RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Hydraulic Modelling Report (Short Listing Phase)

October 2016

FinalReport

REVISION SCHEDULE					
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Limitations

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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 April 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.

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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 River Avon in Bristol.

As part of this commission, a hydraulic modelling study of the region was required to define the baseline tidal flood risk. Hydraulic modelling and simulation of extreme water levels is a key aspect of the Strategy development and is required to understand the risks faced, demonstrate the mechanisms of flooding, inform the delivery of the economic case and also for testing and confirming management options.

1.2 Hydraulic Modelling Report

To support the Strategy, this report details the model build, methodology for the modelling study and provides the baseline results for a range of return periods over time, namely the 'Do Nothing', 'Do Minimum'. The 'Do Something' scenario has also been simulated. The resultant hydraulic model outputs have been used to develop baseline flood damages assessments.

At the outset, Bristol City Council stated that the walk-away solution, or 'Do Nothing', is not congruent with the outputs of previous studies and vision for the City, which promotes integrated and sustainable solutions. Furthermore, the ensuing high risk to life and property makes the 'Do Nothing' scenario unrealistic. It is however an important baseline against which management options to reduce flood risk can be compared.

The emphasis of the Strategy is to reduce tidal flood risk beyond the current 'Do Minimum management regime, where the 'status quo' is maintained. Therefore, even though the 'Do Nothing' scenario is not considered as a suitable option it has been necessary to simulate the flood risk under this scenario to derive and compare the economic benefits and the relative merits of the various 'Do Something' options. This ensures that the Strategy requirements are met and the most economically favourable options are pursued, whilst also focusing work on developing and delivering reductions in flood risk over and above the current situation.

This Strategy therefore focuses attention on:

- Investigating a range of combined engineering solutions throughout Bristol to improve resilience against tidal inundation;
- Working closely with key operational teams and stakeholders to develop realistic solutions; and,
- Developing a range of preferred solutions through understanding the existing and future baseline economic risk and benefits which may be available.

1.3 Background

Bristol City Council owns an extensive volume of hydraulic model development and available information and a technical modelling review was completed by AECOM in March 2016. The technical modelling review formed the basis of assessing the suitability of the available models completed within the Bristol Central Area Flood Risk Assessment (CAFRA).

The CAFRA study followed a workstream approach with a number of packages of work within each workstream. Each workstream (WS) has been reported separately, often with a number of additional technical notes and appendices to support the main report. The four CAFRA WS's were:

- **WS1** – Collection & Review of existing hydraulic models, studies and survey data.
- **WS2** – Hydrological statistical analysis of key sub-catchments to derive peak flows. These were used with predicted upper end tidal levels to inform the hydraulic model boundary conditions. The study considered the joint probability of high river flows coinciding with tidal surges and assessed climate change impacts for 2060 and 2110 epochs.
- **WS3** – Documents the 1D-2D hydrodynamic model build. Combined predictions of flood water peak depth and extent for present day and with climate change allowances. Predicted flood risk assessed as the maximum of a composite range of tidal and fluvial events with the same probability of occurrence.
- **WS4** – Reviewed fluvially-dominated flood risk, scoped fluvial flood risk management interventions and assessed the NSWI intake operational procedure. Included a parallel Harbour Study focussed on the tidally dominated central Bristol with separate modelling, building on the work of the Floating Harbour asset management strategy. Also included a pre-feasibility study of nominal River Avon tidal barrier options.

In addition to representing the interaction between the in-channel conditions and floodplain propagation of fluvial and tidal events, the WS3 model was also calibrated, verified, peer reviewed and approved. As such, BCC and the Environment Agency confirmed that the WS3 model is considered to be the accepted baseline for flood risk assessment in Bristol at a strategic level.

As an addendum to the original 2010-2012 CAFRA WS3 modelling, two significant updates to the CAFRA WS3 modelling have been undertaken more recently:

- **2014** - Assessment of the St Philips Marsh Flood Defences and lower return period events; and
- **2015** - Update work for climate change scenarios on tidally dominated events and assessment of the Cumberland Road defence.

As a result of utilising the existing CAFRA WS3 hydraulic model, this report does not focus on the general model development prior to the Bristol TFRMS. The CAFRA WS3 hydraulic model development is extensively reported within the 'Central Area Flood Risk Assessment – Modelling Report (Workstream 3)' (BCC, 2012). The report herein describes the process whereby the existing model data in CAFRA WS3 is updated to represent the requirements of the Strategy.

1.4 Study Area

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

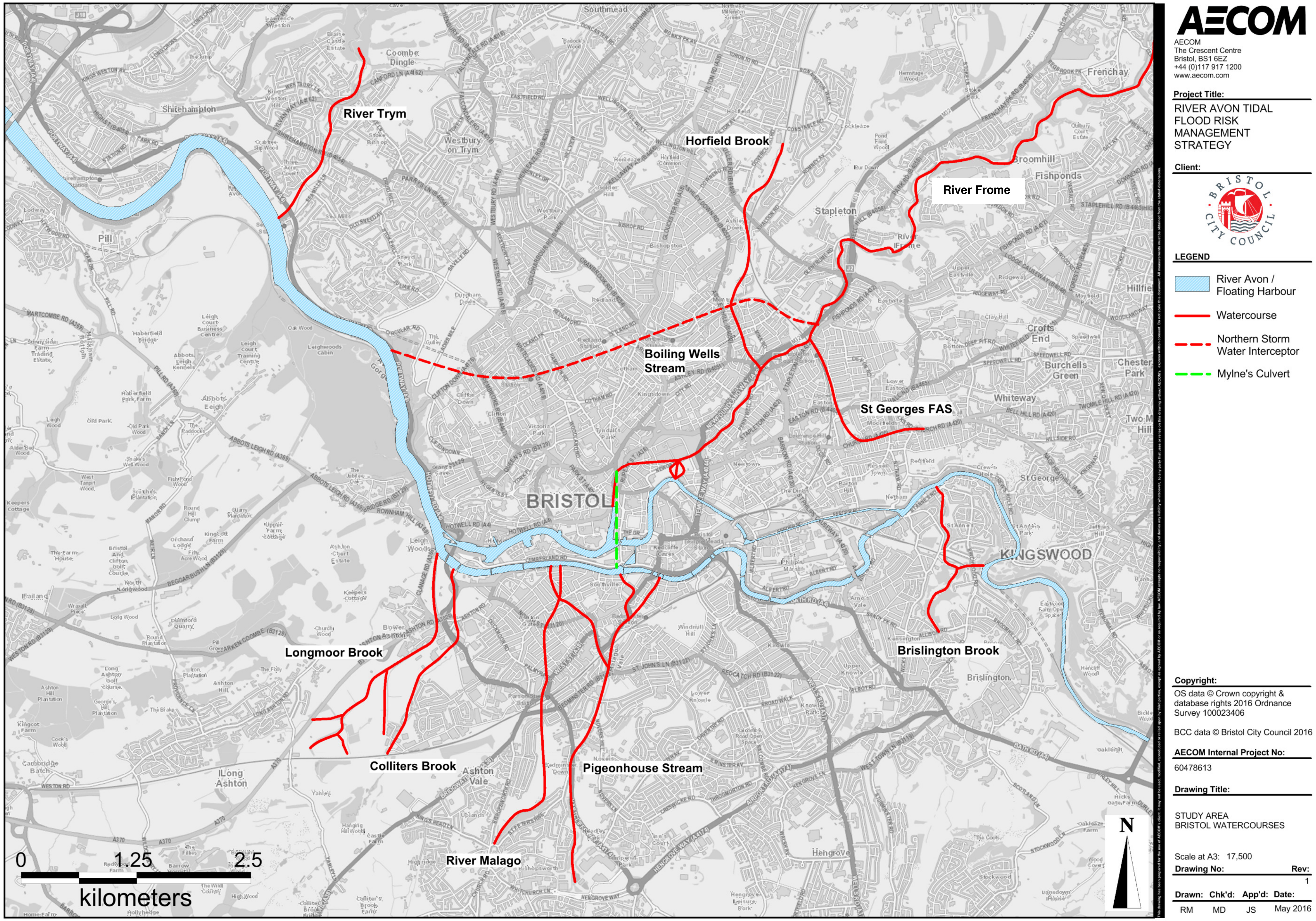


Figure 1: Study Area

1.5 Strategic Issues

Through the review of available studies, alongside discussions with BCC and the Environment Agency, it has been concluded that the following strategic issues will have a large influence on the preferred solution for the Strategy:

- Review of available studies indicates that large-scale capital works alone may not adequately address combined flood risk in Bristol. This reflects the complex interaction between tidal and fluvial sources;
- A combination of a phased and/or integrated approach between capital scheme, conveyance improvement and structural operation and maintenance work may be necessary to provide an improved resilience for varying low to high frequency tidal flood events;
- Flood management approaches must integrate with environmental and planning regimes; and,
- Strategic partnerships, stakeholder engagement and collateral funding mechanisms are critical to the long-term sustainability of tidal flood risk management throughout Bristol.

2. MODELLING METHODOLOGY

The appropriate creation or adoption of a numerical flood inundation hydraulic model is a key part of delivering a technically robust assessment of tidal flood risk to support the development of the Strategy.

The numerical modelling process:

- Facilitates a greater understanding of flood inundation risk associated with extreme water level events;
- Simulates the overtopping of existing bank heights and defences associated with combined tidal and fluvial events;
- Determines flood depths and extents under a range of scenarios which can be efficiently used to provide flood damages required for the economic assessment;
- Delivers an efficient tool to explore and demonstrate the effectiveness of potential management options; and
- Provides flood mapping to help illustrate the issues, and demonstrate the benefits of the Strategy to various stakeholders.

2.1 Overview of the Study and Tasks

The modelling approach incorporated the adoption and updating of the existing BCC CAFRA WS3 hydraulic model. Adopting an Environment Agency approved model provides regional model development efficiencies covering the Strategy study area (Figure 1) and a robust background for future work.

The key objectives, tasks and activities undertaken are summarised below, and are covered in more detail in subsequent chapters:

Model Setup (Section 2)

This section describes the methodology and assumptions regarding the update to the CAFRA WS3 hydraulic model to represent the following baseline scenarios:

- Do Nothing – Hypothetical baseline; and,
- Do Minimum – Maintain ‘status quo’.

Baseline Results (Section 3)

This section appraises the results of Section 2 (baseline modelling) and details the resultant economic assessment of all baseline scenarios, namely:

- The number of residential and non-residential properties at risk for each return period;
- Baseline damages and economic assessment; and,
- Observations to be taken forward for Options Testing.

Options Testing (Section 4)

This section details the process undertaken, proceeding from the baseline representation of tidal flood risk, in determining the options which have been discussed and tested as part of this Strategy. Specifically, this section includes details regarding;

- Discussion of options considered and options rejected;
- Model simulations undertaken to represent options; and,
- Presentation of preferred options, including;
    - Environmental considerations;
    - Key delivery risks;
    - Economic summary, Outcome Measures and Priority; and,
    - Funding Contributions.

Conclusions and Recommendations (Section 5)

This section discusses the outcome of the hydraulic modelling study providing recommendations for 'next steps' to progress the Strategy.

2.2 Model Setup

2.2.1 *Modelling Software*

The CAFRA WS3 ISIS-TUFLOW model has been retained to model a range of flood event scenarios, allowing for full hydraulic linking between the complex and numerous floodplain regions within Bristol.

ISIS is a one-dimensional (1D) package used for modelling river channels, including bridges, culverts, weirs and other structures, calculating the varying water levels within the channel. TUFLOW is a two-dimensional (2D) hydraulic modelling package that simulates hydrodynamic behaviour of flood waters across the floodplain. Combining the two software packages is achieved through a hydraulic link to simulate the effects of channel flow entering the floodplain and vice versa at a grid resolution appropriate for ensuring that all flood mechanisms are accurately represented. This modelling software is widely used for modelling complex tidal and fluvial inundation scenarios and is considered as industry standard by the Environment Agency.

The original CAFRA WS3 model is a multi-domain ISIS-TUFLOW model with more than 2,500 ISIS nodes and eight TUFLOW 2D domains. The original model was developed and run using ISIS Version 3.5 and TUFLOW Version 2011-09-AE-iSP-w64 software builds. The 2015 Climate Change update runs have been run using the latest versions of the ISIS and TUFLOW software which has resulted in some minor changes in water levels compared to previous versions, particularly in the fluvial reaches of the model (with no interaction with the Floating Harbour). All modelling undertaken by AECOM as part of this study for the Bristol TFRMS has used the following software versions:

- ISIS – v3.7
- TUFLOW – 2013-12-AC-iDP-w64

2.2.2 *Tidal Hydrology*

The original 2010-2012 CAFRA WS3 modelling adopted the "Upper End Estimates" for sea level rise, as defined in the Environment Agency's guidance on Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities (Environment Agency, 2011). The "Upper End Estimates" for sea level rise are based on the 'high' emissions climate change scenario. This scenario equates to sea level rise of +1.01m over the 100 year study period. This precautionary approach was adopted because of the potentially very high consequences of tidal flooding to Bristol and the close alignment with planning guidance (NPPF) which sets out development policy to adopt the Defra 2006 'high emissions' scenarios of climate change.

The tidal boundaries used in the original CAFRA modelling related to a 2008 baseline from the Environment Agency National Coastal Boundary dataset. These were updated in WS3 to a 2010 baseline using the Upper End Estimates for sea level rise.

The 2015 climate change update used the predicted Severn Estuary Strategy (Environment Agency, 2011) climate change allowance of 2.4mm/yr to derive sea level rise allowances from 2008-2015.

For the CAFRA WS3 updated modelling study (2015), UKCP09 Medium Emissions 95%ile and UKCP09 High Emissions 95%ile (including allowances for vertical land movement) were investigated in order to support the assessment and management of flood risk in Bristol. Tide levels for the 2030, 2065 and 2115 epochs used in the climate change update study (Table 1).

The Bristol TFRMS economic assessment (damages and benefits) adopted the Medium Emissions 95%ile scenario as the change factor for future tide levels (Table 1). This ensures that the appraisal is consistent with other FCERMS projects and so the GiA eligibility can be assessed in accordance with FCERM-AG.

To reduce the number of runs required, the proposed tidal levels for each scenario were examined and simulations were only generated for events which could not be assigned equivalent results (generally +/-50mm) from other simulated design events or climate change scenarios. The 2015 climate change update includes an equivalency table summarising where it was possible to use previously run design events or climate change scenarios and where new events were run for the update. This is referred to as a ‘substitution’ or ‘equivalency’ approach, adopting the same equivalency approach as taken in the 2015 climate change update within the Bristol TFRMS modelling work.

It was agreed between AECOM, BCC and the Environment Agency that for the Strategy modelling to underpin the economic appraisal, AECOM would proceed with the recommended change factor for sea level rise and adopts the central estimate for fluvial flows. This results in no required boundary changes in the model and means previous model outputs (e.g. for Do Minimum) can be utilised, minimising the number of simulations required. This approach would ensure consistent climate change allowances with other strategies and is in keeping with FCERM-AG recommendations.

Proportionate sensitivity testing of Lower and Upper fluvial and sea level rise allowances will be carried as part of assessing managed adaptive capacity and Strategy robustness in the context of the range of potential climate change futures. This information will also help inform other wider aspects such as planning, which requires a more precautionary consideration of climate change.

Table 1: Extreme Tide Levels (2015 Climate Change Update)

Epoch	Return Period	Combined Return Period (Sources)		Tide Level (m AOD)		
		Fluvial	Tidal	Upper End SLR	Medium Emissions 95%ile SLR	High Emissions 95%ile SLR
2015	20yr	BASE	20yr	8.69	8.69	8.69
	75yr	BASE	75yr	8.94	8.94	8.94
	200yr	2yr	200yr	9.13	9.13	9.13
	1000yr	12yr	1000yr	9.45	9.45	9.45
2030	20yr	BASE	20yr	8.78	8.77	*Not considered*
	75yr	BASE	75yr	9.03	9.02	*Not considered*
	200yr	2yr	200yr	9.22	9.21	*Not considered*
	1000yr	12yr	1000yr	9.54	9.53	*Not considered*
2065	20yr	BASE	20yr	9.11	9.01	9.08
	75yr	BASE	75yr	9.36	9.26	9.33
	200yr	2yr	200yr	9.55	9.45	9.52
	1000yr	12yr	1000yr	9.87	9.77	9.84
2115	20yr	BASE	20yr	9.84	9.43	9.59
	75yr	BASE	75yr	10.09	9.68	9.84
	200yr	2yr	200yr	10.28	9.87	10.03
	1000yr	12yr	1000yr	10.60	10.19	10.35

The 2yr Return Period was not included as part of the 2015 Climate Change Update

2.2.3 *Fluvial Hydrology*

As part of the Bristol TFRMS, AECOM completed a Technical Note, March 2016 (Appendix A), to appraise the available hydrological approaches for CAFRA WS3 and WS4. It was decided to investigate the hydrographs in WS3 and WS4 in more detail, as the difference in fluvial inflow volume and flow rates is an important consideration for flood risk management options within the Strategy.

As a result of the Technical Note, AECOM, BCC and the Environment Agency agreed on the fluvial hydrological approach to be taken forward to support the hydraulic modelling phase.

2.2.3.1 *Hydrological Approach Adopted for Bristol TFRMS*

The Technical Note (Appendix A) presented a comparison of the WS3 and WS4 hydrographs. Some significant differences were identified, mainly relating to the overall volume of fluvial discharge over the run period with WS4 hydrographs having up to a 20% greater total volume over the simulation period. However, total peak discharges were shown to be very similar.

To ensure that an approach representative of the catchment for the nature of a strategic study, BCC and the Environment Agency accepted the current fluvial and tidal phasing settings in WS3 to represent a worst case representation of event timing peaks. The resulting limitations are considered to be proportionate and acceptable for a strategic study of this nature.

Beyond the current scope of the Bristol TFRMS, further modelling exploring the impacts and scale of uncertainties relating to the timing and phasing of tidal and fluvial peaks should be carried out in order to support detailed design of schemes. Depending on the significance of the results of any sensitivity testing, the appropriate timing shifts could be applied and utilised in assessing design conditions / parameters.

As the primary focus of the Strategy is on potential tidal inundation, only low fluvial return periods were taken forward when considered in conjunction with large tidal events. This assumption has been based on the local joint probability dependence of both sources. The determination of flows and joint probability methodology has been described in detail within the ‘Central Area Flood Risk Assessment – Modelling Report (Workstream 3)’ (BCC, 2012) and as such is not described further within this report.

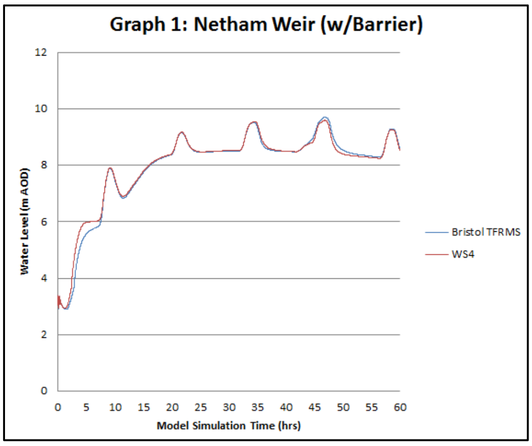
2.2.3.2 *Hydrological Approach to Tidal Barrier Testing*

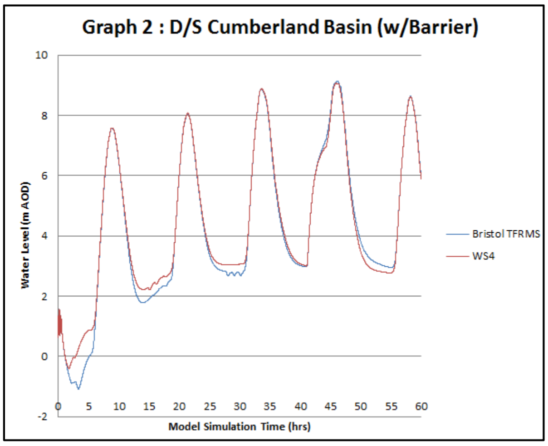
To facilitate testing of tidal barrier representation within the hydraulic model, the one-dimensional ISIS/Flood Modeller Pro model produced as part of WS4 was selected due to the efficiency of demonstrating multiple scenarios with minimal impact on simulation instability.

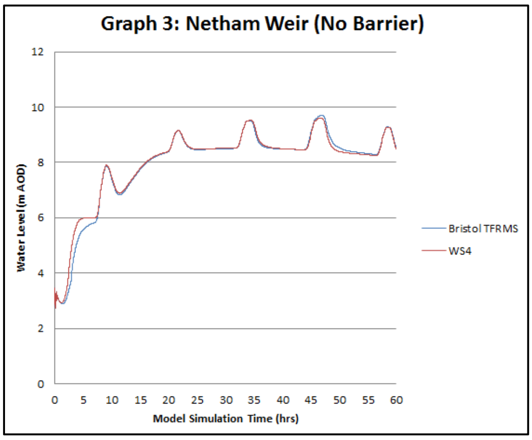
To facilitate the use of the WS4 model for barrier testing, tributary inflows were updated using the ReFH hydrology approach in WS3 to ensure that the peak of each hydrograph is synchronised, coinciding with the tidal peak, which varies significantly under the original WS4 model. This allows for the assessment of worse case fluvial storage to determine impacts associated with the tidal barrier. The primary upstream inflows to the River Avon from Bath remain unchanged, adopting the WS4 hydrology as this provides the largest volumetric inflow to the model.

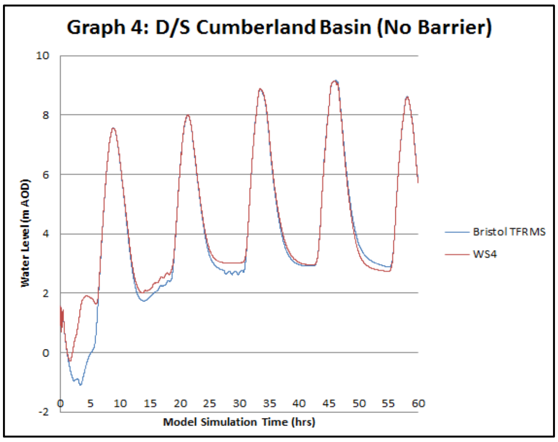
The updated tributary hydrology introduced to the WS4 model from the WS3 model is described in more detail within Section 4.4.To demonstrate the differences between the WS4 model and Bristol TFRMS a comparison of water levels during a 200 year fluvial event (2115) and 2 year tidal event (2115) are presented in Graph 1-4 for scenarios with and without a tidal barrier representation at Netham Weir and immediately downstream of Cumberland Basin.

Graph 1-4 show that there is very little volumetric or phasing differences and that the Bristol TFRMS approach is considered to be the more conservative approach for testing of a barrier solution within the River Avon. As such, the approach adopted by Bristol TFRMS is considered to be appropriate and proportionate representation of hydrology for the desired purpose within this strategic study.









2.2.3.3 *Hydrological Inflows*

Based on the approved approach to representation of concurrent fluvial and tidal events, the following fluvial return periods were required within this study and displayed for each watercourse in Table 2:

- Q Base
- 2yr Return Period
- 12yr Return Period
- 200yr Return Period

Table 2: Design Fluvial Flow Peaks (m^3/s) – Bristol TFRMS

Inflow Name	Source	2015 Epoch			2030 Epoch			2065 Epoch			2115 Epoch			
		Base	2yr	12yr	Base	2yr	12yr	Base	2yr	12yr	Base	2yr	12yr	200yr
Bath Ultra	WS4	-	-	-	-	-	-	-	-	-	-	-	309.00	451.38
River Boyd	WS4	-	-	-	-	-	-	-	-	-	-	-	27.88	60.00
TribsNOct 00b	WS4	-	-	-	-	-	-	-	-	-	-	-	10.12	21.02
TribsSOct 00b	WS4	-	-	-	-	-	-	-	-	-	-	-	10.12	20.69
TribsNOct 00a	WS4	-	-	-	-	-	-	-	-	-	-	-	10.12	20.69
TribsNOct 00c	WS4	-	-	-	-	-	-	-	-	-	-	-	10.12	20.69
Siston Brook	WS4	-	-	-	-	-	-	-	-	-	-	-	12.71	26.40
RC05754 C	WS4	-	-	-	-	-	-	-	-	-	-	-	44.50	100.25
SGFAS	WS4	-	-	-	-	-	-	-	-	-	-	-	12.63	16.63
Windsor	WS4	-	-	-	-	-	-	-	-	-	-	-	4.88	7.63
Cranbrook	WS4	-	-	-	-	-	-	-	-	-	-	-	3.88	5.13
Dungar	WS4	-	-	-	-	-	-	-	-	-	-	-	1.5	2.13
Clifton	WS4	-	-	-	-	-	-	-	-	-	-	-	6.00	9.75
Hanham	WS3	4.26	17.00	22.55	4.26	18.70	24.81	4.26	20.40	27.06	4.26	21.25	-	-
Saltford	WS3	65.66	182.00	252.00	65.66	200.20	277.20	65.66	218.40	302.40	65.66	227.50	-	-
Frenchay	WS3	3.85	30.60	47.00	3.85	33.66	51.70	3.85	36.72	56.40	3.85	38.25	58.75	97.86
FR2170	WS3	0.20	3.90	6.95	0.20	4.29	7.65	0.20	4.68	8.34	0.20	4.88	8.69	15.46
Fishponds	WS3	0.07	1.40	2.50	0.07	1.54	2.75	0.07	1.68	3.00	0.07	1.75	3.13	5.55
Coombe Brook	WS3	0.06	1.20	2.14	0.06	1.32	2.35	0.06	1.44	2.57	0.06	1.50	2.68	4.76
Horfield	WS3	0.60	2.50	4.02	0.60	2.75	4.42	0.60	3.00	4.82	0.60	3.13	5.03	10.20
Stream	WS3	0.03	0.10	0.17	0.03	0.11	0.19	0.03	0.12	0.20	0.03	0.13	0.21	-
Boiling	WS3	0.03	0.70	1.06	0.03	0.77	1.17	0.03	0.84	1.27	0.03	0.88	1.33	2.75
Bishopst'n	WS3	0.18	3.50	6.24	0.18	3.85	6.86	0.18	4.20	7.49	0.18	4.38	7.80	13.88
Longm'r	WS3	0.18	1.35	2.37	0.18	1.49	2.61	0.18	1.62	2.84	0.18	1.69	2.96	11.45
IL_02	WS3	0.04	0.30	0.53	0.04	0.33	0.58	0.04	0.36	0.63	0.04	0.38	0.67	-
IL_03	WS3	0.02	0.19	0.34	0.02	0.21	0.37	0.02	0.29	0.41	0.02	0.24	0.42	-
IL_04	WS3	0.01	0.03	0.06	0.01	0.03	0.06	0.01	0.04	0.07	0.01	0.04	0.07	-
IL_01	WS3	0.08	0.73	1.23	0.08	0.80	1.35	0.08	0.88	1.48	0.08	0.91	1.54	-
CollBrook	WS3	0.40	1.75	3.16	0.40	1.93	3.48	0.40	2.1	3.79	0.40	2.19	3.95	13.40
IC_01	WS3	0.03	1.05	1.58	0.03	1.16	1.74	0.03	1.26	1.90	0.03	1.31	1.95	-
IC_02	WS3	0.01	0.45	0.68	0.01	0.50	0.75	0.01	0.54	0.82	0.01	0.56	0.85	-
UpperTry m	WS3	0.389	7.30	11.37	0.389	8.03	12.51	0.39	8.76	13.64	0.389	9.13	14.21	25.11
IT_01	WS3	0.01	0.24	0.35	0.01	0.26	0.39	0.01	0.29	0.42	0.01	0.30	0.44	-
IT_02	WS3	0.01	0.16	0.25	0.01	0.19	0.28	0.01	0.19	0.30	0.01	0.20	0.31	-
Markham	WS3	0.17	1.21	2.08	0.17	1.33	2.29	0.17	1.45	2.50	0.17	1.51	2.60	5.31
Brislint'n	WS3	0.50	6.57	13.25	0.50	7.23	14.58	0.50	7.884	15.90	0.50	8.21	16.56	52.81

Airport Road	WS3	0.04	1.07	2.16	0.04	1.18	2.38	0.04	1.28	2.59	0.04	1.34	2.70	-
Pigeon house	WS3	0.40	4.40	8.88	0.40	4.84	9.77	0.40	4.22	10.66	0.40	4.40	11.10	35.36
Lower Malago	WS3	0.10	3.44	6.17	0.10	3.78	6.79	0.10	4.30	7.40	0.10	4.44	7.71	16.49
Upper Malago	WS3	0.40	3.93	7.93	0.40	4.32	8.72	0.40	4.77	9.52	0.40	4.93	9.91	31.59

2.2.3.4 *Comparison of Hydrological Flows Against Other Studies*

Under the Environment Agency's Water Environment Management (WEM) Framework, Capita AECOM are undertaking a hydraulic modelling study between Bath and Netham Weir, which is due for completion in 2016 which is being run simultaneous to this Strategy. Included within this study is a hydrological assessment, where the output of this assessment could improve the confidence of fluvial input to the River Avon at Netham Weir to the WS3 CAFRA model.

In April 2016, with the Environment Agency's permission under WEM, Capita AECOM made available the results from the preliminary hydrological assessment. Table 3 presents the preliminary design flows at key locations on the River Avon at Hanham and Saltford, where both sites are located upstream of Netham Weir, for a range of return periods.

Table 3: Extreme Tide Levels (2015 Climate Change Update)

Location	Study	Peak Flow Estimates for Fluvial Return Period events (m^3/s)											
		2yr	5yr	10yr	20yr	30yr	50yr	75yr	100yr	100yr +CC	200yr	200yr +CC	1000yr
Hanham	WEM (2016)	194.8	237.1	265.7	294.9	312.7	336.3	356.0	370.6	444.8	408.0	489.6	508.8
	CAFRA (2011)	199.0	240.0	267.0	295.0	-	332.0	350.0	363.0	-	396.0	-	483.0
Saltford	WEM (2016)	177.3	215.8	241.9	268.5	284.7	306.2	324.1	337.4	404.9	371.5	445.8	463.3
	CAFRA (2011)	182.0	220.0	245.0	271.0	-	306.0	322.0	336.0	-	365.0	-	446.0

Table 3 shows that the WEM study (2016) hydrological flows are very similar to those created for CAFRA WS3 (2011) up to the 100 year return period. Beyond the 100 year return period, the flows in the 2016 study are shown to be slightly greater than those in the WS3 CAFRA study. This is believed to be due to their hydrological analysis creating a slightly steeper growth curve.

It was considered that the results in Table 3 show a good level of agreement, typically within 1-2% difference and that as the Bristol TFRMS is primarily a tidal study, there is unlikely to be a significant impact on tidal risk in Bristol as a result of the WEM study (2016). It has therefore been accepted by BCC and Environment Agency that the Bristol TFRMS can proceed with the original hydrology (CAFRA WS3).

2.4 Model Domain

Following a review of available verification reports, it was clearly demonstrated that the inherited CAFRA WS3 model predicts larger flood extents than which are experienced during a specific event. The discrepancy between observed and modelled results is reported to be due to defacto defences or misrepresentation of ground levels at key overtopping regions.

Following discussion with BCC and the Environment Agency, it was concluded that as part of the Bristol TFRMS, checks of ground elevation and the impact of defacto defences at key locations should be undertaken. This section describes the outcome of this review, described in further detail in Appendix A.

2.4.1 *Defacto Defences*

A decision regarding the incorporation of defacto defences was required to quantify existing and future flood risk management, identify opportunities and to also inform the hydraulic model assumptions. The definition of a defacto flood defence according to the Avon Defacto Defences Report (BCC, 2016) is provided below:

> *A 'defacto' flood defence is a structure not built and/or maintained for the primary purpose of flood defence but which limits the spread of flooding, for example a boundary wall. They have not been specifically designed to retain flood water and they may fail under the hydraulic loading from a flood event.*

The two options available were to:

- Do Nothing – By not installing defacto defences into the model this will represent a conservative level of flood risk, whereby the flood extent may be greater or lesser than observed information; or

- Inclusion of defacto defences – Through installing defacto defences into the hydraulic model, this may provide a more accurate representation of flood risk, albeit assuming that the defacto defences are well maintained throughout their design life, successfully retain flood water and do not structurally deteriorate before, during or following a design flood event of a representative epoch

Key considerations were discussed between AECOM, BCC and the Environment Agency which demonstrated that:

- Defacto defences cannot currently be relied on in a flood event;

- There are often cracks and gaps in the walls which have the potential to allow water to pass through during a flood event;

- Structural conditions of defacto defences are variable (age of structures and states of repair) therefore it is not possible to provide a prediction as to how long the walls can continue to function as defacto defences. If estimates have been provided, they are considered to be short (5-10 years);

- If the walls were to be relied on to function as defacto defences, it is recommended that they are inspected annually;

- Potential failure/protection levels vary significantly;

- There is a risk that without improved representation, the flood extents and subsequent damages for lower events, challenges could be made to subsequent business case approvals and GiA funding applications.

To progress the study, a proportionate and pragmatic approach was discussed with BCC and the Environment Agency. As the defacto defences affect lower return period events, within the more immediate epochs, an opportunity was identified to improve representation of damages and benefits within the regions where defacto defences are believed to have an influence on the flood regime.

It was proposed that flood damages currently shown for low return period events (e.g. up to a 20yr event) in the short term (i.e. up to 2030) in the defacto defence influenced areas could be screened out from the economic appraisal (utilising a GIS based approach). Beyond the 2030 epoch, the assessment would not propose to modify and screen out the damages for defacto defences as these assets are not subject to routine maintenance, have short residual lives and because they are not designated flood risk management assets.

The approach detailed above should more closely reflect the potential impacts of the defacto defences during low return period tidal events and in doing so would be more in line with observations of known events in the regions of the reported defacto defences. This approach would provide a conservative estimate (lower boundary) of Do Nothing damages and benefits as it assumes the defacto defences prevent all flooding for these frequent events.

Current modelling and economic outputs have not accounted for the potential effects of defacto defences, but these could be included as part of future work if instructed to do so by the client.

2.4.2 *Pill / Shirehampton 1-D model limitations*

Due to 1D setup rather than 2D representation at Pill and Shirehampton, the model does not accurately represent raised defences in this area. Once water rises up to the peak, the model will already show water to be present behind it i.e. it doesn't spill over the peak. The outcome is therefore an overrepresentation of flood extent and depth.

As this area is outside the primary focus area of central Bristol, and as the WS3 model has been signed off by the Environment Agency as appropriate for strategic representation of flood risk, a proportionate and pragmatic recommendation to improve the representation of flood risk in this area has been put forward (avoiding significant model changes and re-runs).

The proposed approach is to manually remove flooding currently shown behind defences for events below defence crest levels (under the Do Minimum and 'Do Something' options where gates are represented as closed). This would be achieved by correcting the output results from the modelling runs for this area, using GIS based approach. No modification would be made to the simulated flood risk under the Do Nothing scenario (assuming flood gates fail open) accepting the results are likely to provide an over representation of flood risk for this worst case 'hypothetical' scenario.

The residual uncertainty in the flood modelling outputs and damages in this area will then remain in this area and this would need to be resolved when more detailed appraisals are undertaken for potential schemes in this area.

Should Bristol City Council chose to proceed with this recommendation, the work would be carried out through an agreed Compensation Event during the next phase of work in appraisal of the shortlist options

2.4.3 *Ground Level Information*

Given that the model Digital Terrain Model (DTM) is underpinned by LiDAR data, an exercise to ground truth and investigate the elevation in key areas using available topographic survey. To assist with the review, it was concluded that the key areas to focus on should be:

- Cumberland Road (Bedminster Bridge Roundabout to Bathurst Basin);
- Cumberland Road (Bathurst Basin to Smeaton Road junction);
- Cattlemarket Road and Feeder Road (adjacent Arena Island); and,
- St Phillips Greenway.

The results of this review in Appendix A demonstrate that apart from some significant localised anomalies, the majority of the differences between topographic data and LiDAR data were considered to fall within acceptable tolerances (generally +/-150mm). Given the localised nature of any discrepancies it was confirmed with BCC to not update the model DTM at this stage, accepting that for a strategic level study, the errors in elevation in the model are tolerable. For the development of engineering options, the topographic data has been considered as appropriate.

2.5 Baseline Scenario Setup

This section sets out the definition of baseline scenarios for the Strategy and details the approach to representation for the hydraulic simulation of associated flood risk to support the damage assessment as part of the baseline economic appraisal. The following two baseline scenarios will be adopted in the Strategy:

- Do Nothing
- Do Minimum

2.5.1 *Do Nothing Scenario*

The Do Nothing scenario assumes all maintenance, repair and renewal work of 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 option 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.

For the purpose of clarity the following definitions have been provided:

- **Lock Gate** – Maintain harbour level during low tides and are associated with the legal duty of providing a safe haven within the Floating Harbour
- **Stop Gate** – Deployed during periods of surge to restrict water entering the Floating Harbour

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. Eventually many of the existing residential and commercial assets would be written off with abandonment of much of the centre of Bristol.

This approach would result in the escalation of uncertainty and this, with the loss of investor confidence, and lack of policy or infrastructure solution will result in the whole city and environs being prejudiced, and investment will be blocked or will be withdrawn. The community will face deteriorating property values and businesses will relocate. This will result in decline in its economic prospects and community viability which will be politically unacceptable.

2.5.2 *Do Minimum Scenario*

The Do Minimum scenario represents what would likely happen if the continuation of current investment was provided to maintain 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. The raised defences and mechanical infrastructure within the city will be maintained to ensure their flood defence function continues; however, the defences will not be raised and consequently the standard of flood protection will fall over time, in response to sea level rise.

Efficiencies were made in minimising additional runs by using the model results from the CAFRA WS3 updated model (2015). The only exception was for the 2 year return period which wasn’t included as part of the WS3 model update, therefore these simulations were undertaken as part of this Strategy.

Sensitivity tests were also undertaken to understand management of water levels within the Floating Harbour. This involved lowering the initial water level within the harbour from 6.2m AOD to 5.7m AOD, to represent pre-lowering in advance of a forecasted event to create additional storage within the Floating Harbour. Through comparison of the results associated with the 1 in 200 year tidal event coinciding with a 1 in 2 year fluvial event, it has been shown that there is a negligible difference in the overall flood extent. Comparison of flood levels show slight decreases (approximately 20mm) at Netham and around the Entrance Lock, with increases of approximately 20mm in areas north of the Floating Harbour associated with the River Frome. With no significant differences, the initial water level of 6.2m AOD (which was specified within the received model) was retained.

2.5.3 *Timeline of Asset Failure*

Table 4 and Table 5 present the time epochs in which the existing flood defence assets within the Strategy area are assumed to fail. The location of these flood defence assets located around the Floating Harbour area are also shown within Figure 2. For both the Do Nothing and Do Minimum scenarios, the appropriate asset failures and representations with respect to epochs have been agreed with BCC and the Environment Agency and incorporated into the baseline modelling runs. A number of assumptions have been made in defining the timelines of asset failure. These are discussed below:

- For the Do Nothing scenario, following the initial failure of an asset, it is assumed that the asset will remain in a failed condition for the remainder of the Strategy appraisal period. For instance, if an asset is expected to fail in 2015 (epoch 1) by breaching, it is assumed that this asset will continue to be breached during epochs 2 and 3 of the Strategy appraisal period (2065 and 2115 respectively).

- For the Do Nothing scenario, it is assumed that the Floating Harbour water level controls such as the flood gates, sluices and lock systems (i.e. the ‘moving parts’) will initially fail in an ‘open’ position and will remain so for the duration of the appraisal period.

- Given the minimal impact on tidal flood risk, the failure of specific culverts (e.g. Mylnes culvert) will not be considered.

- No consideration has been made to the potential failure of sewers, such as the Northern Storm Water Interceptor (NSWI), which are in operation within the study area. These assets do not directly impact on tidal flood risk and their potential failure has therefore been excluded from this assessment.

- No consideration has been made to the potential failure of the Floating Harbour retaining walls, channel and dockside walls. There is a considerable risk under the Do Nothing scenario that water levels in the Floating Harbour will dramatically fall through a drawdown process following failure of the water level control structures. It is likely that this drop in water level could lead to the collapse of retaining and dockside walls. However, this is not expected to increase the tidal flood risk due to higher land levels being equivalent or higher than waterside structures and has therefore not been considered in any more detail in this assessment.

- The defences along the River Frome, Brislington Brook and Longmore Brook, such as at IKEA, Abercombe Walk, Ashton Vale and Lyons Court Road have been kept in position (no breach) in the Strategy baseline model runs as the flood risk in the areas defended by the above structures is not considered to be tidally dominated.

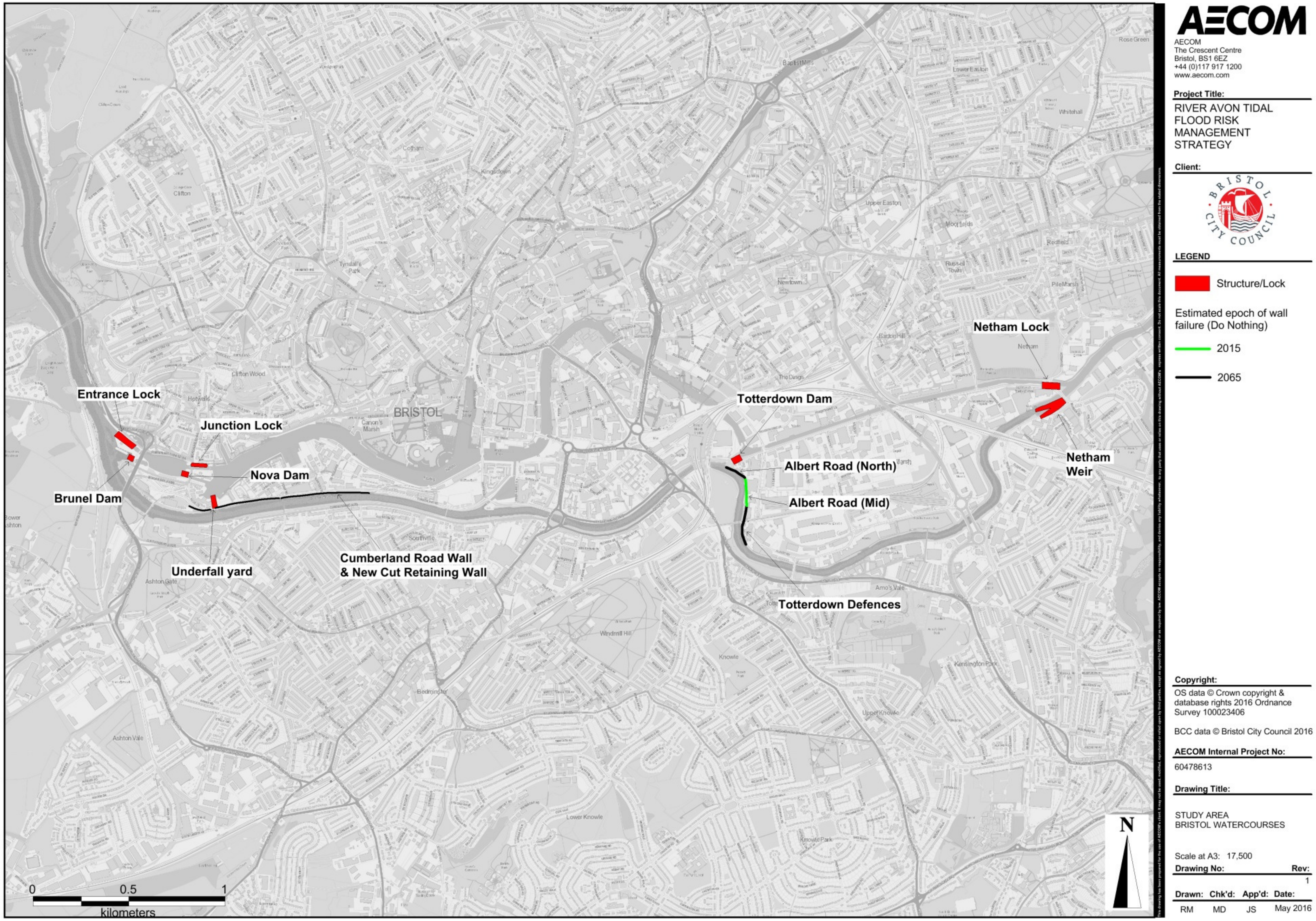


Figure 2: Failing Assets

Table 4: Do Nothing Scenario: Asset Representation

Epoch	Asset Location	Comments/Assumptions	Asset Representation
2015 to 2030	Albert Road, Totterdown – Mid Section	Poor condition, failing. Local issues/gaps in defences.	Modelling to assume failure in across all epochs.
	Pill and Shirehampton; Raised Flood Gates	Manually operated.	Location of defence within 1D domain. As such, this defence is represented as 'failed' within both the Do Nothing and Do Minimum model setup for all epochs.
	Netham Lock Gates and Sluices	New lock gate – Good condition. Sluice paddles and operating system – Poor condition. Resilience of operation system believed to be poor.	Modelling to assume failure in 'open' position across all epochs.
	Totterdown Dam and Lock System	No available info. Construction form unknown having been infilled and covered. Assume condition is fair.	Assume solid structure with minimal chance of failure. This structure has been represented as 'not failed' for all epochs.
	Nova Dam and Sluices	Nova Dam – Fair condition. Sluices and electrical system – very good condition. Standby generator may be vulnerable to flooding.	Modelling to assume failure in 'open' position across all epochs.
	Junction Lock Gate and Sluices	New stop gates, upper gates and sluices – Very good condition. Old backup gates – Poor condition (inundated during spring tides).	
	Entrance Lock Gates	Resilient against flooding.	Modelled as 'open' in both Do Nothing and Do Minimum scenario.
	Underfall Yard: Culverts, Sluices and Gates	High vulnerability to flooding – Poor condition.	Modelling to assume failure in 'open' position across all epochs.
	Brunel Dam Sluices / Gates	High vulnerability to flooding – Poor condition.	
2065 to 2115	1 - Marine Parade (Pill); Masonry Flood Wall 2 - Marine Parade (Pill); Embankment 3 - Shirehampton Sailing Club; Embankment 4 - Shirehampton Sailing Club; Flood Wall	1 - Good condition. 2 - Fair condition. 3 - Good condition. 4 - Good condition.	1-4: Location of defences within 1D domain. As such, this defence is represented as 'failed' within both the Do Nothing and Do Minimum model setup for all epochs.
	Albert Road, Totterdown – North Section	Fair condition.	Modelling to assume failure for this epoch only.
	Totterdown – Defences adjacent Bristol RSPCA (concrete wall)	Fair condition. Current failure experienced through breaching.	
	Totterdown – Defences downstream of Bristol RSPCA (embankment)	Constructed in 2003. Good condition.	
	Cumberland Road Wall Defence	New structure with less than 50 year design life without	

		maintenance.	
	New Cut: Retaining Wall and Drainage (900m).	Risk to Cumberland Road Wall.	
	Netham Weir masonry sub-structure, concrete crest and rock apron.	Sub-structure and concrete crest currently in fair condition. Rock apron in poor condition. Consequence of rock apron failure likely to lead to undermining and failure of weir.	Assumed that the rock apron will fail in 2065, which will undermine and lead to failure of the weir itself. However in the Do Nothing model simulations the weir structure will not be breached as the flood risk arising from failure of the structure will be represented by the failure of Netham gates and sluices.

Table 5: Do Minimum Scenario: Asset Representation

Epoch	Asset Location	Comments/Assumptions	Asset Representation
2015 to 2115	All assets functioning as present day (Floating Harbour Water Level Control Structures and Raised Defences)	Assumed that maintenance work would be carried out to ensure the continued operation and improved resilience of the Floating Harbour Water Level Control Structures (i.e. raising level of electrical control systems during maintenance). Raised defences to be maintained/reconstructed to the existing standard of flood protection to ensure that the flood defence function of the assets is sustained.	Maintain representation as per existing – CAFRA WS3/4 include continued operation of MEICA systems and presence of raised defences.

2.6 Model Simulations

Table 6 and Table 7 details the model simulations required as part of the baseline modelling for the Do Nothing and Do Minimum scenarios respectively. Utilising the above approach, efficiencies were made in minimising additional runs where the Do Minimum scenario is required.

For consistency, the Do Nothing scenarios were simulated for the equivalent scenarios to allow for a direct comparison of results which are utilised as part of the damages (and benefits) and economics assessment.

Table 6: Baseline Model Simulations - Do Nothing

Run ID	Epoch	Return Period
1	2015	2
2		20
3		75
4		200
5		1000
6	2030	2
7		20
8		75
9		200
10		1000
11	2065	2
12		20
13		75
14		200
15		1000
16	2115	2
17		20
18		75
19		200
20		1000

Table 7: Baseline Model Simulations - Do Minimum

Run ID	Epoch	Return Period
21	2015	2
22		20
23		75
24		200
25		1000
26	2030	2
27		20
28		75
29		200
30		1000
31	2065	2
32		20
33		75
34		200
35		1000
36	2115	2
37		20
38		75
39		200
40		1000

3. FLOOD RISK

This section details the baseline hydraulic modelling results. The baseline hydraulic modelling represents the 'Do Nothing' and 'Do Minimum' scenarios, both of which are specified in Table 6 and Table 7.

The baseline hydraulic model results and associated flood envelopes demonstrate that there is a relative increase in the depth and level of tidal inundation with respect to the increase in magnitude of event for each scenario. The flood mapping of the baseline hydraulic modelling can be viewed in Appendix B.

As the received hydraulic model has been previously calibrated and verified against known events, there was no requirement as part of this study to undertake any testing beyond the changes required to assist in representing the effects of the 'Do Nothing' and 'Do Minimum' scenarios.

3.1 Total Residential and Commercial Properties at Risk

Table 8 and Table 9 summarises the principal residential and commercial properties at risk of flooding for the 'Do Nothing' and 'Do Minimum' scenario for each tidal return period simulation.

Table 8: Do Nothing Simulation – Properties at Risk of Inundation

Return Period	Epoch	Residential Properties at risk of flooding	Commercial Properties at risk of flooding	Total Properties at risk of flooding
2	2015	486	225	711
	2030	625	264	889
	2065	777	421	1198
	2115	1318	738	2056
20	2015	883	476	1359
	2030	992	577	1569
	2065	1706	910	2616
	2115	1876	1002	2878
75	2015	1245	679	1924
	2030	1308	713	2021
	2065	1308	714	2022
	2115	2061	1199	3260
200	2015	1743	978	2721
	2030	1874	1064	2938
	2065	2092	1233	3325
	2115	2724	1621	4345
1000	2015	2290	1316	3606
	2030	2447	1382	3829
	2065	2291	1324	3615
	2115	3740	2011	5751

For the present day Do Nothing simulation (2015), 2721 properties are shown to be at risk during a 1 in 200 year joint probability event. Approximately 64% of these are residential properties with the remainder being non-residential or commercial. Within the Do Nothing simulation, by 2115 the total number of properties at risk from a 1 in 200 year event is expected to increase to 4345. Approximately 63% of these properties are residential. From a review of property location, the areas within Bristol City Centre which are exposed to the greatest level of flood risk during these simulations are at Cumberland Basin, St Phillips Marsh, Totterdown (Victor Street), Albert Road and immediately downstream of Netham Weir.

Table 9: Do Minimum Simulation – Properties at Risk of Inundation

Return Period	Epoch	Residential Properties at risk of flooding	Commercial Properties at risk of flooding	Total Properties at risk of flooding
2	2015	171	60	231
	2030	186	84	270
	2065	222	129	351
	2115	331	273	604
20	2015	236	158	294
	2030	267	189	456
	2065	339	129	468
	2115	795	474	1269
75	2015	319	257	576
	2030	339	278	617
	2065	531	383	914
	2115	1519	826	2345
200	2015	547	462	1009
	2030	758	522	1280
	2065	1686	971	2657
	2115	2365	1353	3718
1000	2015	1686	971	2657
	2030	2118	1090	3208
	2065	1684	900	2584
	2115	3506	1903	5409

For the present day Do Minimum simulation (2015) 1009 properties are shown to be at risk from a 1 in 200 year joint probability event. Approximately 54% of these are residential properties with the remainder being non-residential or commercial. By 2115 the total number of properties at risk from a 1 in 200 year event is expected to increase to 3718. Approximately 64% of these properties are residential. From a review of property location, the areas exposed to the greatest level of flood risk during these simulations are located at Cumberland Basin, Cumberland Road St Phillips Marsh, Totterdown (Victor Street), Albert Road and downstream of Netham Weir, consistent with the Do Nothing observations.

3.2 Baseline Modelling – Asset Failure Summary

Following the baseline hydraulic modelling of the 'Do Nothing' and 'Do Minimum' scenarios, Table 10 and Table 11 highlights the effects of the individual asset failure against the relevant return periods and epochs for each scenario.

Table 10: Do Nothing Scenario: Asset Inundation Commentary

Epoch	Asset Location	Asset Representation	Breach/Overtopping First Experienced	Asset Commentary
2015 to 2030	Albert Road, Totterdown – Mid Section	Modelling to assume failure in across all epochs.	Run ID 1 – 2015, 2yr RP	Floodwater reaches Albert Road, parallel with the River Avon during the 2yr RP (2015) which propagates north and eastwards on Feeder Road and adjoins with the flood extent from Feeder Canal. Floodwater propagates further east during 75yr RP increasing to 200yr RP and 1000yr RP event, adjoining flood extents further upstream opposite Paintworks (left bank). The greatest flood depths (>2.00m) are recorded along Albert Road during the 1000yr RP event.
	Pill and Shirehampton; Raised Flood Gates	Location of defence within 1D domain. As such, this defence is represented as 'failed' within both the Do Nothing and Do Minimum model setup for all epochs. 1D node located within hydraulic model at Av7_0873.	Pill – Run ID 1 2015, 2yr RP Shirehampton - Run ID 1 2015, 2yr RP	Due to the simplicity of the model representation at this location, the levels of the base of the defence are assumed to be the location of breach, as specified below. Pill (Left Bank) – Breach Ground Level 7.56m AOD – Water Level (First Breach - 2yr RP) 8.38m AOD Shirehampton (Right Bank) – Breach Level 8.24m AOD – Water Level (First Breach - 2yr RP) 8.38m AOD
	Netham Lock Gates and Sluices	Modelling to assume failure in 'open' position across all epochs.	Run ID 1 – 2015, 2yr RP	Netham lock arrangement located within main waterway. As such, representing as 'open' facilitates flow, both fluvial and tidal, to be conveyed during all return periods. This is contrary to the 'Do Minimum' scenario which represents this structure as 'closed'.
	Totterdown Dam and Lock System	Assume solid structure with minimal chance of failure. This structure has been represented as 'not failed' for all epochs.	Run ID 1 – 2015, 2yr RP	Floodwater first propagates onto Totterdown Dam (left bank) at Feeder Road/Cattlemarket Road from Feeder Canal, west of Albert Road. Inundation propagates southwards on Albert Road during the 20yr RP, where the flood extents connect with the River Avon. The right bank of Feeder Canal at the Totterdown Lock System is first overtopped during the 20yr RP where flood extents and depth increases in an easterly direction along Feeder Canal. Inundation of Avon Street and Silverthorne Lane occurs during the 75yr RP, where topography naturally rises creating a barrier on Gas Lane.
	Nova Dam and Sluices	Modelling to assume failure in 'open' position across all epochs.	Run ID 1 – 2015, 2yr RP	Nova Dam arrangement located within main waterway. As such, representing as 'open' facilitates flow, both fluvial and tidal, to be conveyed during all return periods. This is contrary to the 'Do Minimum' scenario which represents this structure as 'closed'.
	Junction Lock Gate and Sluices	Modelling to assume failure in 'open' position across all epochs.	Run ID 1 – 2015, 2yr RP	Junction Lock Gate arrangement located within main waterway. As such, representing as 'open' facilitates flow, both fluvial and tidal, to be conveyed during all return periods. This is contrary to the 'Do Minimum' scenario which represents this structure as 'closed'.
	Entrance Lock Gates	Modelled as 'open' in both Do Nothing and Do Minimum scenario.	Run ID 1 – 2015, 2yr RP	Entrance Lock Gate arrangement located within main waterway. As such, representing as 'open' facilitates flow, both fluvial and tidal, to be conveyed during all return periods.

	Underfall Yard: Culverts, Sluices and Gates	Modelling to assume failure in 'open' position across all epochs.	Run ID 1 – 2015, 2yr RP	The invert level within the ISIS model connecting node Av6_0919 to the Underfall Sluice and Gate configuration is 6.20m AOD. This invert level is exceeded within the lowest tidal return period (2yr, 2015) under the Do Nothing scenario. As the water level associated with this return period event is greater than the invert level of the structure, all return period events represented in this modelling assessment provide a flow link between the Underfall Yard sluice and gate arrangement and the Floating Harbour (where levels are above 6.20m AOD).
	Brunel Dam Sluices / Gates	Modelling to assume failure in 'open' position across all epochs.	Run ID 1 – 2015, 2yr RP	Brunel Dam arrangement located within main waterway. As such, representing as 'open' facilitates flow, both fluvial and tidal, to be conveyed during all return periods. This is contrary to the 'Do Minimum' scenario which represents this structure as 'closed'.
2065 to 2115	Site 1 - Marine Parade (Pill); Masonry Flood Wall Site 2 - Marine Parade (Pill); Embankment Site 3 - Shirehampton Sailing Club; Embankment Site 4 - Shirehampton Sailing Club; Flood Wall	Location of defences within 1D domain. As such, this defence is represented as 'failed' within both the Do Nothing and Do Minimum model setup for all epochs. Site 1 - 1D node located within hydraulic model at Av7_0873 Site 2 - 1D node located within hydraulic model at Av7_0552. Site 3 - 1D node located within hydraulic model at Av7_0873. Site 4 - 1D node located within hydraulic model at Av7_0873.	Site 1 – Run ID 11 2065 2yr RP Site 2 - Run ID 12 2065 20yr RP Site 3 – Run ID 11 2065 2yr RP Site 4 – Run ID 11 2065 2yr RP	Due to the simplicity of the model representation at this location, the levels of the base of the defence are assumed to be the location of breach, as specified below. Site 1 (Left Bank) – Breach Ground Level 7.84m AOD – Water Level (First Breach - 2yr RP) 8.38m AOD Site 2 (Left Bank) – Breach Ground Level 8.91m AOD – Water Level (First Breach - 20yr RP) 9.47m AOD Site 3 (Right Bank) – Breach Ground Level 8.21m AOD – Water Level (First Breach - 2yr RP) 8.38m AOD Site 4 (Right Bank) – Breach Ground Level 8.21m AOD – Water Level (First Breach - 2yr RP) 8.38m AOD
	Albert Road, Totterdown – North Section	Modelling to assume failure for this epoch only.	Run ID 11 – 2065 2yr RP	Floodwater reaches Albert Road, parallel with the River Avon during the 2yr RP (2065) which propagates north and eastwards on Feeder Road and adjoins with flood extents from Feeder Canal. Floodwater propagates further east during the 20yr RP increasing to 200yr RP and 1000yr RP event, adjoining flood extents further upstream opposite Paintworks (left bank). The largest flood depths (>2.50m) are recorded along Albert Road during 200yr RP event.
	Totterdown – Defences adjacent Bristol RSPCA (concrete wall)	Modelling to assume failure for this epoch only.	Run ID 11 – 2065 2yr RP	
	Totterdown – Defences downstream of Bristol RSPCA (embankment)	Modelling to assume failure for this epoch only.	Run ID 11 – 2065 2yr RP	
	Cumberland Road Wall Defence	Modelling to assume failure for this epoch only.	Run ID 11 – 2065 2yr RP	Water propagates from the right bank of the River Avon onto Cumberland Road meeting the flood extents caused by the Floating Harbour inundation at Avon Crescent during Run ID 11 (2065, 2yr RP) to a depth of approximately 0.80m. The flood extents are further exacerbated with the increase in return period resulting in the almost complete inundation of Spike Island during Run ID 20 (2115, 1000yr RP) with depths of approximately 2.20m occurring along Avon Crescent.

	New Cut: Retaining Wall and Drainage (900m).	Modelling to assume failure for this epoch only.	Run ID 11 – 2065 2yr RP	The defence is breached connecting the Floating Harbour flood extents at Avon Crescent during Run ID 11 (2065, 2yr RP). Flood depths at Avon Crescent reach ~2.10m during Run ID 20 (2115, 1000yr RP)
	Netham Weir masonry sub-structure, concrete crest and rock apron.	Assumed that the rock apron will fail in 2065, which will undermine and lead to failure of the weir itself. However in the Do Nothing model simulations the weir structure will not be breached as the flood risk arising from failure of the structure will be represented by the failure of Netham gates and sluices.	N/A	Asset Commentary not required.

Table 11: Do Minimum Scenario: Asset Representation

Epoch	Asset Location	Asset Representation	Breach/Overtopping First Experienced	Asset Commentary
2015 to 2115	Albert Road, Totterdown – Mid Section	Assumed that maintenance work would be carried out to ensure the continued operation and improved resilience of the Floating Harbour Water Level Control Structures (i.e. raising level of electrical control systems during maintenance). Raised defences to be maintained/reconstructed to the existing standard of flood protection to ensure that the flood defence function of the assets is sustained. Maintained as per present day condition (2015)	Run ID 21 2015, 2yr RP	Floodwater reaches Albert Road, parallel with the River Avon during the 2yr RP (2015) which propagates north and eastwards on Feeder Road and adjoins with flood extents from Feeder Canal. Floodwater propagates further east during the 75yr RP increasing to 200yr RP and 1000yr RP event, adjoining flood extents further upstream opposite Paintworks (left bank). The greatest flood depths (>3.00m) are recorded along Albert Road during the 1000yr RP 2115 event.
	Pill and Shirehampton; Raised Flood Gates 1D node located within hydraulic model at Av7_0873.		Pill – Run ID 25 2015, 1000yr RP Shirehampton - Run ID 23 2015, 75yr RP	Due to the simplicity of the model representation at this location, the levels of the height of the defence has been determined by the representation within the 1D model, as specified below. Pill (Left Bank) – Defence Height 9.30m AOD – Water Level (First Overtop - 1000yr RP) 9.45m AOD Shirehampton (Right Bank) – Defence Height 8.90m AOD – Water Level (First Overtop - 75yr RP) 9.02m AOD
	Netham Lock Gates and Sluices 1D node located within hydraulic model at FH5990.		Run ID 24 2015, 200yr RP	Lock gate height: 9.10m AOD. First overtop occurs during the 200yr RP (water level 9.40m AOD). It is possible that this occurs due to floodwater from the River Avon propagating north, into the Feeder Canal raising the water level. The flood extent in this area covers the industrial estate between Feeder Canal and the River Avon, however no inundation occurs to the north of the Canal
	Totterdown Dam and Lock System		Run ID 22 2015, 20yr RP	Floodwater firstly propagates in southerly direction meeting floodwater from the River Avon At the Cattlemarket Road/Albert Road highway junction. The right bank at Totterdown Lock System is inundated during the 1000yr 2015 scenario.
	Nova Dam and Sluices		Run ID 22 2015, 20yr RP	Floodwater first overtops Nova Dam along Merchants Road from Cumberland Basin. Beyond the 20yr 2015 event it is unclear to delineate between the primary sources of flooding which contribute to the overall flood extents due to widespread flooding from the River Avon which leads to greater flood extents relative to event magnitude.
	Junction Lock Gate and Sluices		Run ID 21 2015, 2yr RP	Floodwater first overtops and circumvents the lock gates on land without inundating any adjacent properties. The Pump House first becomes inundated during Run ID 23 (75yr RP, 2015) incrementally causing further inundation to the Hotwells region with increasing magnitude and epoch events.

	Entrance Lock Gates		Run ID 21 2015, 2yr RP	Beyond the 2yr 2015 event it is unclear to delineate between the primary sources of flooding which contribute to the overall flood extents due to widespread flooding from the River Avon which leads to greater flood extents relative to event magnitude.
	Underfall Yard: Culverts, Sluices and Gates		Run ID 21 2015, 2yr RP	Operates as designed. First sign of operation occurs during the 2yr 2015 event.
	Brunel Dam Sluices / Gates		Run ID 21 2015, 2yr RP	Beyond the 2yr 2015 event it is unclear to delineate between the primary sources of flooding which contribute to the overall flood extents due to widespread flooding from the River Avon which leads to greater flood extents relative to event magnitude.
	1 - Marine Parade (Pill); Masonry Flood Wall 1D node located within hydraulic model at Av7_0873 2 - Marine Parade (Pill); Embankment 1D node located within hydraulic model at Av7_0552. 3 - Shirehampton Sailing Club; Embankment 1D node located within hydraulic model at Av7_0873. 4 - Shirehampton Sailing Club; Flood Wall 1D node located within hydraulic model at Av7_0873.		Site 1 – Run ID 25 2015 1000yr RP Site 2 - Run ID 25 2015 1000yr RP Site 3 – Run ID 23 2015 75yr RP Site 4 – Run ID 23 2015 75yr RP	Due to the simplicity of the model representation at this location, the levels of the height of the defence has been determined by the representation within the 1D model, as specified below. Site 1 (Left Bank) – Defence Height 9.30m AOD – Water Level (First Overtop - 1000yr RP) 9.45m AOD Site 2 (Left Bank) – Defence Height 9.514m AOD – Water Level (First Breach - 10000yr RP) 10.2m AOD Site 3 (Right Bank) – Defence Height 8.83m AOD – Water Level (First Breach - 75yr RP) 9.02m AOD Site 4 (Right Bank) – Defence Height 8.83m AOD – Water Level (First Breach - 75yr RP) 9.02m AOD
	Albert Road, Totterdown – North Section		Run ID 21 2015, 2yr RP	Floodwater circumvents the Totterdown defences, reaching Albert Road during the lowest return period.
	Totterdown – Defences adjacent Bristol RSPCA		Run ID 21 2015, 2yr RP	

	(concrete wall)			
	Totterdown – Defences downstream of Bristol RSPCA (embankment)		Run ID 21 2015, 2yr RP	
	Cumberland Road Wall Defence		Run ID 24 2015, 200yr RP	The simulation of the Cumberland Road Wall Defence confirms the present day standard of protection is in line with the 200yr return period. During the 2115 simulations, the standard of protection is reduced to a 20yr RP (Run ID 37)

4. OPTION TESTING

The CAFRA WS3 hydraulic model has been updated to represent the 'Do Nothing' and 'Do Minimum' baseline scenario of flooding within Bristol, where the 'Do Minimum' model has been updated to assess and refine engineering Options ('Do Something') to reduce the risk of flooding. Revised flood extent outlines, depth, velocity and water level results across Bristol were produced for an extensive suite of design flood events for the baseline and option scenarios.

Options for reducing flood risk were tested both in isolation and in combination, with numerous iterations to optimise the hydraulic design. In total this amounted to over 12 primary options (Table 12) with several iterations of each, to account for ensuring stability and engineering refinement simulations, reflecting both the complexity of the flooding problem in Bristol and the robust economic appraisal of the identified flood risk management options. As such, a proportionate and risk-based approach was adopted for the determination and analysis of options for reducing flood risk in Bristol, in line with the FCERM-AG guidance. This approach ensured that the degree of analysis undertaken was sufficient at every stage to enable the identification and refinement of options, leading to a Preferred Option, but without excessive technical analysis where the conclusions are readily apparent.

4.1 Options Considered

Following the results of the Do Nothing and Do Minimum model results, a long list of high-level options was developed collaboratively between AECOM, BCC and the Environment Agency. The 'Do Something' options which were tested and modelled are described below:

- High defences (flood walls/embankments) raised around the Entrance Lock, Netham Lock and at various locations along the River Avon to ensure protection to the Floating Harbour up to 2115 (based on a 200yr tidal event). This will also involve raising the lock gates at both the entrance to the Floating Harbour and also at Netham;
- Narrow tidal barrier located at the Cumberland Basin; and
- Wide tidal barrier located a Pill/Shirehampton.

4.2 Model Simulations

Hydraulic modelling testing was undertaken and the subsequent results reviewed to identify the contribution each option made towards a reduction in flood levels for a range of flood magnitude events. The options investigated against specific flood return periods are presented in Table 12 and discussed in Section 4.4.1.

Table 12: Option Testing

Run ID	Option	Epoch	Event	Description
41	Raised flood wall and lock gates to 10.2m AOD	2115	200yr Tide 2yr Fluvial	Raised lock gates and flood wall around the entrance lock to 10.2m AOD. Two simulations required to optimise wall performance.
42		2115	200yr Tide 2yr Fluvial	Raised lock gates and flood wall around Netham Lock to 10.2m AOD. Two simulations required to optimise wall performance.
43		2115	200yr Tide 2yr Fluvial	Merged the entrance lock wall and Netham lock wall together effectively 'shutting off' the Floating Harbour.
44		2115	200yr Tide 2yr Fluvial	Raised the Cumberland Road defence to 10.2m AOD and extent further east. Flood walls developed along areas of the New Cut to protect Floating Harbour. Three simulations required to optimise wall performance.
45	Tide Barrier – Pill/Shirehampton	2115	2yr Tide 200yr Fluvial	Wide barrier at Pill/Shirehampton (XS Av6_0552) with a design height of 10.9m AOD. Three gated weirs used with time controls based on tidal peaks.
46		2115	Spring Tide 200yr Fluvial	Similar simulation to Run. 45, however a Spring Tide was used (peak of 8m AOD). Two simulations were undertaken, one with the barrier in place and one without, to compare the fluvial impact on the Floating Harbour.
47	Tide Barrier – Cumberland Basin	2115	2yr Tide 200yr Fluvial	Narrow barrier at the Cumberland Basin (Av6_0001) with a design height of 11m AOD. Two gated weirs used with time controls based on tidal peaks. Four simulations required due to stability issues.
48	Tide Barrier – WS4 1D Model	2115	2yr Tide 200yr Fluvial	Due to stability issues associated with the Cumberland Basin barrier run (ID. 47) the WS4 1D model was used to assess the impact of a barrier at this location. Initially the received model was simulated to ensure that the model worked. The following models were then simulated.
49		2115	2yr Tide 200yr Fluvial	WS4 model updated with hydrology from WS3 for consistent approach. Baseline model then simulated without a barrier in place.
50		2115	2yr Tide 200yr Fluvial	Two simulations – one with barrier at Pill/Shirehampton and one at Cumberland Basin. With each simulation the gate began to close at 40.00 hrs and was then fully open at 49.25 hrs (closed for full tide curve).
51		2115	2yr Tide 200yr Fluvial	Two simulations – one with barrier at Pill/Shirehampton and one at Cumberland Basin. With each simulation the gate began to close at 40.00 hrs and was then fully open at 47.00 hrs (opened when tide level decreased 1m below peak).
52		2115	2yr Tide 200yr Fluvial	Two simulations – one with barrier at Pill/Shirehampton and one at Cumberland Basin. With each simulation the gate began to close at 44.40 hrs and was then fully open at 49.25 hrs (closed around the peak only).

4.3 High Defences

The ‘High Defences’ measure comprises linear defences (walls/embankments) to provide a high standard of protection in a single implementation phase. The implementation involves identifying low spots or gaps in the existing defences and then raising the crest height or constructing new flood walls/embankments.

For the purpose of the short list appraisal it is assumed that the defences would need to be constructed to a 1 in 200 year standard of protection (2115). Based upon the Do Minimum modelling outputs, a first pass assessment was carried out to identify the areas where raised high defences would be required to prevent tidal flooding during this event. The assessment was based upon a visual analysis in GIS, whereby the areas of tidal flooding were identified and indicative route alignments needed to block the path of flooding were established.

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

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

During normal operation, water levels within the Floating Harbour are controlled by lock gates and sluice systems, the most notable are located at Junction Lock (tidal entrance to harbour) and at Netham (upstream entrance to harbour). During large magnitude tidal events, a major pathway for floodwater inundating the harbour is at these locations. Either the lock gates themselves are inundated or water flows up and over the land adjacent to the gate system.

Therefore, to ensure that water does not enter the Floating Harbour from the River Avon during the 1 in 200 year event (2115) the entrance lock gates and surrounding walls were all raised to 10.20m AOD. This takes into account the design water level for a 1 in 200 year event in 2115 (9.87m AOD – medium emissions 95th%ile climate change scenario) and includes just over a 0.30m freeboard. At the upstream end of the harbour, the Netham Lock gates and defence wall running parallel were also raised to the same level (Figure 3).

‘Sealing-off’ the entrances to the harbour would effectively prevent tidal inundation at these locations, however there are a number of alternative flood pathways into the Floating Harbour from the River Avon and therefore high defences would be required at these locations (Figure 3). The main areas where new defences are required include:

- Cumberland Road;
- Bathurst Basin Dam;
- Clarence Road; and
- Totterdown near Cattlemarket Road and Albert Road (i.e. near Temple Meads).

The alignments above assume a 1 in 200 year standard of protection (2115) and will therefore also have a design crest level of 10.20m AOD. Results from this model, which combines all measures identified within Figure 3, indicates a significant improvement to flooding within the Floating Harbour. The only exception is down near the Entrance Lock near Smeaton Road/Brunel Lock Road and at Netham lock where defences are overtopped during the tidal peak. Depths in these areas reach approximately 0.6m and 0.3m respectively and therefore it may be required to address the defence height within these areas going forward. Along the River Avon results have shown that there is no overtopping of the proposed defences (Appendix C).

For the Ashton area, a review of PLP and temporary barriers shall be assessed as part of this study. It is appreciated that there is an inherent risk at Ashton Gate from fluvial and pluvial sources, where a solution should be concentrated around reducing discharge from or increasing storage within the Malago and Ashton watercourses. This is considered to be a residual risk that shall still exist, and remain unaffected, following construction the proposed solution as part of this tidal strategy.

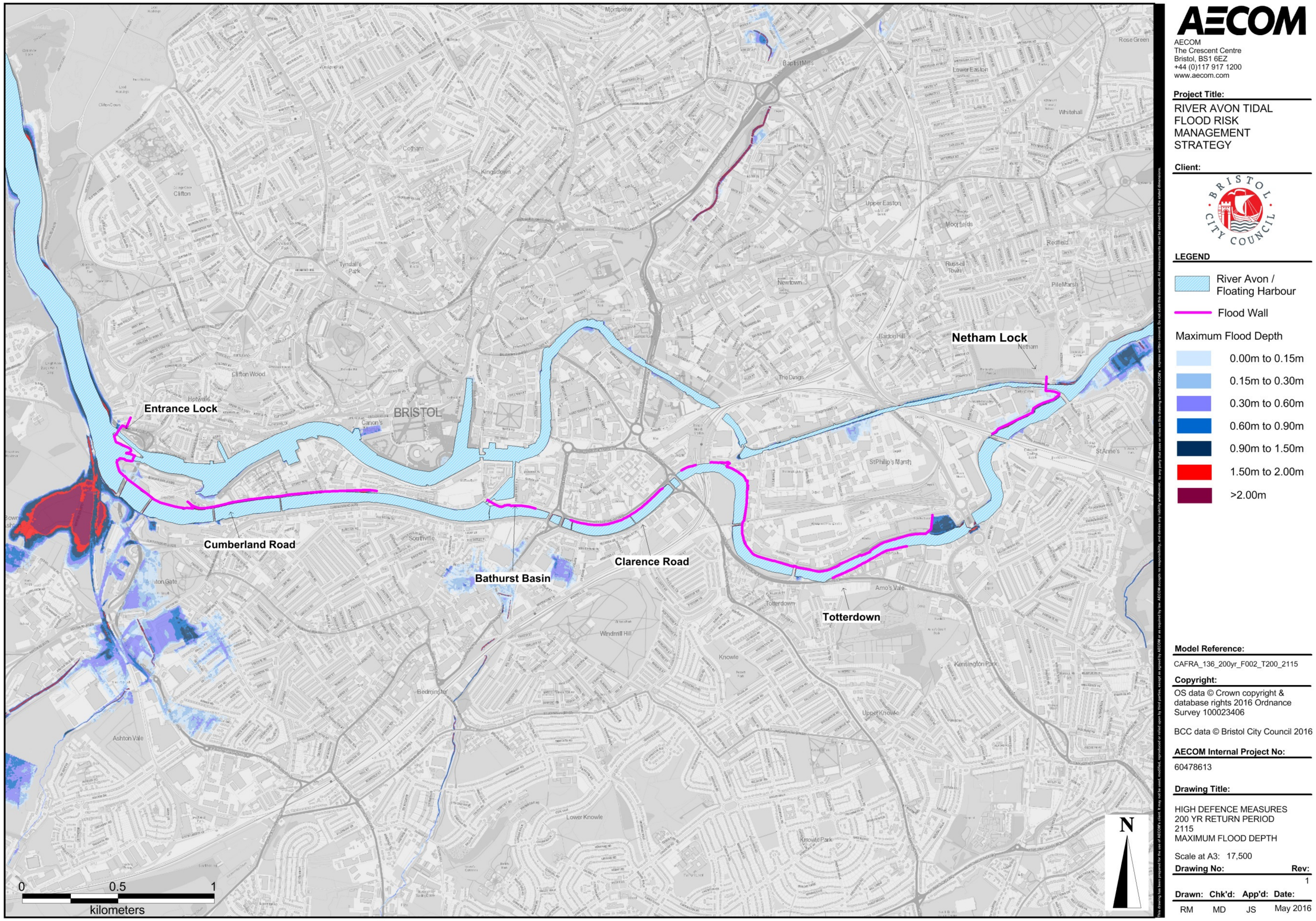


Figure 3: High Defence Measures (Run ID 44 – 200yr Return Period, 2115)

4.4 Tidal Barriers

To assess the impact of placing a barrier across the River Avon, the WS3 model was initially used to represent both a wide barrier approximately 500m upstream of the M5 road bridge (downstream extent of Pill to the railway line near Shirehampton) and a narrow barrier at the Cumberland Basin (150m downstream of the Junction Lock). The 1D aspect of the model was updated, with gated weir structures inserted at cross-sections Av6_0552 (Pill/Shirehampton) and Av6_0001 (Cumberland Basin). The location and timing of the operation to raise and lower the gates was based on the tidal surge, fluvial flows and potential storage capacity behind the barrier structure. For this particular study, the barrier was only operational during the peak tidal curve as this represents the worst-case scenario. This can be optimised further, should this become the preferred flood management option.

4.4.1 *Testing technical feasibility – fluvial storage capacity*

One of the key aims of the tidal barrier testing was to assess the impacts of the structure on fluvial storage (impounding) and to investigate any potential increase in flood risk from the operation of the barrier as a result. This aspect was identified as a key consideration in the pre-feasibility study and a critical driver for determining feasible barrier locations.

By 2115 a 2yr RP tidal event causes significant flooding in central Bristol and the barrier would need to be closed to prevent tidal flooding. Taking the Joint probability combinations derived for use in this study, in theory this tidal event could be accompanied by a 200 yr fluvial return period event. Therefore in terms of storage, this represents a worst case event to test to ensure the barrier deployment does not make upstream levels worse (i.e. it does not exacerbate the fluvial flood risk).

4.4.2 *Model testing for fluvial storage capacity*

While the model representing the Pill/Shirehampton and Nibley/Ham Green barrier simulated without any issues, there were significant stability issues associated with the Cumberland Basin barrier model. The problems experienced were due to storage issues upstream of the barrier and in turn resulted in instabilities between Cumberland Basin and Netham Weir.

To assist in testing barrier representation the WS4 ISIS model was used to assess the impact of the barrier through consideration of peak water levels, based on different control operations of the barrier. To be consistent with the rest of the study the hydrology was updated based on the WS3 model where this was available. The WS4 model used different fluvial inflow volumes and timings, therefore it was considered important to retain the use of the WS3 hydrology (Appendix A).

The hydrology was only updated where inflow locations between WS3 and WS4 were identical. Table 13 provides an overview of which inflows were updated using WS3 and retained from the WS4 model. While the majority were updated, there were a few, most of which were located downstream of the Floating Harbour, where they could not be updated due to significant variances in the model setups.

Table 13: Hydrology Updates

Inflow ID	Updated?	Comments
BathUltra	No	ISIS Event Data (IED) existed within WS4 model but not within the WS3 model. Hydrology retained from WS4 model
RiverBoyd	No	IED existed within WS4 model but not within the WS3 model. Hydrology retained from WS4 model
TribsNOct00b	No	IED existed within WS4 model but not within the WS3 model. Hydrology retained from WS4 model
TribsSOct00a	No	IED existed within WS4 model but not within the WS3 model. Hydrology retained from WS4 model
TribsSOct00b	No	IED existed within WS4 model but not within the WS3

		model. Hydrology retained from WS4 model
TribsSOct00c	No	IED existed within WS4 model but not within the WS3 model. Hydrology retained from WS4 model
SistonBrook	No	IED existed within WS4 model but not within the WS3 model. Hydrology retained from WS4 model
RC05754C	No	IED existed within WS4 model but not within the WS3 model. Hydrology retained from WS4 model
Frenchay	Yes	Hydrology imported from WS3 model
FR2170inf	Yes	Hydrology imported from WS3 model
Fishponds	Yes	Hydrology imported from WS3 model
CoombeBrk	Yes	Hydrology imported from WS3 model
Bishopston	Yes	Hydrology imported from WS3 model
Boiling	Yes	Hydrology imported from WS3 model
SGFAS	No	IED existed within WS4 model but not within the WS3 model. Hydrology retained from WS4 model
Horfield	Yes	Hydrology imported from WS3 model
Windsor	No	IED existed within WS4 model but not within the WS3 model. Hydrology retained from WS4 model
Cranbrook	No	IED existed within WS4 model but not within the WS3 model. Hydrology retained from WS4 model
Dungar	No	IED existed within WS4 model but not within the WS3 model. Hydrology retained from WS4 model
Clifton	No	IED existed within WS4 model but not within the WS3 model. Hydrology retained from WS4 model
Brislington	Yes	Hydrology imported from WS3 model
Pigeonhse	Yes	Hydrology imported from WS3 model
UprMalago	Yes	Hydrology imported from WS3 model
LwrMalago	Yes	Hydrology imported from WS3 model
Colliters	Yes	Hydrology imported from WS3 model
Longmoor	Yes	Hydrology imported from WS3 model
Trym	Yes	Hydrology imported from WS3 model
Markham	Yes	Hydrology imported from WS3 model

Within the WS3 model there were also inflows associated with Saltford, Hanham and Airport Road, however these did not match any of the IDs in the WS4 model and therefore they were not included/updated.

4.4.3 *Barrier Representation – Wide Barrier*

Using the same methodology as the WS3 barrier models, the barrier was represented in the WS4 ISIS model using gated weir units. The arrangement of the structures inserted at cross-sections Av6_0552 (Pill/Shirehampton) is shown in Figure 4.

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

Within the model, the shape of the cross-section meant that three gates were represented, each measuring 40m in width and ranging in height from 11.4m to 17.9m. On the south (left bank) side the barrier will tie into the existing Pill flood defence embankments which will need to be raised by up to 2m. On the north (right) bank the main structure will tie into high ground via an earth embankment across a grassed field and the access to the Sailing Club. Additional topographic survey data is required to assess the extent of the tie in. With this barrier position it may be necessary to carry out works across or alongside the Severn Beach railway to provide the full flood risk benefits up to 2115. The overall width of the barrier would be 355m and there would need to be additional raising of the existing Pill flood defence embankments to prevent outflanking.

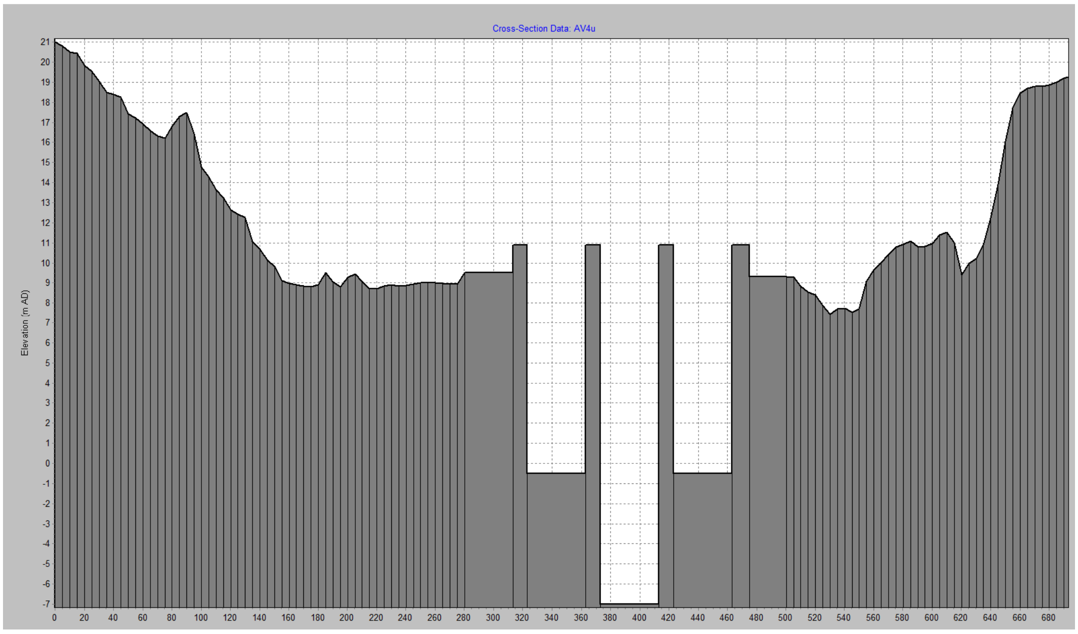


Figure 4: Pill/Shirehampton Barrier Cross-section (Av6_0552)

4.4.4 *Barrier Representation – Narrow Barrier*

Two locations were initially considered for the narrow barrier. The first of these, designated 'Ham Green/Nibley Road' is located 1500m upstream of the wide barrier position and extends between Ham Green on the south (left) bank and the Nibley Road allotments on the north (right) bank.

The design tide level for this barrier is 11.0m AOD with a bed level of approximately -5.0m AOD (Figure 5). The barrier in this location would comprise of 3 gates, 40m wide.

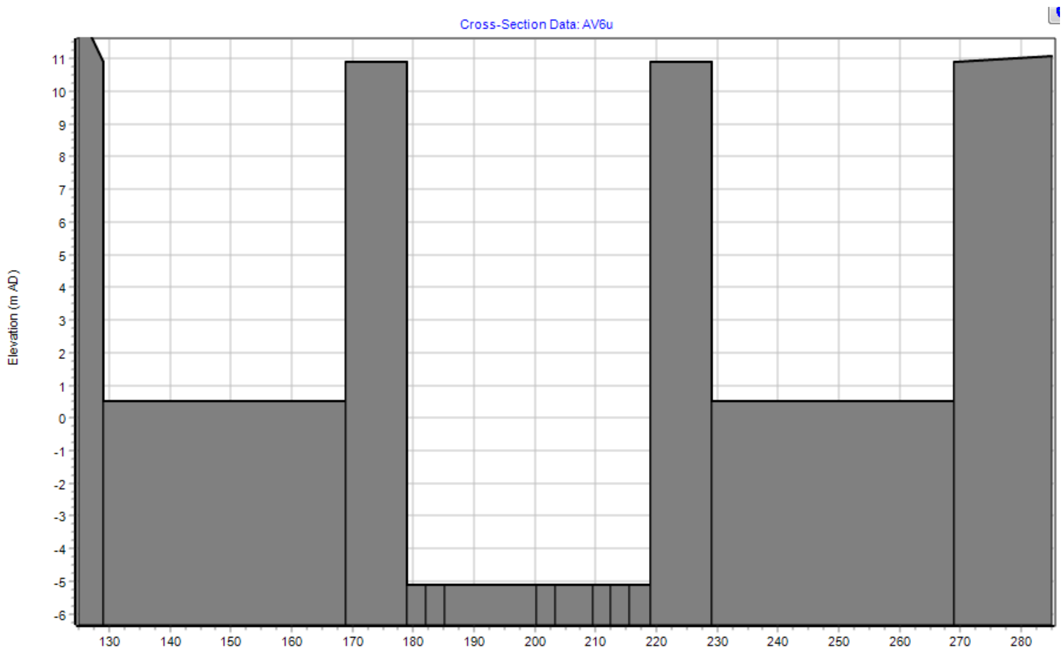


Figure 5: Nibley/Ham Green Barrier Cross-section (Av6u)

The second 'narrow' barrier location designated 'Cumberland Basin' is located close to the city centre, 150m downstream of the Junction Lock entrance to Cumberland Basin. For the purpose of this assessment, the Cumberland Basin barrier was taken forward, due to its close proximity to the city.

The design tide level for this barrier is 11.0m AOD with a bed level of approximately -3.5m AOD (Figure 6). The barrier in this location would comprise of 2 gates, one 20m wide and 10m high, the other 30m wide and 14.5m high. On the south (left) bank, the Portishead railway, an unclassified access road the Avon trail would need to be raised on embankments up to 4m high. On the north (right) bank, the A4 Hotwells Road would need to be raised by up to 2.5m. Alternatives to raising the transport infrastructure would be to allow temporary or demountable defences or flood gates to be used for all or part of the tie in but this would increase the residual flood risk if there were to be any operational failures.

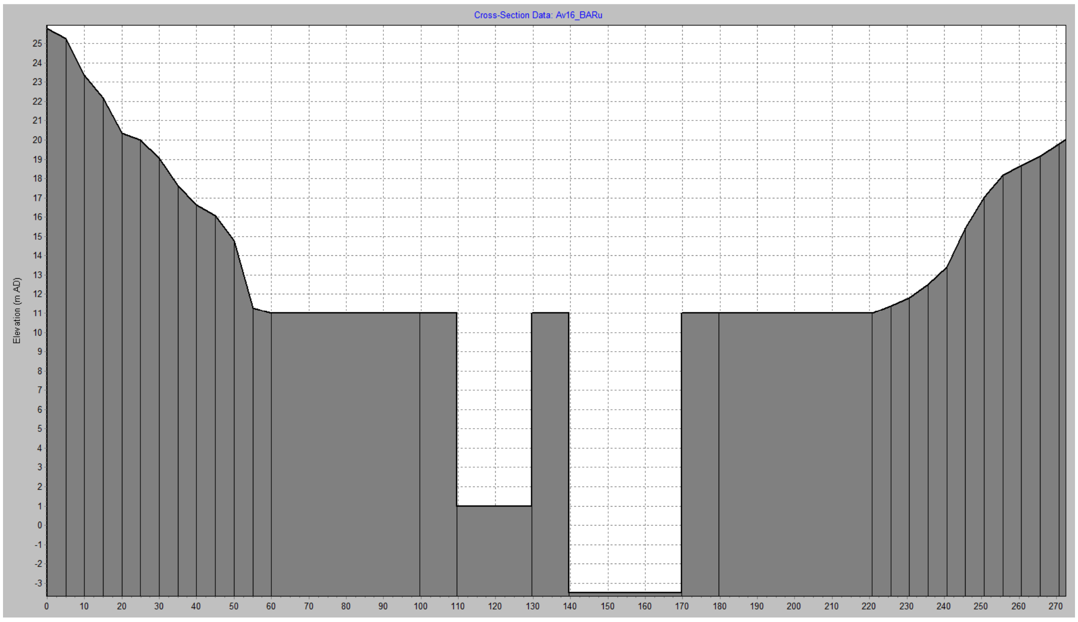


Figure 6: Cumberland Basin Barrier Cross-section (Av6_0001)

4.4.5 *Barrier Operation*

Several control operations were tested at each barrier location 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 14.

Table 14: 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
49	2115	2yr Tide 200yr Fluvial	n/a	n/a	n/a	n/a
50	2115	2yr Tide 200yr Fluvial	40.00 hrs	41.25 hrs	48.00 hrs	49.25 hrs
51	2115	2yr Tide 200yr Fluvial	40.00 hrs	41.25 hrs	46.00 hrs	47.00 hrs
52	2115	2yr Tide 200yr Fluvial	44.40 hrs	44.85 hrs	46.00 hrs	47.00 hrs

Run ID 49 represents the bassline scenario with no barrier in place at Pill/Shirehampton or at the Cumberland Basin. The operation controls within Run ID 50 represent a barrier closure of entire peak tidal curve (Figure 7), while during Run ID 51 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 8). During Run ID 52, 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 9).

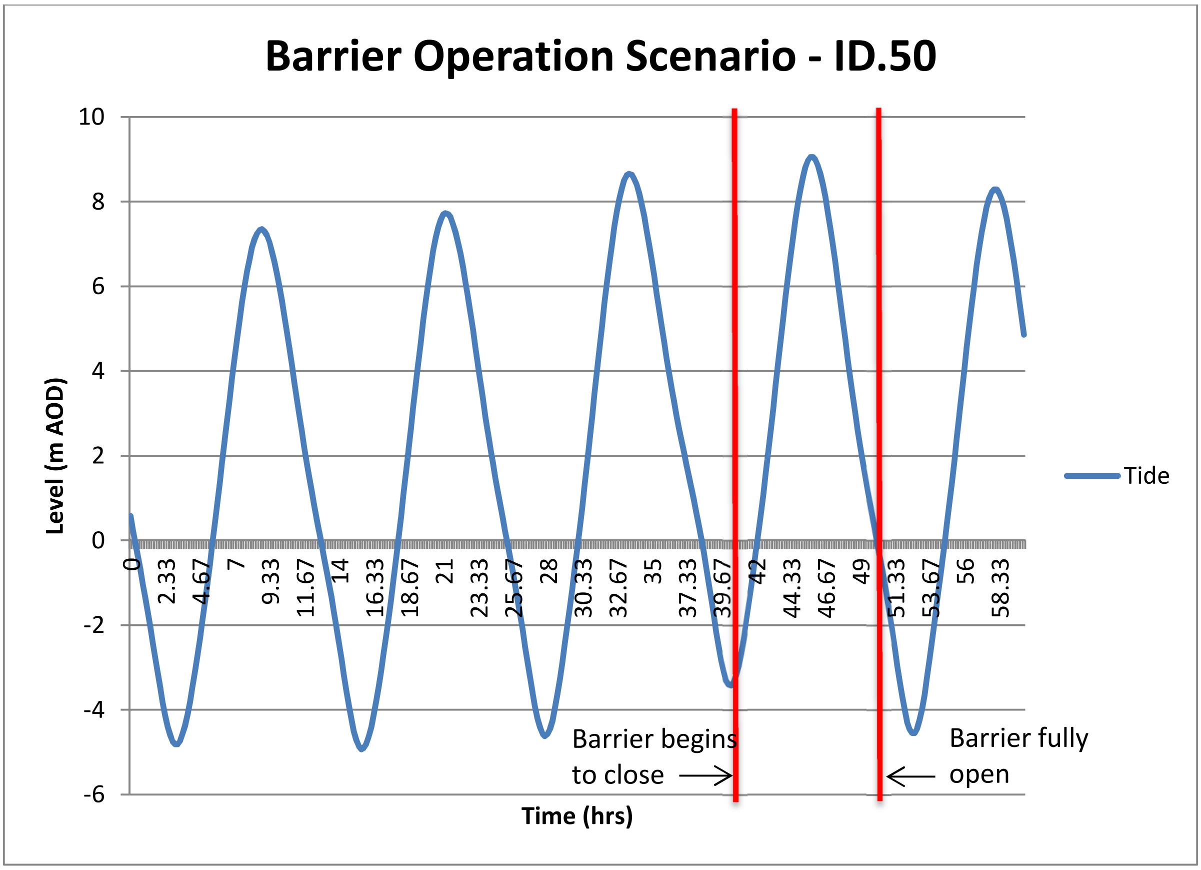


Figure 7: Barrier Operation Scenario (Run. ID 50)

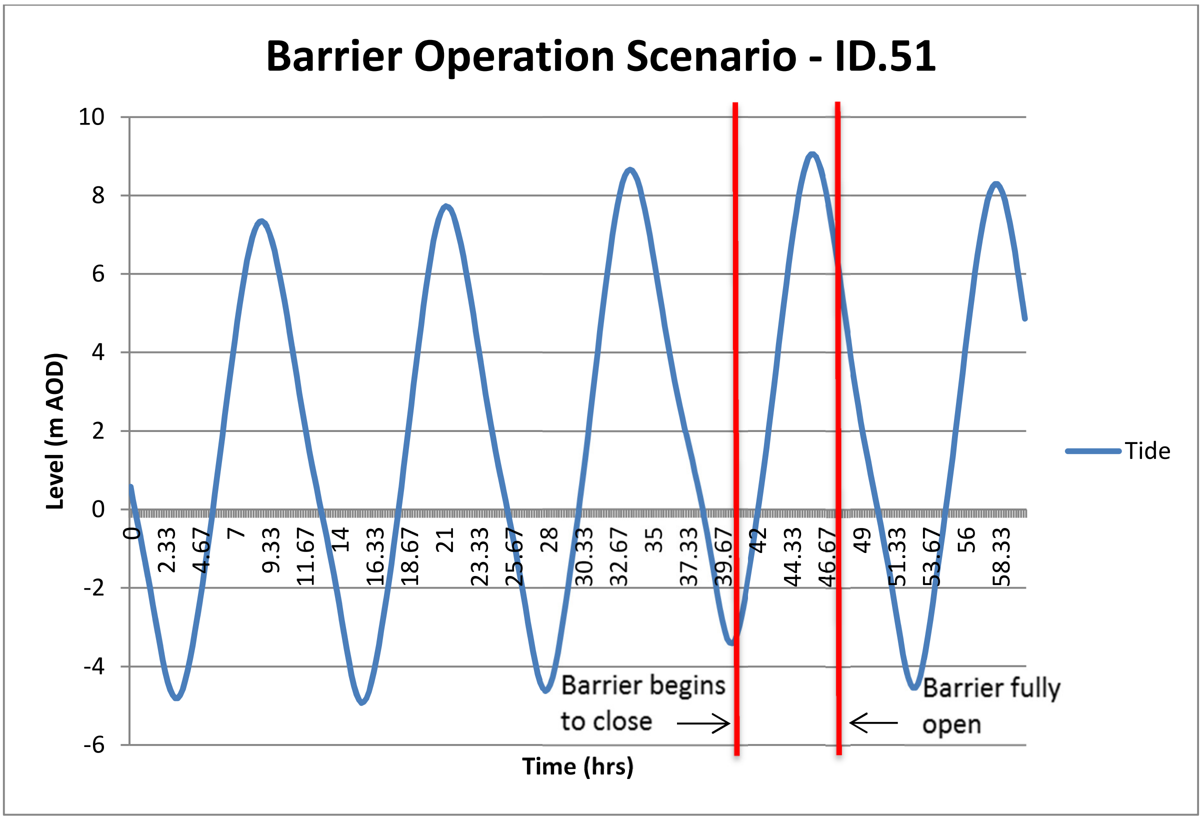


Figure 8: Barrier Operation Scenario (Run. ID 51)

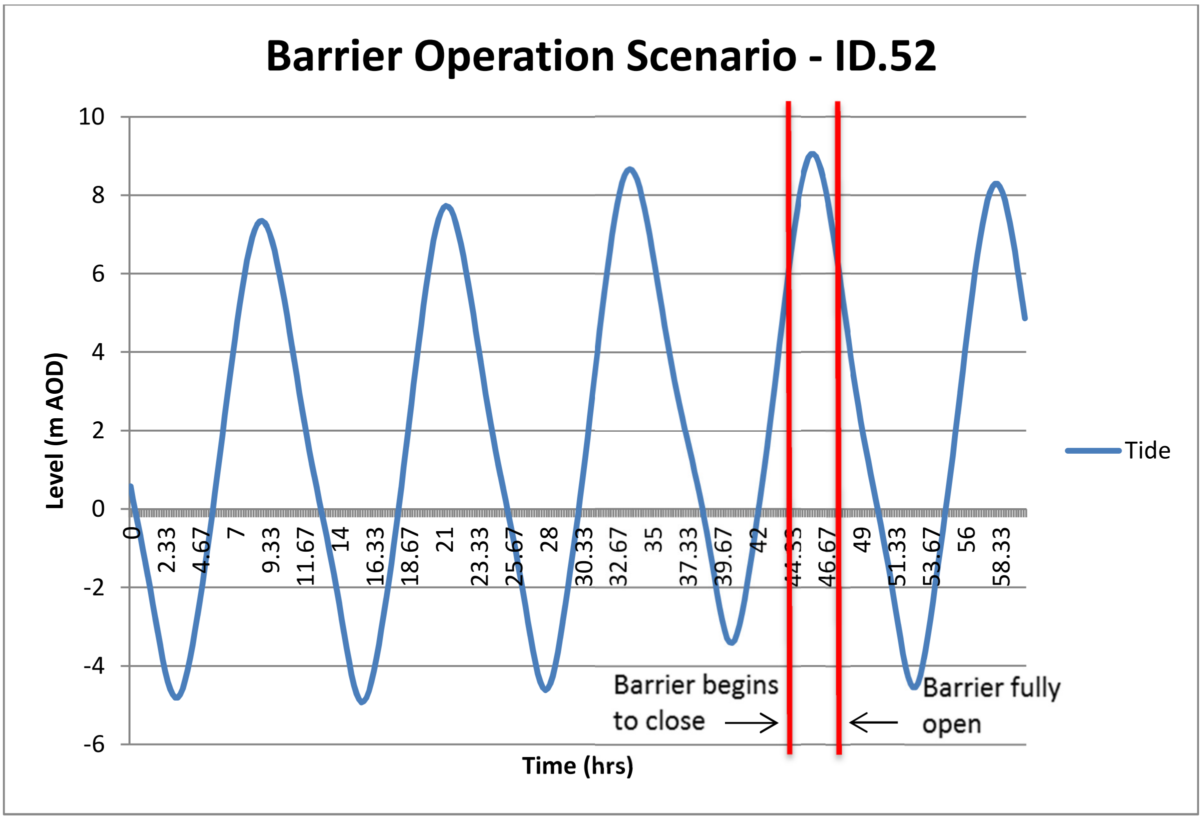


Figure 9: Barrier Operation Scenario (Run. ID 52)

4.4.6 *Barrier Results – Wide Barrier*

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

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

To assess the impact of the barrier on flood levels upstream (to the eastern side), a number of cross-sections were chosen for data extraction. These included the reservoir unit used to represent the Floating Harbour (R11bd), the cross-section representing the Junction Lock between the Cumberland Basin and the Floating Harbour (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 10.

A limited modelling programme has been undertaken for the Wide Barrier and, while results are not fully conclusive, there is an indication that there would be sufficient storage capacity to accommodate high fluvial flows, however the use of a barrier as a solution would not eliminate flood risk from fluvial sources. The barrier would therefore require supplementary flood defence walls to ensure that no residual flood risk occurs as a result.

Results from the figures below (Figures 11 – 14) show that there is no significant increase in water levels at the cross-sections upstream of the barrier indicating that there is sufficient storage capacity. It should be noted, however, Figure 11, showing water levels in the Floating Harbour highlights that the 200 year fluvial flows in 2115 would result in water levels being raised to approximately 9m AOD. Since the crest of the harbour walls in the Floating Harbour are around 8.5m AOD, it will be necessary to consider the need for walls around the Floating Harbour to address fluvial flood risk, regardless of whether a barrier is present or not i.e. the barrier is predicted not to exacerbate this scenario.

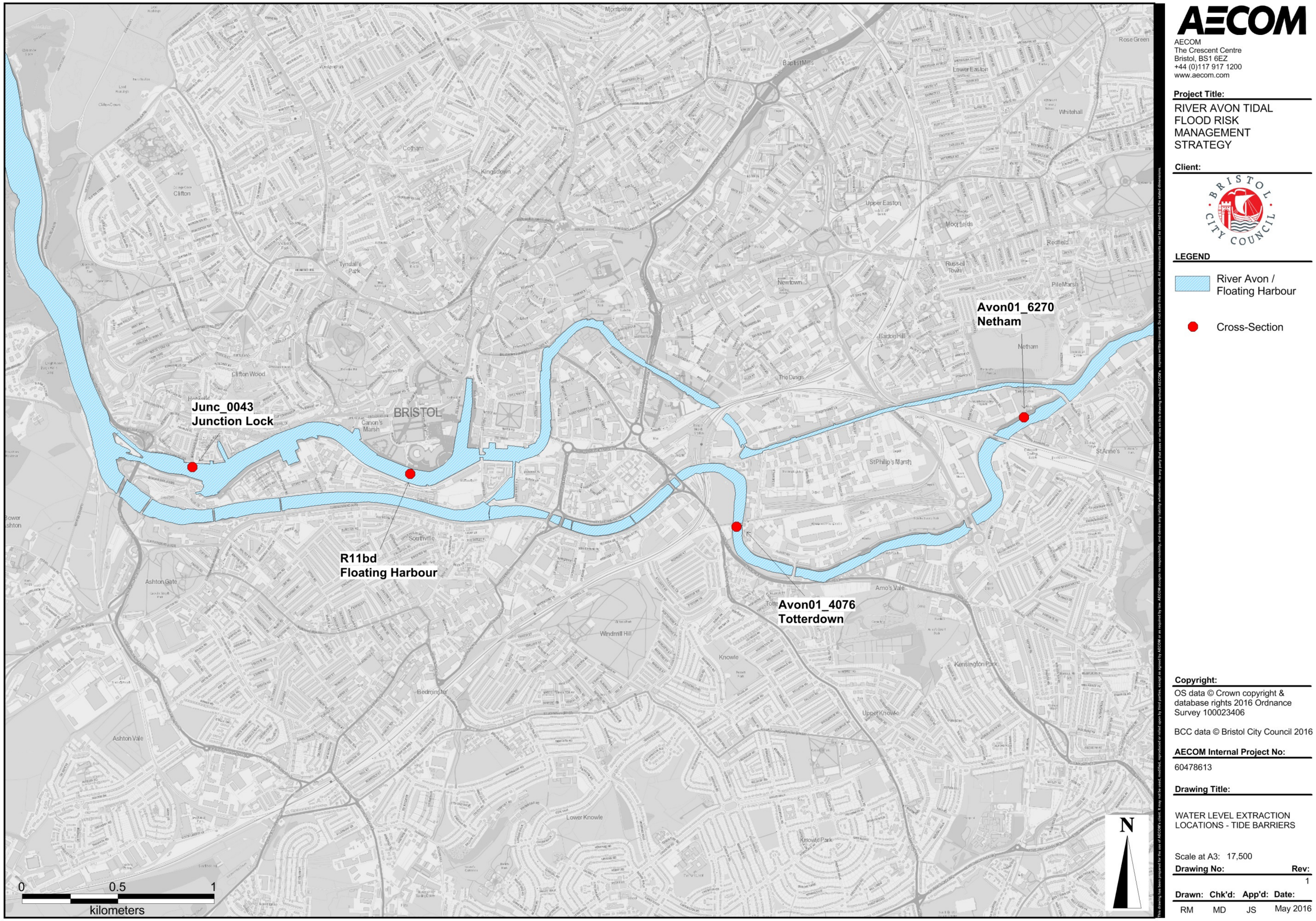


Figure 10: Cross Sections used for Water Level Extraction

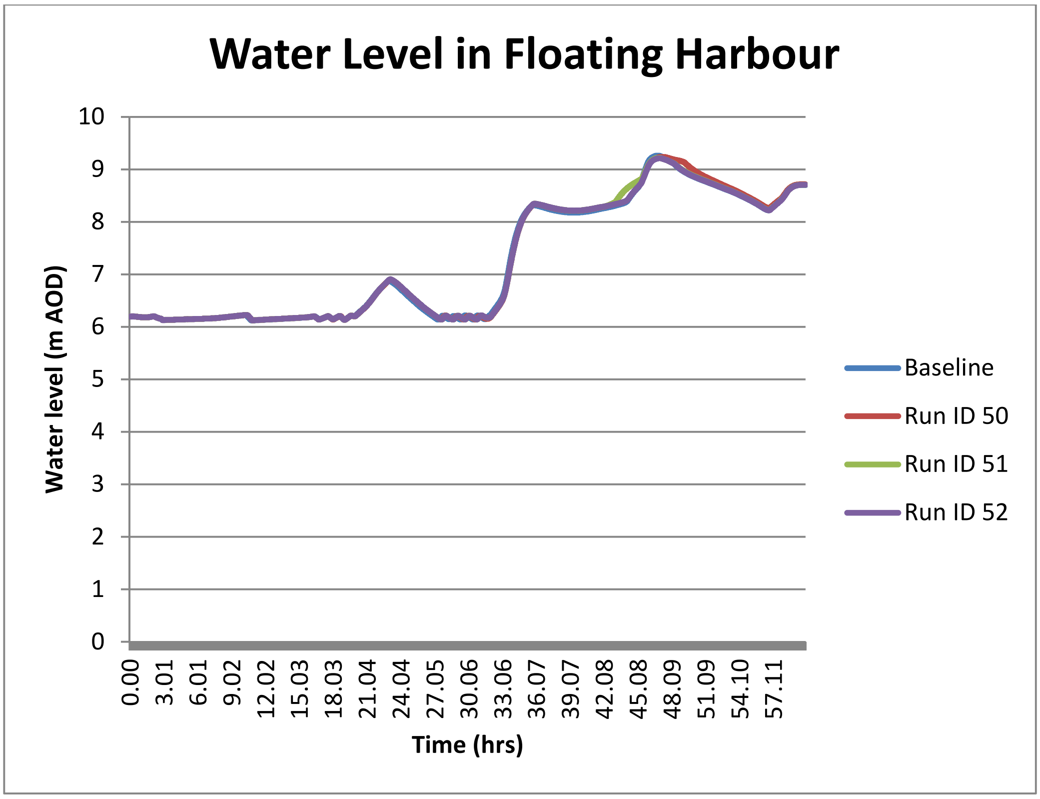


Figure 11: Water Level in Floating Harbour (Pill/Shirehampton Barrier)

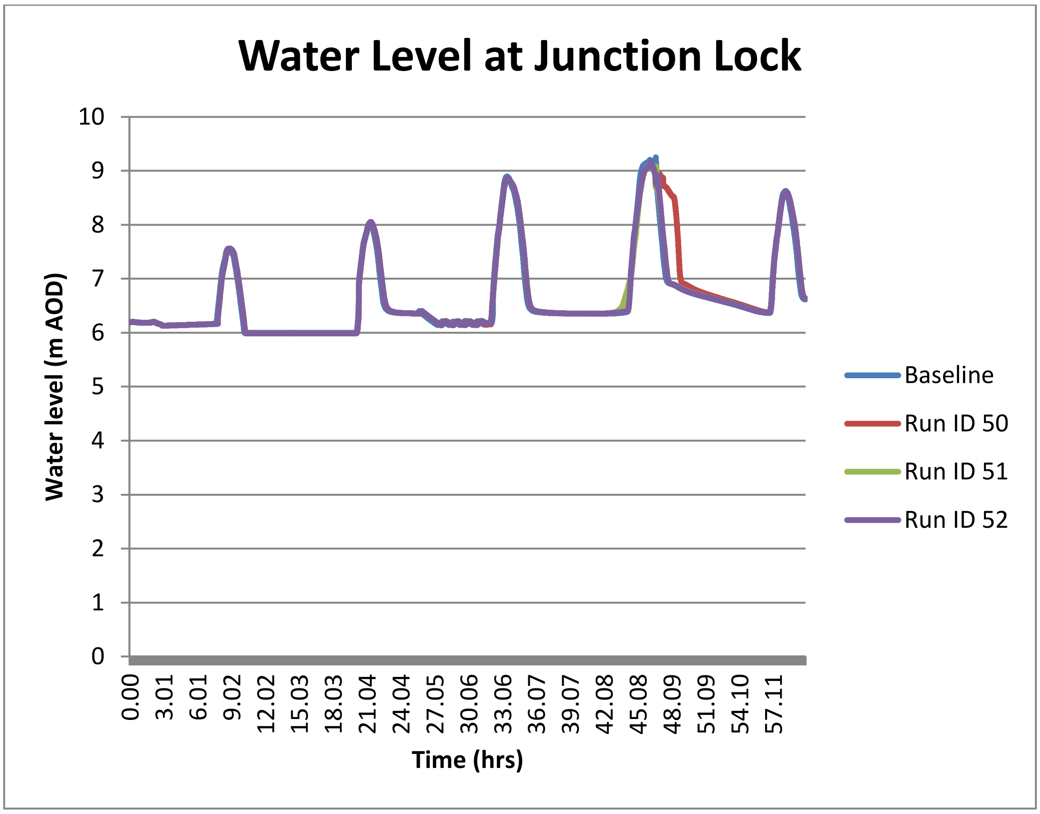


Figure 12: Water Level at Junction Lock (Pill/Shirehampton Barrier)

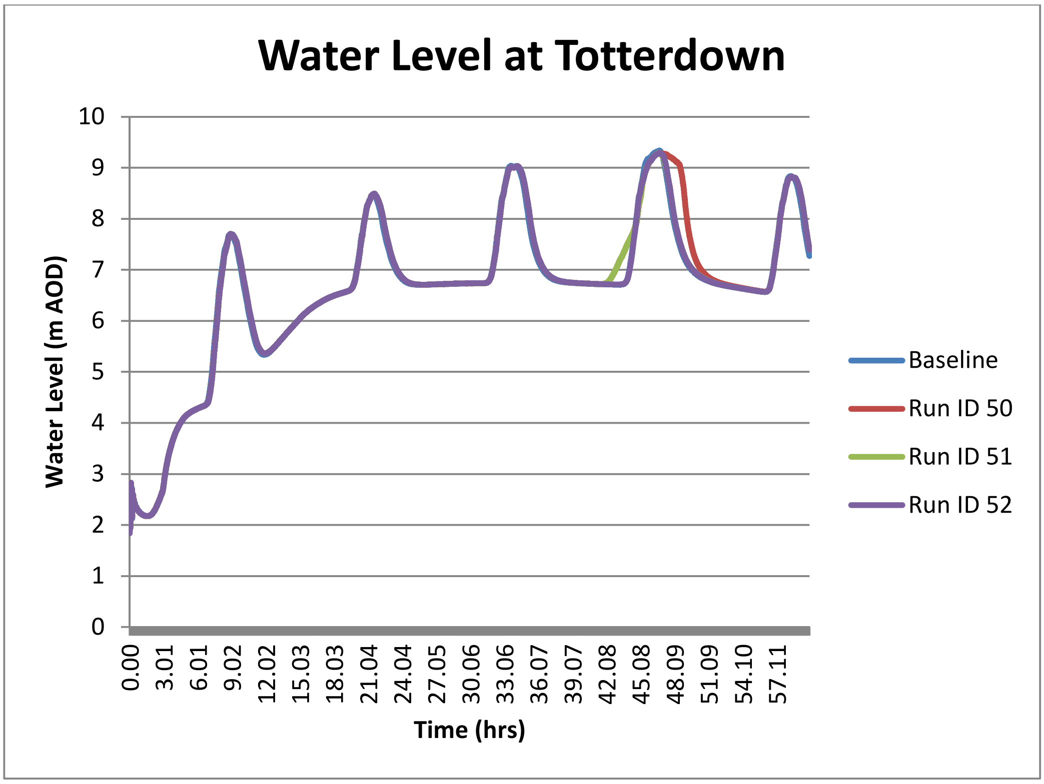


Figure 13: Water Level at Totterdown (Pill/Shirehampton Barrier)

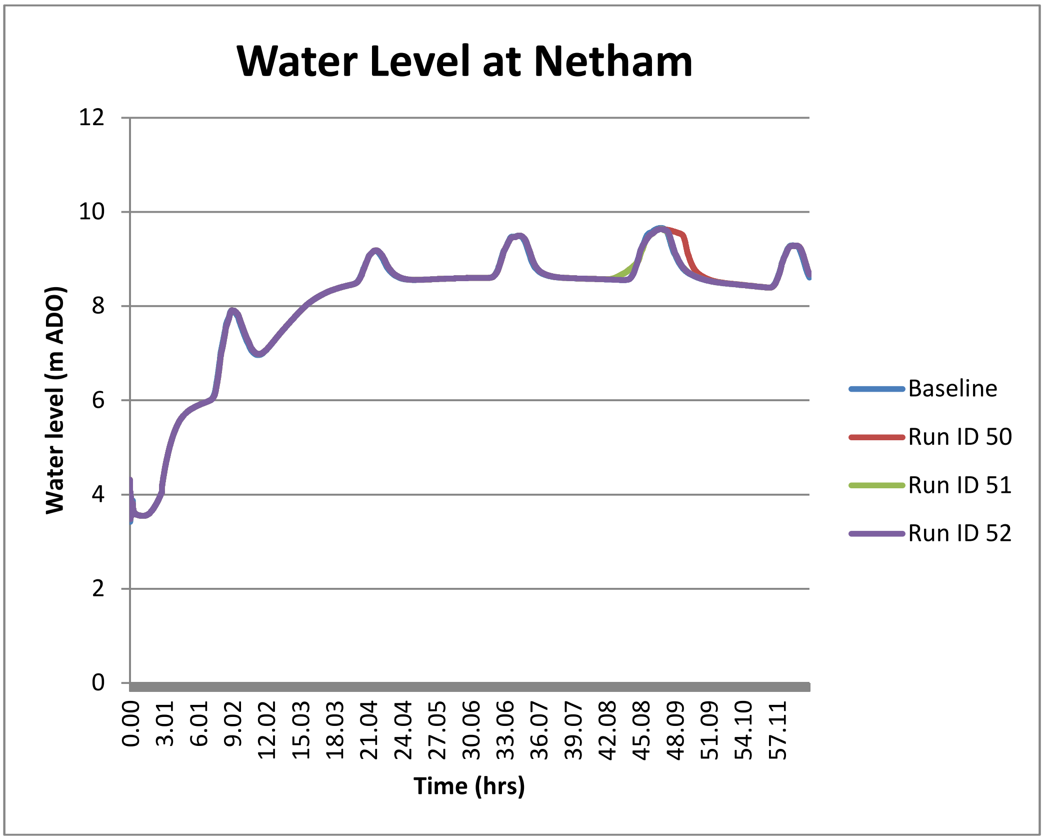


Figure 14: Water Level at Netham (Pill/Shirehampton Barrier)

4.4.7 *Barrier Results – Narrow Barrier*

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

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

The feasibility of this location in respect of ability to pass fluvial flows has been assessed through limited hydraulic modelling. Although the modelling should not be regarded as definitive in terms of validation, model results suggest that the barrier would cause a significant increase in flood levels upstream,

To assess the impact of the barrier on flood levels upstream (to the eastern side), a number of cross-sections were chosen for data extraction. These included the reservoir unit used to represent the Floating Harbour (R11bd), the cross-section representing the Junction Lock between the Cumberland Basin and the Floating Harbour (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 10.

As can be seen from Figures 15 – 18, during the model simulations based on the operating conditions associated with Run ID 50 and 51 (where the barrier is closed for the longest periods) there is a significant increase in water levels at all locations that have been assessed upstream of the barrier. Most significant are the increases within the Floating Harbour. Even when the barrier is closed for a shorter period (Run ID 52) there is still an increase in water levels at all cross-section upstream of the barrier which indicates that there is not sufficient storage to cope with a high fluvial event.

With results indicating increases in flood levels upstream, it is considered that a barrier at this location would need to be coupled with flood walls on the River Avon, thereby negating the advantage of a barrier. It has therefore been concluded from this work that, in principle, this location is not suitable for a tidal flood barrier.

It should be noted that at Junction Lock the water level does not fall below 6m AOD, even at low tide when the barrier (both wide and narrow) is closed. It is considered that this is a reflection of the Floating Harbour management controls specified within the model which prevents the water from dropping below this level, combined with the high fluvial flows associated within the 1 in 200 year event.

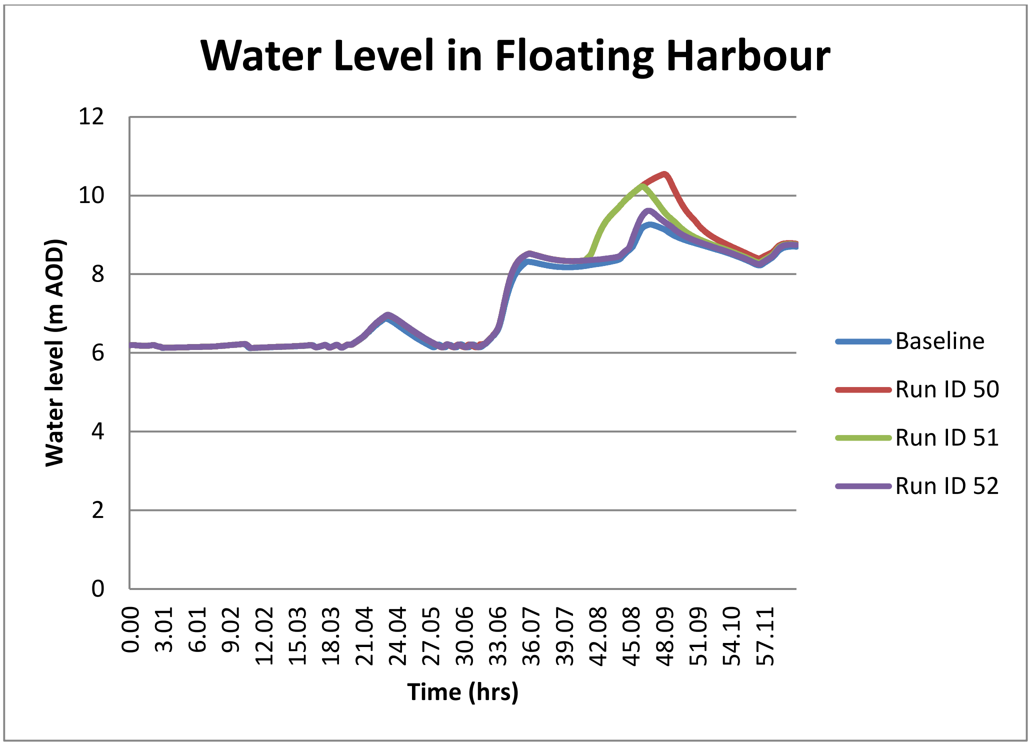


Figure 15: Water Level in Floating Harbour (Cumberland Basin Barrier)

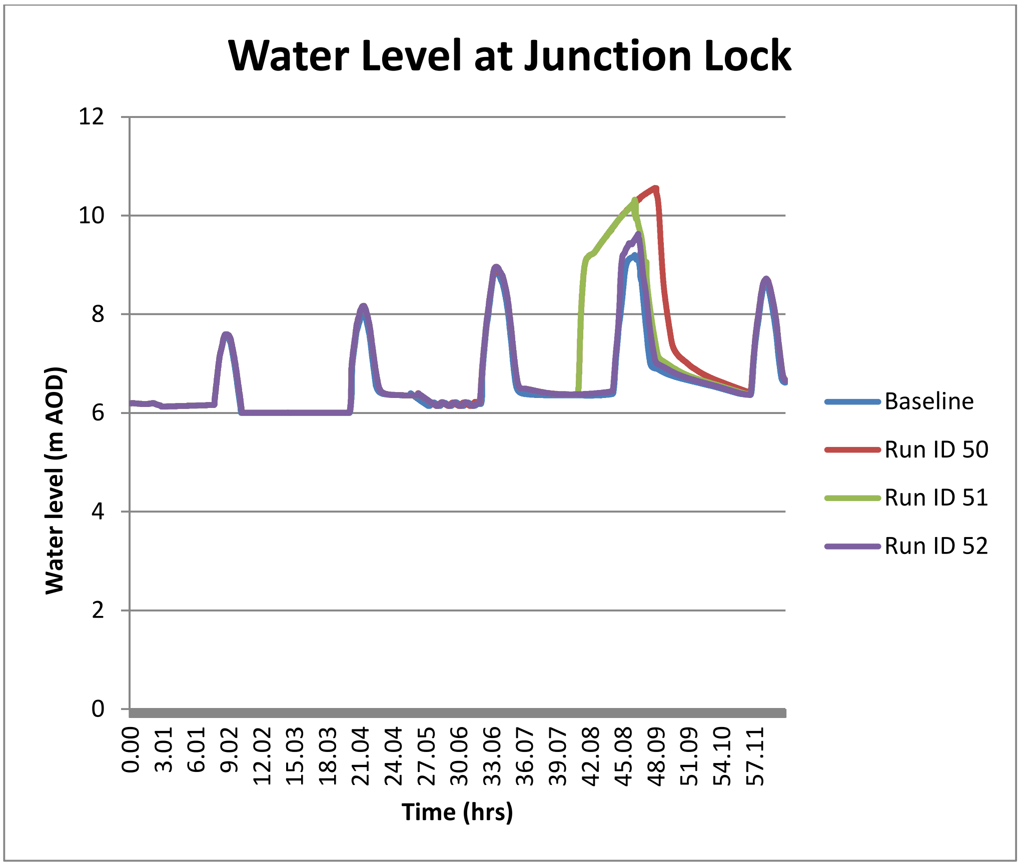


Figure 16: Water Level at Junction Lock (Cumberland Basin Barrier)

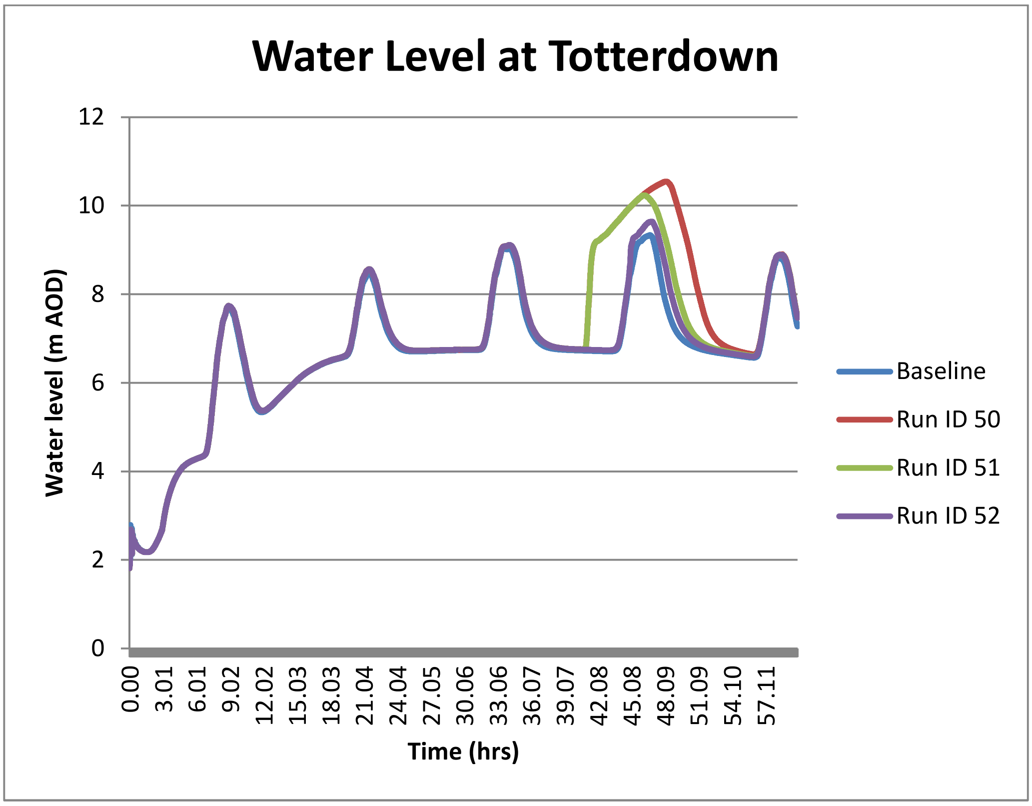


Figure 17: Water Level at Totterdown (Cumberland Basin Barrier)

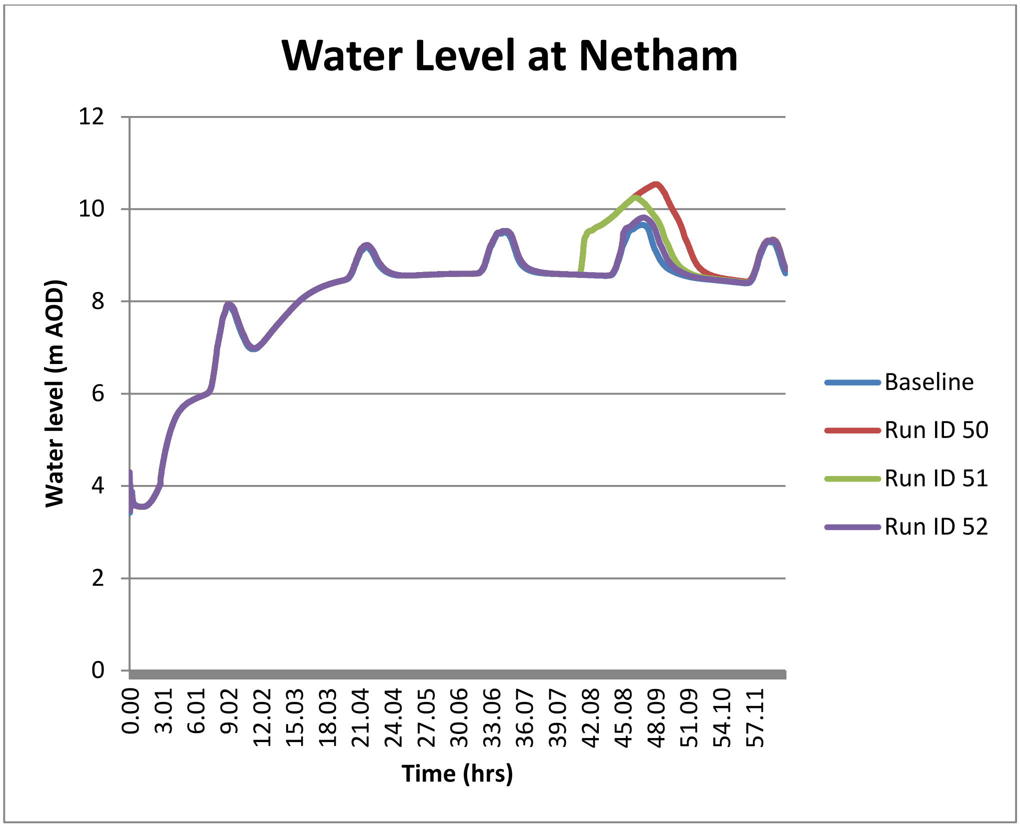


Figure 18: Water Level at Netham (Cumberland Basin Barrier)

4.4.8 ***Assessing the impact of barrier closure on upstream levels for the tidal extreme design event***

In order to assess betterment in upstream tidal levels resulting from barrier deployment, and to confirm that the barriers provide a robust solution to address tidal flood risk, the WS4 model was used to test the three barrier locations against a 1:200 yr (0.5%AEP) tidal event at 2115 (the design event). A fluvial base flow was applied to represent 'normal' conditions in the catchments. The peak water levels upstream of the deployed barriers were extracted and compared to the equivalent event simulated in the Do Nothing scenario (Table 15)

Table 15: Barrier impacts on upstream water levels under a 1:200 year tidal event, with base fluvial flows at 2115.

Barrier Location	XS Location	Baseline	With Barrier (closed)	Difference
Pill	Immediately upstream	9.9 m AOD	3.8 m AOD	- 6.1 m
	Netham	9.7 m AOD	4.0 m AOD	- 5.7 m
	Totterdown	9.6 m AOD	3.9 m AOD	- 5.8 m
	Cumberland	9.7 m AOD	3.8 m AOD	- 5.9 m
Cumberland	Immediately upstream	9.8 m AOD	6.0 m AOD	- 3.8 m
	Netham	9.7 m AOD	6.1 m AOD	- 3.6 m
	Totterdown	9.6 m AOD	6.1 m AOD	- 3.5 m
	Cumberland	9.7 m AOD	6.1 m AOD	- 3.6 m
Nibley	Immediately upstream	9.9 m AOD	3.7 m AOD	- 6.2 m
	Netham	9.7 m AOD	4.0 m AOD	- 5.7 m
	Totterdown	9.6 m AOD	3.9 m AOD	- 5.7 m
	Cumberland	9.7 m AOD	3.8 m AOD	- 5.9 m

These results show that a barrier will prevent tidal flooding against the design event at all three locations.

Nibley and Pill locations produce maximum upstream betterment (reduction in peak levels against the baseline) as these allow much larger storage volumes for fluvial flows upstream of the barrier.

A barrier at Cumberland basin also adequately protects against tidal flooding from this event and also has sufficient storage for fluvial base flow conditions. However as shown in 4.4.7 this location does not provide sufficient storage to accommodate larger fluvial flows and exacerbates the risk posed by this source.

4.4.9 ***Assessing the impact of barrier closure on downstream extreme tidal levels***

Deploying a tidal barrier in the channel prevents the tidal inundation up the Avon and has the potential to increase the extreme water levels downstream of the barrier (against the baseline without a barrier present in the channel). This is due to water being reflected and backing up against the physical barrier.

The WS4 model was used to quantify the increase in peak levels immediately downstream of the barrier at the three different locations. In order to achieve this a 1:200 year extreme tidal event was simulated at 2115 for the three different barrier locations in the channel and then the peak water level immediately downstream of the barrier was extracted and compared to the equivalent event simulated in the Do Nothing scenario (Table 16).

To assess maximum potential downstream impacts a simplistic 'worst case' closure assumption from low water up to two hours after high water was adopted (9 hour closure period). This is reasonable when considering downstream worst case 'detriment'. However, as shown in the fluvial storage testing graphs, this closure routine is not likely to be optimal for maximising upstream betterment. i.e. if you want to maximise the betterment upstream a shorter closure period over the top of the tide only is needed. Optimisation of closure routines for upstream betterment will be addressed at the next stage of the project if the barrier is taken forward as the preferred option.

Table 16: Barrier impacts on downstream water levels under a 1:200 year tidal event at 2115.

Barrier Location	XS Location	Baseline Water level (with no barrier present)	With Barrier (closed)	Difference in Water Level
Pill / Shirehampton	Immediately Downstream of barrier	9.90m AOD	9.90m AOD	0.00m
Cumberland Basin	Immediately Downstream of barrier	9.82m AOD	10.03m AOD	+0.21m
Nibley / Ham Green	Immediately Downstream of barrier	9.90m AOD	9.94m AOD	+0.04m

The results in Table 15 demonstrate that at the Pill / Shirehampton and Nibley Road locations there is no significant difference in peak water levels immediately downstream as a result of barrier closure. This fits with their location much closer to the 'open' sea where reflected / displaced water volume spreads out into an almost infinite volume so does not increase downstream levels. The downstream increase is much greater (21cm) with the Cumberland basin barrier location as the channel is much more constrained (i.e. by the gorge) so reflected / displaced volume is essentially 'trapped' within the Cumberland Basin area.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Modelling Results

The hydraulic modelling study has been undertaken to assess the risk of flooding to Bristol as part of the Tidal Flood Risk Management Strategy (TFRMS). The study area includes the City Centre (between Cumberland Basin and Netham) and extends north up to Shirehampton and Avonmouth.

The flood risk in the study area is dominated by tidal events and has therefore been 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.

As part of the modelling study the following technical aspects were completed:

- Numerical modelling of flood risk for the Do Nothing and Do Minimum Options, as well as selected modelling of barrier options. Mapping of the Do Nothing and Do Minimum results which have been used to assess flood damages;
- A range of measures to protect Bristol from flooding have been conceived and modelled to assess their feasibility (Do Something). These include a number of different tidal barriers at various locations along the River Avon and a number of variants using flood walls. In the case of tidal flood barrier this has also included numerical modelling to test whether the barrier is able to pass fluvial flood flows without causing an increase in fluvial flood risk.

Below provides a summary of each of the protection measures that were modelled following the initial Do Nothing and Do Minimum stages:

- All barriers, when deployed could provide tidal flood protection to central Bristol for the 2115 1:200 year design standard (see Section 4.4.8)
- Wide Tidal Barrier – Modelled approximately 500m upstream of the M5 road bridge (downstream extent of Pill) using various controls on the operation of the gated structures. While results were not fully conclusive, there is an indication that there would be sufficient storage capacity behind the barrier to accommodate high fluvial flows and not cause an increase in flood risk from this source in central areas.
- Narrow Tidal Barrier – Modelled at the Cumberland Basin approximately 150m downstream of the Junction Lock using various controls on the operation of the gated structures. Results have shown that there was a significant increase in water levels in areas further upstream from the barrier, including the Floating Harbour, Totterdown and Netham, suggesting that with the location of the barrier so close to the City Centre does not provide sufficient storage to cope with a high fluvial event when in a closed position. It is considered that this barrier would need to be coupled with flood walls on the River Avon, if it were to be taken forward.
- The barrier locations at Pill / Shirehampton and at Nibley road do not significantly increase downstream peak water levels in extreme tidal events. The Cumberland basin barrier location would lead to downstream peak tidal levels being increased by over 20cm under extreme events.
- High Defences – This measure comprises linear defences (walls/embankments) to provide a high standard of protection in a single implementation phase. For the purpose of the short list appraisal it was assumed that the defences would need to be constructed to a 1 in 200 year standard of protection 2115. This requires raising all identified defences to 10.20m AOD, which was approximately 0.3m above the 1 in 200 year (2115) design water level. The defences identified as part of this measure consist of flood walls/embankments along the River Avon and improvements to crest level at either end of the Floating Harbour. Results from this model have shown a significant reduction in flooding to areas around the Floating Harbour.

Through modelling of the above, the results were analysed and options were identified and taken forward to the short list assessment stage.

5.2 Next Steps

In the next stage of the project a more detailed appraisal of the short listed options will be carried out to select the draft preferred Strategy option. In terms of hydraulic modelling, this will include the following activities:

- Further development of options, including spatial requirements and alignments, typical details and engineering concepts;
- Further technical appraisal of option feasibility, risks and uncertainty.
- Further modelling of option scenario to establish benefits;
- Consideration of different futures (e.g. sensitivity testing different climate change scenarios, development and funding cases) and their impact on outcomes.

The culmination of the above activities along with more detailed economic appraisals, environment assessment and stakeholder engagement, will lead to the selection and recommendation of the draft preferred options.

APPENDIX A

Technical Note

Hydrology and Topographic Data Review

Project Name:	Avon Tidal Flood Risk Management Strategy	Date:	16th March 2016
Subject:	Hydrology and Topographic Survey Checks	Prepared by:	Richard Moore
Version:	Draft V 1.0	Reviewed:	Mark Davin
Project Reference:	60478613	Approved:	Mark Davin

1.0 HYDROLOGY

The objective of this Technical Note is to appraise the available hydrological approaches for the Central Area Flood Risk Assessment (CAFRA), within Workstream 3 (WS3) and Workstream 4 (WS4). It was decided to investigate the hydrographs in WS3 and WS4 in more detail, as the difference in fluvial inflow volume and flow rates is an important consideration for flood risk management options within the Avon TFRMS project.

WS3 - The WS3 approach adopts ReFH design event hydrograph shapes, scaled to fit FEH statistical peak flow estimates. It was assumed that each fluvial sub-catchment had its own critical storm duration and that these inflows were phased to coincide with the peak flow on the receiving primary watercourse (i.e. River Avon) and in turn phased to coincide with the peak of the tidal surge. Overall, this was considered to be a conservative approach.

WS4 - The WS4 approach involved deriving standardised hydrograph shapes using observed (gauged) data from three significant events. This approach demonstrated that the hydrographs derived by this approach tended to have a greater total volume than the ReFH design event hydrographs previously used; although the peak flow rates, when compared to WS3, are similar in magnitude for each return period.

Comparison of Fluvial Input

This section details a comparison of the two hydrological approaches within WS3 and WS4 based on the fluvial model inflows at Frenchay and Brislington; tributaries of the River Avon. The 1 in 2 year fluvial event has been used, with 100 years climate change (2110) and reflects a 51 hour simulation period. It should be highlighted at this stage, that an objective of this document is to demonstrate the difference in flow volume and not the phasing (time) of peak flows.

<u>Fluvial Inflow Site 1: Frenchay</u>

The graph displayed in Figure 1 demonstrates the difference in total flow from Frenchay using both the WS3 and WS4 approach. The results confirm that for the WS4 approach, there is a significant increase in the total volume of water. Calculations of this difference show that for the WS3 approach there is a total volume of 3,259,298m^3, however for the WS4 approach this increases to 4,039,566m^3. This is an approximate 20% increase in total volume, using WS3 as the benchmark, which emphasises that the differences between approaches may be significant, where the differences between WS3 and WS4 increase with event magnitude. With regards to peak flows, the two approaches are very similar with WS3 having a peak flow of 38.25m^3/s and WS4 having a peak of 37.84m^3/s for the 2yr return period (2110).

<u>Fluvial Inflow Site 2: Brislington</u>

The difference between the total volume of water is not considered significant at Brislington when compared to Frenchay. The graph displayed in Figure 2 shows that the total volume is similar, as are the peak flows. The total volume of water associated with the WS3 approach for this inflow is 129,675m^3 in comparison to 121,165m^3 which is associated with the WS4 approach. This is approximately a 7% decrease in the total volume of water, using WS3 as the benchmark.

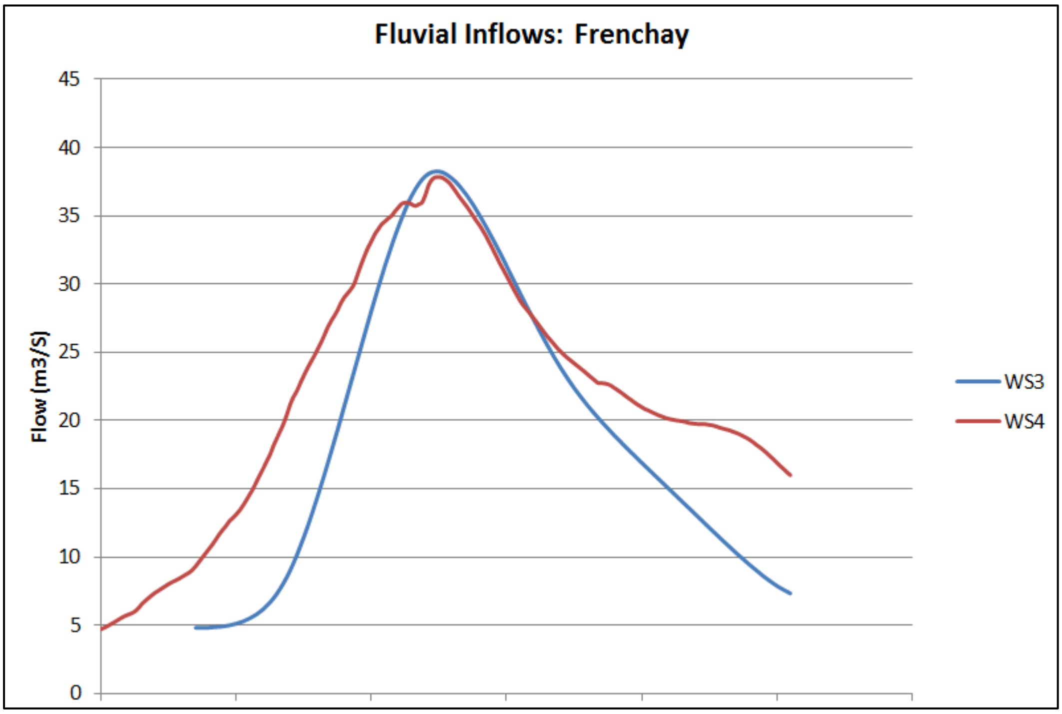


Figure 1: Flow Hydrograph for Frenchay based on the 1 in 2 Year Fluvial Event (2110)

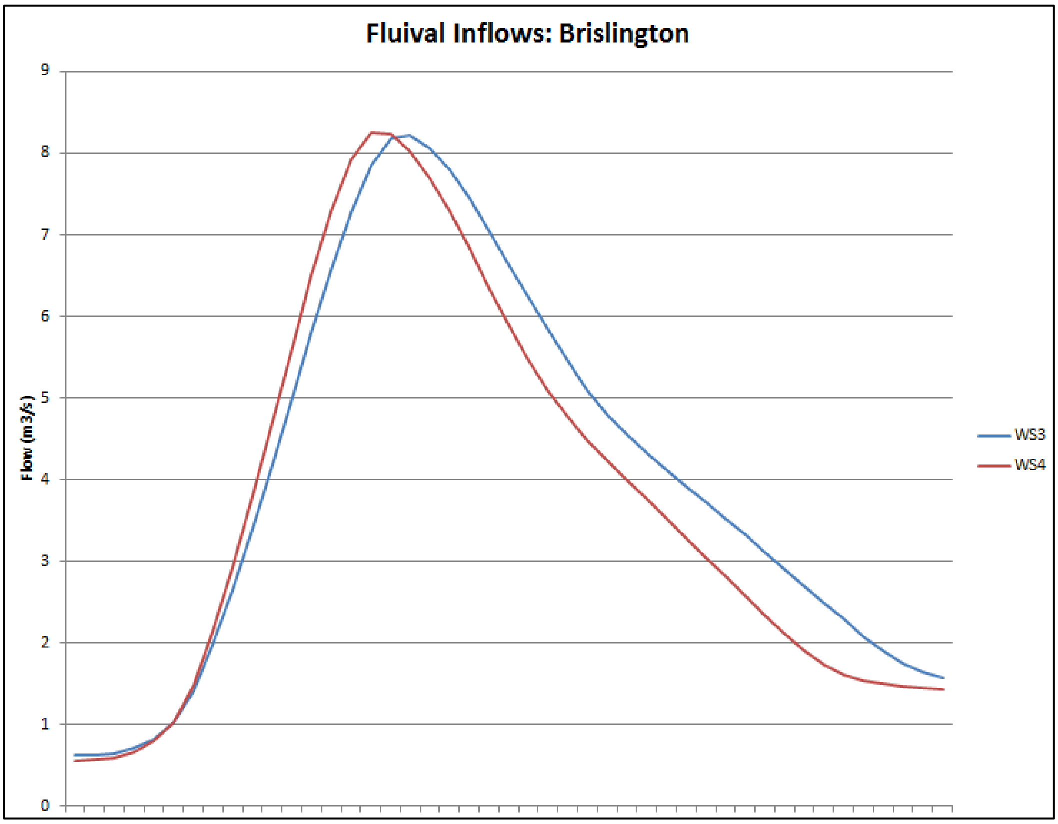


Figure 2: Flow Hydrograph for Brislington based on the 1 in 2 Year Fluvial Event (2110)

The comparison between inflows for smaller catchments, such as Brislington, the difference between the flow volumes for each approach may not be notably different. However for the larger catchments, such as Frenchay, the difference is much more significant and could have a greater impact on flood management options, especially those that involve storage and impounding of the fluvial hydrograph during an event.

2.0 TOPOGRAPHIC SURVEY

Additional topographic surveys have been made available by BCC where a spot-check review has been completed by AECOM to compare the accuracy of the LiDAR DTM used within the CAFRA model. This includes:

- The length of Commercial Road from Bedminster Bridge Roundabout to Bathurst Basin (source: Base Topo (inc Bathurst) DWG) ;
- The length of Cumberland Road from Bathurst Basin to the junction with Smeaton Road / Ashton Avenue (source: Base Topo (inc Bathurst) DWG).
- The area adjacent to Cattle Market Road / Feeder Road where the new bridge has been constructed connecting Cattle Market Road with the new Arena Island (source: Q80004-0100-002 Rev B Contours PDF, 2012); and
- St Phillips Greenway which runs parallel to the River Avon from Feeder Road in the north down to St Phillips Causeway in the south-east (source: 20140828 ARP_Additional Topo Survey_Overlay DWG, 2014);

Other datasets of the above areas have been provided and checked, however those mentioned above are considered to be the most recent and accurate. For each area the topographic levels were compared against the LiDAR DTM used within the CAFRA model. To emphasise the changes within each area, levels were taken from a number of points and are included within Tables 1-6. The locations of each spot-check point can be viewed in Appendix A.

Cumberland Road, Commercial Road and Bathurst Basin - Levels were compared along both the road and banks as part of this spot-check assessment. Results have shown that the levels within the LiDAR DTM and topographic survey appear to predominantly tie in well with no significant differences in most areas. The areas where significant variations do occur are located along the 'Chocolate Path' (Tables 2 and 3) which runs parallel to Cumberland Road. LiDAR DTM levels along this route were reviewed as being consistently lower than the levels within the topographic survey.

Table 1: Ground Level Comparison – Commercial Road

Point	LiDAR Level (m AOD)	Topo Level (m AOD)	Difference (m)
1	10.34	10.37	-0.03
2	9.73	9.75	-0.02
3	8.92	8.97	-0.05
4	8.96	9.01	-0.05
5	8.98	8.99	-0.01
6	9.15	9.31	-0.16
7	9.82	10.00	-0.18
8	10.76	10.86	-0.10

Table 2: Ground Level Comparison – Cumberland Road (Upper)

Point	LiDAR Level (m AOD)	Topo Level (m AOD)	Difference (m)
1	8.89	14.20	-5.31
2	13.40	13.40	0.00
3	11.70	11.68	0.02
4	9.90	9.93	-0.03
5	8.29	8.34	-0.05
6	8.58	8.59	-0.01
7	8.65	8.71	-0.06
8	8.64	8.65	-0.01
9	8.45	8.45	0.00
10	8.52	8.56	-0.04
11	8.10	8.06	0.04
12	7.60	8.50	-0.90
13	7.04	8.53	-1.49

Table 3: Ground Level Comparison – Cumberland Road (Lower)

Point	LiDAR Level (m AOD)	Topo Level (m AOD)	Difference (m)
1	10.13	10.14	-0.01
2	8.20	8.61	-0.41
3	10.76	10.82	-0.06
4	8.62	8.60	0.02
5	11.51	11.55	-0.04
6	8.56	8.66	-0.10
7	12.53	12.62	-0.09
8	6.50	8.61	-2.11
9	14.10	14.10	0.00

Cattle Market Road - There are significant differences along the bank of the River Avon as a result of the bridge construction. As demonstrated within Table 4 there are areas where the CAFRA model LiDAR DTM are consistently less than the levels within the topographic survey which could have a significant impact on the flood inundation within this area.

St Phillips Greenway - The topographic levels along the entire bank and path from Feeder Road to St Phillips Causeway were assessed against the LiDAR DTM. In particular, specific analysis was undertaken in areas of overtopping which were identified within the 'Verification of CAFRA models against 2014 tides' Technical Note (Hyder, 2015). As can be seen in Table 5, which assesses the area located around the railway/footbridge that connects Victor Road with Bath Road, there is a significant variation in levels between the topographic survey and the LiDAR DTM. In most cases, the LiDAR DTM level has again been reviewed to be lower than the level recorded within the topographic survey. In contrast, Table 6, which includes results from the area to the west of St Phillips Causeway Bridge demonstrate that the LiDAR DTM levels tie in well with the topographic survey.

Table 4: Ground Level Comparison – Cattle Market Road

Point	LiDAR Level (m AOD)	Topo Level (m AOD)	Difference (m)
1	8.66	8.79	-0.13
2	9.30	9.31	-0.01
3	8.46	8.32	0.14
4	4.03	9.35	-5.32
5	8.17	8.26	-0.09
6	7.93	8.06	-0.13
7	6.88	7.18	-0.30
8	8.70	10.00	-1.30
9	8.64	9.25	-0.61
10	8.71	8.78	-0.07
11	9.36	9.50	-0.14
12	9.35	9.50	-0.15
13	8.62	8.75	-0.13
14	8.41	8.50	-0.09
15	8.74	8.75	-0.01

Table 5: Ground Level Comparison – St Phillips Greenway (D/S)

Point	LiDAR Level (m AOD)	Topo Level (m AOD)	Difference (m)
1	8.73	8.41	0.32
2	7.85	8.44	-0.59
3	8.30	8.54	-0.24
4	8.97	8.98	-0.01
5	8.29	8.12	0.17
6	8.80	8.89	-0.09
7	8.34	8.50	-0.16
8	8.43	8.47	-0.04
9	8.50	8.65	-0.15
10	8.54	8.64	-0.10
11	8.37	8.53	-0.16
12	8.36	8.30	0.06
13	8.78	8.90	-0.12
14	8.77	8.90	-0.13

Table 6: Ground Level Comparison – St Phillips Greenway (U/S)

Point	LiDAR Level (m AOD)	Topo Level (m AOD)	Difference (m)
1	9.18	9.14	0.04
2	8.94	8.95	-0.01
3	8.37	8.41	-0.04
4	9.08	9.01	0.07
5	9.68	9.71	-0.03
6	9.23	9.30	-0.07

APPENDIX A
Ground Level Comparison Figures

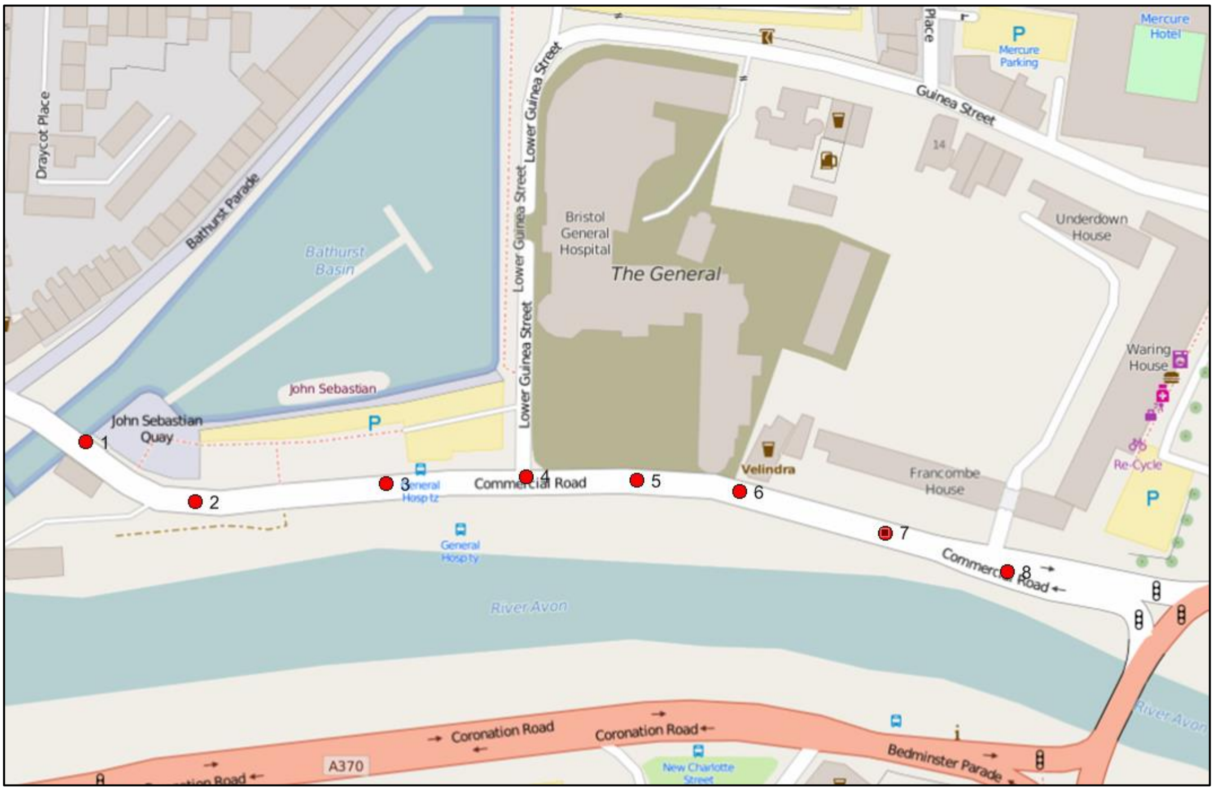


Figure A1: Commercial Road

Figure A2: Cumberland Road (Upper Extent)

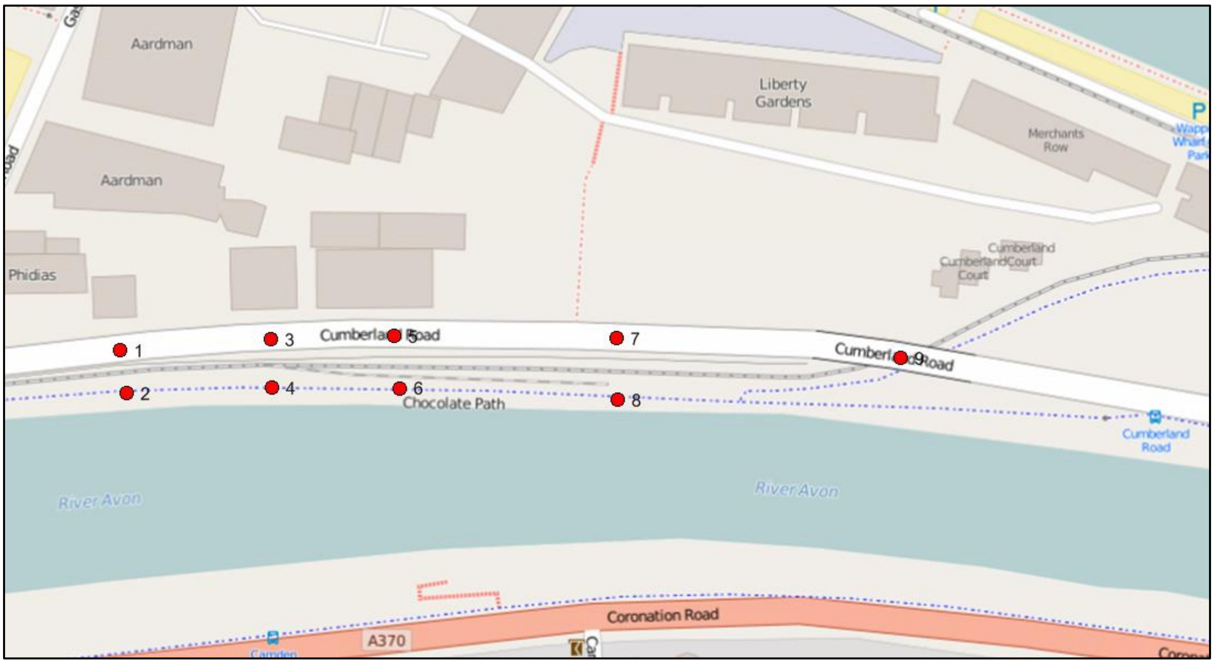


Figure A3: Cumberland Road (Lower Extent)

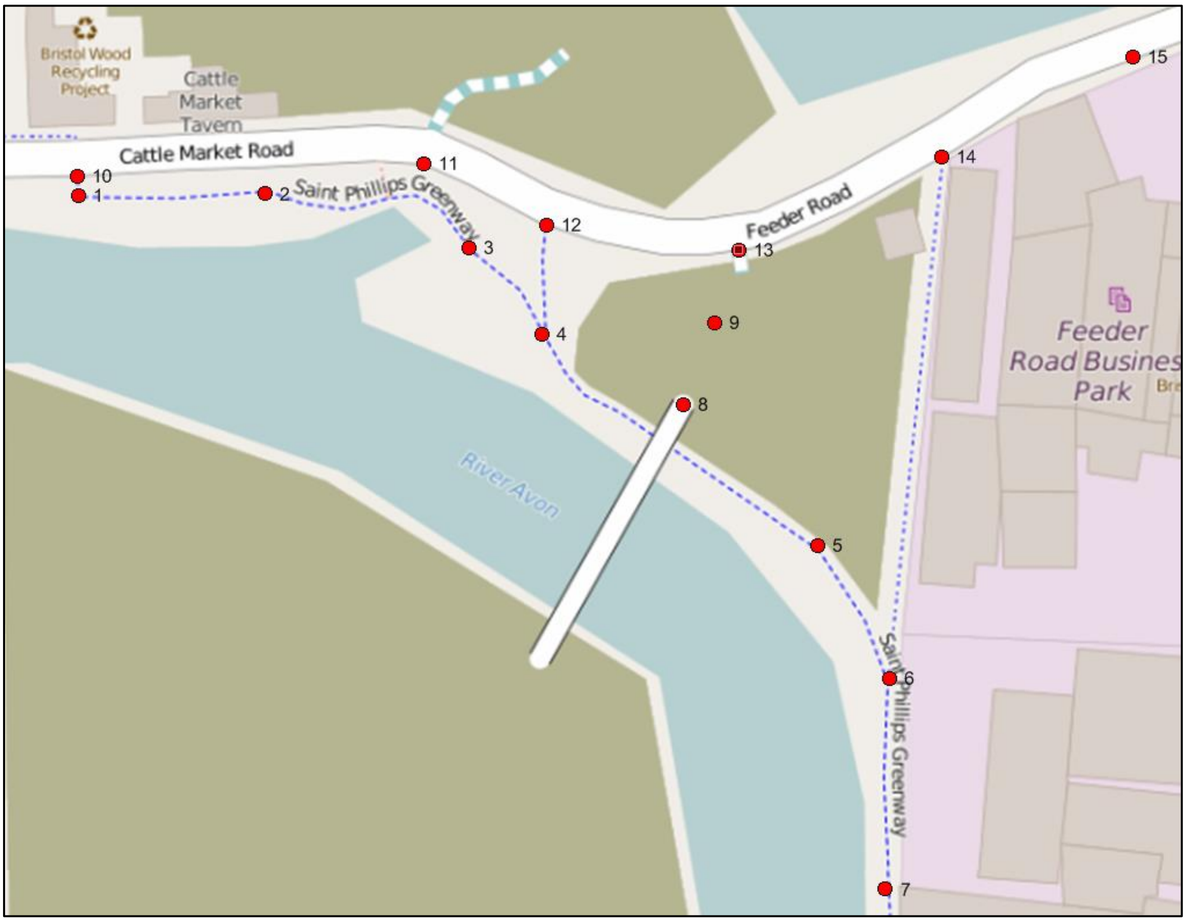


Figure A4: Cattle Market Road

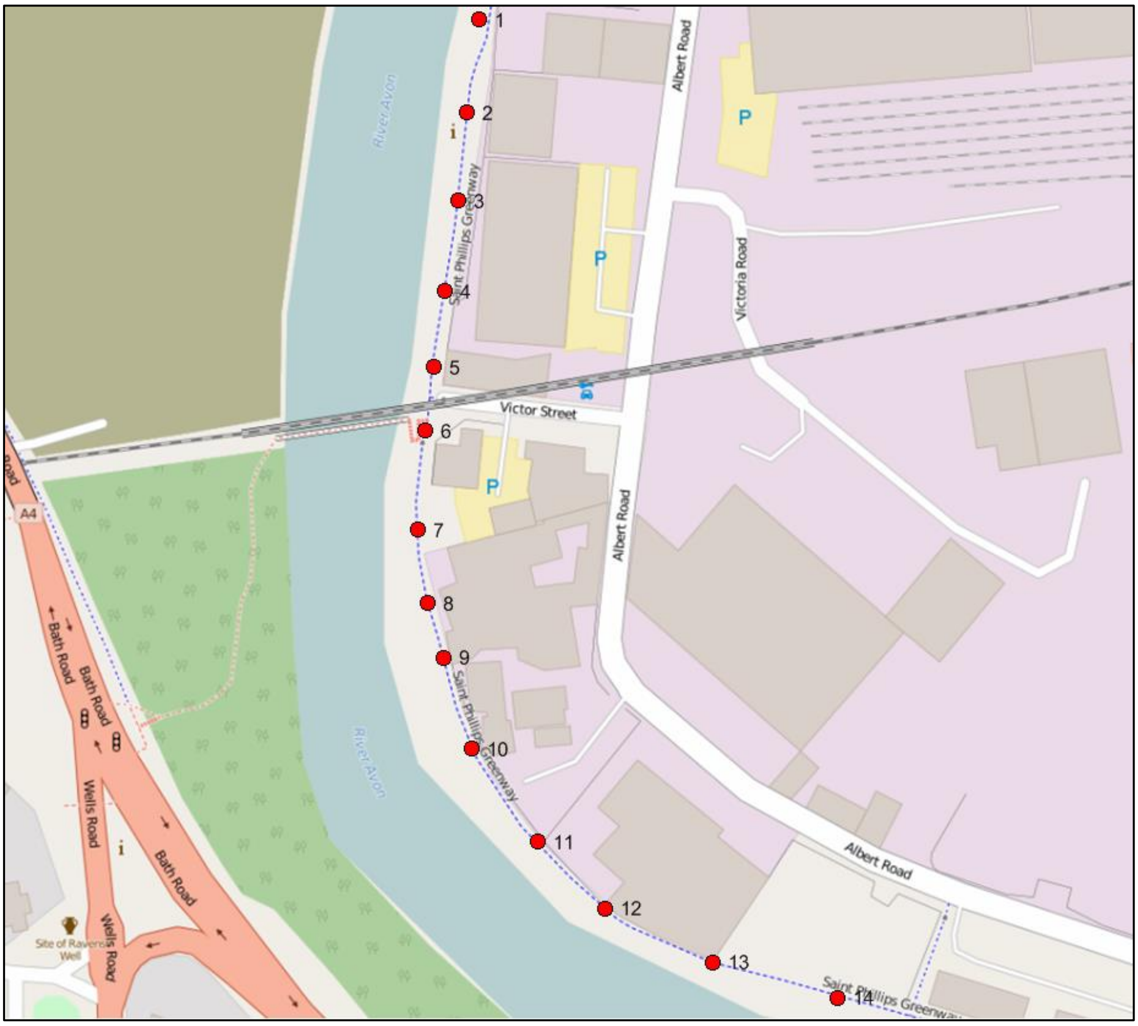


Figure A5: St Phillips Greenway (D/S)

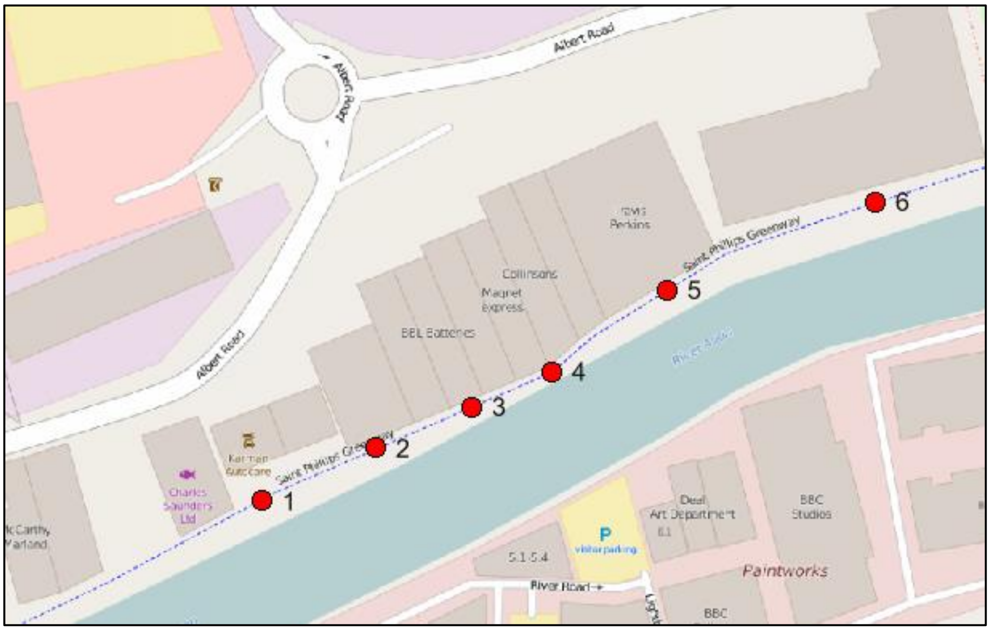
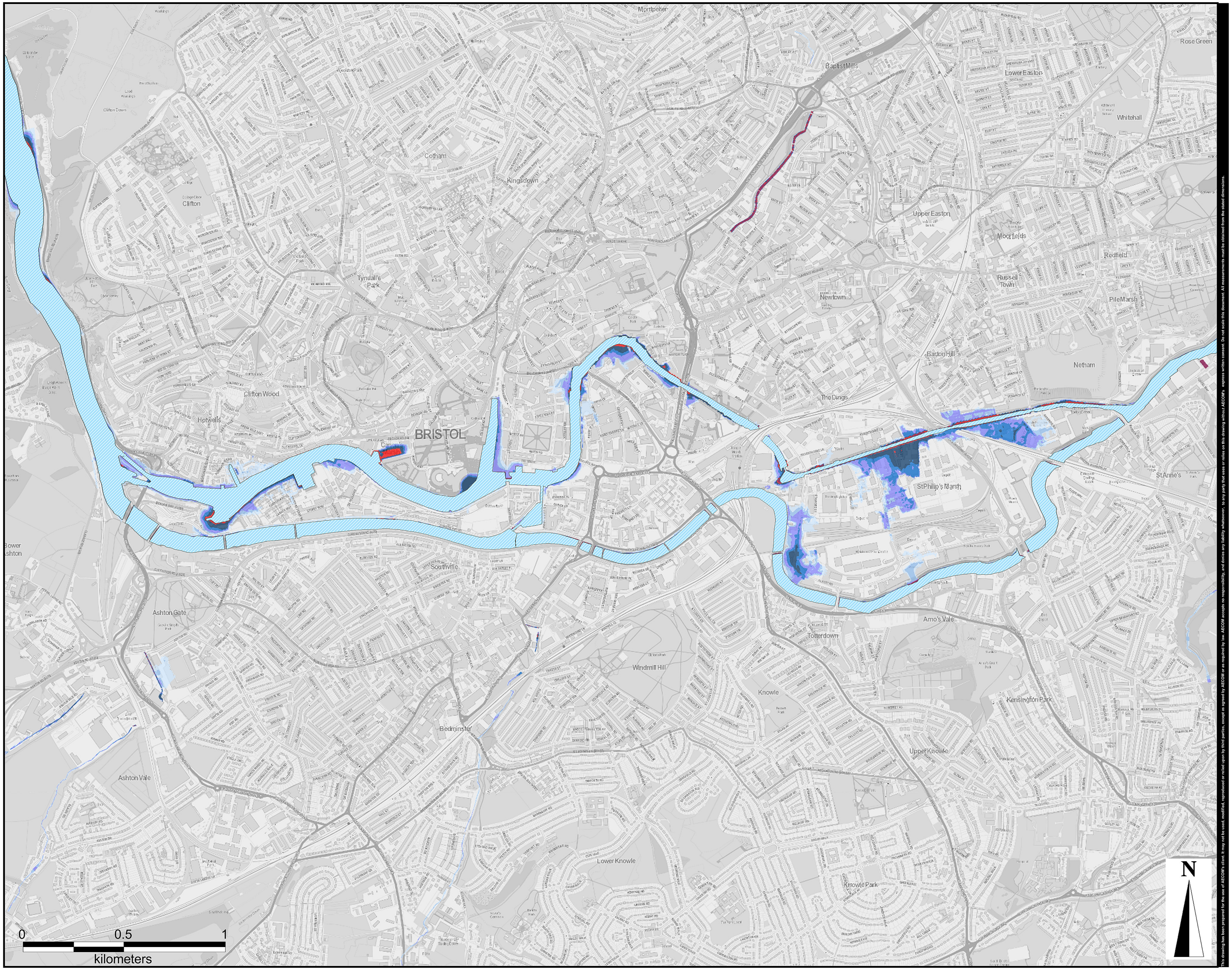


Figure A6: St Phillips Greenway (U/S)

APPENDIX B

Baseline Flood Maps



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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_134_2yr_FBASE_T002_2015

Copyright:

AECOM Internal Project No:

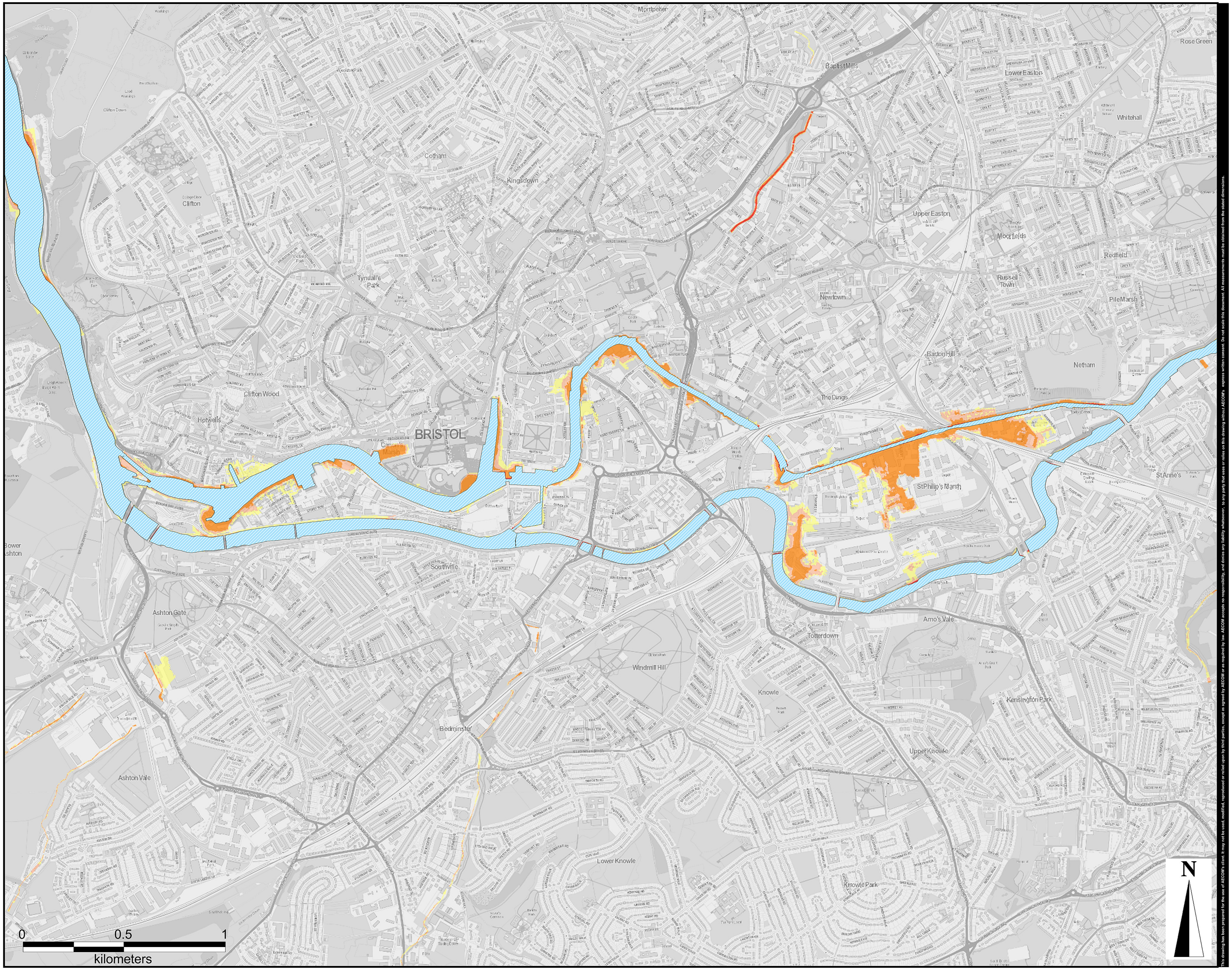
60478613

Drawing Title:

RUN ID 1 - DO NOTHING
2 YR RETURN PERIOD
2015
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

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



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

- River Avon / Floating Harbour

Maximum Flood Hazard

- Caution
- Danger for Some
- Danger for Most
- Danger for All

Model Reference:

CAFRA_134_2yr_FBASE_T002_2015

Copyright:

AECOM Internal Project No:

60478613

Drawing Title:

RUN ID 1 - DO NOTHING
2 YR RETURN PERIOD
2015
MAXIMUM FLOOD HAZARD

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-1b			1
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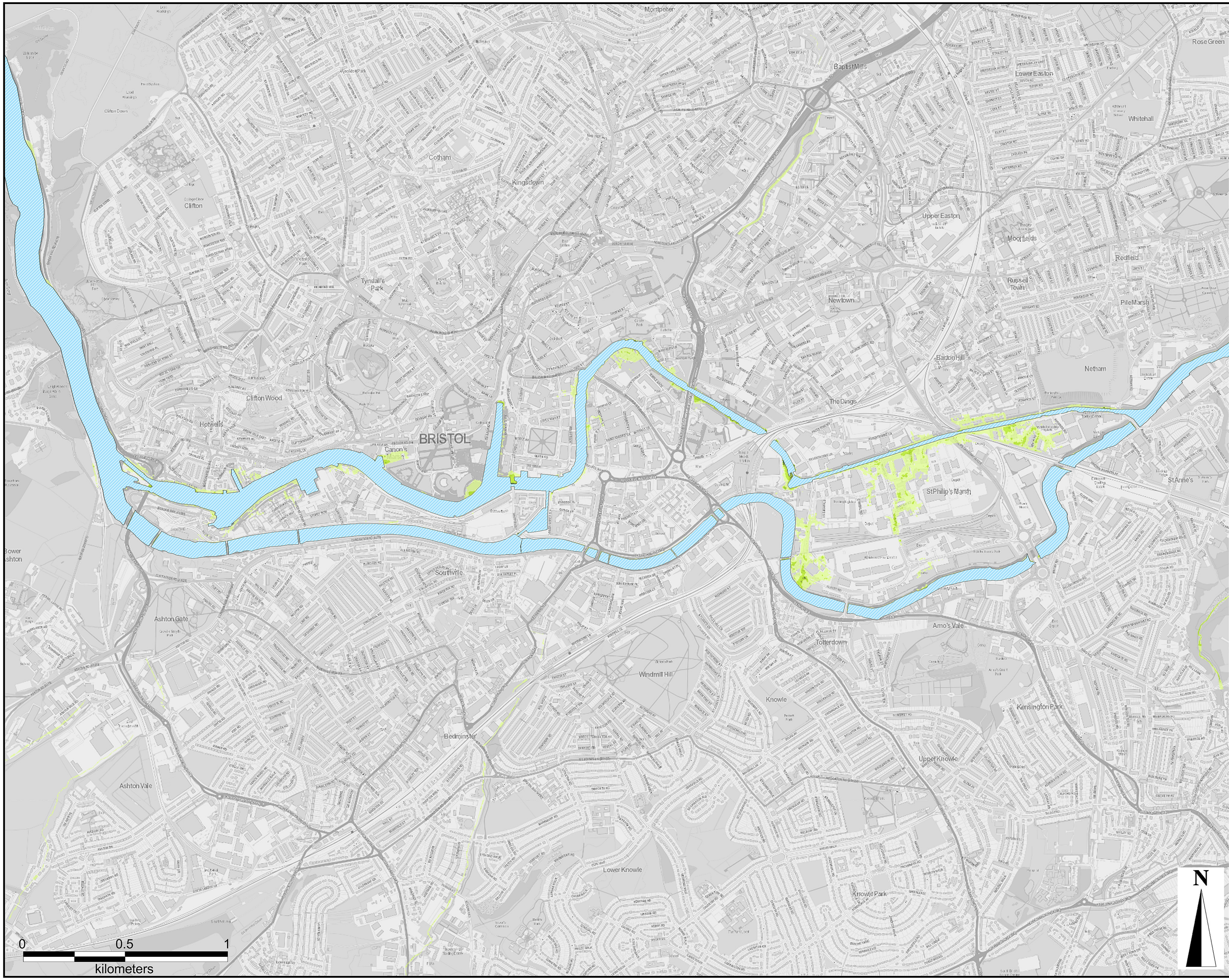
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

- River Avon / Floating Harbour

Maximum Flood Veloctiy

- 0.1m/s to 0.5m/s
- 0.5m/s to 1.0m/s
- 1.0m/s to 1.5m/s
- 1.5m/s to 2.0m/s
- >2.0m/s

Where velocity is less than 0.1m/s, this is not shown in the figure

Model Reference:

CAFRA_134_2yr_FBASE_T002_2015

Copyright:

AECOM Internal Project No:

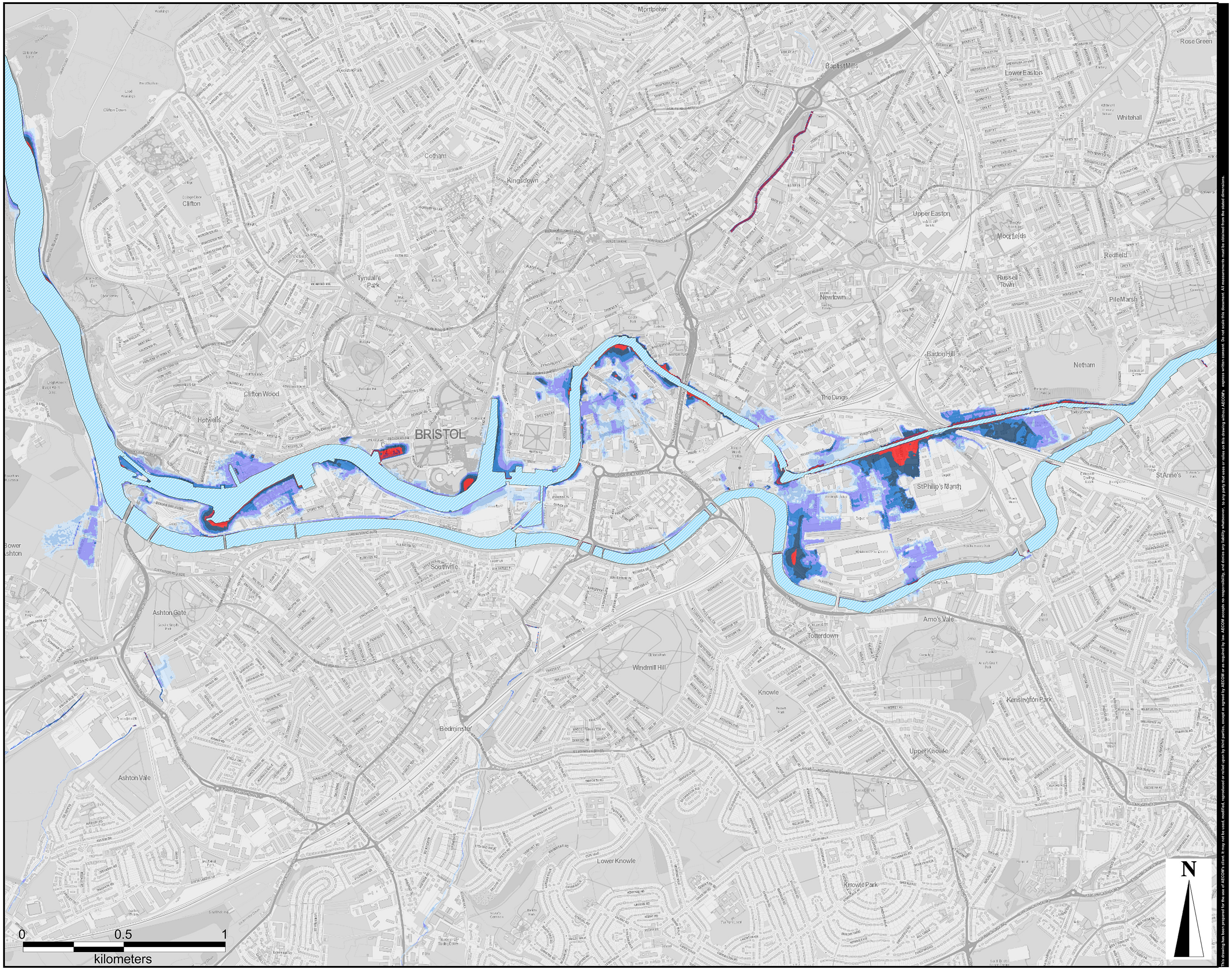
60478613

Drawing Title:

RUN ID 1 - DO NOTHING
2 YR RETURN PERIOD
2015
MAXIMUM FLOOD VELOCITY

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-1c			1
Drawn:	**Chk'd:**	**App'd:**	**Date:**
RM	MD	JS	May 2016



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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_134_20yr_FBASE_T020_2015

Copyright:

AECOM Internal Project No:

60478613

Drawing Title:

RUN ID 2 - DO NOTHING
20 YR RETURN PERIOD
2015
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-2a			1
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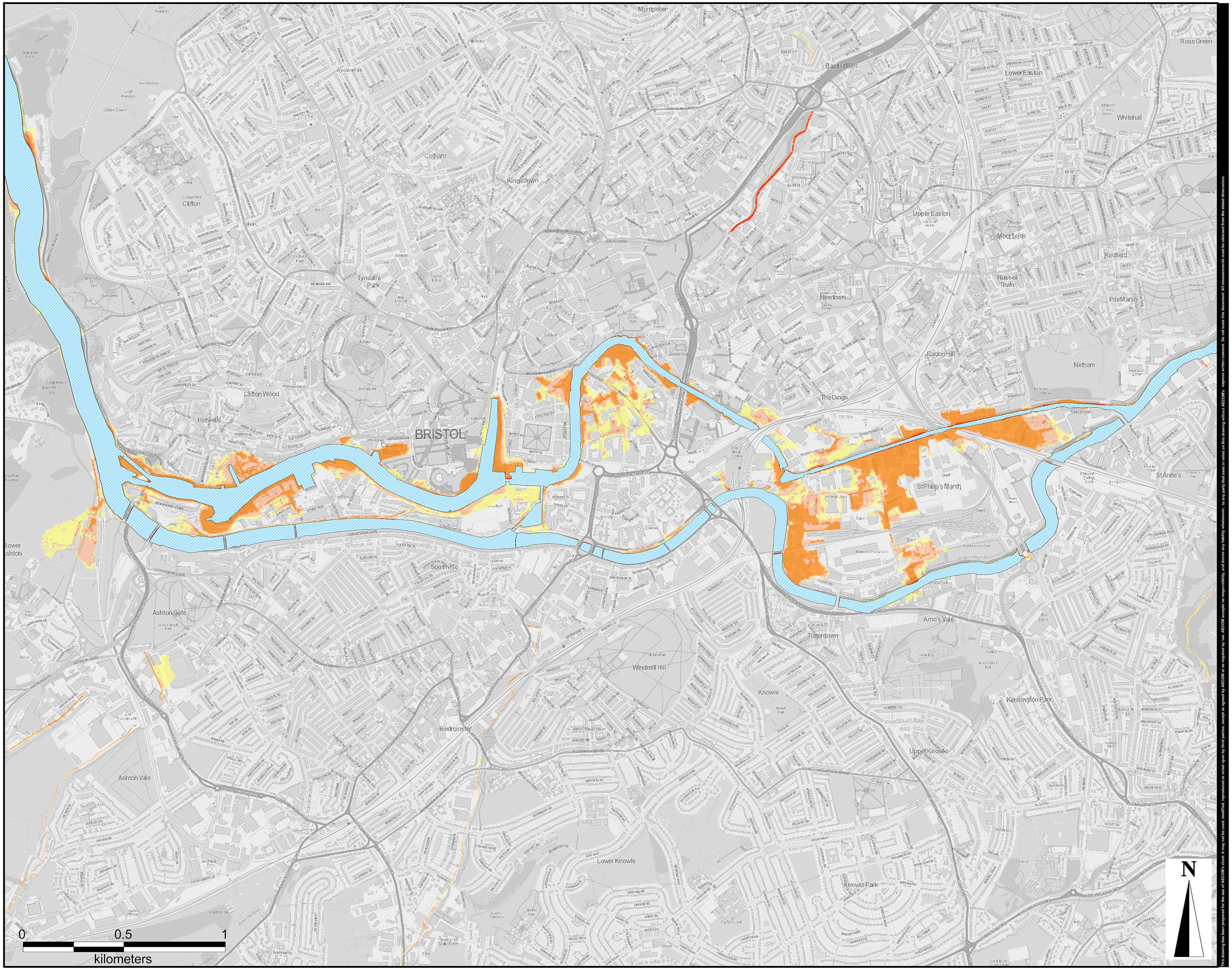
RM	MD	JS	May 2016



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Project Title:

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Client:

BRISTOL CITY COUNCIL

LEGEND

- River Avon / Floating Harbour

Maximum Flood Hazard

- Caution
- Danger for Some
- Danger for Most
- Danger for All

Model Reference:

CAFRA_134_20yr_FBASE_T020_2015

Copyright:

AECOM Internal Project No:

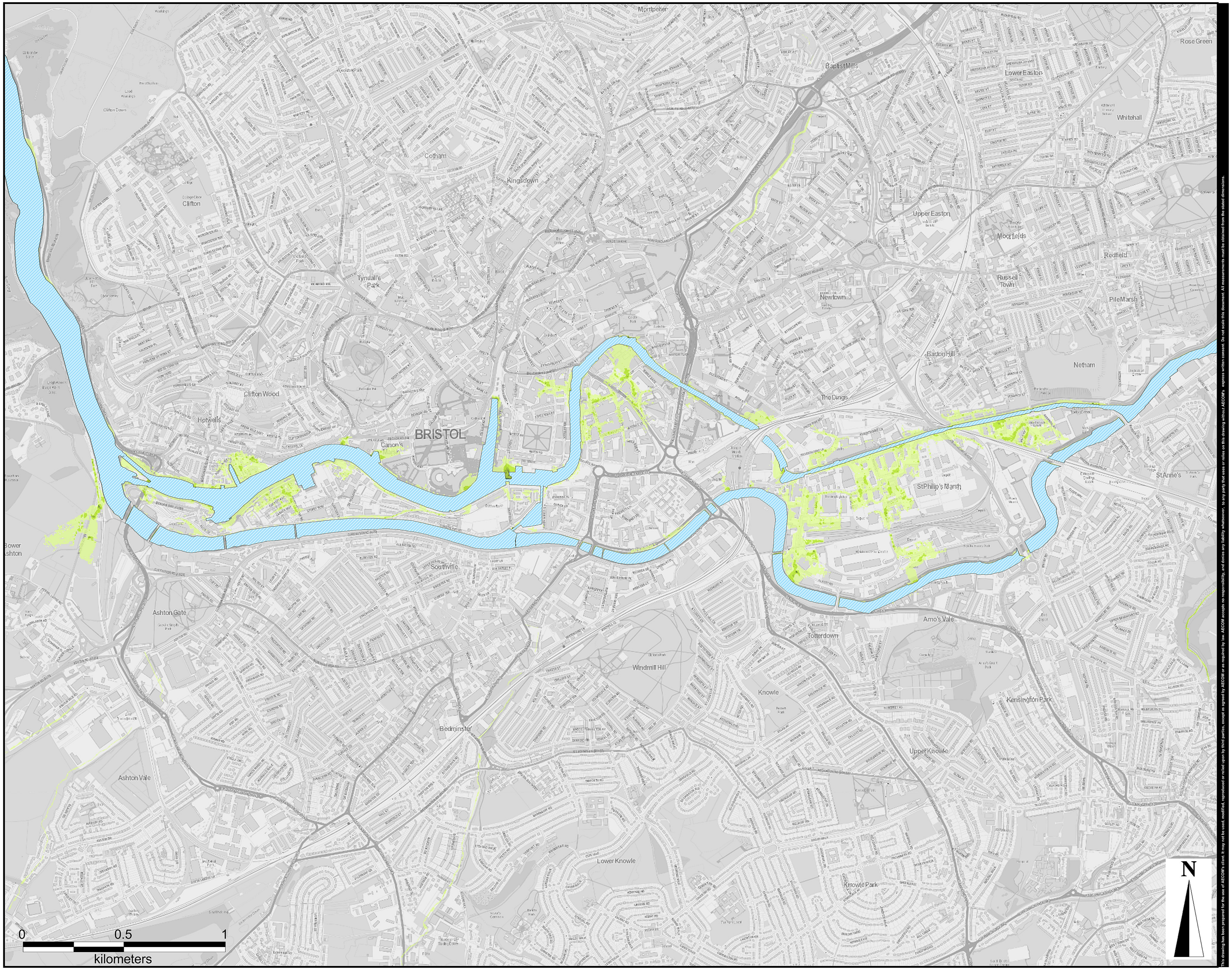
60478613

Drawing Title:

RUN ID 2 - DO NOTHING
20 YR RETURN PERIOD
2015
MAXIMUM FLOOD HAZARD

Scale at A3: 17,500

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



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Veloctiy

- 0.1m/s to 0.5m/s
- 0.5m/s to 1.0m/s
- 1.0m/s to 1.5m/s
- 1.5m/s to 2.0m/s
- >2.0m/s

Where velocity is less than 0.1m/s, this is not shown in the figure

Model Reference:

CAFRA_134_20yr_FBASE_T020_2015

Copyright:

AECOM Internal Project No:

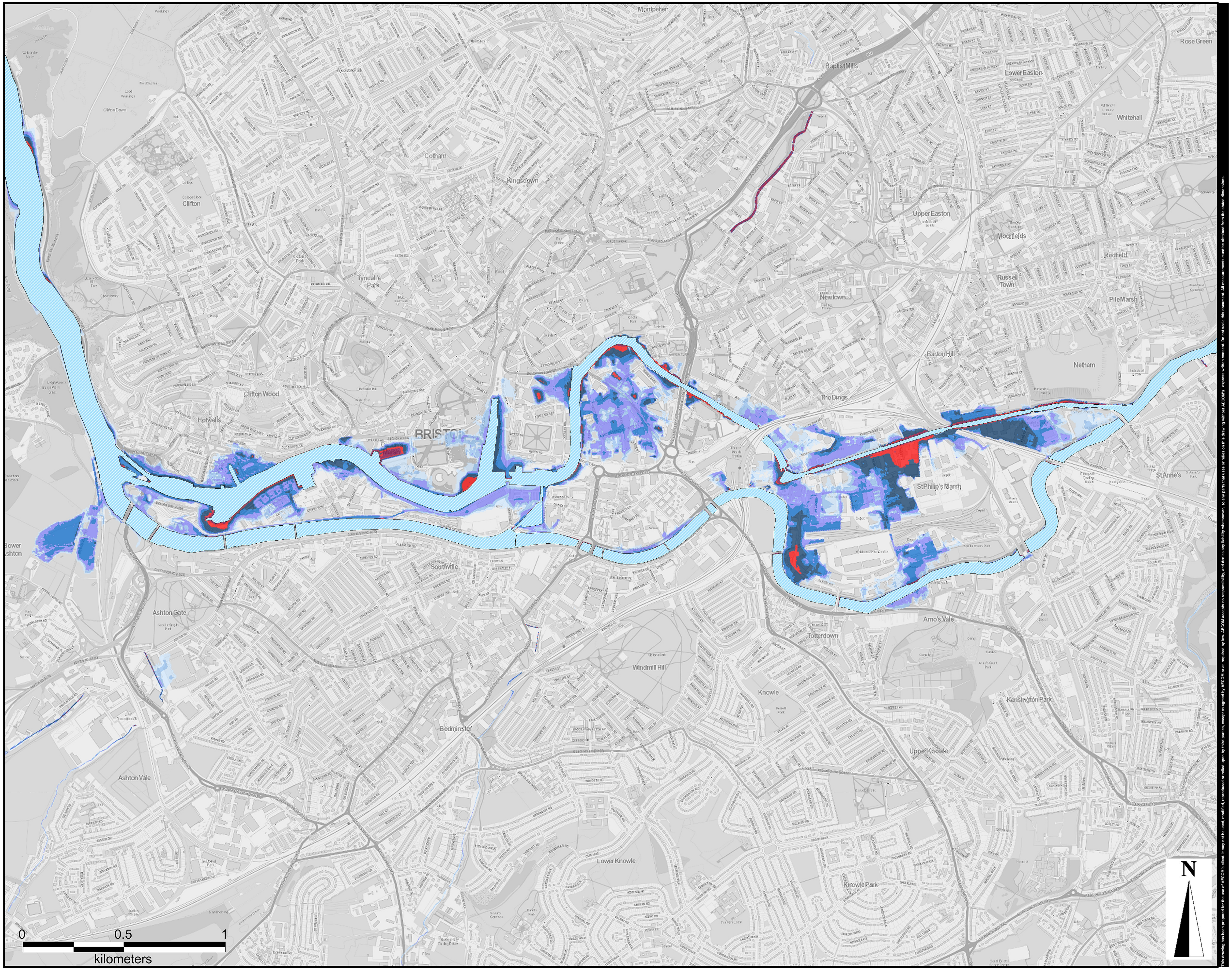
60478613

Drawing Title:

RUN ID 2 - DO NOTHING
20 YR RETURN PERIOD
2015
MAXIMUM FLOOD VELOCITY

Scale at A3: 17,500

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



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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_134_75yr_FBASE_T075_2015

Copyright:

AECOM Internal Project No:

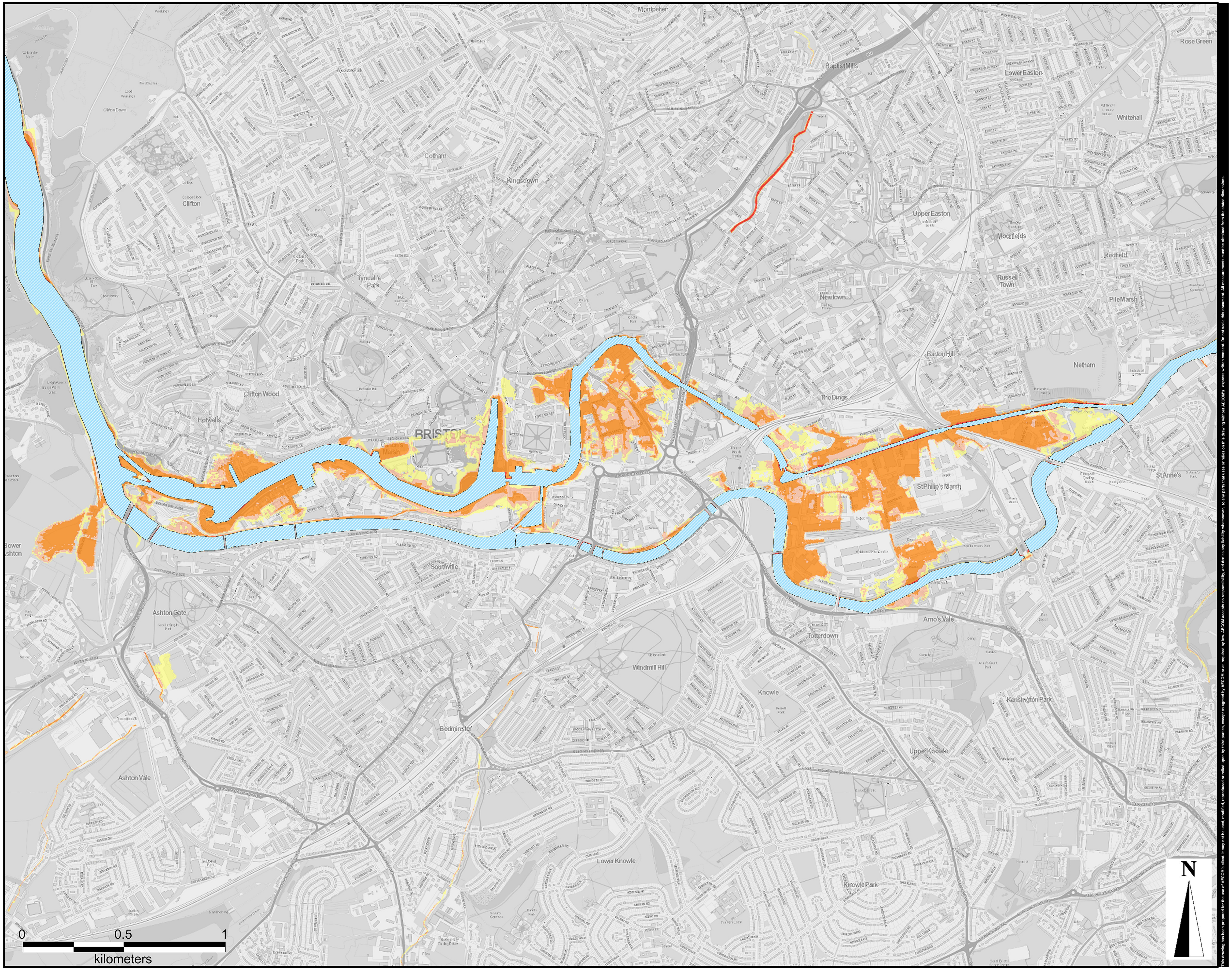
60478613

Drawing Title:

RUN ID 3 - DO NOTHING
75 YR RETURN PERIOD
2015
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

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



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Hazard

- Caution
- Danger for Some
- Danger for Most
- Danger for All

Model Reference:

CAFRA_134_75yr_FBASE_T075_2015

Copyright:

AECOM Internal Project No:

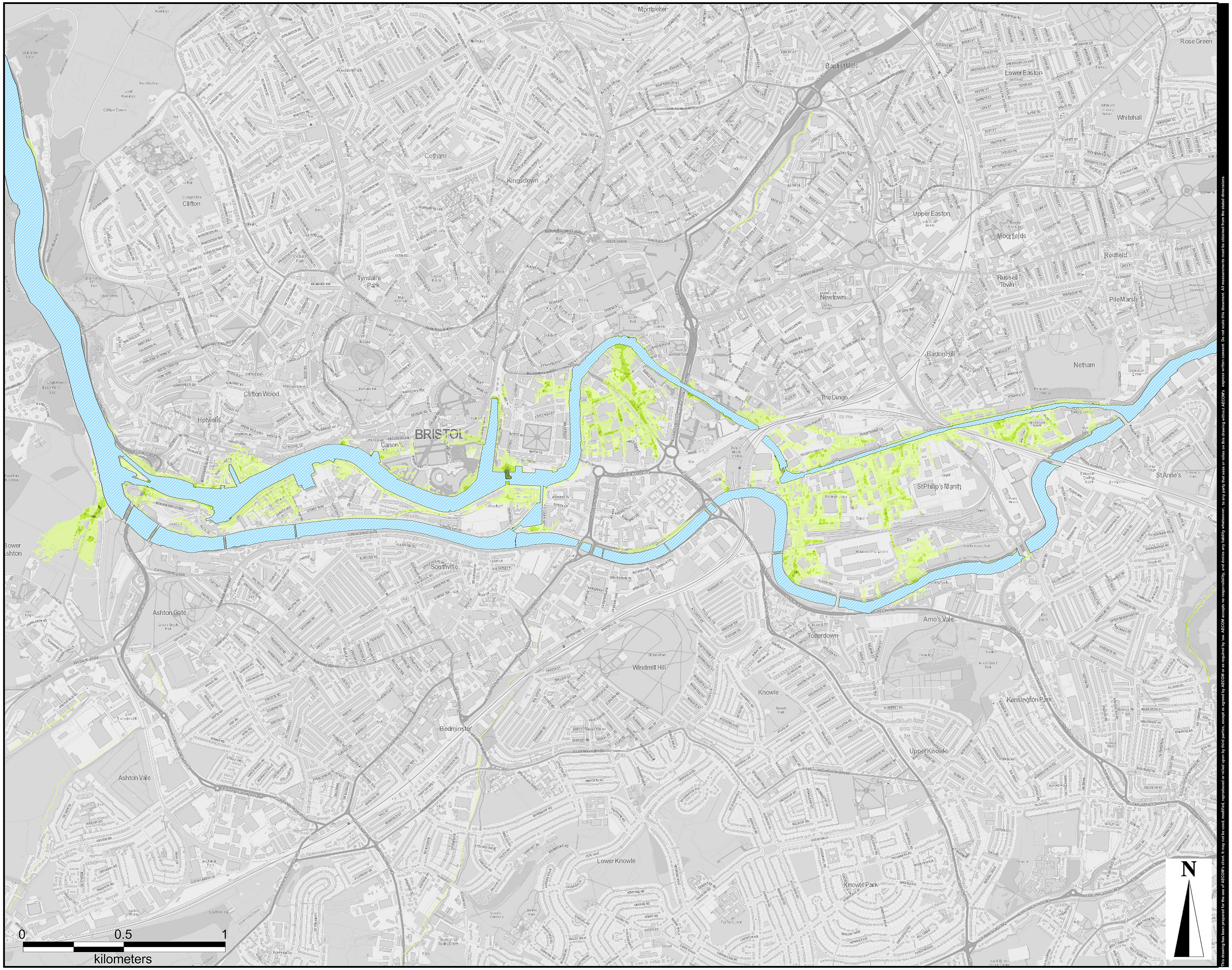
60478613

Drawing Title:

RUN ID 3 - DO NOTHING
75 YR RETURN PERIOD
2015
MAXIMUM FLOOD HAZARD

Scale at A3: 17,500

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



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Veloctiy

- 0.1m/s to 0.5m/s
- 0.5m/s to 1.0m/s
- 1.0m/s to 1.5m/s
- 1.5m/s to 2.0m/s
- >2.0m/s

Where velocity is less than 0.1m/s, this is not shown in the figure

Model Reference:

CAFRA_134_75yr_FBASE_T075_2015

Copyright:

AECOM Internal Project No:

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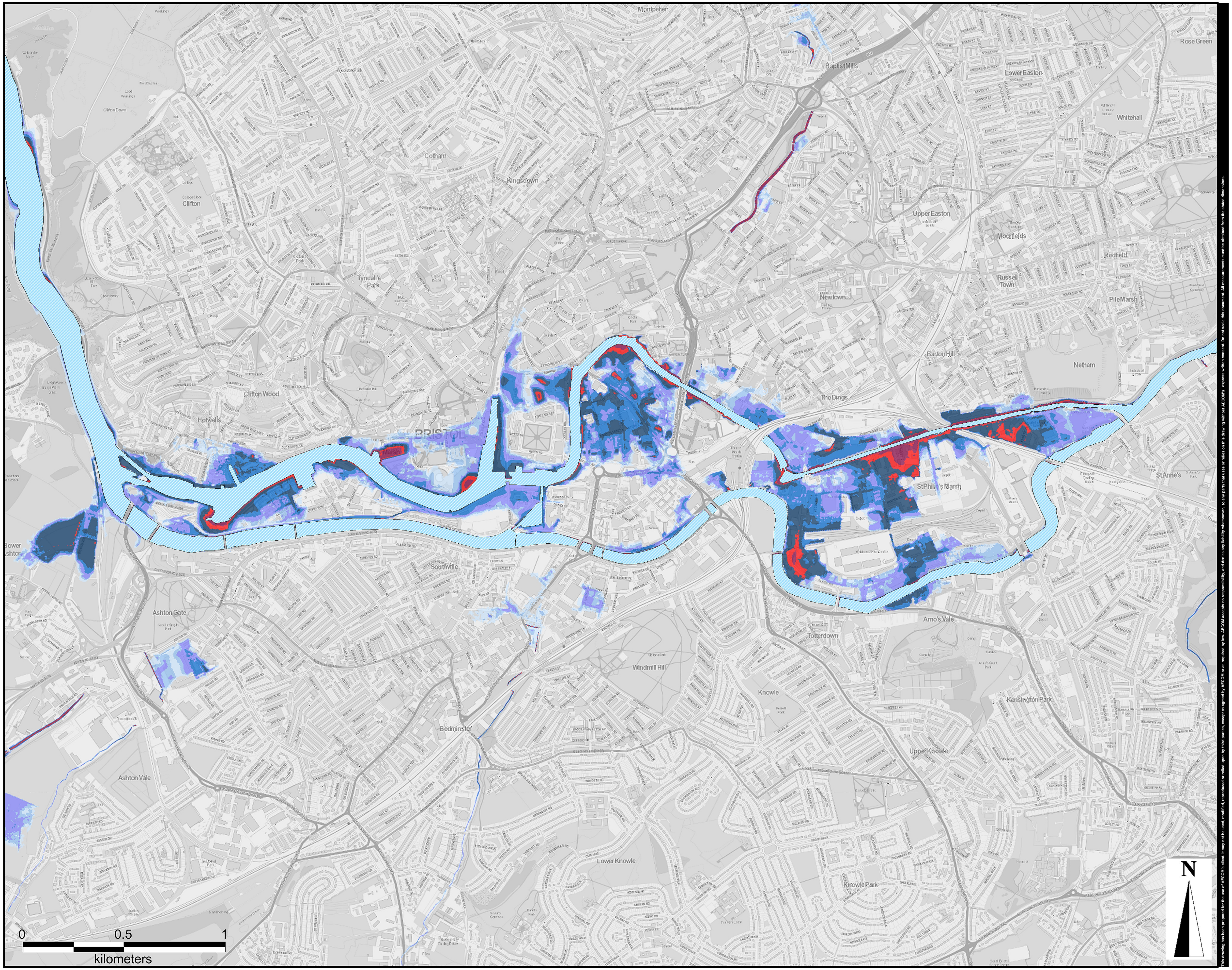
Drawing Title:

RUN ID 3 - DO NOTHING
75 YR RETURN PERIOD
2015
MAXIMUM FLOOD VELOCITY

Scale at A3: 17,500

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



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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_134_200yr_F002_T200_2015

AECOM Internal Project No:

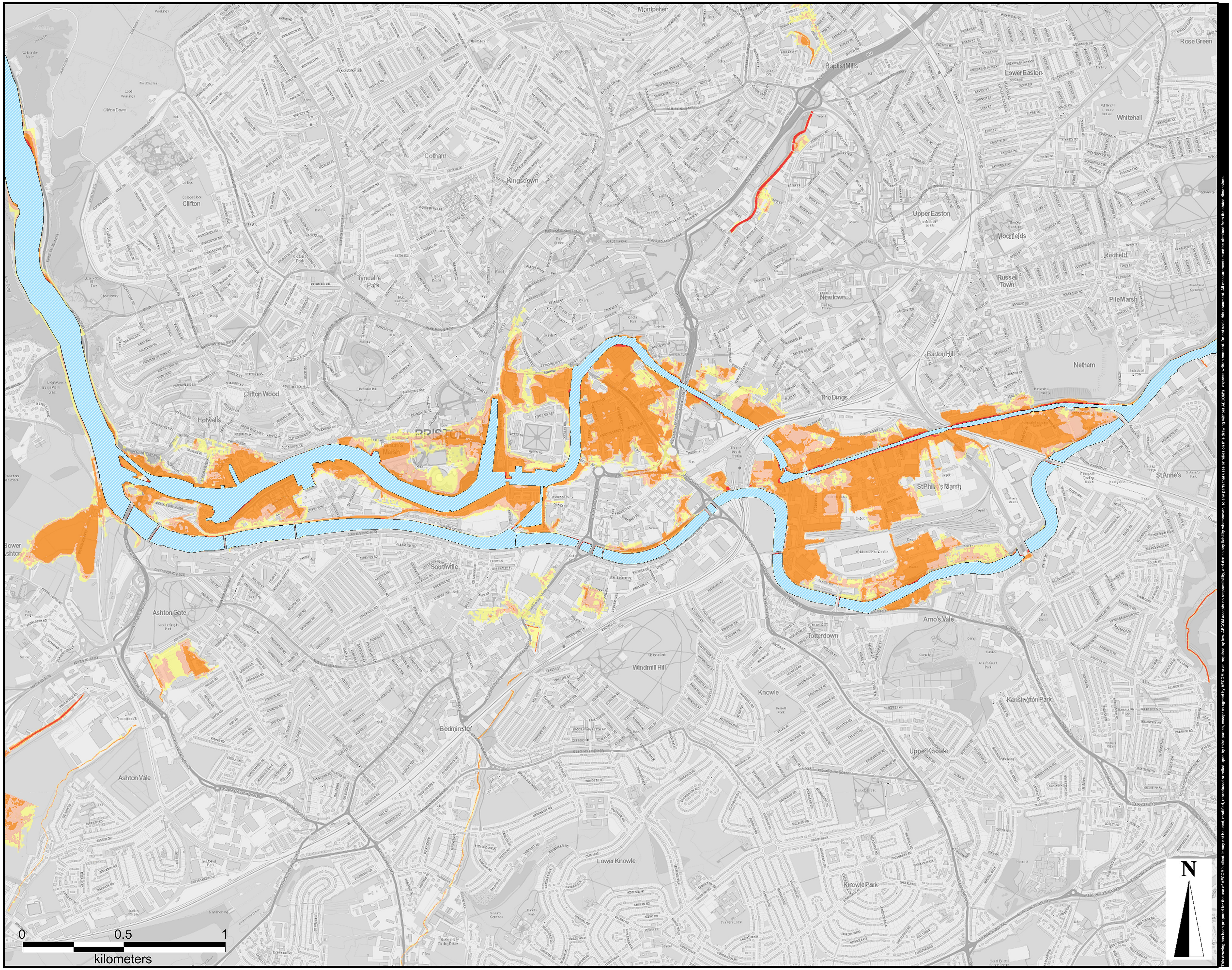
60478613

Drawing Title:

RUN ID 4 - DO NOTHING
200 YR RETURN PERIOD
2015
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-4a			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Hazard

- Caution
- Danger for Some
- Danger for Most
- Danger for All

Model Reference:

CAFRA_134_200yr_F002_T200_2015

Copyright:

AECOM Internal Project No:

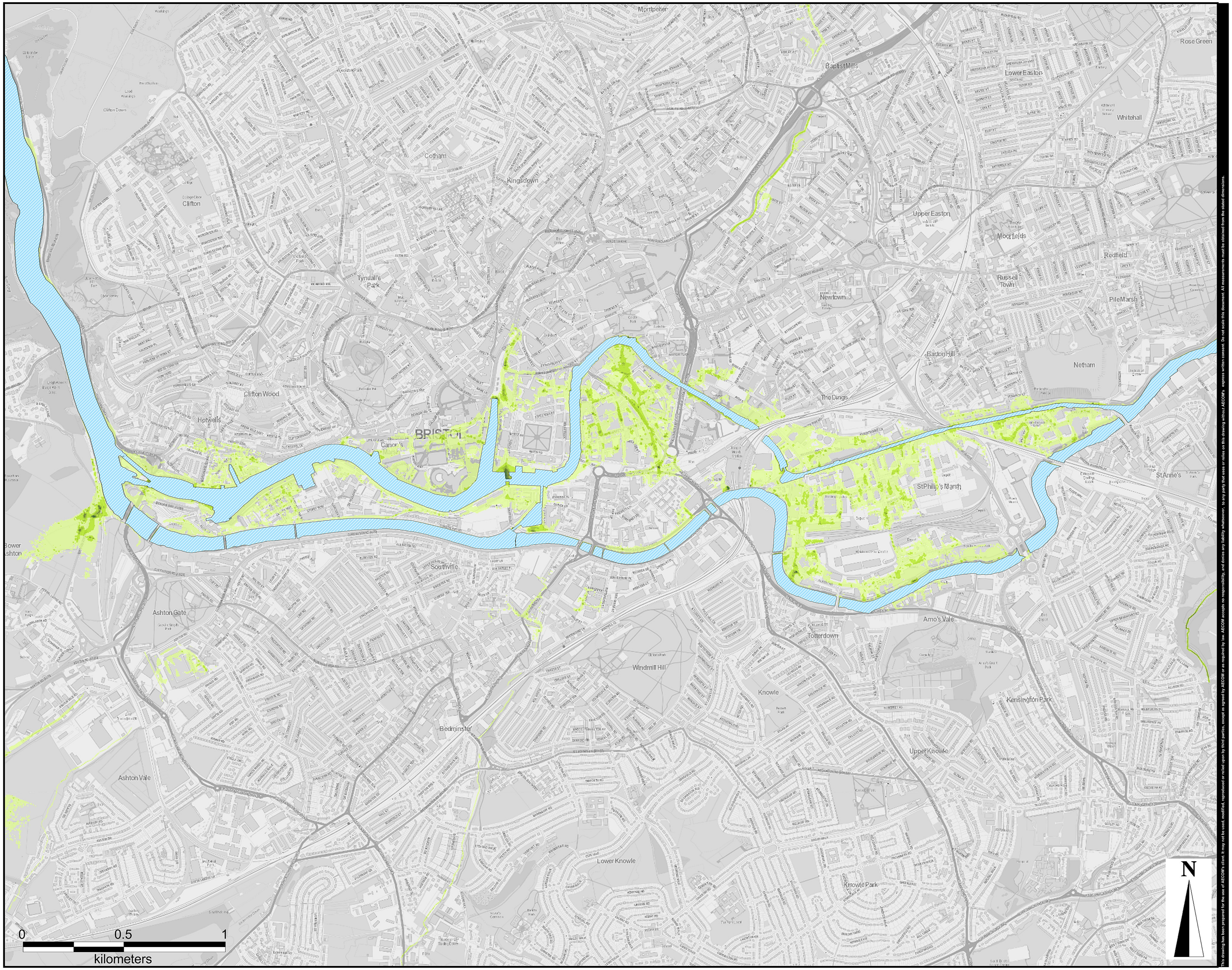
60478613

Drawing Title:

RUN ID 4 - DO NOTHING
200 YR RETURN PERIOD
2015
MAXIMUM FLOOD HAZARD

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-4b			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Velociy

- 0.1m/s to 0.5m/s
- 0.5m/s to 1.0m/s
- 1.0m/s to 1.5m/s
- 1.5m/s to 2.0m/s
- >2.0m/s

Where velocity is less than 0.1m/s, this is not shown in the figure

Model Reference:

CAFRA_134_200yr_F002_T200_2015

Copyright:

AECOM Internal Project No:

60478613

Drawing Title:

RUN ID 4 - DO NOTHING
200 YR RETURN PERIOD
2015
MAXIMUM FLOOD VELOCITY

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-4c			1
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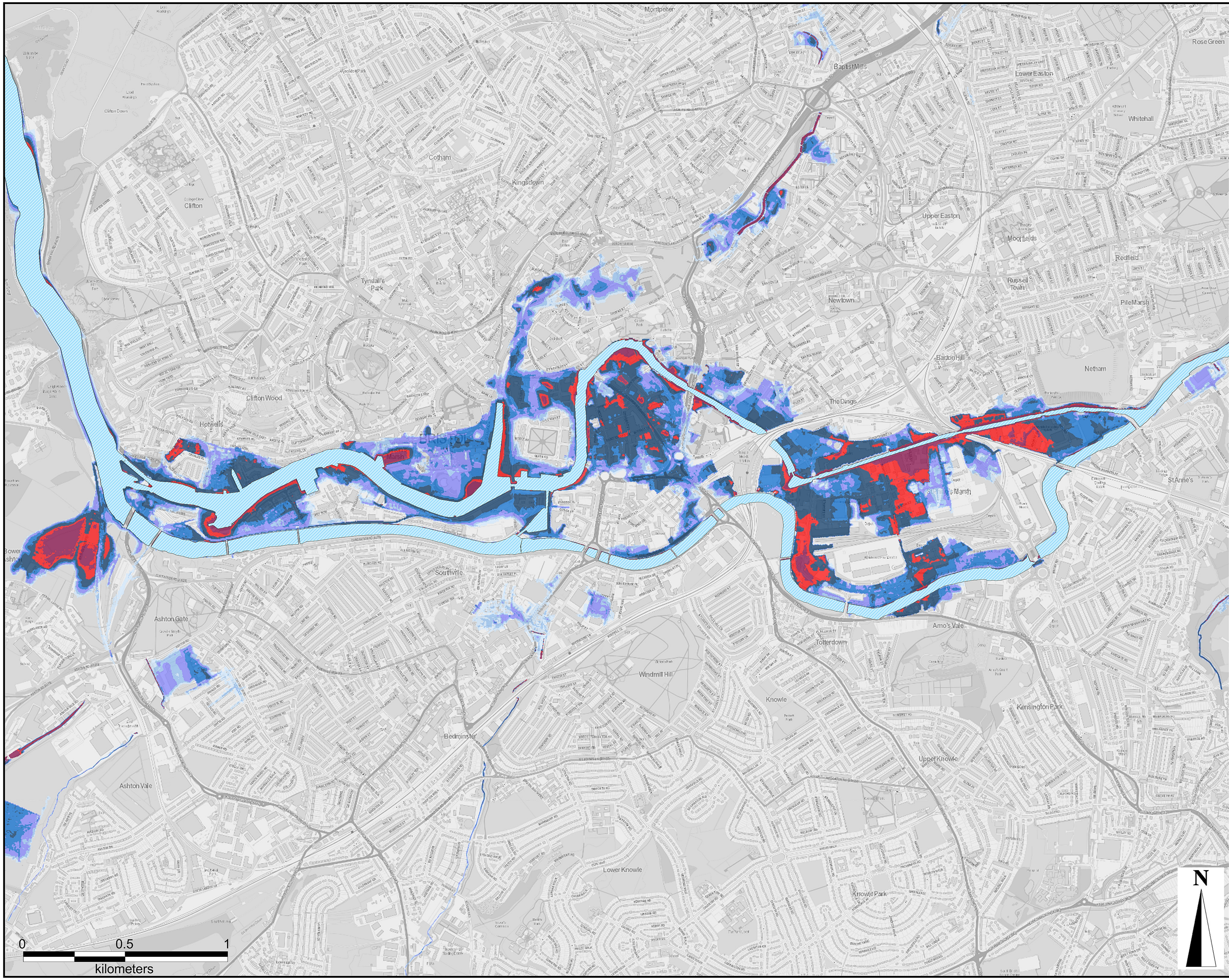
RM	MD	JS	May 2016



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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_134_1000yr_F012_T1000_2015

Copyright:

AECOM Internal Project No:

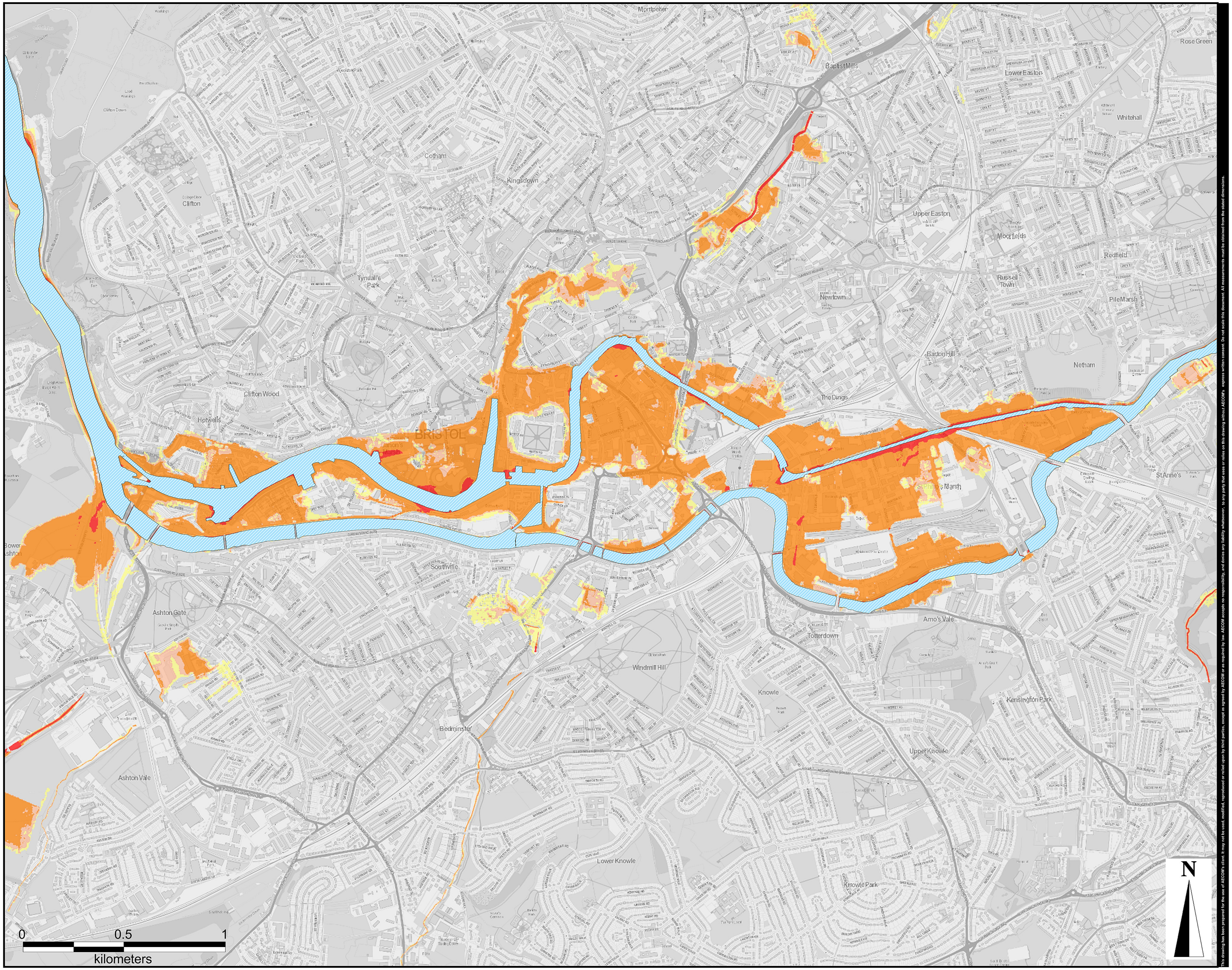
60478613

Drawing Title:

RUN ID 5 - DO NOTHING
1000 YR RETURN PERIOD
2015
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-5a			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Hazard

- Caution
- Danger for Some
- Danger for Most
- Danger for All

Model Reference:

CAFRA_134_1000yr_F012_T1000_2015

Copyright:

AECOM Internal Project No:

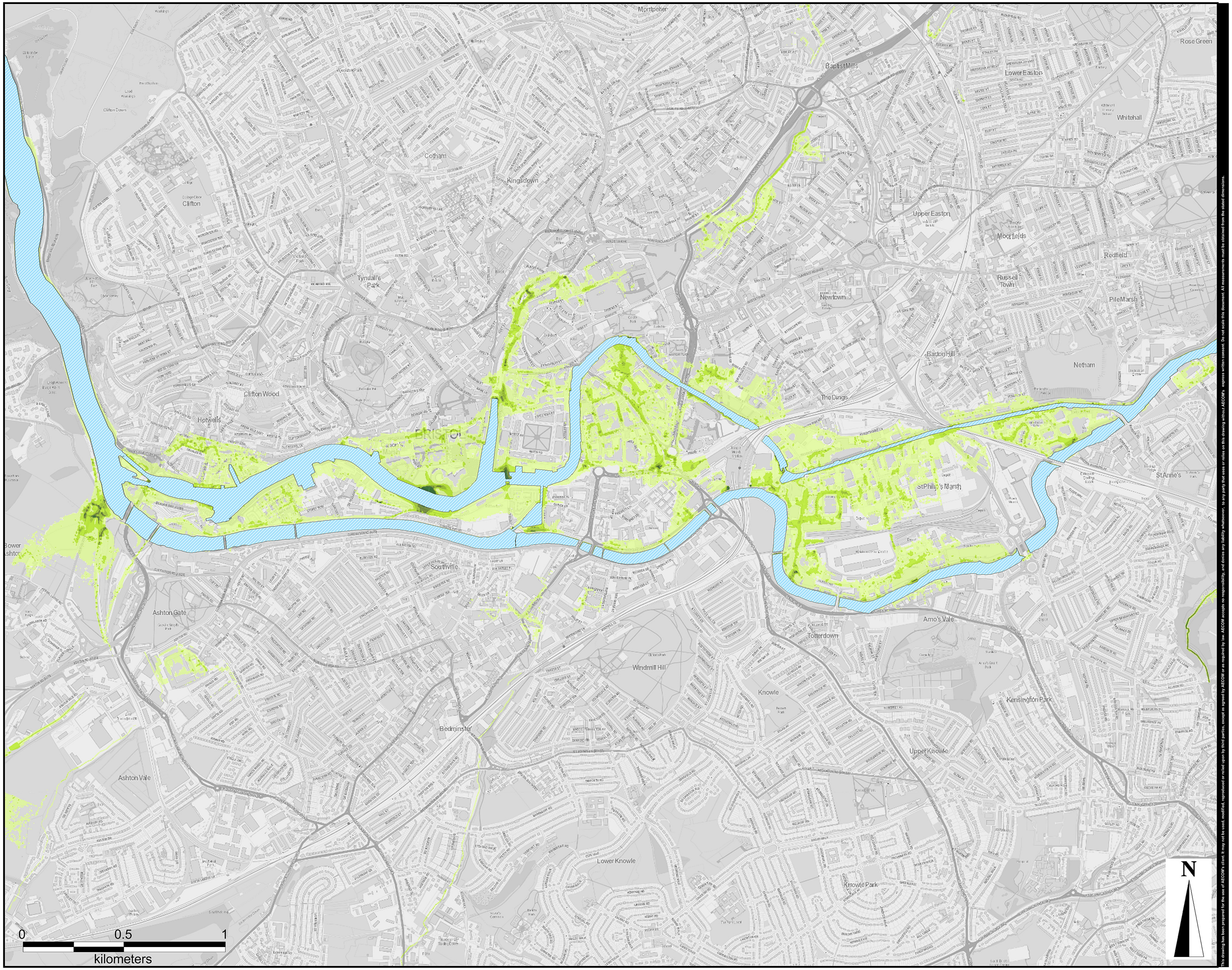
60478613

Drawing Title:

RUN ID 5 - DO NOTHING
1000 YR RETURN PERIOD
2015
MAXIMUM FLOOD HAZARD

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-5b			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Velectiy

- 0.1m/s to 0.5m/s
- 0.5m/s to 1.0m/s
- 1.0m/s to 1.5m/s
- 1.5m/s to 2.0m/s
- >2.0m/s

Where velocity is less than 0.1m/s, this is not shown in the figure

Model Reference:

CAFRA_134_1000yr_F012_T1000_2015

Copyright:

AECOM Internal Project No:

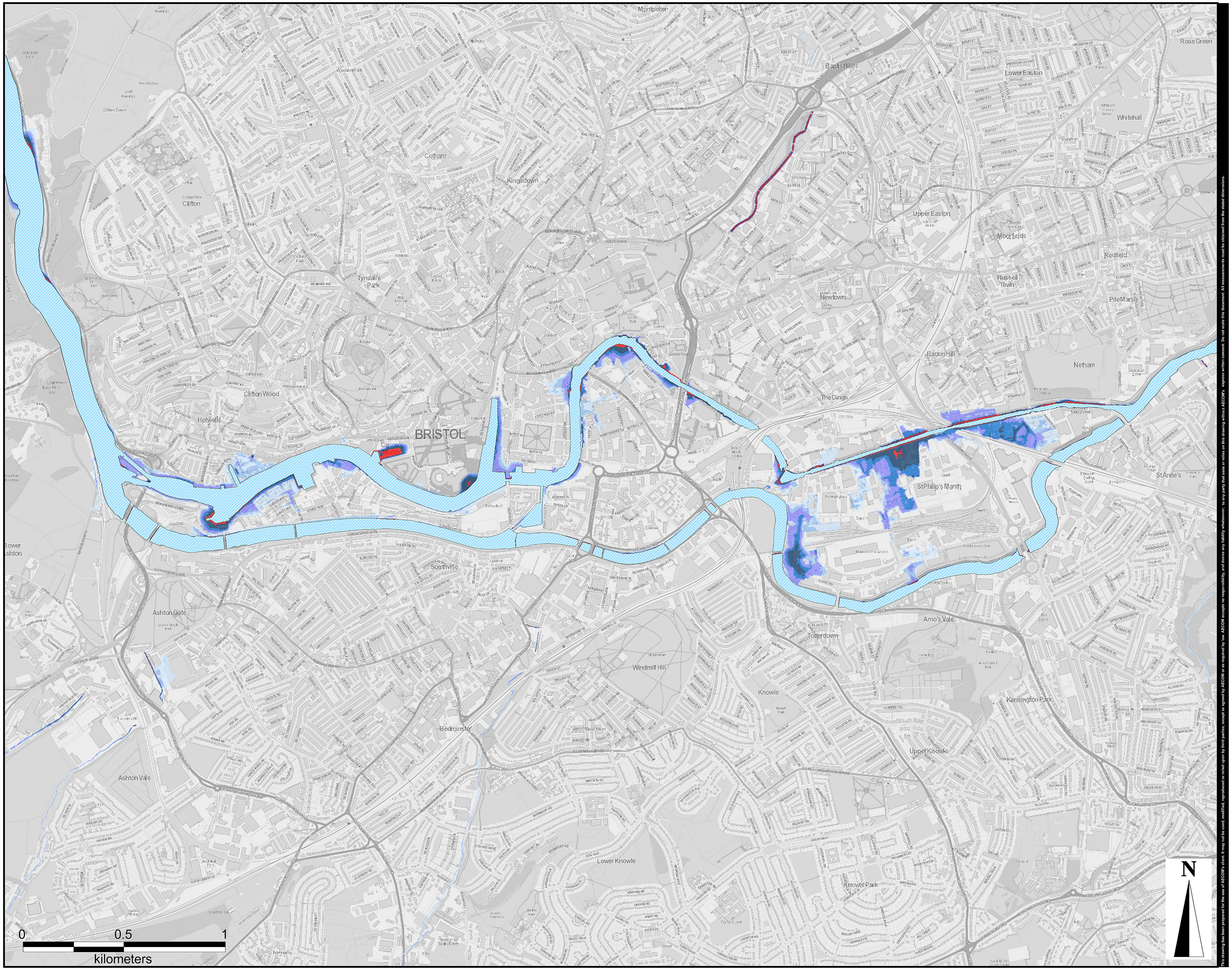
60478613

Drawing Title:

RUN ID 5 - DO NOTHING
1000 YR RETURN PERIOD
2015
MAXIMUM FLOOD VELOCITY

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-5c			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

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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_134_2yr_FBASE_T002_2030

Copyright:

AECOM Internal Project No:

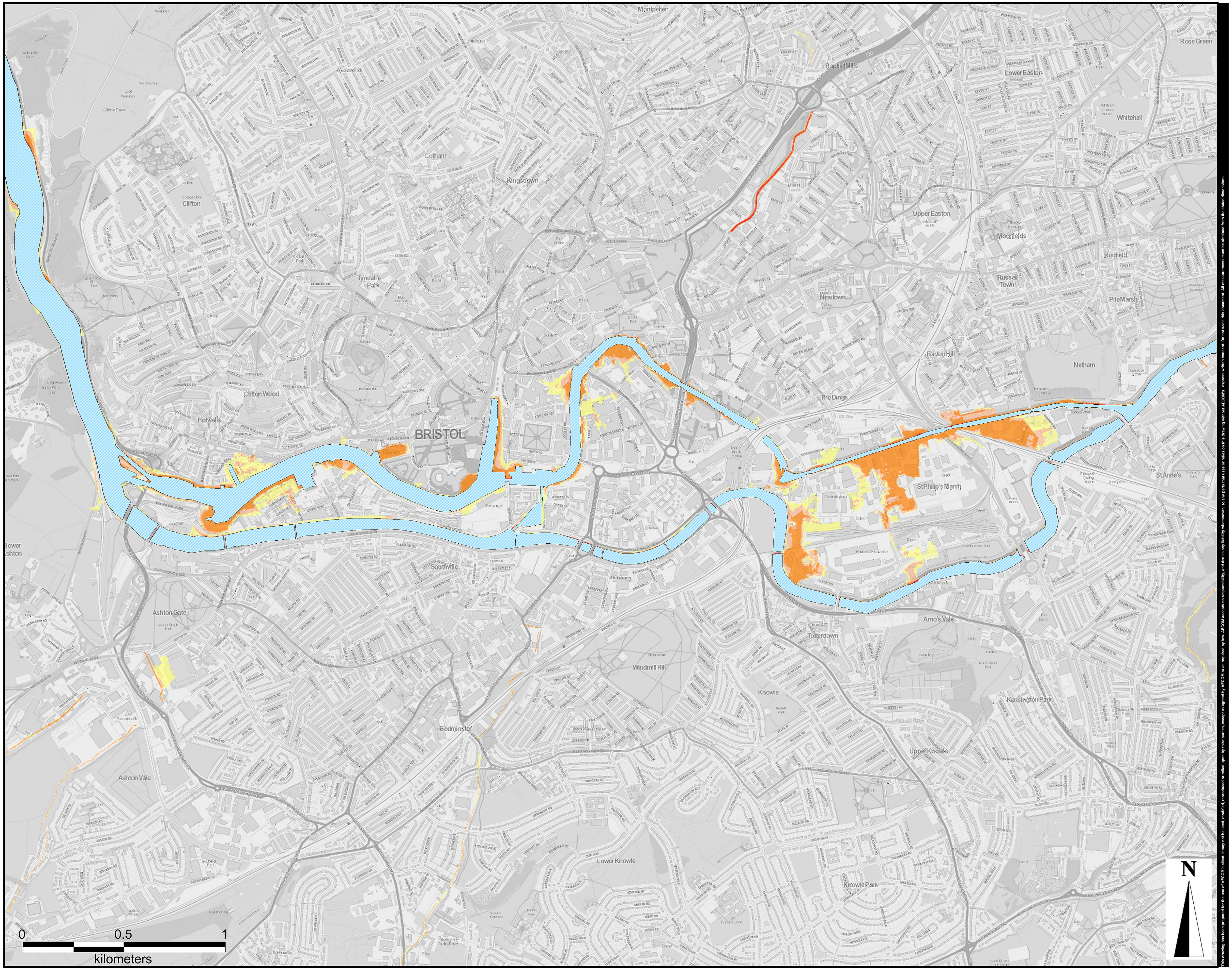
60478613

Drawing Title:

RUN ID 6 - DO NOTHING
2 YR RETURN PERIOD
2030
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-6a			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Hazard

- Caution
- Danger for Some
- Danger for Most
- Danger for All

Model Reference:

CAFRA_134_2yr_FBASE_T002_2030

Copyright:

AECOM Internal Project No:

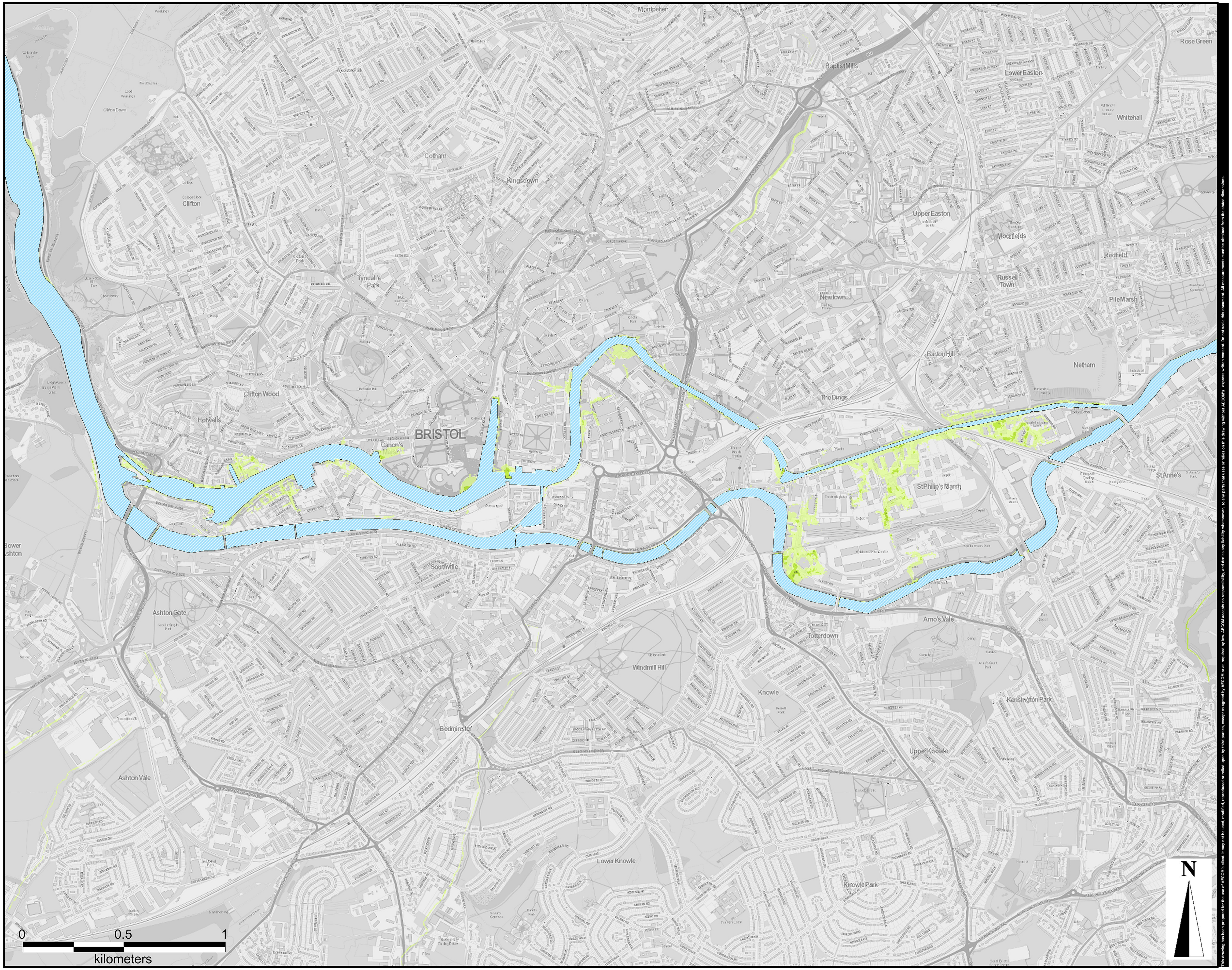
60478613

Drawing Title:

RUN ID 6 - DO NOTHING
2 YR RETURN PERIOD
2030
MAXIMUM FLOOD HAZARD

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-6b			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Velocity

- 0.1m/s to 0.5m/s
- 0.5m/s to 1.0m/s
- 1.0m/s to 1.5m/s
- 1.5m/s to 2.0m/s
- >2.0m/s

Where velocity is less than 0.1m/s, this is not shown in the figure

Model Reference:

CAFRA_134_2yr_FBASE_T002_2030

Copyright:

AECOM Internal Project No:

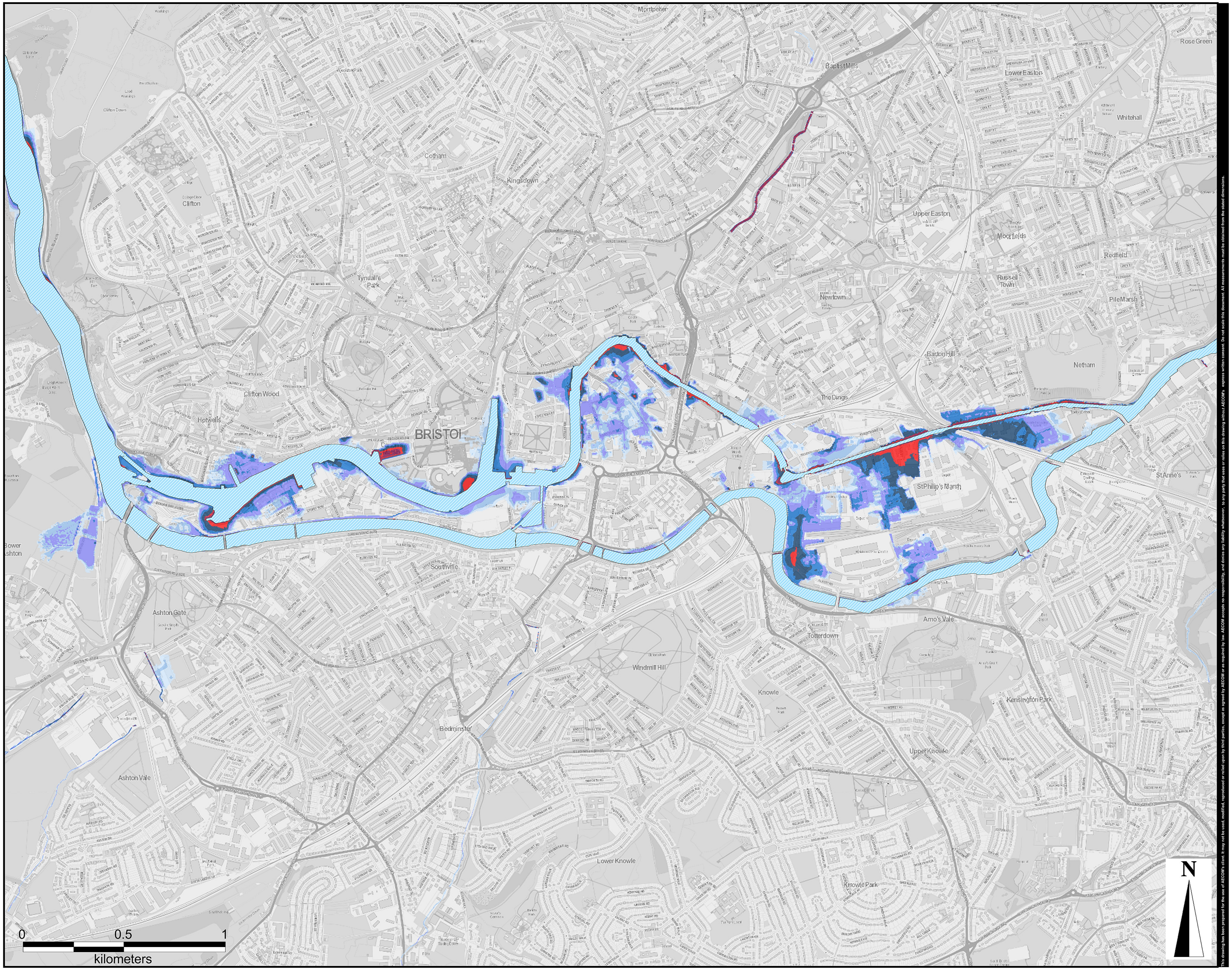
60478613

Drawing Title:

RUN ID 6 - DO NOTHING
2 YR RETURN PERIOD
2030
MAXIMUM FLOOD VELOCITY

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-6c			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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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_134_20yr_FBASE_T020_2030

Copyright:

AECOM Internal Project No:

60478613

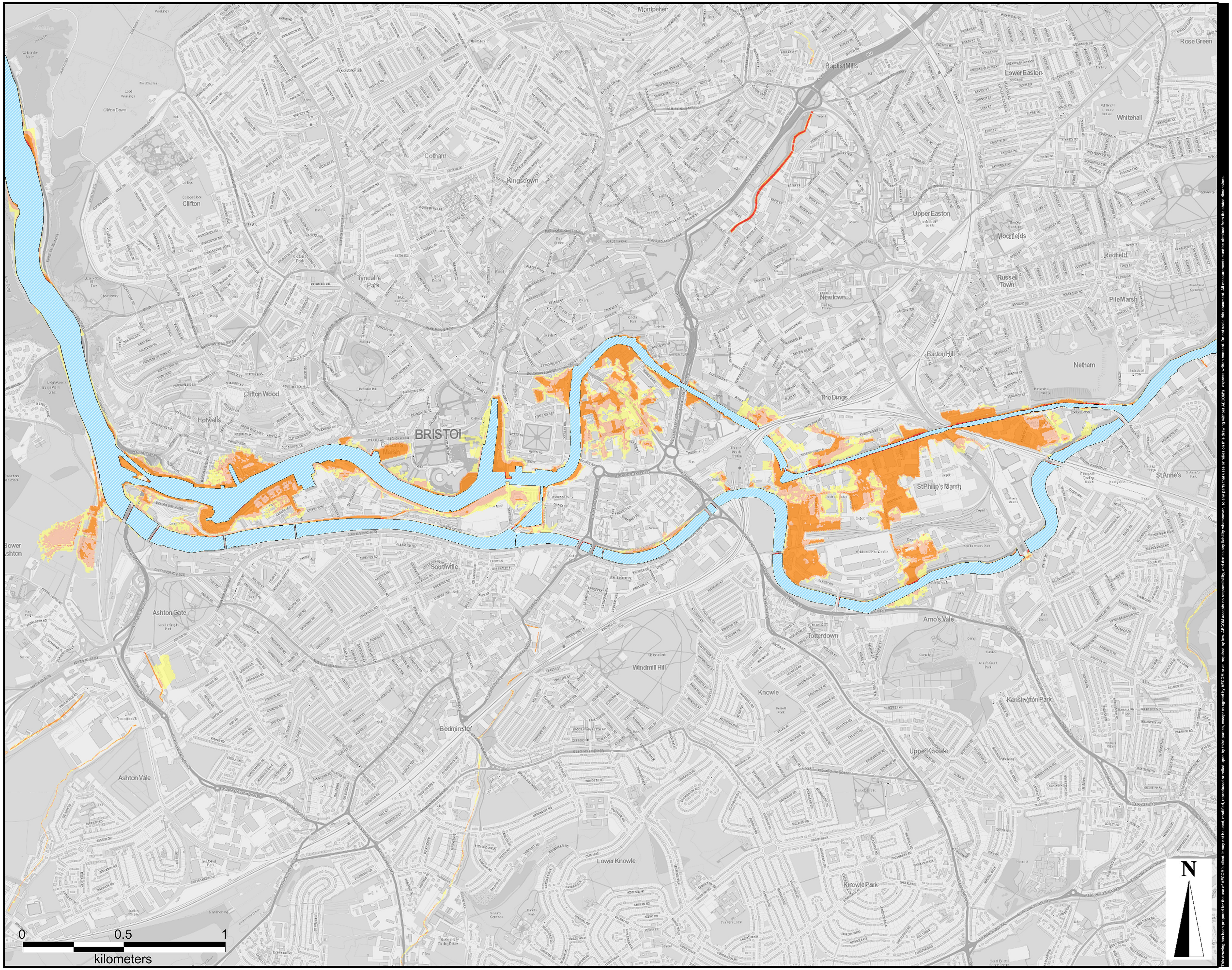
Drawing Title:

RUN ID 7 - DO NOTHING
20 YR RETURN PERIOD
2030
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-7a			1

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



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Project Title:

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Client:

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LEGEND

- River Avon / Floating Harbour

Maximum Flood Hazard

- Caution
- Danger for Some
- Danger for Most
- Danger for All

Model Reference:

CAFRA_134_20yr_FBASE_T020_2030

Copyright:

AECOM Internal Project No:

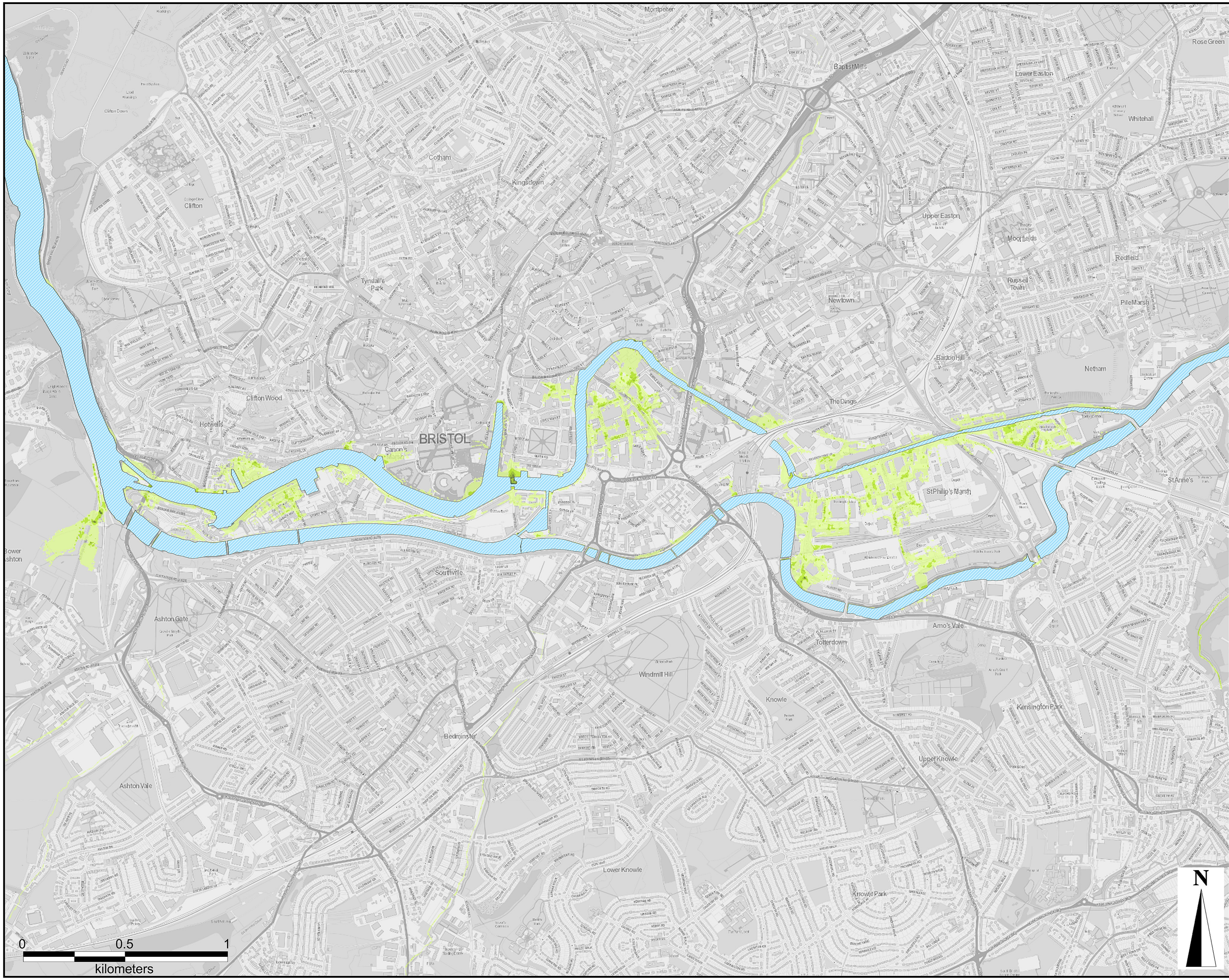
60478613

Drawing Title:

RUN ID 7 - DO NOTHING
20 YR RETURN PERIOD
2030
MAXIMUM FLOOD HAZARD

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-7b			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

- River Avon / Floating Harbour

Maximum Flood Velocity

- 0.1m/s to 0.5m/s
- 0.5m/s to 1.0m/s
- 1.0m/s to 1.5m/s
- 1.5m/s to 2.0m/s
- >2.0m/s

Where velocity is less than 0.1m/s, this is not shown in the figure

Model Reference:

CAFRA_134_20yr_FBASE_T020_2030

Copyright:

AECOM Internal Project No:

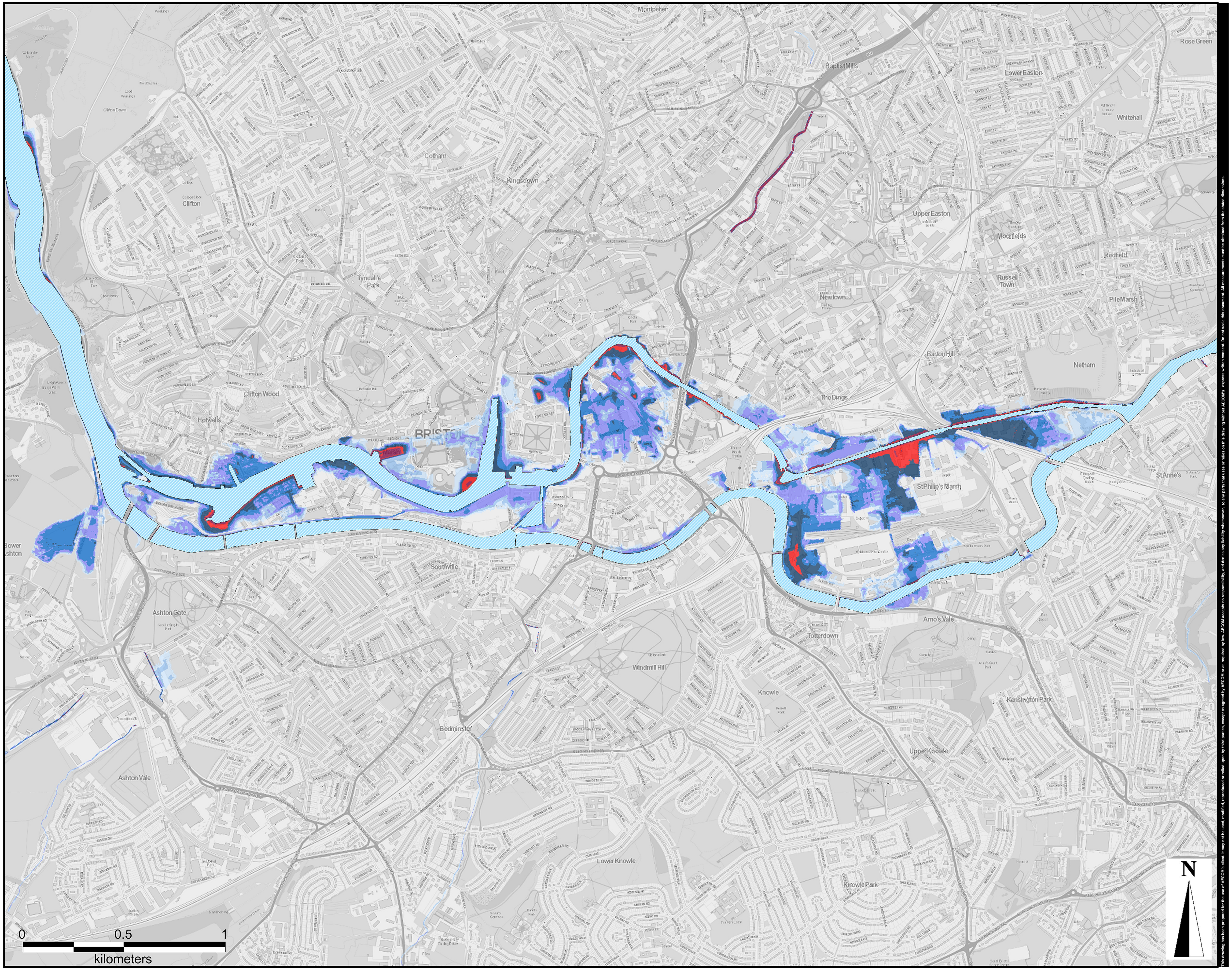
60478613

Drawing Title:

RUN ID 7 - DO NOTHING
20 YR RETURN PERIOD
2030
MAXIMUM FLOOD VELOCITY

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-7c			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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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_134_100yr_FBASE_T100_2015

Copyright:

AECOM Internal Project No:

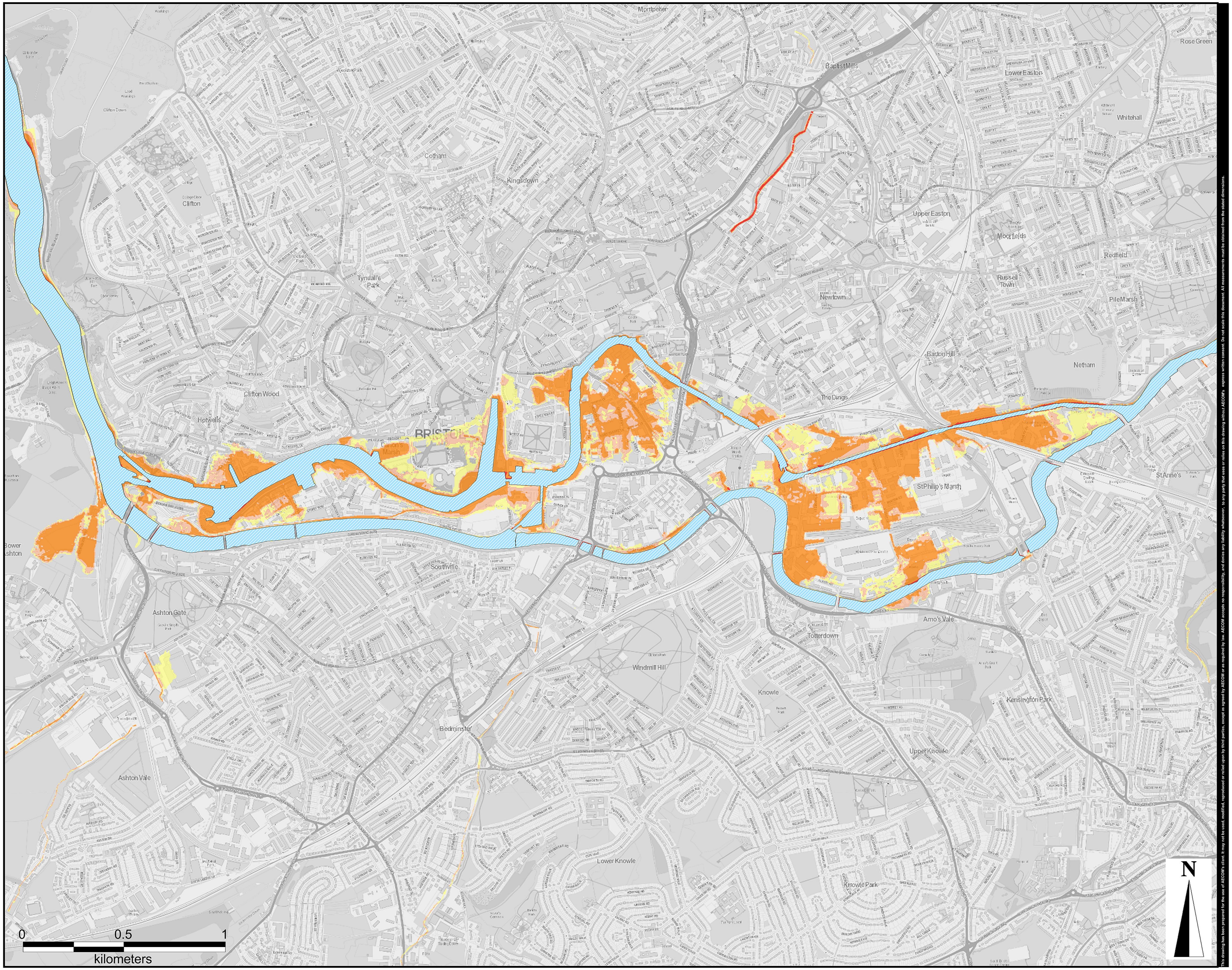
60478613

Drawing Title:

RUN ID 8 - DO NOTHING
75 YR RETURN PERIOD
2030
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-8a			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Hazard

- Caution
- Danger for Some
- Danger for Most
- Danger for All

Model Reference:

CAFRA_134_100yr_FBASE_T100_2015

Copyright:

AECOM Internal Project No:

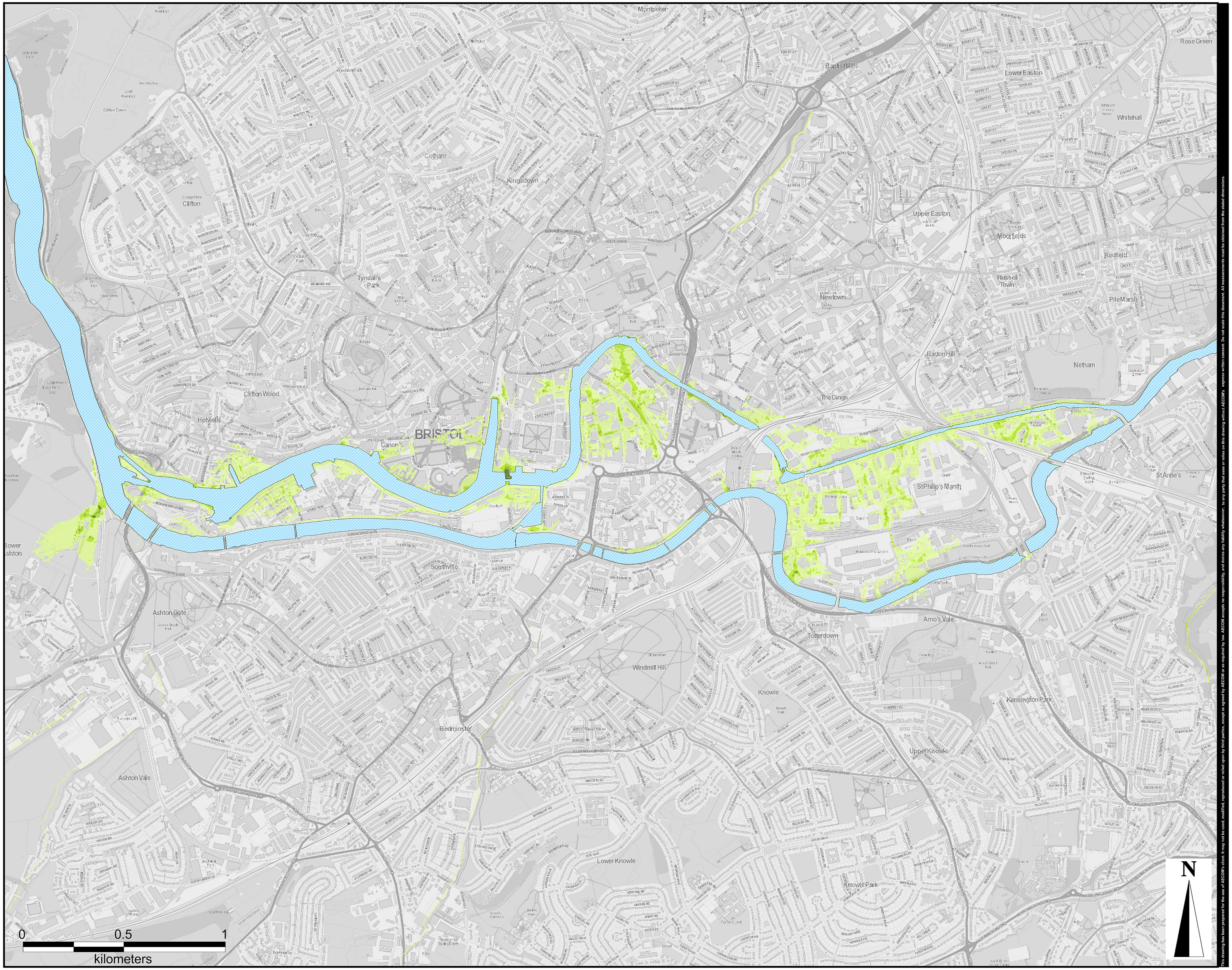
60478613

Drawing Title:

RUN ID 8 - DO NOTHING
75 YR RETURN PERIOD
2030
MAXIMUM FLOOD HAZARD

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-8b			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Veloctiy

- 0.1m/s to 0.5m/s
- 0.5m/s to 1.0m/s
- 1.0m/s to 1.5m/s
- 1.5m/s to 2.0m/s
- >2.0m/s

Where velocity is less than 0.1m/s, this is not shown in the figure

Model Reference:

CAFRA_134_100yr_FBASE_T100_2015

Copyright:

AECOM Internal Project No:

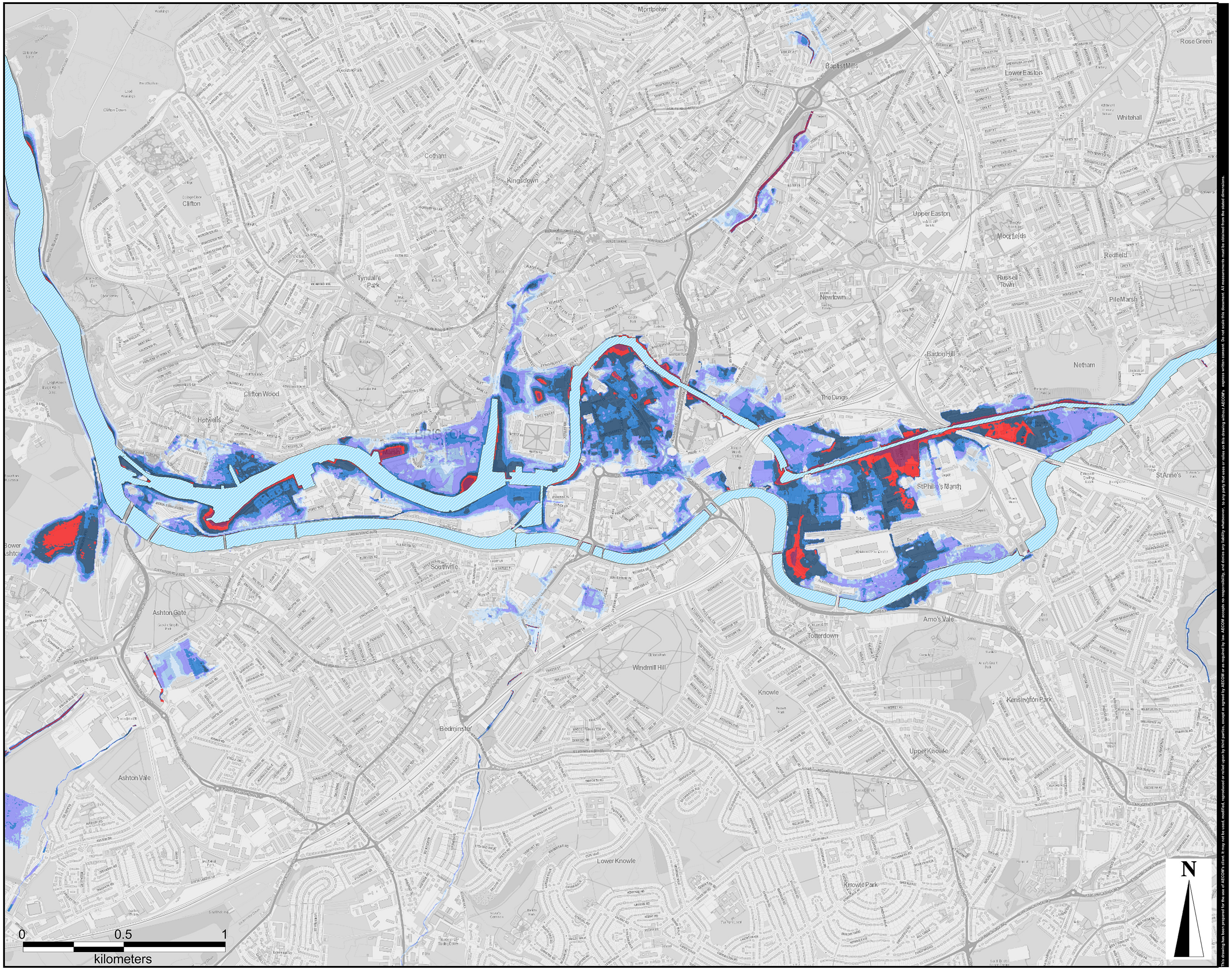
60478613

Drawing Title:

RUN ID 8 - DO NOTHING
75 YR RETURN PERIOD
2030
MAXIMUM FLOOD VELOCITY

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-8c			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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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_134_200yr_F002_T200_2030

Copyright:

AECOM Internal Project No:

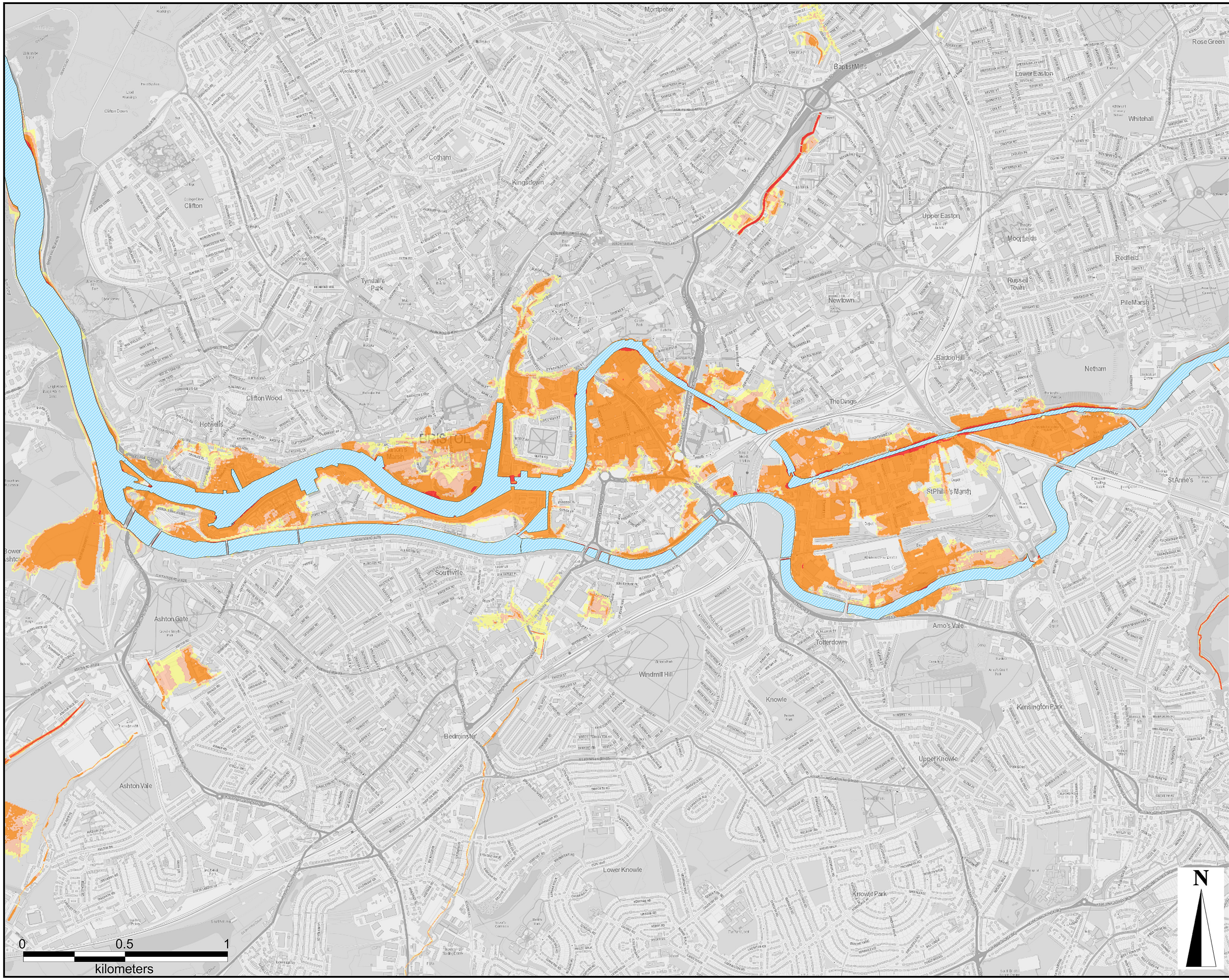
60478613

Drawing Title:

RUN ID 9 - DO NOTHING
200 YR RETURN PERIOD
2030
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-9a			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Hazard

- Caution
- Danger for Some
- Danger for Most
- Danger for All

Model Reference:

CAFRA_134_200yr_F002_T200_2030

Copyright:

AECOM Internal Project No:

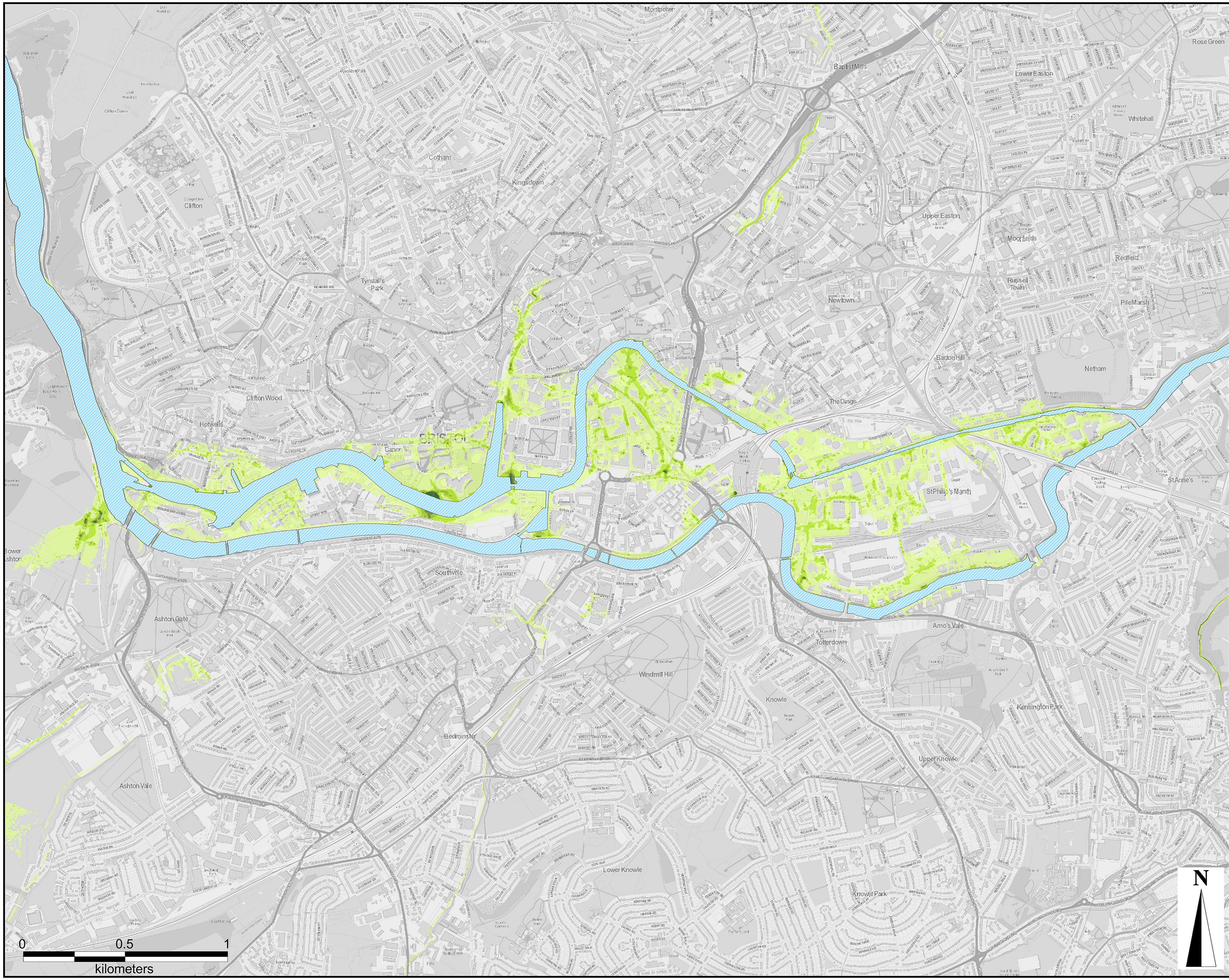
60478613

Drawing Title:

RUN ID 9 - DO NOTHING
200 YR RETURN PERIOD
2030
MAXIMUM FLOOD HAZARD

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-9b			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

- River Avon / Floating Harbour

Maximum Flood Velociy

- 0.1m/s to 0.5m/s
- 0.5m/s to 1.0m/s
- 1.0m/s to 1.5m/s
- 1.5m/s to 2.0m/s
- >2.0m/s

Where velocity is less than 0.1m/s, this is not shown in the figure

Model Reference:

CAFRA_134_200yr_F002_T200_2030

Copyright:

AECOM Internal Project No:

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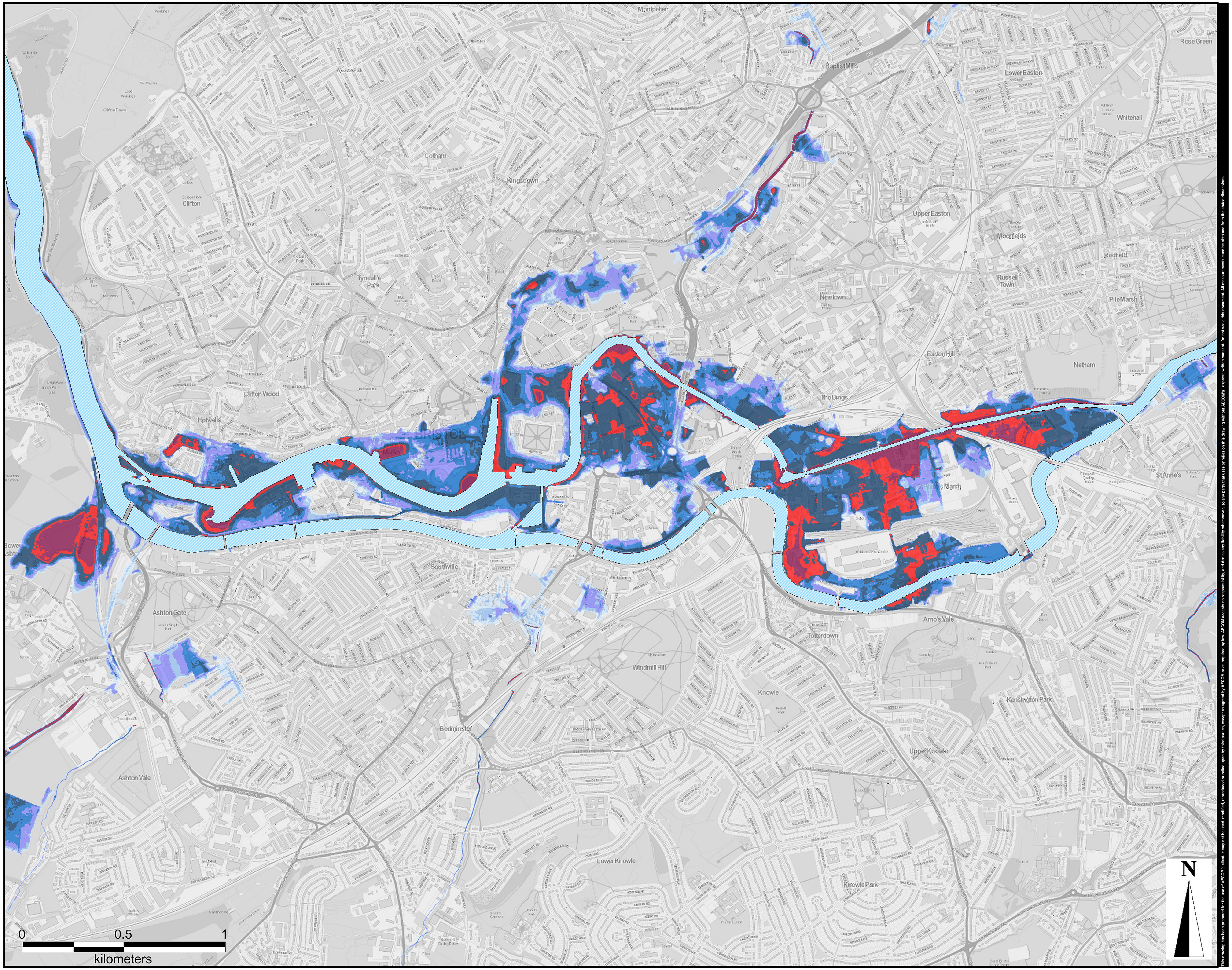
Drawing Title:

RUN ID 9 - DO NOTHING
200 YR RETURN PERIOD
2030
MAXIMUM FLOOD VELOCITY

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-9c			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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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_134_1000yr_F012_T1000_2030

Copyright:

AECOM Internal Project No:

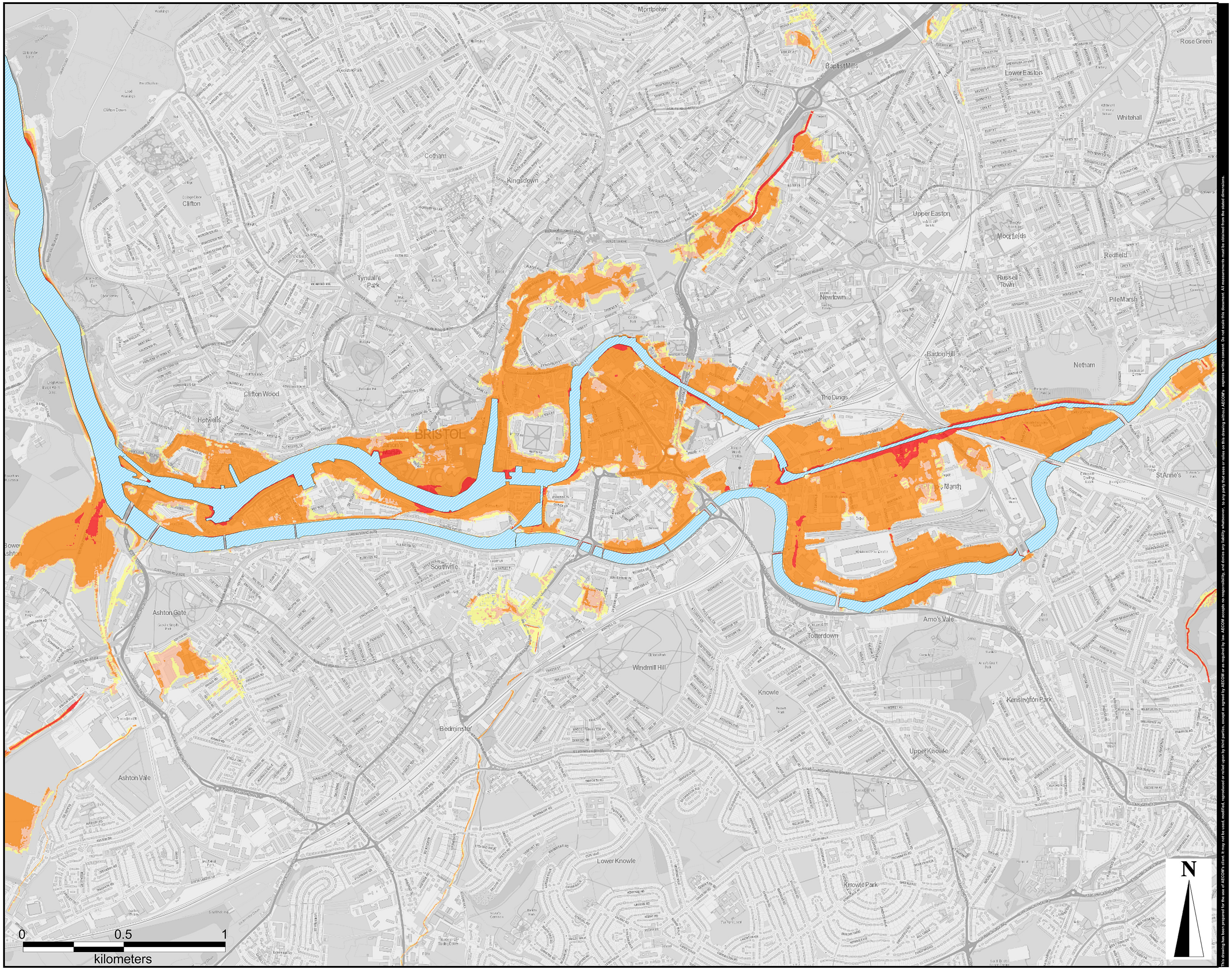
60478613

Drawing Title:

RUN ID 10 - DO NOTHING
1000 YR RETURN PERIOD
2030
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-10a			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Hazard

- Caution
- Danger for Some
- Danger for Most
- Danger for All

Model Reference:

CAFRA_134_1000yr_F012_T1000_2030

AECOM Internal Project No:

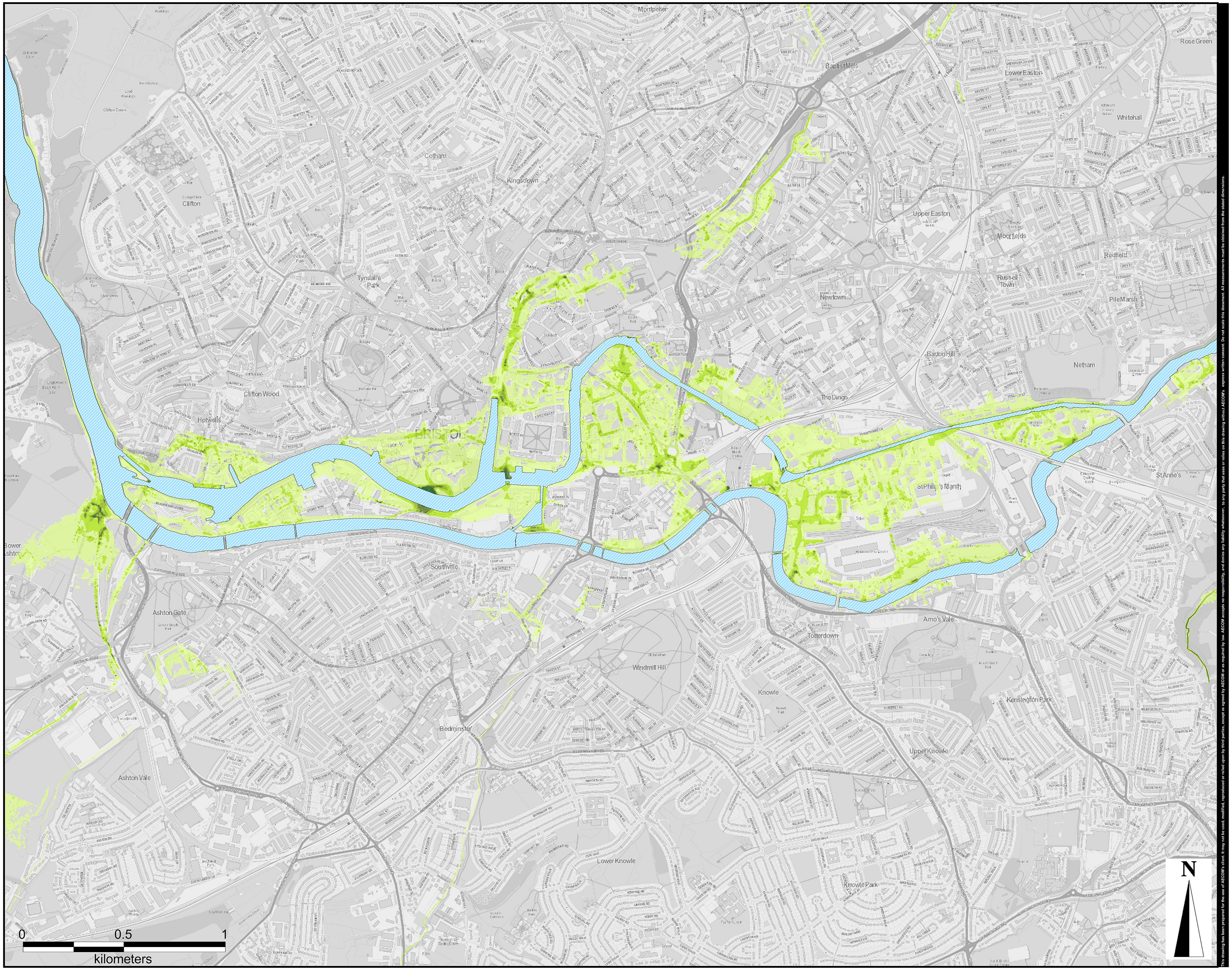
60478613

Drawing Title:

RUN ID 10 - DO NOTHING
1000 YR RETURN PERIOD
2030
MAXIMUM FLOOD HAZARD

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-10b			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Veloctiy

- 0.1m/s to 0.5m/s
- 0.5m/s to 1.0m/s
- 1.0m/s to 1.5m/s
- 1.5m/s to 2.0m/s
- >2.0m/s

Where velocity is less than 0.1m/s, this is not shown in the figure

Model Reference:

CAFRA_134_1000yr_F012_T1000_2030

Copyright:

AECOM Internal Project No:

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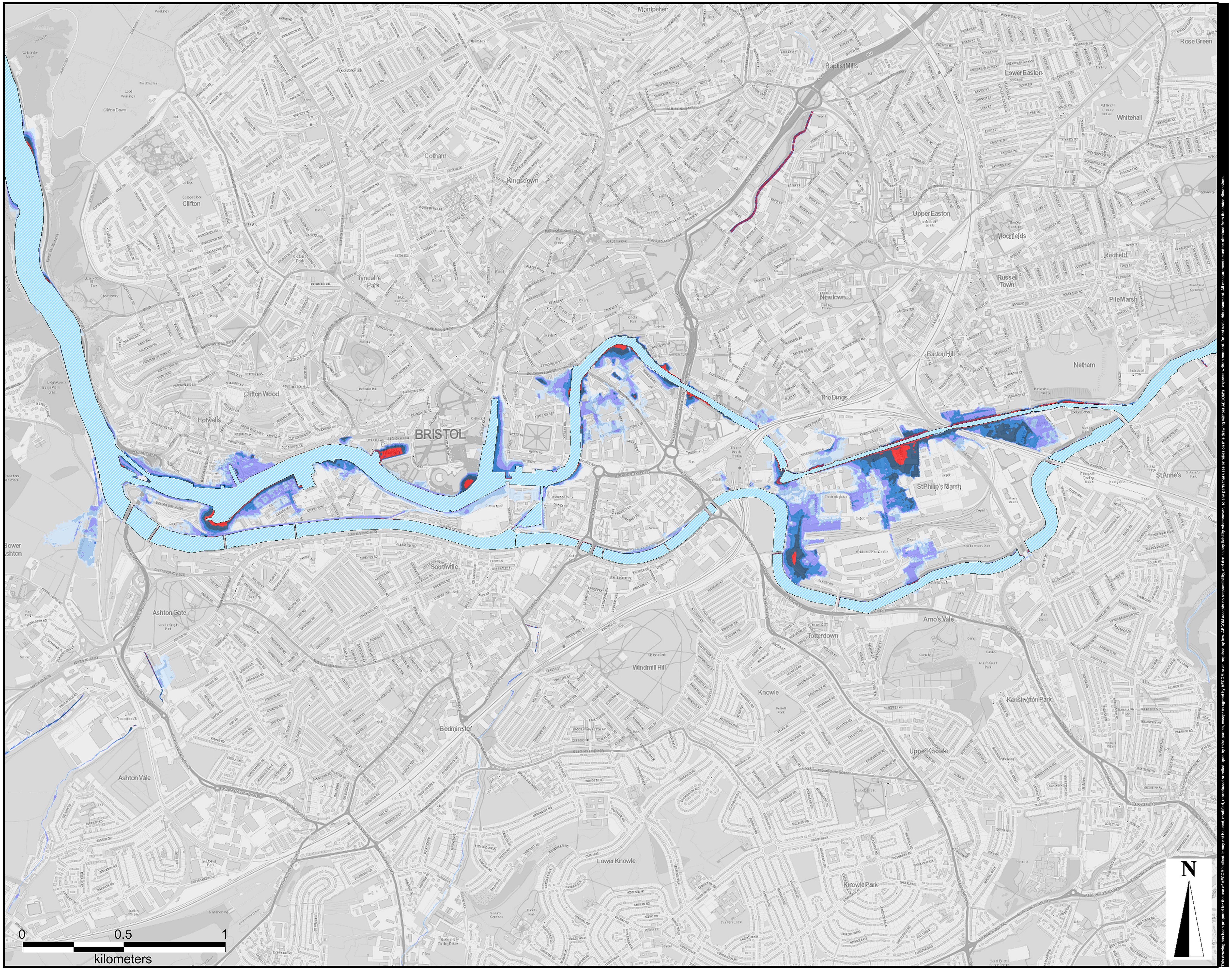
Drawing Title:

RUN ID 10 - DO NOTHING
1000 YR RETURN PERIOD
2030
MAXIMUM FLOOD VELOCITY

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-10c			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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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_135_2yr_FBASE_T002_2065

Copyright:

AECOM Internal Project No:

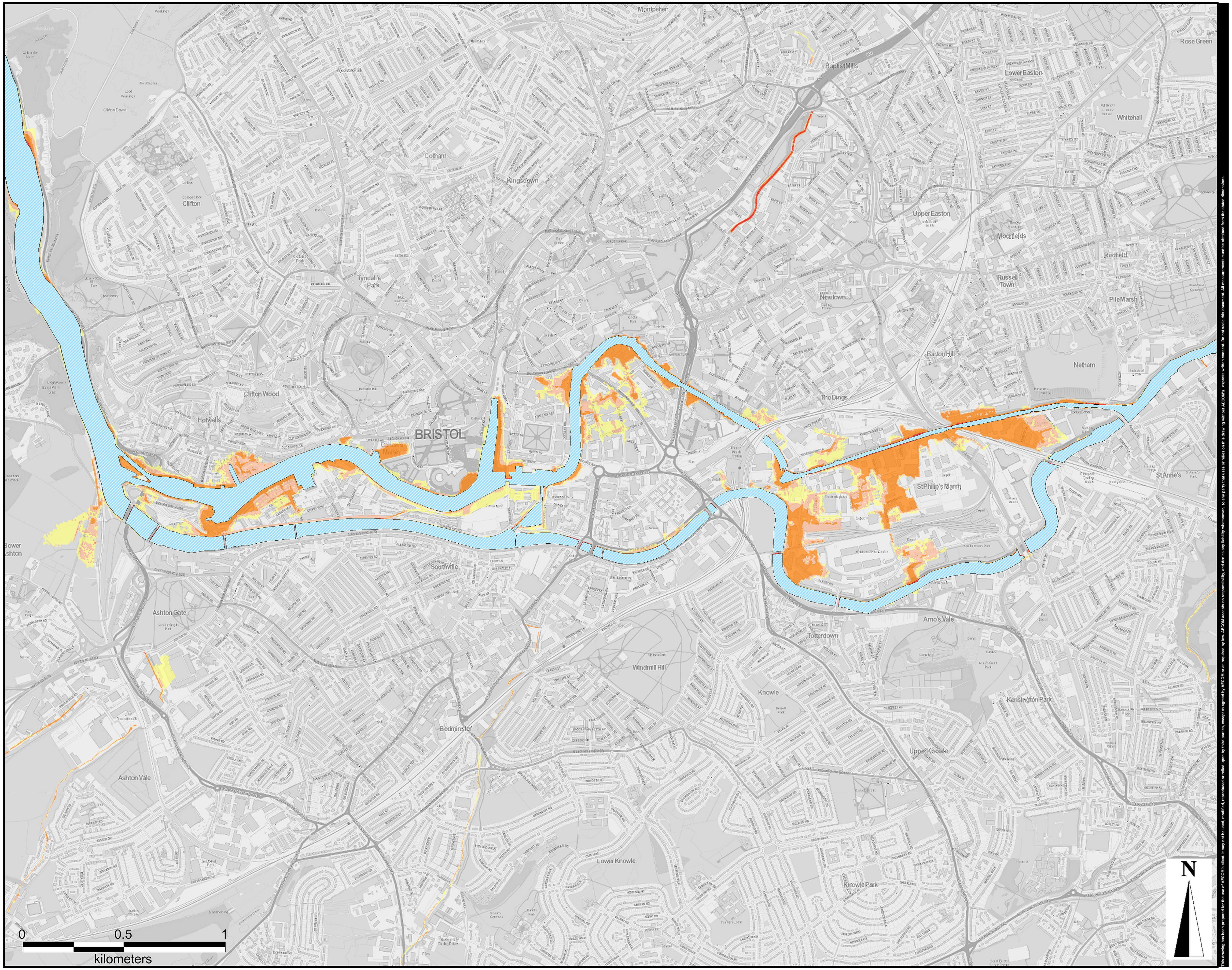
60478613

Drawing Title:

RUN ID 11 - DO NOTHING
2 YR RETURN PERIOD
2065
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-11a			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

- River Avon / Floating Harbour

Maximum Flood Hazard

- Caution
- Danger for Some
- Danger for Most
- Danger for All

Model Reference:

CAFRA_135_2yr_FBASE_T002_2065

Copyright:

AECOM Internal Project No:

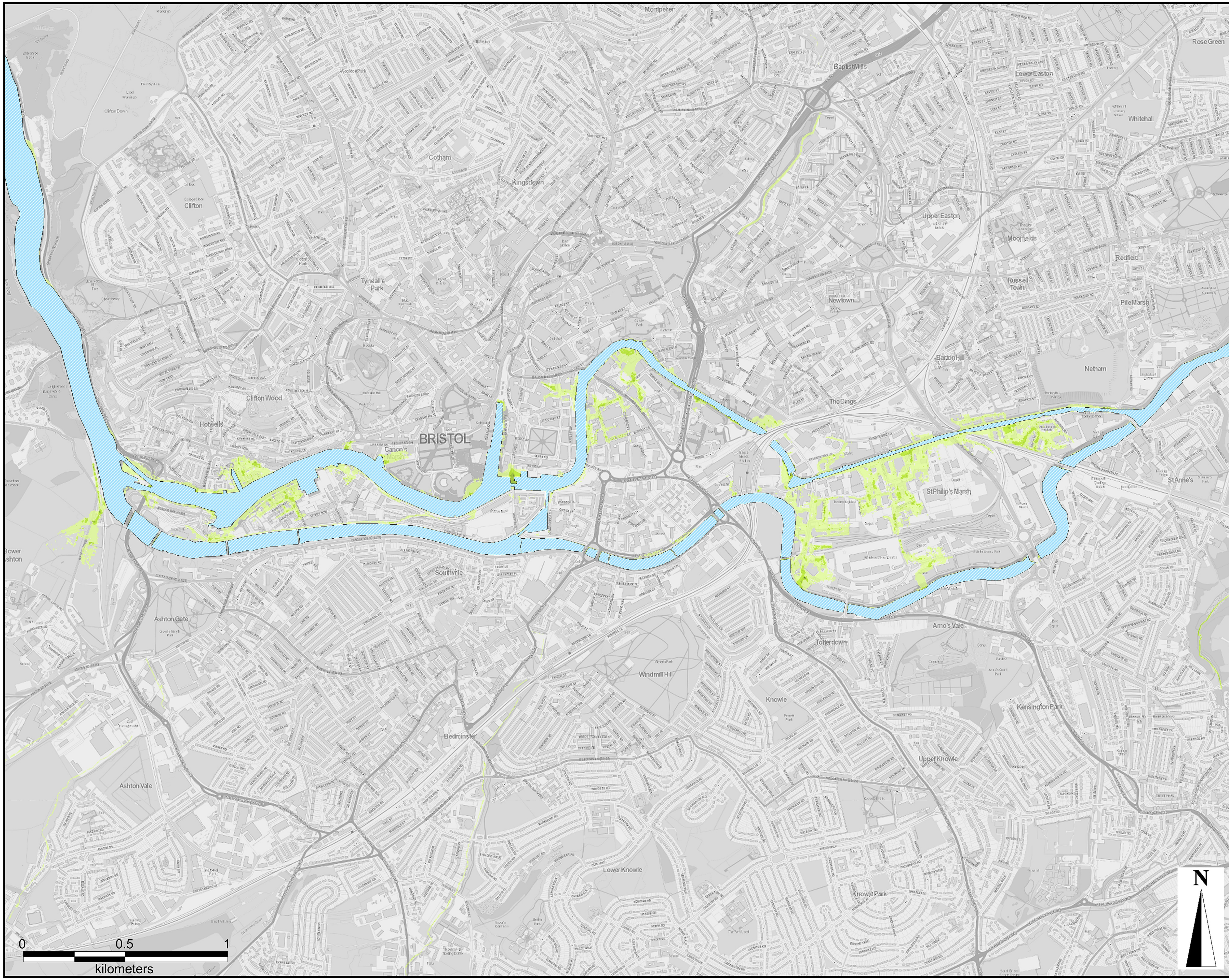
60478613

Drawing Title:

RUN ID 11 - DO NOTHING
2 YR RETURN PERIOD
2065
MAXIMUM FLOOD HAZARD

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-11b			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Velectiy

- 0.1m/s to 0.5m/s
- 0.5m/s to 1.0m/s
- 1.0m/s to 1.5m/s
- 1.5m/s to 2.0m/s
- >2.0m/s

Where velocity is less than 0.1m/s, this is not shown in the figure

Model Reference:

CAFRA_135_2yr_FBASE_T002_2065

Copyright:

AECOM Internal Project No:

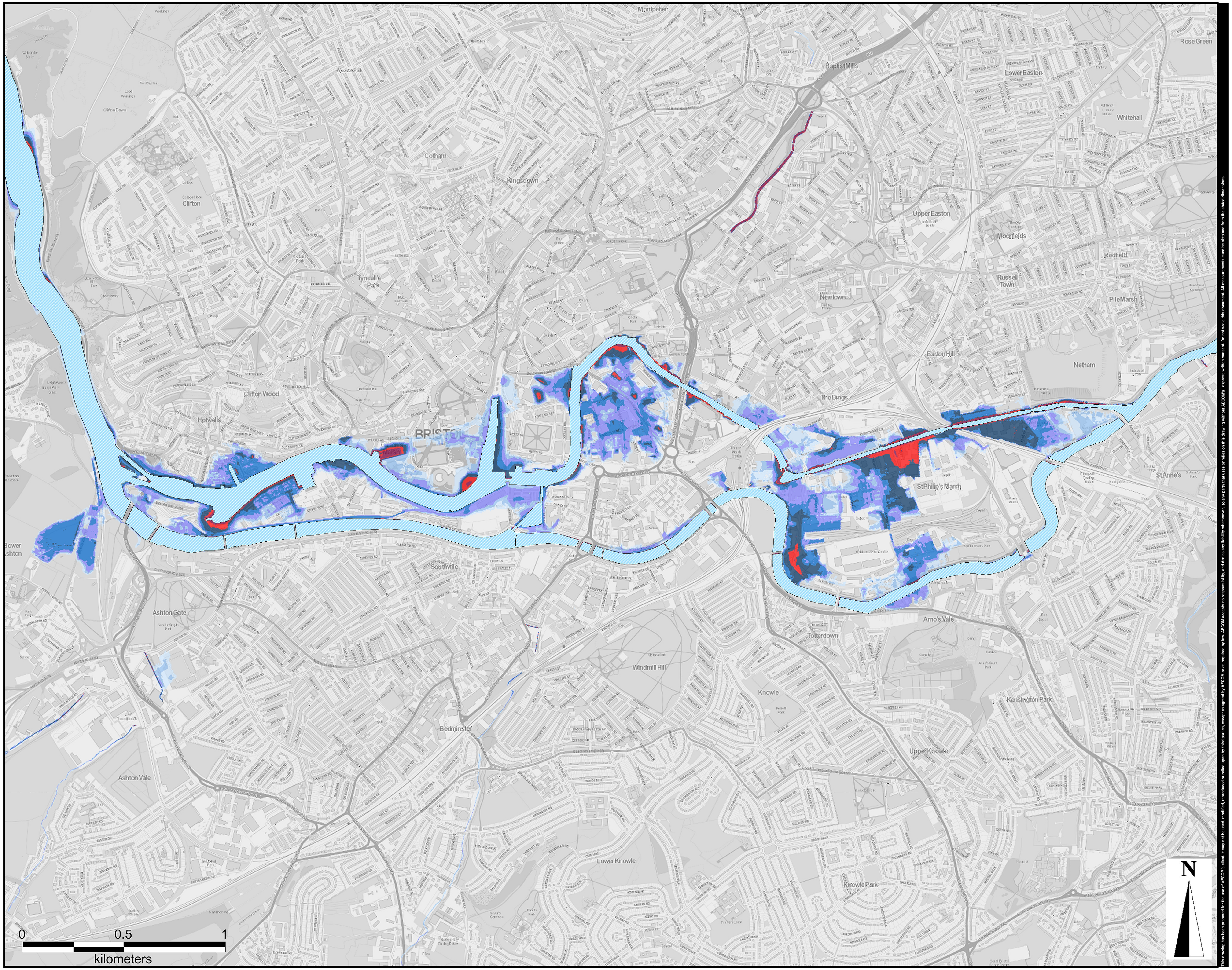
60478613

Drawing Title:

RUN ID 11 - DO NOTHING
2 YR RETURN PERIOD
2065
MAXIMUM FLOOD VELOCITY

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-11c			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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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_135_100yr_FBASE_T100_2015

AECOM Internal Project No:

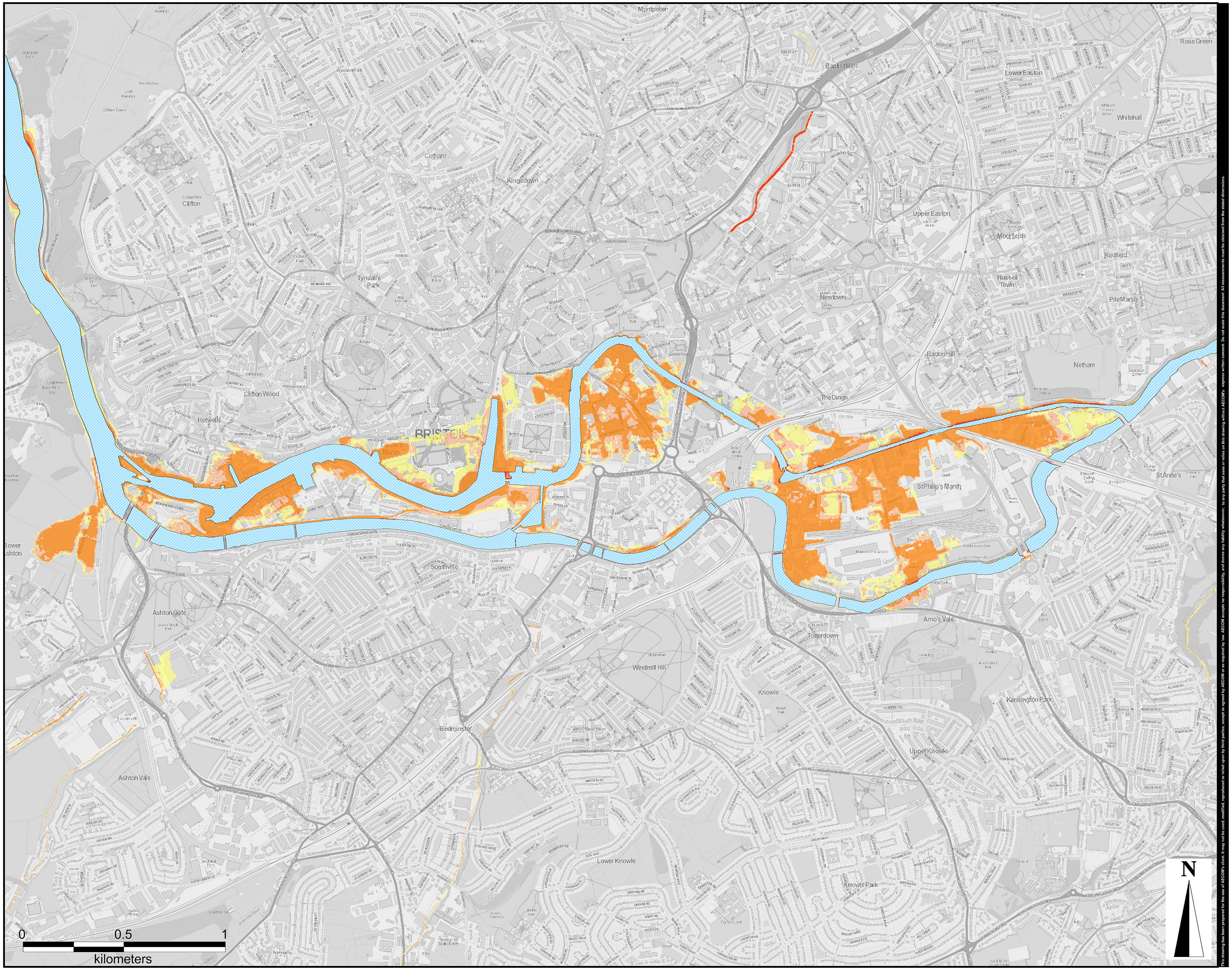
60478613

Drawing Title:

RUN ID 12 - DO NOTHING
20 YR RETURN PERIOD
2065
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-12a			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

- River Avon / Floating Harbour

Maximum Flood Hazard

- Caution
- Danger for Some
- Danger for Most
- Danger for All

Model Reference:

CAFRA_135_100yr_FBASE_T100_2015

Copyright:

AECOM Internal Project No:

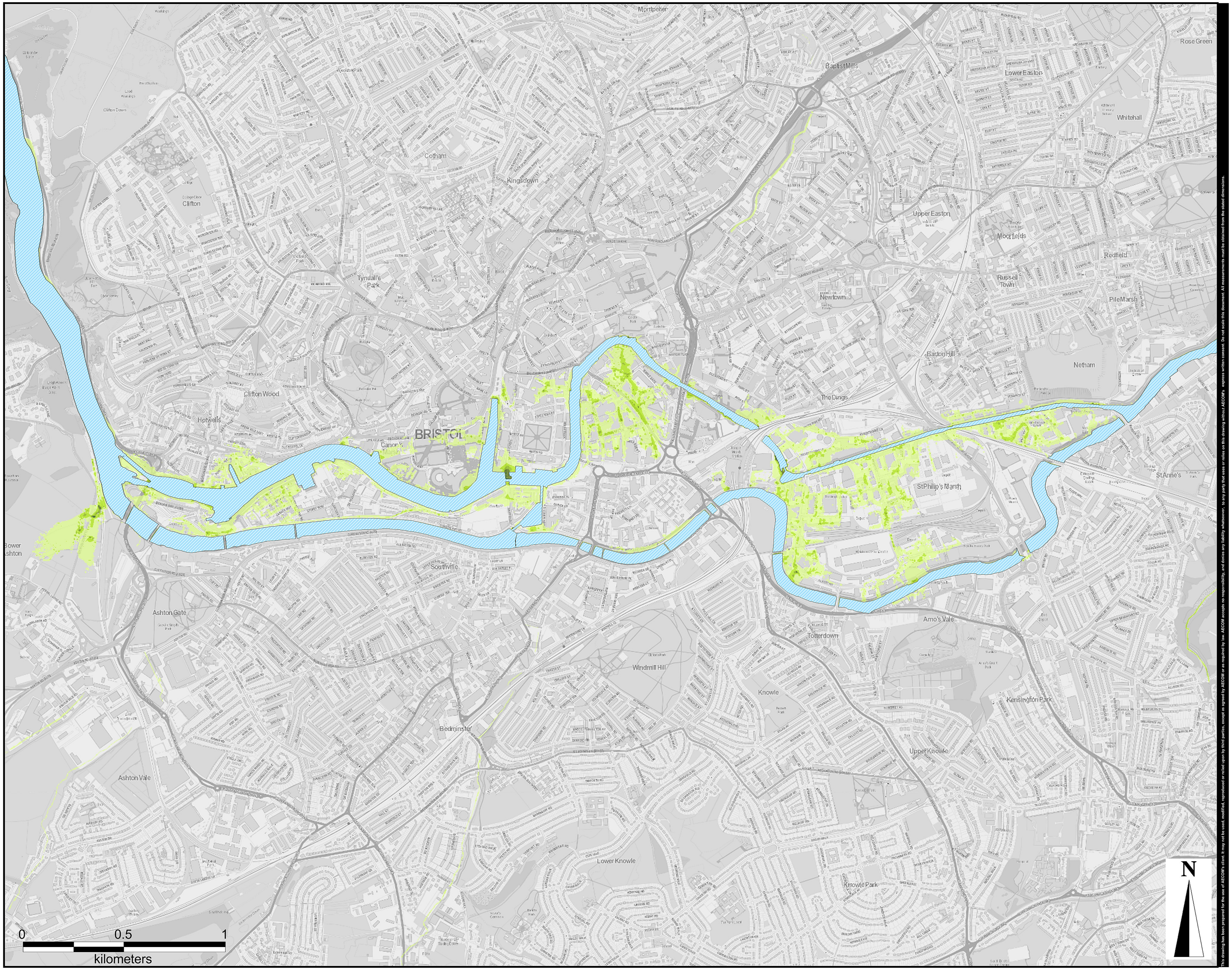
60478613

Drawing Title:

RUN ID 12 - DO NOTHING
20 YR RETURN PERIOD
2065
MAXIMUM FLOOD HAZARD

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-12b			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

- River Avon / Floating Harbour

Maximum Flood Veloctiy

- 0.1m/s to 0.5m/s
- 0.5m/s to 1.0m/s
- 1.0m/s to 1.5m/s
- 1.5m/s to 2.0m/s
- >2.0m/s

Where velocity is less than 0.1m/s, this is not shown in the figure

Model Reference:

CAFRA_135_100yr_FBASE_T100_2015

AECOM Internal Project No:

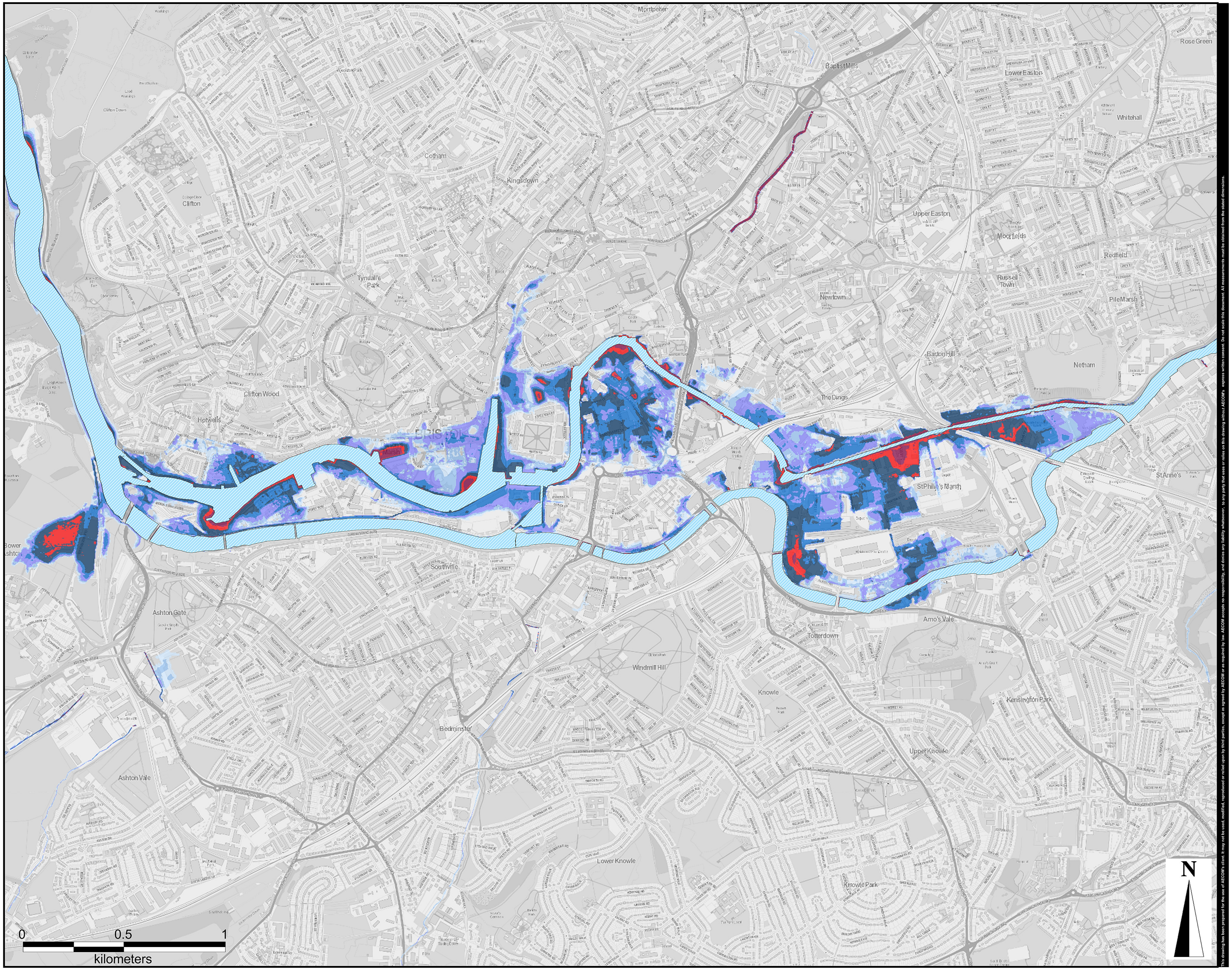
60478613

Drawing Title:

RUN ID 12 - DO NOTHING
20 YR RETURN PERIOD
2065
MAXIMUM FLOOD VELOCITY

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-12c			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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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_135_75yr_FBASE_T075_2065

Copyright:

AECOM Internal Project No:

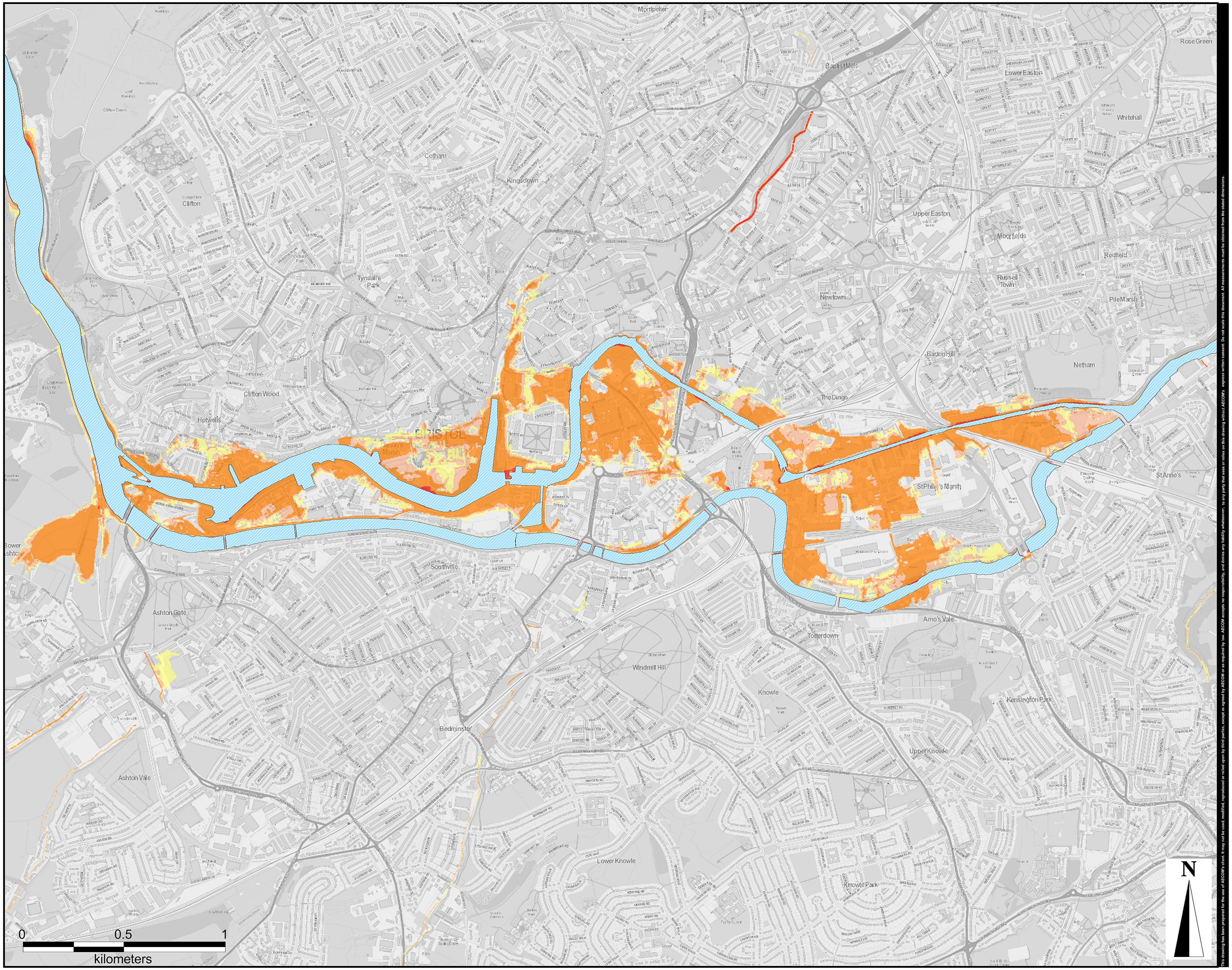
60478613

Drawing Title:

RUN ID 13 - DO NOTHING
75 YR RETURN PERIOD
2065
MAXIMUM FLOOD DEPTH

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-13a			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

RIVER AVON TIDAL FLOOD RISK MANAGEMENT STRATEGY

Client:

BRISTOL CITY COUNCIL

LEGEND

- River Avon / Floating Harbour

Maximum Flood Hazard

- Caution
- Danger for Some
- Danger for Most
- Danger for All

Model Reference:

CAFRA_135_75yr_FBASE_T075_2065

AECOM Internal Project No:

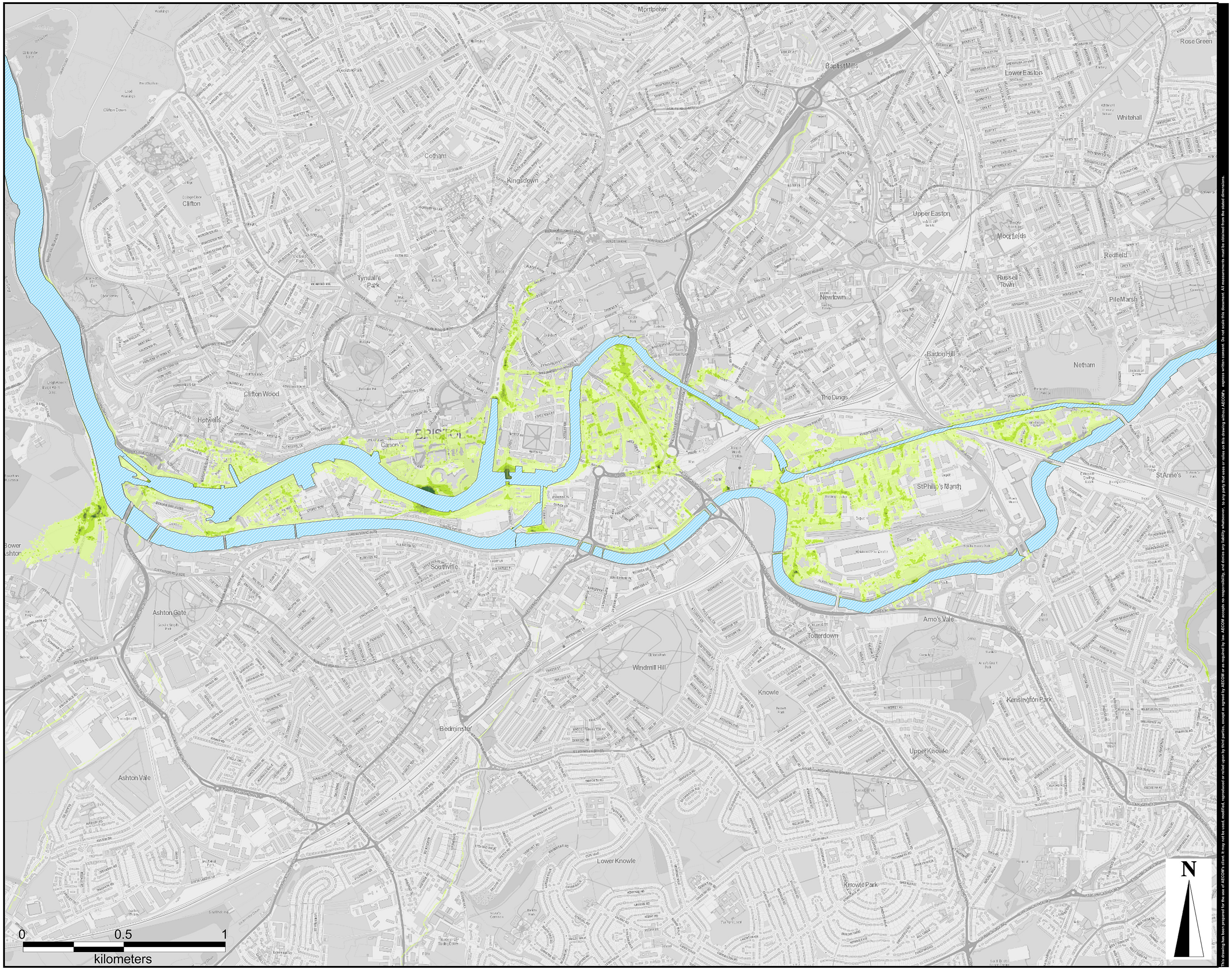
60478613

Drawing Title:

RUN ID 13 - DO NOTHING
75 YR RETURN PERIOD
2065
MAXIMUM FLOOD HAZARD

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-13b			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016



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Project Title:

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Client:

BRISTOL CITY COUNCIL

LEGEND

River Avon / Floating Harbour

Maximum Flood Veloctiy

- 0.1m/s to 0.5m/s
- 0.5m/s to 1.0m/s
- 1.0m/s to 1.5m/s
- 1.5m/s to 2.0m/s
- >2.0m/s

Where velocity is less than 0.1m/s, this is not shown in the figure

Model Reference:

CAFRA_135_75yr_FBASE_T075_2065

Copyright:

AECOM Internal Project No:

60478613

Drawing Title:

RUN ID 13 - DO NOTHING
75 YR RETURN PERIOD
2065
MAXIMUM FLOOD VELOCITY

Scale at A3: 17,500

Drawing No:			Rev:
FIGURE B-13c			1
Drawn:	Chk'd:	App'd:	Date:
RM	MD	JS	May 2016