AECOM

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Hydraulic Modelling Report (Option Phase)

October 2016

Final Report

REVISION SCHEDULE					
Rev	**Date**	**Details**	**Prepared by**	**Reviewed by**	**Approved by**
1	4/8/2016	Draft for client comment	Richard Moore **Senior Assistant Flood Risk Consultant** Mark Davin **Principal Engineer**	Mark Davin **Principal Engineer**	David Dales **Director**
2	14/10/2016	Final - response to draft comments	Richard Moore **Senior Assistant Flood Risk Consultant**	Mark Davin **Principal Engineer** Jon Short **Principal Consultant**	David Dales **Director**

AECOM
The Crescent Centre,
Temple Back,
Bristol,
BS1 6EZ,
United Kingdom

Tel +44 (0) 20 7798 5000

www.aecom.com

Limitations

AECOM Infrastructure & Environment UK Limited ("AECOM") has prepared this Report for the sole use of Bristol City Council ("Client") in accordance with the Agreement under which our services were performed **River Avon Tidal Flood Risk Management Strategy RESP1007626 (23/10/15) and Response to Tender Submission Clarifications (03/11/15) (the "Agreement")**. The report takes into account the particular instructions and requirements of the Client in accordance with the provisions of the Agreement. It is not intended for and cannot be relied upon by any third party. No liability is accepted by AECOM and no responsibility is undertaken to any third party.

Information obtained by AECOM has not been independently verified by AECOM, unless otherwise stated in the Report.

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

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

TABLE OF CONTENTS

LIST OF APPENDICES

Appendix A - Flood Depth Maps

Appendix B - Barrier Impedance Results

GLOSSARY AND ABBREVIATIONS

CAFRA	Bristol Central Area Flood Risk Assessment (Bristol City Council, 2010-2012). CAFRA consisted of four Workstreams undertaken by Hyder and supported by others, described in more detail in this report. In the context of this report, CAFRA is typically used to refer to the 1D-2D (ISIS-TUFLOW) hydraulic model of Bristol that was developed as part of the CAFRA package of works. The CAFRA model is the accepted strategic baseline model for the city centre area and can be used to assess fluvial and tidal risk (and combinations of both).
FCERM	Flood and Coastal Erosion Risk Management. In the context of this report, FCERM relates to the DEFRA guidance for scheme appraisal.
FEH	Flood Estimation Handbook. The UK industry standard methodology used in hydrological analyses for the estimation of design event peak flows and hydrograph shapes.
GiA	Grant in Aid. This is a funding mechanism within the DEFRA guidance for FCERM scheme appraisal.
ISIS	1D Hydraulic modelling software (CH2MHill), now sold as Flood Modeller Pro. ISIS has been used for the 1D (in-channel) component of the CAFRA model.
QMED	The Median Annual Flow of a river, i.e. the flow which is statistically likely to be exceeded, on average, once every two years. An important component of the FEH methods.
TUFLOW	2D Hydraulic modelling software (BMT-WBM). TUFLOW has been used for the 2D (floodplain) component of the CAFRA model and also to represent the storage available in the Floating Harbour. TUFLOW models use a fixed (square) grid of cells but it is possible, as in the case of CAFRA, to have a multi domain model with a number of connected or unconnected 2D domains of differing grid sizes and dimensions.
UKCIP09	UK Climate Impact Predictions, 2009 Used to define the projected sea level rise allowances for climate change in the CAFRA model and TFRMS. UKCIP09 includes sea level rise allowances for a range of different emission scenarios. The TFRMS will be focussed on the Medium 95%ile emissions scenario, as per the DEFRA guidance for FCERM scheme appraisal.

1 INTRODUCTION

1.1 Commission

AECOM Infrastructure & Environment UK Limited (AECOM) was commissioned by Bristol City Council (BCC) to develop a Tidal Flood Risk Management Strategy (TFRMS) (hereafter referred to as 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.

The flood risk in the study area is dominated by tidal events and this is therefore the focus of the study. The development of the Strategy will be underpinned by an appraisal of management options to address present and future tidal flood risk, while also taking fluvial flood risk into consideration.

1.2 Strategy Objectives

The objectives of the TFRMS, 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.

1.3 Study Background

As part of this commission, a hydraulic modelling study of the region was undertaken to define the baseline tidal flood risk. Results from this study were used to understand the risks posed to areas in Bristol and demonstrated the various mechanisms of flooding. The delivery of the economic case was also based on these results, assisting to develop and refine options which have been explored in detail as part of this report.

This report therefore follows on from the Hydraulic Modelling Report: Short Listing Phase (AECOM, 2016) which included:

- Numerical modelling of flood risk for the Do Nothing and Do Minimum options, as well as selected modelling of barrier options. The CAFRA Workstream 3 (WS3) model was modified to represent the Do Nothing (walk away) scenario and a series of model runs were completed to represent different tidal events over three epochs. The model was also modified to represent the Do Minimum (continue with existing defences and maintenance) scenario and simulated for the same tidal events over three epochs.

- Assessment of Do Nothing and Do Minimum flood damages. Flood extents have been mapped and damages have been calculated using the methods mandated by the Environment Agency's procedures for flood and coastal risk management studies.

- Concept designs of measures and assessment of technical feasibility. A range of measures to protect Bristol from flooding have been developed and their feasibility assessed. Measures include Property Level Protection (PLP), variants of a tidal flood barrier and flood walls. In the case of tidal flood barriers this has included initial numerical modelling to test whether the barrier is able to pass fluvial flood flows without causing an increase in flood risk. The tidal barrier aspect is discussed further within this report.

1.4 Modelling Background

As discussed at length within the Hydraulic Modelling Report: Short Listing Phase (AECOM, 2016), the modelling approach incorporated the adoption and updating of the existing BCC CAFRA WS3 hydraulic model. The only exception to this was for the testing of the tidal barrier, where the one-dimensional (1D) ISIS/Flood Modeller Pro model produced as part of WS4 was utilised. For consistency purposes, this approach was taken forward for the preferred option testing with linear flood defences modelled using the WS3 model and testing of barrier scenarios modelled using the WS4 approach.

It should be noted that this report follows on from the hydraulic modelling study discussed in Section 1.3 and therefore aspects regarding the modelling methodology and hydrological approach have not been included. Discussion of these aspects can be found within Section 2 of the Hydraulic Modelling Report: Short listing Phase (AECOM, 2016).

1.5 Study Area

Figure 1 presents the study area alongside the contributing watercourses within the BCC region. The project includes the total area of Bristol at risk of flooding from the River Avon including the City Centre, Cumberland Basin, Netham, Pill and Shirehampton.

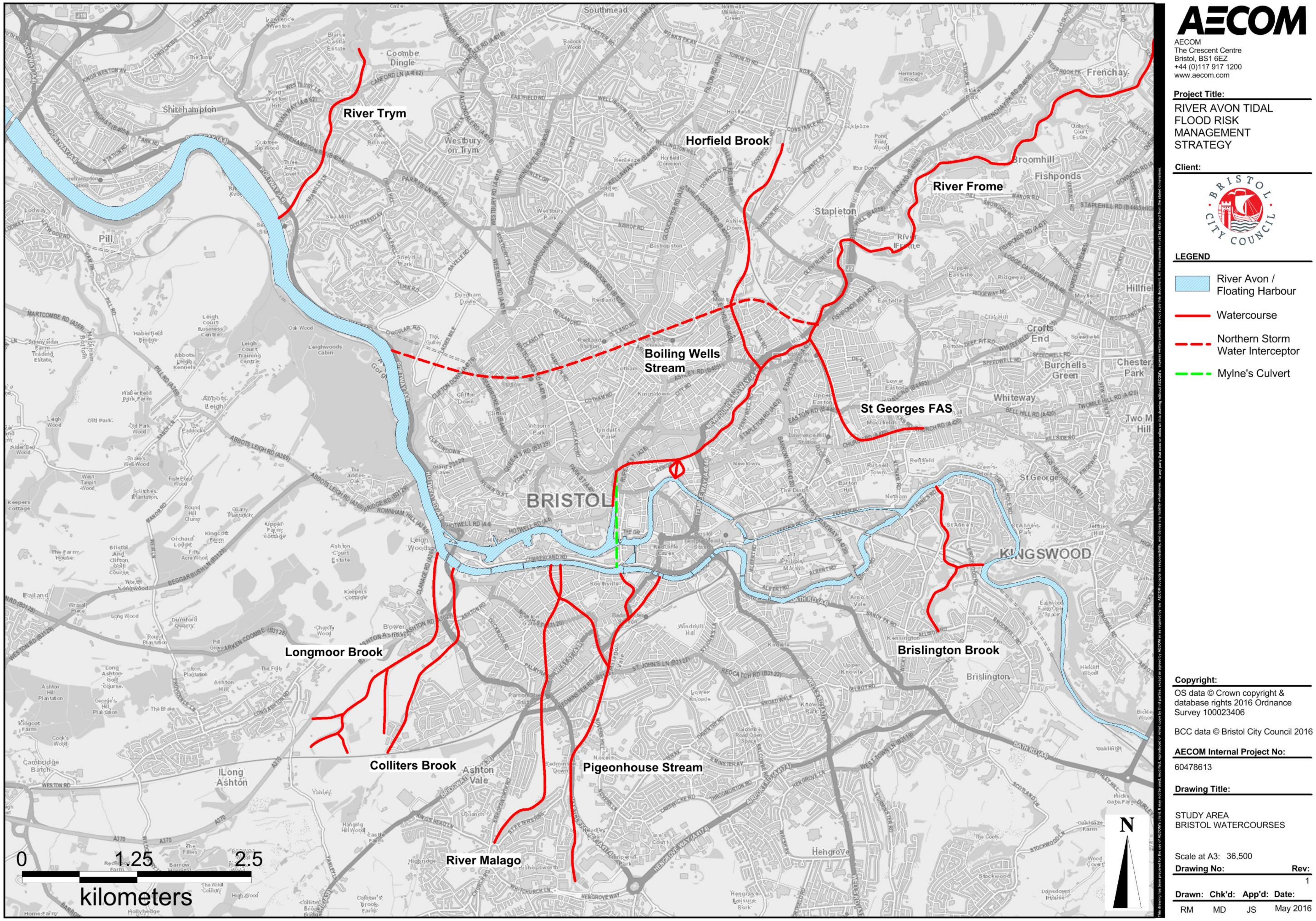


Figure 1: Study Area

2 Flood Risk

2.1 Overview of Tidal Flood Risk in Bristol

As part of the baseline/short listing phase, hydraulic modelling has been undertaken for the Do Nothing scenario and Do Minimum scenarios using CAFRA's WS3 approach. The results from this modelling have provided an indication of current flood risk and how risk is expected to evolve over time with respect to climate change predictions.

An overview of the tidal flood risk in the Strategy area is provided in the Hydraulic Modelling Report: Short Listing Report (AECOM, 2016). Within this report, it was identified that low spots along the banks of the River Avon, notably at Avon Crescent, Junction Lock and Bathurst Basin are the first pathways for flood water which leads to the inundation of a significant number of properties in central Bristol. Other areas, such as Baltic Wharf are also at risk as water levels rise within the Floating Harbour and overtop low spots along the defences. Under present day conditions (no allowance for climate change) a number of low lying areas at St. Phillips Marsh, Cumberland Basin and Netham are at risk of flooding. The flood risk is expected to increase in the future due to predictions related to climate change which include higher extreme tide water levels.

2.2 Do Nothing

The Do Nothing scenario represents a hypothetical baseline against which all other measures and strategic options can be compared. The Do Nothing approach assumes all maintenance, repair and renewal work on existing flood defences, together with assets whose function influences flood risk throughout the study area would cease immediately. There would be no investment in asset maintenance from the present day onwards. If this approach were adopted, existing flood defences would deteriorate and any damage would not be repaired. It is assumed that all water level management assets, including lock gates and stop gates, would fail and remain in an open position throughout the duration of the appraisal period.

As sea levels rise and the defence deteriorates, flood risk would increase significantly from failure of defences and through inundation over the low-lying topography. Many of the existing residential and commercial assets would be written off with a potential abandonment of much of the centre of Bristol.

Eventually many of the existing residential and commercial assets within Bristol would be written off. Economic prosperity, opportunities for growth and community viability in Bristol would significantly decrease, and therefore a Do Nothing approach would be unacceptable. Doing Nothing would likely result in the escalation of uncertainty and this, with the loss of investor confidence, and lack of policy or infrastructure solution would result in the whole city and environs being prejudiced, and investment blocked or withdrawn

The Do Nothing approach is therefore not considered a feasible approach to flood risk management and is not incorporated into future management strategies.

2.3 Do Minimum

The Do Minimum scenario represents what would likely happen if the current investment approach was continued, maintaining existing flood defence structures for the duration of the Strategy (2015-2115). This scenario does not consider an improvement in performance of existing structures over time, nor does it consider maintenance which would result in an increase in the existing standard of protection.

It is assumed that under this scenario the functioning of the Floating Harbour water level control structures will be sustained until 2115, and maintenance will include improving the resilience of MEICA control systems and electrical systems to flooding. It is also assumed that like-for-like replacement of mechanical infrastructure e.g. lock gates would be undertaken but with no improvements in performance to account for sea level rise. The raised defences within the city and at Avonmouth (including Pill and Shirehampton) would be maintained to ensure their flood defence function continues; however, the defences would not be raised and consequently the standard of flood protection would be expected to fall over time in response to sea level rise. The Do Minimum approach is considered a feasible approach to managing tidal flood risk and has therefore been incorporated into future management strategies.

3 OPTION APPRAISAL

3.1 Option Objectives

The Option Objectives provide a means of considering multiple factors for each option to achieve a balanced Strategy and outcome. However, it is recognised that the principal aim for the Strategy is to reduce flood risk and the restrictions it may bring to future development. The Option Objectives are as follows:

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

3.2 Strategy Epochs

To facilitate the development of the Strategy and appraisal of options, the 100 year appraisal period (2015 – 2115) was split into three time epochs:

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

By developing management options in accordance with these time epochs it will allow for an adaptive approach to management to be developed that keeps pace with climate change and potential sea level rise. In addition, the approach has sufficient flexibility to address uncertainty, thereby ensuring the most appropriate strategic choices are taken now and at key points in the future.

As the Strategy is implemented in phases, to help inform the best time to implement the recommended management interventions, various risk 'thresholds' and 'tipping points' will be outlined. For instance, the Strategy may initially recommend that a scheme is implemented at the start of Epoch 2, but, if sea level rise occurs more slowly than expected and the exceedance of the risk threshold does not occur, the scheme could be delayed until a later stage.

3.3 Short List Options

In total, seven strategic options were identified from a long list of thirty-nine strategic options. More detail on how the seven short list options were selected and which assumptions made when developing the strategic options, is given in the Short List Options Report (AECOM, 2016).

For each strategic option, a 'measure' was assigned to each time epoch, so for instance one of the strategic options suggests Property Level Protection (PLP) in the short term (2015-

2030), implementing Low Defences in the medium term (2030-2065) and then raising these defences to High Defences in the long term (2065-2115). For the purpose of the appraisal, it has been assumed that the measure for each time epoch will be constructed / implemented at the start of each time epoch.

The measures from which the strategic options were developed included:

- Do Minimum
- Property Level Protection (PLP) / temporary defences
- Low Defences
- High Defences
- Tidal Barrier

To inform the selection of a preferred option, the measures have been developed in more detail. More detailed alignments, indicative cross sections and estimated heights of low and high defences from ground level (based modelling results) have been produced which have been used within the modelling approach discussed below. For the Tidal Barrier, the gating arrangement has been reviewed and the type of gate has been confirmed. Consideration has been given to the extent and type of ancillary structures such as compounds and navigational aids.

In terms of modelling, no additional model simulations were required for the Do Minimum option or for the PLP Zones. However, further simulations were undertaken which assessed the detailed alignments associated with the proposed ‘Low’ and ‘High’ Defences, along with the Tidal Barrier configuration. These are discussed in more detail within Section 4.

4 OVERVIEW OF MODELLED MEASURES

This chapter provides an overview of the various measures that form the short-listed options, all of which have been modelled to help inform selection of the preferred option. The measures include low defences, high defences and a Tidal Barrier.

4.1 Low Defences

The low defence measure comprises linear defences (walls and embankments) to provide a high standard of protection, but for a limited time only. After this, the defence would be raised further or an alternative measure implemented. Low defences represent an adaptive solution to manage tidal flood risk and sea level rise.

The implementation of low defences involves identifying low spots or gaps in the existing defences and then raising the existing defence levels, constructing new flood walls or similar defences (e.g. embankments) in these locations. For the purpose of modelling new flood defences, detailed levels were provided for Pill, Shirehampton, Entrance Lock, Cumberland Road, Commercial Road, Clarence Road, Cattle Market Road, Totterdown/St.Phillips, Netham and Bath Road, as shown in Figure 2. As part of the low defence measures, new tidal stop gates and supporting infrastructure will also be required at Entrance Lock and Netham Lock.

Table 1 and Table 2 provide information regarding defence location and heights associated with the ‘low’ defences for 2015 and 2030 respectively. These include respective tide levels for the 1 in 200 and 1 in 1000 year events; defence location and defence crest height.

Table 1: Low Defences (2015)

1 in 200 Year Tide Level (m AOD) (Medium Emissions 95%ile SLR) 2015	1 in 1000 Year Tide Level (m AOD) (Medium Emissions 95%ile SLR) 2015	Location	Design crest level (including 0.15m freeboard) (m AOD)
9.13	9.45	Entrance Lock	9.47
		Cumberland Road	9.47
		Cumberland Road East	9.47
		Commercial Road	9.49
		Clarence Road	9.49
		Cattle Market Road	9.52
		Totterdown	9.54
		Netham	9.57
		Bath Road	9.54

Due to the 1D setup rather than 2D representation at Pill and Shirehampton, the WS3 model does not accurately represent raised defences in this area and therefore these defences could not be updated within the model without significant update and calibration of the existing model. The ‘manual’ approach used within the initial modelling phase (Section 2.4.2 of the Hydraulic Modelling Report: Short Listing Phase (AECOM, 2016)) has therefore been adopted for these locations.

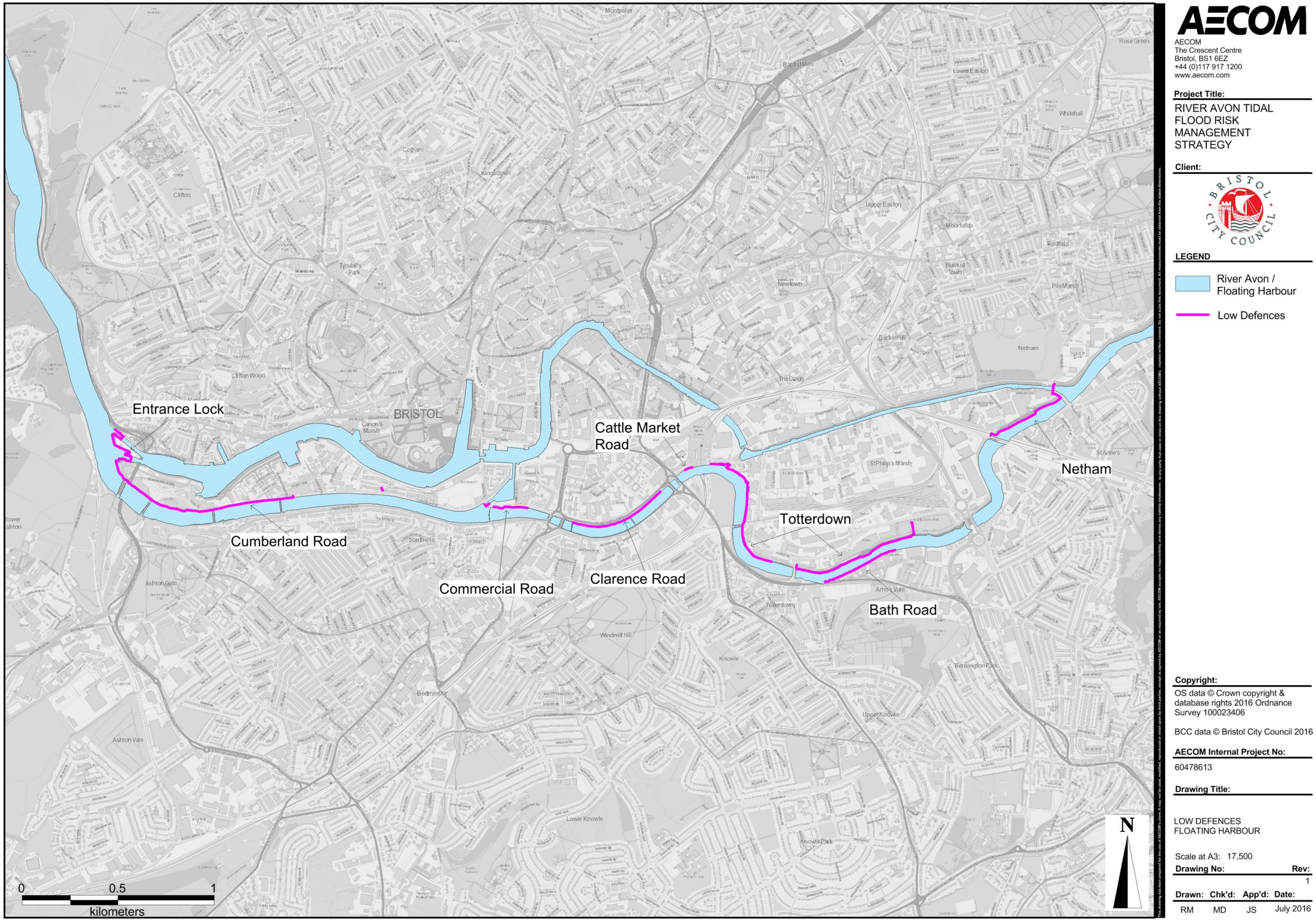


Figure 2: Floating Harbour Low Defence Alignments

Table 2: Low Defences (2030)

1 in 200 Year Tide Level (m AOD) (Medium Emissions 95%ile SLR) 2030	1 in 1000 Year Tide Level (m AOD) (Medium Emissions 95%ile SLR) 2030	Location	Design crest level (including 0.15m freeboard) (m AOD)
9.21	9.53	Entrance Lock	9.50
		Cumberland Road	9.50
		Cumberland Road East	9.50
		Commercial Road	9.51
		Clarence Road	9.51
		Cattle Market Road	9.54
		Totterdown	9.56
		Netham	9.61
		Bath Road	9.56

Following the modelling of the low defences (as detailed in Table 1 and Table 2), a direct comparison was made with the Do Minimum results to see how flood extents and associated flood levels had changed. The Do Minimum results showed that much of the flooding was caused by high water levels in the Floating Harbour which is shown to be a result of overland flow spilling out of the River Avon and overflowing defences, leading directly into the Floating Harbour by overflowing locks/defences at the entrances at upstream (Entrance Gate Lock) and downstream (Netham) locations. This was investigated in more detail as part of the baseline modelling which led to the design and placement of the low defence walls (Figure 2).

In order to understand the impact to individual properties, a high level property assessment has been carried out. A spreadsheet of all buildings/properties was provided by BCC which was used to create a point file representing each individual property and this was used to undertake a 'point inspection' using the survey data in conjunction with modelling results.

The results from the **1 in 200 year tidal event combined with a 2 year fluvial event for the 2015 defended scenario** show that the area adjacent to the Floating Harbour is no longer inundated (Figure 1A, Appendix A). The defences along the River Avon prevent any overtopping and therefore floodwater is unable to propagate into the Floating Harbour as occurs during the Do Minimum scenario. There is however an increase in flood depths in Bower Ashton where depths increase by approximately 0.10m. With water no longer able to overtop the right bank of the River Avon into the Floating Harbour, more water overtops the left bank which causes increased flood depths within Bower Ashton. According to the property assessment there are a total of 12 properties inundated during the Do Minimum scenario, which increases by one to 13 properties during the 2015 low wall defended scenario. None of these properties are residential. Furthermore, tide-locking could potentially be an issue which exacerbates fluvial flooding in this area.

There is also an area near St Philips Marsh (Sparke Evans Park – adjacent to Albert Road) where flood depths increase during the defended scenario by approximately 0.13m. With no residential or commercial properties located within this area, defences have been designed to allow this area to flood during high tidal events. This area of the Floating Harbour has therefore not been considered further within this report.

The results from the **1 in 1000 year tidal event combined with a 12 year fluvial event for the 2015 defended scenario** show that during the third tidal cycle the low defences are not overtopped, however this causes more water to overtop the left bank near Bower Ashton (Figure 1E, Appendix A). During the fourth tidal cycle i.e. the peak of the simulation, water overtops all defences along the River Avon, causing inundation of the Floating Harbour. When compared with the Do Minimum figures, the flood extent is significantly reduced within Totterdown, Netham and central areas.

The results from the **1 in 200 year tidal event combined with a 2 year fluvial event for the 2030 defended scenario** are similar to the 2015 defended scenario (Figure 1C, Appendix A). No flooding is experienced in the area surrounding the Floating Harbour, however flood depths have increased within the Bower Ashton to an equivalent depth as the 2015 defended scenario. 13 properties become inundated during the Do Minimum scenario, which remains unchanged during the 2030 low wall defended scenario.

During the 1 in 1000 year event which is combined with a 12 year fluvial event for the 2030 defended scenario, flooding is very similar to the 2015 scenario (Figure 1F, Appendix A). The defences are overtopped during the peak of the tidal cycles causing area of the Floating Harbour to become inundated. However, when compared with the Do Minimum scenario, the flood extents are significantly reduced.

4.2 High Defences

The high defence measures comprise linear defences (walls and embankments) to provide a high standard of protection in a single implementation phase. Similar to the low defence approach, the implementation of the high defences involves identifying the low spots or gaps in the existing defences and then raising the crest levels or constructing new floodwalls or similar defence in these locations.

The design standard of protection for the high defences is a 1 in 200 year standard for 2115 and therefore the high defences represent a precautionary approach and would provide long term protection from tidal flood risk by considering sea level rise and climate change projections until 2115. Being a precautionary measure, high defences could be constructed in epoch 1, 2 or 3. Irrespective of the timing, the protection afforded by the defences shall be for the 1 in 200 year return period in 2115 (the duration of the strategy period).

For the purpose of modelling new flood defences, alignments were provided in similar locations to the low defences (Table 3). This includes include Pill, Shirehampton, Entrance Lock, Cumberland Road, Commercial Road, Clarence Road, Cattle Market Road, Totterdown / St. Phillips, Netham and Bath Road, as shown in Figure 3. Stop gates and operational infrastructure at Entrance Lock and Netham Lock would also be required.

Table 3: High Defences (2115)

1 in 200 Year Tide Level (m AOD) (Medium Emissions 95%ile SLR) 2115	1 in 1000 Year Tide Level (m AOD) (Medium Emissions 95%ile SLR) 2115	Location	Design crest level (including 0.15m freeboard) (m ODN)
9.87	10.19	Entrance Lock	10.15
		Cumberland Road	10.15
		Cumberland Road East	10.15
		Commercial Road	10.15
		Clarence Road	10.15
		Cattle Market Road	10.20
		Totterdown	10.20
		Netham	10.25
		Bath Road	10.20

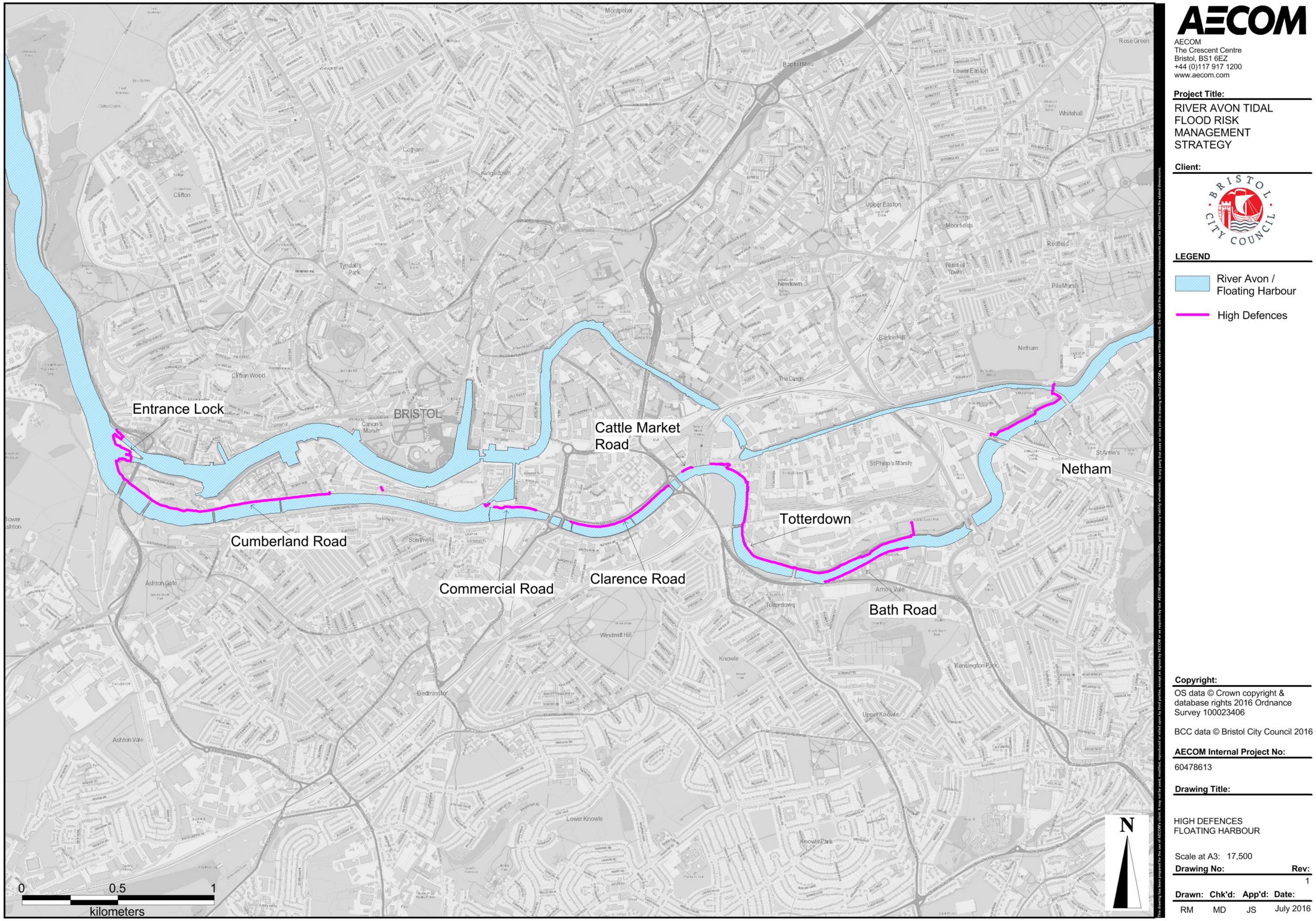


Figure 3: Floating Harbour High Defence Alignments

To assess the impacts of the high walls, a range of scenarios (shown below) were simulated. For the fluvial events both a defended and undefended scenario was simulated allowing for a direct comparison. This included 1 in 1000 year return period as the extreme exceedance event.

- 1 in 200 year tidal event combined with a 1 in 2 year fluvial event (2015);
- 1 in 200 year tidal event combined with a 1 in 2 year fluvial event (2115);
- 1 in 1000 year tidal event combined with a 1 in 12 year fluvial event (2115)
- 1 in 200 fluvial event combined with a base tide (2015);
- 1 in 200 fluvial event combined with a base tide (2030);
- 1 in 200 fluvial event combined with a base tide (2065);
- 1 in 200 fluvial event combined with a base tide (2115);

Tidal Events

1 in 200 year tidal event combined with a 1 in 2 year fluvial event (2015) – Results from this scenario have shown that with the high walls in place, no overtopping of the River Avon occurs and therefore the area surrounding the Floating Harbour no longer becomes inundated by floodwater (Figure 2A, Appendix A). The only exception to this is at the downstream end of the study area where the left bank of the River Avon overtops near Brunel Way (A3029) inundating an area in Bower Ashton (similar to the low defence scenarios). Although this area is inundated during the Do Minimum scenario, depths increase by approximately 0.10m when flood defences are installed along the River Avon. It is likely that as water can no longer overtop the right bank due to the development of the flood defence walls, more water overtops the left bank causing the increase in flood depths. As discussed above, there are a total of 12 properties inundated during the Do Minimum scenario, which increases by one to 13 properties during the 2015 defended scenario. From a review of the area no residential properties fall within the flood extents, however there are a number of commercial units.

1 in 200 year tidal event combined with a 1 in 2 year fluvial event (2115) – Results from this scenario have shown similar increases in flood depths as described in the 2015 scenario. There is a significant reduction of overtopping within the Floating Harbour area, however there is an increase in flood depths at Bower Ashton, Ashton and Netham (Figure 2C, Appendix A). These are shown in detail within Figure 4 - 9.

With Ashton and Bower Ashton (Figures 4 - 7) water appears to overtop the left bank of the Avon near Brunel Way (A3029), before propagating south. During the Do Minimum scenario overtopping and flooding occurs in a similar way, however due to the introduction of flood walls along the right bank, more water overtops the left bank which causes an increase in flood depths. At Bower Ashton the general increase in flood depth is approximately 0.22m. The only exception to this is at the University Campus, where the area becomes inundated during the defended scenario with depths of up to approximately 0.30m to 0.60m. In Ashton flood depths generally increase by up to 0.16m. Again the exception to this is at Hendre Road where inundation of floodwater occurs during the defended scenario causing flood depths of approximately 0.30m to 0.60m.

The property assessment has shown that during the Do Minimum 1 in 200 year tidal event combined with a 1 in 2 year fluvial event (2115) there are a total of 81 properties which are inundated, 21 of which are residential (Table 4). When the high wall defences are implemented, the amount of properties that are inundated by floodwater increases to 206. Out of these, 115 are residential with the majority located along Hendre Road, Duckmoor Road, Banwell Road and Smyth Road.

At Netham there is an increase in flood depths (up to 0.28m) in the area where Brislington Brook discharges into the River Avon (Figure 8 - 9). Similar to the issues in Ashton and Bower Ashton, flood defences have been introduced along the right bank of the River Avon near Netham Lock and as a result water is overtopping in other low, undefended areas. Further to this, with increased levels within the River Avon, it is possible that tide-locking presents an issue which is exacerbating flood risk in this area.

To provide additional benefit, water level difference figures have also been produced for each key location which provides a comparison between the Do Minimum scenario and the 'defended' scenario.

The property assessment has revealed that during the Do Minimum 1 in 200 year tidal event combined with a 1 in 2 year fluvial event (2115) there are a total of 39 properties which are inundated, 18 of which are residential dwellings (Table 4). When the high defences are implemented, the amount of properties that are inundated by floodwater increases to 94. Out of these, 54 are residential with the majority located around Burgess Green Close.

Table 4: Number of properties inundated by floodwater during different scenarios

Location	Do Minimum (T200F002, 2015) No. of Properties	Defended (T200F002, 2015) No. of Properties	Difference (m)	Do Minimum (T200F002, 2030) No. of Properties	Defended (T200F002, 2030) No. of Properties	Difference (m)	Do Minimum (T200F002, 2115) No. of Properties	Defended (T200F002, 2115) No. of Properties	Difference (m)
Bower Ashton Only	12 (0)	13 (0)	+1 (0)	-	-	-	-	-	-
Bower Ashton + Ashton	-	-	-	54 (12)	54 (12)	0 (0)	81 (15)	206 (115)	+125 (+100)
Netham	-	-	-	-	-	-	39 (18)	94 (54)	+55 (+36)

Numbers in brackets indicates number of residential dwellings that are inundated.

With significant increases in affected properties during some of the defended scenarios, especially the 1 in 200 year tidal event combined with the 2 year fluvial event 2115, it is likely that additional mitigation will be required within the areas of Ashton and Netham. Measures such as localised flood walls and/or PLP could be implemented to combat the effect of flooding within these areas. It should be noted that this has not been investigated as part of this project due to the multi-source nature of flooding, however it is recommended that these areas are investigated as part of future studies.

1 in 1000 year tidal event combined with a 1 in 12 year fluvial event (2115) – results from this scenario show that all high defences are overtopped during the peak of the tidal cycle. When compared with the Do Minimum scenario, the flood extent and associated depths are much less which shows that the Floating Harbour benefits significantly from high defences during this extreme exceedance event.

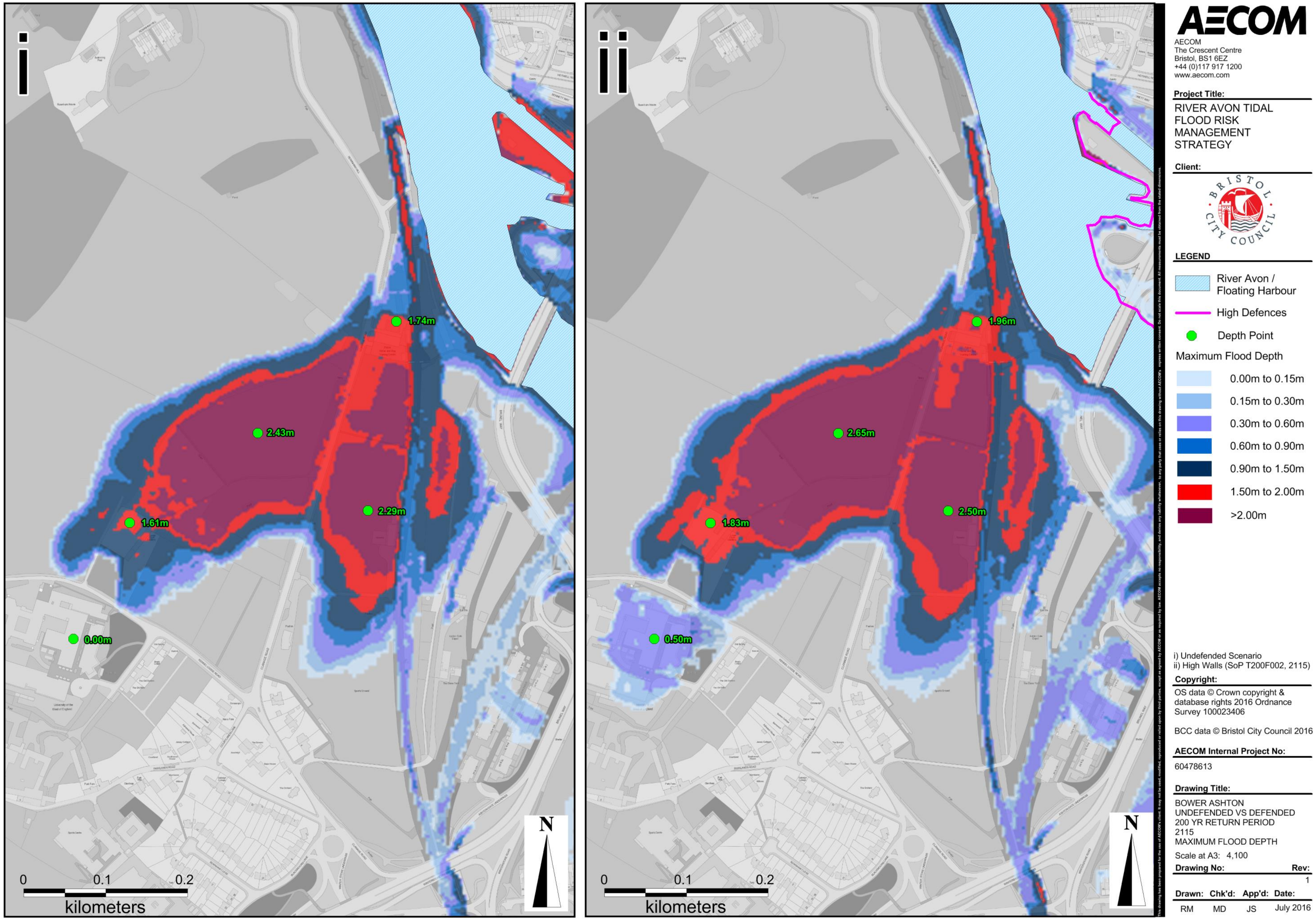


Figure 4: Bower Ashton Flood Depth Comparison (200 year tidal return period, 2115)

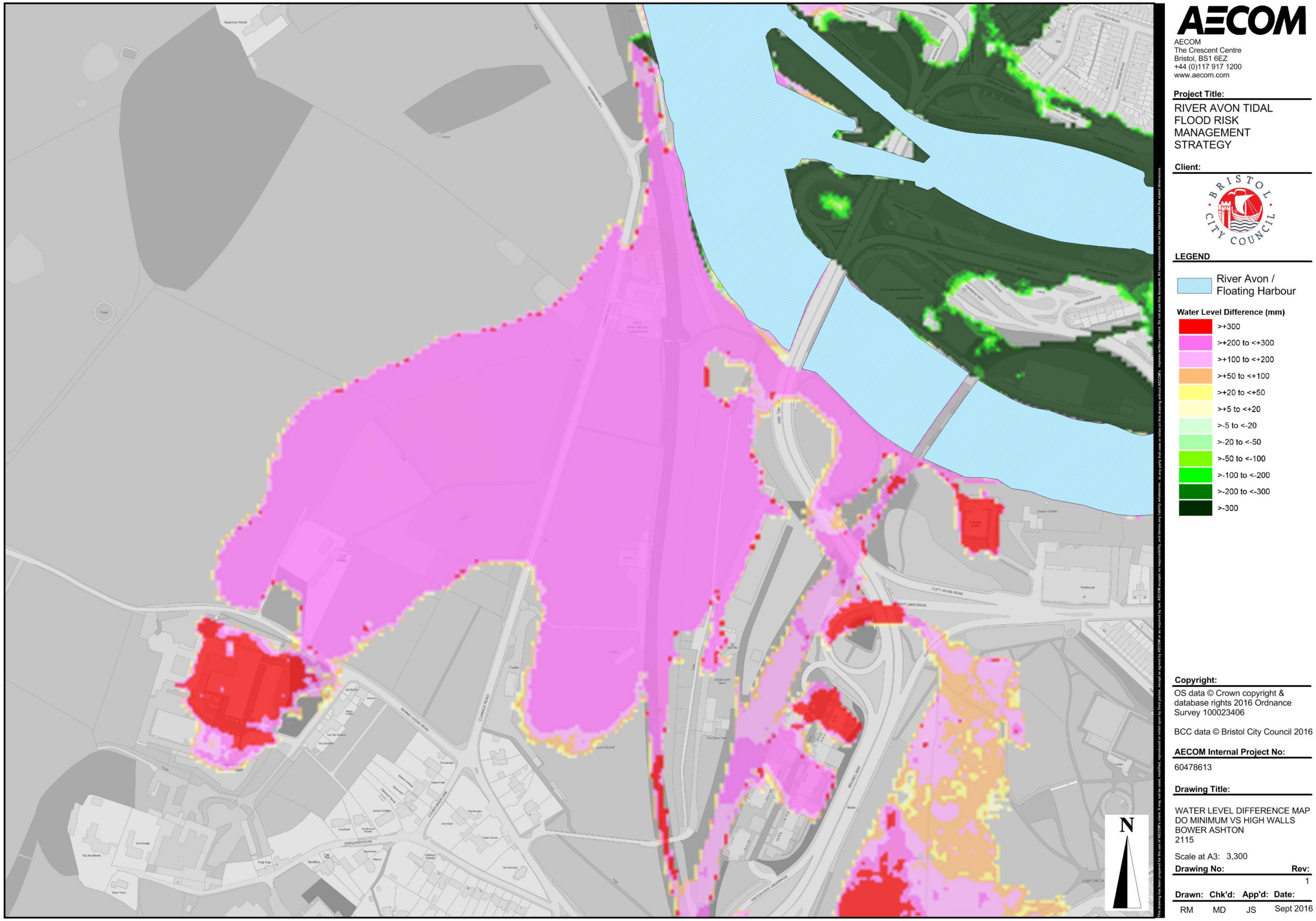


Figure 5: Bower Ashton Water Level Difference Map (200 year tidal return period, 2115)

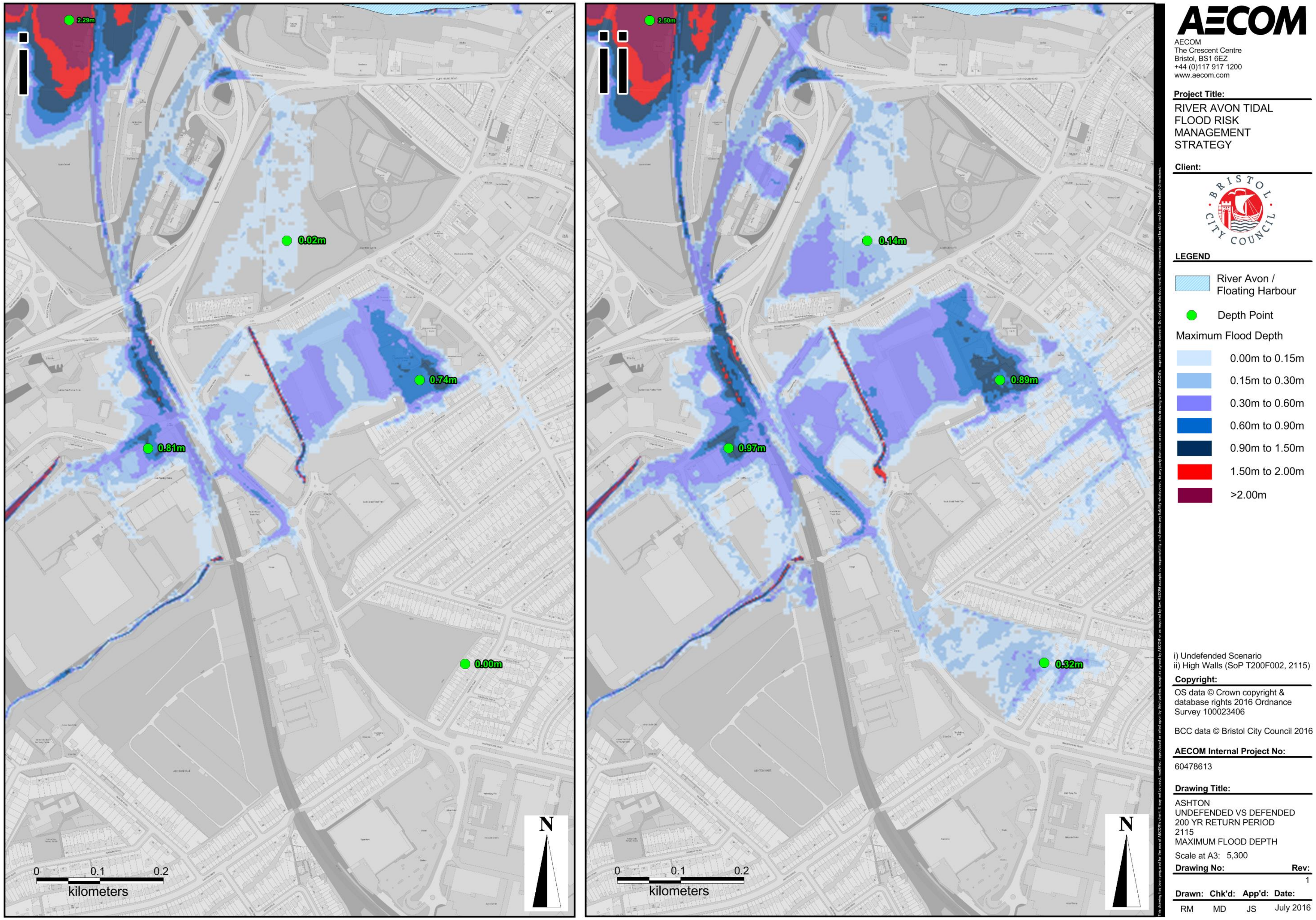


Figure 6: Ashton Flood Depth Comparison (200 year tidal return period, 2115)

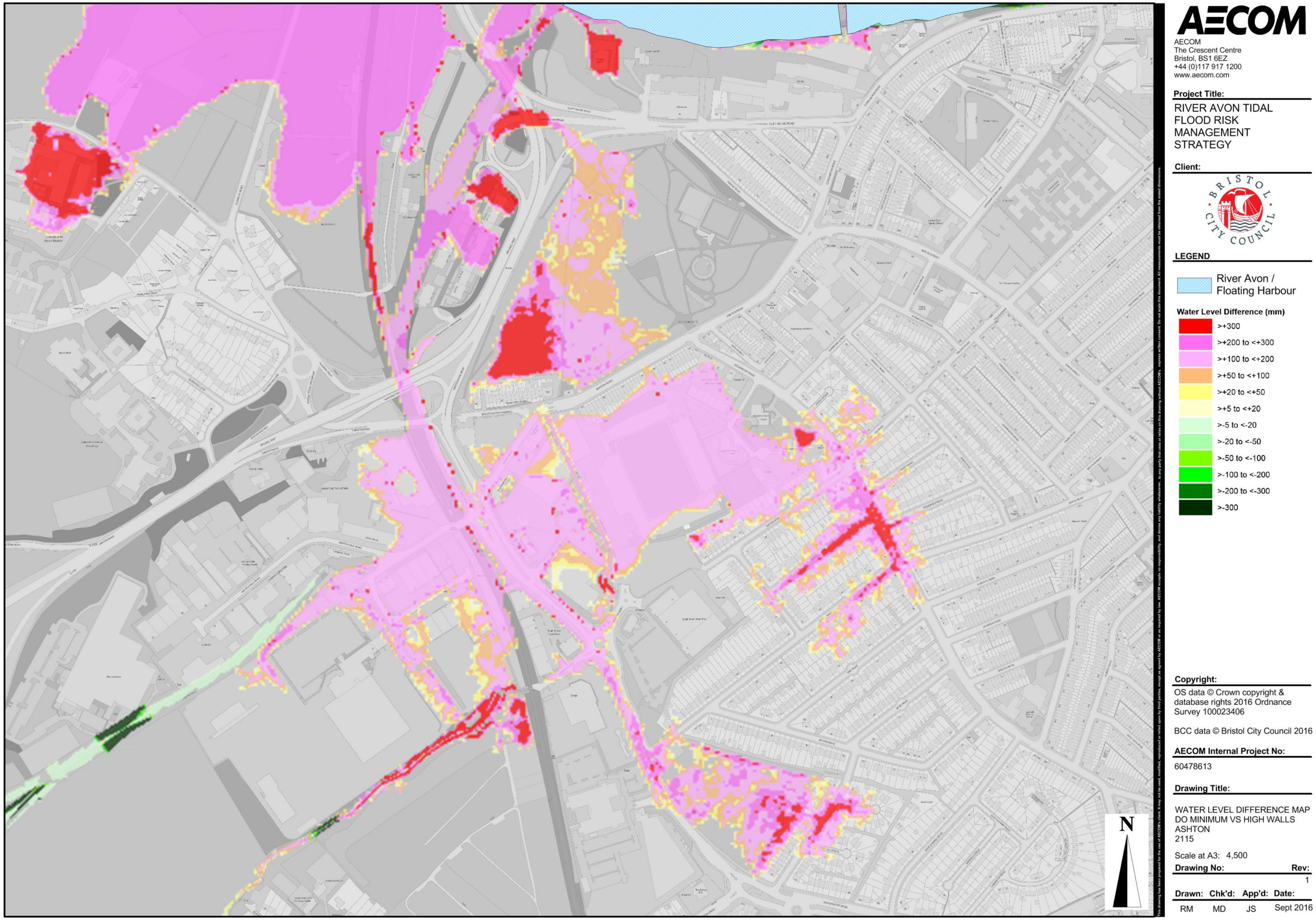


Figure 7: Ashton Water Level Difference Map (200 year tidal return period, 2115)

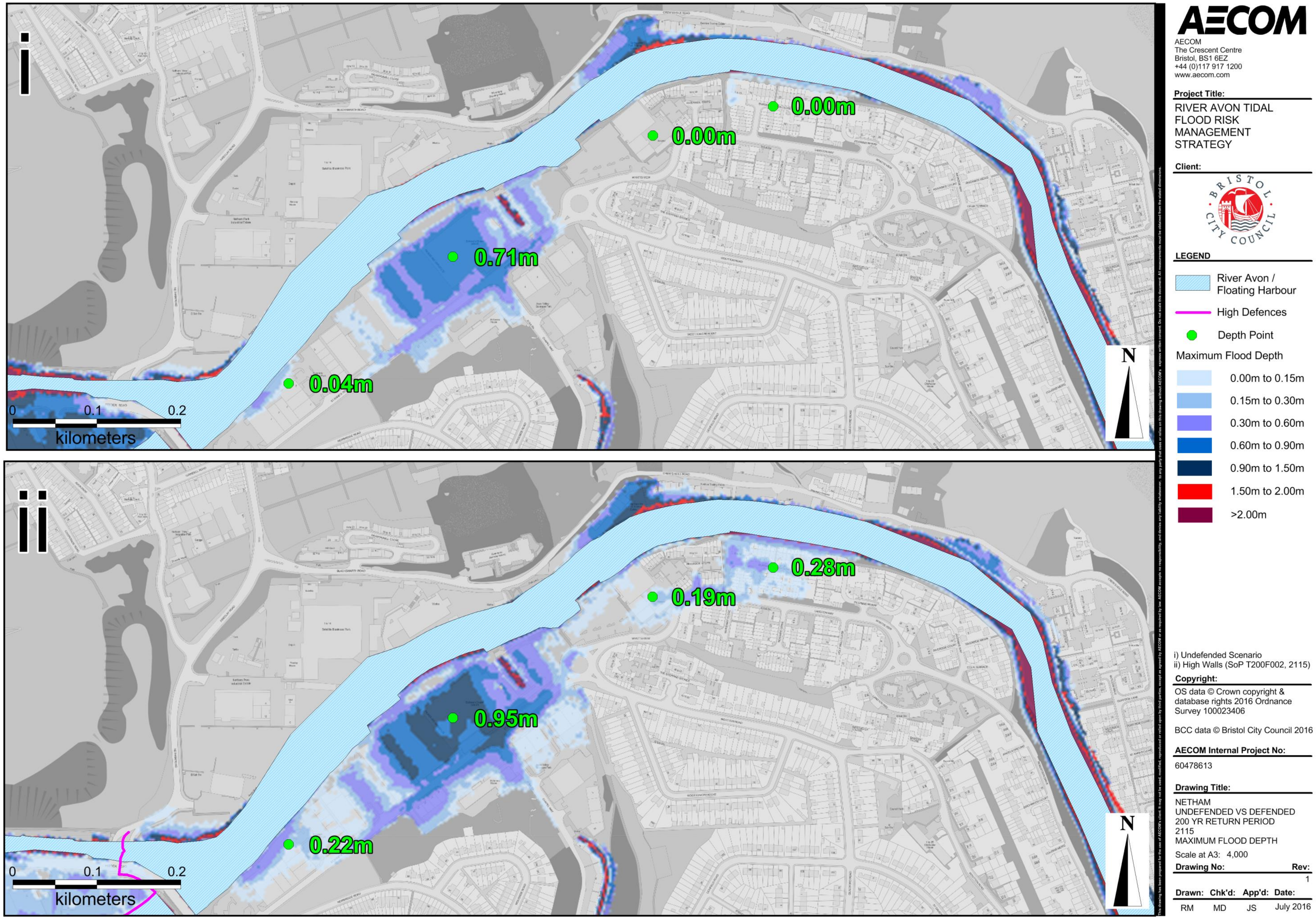


Figure 8: Netham Flood Depth Comparison (200 year tidal return period)

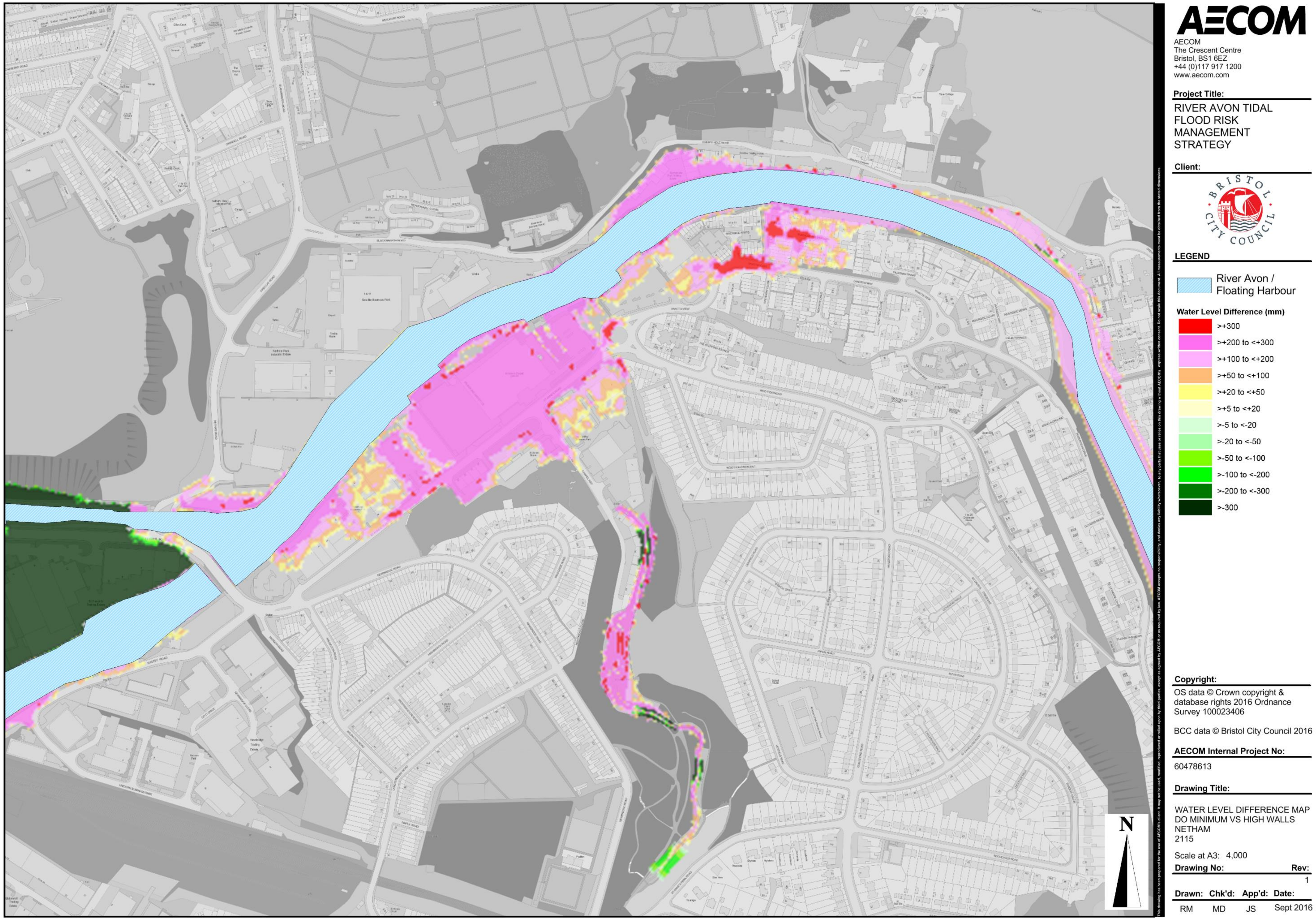


Figure 9: Netham Water Level Difference Map (200 year tidal return period)

Fluvial Events

To compare results for the fluvial events, Table 5 has been created showing changes in flood depths for key locations within the study area (based on a 200 year fluvial event). The keys areas identified include Upper Easton (Newfoundland Way), Lower Easton (M32 Underpass) and Netham. Flood depth figures and water level difference maps showing flood extent comparisons (defended vs undefended) are located within Appendix A (Figures 3A–3H).

For Easton, there is a marginal increase in flood depths (0.01m-0.02m) for the 2015 epoch, however flood depths generally decrease for the higher epochs. For Netham, there is a significant increase in flood depths during the 2065 epoch and 2115 epoch when flood walls are introduced. During the 2065 epoch there are areas within Netham (in the location where Brislington Brook discharges to the River Avon) which were not initially at risk of flooding, that are now considered at risk. During the 2115 epoch flood depths have increased in areas of residential/commercial use by up to 0.24m.

As for the areas adjacent to the Floating Harbour, comparison of flood extents have shown that although the flood walls have not completely removed flooding, it is not made any worse, and if anything, there is a significant reduction in both flood extents and depths. Water levels are raised within the Floating Harbour due to discharge from the River Frome, however the extents are reduced along the Frome corridor due to additional storage provided by the Floating Harbour under the defended scenario. However, as the River Frome is conveyed to the Floating Harbour via a culvert, the entrance to this culvert remains surcharged during high fluvial events which results in the areas of inundation along this pathway. This is shown in Figure 10, which compares the defended vs undefended scenario based on 1 in 200 year fluvial flood event for 2115.

It should be noted that having modelled fluvial impacts under high walls, it is understood that low walls detriment (2015, 2030) will be no worse i.e. will be the same. It should also be stated here that should the low wall option be retained to 2115, the detriment in the Ashton and Netham regions highlighted within this document will be less than the high walls solution. As a result it is considered that there is no additional merit in further fluvial modelling at this stage. Further investigation and discussion of detriment from walls will be included under the next phase when the preferred option is optimised.

Table 5: Maximum Flood Depths at Easton and Netham

Location	Flood Depths - Undefended (2015) (m)	Flood Depths - Defended (2015) (m)	Difference (m)	Flood Depths - Undefended (2030) (m)	Flood Depths - Defended (2030) (m)	Difference (m)	Flood Depths - Undefended (2065) (m)	Flood Depths - Defended (2065) (m)	Difference (m)	Flood Depths - Undefended (2115) (m)	Flood Depths - Defended (2115) (m)	Difference (m)
Newfoundland Way (Upper Easton)	0.38	0.39	+0.01	0.56	0.56	0.00	0.83	0.77	-0.06	1.08	0.98	-0.10
M32 Underpass (Lower Easton)	0.37	0.39	+0.02	0.62	0.65	0.00	0.80	0.80	0.00	0.83	0.83	0.00
Netham (1)*	-	-	-	-	-	-	-	0.16	+0.16	0.22	0.46	+0.24
Netham (2)*	0.85m	0.85m	0.00m	0.88	0.88	0.00	0.90	0.99	+0.09	1.06	1.28	+0.22
Netham (3)*	-	-	-	-	-	-	-	0.35	+0.35	0.42	0.61	+0.19
Netham (4)*	-	-	-	-	-	-	0.17	0.44	+0.27	0.52	0.72	+0.20

*see Figure 8 for locations of data extraction points

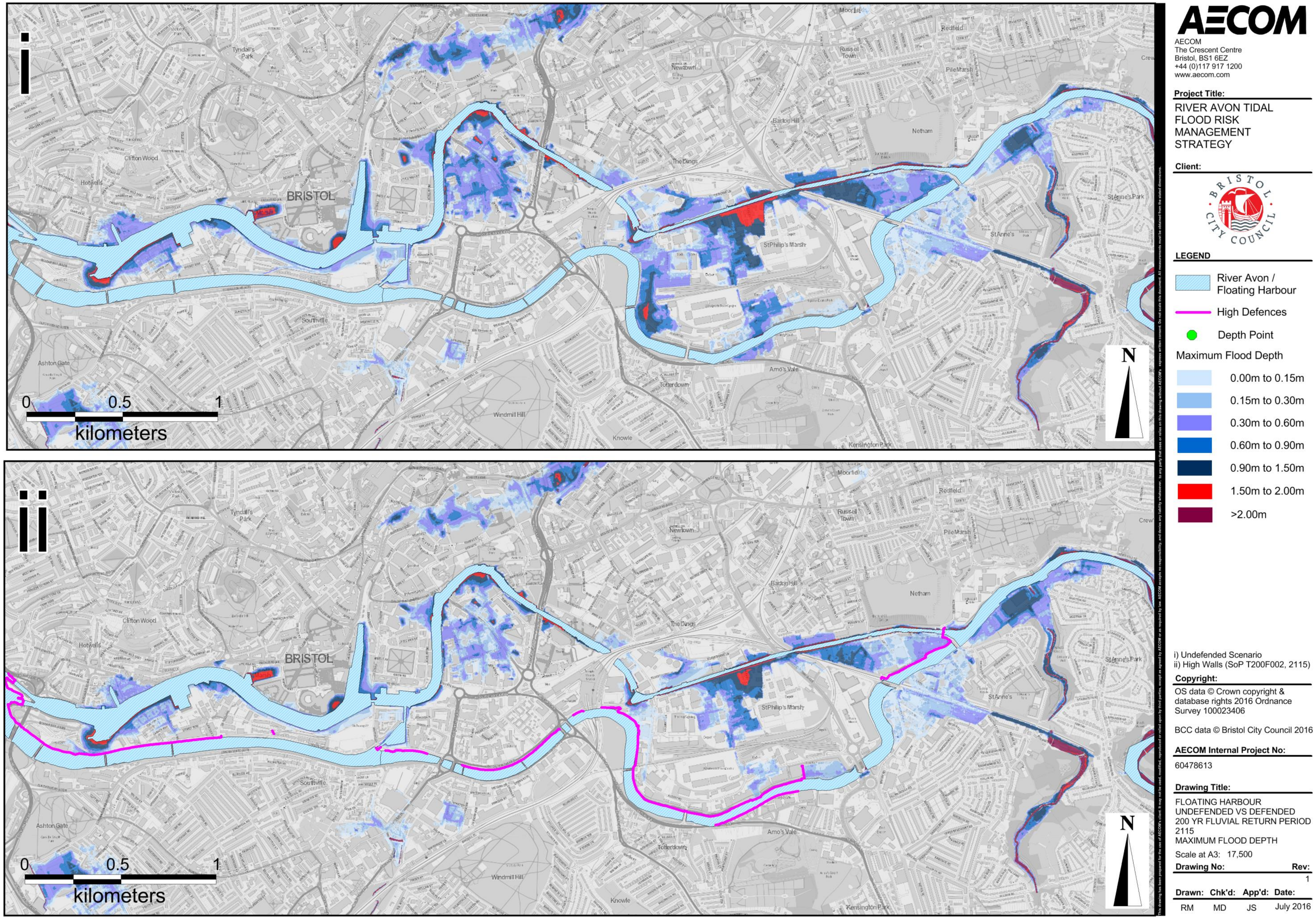


Figure 10: Floating Harbour Flood Depth Comparison (200 year fluvial return period)

4.3 Flood Barrier – Fluvial Storage Assessment

The tidal flood barrier would operate to exclude the highest surge or astronomical tides which otherwise could cause flooding in the city centre. For most of time the barrier gates would be in the open position, allowing largely unimpeded tidal and fluvial flow to propagate within the River Avon as existing.

The proposed barrier location is across the River Avon between the amenity grassland area adjacent to Nibley Road, Shirehampton and the river bank immediately downstream of the Chapel Pill confluence at Ham Green – a so-called 'Narrow' barrier location, to distinguish it from the much wider barrier configuration that would be required downstream.

This location was chosen as it sits within a straight reach of the river, a requirement for navigational safety, provides close to the maximum fluvial flood storage capacity while still being considered as "Narrow", and has sufficient space for the barrier land-side facilities and potential for the required access routes.

It should be noted that this location is indicative at this stage of Strategy development and, if the preferred option includes a barrier, alternative locations between Cumberland Basin and Nibley Road – Ham Green would need to be investigated to identify the optimum position.

To stay consistent with the approach used within the modelling during the shortlisting phase, the WS4 1D model was used to assess the impact of the barrier through consideration of peak water levels, based on different control operations of the barrier.

The hydrology approach included a combination of WS3 and WS4 approaches to confirm the most conservative consideration with regards to volumetric inflows and timing of event peaks. It was determined to use the WS3 hydrology (ReFH) to represent the fluvial hydrology for tributaries to the Avon (such as Frenchay) as this allows the timing of all fluvial peaks to coincide at the same time, thereby providing conservative worst case for testing fluvial storage capacity/barrier impacts. As the peak discharge values and volumetrics of the hydrographs for the tributaries are very similar during the period of closure of the tested barrier, it has been considered as appropriate for the representation and required testing at a strategic level. The primary fluvial flows to the upstream location on the Avon (coming from Bath) remain the same as per the WS4 hydrology.

As a result of the combined hydrology, there is now very little volumetric or phasing difference. This approach is therefore considered to sufficiently demonstrate proportionate representation of hydrology for the desired purpose within a strategic study.

Since the short listing phase of the strategy, the barrier concept has been developed further taking into consideration information generated at a second barrier workshop help between AECOM, BCC, the Environment Agency and BCC's barrier advisor. The issues/changes arising were:

- Rising sector gates similar to those used at the Thames Barrier were confirmed as the preferred approach. This type of gate will sit flush with the bed in normal operation and will revolve to the upright position in advance of a high tide. Consideration was given to horizontal sector gates, lifting gates and sliding gates but all were discounted due to space requirements, navigational difficulties and channel shape.

- Confirmation of a barrier gate crest level of 10.9m AOD. This allows for a 1 in 1000 year (0.1%) water level plus a freeboard of 300mm, taking into account uncertainties in the model and wave action.

- To accommodate the gate size, pier widths were increased to 10m. Numerical modelling has demonstrated that a small increase in impedance (approximately 10-20% from the existing) results in varying significant changes in upstream flood levels (discussed in detail below). Additional modelling will be required to assess the velocity profiles and flowstreams to understand the impact of the barrier on navigation and geomorphology.

The barrier was represented within the WS4 model using gated weir units. The arrangement of the structures inserted at cross section Av6u is shown in Figure 11. As mentioned above, the design tide level of the barrier at this location is 10.9m AOD with a bed level of approximately -5.0m AOD for the main central gate and 0.5m for the two smaller gates. For the purpose of modelling, the barrier was tested with 3 gates, each 40m wide.

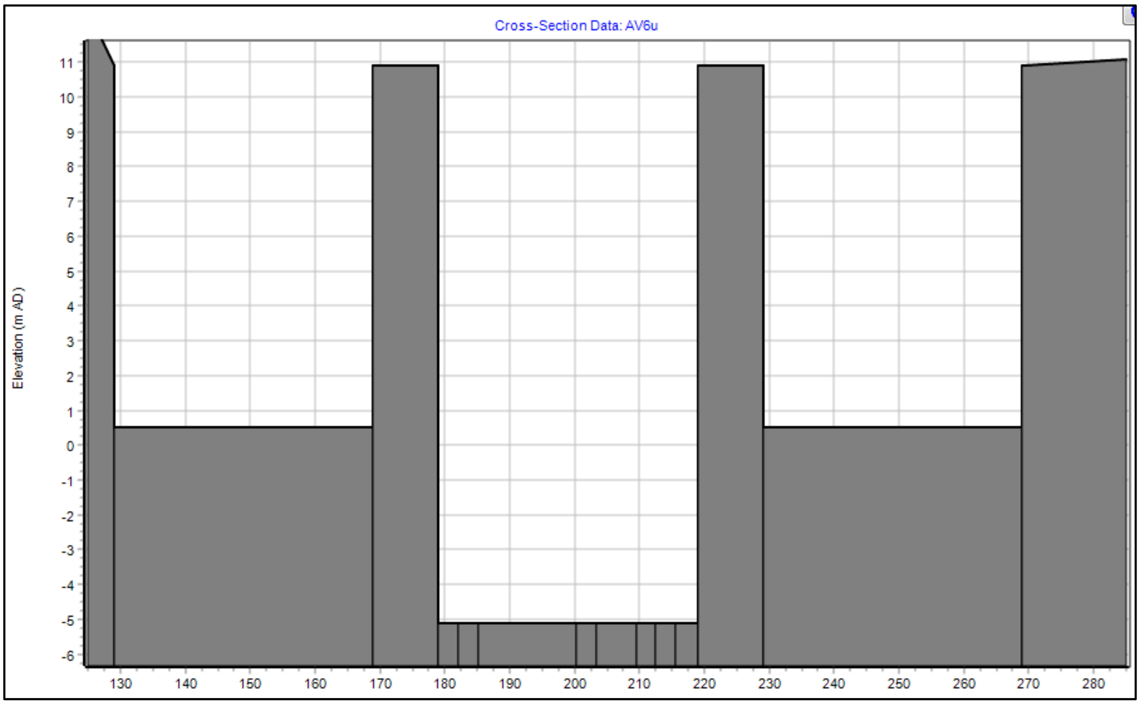


Figure 11: Nibley/Ham green Barrier Cross-section (Av6u)

4.3.1 *Barrier Operation*

Several control operations were tested for the barrier to assess the overall impact on flood levels within the Floating Harbour and further upstream within the River Avon. These are explained in more detail within Table 6.

Table 6: Barrier Operation Scenarios

Run ID	Epoch	Event	Time Barrier Begins to Close	Time Barrier Fully Closed	Time Barrier Begins to Open	Time Barrier Fully Open
Baseline	2115	2yr Tide 200yr Fluvial	n/a	n/a	n/a	n/a
1	2115	2yr Tide 200yr Fluvial	40.00 hrs	41.25 hrs	48.00 hrs	49.25 hrs
2	2115	2yr Tide 200yr Fluvial	40.00 hrs	41.25 hrs	46.00 hrs	47.00 hrs
3	2115	2yr Tide 200yr Fluvial	44.40 hrs	44.85 hrs	46.00 hrs	47.00 hrs

R

Run ID 'Baseline' represents the existing scenario with no barrier in place. The operation controls within Run ID 1 represents a barrier closure of the entire peak tidal curve (Figure 12), while during Run ID 2 represents the barrier closing at the beginning of the tide curve, opening once the tide decreases to 8m AOD, which is approximately 1m lower than the peak (Figure 13). During Run ID 3, the barrier is fully closed when the tide reaches 8m AOD (44.85 hours), and is nearly fully open when the tide decreases to 8m AOD (Figure 14).

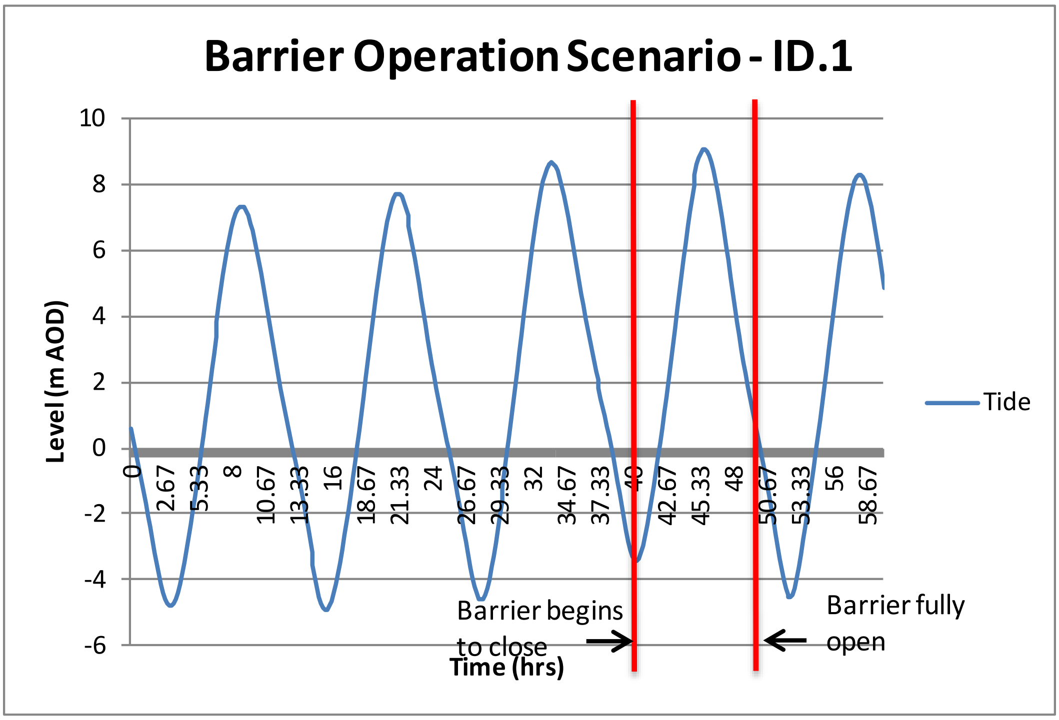


Figure 12: Barrier Operation Scenario (Run. ID 1)

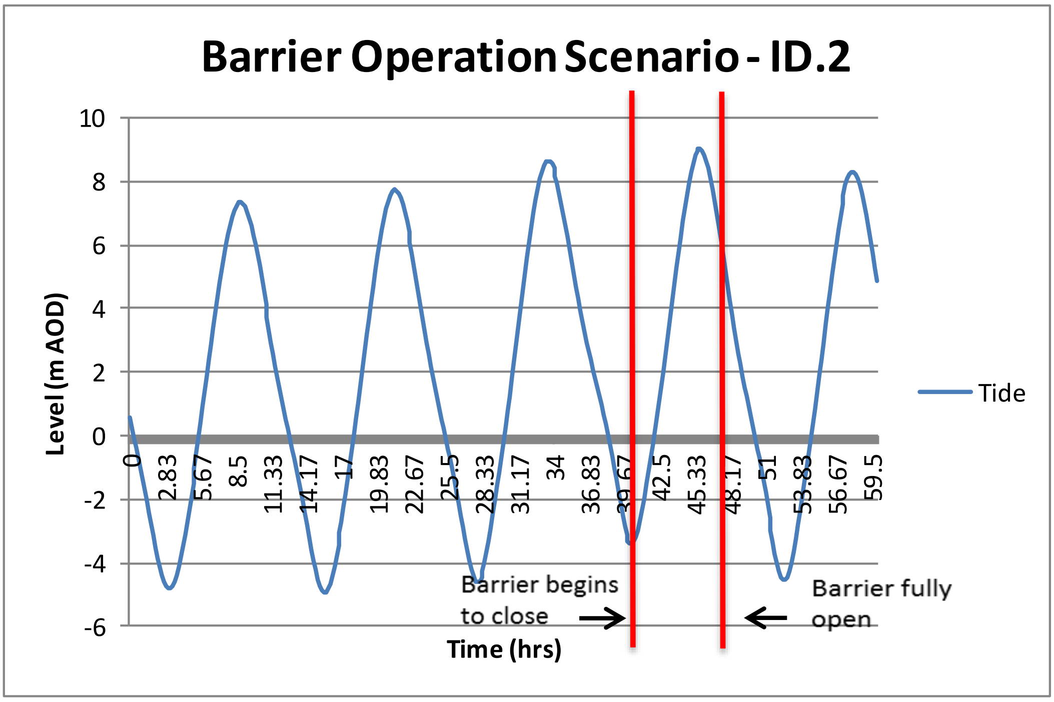


Figure 13: Barrier Operation Scenario (Run. ID 2)

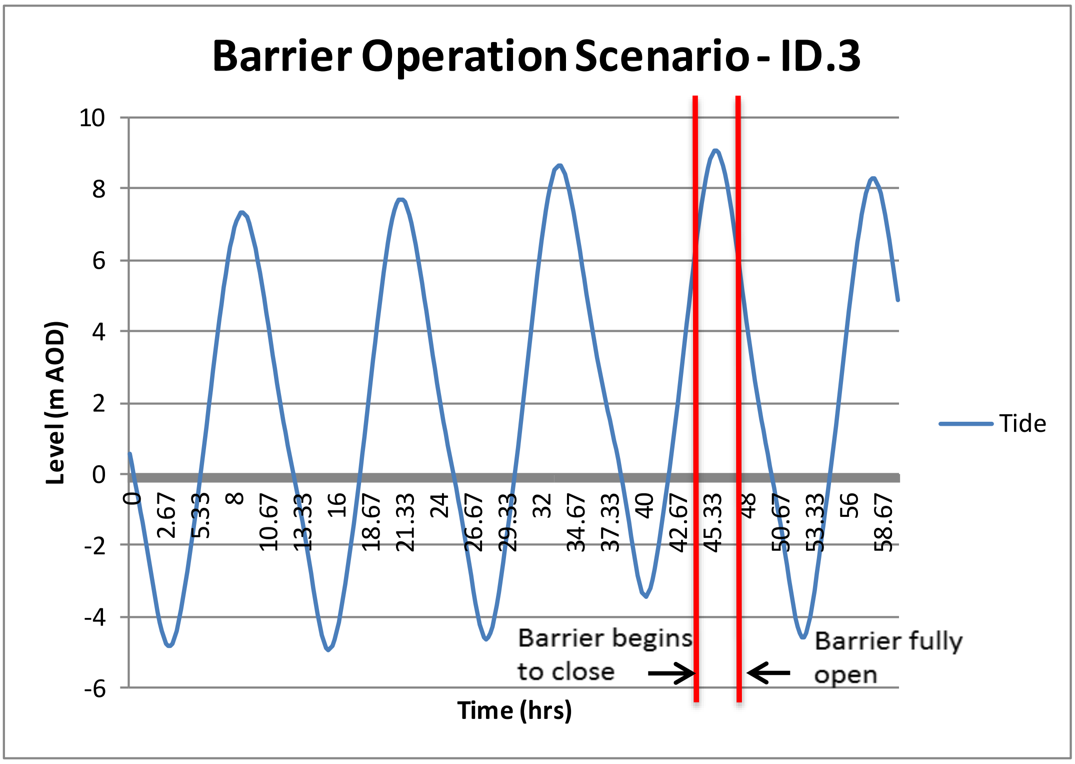


Figure 14: Barrier Operation Scenario (Run. ID 3)

4.3.2 *Barrier Results*

Following on from the approach used when testing the impact of tidal barriers at other locations within the River Avon, a number of cross sections were chosen to assess impacts on flood levels both upstream and downstream of the barrier location. These included the reservoir unit used to represent the Floating Harbour (R11bd), Junction Lock (Junc_0043), a cross-section near Totterdown (Avon01_4076) and a cross section immediately downstream of Netham Lock (Avon01_6270). The locations of these are shown in Figure 15.

As shown in Table 6, the event used to test the operation of the barrier was based on a high fluvial event. This was modelled to represent a worst-case scenario to check the fluvial storage behind the barrier once closed. The tidal return period associated with the peak level is arbitrary in this instance, as the barrier defends from the design tidal return period. For this example, the barrier is operated logically throughout the tidal cycle, opening and closing as specified during the fluvial event. By 2115 a 2 year tidal event would need the barrier to be closed to prevent tidal flooding, so a corresponding extreme fluvial event was tested to check storage capacity.

Run ID 1 – During the scenario where the barrier is closed for the longest period out of the three scenarios (i.e. for the entire peak tidal curve) results have shown that flood levels generally increase in areas upstream. For example, at the Floating Harbour levels are shown to increase by approximately 0.18m from 9.26m AOD to 9.44m AOD. Increases are also experienced at Totterdown, Netham and immediately upstream of the barrier location (Table 7 and Figures 16 – 20).

Run ID 2 – During the scenario where the barrier closure time is reduced (approximately 4.75 hours in total), results are varied. At the Floating Harbour, Totterdown, Netham and immediately upstream of the barrier location, flood levels increase between 0.01m and 0.03m, however at Junction Lock they reduce by approximately 0.05m (Table 7 and Figures 16 – 20).

Run ID 3 - During the scenario where the barrier is closed for the shortest duration out of the three controlled scenarios, flood levels decrease (between 0.02m and 0.07m) at all cross sections upstream of the barrier location (Table 7 and Figures 16 – 20).

It should be noted that levels were also assessed at the cross section immediately downstream of the barrier location, however there were minor differences between the baseline and the barrier scenarios and therefore they have not been included within the tables and figures below.

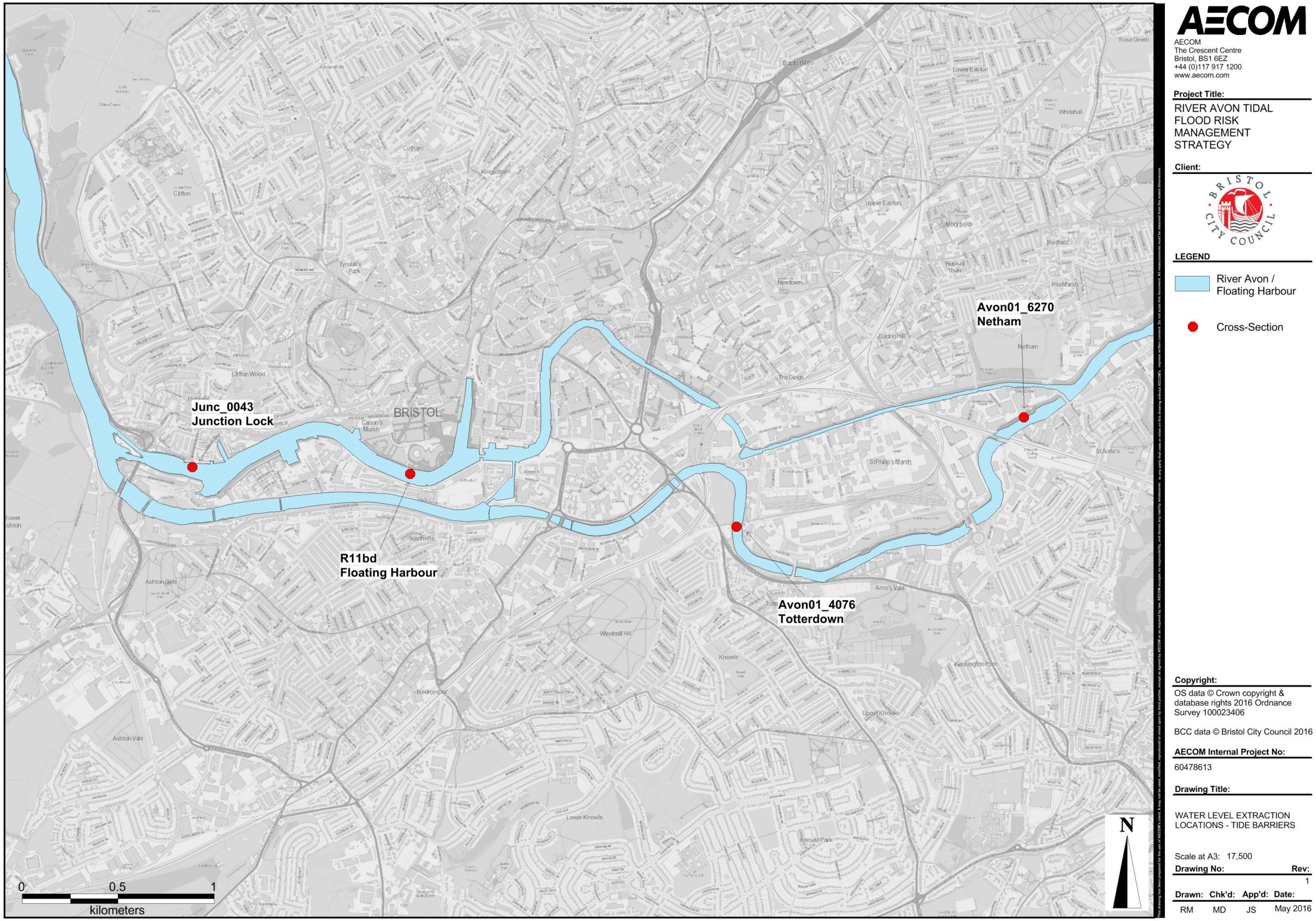


Figure 15: Cross Sections used for Water Level Extraction

Table 7: Maximum Water Levels

XS Location	Baseline (m AOD)	Run ID 1 (m AOD)	Difference (m)	Run ID 2 (m AOD)	Difference (m)	Run ID 3 (m AOD)	Difference (m)
R11bd (Floating Harbour)	9.26	9.44	+0.18	9.29	+0.03	9.23	-0.03
Junc_0043 (Junction Lock)	9.25	9.33	+0.08	9.20	-0.05	9.23	-0.02
Avon01_4076 (Totterdown)	9.34	9.48	+0.14	9.35	+0.01	9.30	-0.04
Avon01_6270 (Netham)	9.66	9.71	+0.05	9.67	+0.01	9.64	-0.02
AV7 (XS directly US of barrier)	9.12	9.25	+0.13	9.13	+0.01	9.05	-0.07

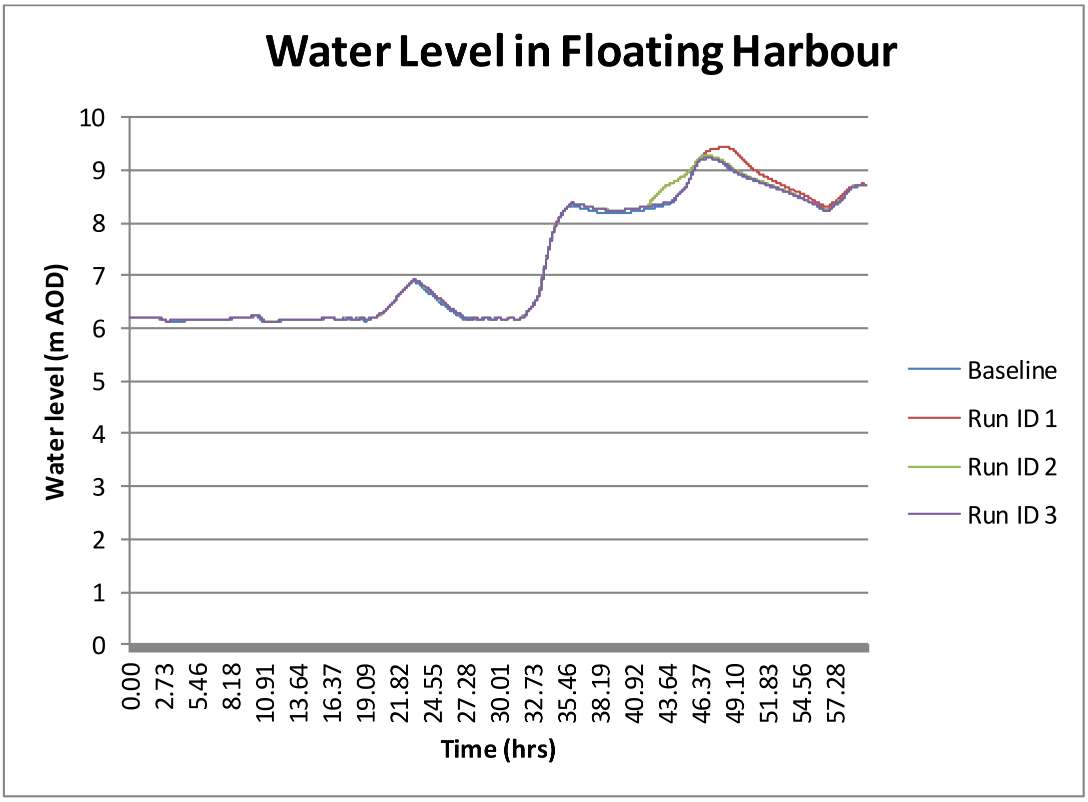


Figure 16: Water Level in Floating Harbour

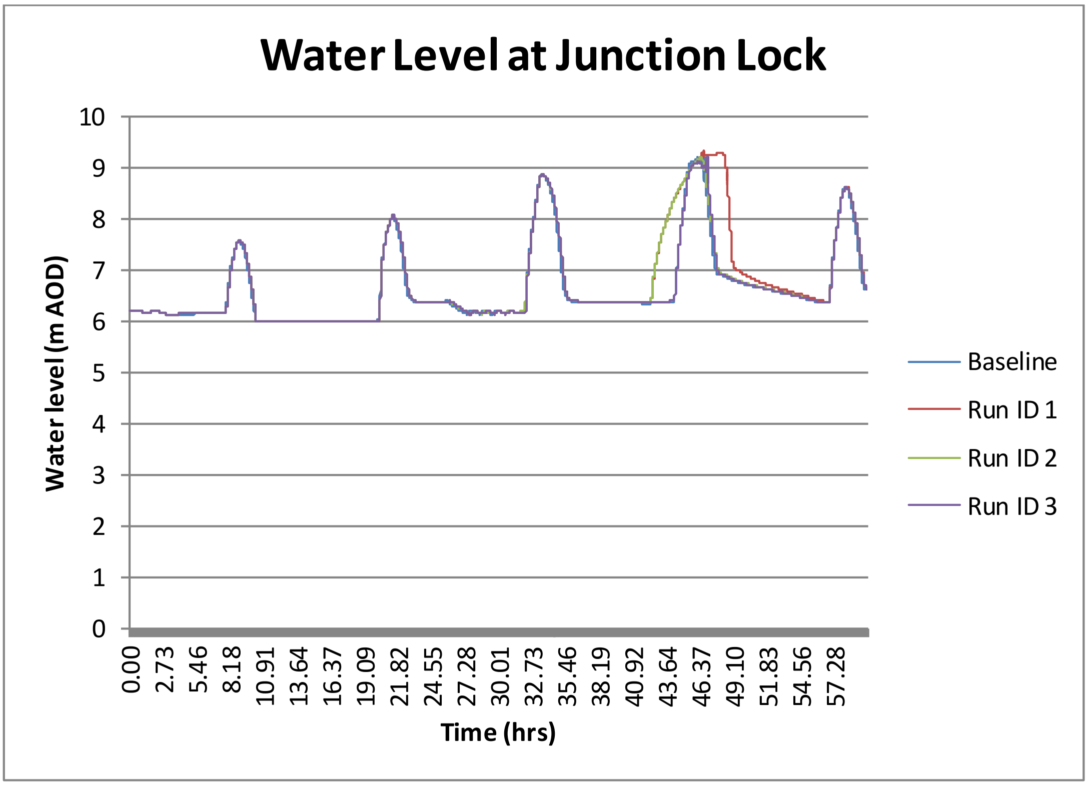


Figure 17: Water Level at Junction Lock

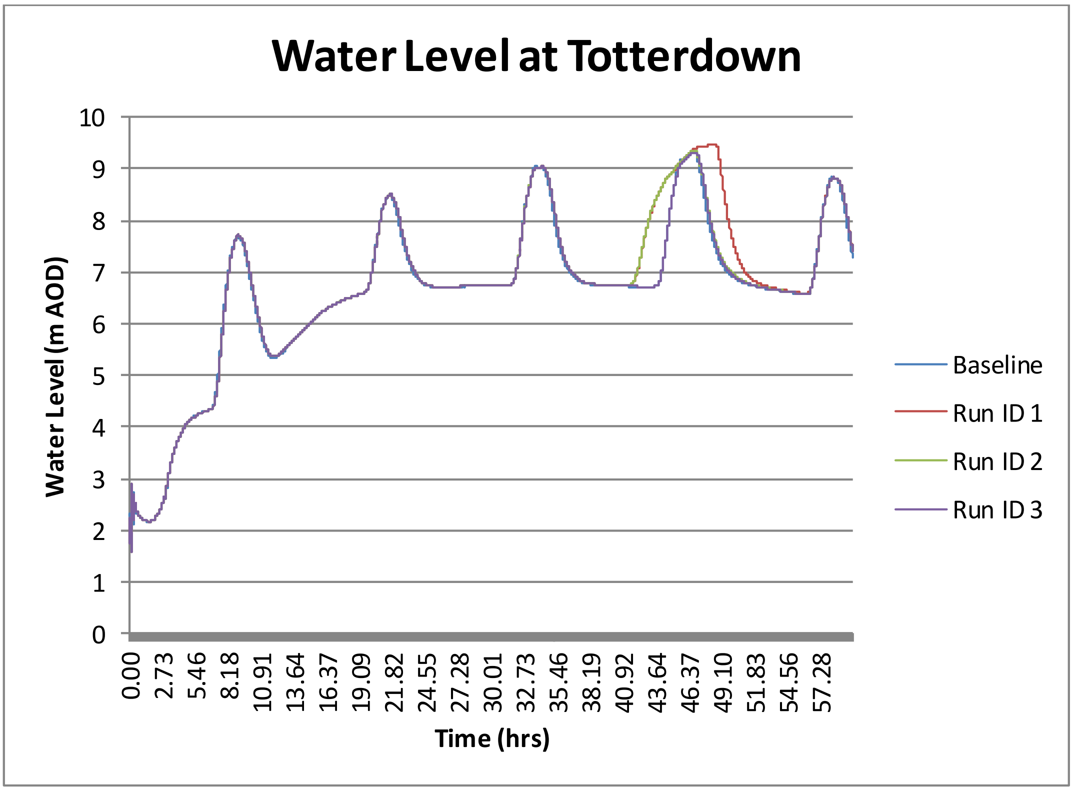


Figure 18: Water Level at Totterdown

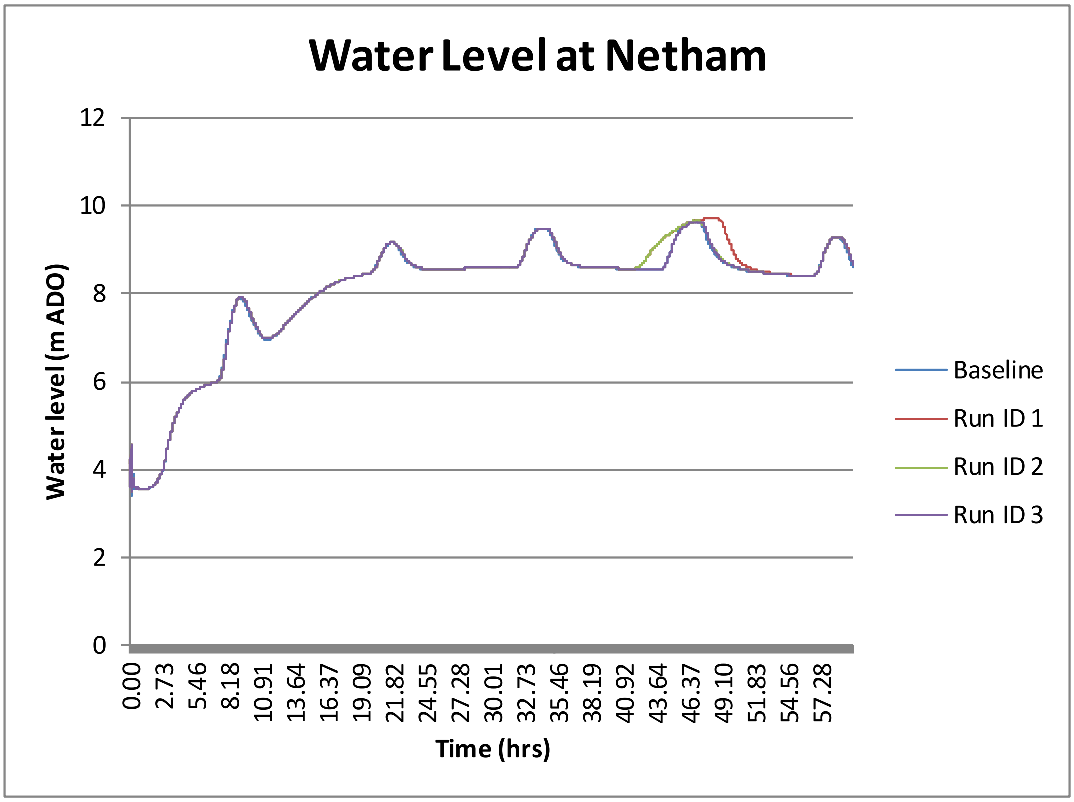


Figure 19: Water Level at Netham

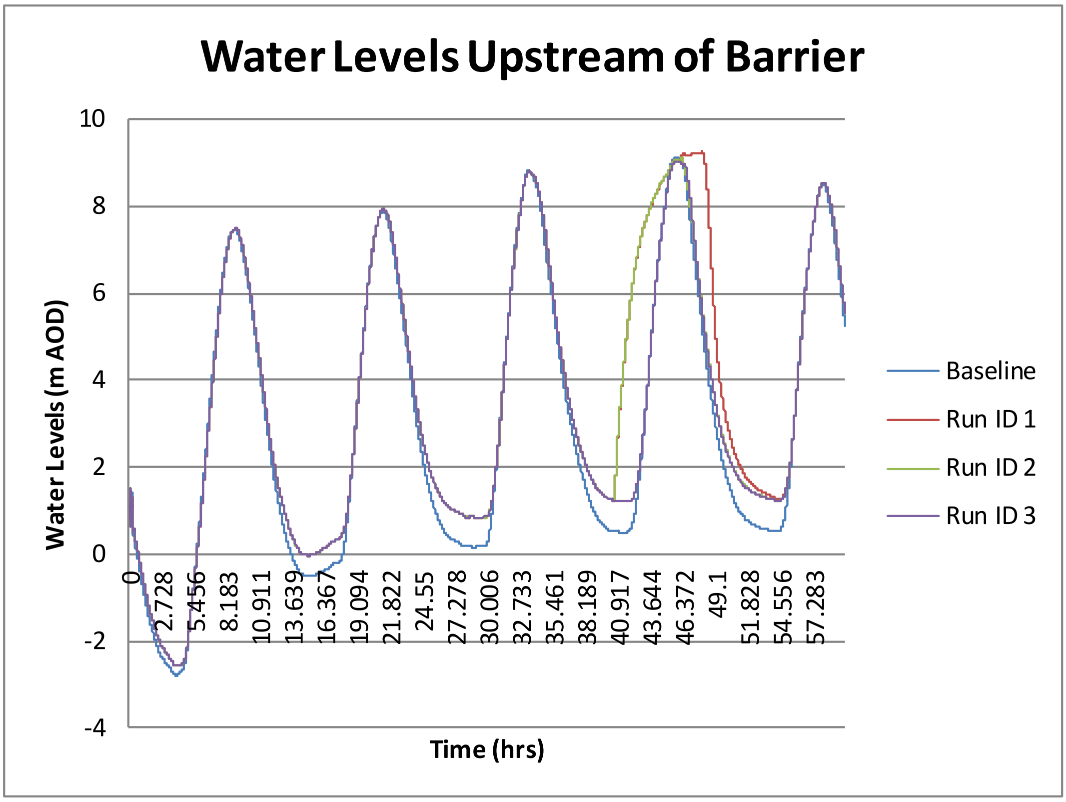


Figure 20: Water Level Upstream of Barrier

The results in Figures 16 - 20 suggest that when the barrier is closed for a shorter period, there is a decrease in water levels at all cross sections upstream of the barrier which indicates that there is sufficient storage to cope with a high fluvial event. With results indicating increases in flood levels upstream for the scenarios where the barrier is closed for a longer period of time, it is considered that a barrier would need to be coupled with flood walls around the Floating Harbour for sole fluvial events, particularly for future epochs, should a barrier control approach be taken forward.

4.3.3 *Barrier Impedance*

To aid the decision making regarding the size of gates to be used as part of the barrier option, additional model runs were undertaken to see whether impedance within the channel caused a detrimental impact on fluvial flows and flood risk.

A range of impedance runs were simulated as part of the assessment using the 1 in 200 year fluvial event with a base tide for 2015 and a 1 in 200 year fluvial event with a Mean High Water Spring (MHWS) tide for 2115. The impedance runs included:

- Baseline Scenario – gate widths 40m (x3);
- 10% Impedance – reducing the gate widths from 40m (x3) to 36m (x3);
- 20% Impedance – reducing the gate widths from 40m (x3) to 32m (x3);
- 30% Impedance – reducing the gate widths from 40m (x3) to 28m (x3);
- 40% Impedance – reducing the gate widths from 40m (x3) to 24m (x3);

It should be noted that a 50% impedance test was simulated which reduced each of the gates widths to 20m; however stability issues prevented these models from completing. Each of the cross sections included within the working models are shown in Figure 21.

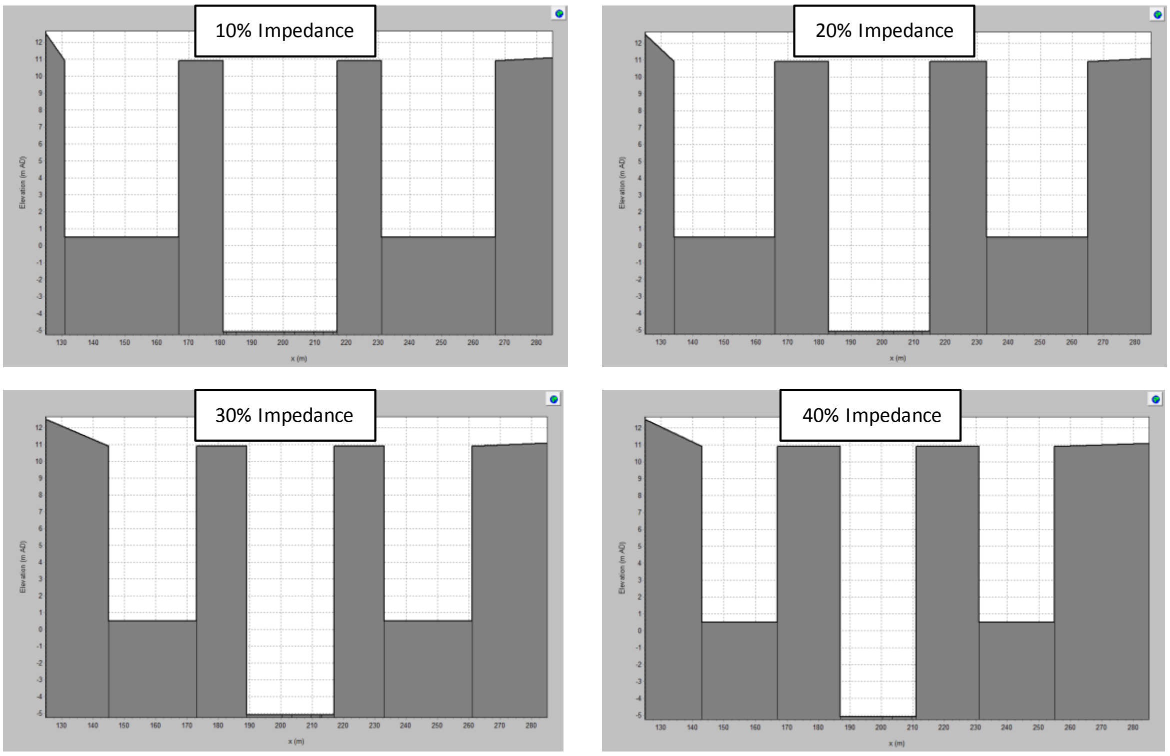


Figure 21: Impedance Cross Sections

To assess the impact of impedance within the channel, water levels have been taken from a number of cross sections at a time step (28.5 hours) commensurate with the fluvial peak. The results from the 2015 simulations are shown in Table 8 while the 2115 results are shown in Table 9. It should be noted that due to stability issues, some results have not been displayed within the table.

Table 8: Water Levels associated with Fluvial Peak (2015)

Location	1 in 200 Year Fluvial + Base Tide (2015)				
	Baseline (m AOD)	10% Impedance (m AOD)	20% Impedance (m AOD)	30% Impedance (m AOD)	40% Impedance (m AOD)
US of Barrier (Av7)	4.27	4.27	4.27	-*	-*
DS of Barrier (Av5)	-0.91	-0.90	-0.91	-0.88	-*
Barrier Location (Av6u)	-0.69	-0.76	-0.89	-*	-*
Cumberland Road (Avon01_2149)	-0.09	-0.03	-0.03	-0.23	-*

*model stability issues

Table 9: Water Levels associated with Fluvial Peak (2115)

Location	1 in 200 Year Fluvial + MHWS (2115)				
	Baseline (m AOD)	10% Impedance (m AOD)	20% Impedance (m AOD)	30% Impedance (m AOD)	40% Impedance (m AOD)
US of Barrier (Av7)	4.70	4.70	4.71	-*	-*
DS of Barrier (Av5)	-0.49	-0.48	-0.49	-0.47	-*
Barrier Location (Av6u)	-0.31	-0.41	-0.57	-*	-*
Cumberland Road (Avon01_2149)	0.35	0.40	0.50	0.71	-*

*model stability issues

During the 30% and 40% scenario the model becomes unstable during the peak of the fluvial hydrograph which causes inaccurate and unreliable results. For the scenarios where impedance is increased by 10%, 20% and 30% the change in water level is of varying significance and is likely to have an impact upstream, demonstrated by the comparisons made at Cumberland Road. Where a greater impedance to flow is adopted, this leads to a respective increase in water levels upstream.

Should the narrow tidal barrier be taken forward, the positioning of the barrier, optimisation of operation and impedance caused by barrier openings/pier dimensions will require further understanding as to the inherent risks.

4.4 Flood Barrier – Tidal Inundation Assessment

Following the fluvial storage assessment, additional model runs were undertaken to establish how water levels upstream of the barrier change during a high tidal event with a 2 year fluvial event. This was modelled to show how the barrier can be used to mitigate the risk of tidal inundation further upstream around the Floating Harbour.

To show the change in upstream levels the 200 year tidal event combined with a 2 year fluvial event 2115 was simulated, with levels at Netham (Avon01_6270), Totterdown (Avon01_4076) and Cumberland Road (Avon01_2149) extracted and then compared against baseline levels i.e. with no barrier in place. To stay consistent with the fluvial storage approach, the operation control of the barrier from Run ID 3 (barrier fully closed at 40.00 hours and fully open again at 49.25 hours) was considered.

Table 10 shows that with the barrier in place at Nibley, water levels upstream at Netham, Totterdown and Cumberland Road are significantly reduced when looking at a 200 year tidal event with a year fluvial event.

Table 10: Upstream Water Levels with Operational Tidal Barrier

Barrier Location	1 in 200 Year Tidal + 1 in 2 Year Fluvial (2115)			
	XS Location	Baseline (m AOD)	With Barrier (m AOD)	Difference (m)
Nibley	U/S	9.94	8.74	- 1.20
	Netham	9.66	8.89	- 0.77
	Totterdown	9.64	8.80	- 0.84
	Cumberland Road	9.66	8.78	- 0.88

5 CONCLUSIONS

As part of this report, it has been demonstrated that an improvement to the resilience of Bristol is possible through strategic inclusion of options along the River Avon. A detailed appraisal of the benefits, economics and phased approach to construction of options is presented in the Preferred Option Report.

Key conclusions from the modelling are:

The various low and high defence options are effective at protecting Bristol from an extreme tidal event, both now and in the future.

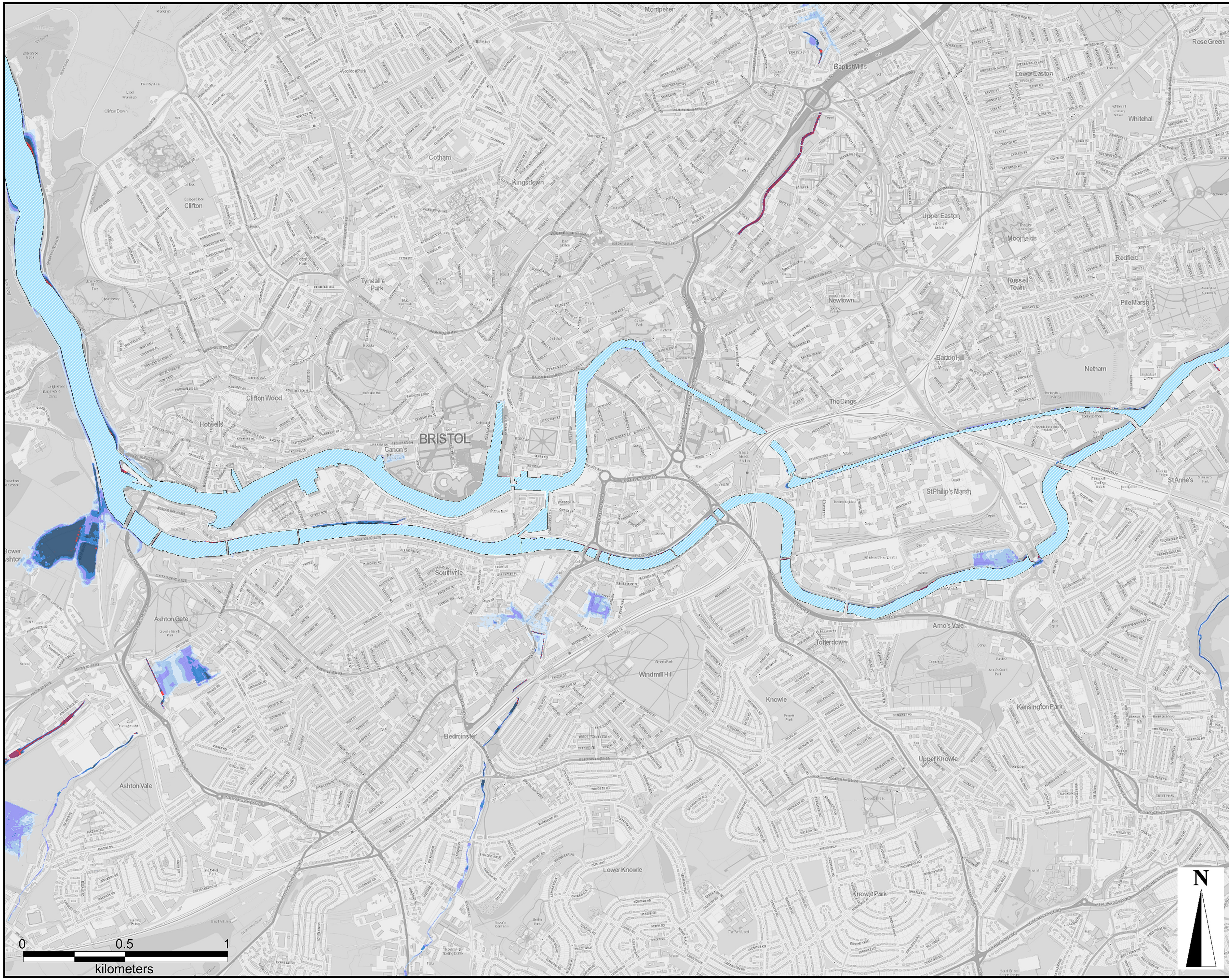
As a result of adopting defence walls, a minor increase in flooding to the Bower Ashton, Ashton and upstream of Netham could be expected. This has been shown to occur during a combined 200yr tidal and 2yr fluvial event, as well as the 200yr fluvial event (Netham only). This adverse consequence would need to be resolved, either by localised wall raising as part of the tidal strategy, or as part of a fluvial strategy.

The low and high defence options also bring about a significant reduction of flood depth and extent at a number of locations across the City, in an extreme fluvial event. The benefits of this could be included in the economic analysis for the tidal strategy.

A tidal flood barrier has been shown to be effective at reducing tidal flood risk for the City. In the open position the barrier piers have been shown to have a varying significance on upstream water levels up to a 20% impedance; further understanding of inherent risks is required if a barrier option is to be progressed. Operation of the barrier to the closed position on a high tide has been simulated and been shown not to cause an increase in upstream water levels, providing that an appropriate operating regime is followed.

APPENDIX A

Flood Depth Figures



AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Depth

- 0.00m to 0.15m
- 0.15m to 0.30m
- 0.30m to 0.60m
- 0.60m to 0.90m
- 0.90m to 1.50m
- 1.50m to 2.00m
- >2.00m

Model Reference:

CAFRA_138_200yr_F002_T200_2015_LD

Copyright:

AECOM Internal Project No:

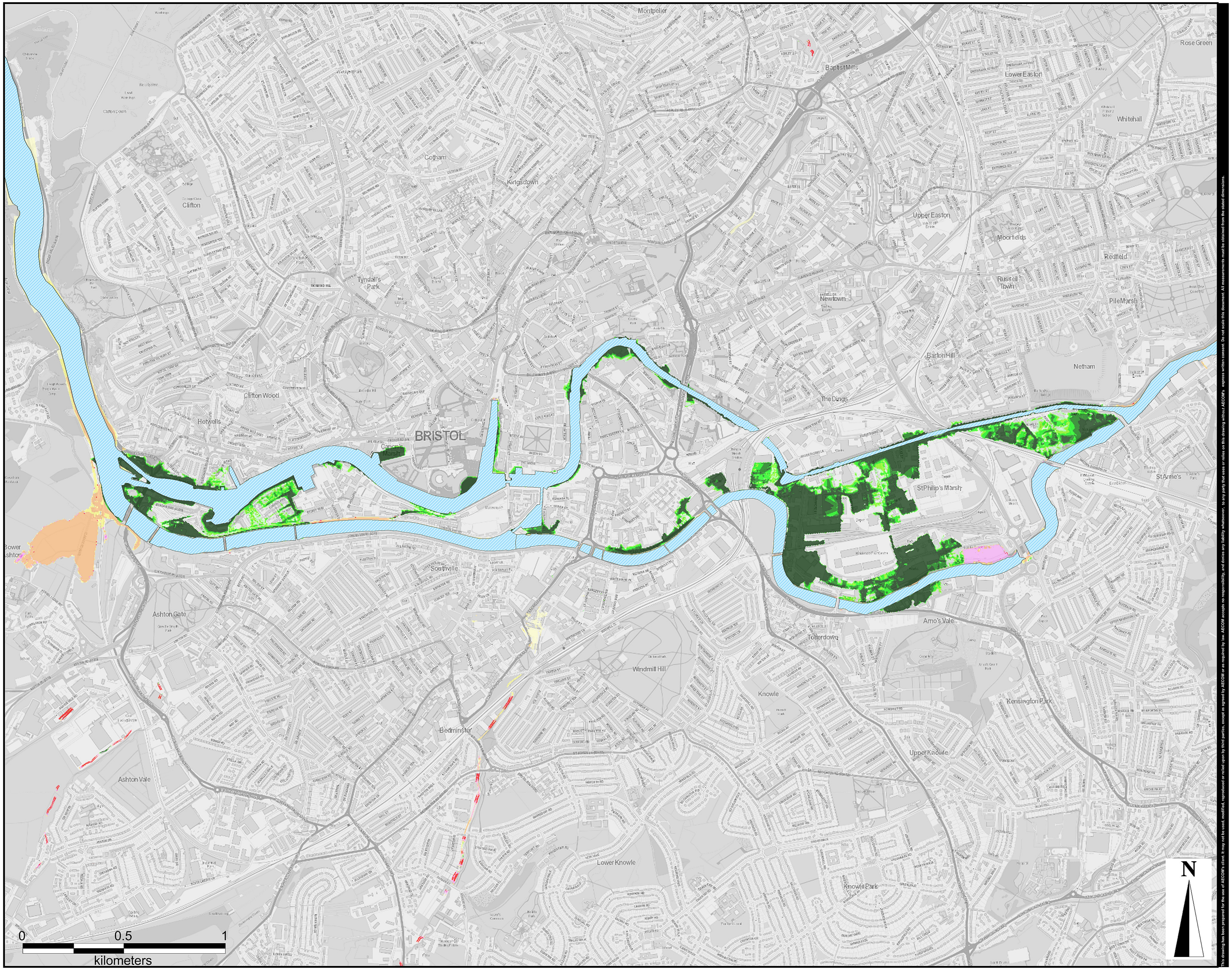
60478613

Drawing Title:

LOW DEFENCES
200 YR TIDAL RETURN PERIOD
2015
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 1A			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+5 to <+20
- >-5 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

Copyright:

AECOM Internal Project No:

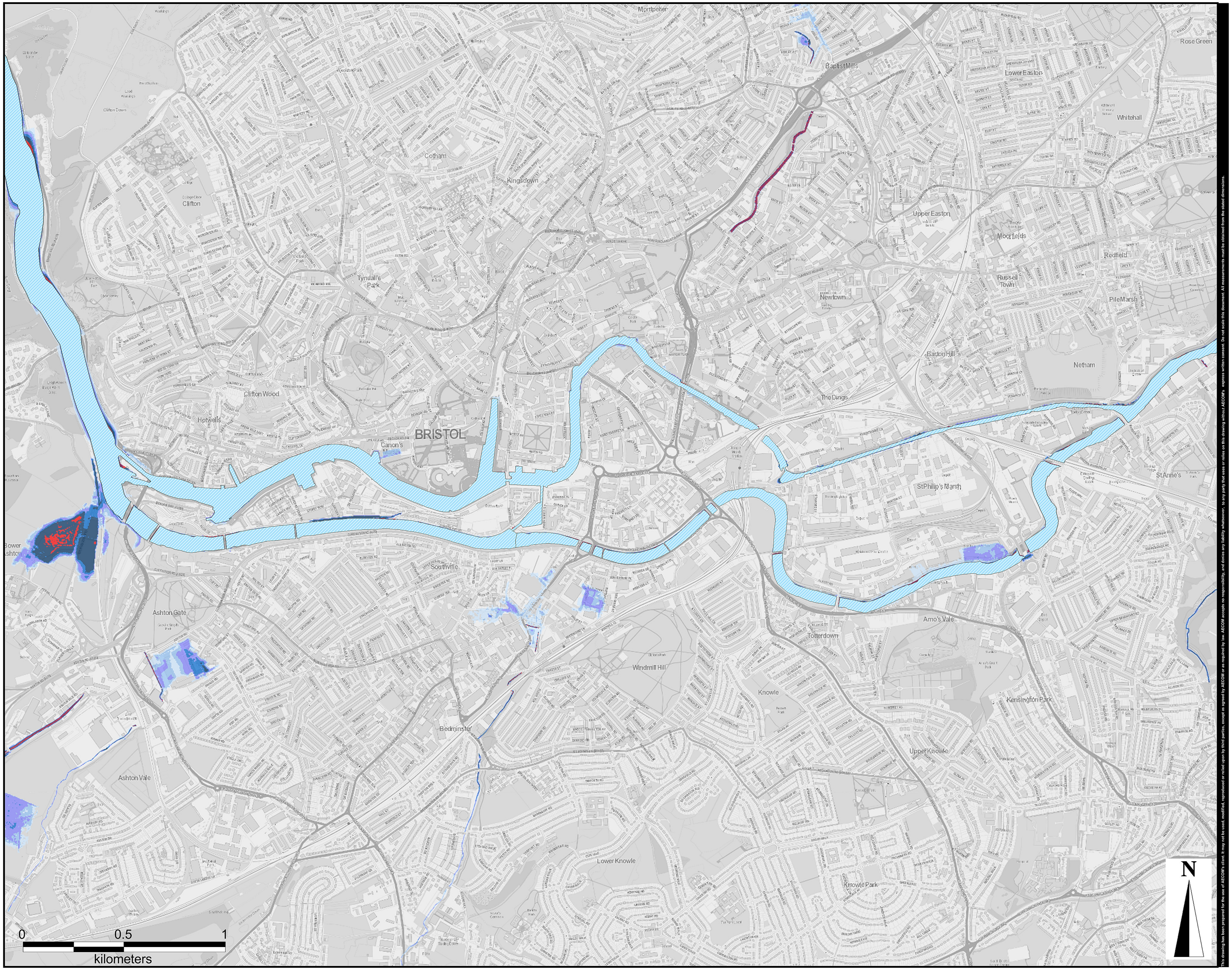
60478613

Drawing Title:

WATER LEVEL DIFFERENCE MAP
DO MINIMUM VS LOW WALLS
200 YR TIDAL RETURN PERIOD
2015

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 1B			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Depth

- 0.00m to 0.15m
- 0.15m to 0.30m
- 0.30m to 0.60m
- 0.60m to 0.90m
- 0.90m to 1.50m
- 1.50m to 2.00m
- >2.00m

Model Reference:

CAFRA_138_200yr_F002_T200_2030_LD

Copyright:

AECOM Internal Project No:

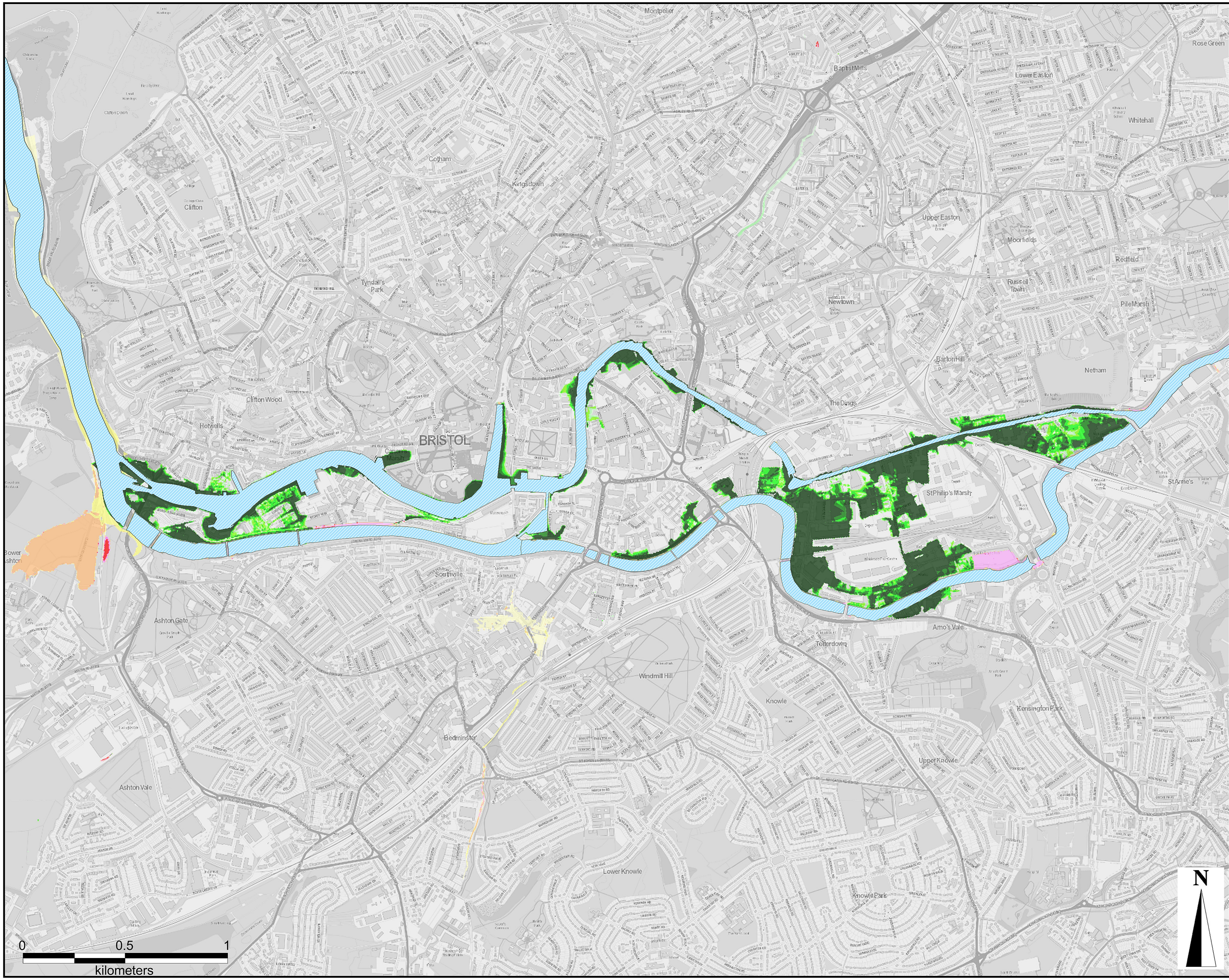
60478613

Drawing Title:

LOW DEFENCES
200 YR TIDAL RETURN PERIOD
2030
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 1C			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+5 to <+20
- >-5 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

AECOM Internal Project No:

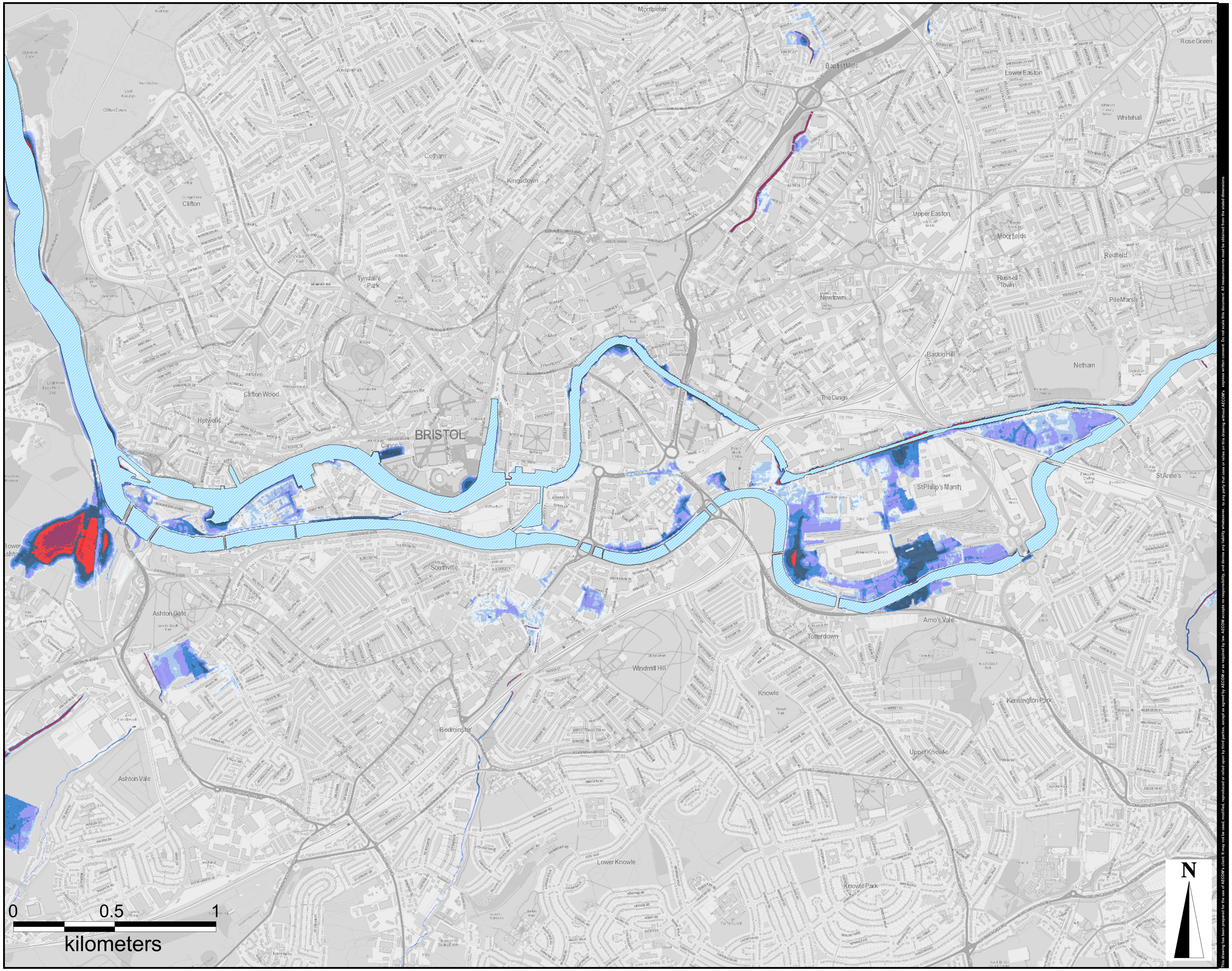
60478613

Drawing Title:

WATER LEVEL DIFFERENCE MAP
DO MINIMUM VS LOW WALLS
200 YR TIDAL RETURN PERIOD
2030

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 1D			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:
RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:
BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Depth

- 0.00m to 0.15m
- 0.15m to 0.30m
- 0.30m to 0.60m
- 0.60m to 0.90m
- 0.90m to 1.50m
- 1.50m to 2.00m
- >2.00m

Model Reference:
CAFRA_138_1000yr_F012_T1000_2015_LD

Copyright:

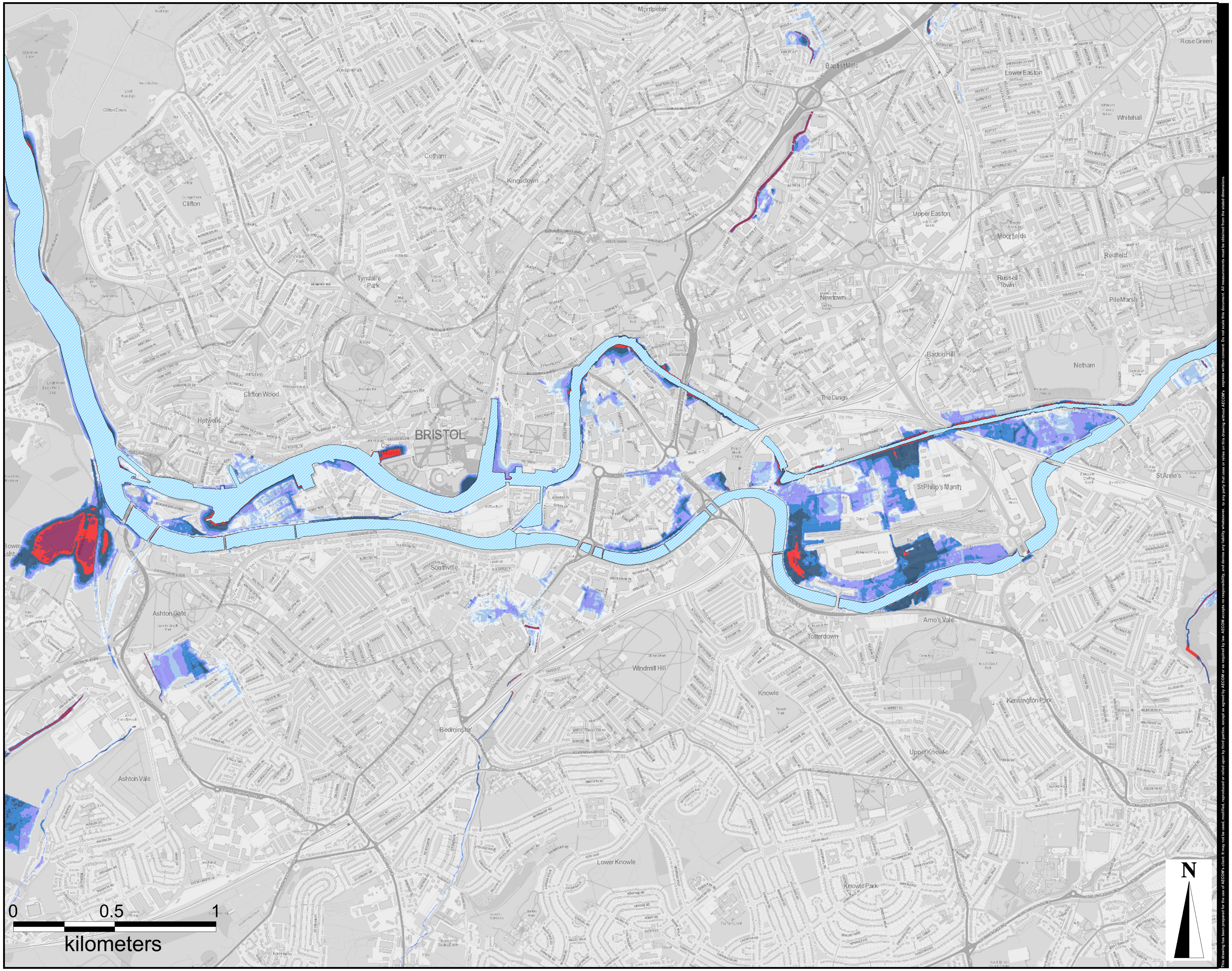
AECOM Internal Project No:
60478613

Drawing Title:

LOW DEFENCE MEASURES
1000 YR RETURN PERIOD
2015
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 1E			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Depth

- 0.00m to 0.15m
- 0.15m to 0.30m
- 0.30m to 0.60m
- 0.60m to 0.90m
- 0.90m to 1.50m
- 1.50m to 2.00m
- >2.00m

Model Reference:

CAFRA_138_1000yr_F012_T1000_2030_LD

Copyright:

AECOM Internal Project No:

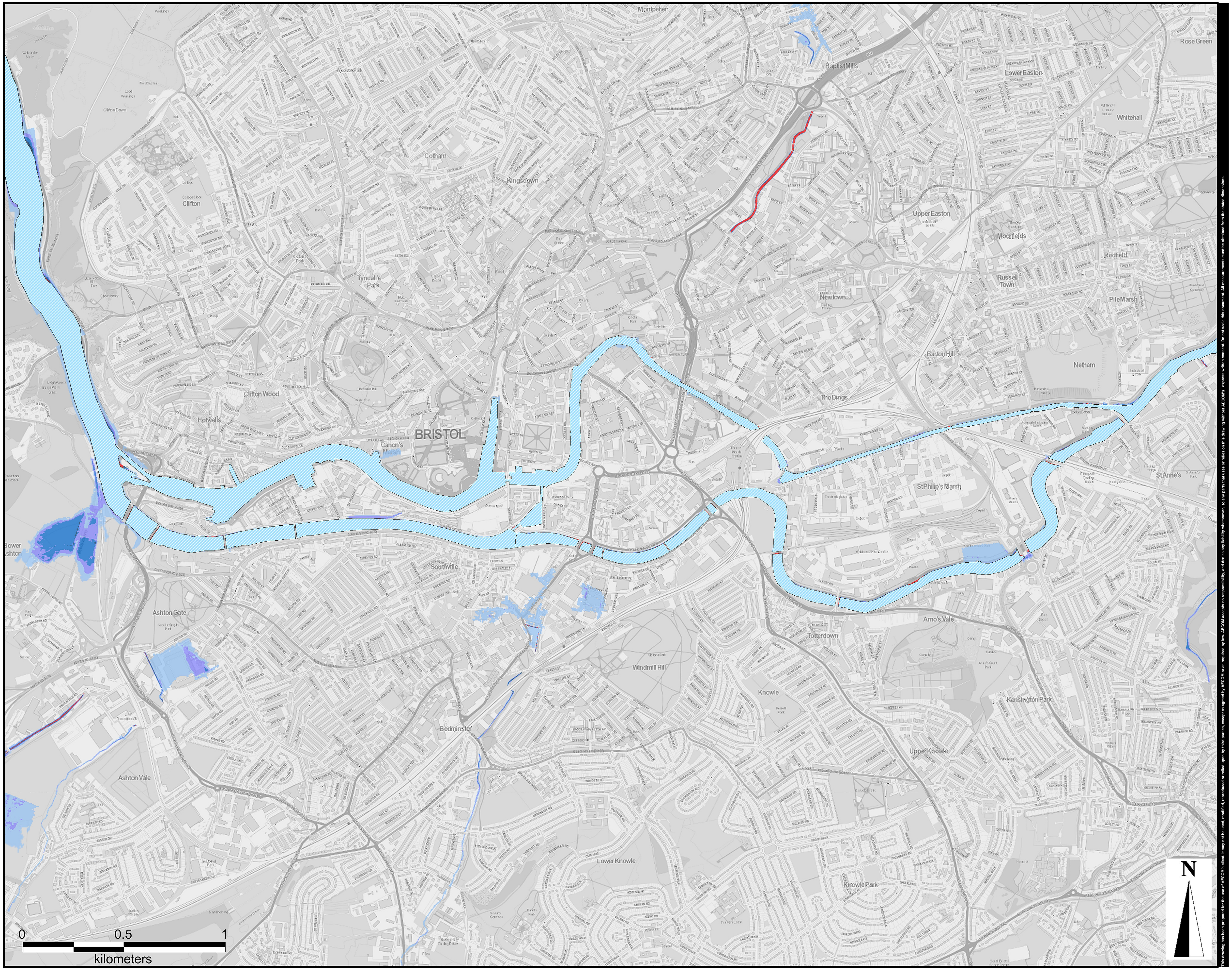
60478613

Drawing Title:

LOW DEFENCE MEASURES
1000 YR RETURN PERIOD
2030
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 1F			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Depth

- 0.00m to 0.15m
- 0.15m to 0.30m
- 0.30m to 0.60m
- 0.60m to 0.90m
- 0.90m to 1.50m
- 1.50m to 2.00m
- >2.00m

Model Reference:

CAFRA_136_200yr_F002_T200_2015_v4

Copyright:

AECOM Internal Project No:

60478613

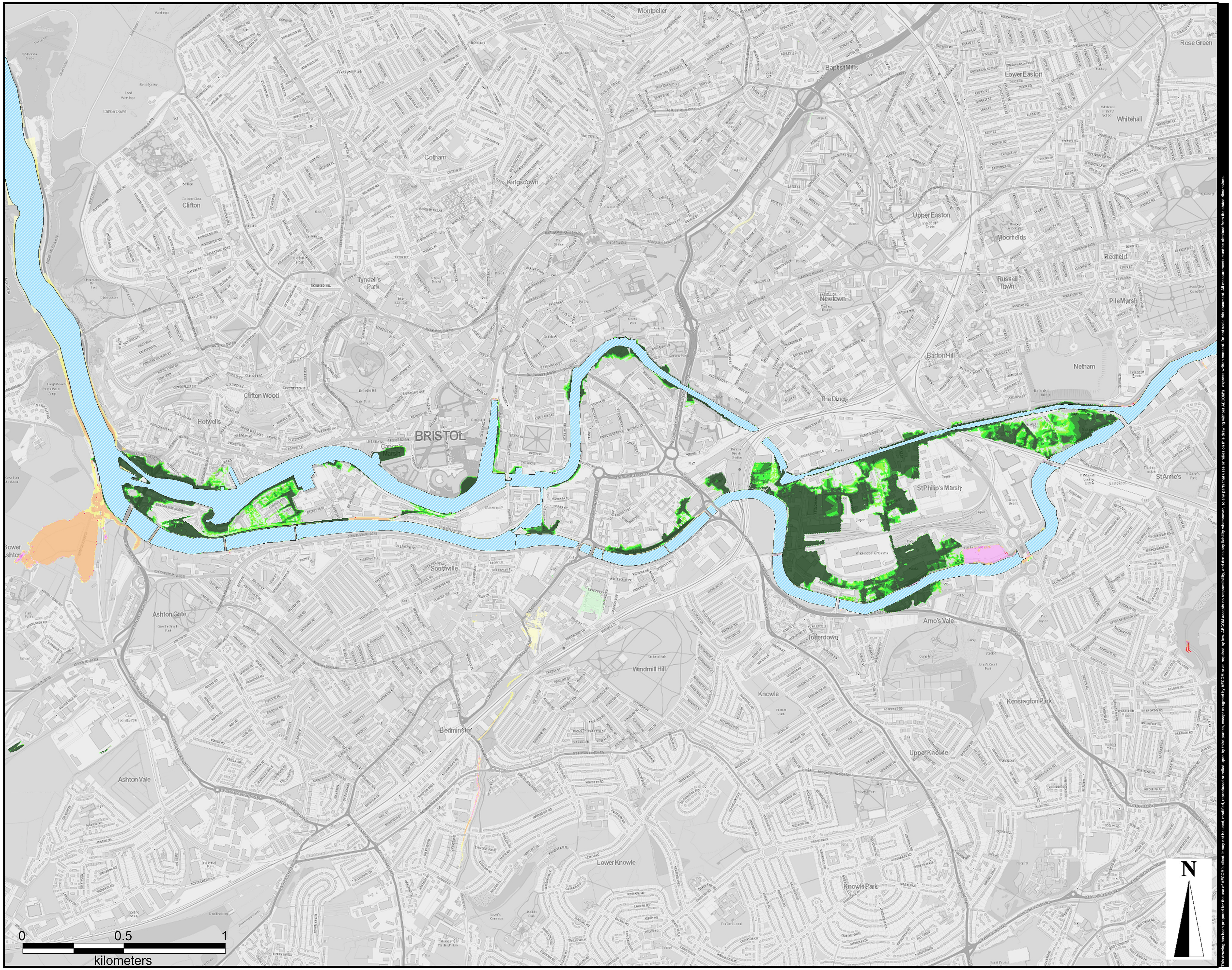
Drawing Title:

HIGH DEFENCES
200 YR TIDAL RETURN PERIOD
2015
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:	Rev:
FIGURE 2A	1

Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+5 to <+20
- >-5 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

AECOM Internal Project No:

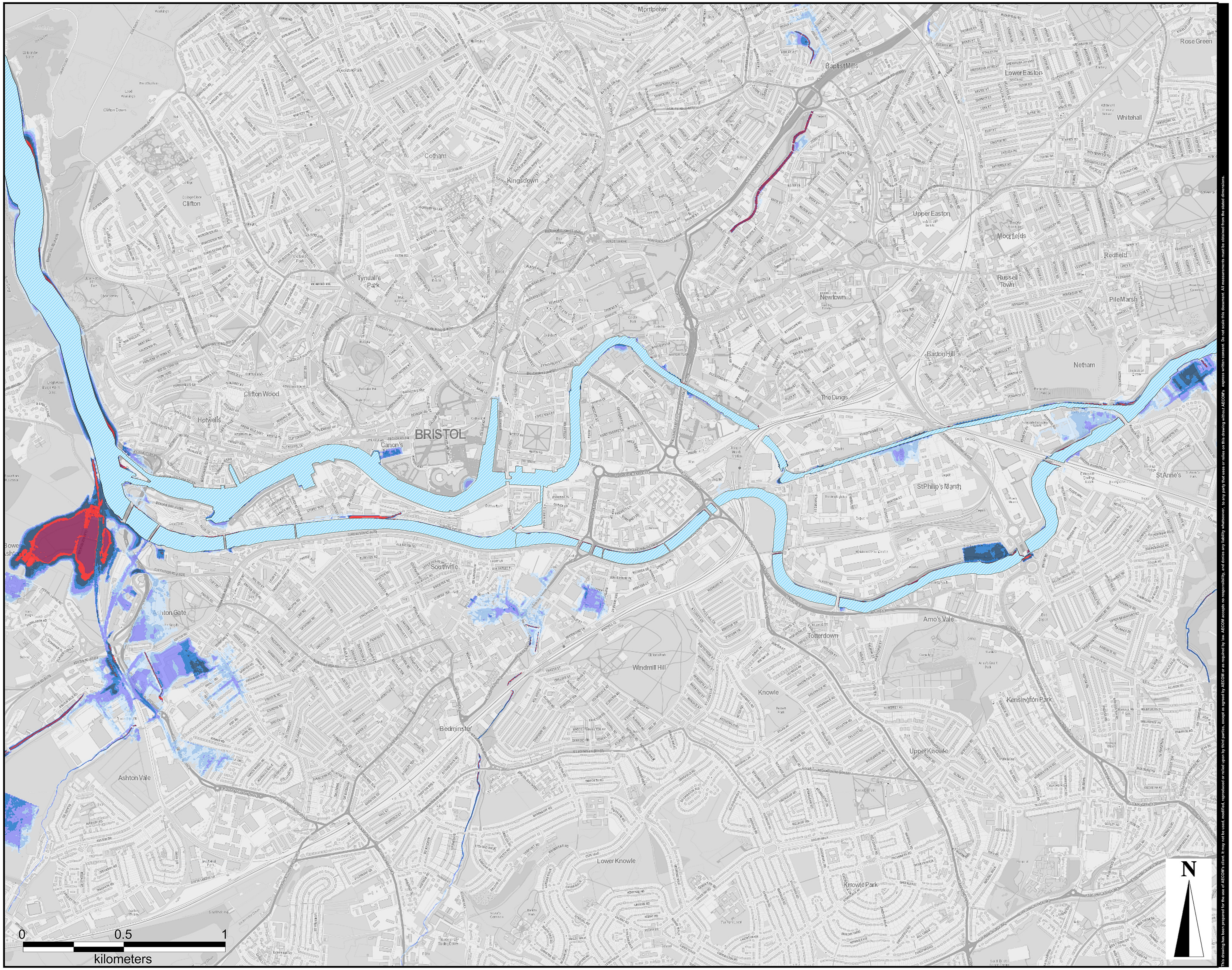
60478613

Drawing Title:

WATER LEVEL DIFFERENCE MAP
DO MINIMUM VS HIGH WALLS
200 YR TIDAL RETURN PERIOD
2015

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 2B			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Depth

- 0.00m to 0.15m
- 0.15m to 0.30m
- 0.30m to 0.60m
- 0.60m to 0.90m
- 0.90m to 1.50m
- 1.50m to 2.00m
- >2.00m

Model Reference:

CAFRA_136_200yr_F002_T200_2115_v4

AECOM Internal Project No:

60478613

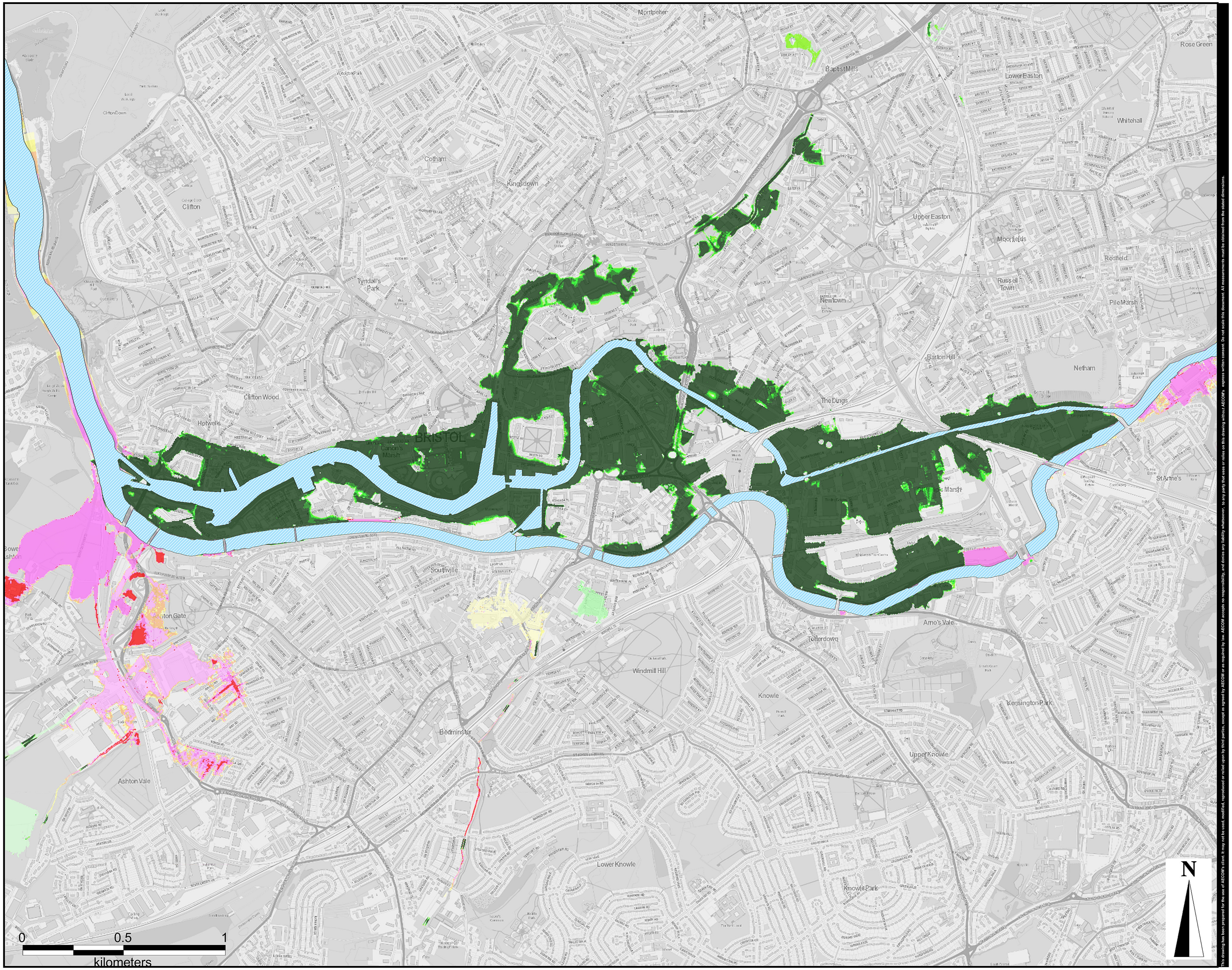
Drawing Title:

HIGH DEFENCES
200 YR TIDAL RETURN PERIOD
2115
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:	Rev:
FIGURE 2C	1

Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+5 to <+20
- >-5 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

AECOM Internal Project No:

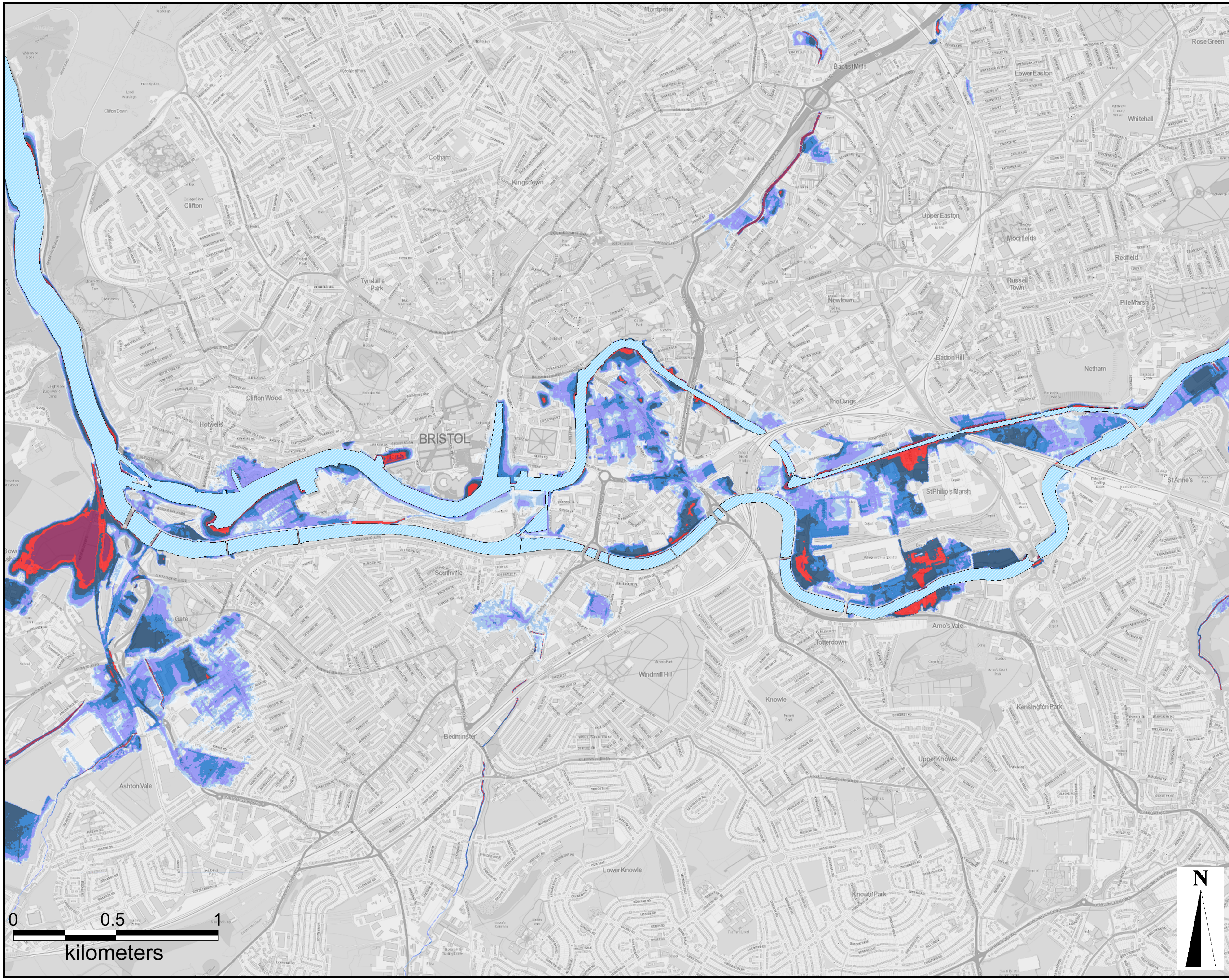
60478613

Drawing Title:

WATER LEVEL DIFFERENCE MAP
DO MINIMUM VS HIGH WALLS
200 YR TIDAL RETURN PERIOD
2115

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 2D			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL
FLOOD RISK
MANAGEMENT
STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Depth

- 0.00m to 0.15m
- 0.15m to 0.30m
- 0.30m to 0.60m
- 0.60m to 0.90m
- 0.90m to 1.50m
- 1.50m to 2.00m
- >2.00m

Model Reference:

CAFRA_136_1000yr_F012_T1000_2115_v4

Copyright:

AECOM Internal Project No:

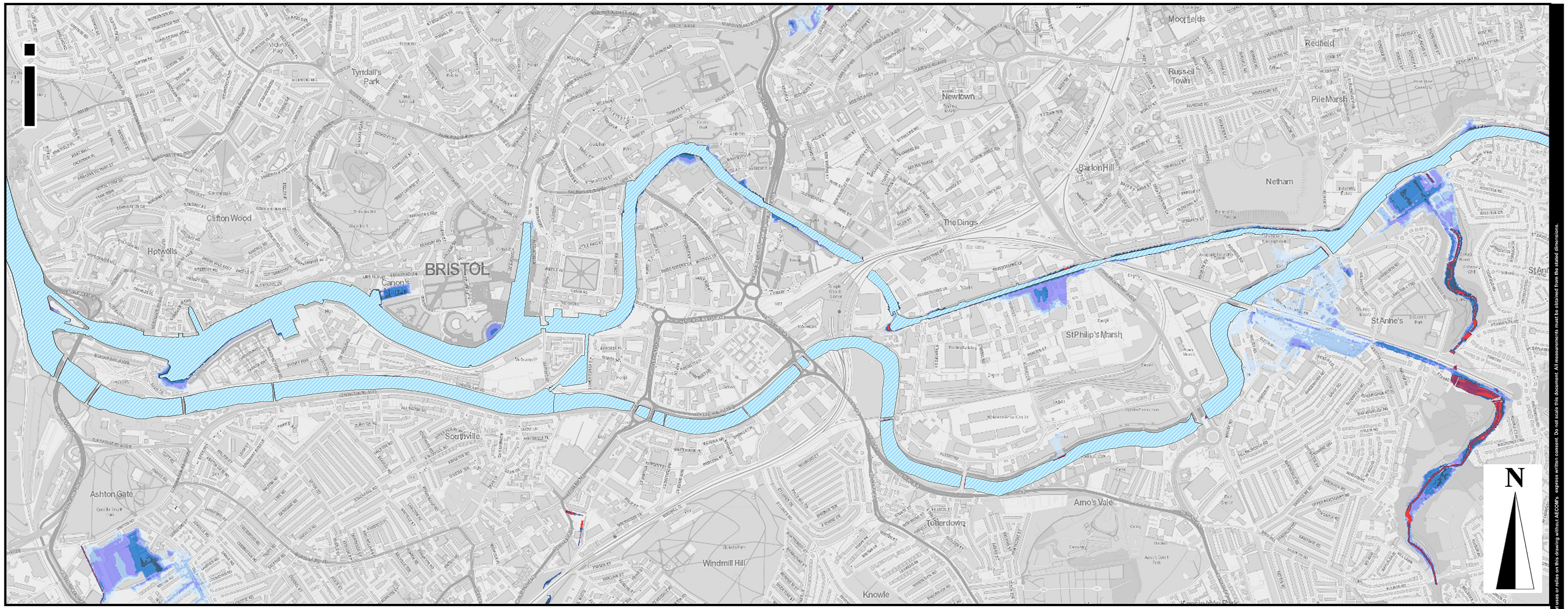
60478613

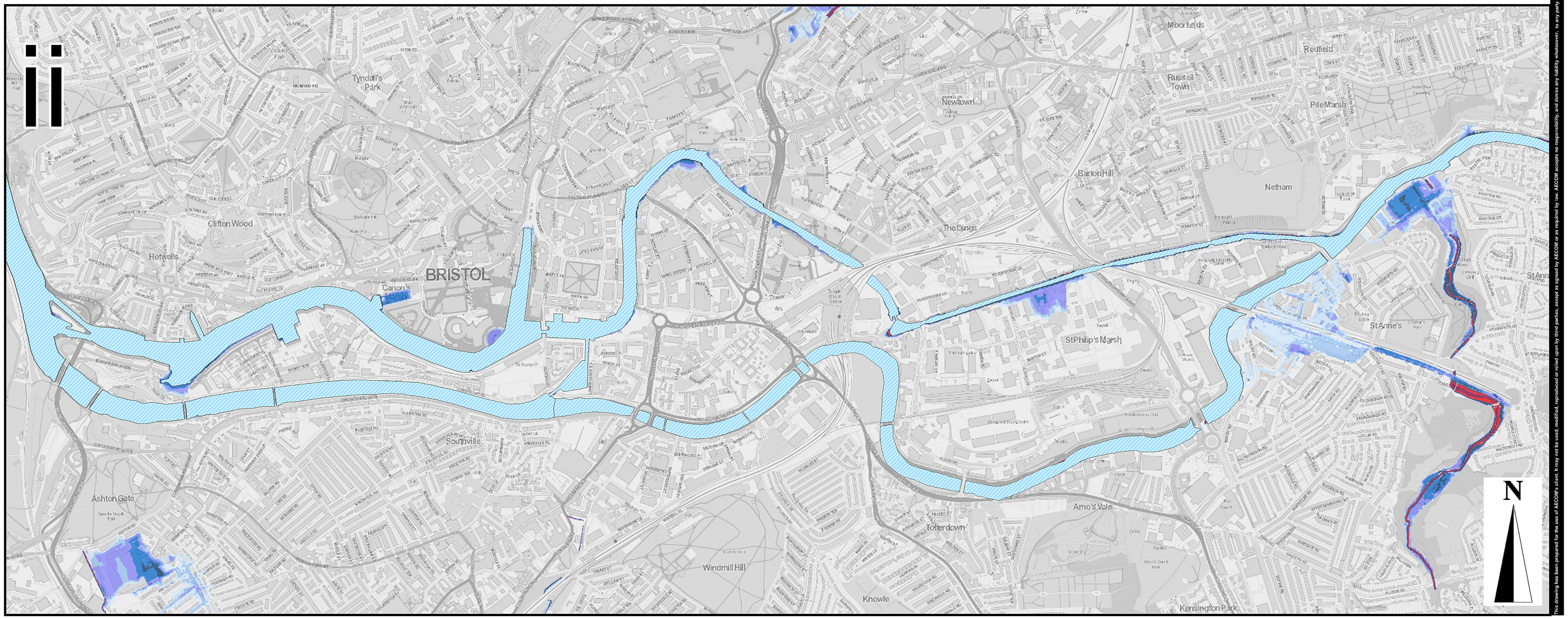
Drawing Title:

HIGH DEFENCE MEASURES
1000 YR RETURN PERIOD
2115
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 2E			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016





AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

- River Avon / Floating Harbour

Maximum Flood Depth

- 0.00m to 0.15m
- 0.15m to 0.30m
- 0.30m to 0.60m
- 0.60m to 0.90m
- 0.90m to 1.50m
- 1.50m to 2.00m
- >2.00m

i) Undefended Scenario
ii) High Walls (SoP T200F002, 2115)

Model Reference:

CAFRA_132_BASE_F200_TBASE_2015
CAFRA_136_BASE_F200_TBASE_2015_HD

Copyright:

AECOM Internal Project No:

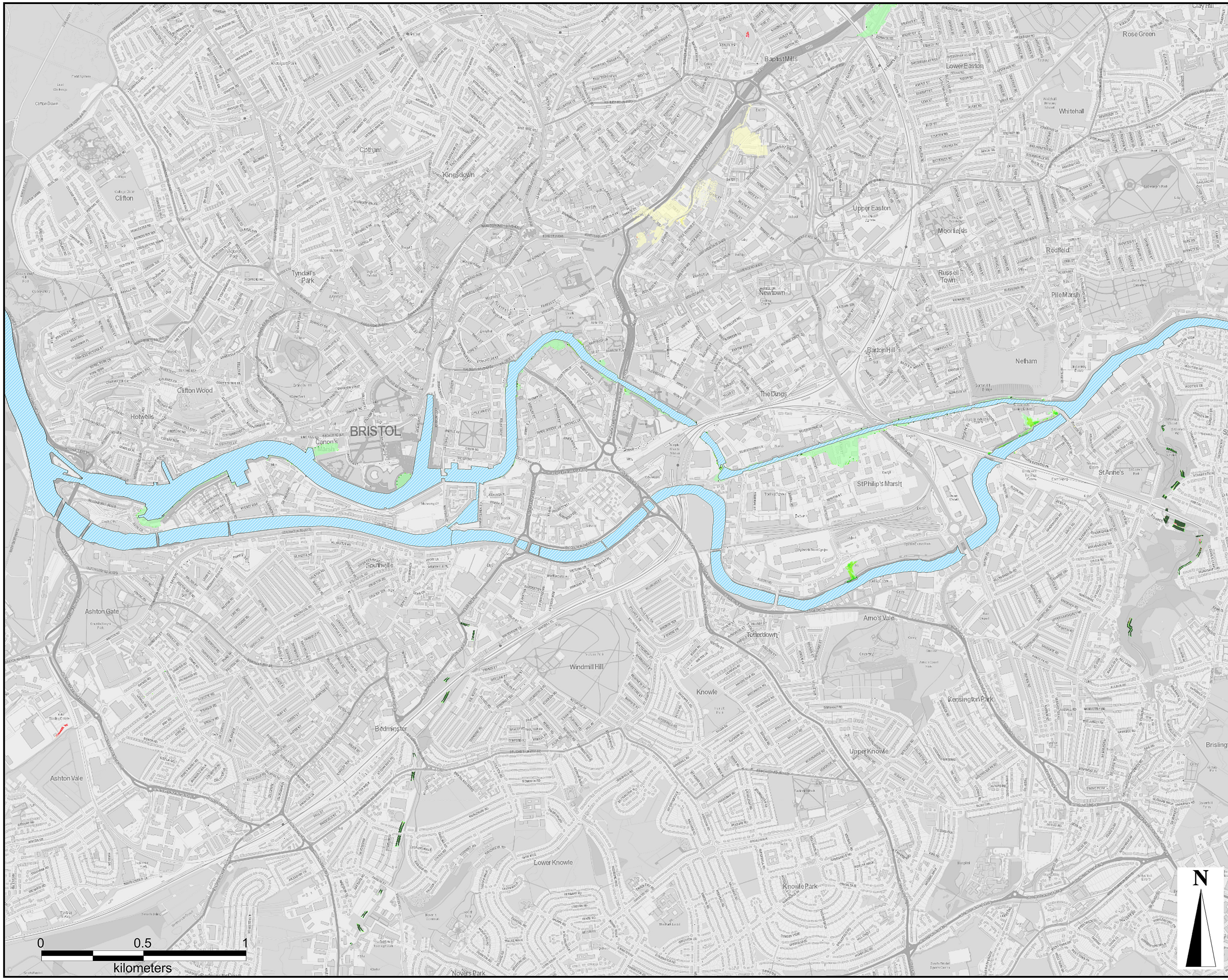
60478613

Drawing Title:

UNDEFENDED VS DEFENDED
200 YR FLUVIAL RETURN PERIOD
2015
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 3A			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+5 to <+20
- >-5 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

Copyright:

AECOM Internal Project No:

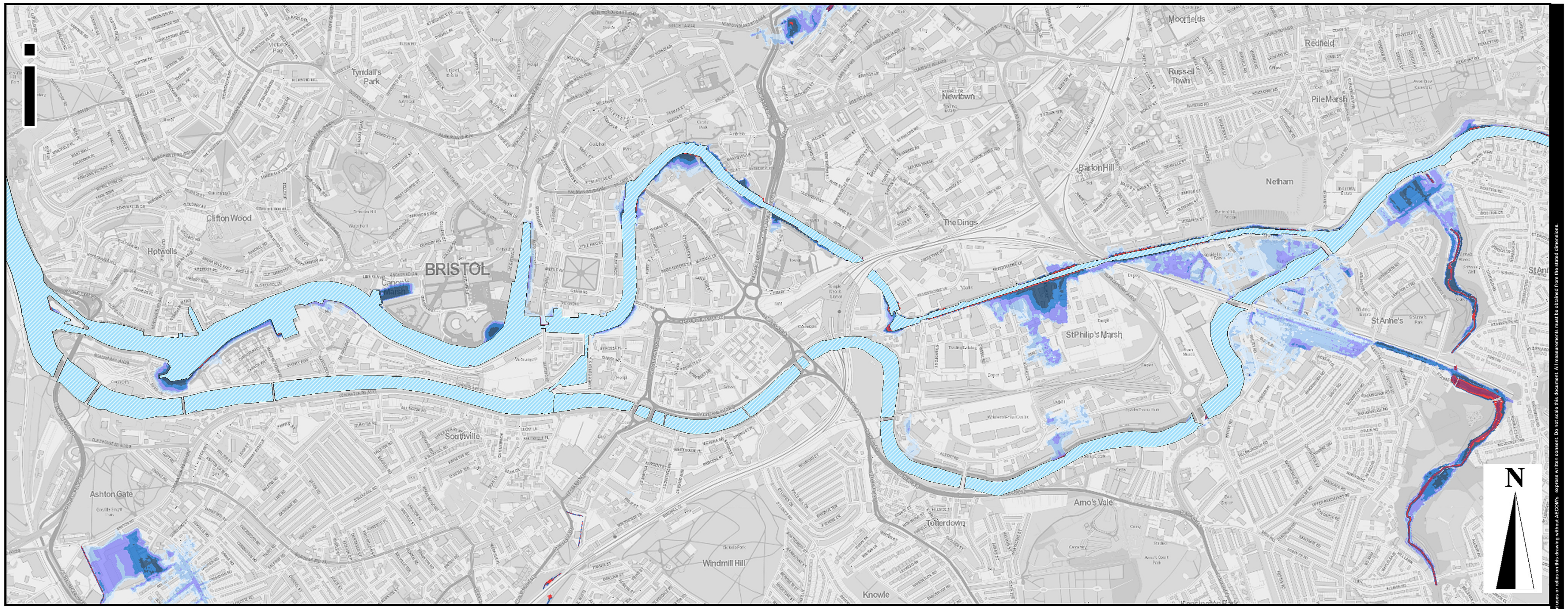
60478613

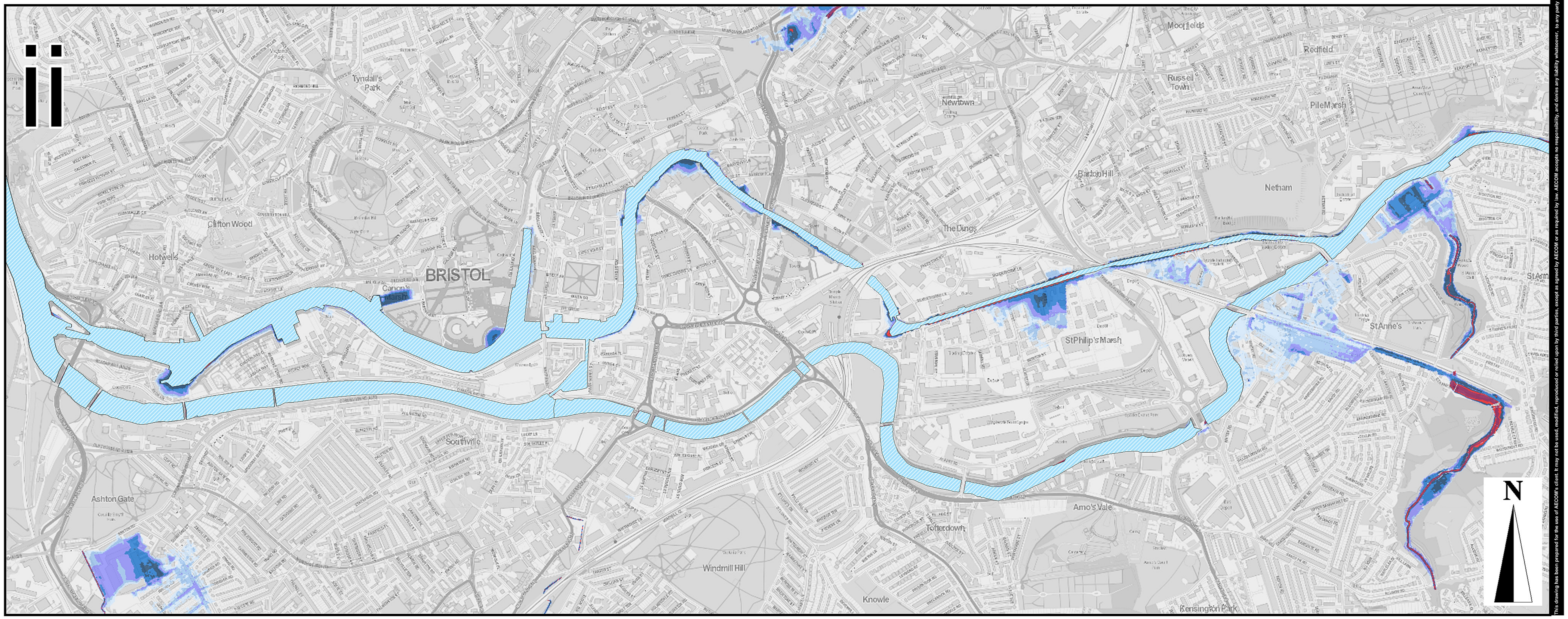
Drawing Title:

WATER LEVEL DIFFERENCE MAP
DO MINIMUM VS HIGH WALLS
200 YR FLUVIAL RETURN PERIOD
2015

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 3B			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016





AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Depth

- 0.00m to 0.15m
- 0.15m to 0.30m
- 0.30m to 0.60m
- 0.60m to 0.90m
- 0.90m to 1.50m
- 1.50m to 2.00m
- >2.00m

i) Undefended Scenario
ii) High Walls (SoP T200F002, 2115)

Model Reference:

CAFRA_132_BASE_F200_TBASE_2030
CAFRA_136_BASE_F200_TBASE_2030_HD

Copyright:

AECOM Internal Project No:

60478613

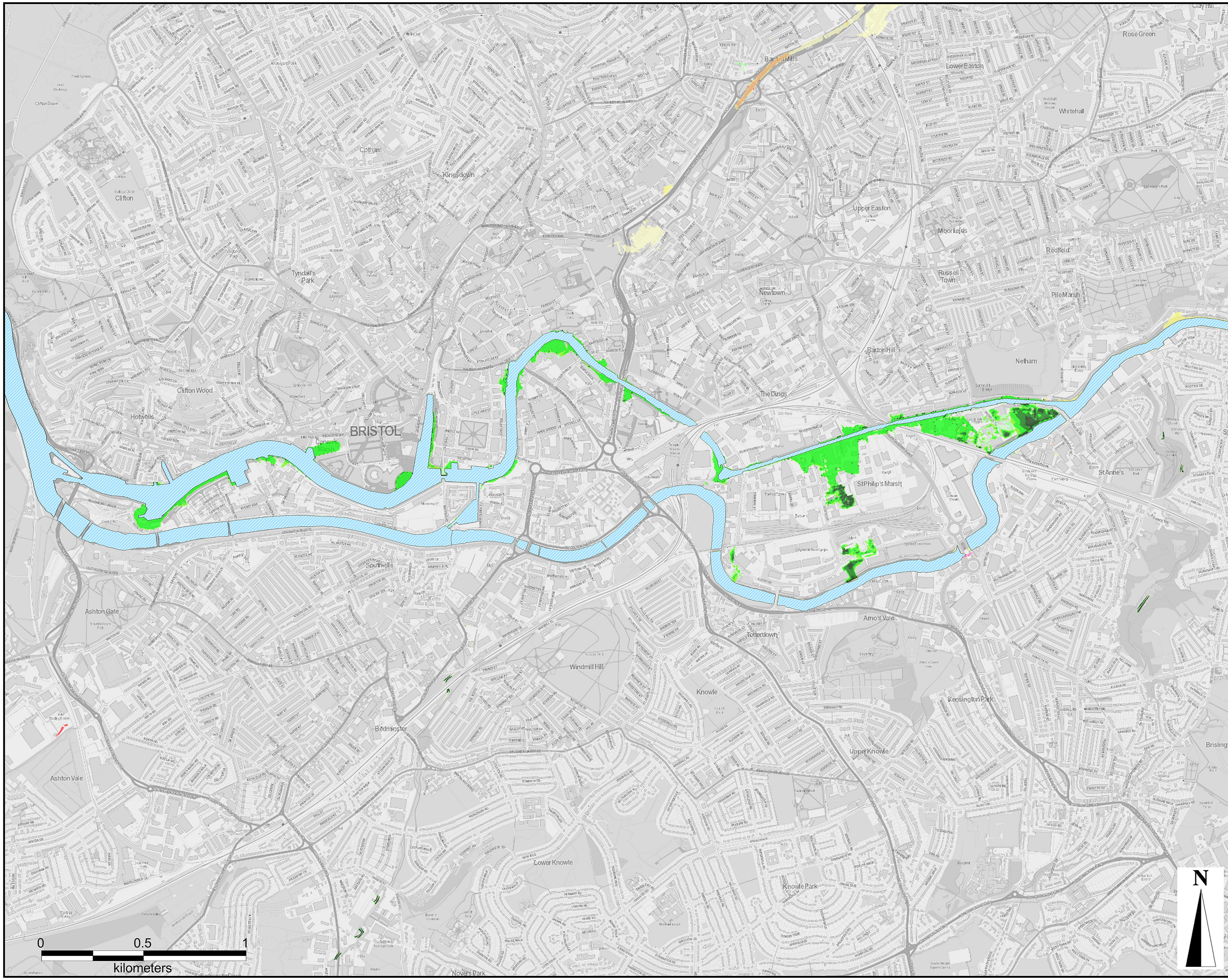
Drawing Title:

UNDEFENDED VS DEFENDED
200 YR FLUVIAL RETURN PERIOD
2030
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:	Rev:
FIGURE 3C	1

Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM
AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+5 to <+20
- >-5 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

AECOM Internal Project No:

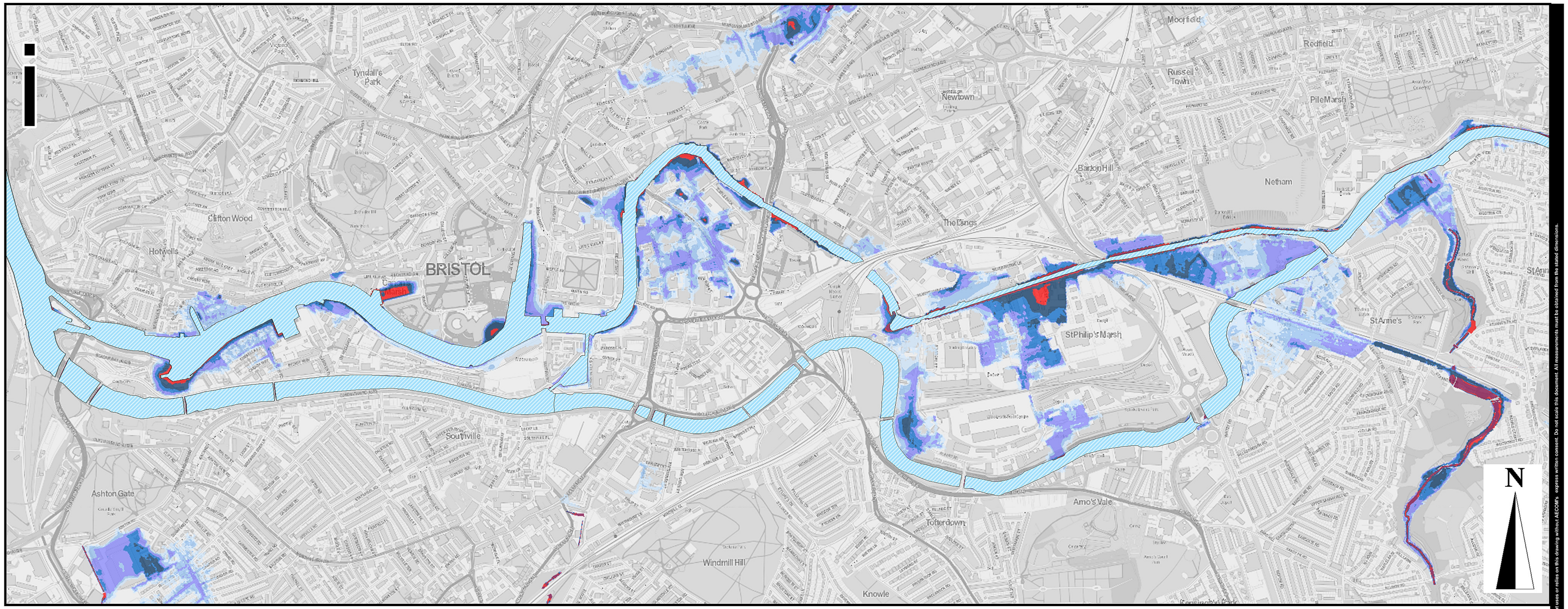
60478613

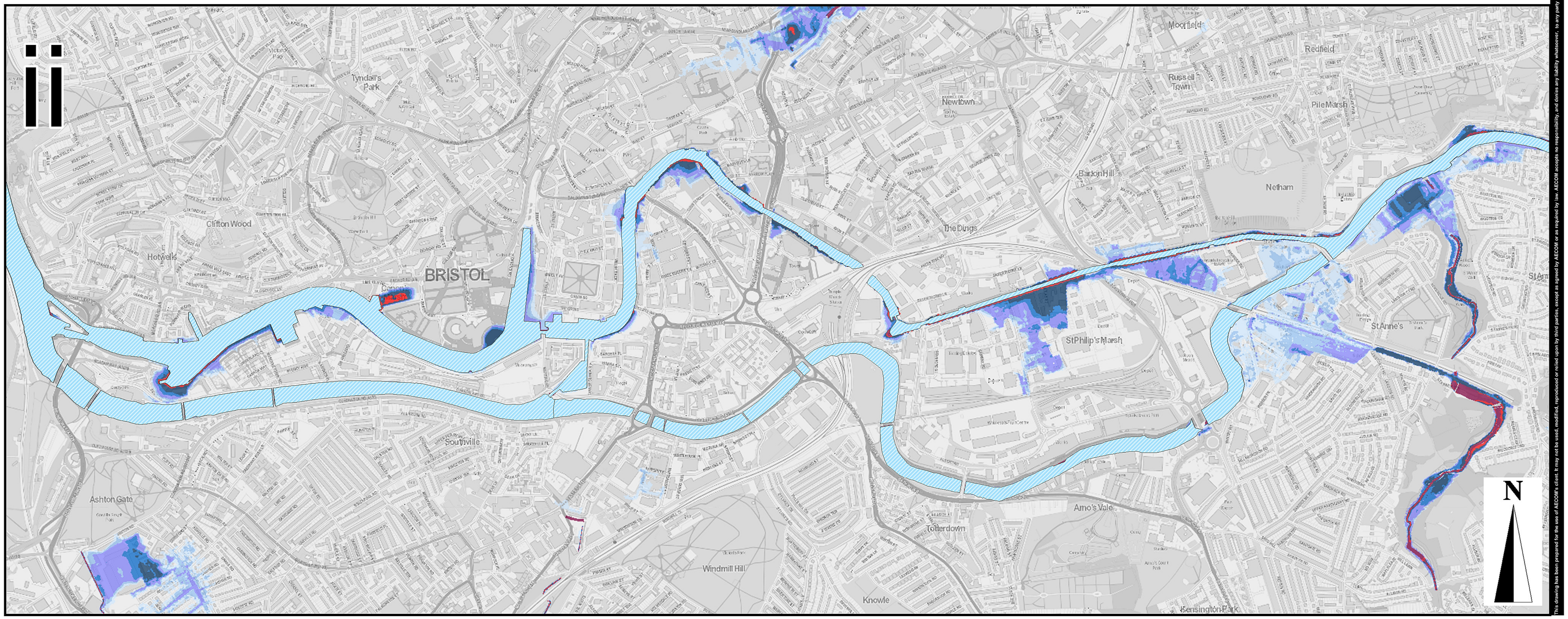
Drawing Title:

WATER LEVEL DIFFERENCE MAP DO MINIMUM VS HIGH WALLS 200 YR FLUVIAL RETURN PERIOD 2030

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 3D			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016





AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Depth

- 0.00m to 0.15m
- 0.15m to 0.30m
- 0.30m to 0.60m
- 0.60m to 0.90m
- 0.90m to 1.50m
- 1.50m to 2.00m
- >2.00m

i) Undefended Scenario
ii) High Walls (SoP T200F002, 2115)

Model Reference:

CAFRA_132_BASE_F200_TBASE_2065
CAFRA_136_BASE_F200_TBASE_2065_HD

Copyright:

AECOM Internal Project No:

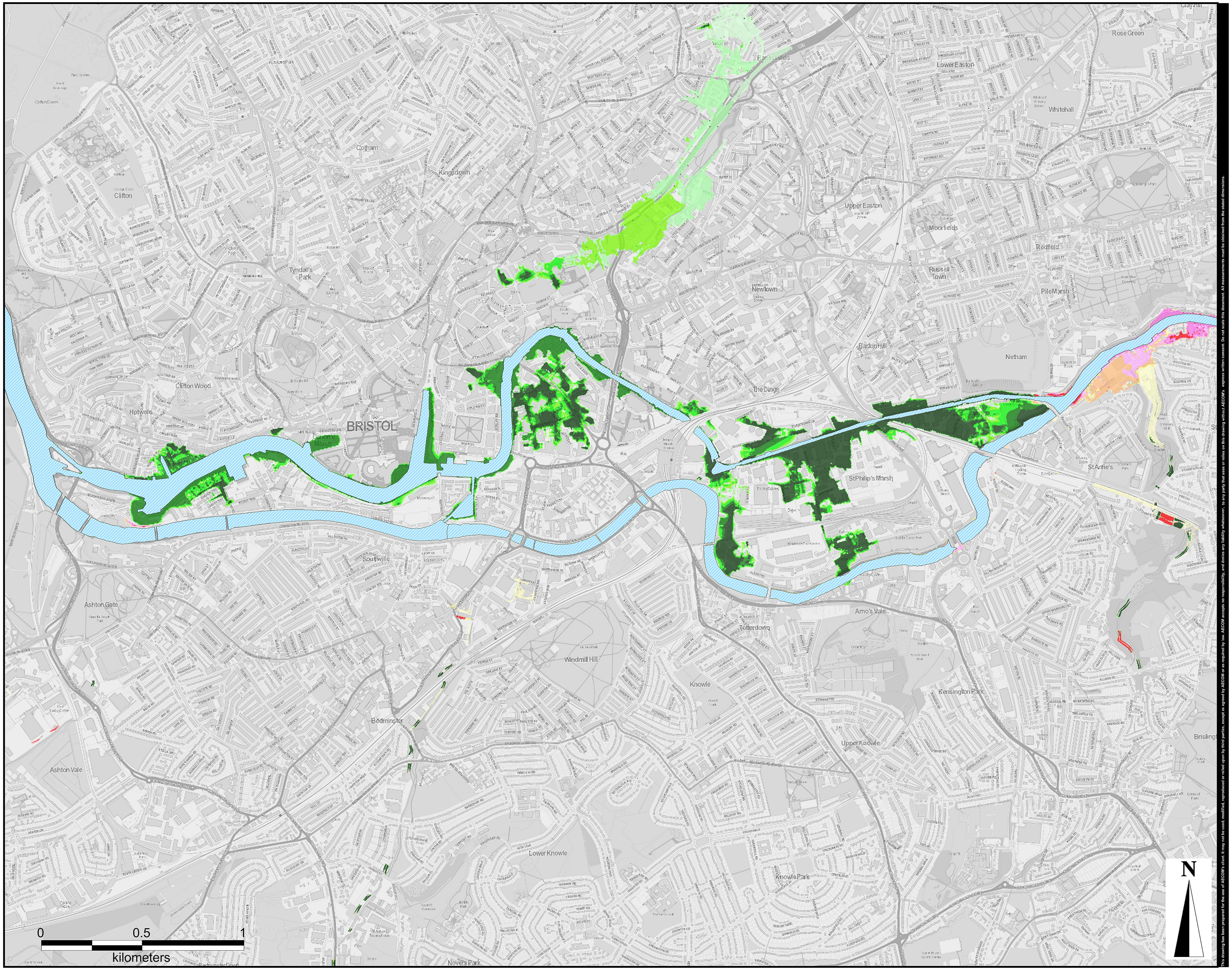
60478613

Drawing Title:

UNDEFENDED VS DEFENDED
200 YR FLUVIAL RETURN PERIOD
2065
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 3E			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM
AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+5 to <+20
- >-5 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

AECOM Internal Project No:

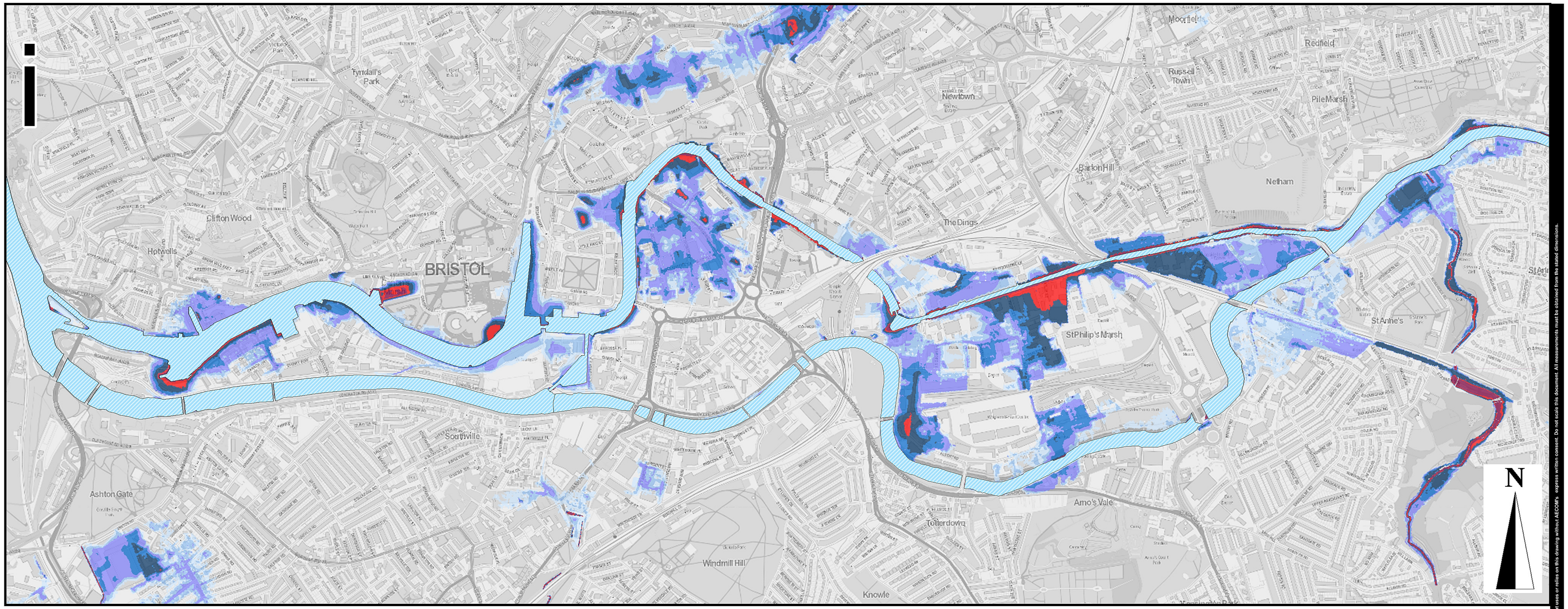
60478613

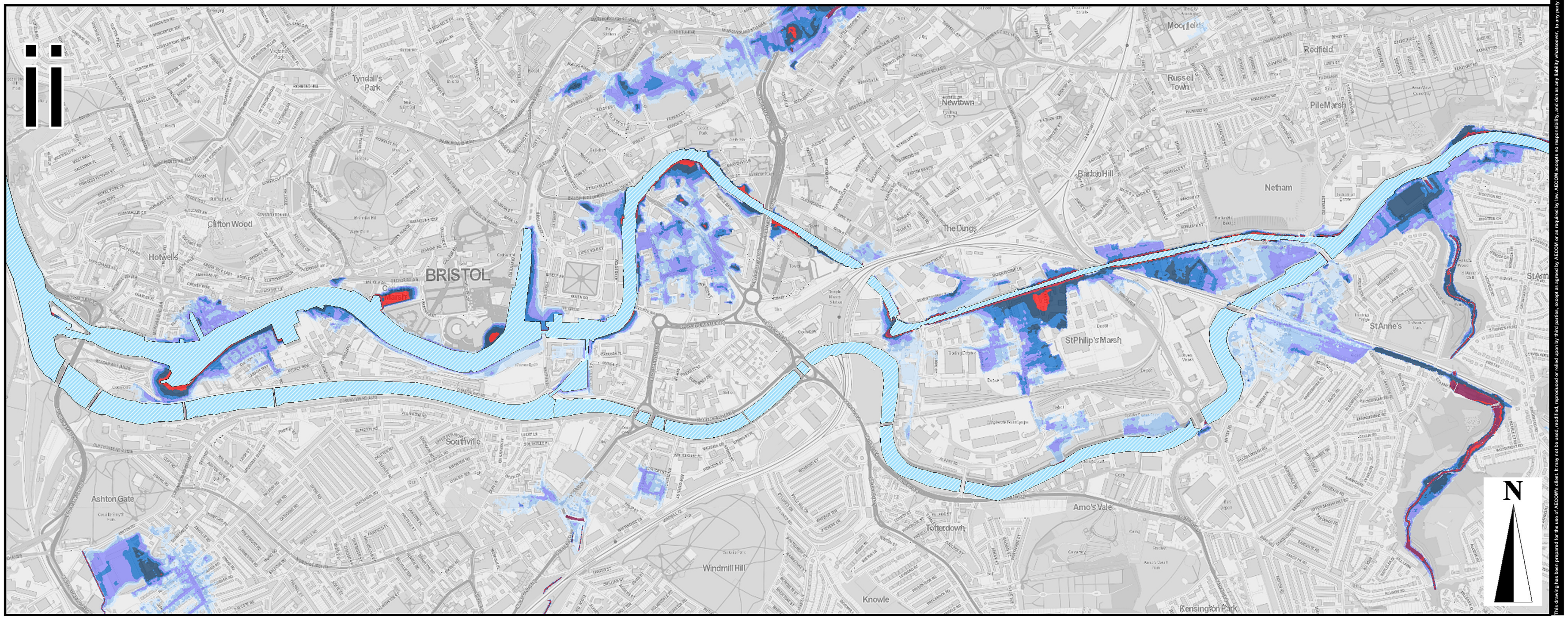
Drawing Title:

WATER LEVEL DIFFERENCE MAP
DO MINIMUM VS HIGH WALLS
200 YR FLUVIAL RETURN PERIOD
2065

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE 3F			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016





AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

- River Avon / Floating Harbour

Maximum Flood Depth

- 0.00m to 0.15m
- 0.15m to 0.30m
- 0.30m to 0.60m
- 0.60m to 0.90m
- 0.90m to 1.50m
- 1.50m to 2.00m
- >2.00m

i) Undefended Scenario
ii) High Walls (SoP T200F002, 2115)

Model Reference:

CAFRA_132_BASE_F200_TBASE_2115

CAFRA_136_BASE_F200_TBASE_2115_HD

Copyright:

AECOM Internal Project No:

60478613

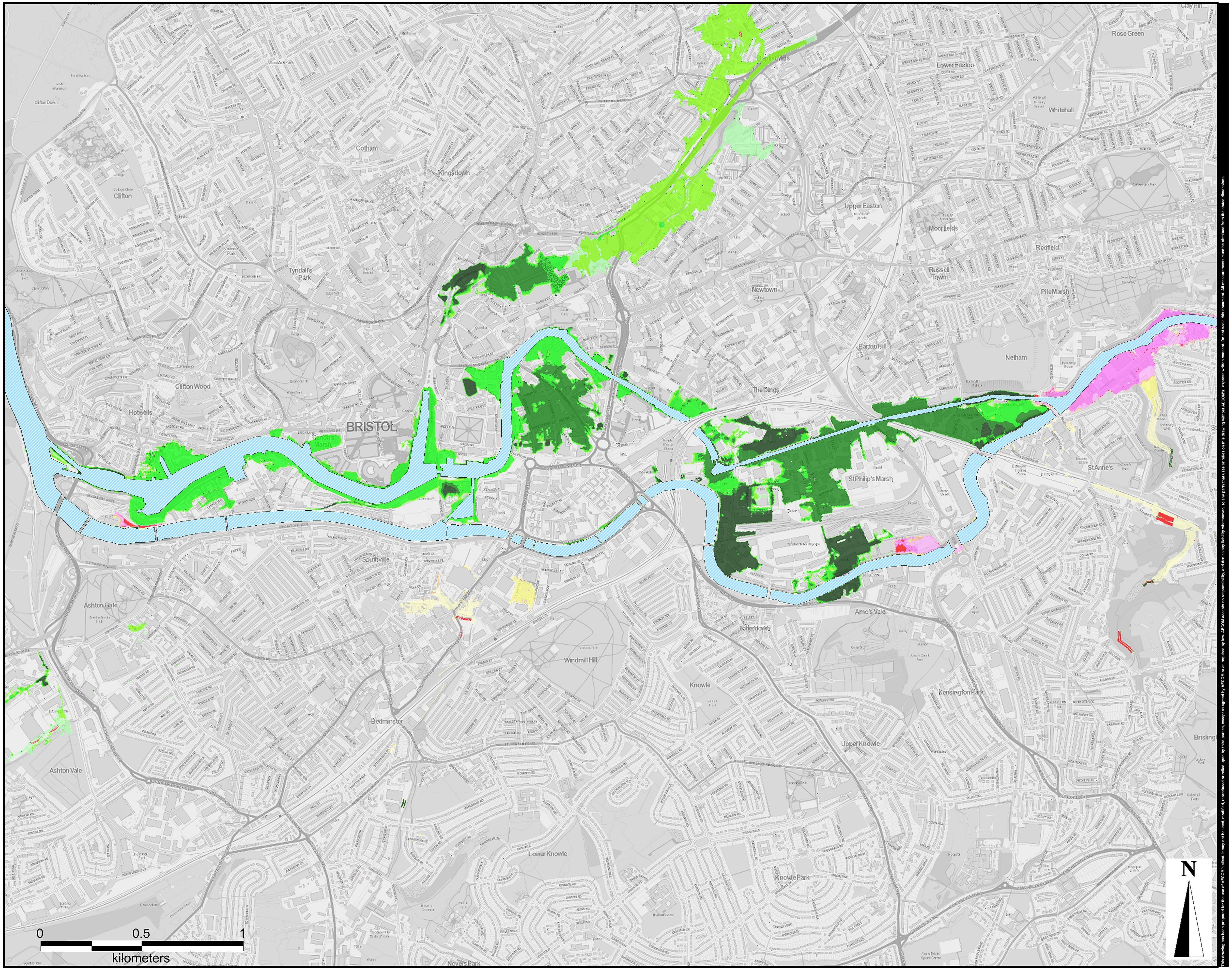
Drawing Title:

UNDEFENDED VS DEFENDED
200 YR FLUVIAL RETURN PERIOD
2115
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:	Rev:
FIGURE 3G	1

Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016



AECOM

AECOM
The Crescent Centre
Bristol, BS1 6EZ
+44 (0)117 917 1200
www.aecom.com

Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+5 to <+20
- >-5 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

Copyright:

AECOM Internal Project No:

60478613

Drawing Title:

WATER LEVEL DIFFERENCE MAP DO MINIMUM VS HIGH WALLS 200 YR FLUVIAL RETURN PERIOD 2115

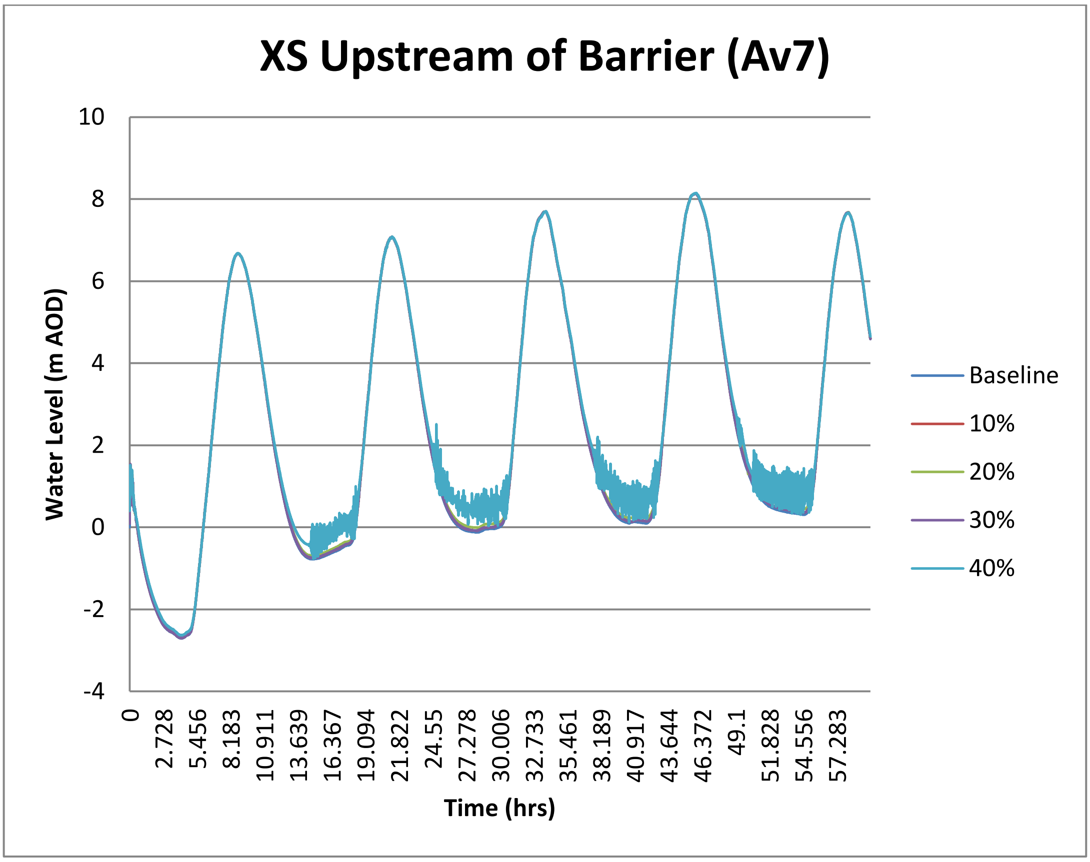
Scale at A3: 17,500

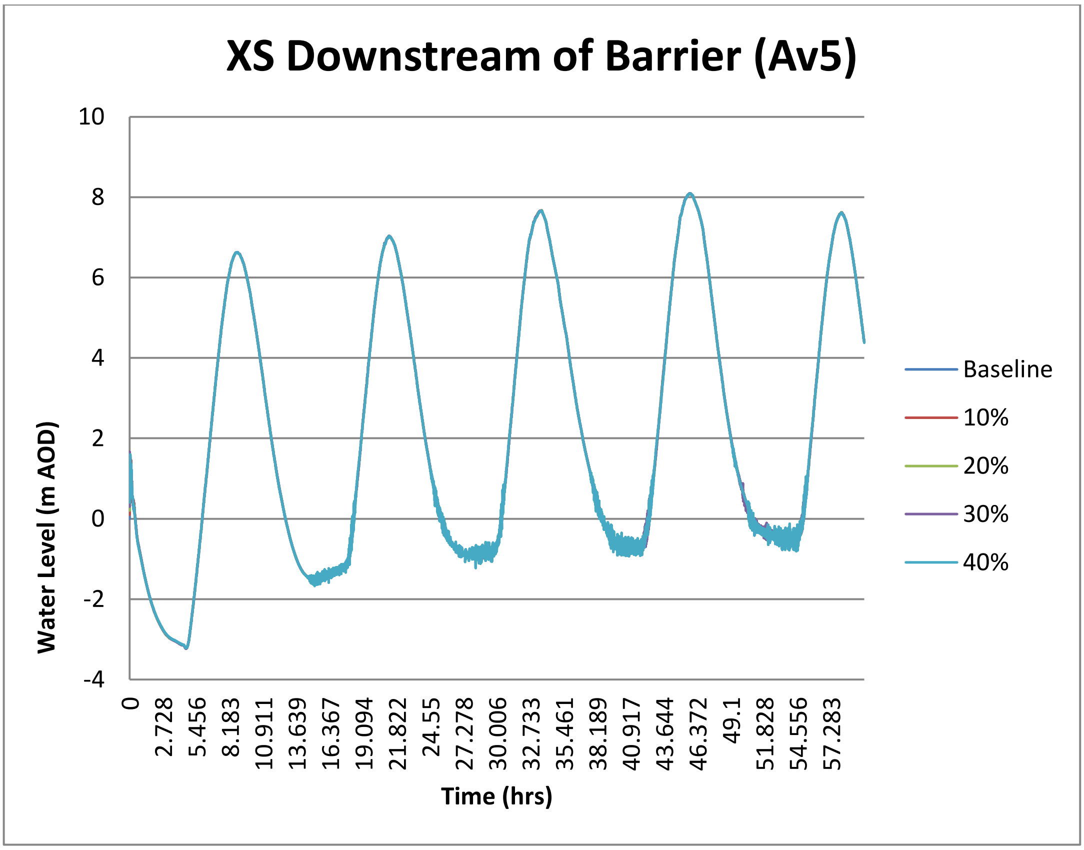
Drawing No:			Rev:
FIGURE 3H			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	Sept 2016

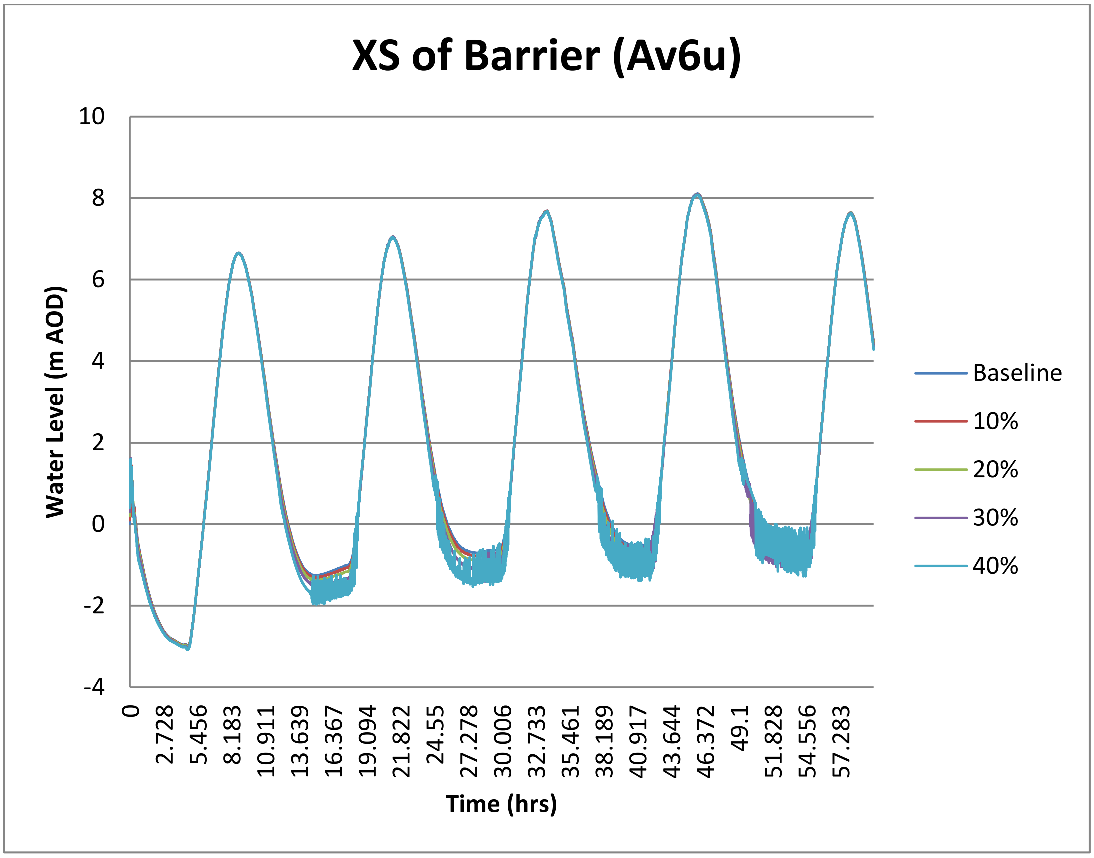
APPENDIX B

Barrier Impedance Results

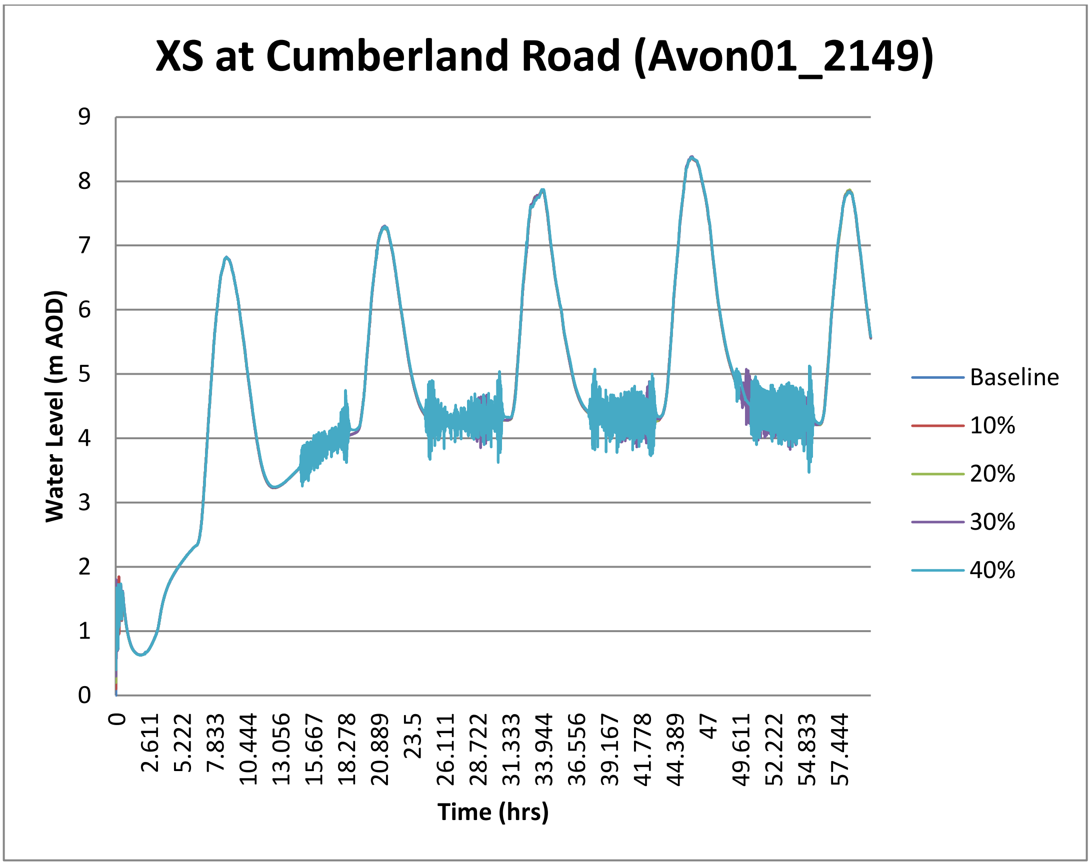
Impedance Testing 2015





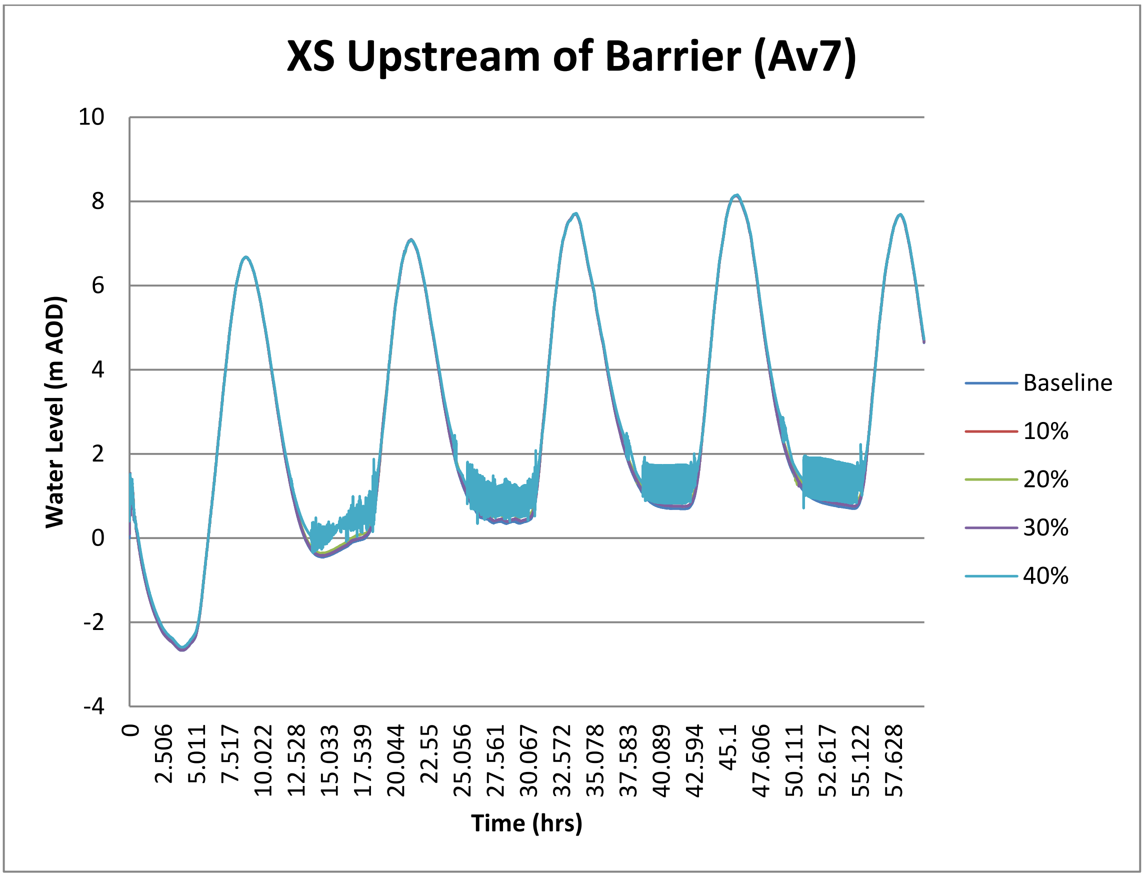


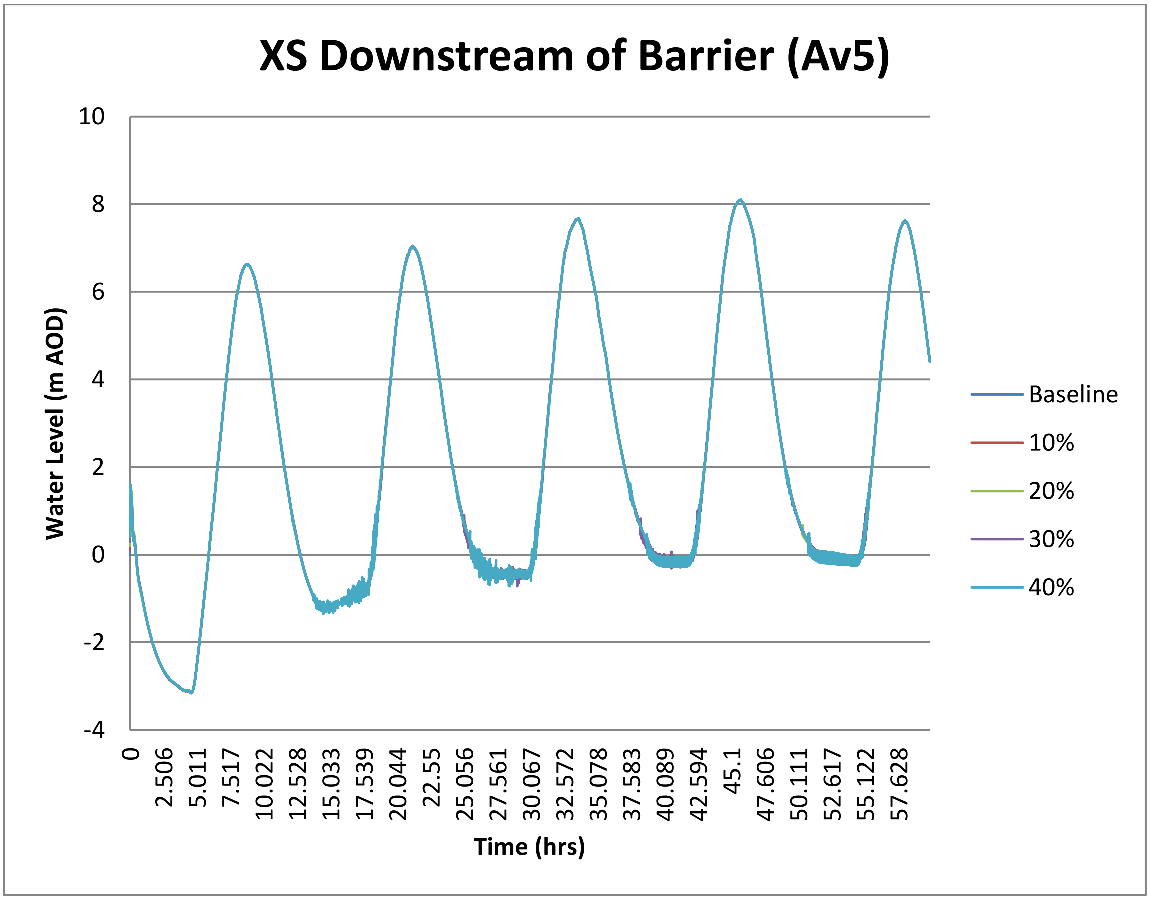
XS of Barrier (Av6u)
Water Level (m AOD)
10
8
6
4
2
0
-2
-4
0
2.728
5.456
8.183
10.911
13.639
16.367
19.094
21.822
24.55
27.278
30.006
32.733
35.461
38.189
40.917
43.644
46.372
49.1
51.828
54.556
57.283
Time (hrs)
Baseline
10%
20%
30%
40%

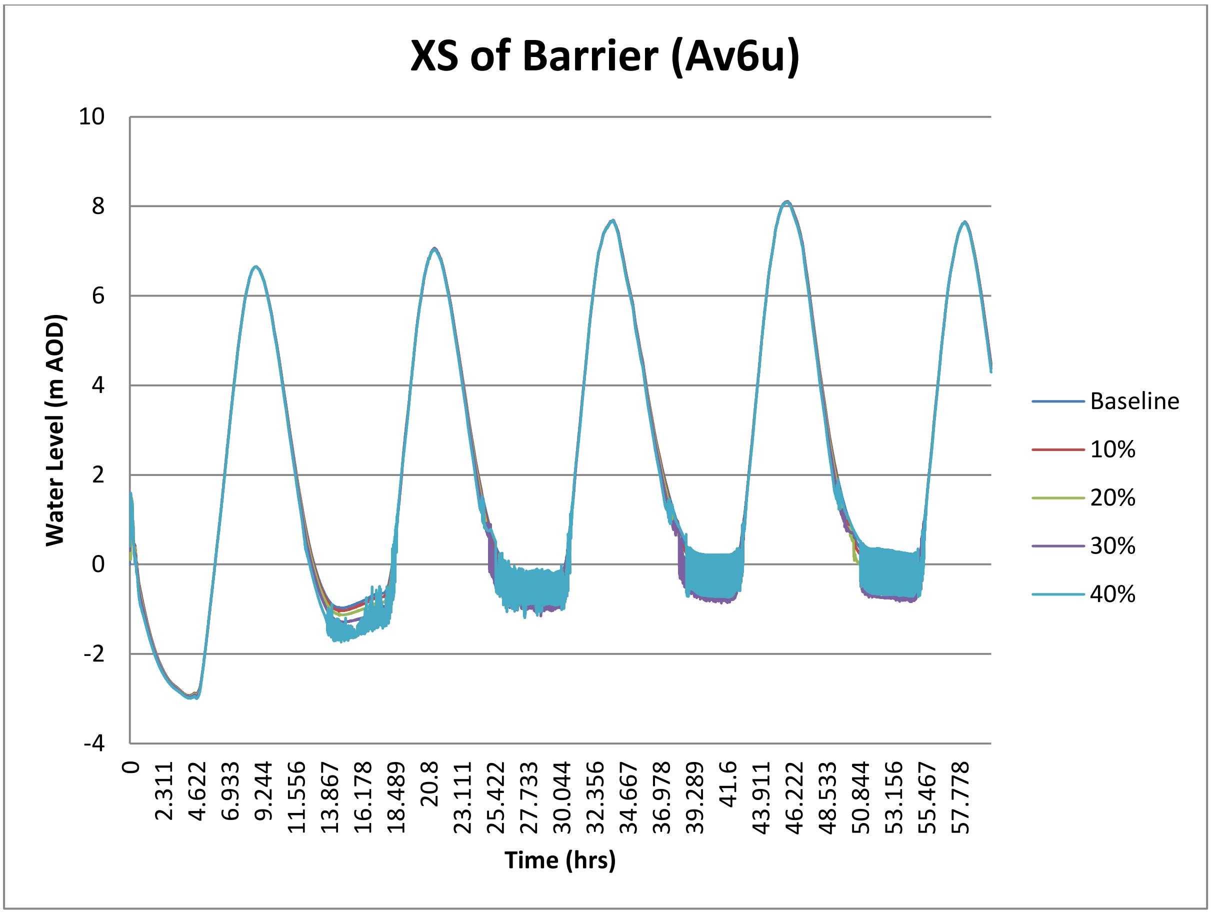


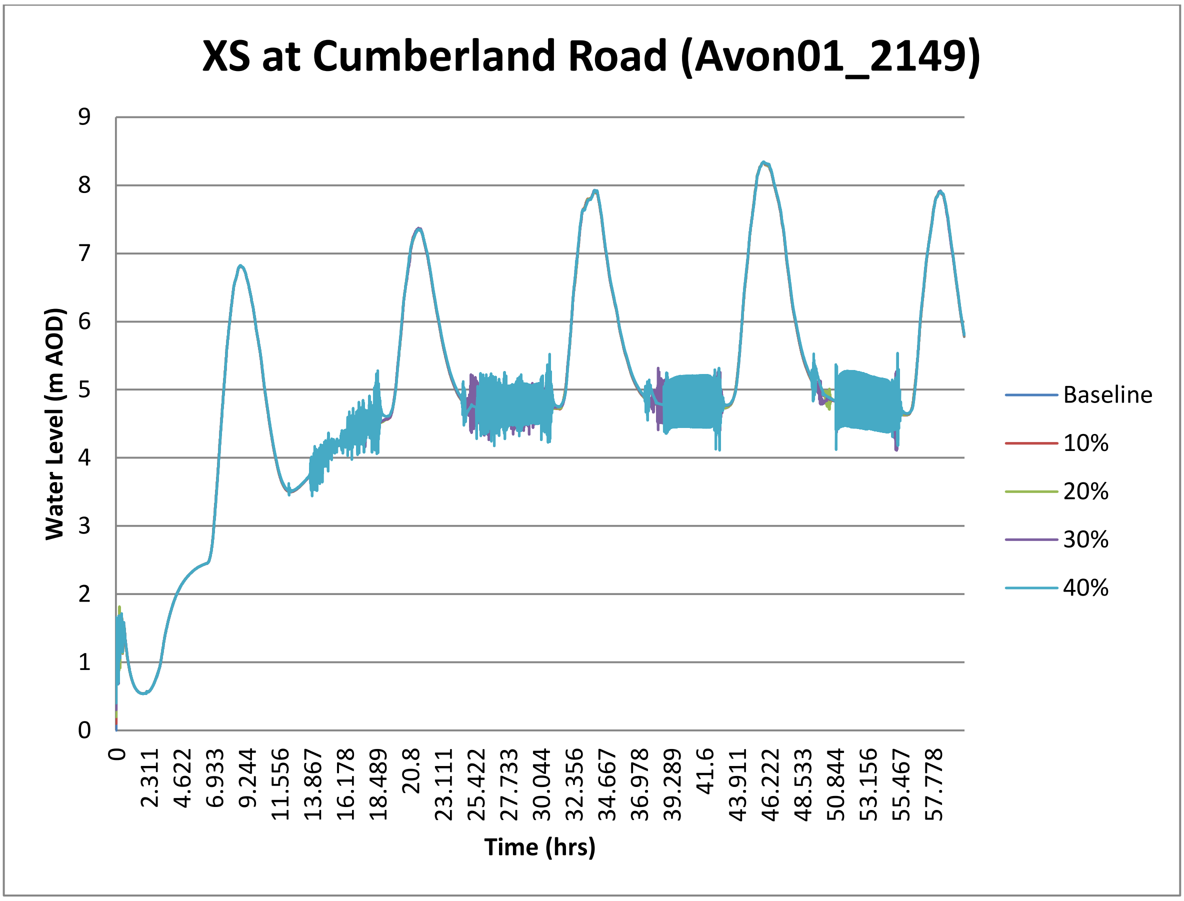
XS at Cumberland Road (Avon01_2149)
Water Level (m AOD)
9
8
7
6
5
4
3
2
1
0
0
2.611
5.222
7.833
10.444
13.056
15.667
18.278
20.889
23.5
26.111
28.722
31.333
33.944
36.556
39.167
41.778
44.389
47
49.611
52.222
54.833
57.444
Time (hrs)
Baseline
10%
20%
30%
40%

Impedance Testing 2115






XS of Barrier (Av6u)
Water Level (m AOD)
10
8
6
4
2
0
-2
-4
0
2.311
4.622
6.933
9.244
11.556
13.867
16.178
18.489
20.8
23.111
25.422
27.733
30.044
32.356
34.667
36.978
39.289
41.6
43.911
46.222
48.533
50.844
53.156
55.467
57.778
Time (hrs)
Baseline
10%
20%
30%
40%


XS at Cumberland Road (Avon01_2149)
Water Level (m AOD)
9
8
7
6
5
4
3
2
1
0
0
2.311
4.622
6.933
9.244
11.556
13.867
16.178
18.489
20.8
23.111
25.422
27.733
30.044
32.356
34.667
36.978
39.289
41.6
43.911
46.222
48.533
50.844
53.156
55.467
57.778
Time (hrs)
Baseline
10%
20%
30%
40%

ABOUT AECOM