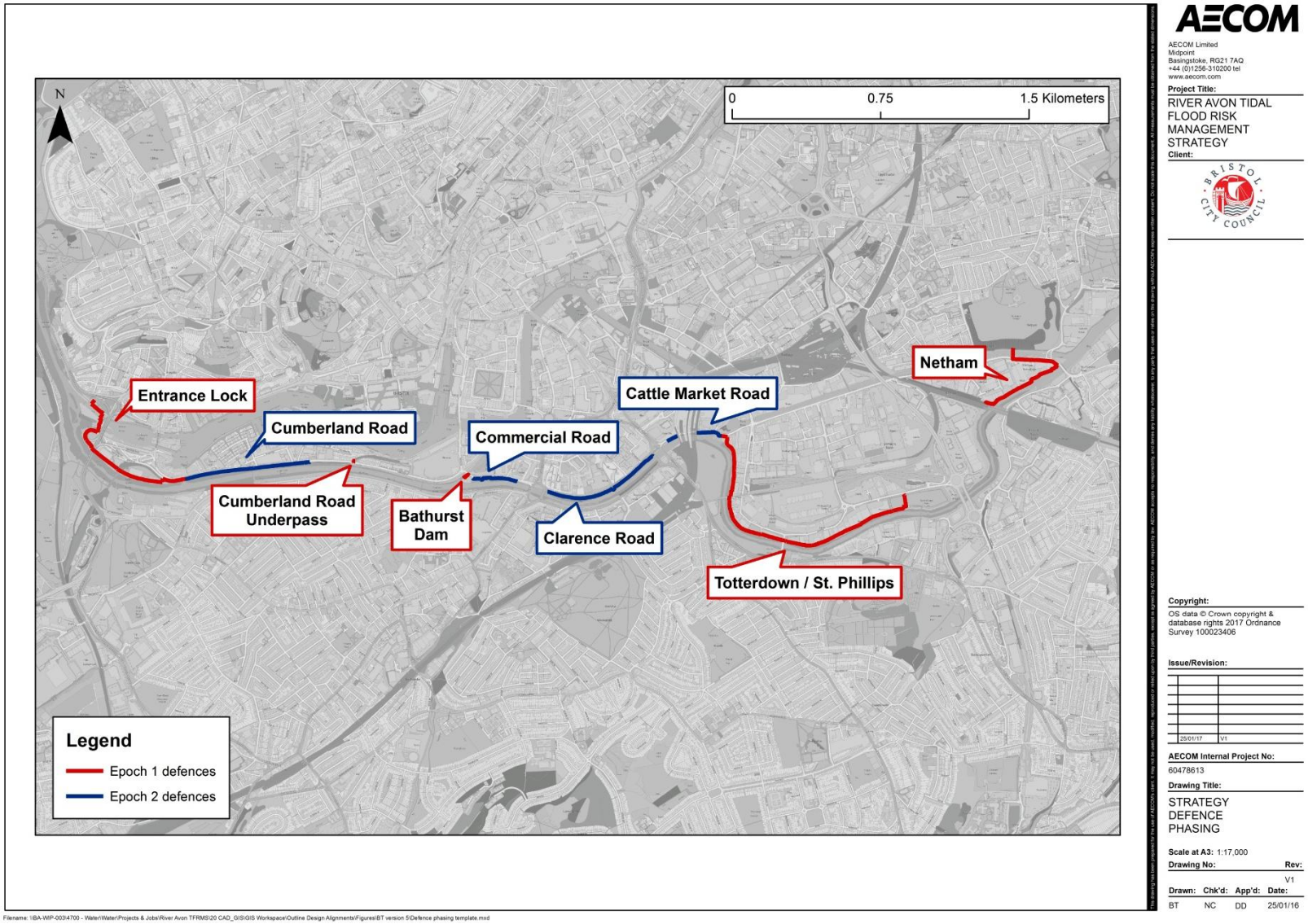
During the lowest return period events the numerical modelling suggests that the New Cut, Totterdown and Floating Harbour sub-cells are separate and flood water does not flow from one cell to another. However this is not the case during larger magnitude events when the Totterdown and New Cut sub-cells appear to merge with the Floating Harbour. With the current modelling it is not possible to accurately determine the flow pathways or the volumes of water involved.

For the purpose of developing the economic assessment in line with the phasing plan it has been necessary to assume that the benefits of the schemes are obtained from the sub-cells directly protected by the defences. This assumption was required in order to sub-divide the defence benefits.

This assumption is considered to be reasonable because the majority of the economic benefits of the defences are driven by the lower return period events and the uncertainty associated with the merging of sub-cells during higher return period events (see section 5.2) is unlikely to significantly influence the economic assessment.

In addition, for the majority of flood events if flow pathways exist between sub-cells then the volume of water flowing into the Floating Harbour is likely to be small in comparison to the large entry points elsewhere (i.e. at Entrance Lock).

Additional modelling is required to investigate flow pathways between the sub-cells in more detail and to determine the volumes of water involved. This information would help to verify the assumptions made in developing the economic assessment.



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Project Title:
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Figure 20 Low defence phasing

5.4 Phasing economic benefits

The economic benefits of the preferred option have been updated to account for the phased delivery of schemes set out in section 5.3. A summary of the updated benefits is provided below. For more details refer to the updated Economics Report; Strategy Phasing and Economic Update.

The economic benefits of the preferred option with the updated phasing are presented in Table 11 below. The benefits are shown in present value (PV) terms for the full Strategy appraisal period (next 100 years). Outside of the areas identified for defence improvements a policy of Do Minimum is applied. As such, the economic benefits of the preferred option include the benefits of Doing Minimum.

Table 11 Present value Do Nothing Damages and benefits expected over the next 100 years for the preferred option with phasing

Do Nothing damages (£k)	*PV 'flood risk' benefits (£k)	PV 'other' benefits (£k)	*PV total benefits (£k)	Residual damages (£k)
1,625,000	1,505,000	26,000	1,531,000	94,000

**note: the option benefits include benefits from doing minimum*

Table 12 compares the economic benefits of the non-phased preferred option (last stage of work) to the phased preferred option. Compared to the preferred option benefits derived during the last stage of work the benefits have reduced by approximately £45m over the lifetime of the scheme. There are two reasons for this. Firstly, the preferred option benefits derived during the last stage of work include benefits at Pill and Shirehampton whilst the updated benefits do not. Secondly, the updated defence phasing results in a number of low defence schemes being delayed to epoch 2. In areas where schemes are delayed the baseline flood damages for epoch 1 are expected to occur which reduces the whole life benefits of the phased preferred option.

Table 12 Comparison of pre-phased and phased preferred option benefits

Option	PV total (£k)	PV change (£k)
Non-phased preferred option*	1,576,000	NA
Phased preferred option	1,531,000	- 45,000

*includes benefits for Pill and Shirehampton schemes

5.5 Cost updates

5.5.1 *Capital costs*

Capital costs refer to the upfront costs of a scheme, including costs for the appraisal, procurement, design and construction. Capital costs do not include future maintenance costs.

The capital costs for the preferred option schemes have been updated during this phase of work. Refer to the Outline Design Briefing report and appendices for a breakdown of the costing approach and an overview of the rates which have been used.

A summary breakdown of the capital costs for the preferred option is provided in Table 13. An optimism bias of 60% has been applied to all capital construction costs. A summary breakdown for the Floating Harbour, Totterdown and New Cut schemes is provided separately in Table 14 to Table 16.

The capital costs for the low defences are typically higher than for the high defences. This is because construction of high defences will generally involve raising the crest level of the existing low defences and there will not be a need for new foundations. The exceptions to this are at Cumberland Road and Totterdown where construction of high defences will require completely new lengths of defence.

Additional lump sum costs for construction and 'other' costs have been included in the overall cost estimate. The lump sum costs have been broken down for the individual schemes by distributing the costs across each defence area in a weighted manner according to the proportions between the scheme and total costs and when the schemes are being undertaken.

The additional lump sum costs for construction includes allowances for service diversions, dealing with existing surface water outfalls, back of wall drainage and landscaping and public realm works.

The additional lump sum costs for 'other' includes allowances for Environmental mitigation for 'coastal squeeze' (compensatory habitat), other environmental mitigation, investigations (e.g. ground surveys, topographic surveys, services etc.), developing the business case and detailed design, compensation and compulsory purchase.

The costs also include an estimate for mitigating potential detriment from the Strategy. For more information on detriment mitigation costs, refer to section 8.2.6. The detriment costs have been broken down for the individual schemes by distributing the costs in a weighted manner according to the proportions between the scheme and total costs. Detriment costs have been apportioned to the Floating Harbour and Totterdown schemes as according to the defence phasing plan these schemes are scheduled to occur first. It has been assumed that planning consents for the low and high defence schemes will only be granted if the suitable detriment mitigation is in place.

Table 13 Updated capital construction costs for the preferred option (including 60% optimism bias)

Scheme	Defence / benefit area	Low Defences Capital cost (£k)	High Defences Capital cost (£k)
Entrance Lock	Floating Harbour	14,020	4,870
Cumberland Road	New Cut	2,190	8,220
Cumberland Road underpass	Floating Harbour	410	190
Bathurst Basin Dam	Floating Harbour	470	100
Commercial Road	New Cut	2,130	640
Clarence Road	New Cut	4,870	1,350
Cattle Market Road	New Cut	1,380	370
Totterdown / St. Phillips	Totterdown	5,570	7,550
Netham	Floating Harbour	10,610	6,830
Detriment mitigation		4,190	1,530
Additional costs – lump sums construction		5,630	3,450
Additional costs – lump sums other*		10,220	9,200
Sub - total		**61,690**	**44,300**
Total (£k)		**105,990**	

*60% optimism bias not applied to 'lump sums other' costs

Table 14 Updated capital costs for the Floating Harbour scheme (including 60% optimism bias)

Scheme	Defence / benefit area	Low Defences Capital cost (£k)	High Defences Capital cost (£k)
Entrance Lock	Floating Harbour	14,020	4,870
Cumberland Road underpass	Floating Harbour	410	190
Bathurst Basin Dam	Floating Harbour	470	100
Netham	Floating Harbour	10,610	6,830
Detriment mitigation		3,350	1,220
Additional costs – lump sums construction		2,330	1,390
Additional costs – lump sums other*		4,090	3,680
Sub - total		**35,280**	**18,280**
Total (£k)		**53,560**	

*60% optimism bias not applied to 'lump sums other' costs

Table 15 Updated capital costs for the Totterdown scheme (including 60% optimism bias)

Scheme	Defence / benefit area	Low Defences Capital cost (£k)	High Defences Capital cost (£k)
Totterdown / St. Phillips	Totterdown	5,570	7,550
Detriment mitigation		840	310
Additional costs – lump sums construction		550	340
Additional costs – lump sums other*		1,020	920
Sub - total		**7,980**	**9,120**
Total (£k)		**17,100**	

*60% optimism bias not applied to 'lump sums other' costs

Table 16 Updated capital costs for the New Cut scheme (including 60% optimism bias)

Scheme	Defence / benefit area	Low Defences Capital cost (£k)	High Defences Capital cost (£k)
Cumberland Road	New Cut	2,190	8,220
Commercial Road	New Cut	2,130	640
Clarence Road	New Cut	4,870	1,350
Cattle Market Road	New Cut	1,380	370
Additional costs – lump sums construction		2,750	1,720
Additional costs – lump sums other*		5,110	4,600
Sub - total		**18,430**	**16,900**
Total (£k)		**35,330**	

*60% optimism bias not applied to 'lump sums other' costs

5.5.2 *Defence maintenance costs*

Defence maintenance costs have been developed from a number of sources, including:

- Environment Agency guidance for estimating maintenance costs for raised defences; *Cost estimation for fluvial defences – summary of evidence, report SC080039/R2, Environment Agency 2015*.
- Environment Agency System Asset Management Plan (SAMP) costs for system FR/14/SO69 Avon Netham to Avonmouth
- Costs for cathodic protection for frontline steel sheet piles

The cost build up for each aspect of maintenance is provided in Table 17 below.

Table 17 Maintenance cost build up

Source	Aspect	Cost (£k)	Frequency
EA guidance for estimating maintenance costs of raised defences	Maintenance of low defences (2015-2030)	7.9	Yearly
	Maintenance of low defences (2030-2065)	9.2	Yearly
	Maintenance of high defences (2065-2115)	8.9	Yearly
EA SAMP costs	Maintenance of existing raised defences, structures and asset operation and incident response	35.1	Yearly
Cathodic protection (sheet pile structures only)	Cathodic protection for low defences	1,872.0	Assumed it will be required every 20 years
	Cathodic protection for high defences	1,915.0	Assumed it will be required every 20 years

Estimates of the total maintenance costs vary according to the time period and schemes in place (i.e. low defences or high defences). For each time epoch in the preferred option an annual maintenance cost has been estimated by adding the annual maintenance cost obtained from the EA guidance to the EA

SAMP costs. For example, for low defences between 2015 and 2030 the annual maintenance cost has been estimated to be £7.9k + £35.1k = £43k.

In addition to the annual maintenance cost, the cost for providing cathodic protection to the sheet pile structures was applied every 20 years. The cost of cathodic protection was not annualised, but was applied as a recurring lump sum in the present value costing sheets (every 20 years).

5.5.3 *Harbour operation and maintenance costs (flood risk protection only)*

The costs and frequency of the various factors involved in operating the Floating Harbour were provided by BCC. From this the harbour costs associated with providing a flood defence function were used to derive a total annual operation cost of the harbour (in terms of flood risk reduction). Table 18 provides a breakdown of the estimated annual operation costs for the present day.

Table 18 Present day harbour operations cost build up

Action	Estimated annual cost (£k)
Pre event incident planning / coordination	2.1
Deployment of stop gates at Junction Lock / Netham	23.9
Pre event harbour lowering	0.2
Various inspections of stop gate pair	10.2
Total	**36.4**

Due to sea level rise the frequency of harbour operations and gate deployment is expected to increase in the future and therefore an uplift was applied to estimate the costs in 2030, 2065 and 2115. Table 19 shows the estimated harbour operations costs for the strategy time epochs.

Table 19 Annual harbour operations costs for different time epochs in the Strategy

Strategy time period	Estimated annual cost (£k)
2015 (present day)	36.4
2030	37.5
2065	55.9
2115	135.3

In addition to the annual operation costs, a cost of £174k associated with maintenance of the stop gates was assumed to occur every 25 years. This cost was provided by BCC as part of the harbour operations costs. This cost was not annualised, but was applied as a recurring lump sum in the present value costing sheets (every 25 years).

5.5.4 *Do Minimum costs*

The cost of the Do Minimum scenario has been updated so that the incremental benefit cost ratio of the preferred option can be identified (see section 5.6.2 later on in the report).

The Do Minimum costs include the costs of harbour operation (see section 5.5.3), maintenance costs for the existing BCC raised defences (at Totterdown and the MetroBus flood wall) and the EA SAMP costs (see section 5.5.2).

The maintenance costs for the existing BCC raised defences (Totterdown / MetroBus) have been estimated using the EA guidance document for estimating maintenance costs for raised defences (see section 5.5.2).

A breakdown of the Do Minimum costs is provided in Table 20.

Table 20 Do Minimum cost breakdown

Source	Aspect	Cost (£k)	Frequency
Harbour operations costs	Operations cost (2015 – present day)	36.4	Yearly
	Operations cost (2030)	37.5	Yearly
	Operations cost (2065)	55.9	Yearly
	Operations cost (2115)	135.3	Yearly
	Maintenance of stop gates	174.0	Assumed every 25 years
Existing raised defences	Totterdown embankment and MetroBus flood wall	1.4	Yearly
EA SAMP costs	Maintenance of existing raised defences, structures and asset operation and incident response	35.1	Yearly

5.5.5 *Present value costs*

The whole life present value cost for the preferred option has been updated to reflect the changes to the option phasing and the updated capital cost estimates.

Present value costs include discounting and enable the whole life cost of an option to be established in today's cost terms. Standard discount rates have been used to convert the non-discounted (cash) cost of the phased preferred option to a present value cost. According to the FCERM-AG, the following variable discount rates have been used; 3.5% for the years 0 to 35, 3.0% for the years 31 to 75 and 2.5% for the years 76 to 99. This results in an overall PV factor over the 100 years at 29.9.

A cost profile for the phased preferred option is presented in Table 21 below. The cost profile has been produced by applying the discount factor to the capital cost of the various schemes for the year in which they are to be implemented. For the purpose of discounting it has been assumed that schemes will be implemented in the first year of the time epoch for which they are scheduled. For instance, with the updated phasing, the low defences at Entrance Lock, Cumberland Road underpass, Bathurst Basin Dam, Netham and Totterdown / St. Phillips are scheduled for epoch 1 and it has been assumed that these schemes will be constructed now. Low defences at Cumberland Road, Commercial Road, Clarence Road and Cattle Market Road are scheduled for epoch 2 and it has been assumed that these schemes will be constructed in 2030.

Maintenance costs and costs associated with sustaining operation of the Floating harbour include an annual average cost for the duration of the appraisal period which has been discounted on a yearly basis. Recurring lump sum costs for maintenance and operation have also been included in the PV cost sheet. In Table 21 maintenance costs refer to the costs associated with maintaining the defences whilst 'other' costs are those costs associated with Floating Harbour operation and maintenance that is specific to managing the flood risk (i.e. deployment and upkeep of stop gates). The average annual non-discounted (cash) cost for these activities differs between time epochs due the implementation of schemes.

For detriment mitigation costs it has been assumed that the full cost for the works to mitigate the impact of low defences will occur at the start of epoch 1. This is because it is recommended that the detriment mitigation is carried out at the time of constructing low defences. For the detriment mitigation costs for high defences it has been assumed that the costs will occur in 2065, at the start of epoch 3.

The cost profile is shown in Table 21. The total present value cost of the phased preferred option is estimated to be approximately £67.7 million. In present value terms the majority of the investment is required in epochs 1 and 2, when the construction of low defences is scheduled. In epoch 3, despite there being a large non-discounted (cash) investment required to upgrade to high defences, the larger discount rate ensures that the present value cost in this epoch is comparatively smaller.

Table 21 Cost profile of non-discounted (cash) and present value (PV) costs for the phased preferred option

Epoch	Non discounted (cash) cost (£k) including 60% optimism bias				Present value cost (£k) including 60% optimism bias			
	Capital	Maintenance	Other*	Total	Capital	Maintenance	Other*	Total
Epoch 1	43,300	650	550	44,500	43,300	510	430	44,240
Epoch 2	18,440	5,290	1,490	25,220	11,000	1,990	550	13,540
Epoch 3	44,240	6,030	5,130	55,400	8,730	680	490	9,890
			Total	125,120			**Total**	67,680

**Other costs refer to the Harbour operation and maintenance costs associated with the provision of flood risk protection.*

Updates to the capital costs and defence phasing have reduced the whole life present value cost of the preferred option compared to the estimate made in the previous phase of work (during the preferred options phase). Whole life non discounted (cash) costs have reduced from £304.2million to £125.1 million and total present value costs have reduced from £166.3million to £67.7 million.

There are two key reasons for the reduction in whole life non-discounted (cash) costs of approximately £179 million since the preferred options stage. Firstly, during the preferred options stage the costing was based on an overly precautious approach. It was assumed that all defences within the Strategy area would be a frontline piled solution which was the most costly structure type considered. During this phase of work more detailed investigations have been undertaken to improve confidence that setback solutions are technically viable and the lower overall non-discounted (cash) cost of the option reflects this. Secondly, the non-discounted (cash) cost presented during the preferred options stage includes costs for defences at Pill and Shirehampton. During this phase of work it was agreed with BCC to exclude these schemes as they are separate schemes in their own right and this phase of work is focussed on central Bristol. During the preferred options stage the total cost estimate for the low defences and high defence upgrade at Pill and Shirehampton was approximately £30 million. This represents approximately 17% of the £179 million cost reduction since the preferred options stage.

The whole life PV cost of the preferred option has also significantly reduced. This is partly due to a reduction in the non-discounted (cash) cost of the option but changes to the phasing of the option has also contributed. By delaying the construction of low defences at Cumberland Road, Clarence Road, Commercial Road, Cattle Market Road and Totterdown / St.Phillips it has resulted in a greater discount factor being applied to these schemes which has helped to reduce the overall PV cost.

5.6 Benefit : Cost ratio

5.6.1 *Average Benefit Cost ratio*

The economic costs and benefits of the preferred option have been updated during this phase of work. Table 22 presents the updated Average Benefit: Cost ratio (ABCR) of the preferred option and also that from the last phase of work prior to the updates.

Table 22 Updated preferred option costs and benefits, compared to in the previous phase of work

Option	Notes	PV costs (£m)	PV benefits (£m)	ABCR
Preferred option prior to updates (last phase of work)*	Original capital cost estimates and phasing (all low defences in epoch 1)	166.3	1,575.9	9:1
Preferred option following updates	Updated capital cost estimates and phasing (New Cut low defences delayed until epoch 2)	67.7	1,531	23:1

*includes costs for Pill and Shirehampton schemes (capital non-discounted cash cost of £30million)

Table 22 demonstrates that both the PV benefits and PV costs have reduced with the updates as a result of delaying some of the low defence schemes to epoch 2 and revising the capital construction costs. Overall the Average Benefit: Cost ratio of the preferred option has improved, rising from 9:1 to 23:1 following the updates.

5.6.2 *Incremental Benefit Cost ratio*

During the last phase of work, the Incremental Benefit Cost ratio (IBCR) of the options was calculated to determine whether there was a case for additional investment to improve the standard of protection. The IBCR of the preferred option prior to the updates which have been discussed in this report was calculated as approximately 1.8 relative to Do Minimum. As part of this stage of work the incremental benefit cost ratio of the revised option has been calculated and is presented in Table 23 below. In order to update the IBCR, the costs for the Do Minimum scenario have also been updated. The basis for the updates to the Do Minimum cost is discussed in section 5.5.4.

Table 23 IBCR assessment

Option	PV costs (£m)	PV benefits (£m)	ABCR	IBCR
Do Nothing	0	0	0	/
Do Minimum	2.6	1,309	503 : 1	503
Preferred option (following updates)	67.7	1,531	23 : 1	3.4

The IBCR of the preferred option relative to Do Minimum is approximately 3.4 (Table 23). This represents a significant increase in the IBCR compared to the ratio which was calculated during the last phase of work (ratio of 1.8). The increase in the IBCR is down to reduced PV costs of the preferred option as a result of revised capital costs and phasing.

An IBCR greater than 1 represents a worthwhile return on additional investment. According to FCERM-AG, to justify an increase in the standard of protection from a 1:75 year standard to a 1:200 year standard it is necessary to have an IBCR of greater than 3. However, the IBCR threshold of >3 only applies if there is no significant contribution to the schemes from BCC or from other sources.

As part of this phase of work the costs have only been updated for the preferred option and no updates have been applied to the remaining short list options from the previous phase. As such, the preferred option selection decision process has not been revisited. Nonetheless, inspection of the additional costing work that has been undertaken shows that if the costs of the other short list options were to be updated, the cost reductions would be similar, leading to a similar conclusion on the preferred option.

5.7 Fluvial benefits

The main purpose of the new tidal flood defences outlined in the preferred option is to prevent tidal flooding. However, the defences will have an additional benefit of protecting against fluvial flood risk along the New Cut and in the Floating Harbour. As part of this additional phase of work it was agreed with BCC to undertake an additional six model runs to help identify the fluvial benefits / impacts of the Strategy. Another reason to undertake the additional fluvial modelling was to ensure that OM2 properties were not 'double counted' in the Partnership Funding assessment.

An overview of the additional fluvial modelling runs which have been undertaken is provided in the Additional Modelling Report. In summary, the following runs were simulated to identify the fluvial benefits / impacts:

- Two runs (20 year fluvial and 75 year fluvial) for the present day (2015) based on the Do Minimum scenario i.e. baseline fluvial risk. Tidal base flow used.
- Two runs (20 year fluvial and 75 year fluvial) for the present day (2015) based on the Preferred Option scenario (low walls). Tidal base flow used.
- Two runs (200 year fluvial) for 2030 and 2065 to consider fluvial impacts. Preferred option in place (low walls) with a tidal base flow.

A comparison of the present day Do Minimum 1:20 and 1:75 year events and the 1:20 and 1:75 year events with the preferred option in place (low walls) shows that the preferred option does not make fluvial flooding worse during these scenarios. Areas of flooding for the 1:200 year scenarios were similar, with expected variances in flood extents and depths associated with the magnitude of each event.

Table 24 below presents the numbers of properties at risk from 1:20, 1:75 and 1:200 year fluvial events with and without the preferred option. It demonstrates that for high return period events (i.e. the present day 1:200 year) the number of properties at risk within central Bristol decreases when the preferred option is in place. For lower return period events, (i.e. present day 1:20 and 1:75 year) there is no difference in the properties at fluvial risk with and without the preferred option. This is because the properties at risk during these events are not located behind the proposed defences but elsewhere within the city centre, most likely at areas upstream of Netham or on the south bank of the New Cut where fluvial risk is known to be an issue. In the future the extent of fluvial flooding is expected to increase and therefore the defences will provide a greater benefit during the lower return period events.

Table 24 Properties at risk from fluvial events with and without the preferred option defences

Fluvial flood event	Numbers of properties at risk without defences	Numbers of properties at risk with preferred option defences	Numbers of properties benefitting
Present day 1:20	114	114	0
Present day 1:75	225	225	0
Present day 1:200	2116	1890	226

It was beyond the scope of the Strategy to undertake a full suite of fluvial (or various combined event) model runs and therefore it has not been possible to derive or monetarise the additional fluvial benefits. This approach was agreed with the Project Board.

The numbers of properties at risk from a range of fluvial events with and without the preferred option in place (Table 24) help to illustrate how the fluvial flood risk will change with the preferred option and it is clear that for the present day, during larger magnitude events, the tidal defences will provide additional fluvial benefit. Further studies and modelling runs will be required to monetise this benefit but for this

phase of work the economic assessment is considered to be conservative in this respect (i.e. it is under-counting potential benefits).

6. STRATEGY IMPLEMENTATION 'TRIGGERS'

The preferred option sets out the timescales / time epochs for various schemes over the next 100 years. When developing the Strategy the epochs provided the basis from which to appraise the various options and to identify the preferred approach. However, the Strategy is adaptive and there is a degree of flexibility to when schemes are implemented. For instance, decision makers may decide that schemes may need to be brought forward in time or delayed depending on the actual rates of sea level rise or the occurrence of development opportunities.

In order to inform this decision making process a number of threshold 'triggers' for implementation have been identified.

6.1 Sea level rise

The most up to date climate change projections have been used to determine the flood risk over the next century. However, sea level rise projections are inherently uncertain and over the next century sea levels could rise more rapidly or more slowly than expected.

Low defences are scheduled to be constructed from the present day and therefore a sea level rise trigger is not needed for this set of schemes. However, for high defences, a sea level rise 'threshold trigger' is needed because these are scheduled for 2065 and sea levels could rise faster or slower than expected. The trigger for high defences depends upon the standard of protection provided by the preceding low defences and how this falls over time.

From 2030 the initial 1:200 year SoP provided by the low defences is expected to gradually fall and based on the sea level rise projections the standard is expected to be just above a 1:75 year by 2065 (the significant risk band). In a planning context, the standard of protection includes the proposed freeboard allowance and is expected to be at the 1:200 year standard by 2065 (see section 2.2.1).

The 2065 1:75 year in-channel water level adjacent to the proposed defences is between 9.35-9.40m ODN. This water level would be caused by tide levels of approximately 9.26m at Avonmouth which is approximately 0.3m higher than the equivalent (1:75) present day level.

Based on this analysis, if sea levels rise faster or slower than projected a suitable trigger for the implementation of the high defences is when mean sea level rises by 0.3m (compared to present day). By constructing high defences at this trigger threshold, it will ensure that the preferred option would provide the standard of protection that it would otherwise deliver if sea levels rise as projected (in FRM and planning terms) and would also ensure that the properties protected by the defences would not fall into the significant risk band.

6.2 Development opportunities and synergies

Some of the defences outlined by the preferred option will be facilitated by development opportunities, for example, the high defences at Totterdown. In this location it is expected that by the time high defences are required that many of the existing buildings / properties along this reach will have been or will be redeveloping.

Given that this is the case, development opportunities should also be used as a trigger for implementing high defences. For instance, if development opportunities at Totterdown were to arise prior to 2065, then BCC should ensure that high defences are incorporated into the redevelopment proposals.

The Strategy preferred option also has a number of synergies including the retaining function for Highways along the New Cut (for example see section 4.7.2). Should the Highway authorities have aspirations to undertake Highway retaining schemes prior to the proposed flood defences then this should act as a trigger to bring forward the flood defence schemes to capture the synergies between the projects.

6.3 Funding opportunities

It is anticipated that BCC will largely be reliant on external funding sources to implement the Strategy (e.g. GiA). However, should BCC secure other sources or be able to fund works themselves then this could be a trigger to implement high defences sooner than 2065. Whilst this approach may be less

favourable from an FCERM perspective (i.e. constructing high defences sooner is less adaptive), political leaders within BCC may wish to pursue the high defences sooner.

7. PARTNERSHIP FUNDING

Partnership funding scores for the schemes which comprise the preferred option have been undertaken. The scores are for the first round of schemes in the Strategy; the low defences outlined for epochs 1 and 2 according to the phasing plan discussed in section 5.3.

To derive the Partnership Funding scores the defences have been grouped into schemes according to the phasing plan outlined in section 5.3; a scheme for the Floating Harbour and Totterdown defences and a scheme for the New Cut defences.

The scheme for the Floating Harbour and Totterdown defences includes the defences at Entrance Lock, Cumberland Road underpass, Bathurst Basin Dam, Netham and Totterdown. As discussed in section 5.3, it is necessary to deliver these defences at the same time in order to fully realise the benefits from the Floating Harbour and Totterdown sub-cells.

The New Cut scheme includes the defences at Cumberland Road, Commercial Road, Clarence Road and Cattle Market Road. These defences have been grouped together as they are the defences scheduled for epoch 2 of the Strategy (from 2030). The baseline for the Partnership funding calculations is the Do Nothing scenario. This is in line with Environment Agency guidelines, as per FCERM appraisal guidance. This is also in accordance with a steer from the Environment Agency during the last phase of work. The partnership funding scores using a Do Minimum baseline are less favourable which highlights the importance of the continued operation of the Floating Harbour to the total flood damages within the study area and the reliance on human intervention and continued management to operate the water level control structures within the harbour.

The revised phasing of the preferred option specifies construction of low defence schemes in epochs 1 and 2. For the purpose of the calculations it has been assumed that schemes will be implemented in the first year of the time epoch for which they are scheduled (i.e. present day for epoch 1 and 2030 for epoch 2). The Floating Harbour and Totterdown / St. Phillips defences are scheduled for construction in epoch 1 and therefore have a base date of the present day for the PF calculations. The New Cut defences (Cumberland Road, Commercial Road, Clarence Road and Cattle Market Road) are not scheduled until epoch 2 and therefore the base date for the PF calculations for the New Cut scheme is 2030. With a 2030 base date the period over which benefits are accrued is delayed and the property counts to derive the OM2 benefit is based on properties at risk in 2030 (rather than present day).

The low defence schemes assessed in the Partnership funding assessment are to be implemented in epochs 1 and 2 of the Strategy and the standard of protection by the end of the scheme life will fall to between 1:75 and 1:200. In the OM2 calculations this corresponds with the moderate risk band and therefore in the partnership funding calculator it has been assumed (conservatively) that the OM2 properties which are protected by the scheme will fall in the moderate risk band at the end of the scheme life. Additional modelling runs with the individual schemes in place would be required to identify if any of the properties would fall in the OM2 low risk band.

Costs for detriment mitigation have been included in the partnership funding calculations because it is assumed that consent for the schemes will be difficult to attain without the necessary mitigation in place. The total costs for mitigating the impact of low defences have been distributed between the Floating Harbour and Totterdown schemes. No detriment costs have been included in the New Cut scheme to avoid double counting of the costs. This is reasonable because it is assumed that this scheme will only be undertaken if the Floating Harbour and Totterdown schemes are already in place (and therefore detriment mitigation will already be in place).

As part of this stage of work additional fluvial runs in 2015 were undertaken; 1:20, 1:75 and 1:200 year runs which correspond to the OM2 property risk bands in the PF calculator. The properties which remain at risk from this source (during the equivalent tidal events after defences have been constructed) have been counted and excluded from the OM2 benefit assessment.

The Partnership Funding calculations indicate the potential amount of government Grant in Aid (GiA) funding which may be available for the schemes. The New Cut Partnership Funding score which has a 2030 base date is indicative as it represents a ‘jump forward’ in time and is based on projected flood risk which may not develop as anticipated. The Partnership Funding calculation should be revisited closer to the time of the construction.

7.1 Partnership Funding score summary

Table 25 outlines the raw partnership funding scores for the low defence schemes using the Do Nothing scenario as a baseline. In cases where the Partnership Funding score falls below the 100% threshold, the table also provides an estimate of the cash shortfall that is required to make up the shortfall and achieve a score of 100%.

Partnership funding calculations have been undertaken for the schemes outlined in the phasing plan; including a scheme for the Floating Harbour and Totterdown / St. Phillips defences and for a scheme for the New Cut defences.

Table 25 Partnership Funding scores for the preferred option schemes

Scheme	Base date for calculation	Raw Partnership Funding Score	Estimated funding shortfall to achieve 100% score	Estimated level of GiA funding available should score reach 100%
Floating Harbour and Totterdown / St.Phillips defences	Present day	135%	£0	£43.3m
Net Cut defences	2030	13%	£15.9m	£2.5m

Table 25 shows that the raw Partnership Funding scores vary for the different low defence schemes. The Floating Harbour and Totterdown / St. Phillips scheme has the strongest score of 135%. This score is above the typical PF threshold (around 100% but variable) for approval.

The New Cut scheme (2030) has a score 13%. This scheme will require significant contributions in order to achieve a PF score above the funding approval threshold. To achieve a score of 100%, a contribution of approximately £15.9m will be required. Possible sources for a funding contribution for the schemes are from BCC, LEP, other public funding sources and beneficiaries from the defences.

The partnership funding scores are discussed in more detail overleaf.

7.2 Floating Harbour and Totterdown / St. Phillips defences

The Floating Harbour and Totterdown scheme is scheduled for epoch 1 of the Strategy. The scheme consists of four individual defence lengths around the Floating Harbour (Entrance Lock, Cumberland Road underpass, Bathurst Basin Dam and Netham) and a single length of defence at Totterdown between rock's Bridge and Sparke Evans Park near St Phillip's Causeway. The defences provide protection to the Floating Harbour and Totterdown sub-cells and in order to achieve the full benefits it is necessary for all the defences to be constructed.

Table 26 Summary of the partnership funding score for combined Floating Harbour and Totterdown scheme (present day)

Funding parameter	Value (£k, unless stated)
Whole life PV costs	46,100
Design and construction costs	43,300
*OM 1 – Economic benefit	1,012,260
OM 2 – Households at risk from flooding	20,030
OM 3 – Households at risk from erosion	0
OM 4 – Statutory Environmental obligations met	0
Total GiA contribution	43,300
Raw outcome measure (OM) score	135%
External contributions (private) required (to achieve a score of 100%)	0
FDGiA sum for approval (towards upfront costs) assuming contributions to achieve 100% if required	NA

**note: OM 1 refers to the total PV benefits of the option less benefits paid for or payments made under the other outcome measures.*

Table **26** presents a summary of the Partnership Funding calculation. The calculation shows that the scheme(s) receive a score of 135%. The amount of GiA likely to be available would be approximately £43.3m.

Table 26 Summary of the partnership funding score for combined Floating Harbour and Totterdown scheme (present day)

Funding parameter	Value (£k, unless stated)
Whole life PV costs	46,100
Design and construction costs	43,300
*OM 1 – Economic benefit	1,012,260
OM 2 – Households at risk from flooding	20,030
OM 3 – Households at risk from erosion	0
OM 4 – Statutory Environmental obligations met	0
Total GiA contribution	43,300
Raw outcome measure (OM) score	135%

External contributions (private) required (to achieve a score of 100%)	0
FDGiA sum for approval (towards upfront costs) assuming contributions to achieve 100% if required	NA

**note: OM 1 refers to the total PV benefits of the option less benefits paid for or payments made under the other outcome measures.*

7.3 New Cut defences

The New Cut scheme consists of four individual defences which have been grouped together (Cumberland Road, Commercial Road, Clarence Road and Cattle Market Road). These defences have been grouped as they are each scheduled for epoch 2 of the Strategy, from 2030 onwards (according to the updated phasing of the preferred option).

Table 27 presents a summary of the Partnership Funding calculation. The calculation shows that the scheme receives a score of 13%. The scheme would require approximately £15.9m of contributions to achieve a score of 100% and attract GiA funding. If a Partnership Funding score of 100% were to be achieved, then the amount of GiA available would be approximately £2.5m.

For the New Cut defences the Partnership Funding calculation has been undertaken using 2030 as a base date. Closer to the time of construction, the calculation will need to be revisited to re-assess the funding case using the latest guidelines at the time and the most up to date information on flood risk. The New cut scheme is not scheduled until 2030 and by this time there could be new funding arrangements in place for acquiring GiA. In addition, by this time there will be a new modelling baseline and updates to the economic assessment will be required given that the Floating Harbour and Totterdown / St. Phillips schemes will have been constructed. Flows from the New Cut sub-cells into the Floating Harbour during high magnitude events could also be captured to potentially increase the scheme benefits.

Table 27 Summary of the Partnership Funding score for New Cut defences (2030 base date)

Funding parameter	**Value (£k, unless stated)**
Whole life PV costs	18,940
Design and construction costs	18,440
*OM 1 – Economic benefit	32,800
OM 2 – Households at risk from flooding	3,020
OM 3 – Households at risk from erosion	0
OM 4 – Statutory Environmental obligations met	0
Total GiA contribution	/
Raw outcome measure (OM) score	13%
External contributions (private) required (to achieve a score of 100%)	£15,980
FDGiA sum for approval (towards upfront costs) assuming contributions to achieve 100% if required	£2,450

**note: OM 1 refers to the total PV benefits of the option less benefits paid for or payments made under the other outcome measures.*

7.4 Combined approach

Prior to updating the preferred option with the latest phasing plan, all the low defences were scheduled to be constructed during epoch 1. A joint partnership funding calculation has not been undertaken for this

approach (i.e. as one combined scheme) because a combined scheme would be based on the total scheme costs and benefits from separate areas / flood sub-cells which would conflict with the GiA cross-subsidy guidance and is therefore likely to be unacceptable.

7.5 Discussion

Partnership funding scores have been calculated based upon the phasing plan developed during this work stage; scores for the Floating Harbour and Totterdown in 2015 and the New Cut in 2030. With this approach the Floating Harbour and Totterdown / St.Phillips scheme has the strongest PF score by a significant margin as this scheme protects the majority of assets and properties at risk. The New Cut defences, whilst having a similar cost profile to the Floating Harbour scheme, protect significantly fewer properties and have a PF score of only 13%.

The phased approach to scheme delivery has been endorsed by the project board in February 2017. There is a strong case for funding the schemes in epoch 1 and the approach is favourable in terms of deliverability and maximising returns on investment.

The PF score for the epoch 1 schemes is in excess of 100% which suggests that the defences could be fully funded by GiA. However, the latest DEFRA target is for schemes to deliver a minimum 10-15% external contribution, even if the score is in excess of 100%.

8. RESIDUAL RISK AND DETRIMENT

8.1 Residual risk

Additional modelling was undertaken during this phase to further investigate residual risk. The modelling included:

- One model run to further investigate the impacts relating to sea level rise and residual risk
- Two model runs to investigate the residual risk associated with a defence breach at the channel entrance points into the Floating Harbour

8.1.1 *Residual risk associated with sea level rise*

Further work has been undertaken to understand the residual risk of flooding from above design standard events with the preferred option in place. This section of the report summarises the work, for more details refer to the Additional Modelling Report.

The preferred option specifies a 2030 1:200 year design standard of protection for low defences and a 2115 1:200 year design standard of protection for high defences. The 1000 year tidal events (with a 12 year fluvial event) for 2015, 2030, 2065 and 2115 with the preferred option in place have been considered to assess the risk associated with the defences being inundated / overtopped. The low defences standard of protection (2030 1:200 year SoP) will gradually fall over epoch 2 due to sea level rise. An additional model run; the 2065 1:200 year tidal event (combined with a 2 year fluvial event) has also been simulated with the preferred option in place to confirm which areas of the Floating Harbour are inundated / overtopped during this event.

A description of the flood risk associated with the above design standard flood events is provided in the Additional Modelling Report. The level of risk from these events varies across the city but it should be recognised that the Strategy is unable to completely protect the city from flooding. Irrespective of the standard of protection provided, there will always be the potential for events which exceed the crest level of the defences and cause flooding. For instance, even if a defences are constructed to a 1:1000 year SoP there is still a residual risk of a 1:2000 year event occurring (albeit, very small).

8.1.2 *Residual risk associated with breaching*

Additional model runs have been undertaken to understand the residual risk associated with breaching of the new flood / lock gates at Entrance Lock and Netham lock. A summary of the results is provided below and more detail can be found in the residual risk technical note (May, 2017).

The additional model runs for breach included:

- One model run (200 year tidal) for 2115 with the preferred option in place (high defences) but with Netham gates in an open position.
- One model run (200 year tidal) for 2115 with the preferred option in place (high defences) but with Entrance Lock gates in an open position. Junction Lock remained closed during this simulation.

A further model run with the preferred option in place (high defences) but with both Junction Lock and Entrance Lock gates open was also included. However this is not considered a breach scenario as it is considered extremely unlikely to occur as it would require the failure of two separate power suppled (to each set of gates) and the operational protocol for manual override at both locations to not be carried out.

<u>Breach at Entrance Lock</u>

In the scenario when Entrance Lock is left open, water can freely flow into Cumberland Basin from the River Avon. During this simulation, Junction Lock is closed with the crest heights of the gates set at

8.73m AOD and 8.53m AOD (i.e. the present day situation). The gates at Netham are also closed during this scenario.

During the first two tidal cycles, the water level in Cumberland Basin does not reach the height of the Junction Lock gates and water is therefore retained within the Cumberland Basin with no overtopping occurring. During the third or fourth (peak) tidal cycles, the Junction Lock gates are overtopped and water flows into the Floating Harbour. This leads to flooding in areas around Entrance Lock, Junction Lock, Victoria Street in Temple Black and at St. Phillips. There is no overtopping at the Netham Lock gate in this scenario.

The likelihood of this event occurring is very low.

Breach at Netham

For the scenario when Netham gates are left open, both Junction Lock gates and Entrance Lock gates remain closed. The model runs also conservatively assumes that there will be a failure to deploy the existing manually operated gates at Netham (which effectively act as stop gates, although they can be overtopped and outflanked).

The results from the scenario when Netham gates are left open show that flooding occurs within the Floating Harbour area.

Depths of between 1-2m are experienced in Netham and St. Phillips however flood depths in some areas are reduced when compared to the Do Minimum scenario in these areas. This is because defences along the River Avon at Netham prevent overtopping and with the Entrance Lock gate closed and raised, there is more storage within the Floating Harbour.

The likelihood of this event occurring is very low.

Likelihood of gate breach and potential mitigation

In terms of the likelihood of failure of the new infrastructure, this is very low given that the new flood / lock gates at Entrance Lock and Netham will be constructed with multiple levels of redundancy to the power supply and operation to reduce the chance of failure. There are also potential 'last resort' means of protection which could be implemented in order to reduce the time period of exposure should a failure occur. For example, at Entrance Lock and Netham a stop-log type system could be deployed or sand-filled bags could be stored on site and placed in the channel during a failure.

It should be noted that for each breach scenario the model has been simulated with a defence failure of 70 hours at each location. This represents a conservative approach as realistically there would be an emergency contingency plan in place should one of the lock gates fail or be left open.

8.1.3 *Residual risk associated with manually operated defences (e.g. temporarily deployed flood gates)*

In the design of the raised defences passive defences have been preferred wherever possible. This has included ramps or ground raising to maintain access across defence alignments rather than installing temporary floodgates.

However in some locations manually operated defences have been identified as the only feasible way of maintaining access. Manually operated (temporarily deployed) flood gates are situated at:

- Entrance Lock (x2)
- Cumberland Road underpass
- Totterdown / St. Phillips (x2 for high defences)

The use of manually operated gates increases the residual risk of defence failure as there is a chance that the gates could be left open during flood events. In the event of a temporarily deployed flood gate being left open, the flow pathway through the defences would be limited and the amount of flooding that would be expected to occur is significantly less than a breach at Entrance Lock or Netham Lock.

It is recommended that the current operational protocols are extended and refined to ensure that BCC have a team to operate and close the flood gates during events. Effective operation will rely on the continued forecasting and warning of flooding prior to events. Instructions to close the gates should be provided with sufficient time to reduce the risk of the gates being left open

8.1.4 *Residual risk summary*

The model runs undertaken during this phase of work have improved the understanding of residual risk. However, whilst some targeted modelling runs have been undertaken the risk has not been comprehensively modelled with a full suite of runs. More model runs could be undertaken in future work should a more detailed understanding of residual risk be required.

It is impossible to remove residual risk completely but the design of the new gates at Entrance Lock and Netham can certainly limit the risk of failure. It may also be necessary for planners for the city to take the above design standard event modelling results and breaching results into account and for site specific Flood Risk Assessments and development plans to consider potential land raising, safe access / egress and evacuation plans. For more information on residual risk, refer to the Residual Risk technical note (February 2017).

At this stage the economic assessment has not accounted for residual risk associated with breaching of the gates at the entry points to the Floating Harbour. An avenue for further work would be to consider this by determining annual probabilities of breaches occurring and building allowance for the potential residual damages.

8.2 Detriment

An unresolved issue from the last phase of work (preferred options assessment) was detriment, especially for the higher return period events in epoch 3 (i.e. 1:200 year events from 2065 onwards). When compared to the Do Minimum scenario, detriment in this context is defined as either:

- additional properties at risk from flooding or;
- properties already at risk of flooding suffering deeper and / or extended durations of inundation.

Whilst the preferred strategic option will protect large areas of the city from flooding, the introduction of the defences will, without mitigation, increase flood risk elsewhere within the Strategy area. The new defences act to reduce the flood storage capacity within central Bristol by isolating the New Cut channel from its floodplain, raising water levels in the channel. The increase in water levels reduces the hydraulic gradient for fluvial flow coming from upstream of the city which in turn raises water levels upstream of the new defences.

Two areas of particular concern with regards to detriment are Bower Ashton and Netham. In these locations the mechanism of flooding is complex combining fluvial and surface water components. In Bower Ashton Longmoor Brook and Colliters Brook and at Netham the Brislington Brook, all present a fluvial flood risk to each area. This fluvial flood risk can be worsened by tide locking or backing up of flows unable to discharge due to high water levels in the River Avon.

To understand the scale of Strategy impacts the modelling results with the preferred option in place have been compared to the Do Minimum model results to identify areas of increased flood risk. During this phase of work a number of additional modelling runs with the preferred option in place have also been undertaken, including the 200yr fluvial event in 2065 and a 200yr tidal event in 2115. These additional model simulations have allowed the detriment from more flood events to be established.

Table 28 summarises the key findings from comparison. The table shows the events in which implementation of the Strategy would lead to betterment (reduction in risk) and detriment (increase in risk) and detriment (increase in risk) in terms of the property numbers affected. Areas of ‘No Change’ are also identified.

Table 28 Summary of detriment and betterment model runs

Area	Events										Overview of impact of proposed Strategy
	2015 200yr tidal 2yr fluvial Low defences	2015 Baseline tidal 75yr fluvial Low defences	2030 200yr tidal 2yr fluvial Low defences	2030 Baseline tidal 200yr fluvial Low defences	2065 200yr tidal 2yr fluvial Low defences	2065 Baseline tidal 200yr fluvial Low defences	2065 200yr tidal 2yr fluvial High defences	2065 Baseline tidal 200yr fluvial High defences	2115 200yr tidal 2yr fluvial High defences	2115 Baseline tidal 200yr fluvial High defences	
Bower Ashton/ Ashton Gate	NC	NC	NC	NC	D	NC	NC	NC	D	NC	Detriment in tidal events from 2065. No impact from fluvial events
Netham / St. Anne's Park	D	NC	D	NC	D	D	D	D	D	D	Detriment from tidal throughout. Detriment from fluvial from 2065
Bedminster	NC	NC	D	NC	NC	D	D	D	D	D	Detriment mainly from tidal and 200yr fluvial from 2065
North – Saint Judes	NC	NC	NC	NC	NC	B	B	B	B	B	Betterment from both tidal and fluvial from 2065
Cumberland Road	B	B	B	B	D	B	B	B	B	B	Betterment throughout except 2065 200yr tidal if still low defences
Burton Road/ Clarence Road	B	NC	B	NC	D	NC	NC	NC	B	NC	Similar issue to Cumberland Road with 2065 200yr tidal with low defences
Albert Road Park	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	Increased flooding but no additional properties at risk
City area	B	B	B	B	B	B	B	B	B	B	Betterment from both tidal and fluvial

D = Detriment, B = Betterment, NC = No Change

In Table 28 whilst some areas are described as 'No Change' it is important to note that this does not necessarily mean that there will be zero impact from the Strategy in terms of flood risk. The 'No Change' description in the table strictly refers to the number of properties that are at risk for given water levels but does not take into account the potential increases in the frequency, depth or duration of property flooding which may occur.

Based on the evidence summarised in Table 28, the following points emerge:

- The modelling results suggest that the Bower Ashton / Ashton Gate area will be at a greater risk of flooding in tidally dominated events after the Strategy has been implemented. Unless mitigation measures are used in this area then the extent and depth of flooding will be increased from 2065 onwards. The Strategy does not impact the level of fluvial flood risk in this area.
- The detriment modelling results suggest that the Netham / St. Anne's area will be at greater risk from tidal events throughout and from fluvial events from 2065 onwards. Very few properties will be affected by the detriment prior to 2065 but mitigation measures will be required to reduce the detriment impact in this area from 2065.
- The Bedminster area will be at increased risk from tidal flood events from present day onwards although there will be very few properties affected. In 2115 the area may also experience a greater risk during fluvially dominated events.
- Albert Road park, which is situated immediately to the east of the proposed Totterdown / St. Phillips defences will have an increased flood risk under most cases. This park is used for recreational purposes and therefore no properties will be at an increased risk from flooding.
- Cumberland Road and Clarence Road will be at detriment from 200yr tidal events in 2065 if the low defences are not raised to high defences. Defence raising in this location in 2065 is part of the preferred strategic option.

The hydraulic modelling report presents figures of the detriment modelling results and shows the areas at risk in more detail.

Table 29 to Table 32 present the number of properties in the detriment areas which are not at risk during the Do Minimum scenarios but are predicted to flood when the Strategy is implemented. These tables do not include the numbers of properties which are already at flood risk in the Do Minimum scenarios but will suffer and change in flood risk due to increased frequency, depth and / or duration of flooding. The tables present numbers for the years 2015, 2030, 2065 and 2115. For each year the tidal or fluvial scenario with the highest number of additional properties at risk has been presented (note that a check has been made to ensure that there are no additional properties at increased risk outside of the flood extent which has been used, for instance from the fluvial event if the tidal event has been used).

Areas of betterment have not been included within these tables and the detriment area at Albert Road Park has been excluded because no properties are at risk in this location.

It should be noted that a number of the property depth increases are within the confidence limits of the modelling. This should be kept in mind when considering the increased flood risk and the mitigation measures to be applied.

Table 29 Additional number of properties at flood risk in 2015, after low defences are implemented (relative to Do Minimum)

Location	Number of additional residential properties at risk	Number of additional non-residential properties at risk	Total number of additional properties at risk	Average flood depth increase (m)
Bower Ashton / Ashton Gate	0	0	0	0
Netham / St. Anne's	0	1	1	0.08
Bedminster	0	0	0	0

Table 30 Additional number of properties at flood risk in 2030, after low defences are implemented (relative to Do Minimum)

Location	Number of additional residential properties at risk	Number of additional non-residential properties at risk	Total number of additional properties at risk	Average flood depth increase (m)
Bower Ashton / Ashton Gate	0	0	0	0
Netham / St. Anne's	1	4	5	0.11
Bedminster	2	1	3	0

Table 31 Additional number of properties at flood risk in 2065, after high defences are implemented (relative to Do Minimum)

Location	Number of additional residential properties at risk	Number of additional non-residential properties at risk	Total number of additional properties at risk	Average flood depth increase (m)
Bower Ashton / Ashton Gate	0	0	0	0
Netham / St. Anne's	42	18	60	0.07
Bedminster	0	5	5	0

Table 32 Additional number of properties at flood risk in 2115, after high defences are implemented (relative to Do Minimum)

Location	Number of additional residential properties at risk	Number of additional non-residential properties at risk	Total number of additional properties at risk	Average flood depth increase (m)
Bower Ashton / Ashton Gate	97	28	125	0.13
Netham / St. Anne's	36	21	57	0.16
Bedminster	2	5	7	0.01

Table 29 to Table 32 show that the majority of additional properties at risk from detriment are at Bower Ashton / Ashton Gate and Netham / St. Anne's. The detriment in these areas is discussed in more detail in the following section. At Bedminster the detriment is highly localised and with only a small number of individual properties at risk.

8.2.1 *Bower Ashton / Ashton Gate*

Flood processes in Bower Ashton are complex and parts of this area are already at risk of flooding in the Do Minimum scenario from a combination of sources. Implementation of low defences in epoch 1 and high defences in 2065 would lead to an increased depth and frequency of flooding in this area due to water levels in the Avon being raised.

In 2015 and 2030 the main difference between the 200yr tidal event and Do minimum is the flood depth, which increases by approximately 0.1m when the defences are implemented. Despite the increased depth the geographic extent of flooding is unchanged and no additional properties are at flood risk during this time period.

In 2065 and 2115 the size of the flooded area increases. During the Do Minimum 200yr event (2115) water overtops the left bank of the Avon near Brunel Way (A3029) before propagating south. In the 200yr (2115) tidal scenario with the Strategy implemented more water inundates the left bank which causes an increase in flood depths of approximately 0.22m at Bower Ashton and 0.16m at Ashton. At the university campus and Hendre Road during the defended scenario the depths increase by 0.30 to 0.60m. The number of properties at risk increases from 81 at risk during the Do Minimum (200yr, 2115) to 206 with the defences in place. Of the 125 additional properties at risk, 97 are residential and are mainly located along Hendre Road, Duckmoor Road, Banwell Road and Smyth Road.

8.2.2 *Netham / St. Anne's*

At Netham / St. Anne's there is an increase in flood depths and extent when defences are implemented elsewhere in the Strategy area. This is most significant during the third epoch when high defences are in place.

The main area of concern is on the south bank of the River Avon where the Brislington Brook discharges into the Avon. The modelling shows that raised levels in the main river channel overtop the existing defences but also cause backing up of levels in the unflapped Brislington Brook. The Brislington Brook then foods from an open channel section immediately behind the River Avon outfall. .

A comparison of the Do Minimum 200yr (2115) tidal event with the 200yr (2115) tidal event show that in the area adjacent to the Brislington Brook the flood depths increase in residential / commercial areas by up to 0.24m. For the Do Minimum event there are a total of 39 properties at risk but when high defences are implemented this number increases to 96. Out of the additional 57 properties 36 are residential and are mainly located around Burgess Green Close.

There is also an increased flood risk on the north bank of the River Avon at Crew's Hole Road where a number of riparian properties will suffer increased depths of flooding of up to 200mm (during the 2115 200yr tidal event). The increase in flood depths extends many metres upstream beyond the limits of the strategy area. Moving upstream the banks become more natural and properties more sparse so the exact number of properties at increased flood risk is difficult to quantify and beyond the scope of this strategy.

8.2.3 *Paintworks*

A new development at the former Paintworks on Bath Road had installed a private flood defence to protect the new properties. The implementation of the strategy will increase water levels by approximately 250mm (during the 2115 200yr tidal event) and causing more frequent overtopping than anticipated when designed.

8.2.4 *Bedminster*

There is an increase in flood depth in the Bedminster area. The flood risk in this area is complex and the modelling suggests that flooding is caused from the Malago tide/locking and overtopping rather than directly from the Avon. The maximum increase in flood depths of properties already at flood risk is 60mm and there are 7 additional properties at risk (from a 2115 200yr fluvial event).

8.2.5 *Mitigation model runs*

Once the detriment baseline had been established additional model simulations were run which included mitigation measures in an attempt to improve the flood risk in Bower Ashton and Netham, without causing further detriment elsewhere. The mitigation runs included:

- One run (200 year tidal) for 2065 with additional walls at Bower Ashton and Netham
- One run (200 year fluvial) for 2065 with additional walls at Bower Ashton and Netham
- One run (200 year fluvial) for 2115 with additional walls at Bower Ashton and Netham

The Additional Modelling Report discusses the detriment flood risk from these events in detail and assesses the effectiveness of the mitigation measures which were considered. A summary of the modelling results and potential mitigation measures at Bower Ashton / Ashton Gate and at Netham / St. Anne's is provided here.

Bower Ashton / Ashton Gate

At Bower Ashton the model simulations included a 400m long raised wall along the left bank of the Avon with a crest height of 10.15m AOD to attempt to cut off the water inundating the area near Brunel Way (A3029). The model runs including this wall show that it significantly reduces the flood depths within the Bower Ashton area. However, the wall was not high enough nor extended far enough to prevent all the overtopping and fully mitigate against the increased flood risk. It did demonstrate the significant improvements that could be achieved by this approach.

Netham / St. Anne's

At Netham two additional sections of raised defences were modelled, a 150m section at Burgess Green Close and a 300m section at the industrial area adjacent to St Anne's Road. Both had a crest level of 10.40m AOD. The results from the model simulations suggest that the defence will reduce the flooding in this area without leading to further detriment elsewhere, however, it is clear that the defence needs to be longer to prevent outflanking.

The modelling also showed that these defences did not prevent the flooding from Brislington Brook and additional mitigation measures would be required to deal with this issue.

8.2.6 *Recommended mitigation measures*

Generally detriment mitigation measures will be required during epoch 1, alongside the first phase of low defences to mitigate the immediate risk caused by the Strategy.

The exception to this is at Bower Ashton / Ashton gate where the onset of additional risk does not occur immediately (in terms of additional properties at risk) and the works could potentially be delayed if there is a commitment from BCC to construct the detriment mitigation.

Bower Ashton / Ashton Gate

To manage the detriment flood risk at Bower Ashton / Ashton Gate it is proposed to raise the existing bank level to prevent overflowing / overtopping of flood water.

To determine the necessary length and height of defence the Do Minimum model results were inspected in GIS against the LiDAR data of the area. The proposed defence encompasses a raised bank approximately 480m long with a crest level of 10.30m (to match the design level for high defences on the north bank). Based upon the alignment shown in Figure 21, the average height of the defence will be approximately 1.40m, with a maximum height of 2.40m. A cost allowance for this defence has been included in the Strategy economics.

During the next phase of the design, additional work should be undertaken to find the most technically feasible and economically viable alignment and height to achieve the desired outcome, whether this simply be for mitigating detriment from the implementation of the strategy or full protection from tidal inundation.

Any future work should also consider a comprehensive solution to include fluvial and surface water issues which may also deal with the increased risk from tidal flooding which may include storage or pumping solutions.

Mitigation measures should be installed in advance of the Strategy implementation to avoid the risk of increased flood depth once the Strategy is in place.

Netham (south bank)

To manage the increased flood risk at Netham (south bank) it is proposed that a number of interventions are undertaken.

In order to manage the mitigation more effectively, the following interventions are proposed:

- Raise the existing sheet piled defence to a height of 10.40m AOD to match the design levels downstream to prevent overflowing / overtopping. The maximum length of defence required is approximately 950m with an average raising of approximately 0.80m.
- Install at tidal flap valve at the Brislington Brook outfall
- Culvert the open section of Brislington Brook or raise the defences around it
- Provide overpumping when Brislington Brook cannot discharge under gravity

These interventions deal with both issues that were identified during the additional detriment modelling; the additional defence length to prevent outflanking from the River Avon and measures to deal with flows in the Brislington Brook.

A cost allowance for the detriment works specified above has been included in the Strategy economics. It is possible that the tidal flap valve at Brislington Brook outfall would be required in the future even if the Strategy was not implemented. However the costs for this have been included in the Strategy as it is expected to make the tide locking in this location worse.

In the next phase of design after the Strategy it is recommended that additional modelling is undertaken to optimise the length and height of the defences. This should be linked to the work to be carried out for the north bank and upstream works as upstream flood storage on the River Avon may preclude the need for raised defences.

Further investigations can be carried out to assess whether Brislington Brook has the capacity to store water which cannot be discharged without the need for overpumping. There appears to be scope upstream in St Anne's Park for some additional storage should this be required.

It is also acknowledged that the proposed culverting of the section of open channel of Brislington Brook is contrary to the Environment Agency's culverting policy and therefore investigations could be undertaken at a later stage to determine whether raising the defences around this section would be viable and preferable or even whether overpumping at the outfall could avoid the need for works to the open channel altogether.

Netham (north bank)

There are a small number of isolated properties at Netham on the north bank of the New Cut channel which are at increased flood risk and a number of mitigation options have been considered.

A new linear defence was dismissed as being too expensive for the number of properties at risk and the length of defence required to prevent outflanking.

The most feasible approach is believed to be the use of upstream flood storage. The modelling suggests that the cause of flooding in this area is a lack of hydraulic gradient causing the fluvial flows to back up and therefore upstream storage is believed to be a viable approach to alleviating the issue. The volume of storage required has not been quantified at this stage but there appear to be a number of locations that could offer storage potential such as Conham River Park and the Eastwood Farm Nature Reserve.

It is recommended that the upstream storage approach is developed further as part of the next phase of design. For the purposes of option costing in the Strategy a cost allowance for flood storage been based on a volume equivalent to the full amount of overtopping flow at Netham (north and south banks) but it is acknowledged that this may underestimate the volume required.

Again, it is recommended that these further studies are incorporated into a comprehensive scheme to consider the fluvial flood risk from the Avon as well as mitigating the impacts of the tidal strategy.

Bedminster

The additional properties at risk from detriment in Bedminster are limited in number and suffer only minor flooding. The construction of a new hard defence against flooding is not considered to be viable to deal with strategy impacts and it is proposed that the seven additional properties at risk should have property level protection systems (PLP) installed. A cost allowance for PLP to these properties has been included within the Strategy economics.

The properties which are already at flood risk will suffer a maximum increase of only 60mm. In some cases the total flood depth exceeds 600mm the depth at which PLP is not considered effective or desirable due to the potential for structural damage.

Further investigations into the cause of flooding from the Malago should be undertaken and a comprehensive solution proposed. This may include the installation of a flap valve on the Malago outfall and if necessary the ability to overpump or provide adequate storage.

Paintworks

It is proposed to raise the existing gabion defences with additional gabions to mitigate the low defence strategy impacts. Given the design life of the gabions it is likely that the paintworks defence will need to be reconstructed prior to the implementation of the high defence strategy walls and at this point a more appropriate solution can be considered. Costs have been included in the Strategy economics for two phases of raising of walls.

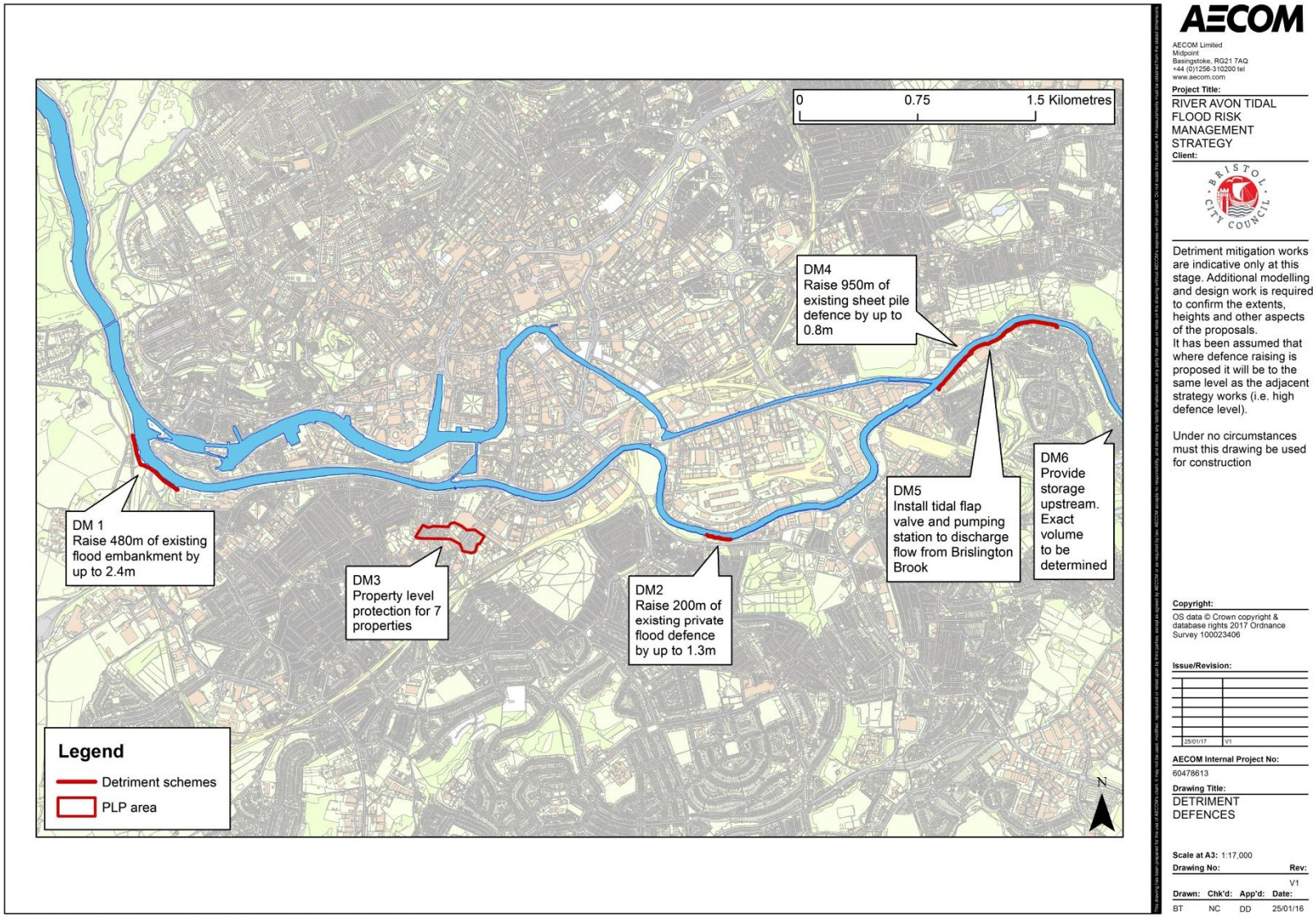

Figure 21 Map of proposed detriment works

8.2.7 *Alternative mitigation measures*

Floating Harbour storage

The Floating Harbour was considered as a flood storage area during tidal flood events. Further modelling is required to confirm:

a) The volume of water that needs to be stored to keep water levels in the New Cut at pre Strategy levels

b) Whether the Floating Harbour has the available capacity to store the water identified in a) with adequate freeboard

c) Whether the stored water can enter the Floating Harbour quickly enough to deal with the tidal surge. Will pumps be required?

d) Where and how the water to be stored enters and leaves the Floating Harbour to ensure that the water levels in the appropriate parts of the city are reduced (e.g. will sluices at Netham mitigate the tidal detriment at Bower Ashton?)

From a conceptual standpoint using the Floating Harbour to store detriment flood water may be feasible. A simple GIS study of volumes of water at the peak of the tide was undertaken to compare the volume of water in the New Cut for the do minimum scenario against the strategy walls. A separate assessment was undertaken to consider the additional volumes of flooding at Bower Ashton and Netham. No allowance was made for the time component of flows and how, if you remove a volume from the New Cut in one time period this may create a hydraulic gradient for water to flow back in from either upstream (fluvial flow) or downstream (tidal) thereby requiring more storage.

From this GIS study it is concluded that there is storage capacity within the harbour for the potential increased volumes of flood water in the New Cut following the Strategy; a lowering of 0.6m from the typical harbour water level produces 196,000m^3 of storage capacity which exceeds the total detriment volume for Bower Ashton / Ashton Gate and Netham / St. Annes of approximately 91,000m^3. Lowering of the water level in the Floating Harbour is known to be technically possible given that water levels are already routinely lowered during tidal flood events (this will not need to continue with the preferred option in place, hence the opportunity to use the harbour to store detriment flood water instead).

However, significant additional work will be required to validate this solution which is outside the scope of the current strategy. If additional modelling were to show that storing flood water within the harbour reduces the detriment then further studies will need to investigate methods to get this water into the harbour during a limited time period in advance of at peak tide. Methods could include systems of sluices / pumps at Entrance Lock, Underfall Yard or Netham or changes to the gate operating regimes to allow some water to enter the harbour.

Property level protection

At Bower Ashton and Netham widespread PLP could be considered as an alternative approach to reduce the impact of the detriment. This would be an effective solution in the interim prior to 2065 when only a small number of properties are at increased flood risk. PLP is only effective up to flood depths of approximately 0.6m and additional work would be required including property threshold surveys to determine the feasibility of this approach. It also requires passive solutions or adequate flood warning to be truly effective and should be considered as a last resort if a more comprehensive solution cannot be identified.

8.2.8 *Discussion*

Additional modelling has been undertaken during this phase of work to improve the understanding of the wider impacts of the Strategy. Two main areas of detriment have been identified; at Bower Ashton / Ashton Gate and at Netham / St. Anne's. Costs have been included with the Strategy economics for the recommended approach to managing the detriment at these and other locations. It is accepted by the project team that it is extremely difficult to implement a strategy with zero impact, however through the mitigation measures that have been recommended above it is expected that the impact can be limited.

Away from Bower Ashton / Ashton Gate and Netham / St. Anne's there are more areas that experience detriment due to the Strategy. However the detriment in these locations is on a local scale and the areas include significantly fewer properties at risk. Localised detriment will need to be assessed on a case by case basis in the future and costs are expected to be small.

9. DELIVERY RISK AND MONTE CARLO ASSESSMENT

9.1 Optimism bias and delivery risk workshop

Optimism bias is a risk allowance which Treasury guidance states should be applied to all projects to take into account the tendency of practitioners to underestimate the out turn costs of projects. DEFRA guidance builds on the Treasury guidance for flood risk management projects and identifies two possible approaches to the calculation of optimism bias at the strategy phase:

- Increasing project costs by 60%
- Carrying out a risk identification process and using Monte Carlo simulations to produce a probability distribution of the likely project outturn then adding the 95%tile cost to the project cost.

The project team convened a delivery risk workshop on 21st December 2016. The purpose of the workshop was to agree the key risks that could impact on the outturn cost, identify and allocate mitigation measures and confirm a more informed risk allowance compared to simply using the 60% of the cost approach that has been used for the project to date. For each risk, the probability of the risk occurring was assigned a probability on a 5 category scale ranging from Very Low through Low, Medium and High to Very High. The consequence /magnitude of the cost and programme impact was also assigned a value using the same ranking scale. Combining the probability and magnitude resulted in a priority (traffic light) grading of Low, Medium or High, along with a Risk sum for each item.

The financial scale for cost impact and temporal impact for programme was based on the project cost and the predicted programme duration. For the workshop, the predicted capital construction costs, at the time of the workshop, for the low defence works immediately after adoption of the Strategy and, secondly in 2030 was used, amounting to approximately £64 million. The predicted programme duration from adoption / endorsement to construction of the low defences was estimated as 3 years. For each probability category, a % minimum and maximum value was defined to provide a lower and upper bound cost or programme value, as shown in the table below. These values could then be applied to each risk item.

Table 33 Probability and Consequence of impact

Probability						Consequence / Impact					
						Cost			Time		
Scale	Likelihood	Min (%)	Max (%)	Scale	Max % of project	Project cost (£k)	Min (£k)	Max (£k)	Project time (wks)	Min (wks)	Max (wks)
VL	Unlikely to occur	0	10	VL	3	64,000	0	1,600	156	0	4
L	Fairly likely to occur	11	30	L	5		1,601	3,200		4	8
M	Likely to occur	31	50	M	10		3,201	6,400		8	16
H	More likely to occur than not	51	70	H	15		6,401	9,600		16	23
VH	Almost certainly will occur	71	100	VH	25		9,601	16,000		23	39

The risk sum allocated to each risk item was derived from the maximum cost impact multiplied by the probability. So, by way of example, the risk item “overarching unforeseen ground conditions” was

deemed a High Risk item with a residual probability of 50% (after mitigation / management). The cost impact was categorised as High and programme impact was categorised as Medium.

The risks confirmed in the workshop risk register are enclosed in Appendix 3. The agreed risk items, allocations of probability, and the magnitude of the cost and programme impacts then underwent a Monte Carlo type assessment. This was completed to consider the likely outcome of different combinations of risks occurring, as opposed to all risks and the total risk sum being realised.

9.2 Monte Carlo assessment

A Monte Carlo assessment considers the probability of each individual risk occurring and runs numerous simulations looking at combinations of risk, the probability of occurrence and the outturn cost. It generates a probability distribution of the outturn cost so that the likelihood of a certain risk value being exceeded can be assessed.

For the Strategy the inputs to the Monte Carlo resulting from the risk workshop were:

- A single probability of each risk occurring
- A maximum cost if that risk occurred

The Monte Carlo assessment was undertaken using @risk software, a plug in to excel spreadsheets. The information provided from the workshop meant that the following assumptions needed to be made:

- All risks were completed independent, i.e. if one risk occurred it did not affect the likelihood or cost of other occurring

Two different probability distributions were used for the Monte Carlo analysis. The first probability distribution was a binomial. This means that the risk either occurred or it didn't (with the probability of occurrence based on the output form the workshop) and if it did occur it cost the maximum amount identified by the workshop. This approach gives a very flat probability distribution output which is broadly similar to the sum of the probability of cost multiplied by the probability of occurrence. It is limited in it does not take into account the potential range of costs that could occur for a given risk.

An alternative approach used a minimum, most likely and maximum cost distribution (known as a triangular distribution within @ risk). The following assumptions were made:

- The minimum cost was zero
- The most likely cost was the probability of occurrence multiplied by the maximum cost
- The maximum cost was what was identified by the risk workshop

No sensitivity tests have been undertaken to see how the outputs change if these assumptions are altered. However the triangular distribution approach gives higher values than the binomial approach.

Using the two approaches the following outputs were generated, based on the prevailing cost estimate at the time of the workshop:

- 50%ile cost (i.e. the value having a 50% chance of being exceeded) = from £27,072k to £38,839k
- 95%tile cost (i.e. the value having a 5% chance of being exceeded) = up to £45,828k

The range from £27,072k to £45,828k equates to 42% to 72% of the construction cost. Based on these results it was concluded that applying the standard 60% optimism bias is a reasonable approach and this has been adopted throughout the economic assessment. The risk workshop identified a total of £89,000k of risk items (if all risks occurred on the project) so as the project goes forward, it is recommended that best practice risk management continues to be applied to deliver risk mitigation with extra focus on higher risk items discussed at the delivery workshop.

9.3 Recommendations for additional work / refinements

Throughout this report there are recommendations for additional work to enable refinements to the preferred strategic option to be made. For clarity these recommendations have been collated in one place and are presented here and include:

- Additional refinement of the defence designs and alignments will be required when developing an Outline Business Case for any schemes that follow on from the Strategy. More details on what surveys need to be undertaken to advance these schemes is provided in section 4.1.1
- Further consideration to maintenance aspects including assessment on a site by site basis
- Further consideration of environmental mitigation measures such as landscaping, public realm improvements and compensatory habitat provision for the loss of intertidal habitat
- Environmental scoping and consenting
- More detailed numerical modelling to investigate flow pathways between flood cells during high magnitude events
- Additional numerical model runs to help quantify the fluvial benefits of the Strategy
- Consider annual probabilities of defence breaches to account for this residual risk in the economic assessment
- Interface with wider opportunities and programmes, including the Harbour Asset Management Strategy

10. SUMMARY

10.1 Overview of findings

The key findings from this latest phase of work are:

- An approach to phasing the preferred option has been agreed with the project team. The phasing plan maximises the return on investment in the early phases of the Strategy and improves deliverability. The phasing involves implementing the Floating Harbour defences and the Totterdown / St. Phillips defences in epoch 1, and delaying the New Cut defences until epoch 2.
- Overall costs of the preferred option have been reduced since the last stage of work. Through a combination of reduced capital costs and defence phasing the PV whole life cost has reduced from £166.3m to £67.7m.
- If the preferred option is phased, the PV benefits for the Strategy period reduce from £1,576m to £1,531m. However due to the greater decrease in costs, the benefit cost ratio of the option increases.
- Partnership funding scores have been calculated based upon the phasing plan developed during this work stage; scores for the Floating Harbour and Totterdown in 2015 and the New Cut in 2030. With this approach the Floating Harbour and Totterdown / St.Phillips scheme has the strongest PF score by a significant margin as this scheme protects the majority of assets and properties at risk. The New Cut defences, whilst having a similar cost profile to the Floating Harbour scheme, protect significantly fewer properties and have a PF score of only 13%.
- The phased approach to scheme delivery has been endorsed by the project board in February 2017. There is a strong case for funding the schemes in epoch 1 and the approach is favourable in terms of deliverability and maximising returns on investment.
- Additional modelling results have improved the understanding of residual risk. They show that should a breach occur at the downstream entry point to the Floating Harbour (i.e. Entrance Lock), then the flood risk in 2115 events is similar to the equivalent Do Minimum scenarios. The design of new flood / lock gates at Entrance Lock and Netham can minimise the residual risk of failure by including multiple levels of redundancy.
- Two main areas of detriment have been identified; at Bower Ashton / Ashton Gate and Netham / St. Anne's. Mitigation measures for the detriment in these areas have been considered through additional flood modelling.
- A map showing the phased preferred option, in addition to the mitigation measures to prevent adverse impacts / detriment is provided in Figure 22.
- A Monte Carlo analysis has been undertaken and it is concluded that a 60% optimism bias allowance is a reasonable approach. This was adopted throughout the economic assessment.

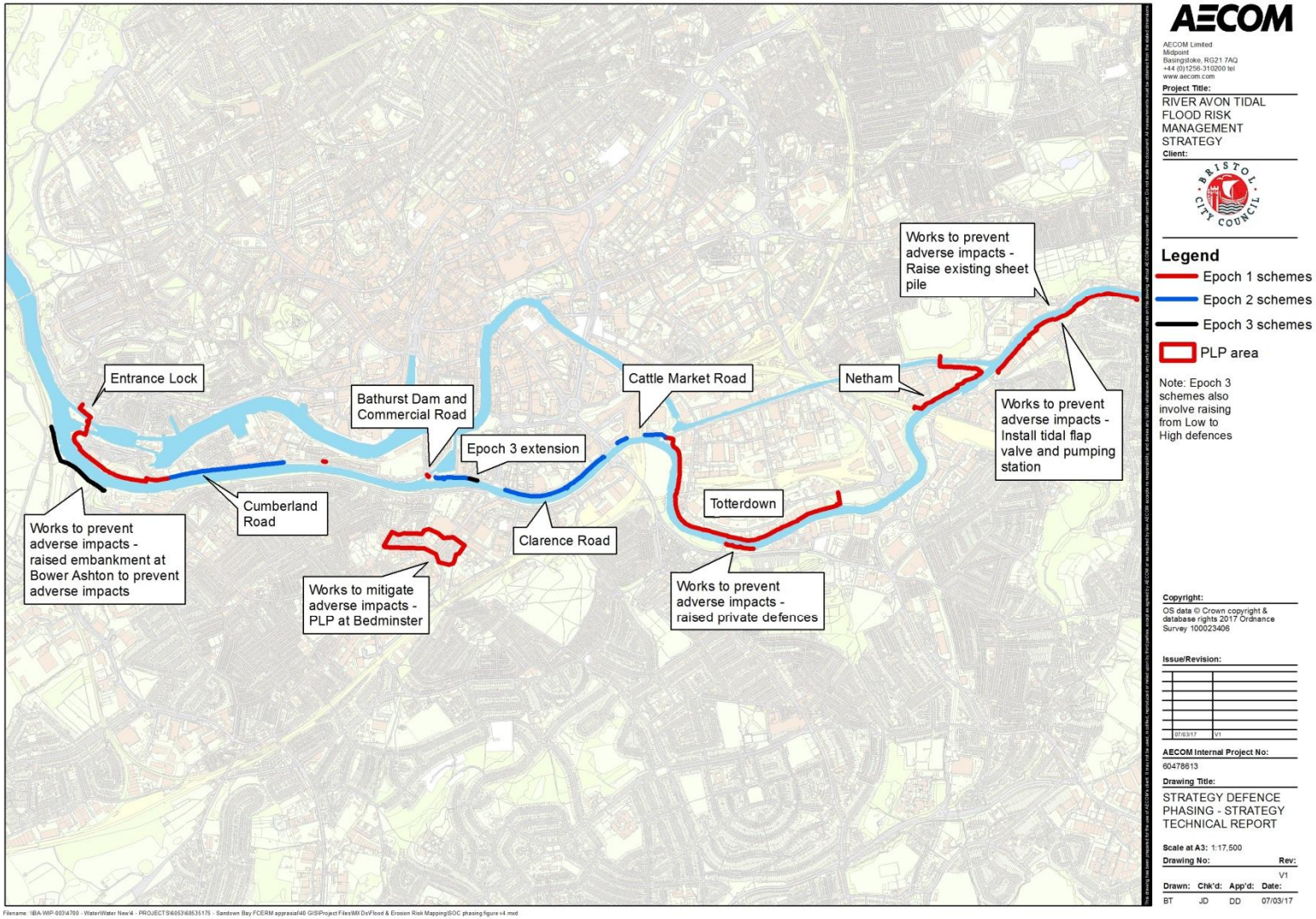

Figure 22 **Map showing the phased preferred option and the measures to prevent adverse impacts / detriment**

11. APPENDICES

List of Appendices

Appendix 1: Beneficiary Mapping

Appendix 2: Visualisations

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Appendix 1: Beneficiary Mapping

N

This map shows land ownership within the flood extent of the modelled 1in200 year in 2110 tidal event (excluding areas covered by the Floating Harbour and New Cut). Property data sources: BCC ownership records; Adopted highway records; Land registry title search purchase (28/06/2016).

- Strategy High Defences
- TQ Enterprise Zone
- 1in200yr Tidal Flood in 2110
- Harbour & New Cut

Owners - Other

- Top 5
- Top 10
- Remainder

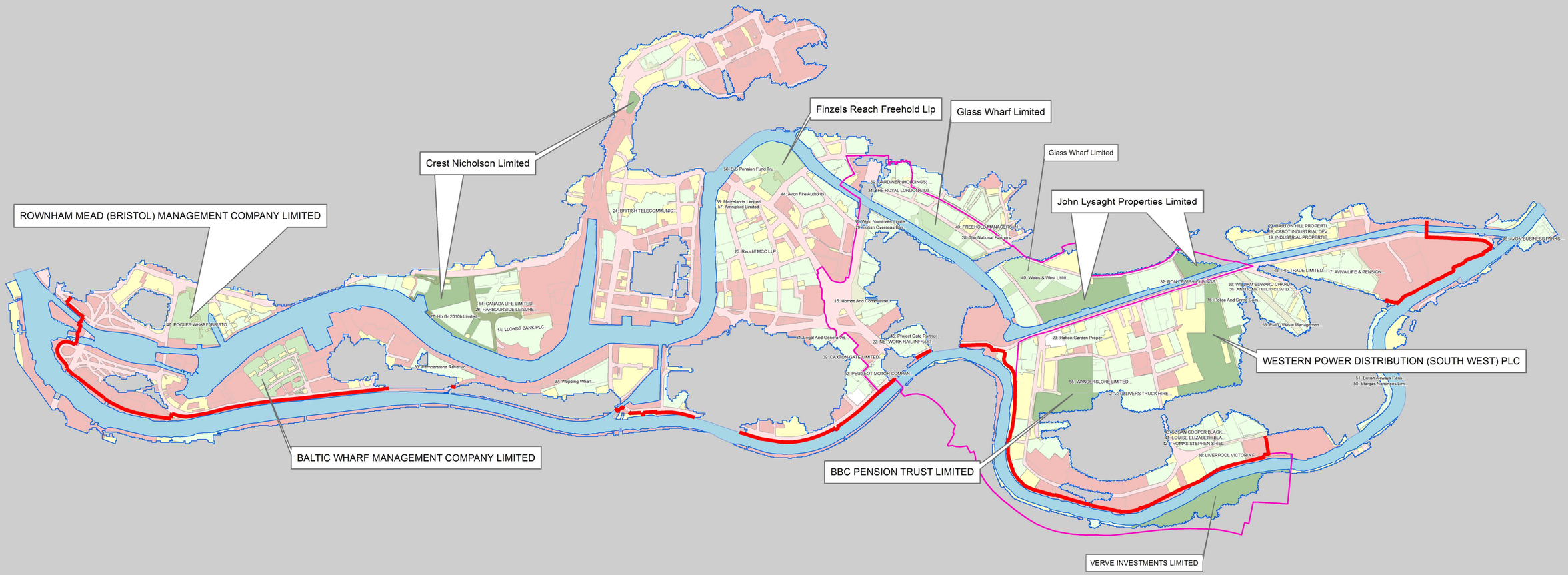
Owners - BCC and Unknown

- Adopted Highway
- BCC
- Unknonwn

Drawn by BCC Flood Risk Team, 20/12/2016

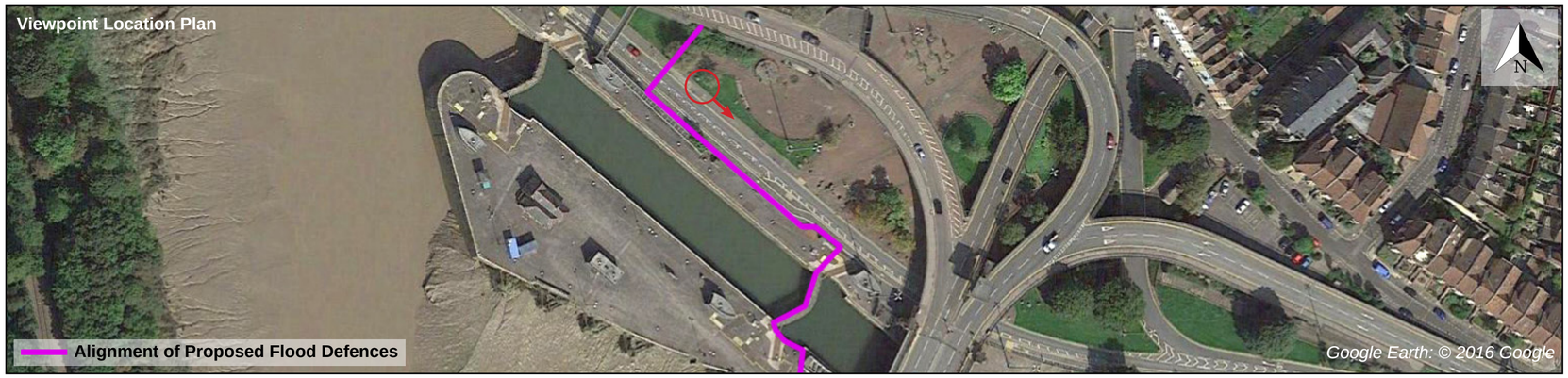
1:7,000 @ A1

0 365 730 Meters



Appendix 2: Visualisations

Project: **River Avon Tidal Flood Risk Management Strategy**
Sheet: **Viewpoint Location Plan**



Notes:

1. Red hatch represents the approximate massing of the Tidal Flood Defence Wall when first constructed (anticipated pre-2020), referred to as 'low defences'. Pink hatch represents proposed increase in wall height in 2065 (referred to as 'high defences') and assuming existing SLR predictions are realised.

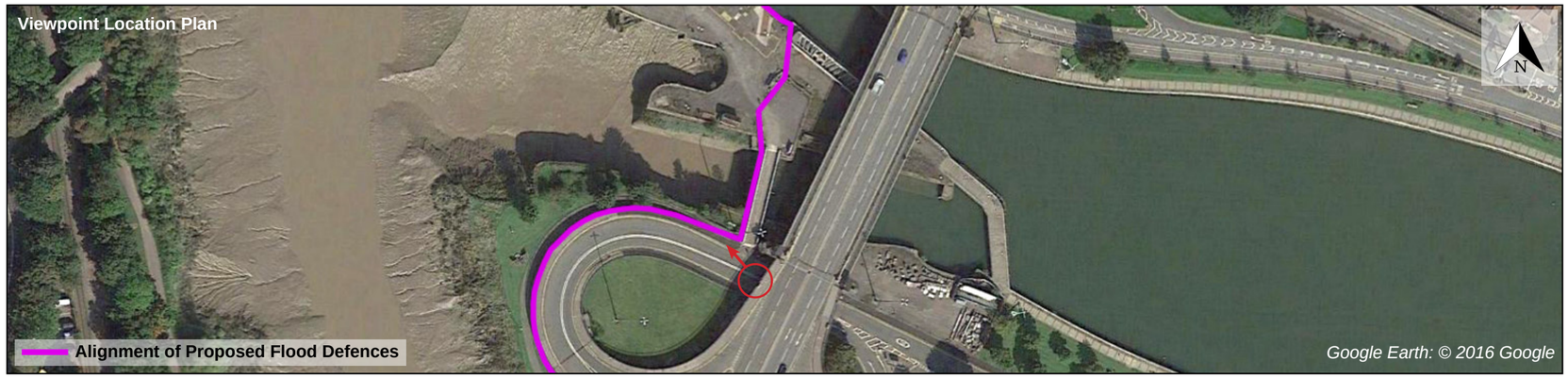
2. Wall heights shown are based upon proposed elevation of 'low defences' and ' high defences' relative to existing ground level.

3. Viewpoint images were taken at an approximate height of 1.6m.

4. Montages are for illustrative purposes only and are non-verifiable. They represent the approximate massing of the structure as based upon current proposals and are not a visualisation of their potential final appearance.

Viewpoint 1 - Tidal Flood Defence Wall Illustration

Project: **River Avon Tidal Flood Risk Management Strategy**
Sheet: **Viewpoint 1 - Cumberland Basin Road**



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Viewpoint 2 - Tidal Flood Defence Wall Illustration

BRISTOL CITY COUNCIL | AECOM

Project: **River Avon Tidal Flood Risk Management Strategy**
Sheet: **Viewpoint 2 - Brunel Dam**

Notes:

1. Red hatch represents the approximate massing of the Tidal Flood Defence Wall when first constructed (anticipated pre-2020), referred to as 'low defences'. Pink hatch represents proposed increase in wall height in 2065 (referred to as 'high defences') and assuming existing SLR predictions are realised.

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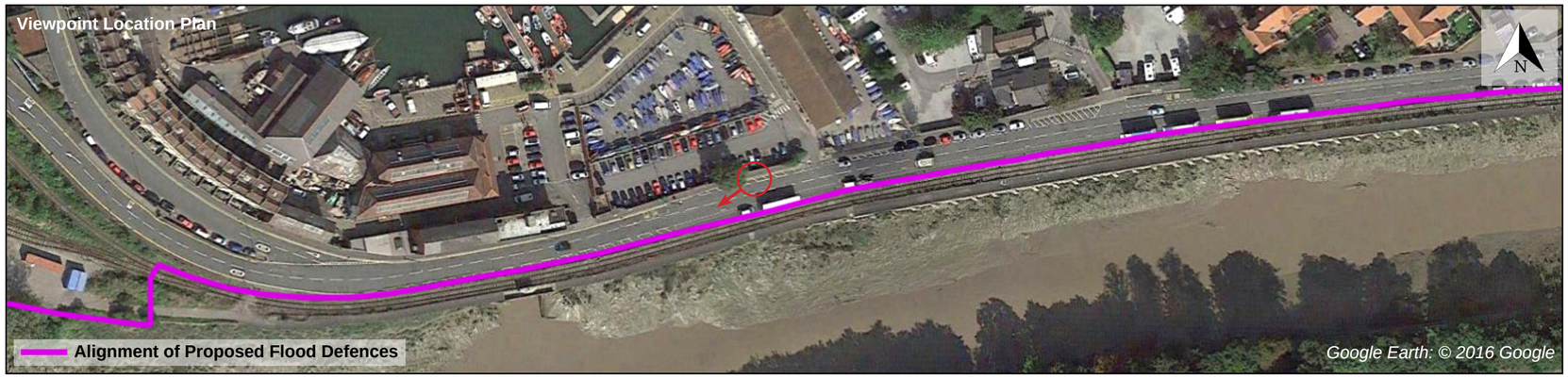
Viewpoint 3 - Tidal Flood Defence Wall Illustration

BRISTOL CITY COUNCIL | AECOM

Project: **River Avon Tidal Flood Risk Management Strategy**
Sheet: **Viewpoint 3 - Create Centre**



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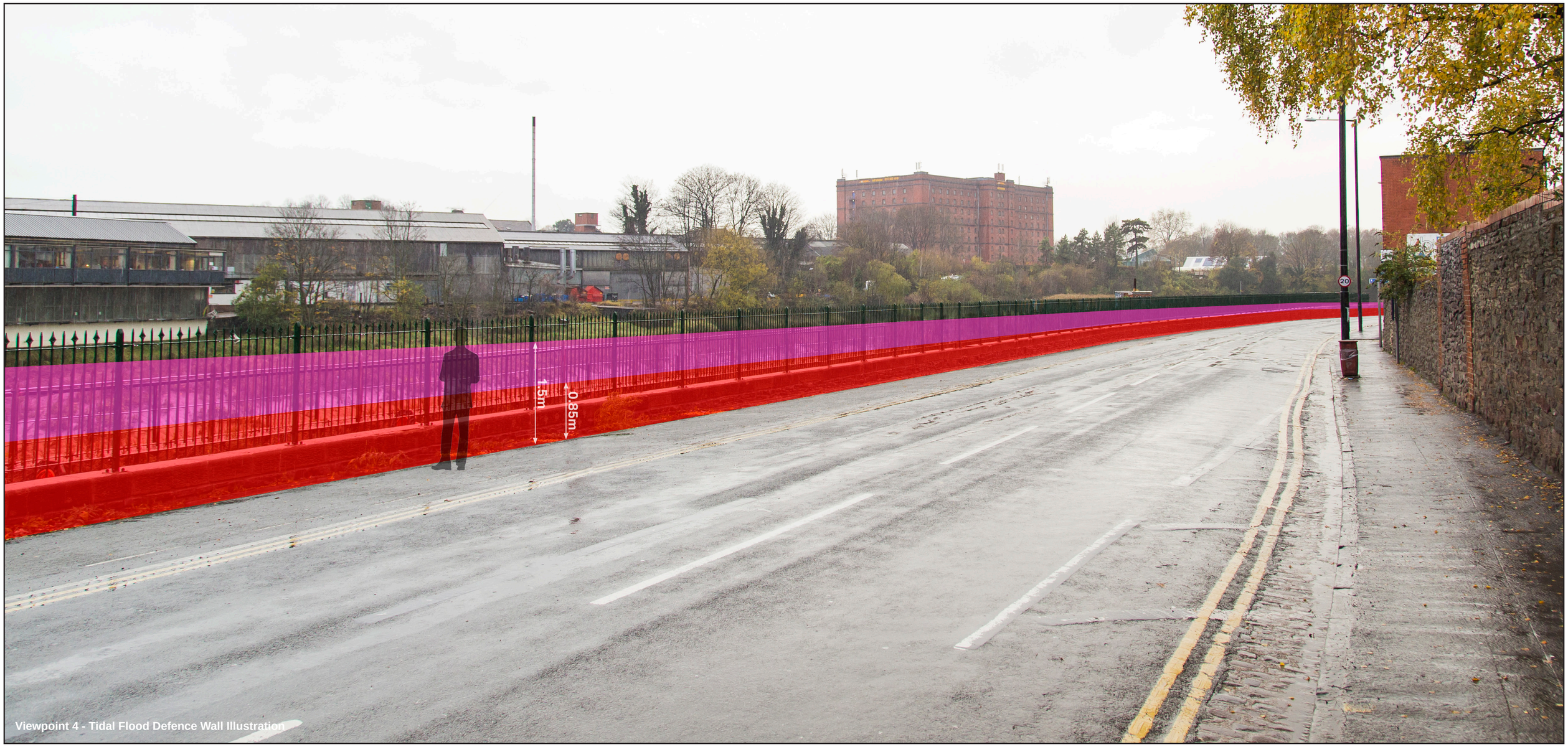
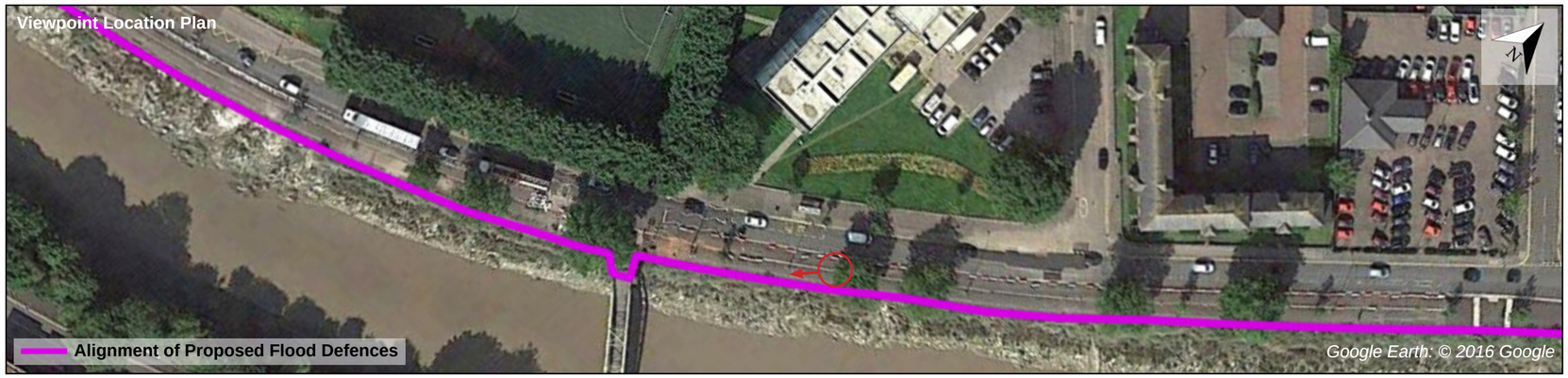


Viewpoint 4 - Tidal Flood Defence Wall Illustration

Project: **River Avon Tidal Flood Risk Management Strategy**
Sheet: **Viewpoint 4 - Cumberland Road**



Notes:

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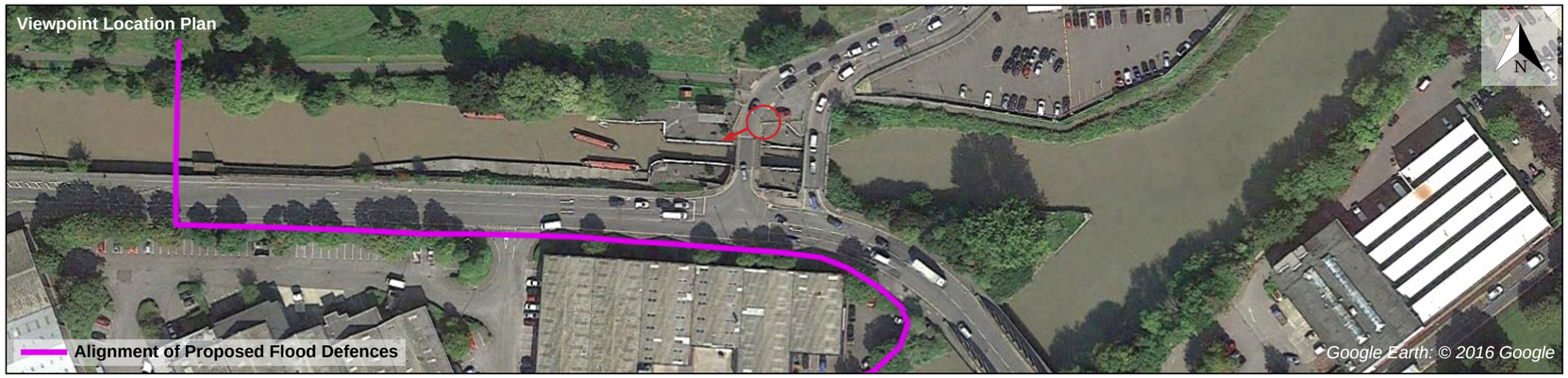
Project: **River Avon Tidal Flood Risk Management Strategy**
Sheet: **Viewpoint 5 - Clarence Road**



Notes:

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Project: **River Avon Tidal Flood Risk Management Strategy**
Sheet: **Viewpoint 6 - Netham Lock**

Littlehampton, West Sussex

Southey Hill, Cumbria

Carlisle

Upton, Worcestershire

Keswick, Cumbria

Keswick, Cumbria

Wisbech, Cambridgeshire

Latchford, Cheshire

Dresden, River Elbe

Project: **River Avon Tidal Flood Risk Management Strategy**
Sheet: **Flood Defence Examples Board**

Appendix 3: Delivery risk register

Risk ID	Risk description			Response Action		Qualitative Ranking (After Response Action)						Assumptions in baseline cost	Strategy Max Cost impact (£m)	Strategy Risk Sum £m (cost x probability)	Strategy % item contribution of Total Risk Sum
	Source of risk	Consequence on project	Existing safeguards in place	Action	Action owner	Residual probability (%)	Probability scale	Cost impact	Time impact	Cost+time impact	Priority				
1	**Procurement: Late contractor involvement in design**	Limited availability leads to increased procurement lead in times with potential for additional cost & time implications	None	Consider alternative procurement route to market; reprofile programme	BCC	10%	VL	L	M	M	L	Zero.	3.2	0.32	1.2
2	**Procurement: Disputes and claims**	Adversarial relationship leads to project delay and increased costs	None	Coherent contract setup and implementation	BCC	30%	L	L	M	M	M	Zero.	3.2	0.96	3.5
3	**Supplier non-performance**	Potential time delays and cost escalation	None	Employ suitably experienced suppliers. Set KPIs and monitor performance. Ensure suitable alternative procurement arrangements in place.	BCC	10%	VL	L	M	M	L	Zero.	3.2	0.32	1.2
4	**Overarching unforeseen ground conditions**	Poor project intelligence results in increased scheme cost, programme delay	Previous BCC project knowledge around the city.	Detailed ground investigation following Eurocode (or national) standards prior to completion of detailed design	Contractor	50%	M	H	M	H	H	Investigations (ground, topo services etc) = 5% Business Case and detailed design = 8%	9.6	4.8	17.7
5	**Navigation and quay access**	Constraints on harbourworking / operations	Liaison with harbour operations on alignments.	Continued engagement throughout detailed design & construction to work with BCC Harbours to minimise disruption	Contractor	30%	L	L	H	H	M	Zero.	3.2	0.96	3.5
6	**Specific technical on site issues identified during detailed design**	Increased cost around need to innovate (non-standard) design and respond to technology advancement	Specific cost allowance, approx. £3m, included in scheme costs	To be addressed at detailed design	BCC	60%	H	VL	L	L	M	Business Case and detailed design = 8% What specific issues and what allowance?	1.6	0.96	3.5
7	**Additional complexity of tidal working**	Increased cost / programme	Assumptions built into Strategy outline design	Clarify assumptions around construction methodology during next stage of project when completing outline and detailed design.	BCC	10%	L	L	L	L	L	Zero.	3.2	0.32	1.2
8	**Key Services and Local services (e.g. private drainage)**	The presence of key services may mean that preferred alignments cannot be achieved. Also if services are not accurately located prior to construction, there is a potential health and safety risk (e.g. cable strikes). Damage to local on site services Severance of major services (unmapped)	Desk based services from previous BCC projects. BCC is principal landowner with facilities management / estate management records	Detailed services searches, liaison with utilities provider, obtain detailed site plans (if available), probe & locate on site during detailed ground investigation & construction.	BCC	55%	H	M	M	M	M	Services diversions temporary and permanent = 5%	6.4	3.52	13.0
9	**Works to bridges to overcome uplift**	Additional design and construction costs	Hydraulic modelling includes bridge structures	Contingency in construction costs	Contractor	10%	VL	VL	M	M	L	Brickworks raising = £150k	1.6	0.16	0.6
10	**Increase in compensation above expected**	Increased scheme cost, programme delay	Provision in costings	Extensive landowner engagement throughout planning application phase, detailed design & construction to work with landowners/operators to minimise disruption; 5% allowance for compensation; any additional compensation costs would have to be sourced from contributions	BCC	50%	M	L	H	H	H	Compensation = 5%	3.2	1.6	5.9
11	**Increased costs associated with reaching individual landowner agreements**	Increased scheme cost, programme delay	Provision in costings	Legal agreements with individual landowners Extensive landowner engagement throughout planning application phase, detailed design & construction to work with landowners/operators to minimise disruption; 5% allowance for compensation; any additional compensation costs would have to be sourced from contributions	BCC	20%	L	VL	M	M	M	Compulsory Purchase - Totterdown St Phillips = 5%	1.6	0.32	1.2
12	**Increased landscape and public realm requirements / mitigation**	Additional design work	Small allowance in costings for basic cladding and like for like reinstatement only	Apply suitable allowance during detailed design	Contractor	90%	VH	M	L	M	H	Landscape and Public Realm = 2% Environmental Mitigation other = 1% What is other??	6.4	5.76	21.3
13	**Change of landowners / uses along the frontage**	Impact on design with additional cost & time requirements	BCC are majority landowner. Funding Strategy identifies potential landowners.	Review land ownership. Costed the worst case for sites currently identified with uncertainty (i.e. redevelopment sites); continued engagement throughout detailed design & construction to work with landowners/operators to identify potential changes as early as possible	BCC	10%	VL	VL	M	M	L	Compulsory Purchase - Totterdown St Phillips = 5%	1.6	0.16	0.6
14	**Health and safety incidents**	Potential time delays and cost escalation	Risk register on drawing	Employ contractors with suitable procedures in place to manage risks.	BCC	0	VL	VL	L	L	L	Deemed not applicable by BCC	1.6	0	0.0
15	**Inadequacy of Business Case / Project Specification**	Project scope changes as a result of of poor requirement specifications and inadequate scope definition	Provision of project requirements and scope at Strategy phase from outset	Review project specifications / scope definition	BCC	0	M	M	VH	VH	H	Deemed not applicable by BCC (Business Case and detailed design = 8%)	6.4	0	0.0
16	**Political Influence e.g. a tidal event changes Council opinion / priorities**	Change in project direction, emphasis and objectives. Programme and cost implications if new personnel disagree with work completed to date and lack commitment to move forward. Also Councillors' view may impact on project direction.	Communications with BCC and Council leadership	Maintain communications with leadership. Keep elected members / mayor / metro mayor briefed during devleopment	BCC	50%	M	VL	M	M	M	Zero.	1.6	0.8	3.0
17	**Funding changes in delivery period**	Risk of additional mob/demob costs	Liaison all potential funding partners / sources	Secure funding contributions. Continued liaison with EA on funding profile updates.	BCC	40%	M	VL	M	M	M	Zero.	1.6	0.64	2.4
18	**Project Team staff changes**	Could increase cost / delay programme	EA and BCC arrangement of working together continues to end of Strategy	Maintain staff continuity where possible and have contingency plans in place for key roles.	BCC	10%	VL	VL	L	L	L	Zero.	1.6	0.16	0.6
19	**Potential for damage to properties during construction**	Vibration during piling could cause damage to nearby buildings	None	Condition survey of buildings prior to construction, monitoring during construction, use of lower impact piling techniques in potentially sensitive locations	Contractor	0	M	L	M	M	M	Deemed not applicable by BCC. (Investigations (ground, topo services etc) = 5%) (Business Case and detailed design = 8%)	3.2	0	0.0
20	**Unexploded Ordnance**	Increased scheme cost, programme delay, H & S risk for customer and third parties	None	Detailed UXO search, watching brief, probe & locate on site during detailed ground investigation & construction; flexibility of construction programme to minimise downtime on discovery of a UXO.	Contractor	20%	L	VL	VL	VL	L	Investigations (ground, topo services etc) = 5%	1.6	0.32	1.2
21	**Collapse of existing wall as a result of vibration from piling works and / or plant movement**	increased costs, programme delay	Previous BCC project knowledge around the city identified residual life assumptions.	Review residual life assumptions. During detailed design contractor to assess high risk areas & plan accordingly with construction methods; monitor movement of existing walls during works.	Contractor	50%	M	VL	M	M	M	Investigations (ground, topo services etc) = 5%	1.6	0.8	3.0
22	**Decisions and endorsements**	Programme delays if decisions cannot be made. Failure to adopt strategy or agree preferred options. Risk of public inquiry / planning challenge. Risk of abortive work, increased programme and costs.	Project Board and Project Team structure. Regular progress meetings and engagement. Understanding of political landscape across organisations and feeding into objectives for apprasial of options.	Memorandum of Understanding between BCC and EA	BCC	15%	L	VL	M	M	M	Zero.	1.6	0.24	0.9
23	**Key Stakeholder / Landowner / Occupier/ public Objections**	Potential for objections/disputes/claims leading to delays. If landowners will not support the scheme the preferred alignment may not be possible. Negotiations may be costly and cause delays. Poor public relations. Alternative routes may need to be considered.	Key stakeholder workshops held to gain buy-in and support during Strategy development. BCC are key landowner (majority) and others are known??	Ensure project team continues to keep key stakeholdersupdated with progress and obtain feedback and implement during development to avoid 'surprises' later. Spend time communicating with landowners and public	BCC	35%	M	VL	H	H	H	Compensation = 5% Compulsory Purchase - Totterdown St Phillips = 5%	1.6	0.56	2.1
24	**Environmental (heritage, archaeology, ecology) constraints and required mitigation impact on timing & method of construction**	Sensitivity of site characteristics result in increased scheme cost, programme delay	Environmental reporting for Strategy	Environmental surveys to inform detailed design. Agreed required mitigation at planning application which can then be accommodated in the detailed design & construction programme. Innovative construction techniques or mitigation utilised by contractor	BCC	51%	H	L	M	M	M	Business Case and detailed design = 8% Environmental Mitigation "coastal squeeze" (compensatory habitat) = 1% Environmental Mitigation other = 1%	3.2	1.632	6.0
25	**Lack of understanding of sedimentation / siltation impacts on engineering design.**	Increased maintenance cost (e.g. dredging), potential for detrimental environmental impacts, potential for reduction in amenity value	Previous BCC project knowledge and publicly available reports around the city and the River Avon	Carry out appraisal of existing silt loads to inform sediment modelling. Identify likely sediment impacts and cost interventions	BCC	0%	L	L	M	M	M	Deemed not applicable by BCC.	3.2	0	0.0
26	**Changes to geomorphology**	Changes to erosion / deposition rates and locations possibly leading to detrimental impacts on existing riparian infrastructure (flood defences, highway, railway, properties)	Previous BCC project knowledge and publicly available reports around the city and the River Avon	Carry out geomorphological modelling to assess likely impacts.	BCC	0%	L	VL	VL	VL	L	Deemed not applicable by BCC.	1.6	0	0.0
27	**Changes in material prices (beyond inflation allowance in costings)**	Increased scheme cost	Optimism bias	Seek to bulk purchase with beneficial prices & store locally	BCC	15%	L	L	L	L	L	None	3.2	0.48	1.8
28	**Technology and Other (insufficient modelling (fluvial))**	Additional scheme reqs	None	Review and address additional fluvial modelling during preparation of Outline Business Case	BCC	30%	M	L	L	L	L	Business Case and detailed design = 8%	3.2	0.96	3.5
29	**Tidal Event disruption to construction (>1:10, non-insurable)**	Increased scheme cost and programme	None	Use best available weather and sea forecasting and monitoring updates	BCC	10%	VL	L	M	M	L	Zero.	3.2	0.32	1.2
30	**Legislation / Policy / Guidance Changes**	Changes in legislation could impact on mitigation required during construction	Adopting latest guidance and follow best practice. Range of water levels, reflecting different sea level rise changes, assessed as part of sensitivity analysis and resolution of uncertainty	Identify, monitor and review any guidance changes as soon as they materialise.	BCC	0%	L	VL	M	M	M	Deemed not applicable by BCC	1.6	0	0.0
												Delivery Risk Register agreed at Delivery Risk Workshop, 21/12/16	**£ 89.60**	**£ 27.07**	**100.0**