ARUP

Bristol City Council

Bristol Avon Flood Strategy OBC

Options modelling report

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1. Introduction

1.1 Purpose of this report

This report summarises the hydraulic modelling undertaken using the updated baseline hydraulic model to support the Bristol Avon Flood Strategy (BAFS) Outline Business Case (OBC). The development of the updated baseline hydraulic model, and comparison of updated results against previous results, is detailed in the Baseline modelling report[1].

This report focusses on options modelling and covers:

- Options modelled and assumptions.
- Flood conditions assessed including climate change allowances.
- Baseline model results.
- Identification and refinement of required flood defence alignments.
- Derivation of flood defence crest levels and freeboard allowances.
- Assessment of flood risk impacts (detriment) to third parties and identification of mitigation measures.
- Modelling to support the economic assessment.
- Assessment of residual flood risk.
- Assessment of impact on surface water and identification of potential mitigation measures.

1.2 Background

Bristol is at risk of widespread flooding from the River Avon from high fluvial flows and from tidal events propagating up the river from the Severn Estuary. Bristol City Council (BCC) have worked with the Environment Agency (EA) and other partners to create a long-term Strategy for managing flood risk from the River Avon. The Strategic Outline Case (SOC) was presented to the EA's Large Project Review Group (LPRG) and assured in January 2021. Following a public consultation, the Strategy was endorsed by BCC cabinet in March 2021.

The preferred option comprises raised defences along the River Avon including new tidal stop gates for the Floating Harbour. The initial phase of construction ('Phase 1') is assumed to start in the 2020s. The flood defences will be constructed sufficiently high to prevent overtopping until the 2060s based on current climate change allowances. For the purposes of modelling, it is assumed that the 2060s corresponds to the epoch year 2069 – this is because the current climate change guidance[2] applies a step change in fluvial flow allowance between 2069 and 2070. Note in the SOC, the 2060s was represented using the epoch year 2065. A subsequent phase ('Phase 2') of constructing additional defences and raising defences is assumed for the 2060s. The location of raised defences proposed in the SOC is shown in Figure 1. The preferred option will include detriment mitigation measures, such as raised flood defences, to manage impact of the preferred option to acceptable levels.

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[1] Bristol Avon Flood Strategy OBC, Baseline modelling report, Arup, November 2023.

[2] Flood and coastal risk projects, schemes and strategies: climate change allowances, Environment Agency, May 2022.

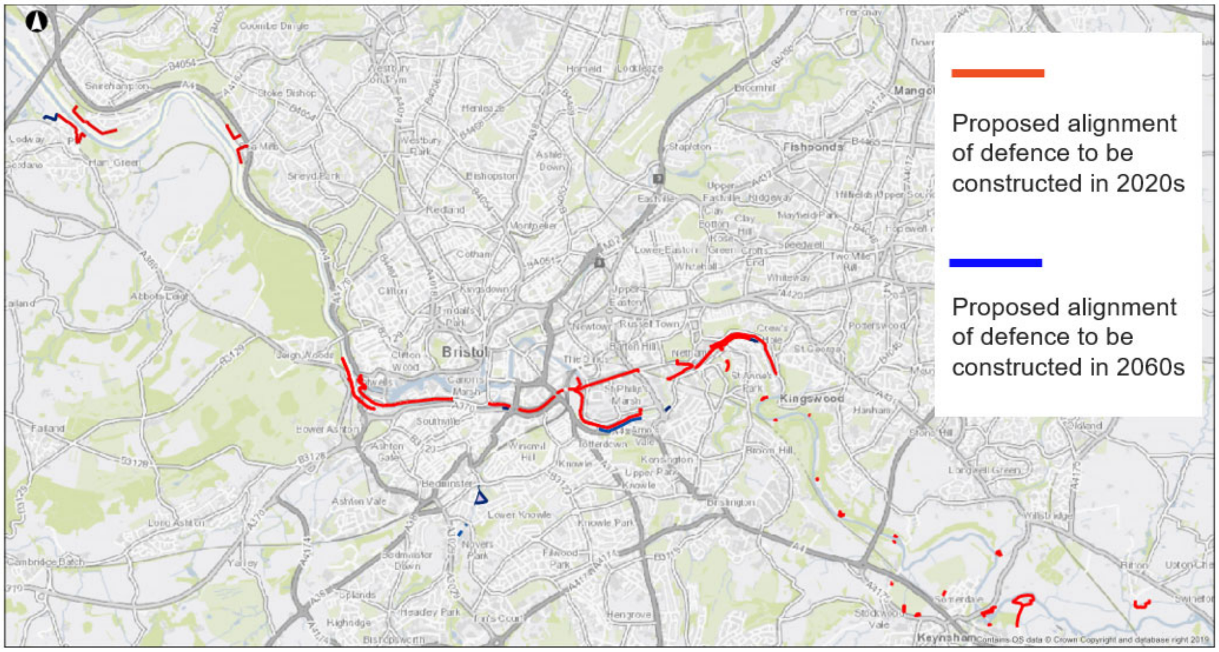


Figure 1: Location of raised defences proposed in the SOC.

2. Baseline model

The baseline model represents the existing business as usual 'Do Minium' scenario (rather than the 'Do Nothing' walkaway economic baseline scenario). The development of the updated baseline hydraulic model, and comparison of updated results against previous results, is detailed in the Baseline modelling report[1]. This chapter presents a brief overview of the model.

The model is a linked 1d-2d model. The 1d component, which is represented in Flood Modeller Pro, represents the watercourses and riverine structures plus some areas of floodplain downstream of Bristol. The 2d component, which is represented in TUFLOW, represents all other floodplain areas, the Floating Harbour and the Feeder Canal. The extents of the 1d and 2d components of the model are shown in Figure 2.

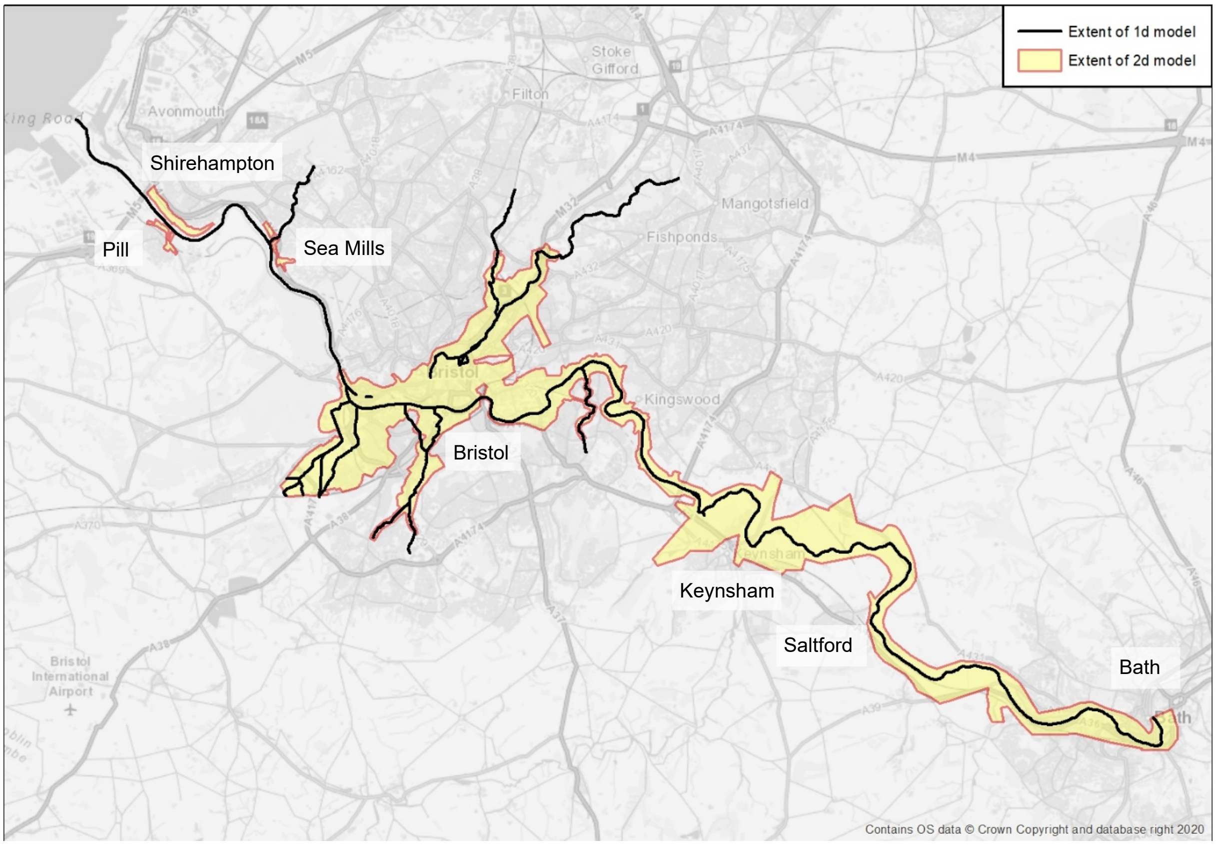


Figure 2: Extent of 1d and 2d model components.

The 1d model covers the Avon from Pulteney Bridge in Bath to Avonmouth where the Avon discharges into the Bristol Channel. The 1d hydraulic model explicitly includes the main river tributaries draining into the Bristol area, namely the Frome, Horfield Brook, Malago, Trym, Colliter's Brook, Longmoor Brook, Pigeonhouse Brook, and Brislington Brook. Markham Brook, which discharges into the Avon at Pill, and tributaries upstream of Brislington Brook are not explicitly included in the hydraulic model but are represented hydrologically as model inflows applied at the respective confluences with the Avon.

The 1d model also includes the Northern Storm Water Interceptor (NSWI) and inlet sluices and weirs, which are represented as fully operational. The NSWI transfers a significant portion of fluvial flow from the River Frome to the River Avon near Clifton Down during fluvial flood events.

The 1d model also includes some areas of floodplain downstream of Entrance Lock; these are represented using extended cross-sections.

The in-channel parts of the 1d model are largely based on topographic survey of the channel and riverine structures collected between 2001 and 2011; most data used in the model is from 2005 onwards.

The 2d model has a 5m resolution and is largely based on the EA LiDAR composite DTM 2020 dataset, which was the most recent composite dataset at the time of modelling in July 2022. This dataset incorporates the January 2019 surveys that were flown for the majority of the study area as part of the EA National LIDAR programme. The 2d model is linked to the 1d model along the river banks and at the lock gates, which are also represented.

The model applies a water level vs time boundary condition at Avonmouth to represent tidal cycles including surge events. The model applies flow vs time boundary conditions at the upstream ends of the modelled watercourses and at locations along the modelled watercourses where flows enter. The phasing of the Avon fluvial flood peak and peak high tide levels is configured so that these are synchronised at Bristol, which is conservative. Each model simulation represents a 70hr duration, which includes five full tidal cycles.

3. Options modelled

Modelling has been undertaken for the options listed below, which are described in the following sub-sections.

- Do Minimum
- Do Nothing
- BAFS scheme Phase 1 flood defences
- BAFS scheme Phase 2 flood defences (from year 2070): This comprises raising the proposed Phase 1 flood defences and constructing / raising some additional flood defences.

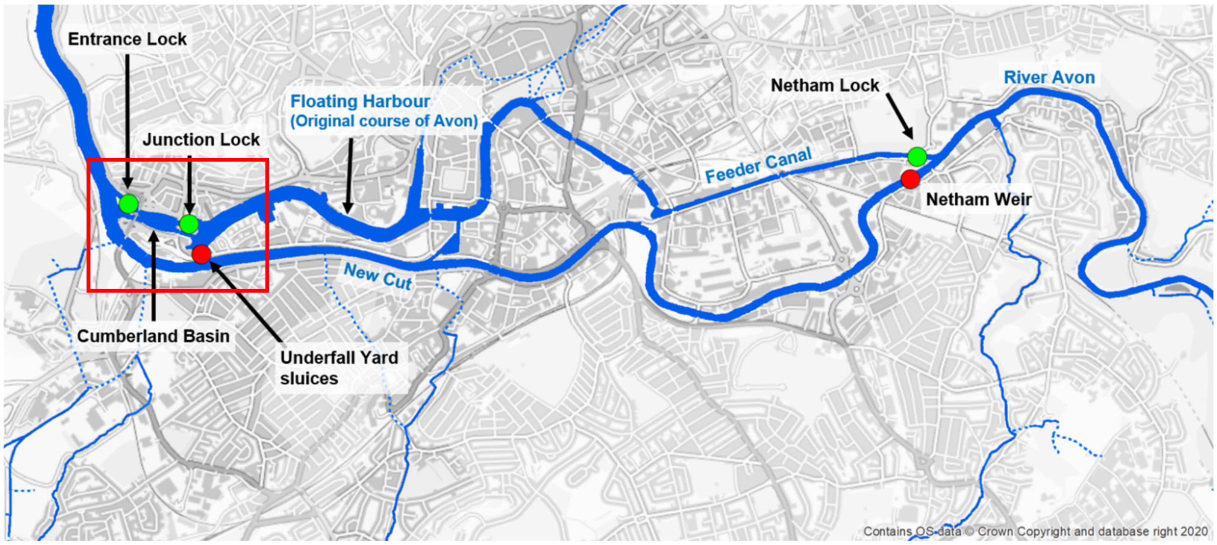
3.1 Do Minimum option

This represents the current / existing situation and assumes the current maintenance regime will continue into the future. This uses the baseline model. The key assumptions associated with the flood management assets are given below. The location of key structures around the Floating Harbour is shown in Figure 3.

- Underfall Yard automatically operated sluices remain operational. There are four sluiced culverts that link the Floating Harbour to the River Avon: one deep and rarely used with a blanking plate, two higher-level operational (automatic) and then one at a higher level which is abandoned. The two automatically operated sluices are included in the model and are represented using sluice units with logical rules set to mimic the automatic operation of these sluices based on water levels in the Avon and Floating Harbour. The other two sluices, which are manually operated, are not included in the model to give a worst-case scenario. This aligns with the preferred option of the EA funded Underfall Yard sluice project (which is FRM GiA) as required for this baseline assumption.
- Northern Storm Water Interceptor Sewer (NSWI) remains operational. This operates in high flow events using a series of sluices and penstocks to divert flows from the River Frome at Eastville into a stormwater tunnel that discharges into the River Avon at Avon Gorge.
- Raised flood defences at Pill, Shirehampton, Cumberland Road and the Paintworks remain operational and do not fail. These are represented in the 2d model using breakline layers.
- Informal third-party flood defence structures at Albert Road and Victor Street: Parts of these flood defences are damaged or removed and do not provide a continues line of defence. These structures are a variety of forms and all outside EA/BCC or other RMA control and have not been formally designated. BCC investigations concluded the structures would pose a risk of breach during more severe events and so cannot be formally relied upon or included in the flood model. Therefore, these structures are excluded from the Do Minimum option.
- Netham Lock gates, which are manually operated, remain operational and set to be permanently closed during flood events for navigational locking purposes. These are represented in the model using a spill unit with elevations set to the crest level of the gates (9.1m AOD).
- Junction Lock flood stop gates remain operational and set to be permanently closed during flood events. The gates are represented in the baseline model using a sluice unit (as there are no dedicated units for lock gates) with the sluices set to be ‘fully closed’ with crest level of 8.7m AOD.
- Brunel Dam remains operational. Brunel Dam is represented using a spill unit with elevations set to the crest level of Brunel Dam (8.28m AOD).
- Nova Dam and sluices remain operational and sluices are set to be permanently closed during flood events as they are not routinely operated. Whilst the dam is a water retaining structure, the buried/silted sluices remain not operational. The only flow route in the baseline model here is for water to overtop Merchants Road (9.6m AOD).
- Netham Weir and fixed weirs on the Avon upstream of Bristol remains intact at current crest levels.

- Lock gates on the River Avon navigation channels upstream of Bristol remain in the closed position.
- The movable radial and vertical sluices on the River Avon at Bath (Twerton and Pulteney) remain operational.
- Other flood risk / water management assets outside the scope of the project remain operational; these include the tributary tunnels south of the Avon, Ashton Avenue pumping station and Markham Brook pumping station. This is consistent with the Strategic Flood Risk Assessment (SFRA) and Central Area Flood Risk Assessment (CAFRA) study assumptions.

The Entrance Lock gates, which are used to enable navigation between the Cumberland Basin and the Avon, do not have a flood risk management function. These lock gates are mitred to retain water in the Cumberland Bain and therefore automatically open when Avon water level exceeds the Cumberland Basin water level. The Entrance Lock gates are represented in the baseline model using a sluice unit (as there are no dedicated units for lock gates) with the sluice operation defined using logical rules so that the sluice automatically opens when the Avon water level exceeds the Cumberland Basin water level.



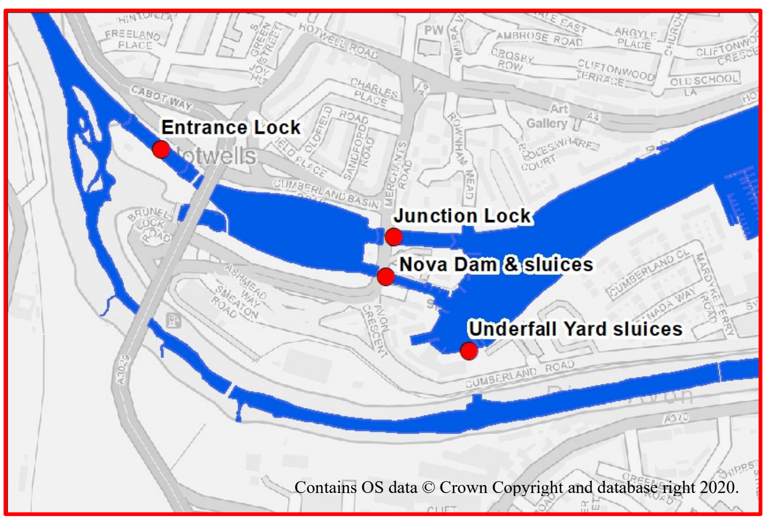


Figure 3: Key structures around the Floating Harbour.

3.2 Do Nothing option

This is a hypothetical baseline against which all other options should be compared and is required for the Flood and Coastal Erosion Risk Management (FCERM) economic appraisal. This option represents a 'walk away' scenario where all maintenance and operation of flood risk assets would cease immediately. Except for Nova Dam (see below), the assumptions agreed in the SOC have been used for this option. These assumptions and their justification are described in more detail within the SOC and OBC appraisal reporting. The modelling assumptions for the Do Nothing option, where different to the baseline Do Minimum option, are given below. Where failure of the asset is represented, this is applied for the duration of the simulated flood event. The Avon river channel through Bristol is not subject to active maintenance and therefore adjustments to bed levels or roughness have not been applied in the Do Nothing option model.

From Year 0:

- Underfall Yard sluices failed in the open position. Failure of these sluices is represented in the Do Nothing model by changing the sluice operation from 'auto' (based on logical rules) to 'manual' and setting the sluices to be fully open. This was applied for the two Underfall Yard sluices included in the model.
- Netham Lock gates, including the flood stop gates, failed in the open position. Netham Lock flood stop gates are represented using a spill unit in the baseline model. Failure of the gates is represented in the Do Nothing model by lowering the spill unit level to 4.5m AOD to match bed levels here.
- Junction Lock gates, including the flood stop gates, failed in the open position. Failure of the gates is represented in the Do Nothing model by changing the sluice from 'fully closed' to 'fully open'.
- Brunel Dam failed in the open position. This is described as being in *"Poor condition."* in the Bristol Tidal FRM Strategy[3]. The Bristol Tidal FRM Strategy modelling and the SOC modelling both assumed this would fail in the open position from day one. Brunel Dam is represented using a spill unit in the baseline model. Failure of Brunel Dam is represented in the Do Nothing model by lowering the spill unit level to 3m AOD. This 3m AOD level is approximately equal to the River Avon mud bank level where the downstream end of the Brunel Dam inlet meets the River Avon. The existing level immediately downstream of the Brunel Dam is at approximately 5m due to the significant siltation; it is assumed that if the Brunel Dam failed, the flows discharging from the Floating Harbour via Cumberland Basin would remove this silt buildup.
- Shirehampton flood defence not operated – it is assumed the flood gate, which is integral to the function of this flood defence and needs to be manually operated, would not be operated and would remain in the open position. For simplicity, this is represented in the Do Nothing model setup by omitting the 2d model layer representing the Shirehampton flood defence.
- 150m length wall failed adjacent to Albert Road. This is represented in the Do Nothing model setup by using an amended version of the model layer that excludes the wall levels here.

From Year 2069:

- 45m length wall failed on right bank immediately downstream of Victor Street. This is represented in the Do Nothing model setup by using an amended version of the model layer that excludes the wall levels here.
- Nova Dam and sluices failed in open position. This is described as being in *"Fair condition. Sluices and electrical system – very good condition. Standby generator may be vulnerable to flooding."* in the Bristol Tidal FRM Strategy[3]. The Bristol Tidal FRM Strategy modelling and the SOC modelling both assumed this would fail in the open position from day one. However, for the OBC, this has been revised to be failed in the 2069 epoch year but not failed from year 0. This is because "fair condition", which is condition Grade 3, has a residual design life of 34 years. The baseline model assumes no flow through Nova Dam or the sluices as they are not routinely operated; the only flow route here is for water to overtop Merchants Road. Failure of Nova Dam and sluices, which is assumed to result in the collapse of Merchants Road, is represented in the Do Nothing model by omitting the layer representing Merchants Road levels over Brunel Dam.

[3] Bristol Tidal FRM Strategy – Hydraulic Modelling Report, AECOM, October 2016.

3.3 Scheme Phase 1 flood defences

Modelling was used to develop and refine this option, including identifying the required alignment of the raised flood defences, deriving flood defence crest levels, and identifying measures required to mitigate flood risk impacts (detriment) to third parties. A model of the final iteration of the option was used to undertake a final assessment of flood risk impact to third parties and residual flood risk. The modelling of this option is described in more detail in subsequent chapters.

The key assumptions for this option, where different to the baseline Do Minimum option, are:

- The scheme will focus on managing flood risk from the River Avon, including the Entrance Lock and Netham Lock gates.
- The scheme will include raised flood defences on the River Avon, raised lock gates at Entrance Lock and Netham Lock. Other measures for managing the flood risk impact from the scheme, such as flood defences upstream of Bristol, were tested in combination with these.
- The Standard of Protection (SoP) assumed is 1:100yr for fluvial events and 1:200yr for tidal events. These return periods have been selected as they are the basis for Flood Zone 3 and represent the minimum design standard that would be required for new development to meet National Planning Policy Framework (NPPF) flood risk requirements if other mitigation such as ground raising was not undertaken. The optimum SoP will be subsequently determined using the EA's standard FCERM economic appraisal and decision rule guidance which may demonstrate that funding for a lower or a higher standard of protection could be justified.
- The standard of protection must be sustained with future climate change up to and including 2069.
- The scheme will include provision for managing water levels in the Floating Harbour during flood events. This will be via the operation of the proposed new lock gate structure(s) at Entrance Lock and also by reducing flood depths and hazard sufficiently so as to reliably enable operation of the existing lock gates at Entrance Lock and Junction Lock. This will enable excess fluvial flows entering the Floating Harbour from the River Frome to be more efficiently discharged when River Avon water levels are low enough.

3.4 Scheme Phase 2 flood defences

Modelling was used to develop and refine this option, including identifying the required alignment of the raised flood defences, deriving flood defence crest levels, and identifying measures required to mitigate flood risk impacts (detriment) to third parties.

The only key assumptions for this option that are different to the scheme Phase 1 flood defences option is that the standard of protection must be sustained with future climate change up to and including the year 2130.

4. Flood conditions

4.1 Joint probability of tide and flow conditions

The modelling methodology developed during the inception stage proposed that the same joint probability assessment (JPA) pairs of tide and flow conditions as used in the BAFS SOC are adopted for the OBC with the exception of the 1:20yr, 1:75yr and 1:100yr return period tidally dominated events. For these events, the 1:1yr flow conditions will be used as opposed to baseflow conditions. The 1:1yr flow conditions have been derived as part of the current study.

Sensitivity testing during the inception stage showed that there is not a city-wide sensitivity to JPA for the baseline Do Minium option and that the main area of sensitivity to JPA is the St Thomas Street / Victoria Street area for tidally dominated events in 2030. Sensitivity testing also showed impact on flood defence levels is less than 0.10m for the majority of defence lengths. Following presentation of this sensitivity testing, it was agreed with BCC and the EA that the JPA used to date should be retained for the OBC modelling and that uncertainty in JPA should be managed in the freeboard allowance.

4.2 Return periods

The model has been used to simulate a range of flood event probabilities for (a) fluvially dominated events; and (b) tidally dominated events. The combined return periods (and the constituent tidal and fluvial return periods) presented within Table 1 have been simulated using the updated model. Note that the BAFS SOC identified that intermediate combinations of fluvial and tidal did not result in higher water levels along the River Avon than the worst-case water level from the fluvially and tidally dominated events. The 1:1000yr return period and the 1:1yr, 1:2yr and 1:12yr tidal events are only required for the economic assessment.

Table 1: Combined return periods and constituent tidal and fluvial return periods.

Type of event	Combined return period (years)	Fluvial return period (years)	Tidal return period (years)
Fluvially dominated	1:20yr	1:20yr	1:1yr
	1:75yr	1:75yr	1:1yr
	1:100yr	1:100yr	1:1yr
	1:200yr	1:200yr	1:2yr
	1:1000yr	1:1000yr	1:12yr
Tidally dominated	1:1yr	Baseflow	1:1yr
	1:2yr	Baseflow	1:2yr
	1:12yr	Baseflow	1:12yr
	1:20yr	1:1yr *	1:20yr
	1:75yr	1:1yr *	1:75yr
	1:100yr	1:1yr *	1:100yr
	1:200yr	1:2yr	1:200yr
	1:1000yr	1:12yr	1:1000yr

* Baseflow was used in the BAFS SOC, which is lower than the 1:1yr flow.

4.3 Epochs

It was agreed with BCC and the EA that the following epochs should be assessed:

- **2030:** This epoch year has been selected as the construction of the proposed Phase 1 flood defences is expected to be complete between 2025 and 2030.

- **2069:** This epoch year has been selected to represent the last year before construction of the Phase 2 flood defences is completed (construction in the "2060s"). Note this has been updated since the SOC, which used 2065.
- **2070:** This epoch year has been selected to represent the first year after completion of the Phase 2 flood defences. The model results for this epoch year are to be used in the economic assessment to represent the step change between pre and post construction of Phase 2, which also coincides with the step change in fluvial flow allowance based on the current climate change guidance.
- **2130:** This epoch has been included to represent the end of the appraisal period. Note the BAFS SOC used 2125.

4.4 Climate change allowances

The latest EA guidance on climate change allowances at the time of writing are:

- *Flood and coastal risk projects, schemes and strategies: climate change allowances, EA, May 2022*. This guidance is for risk management authorities seeking FCERM grant-in-aid (GIA) for FCERM projects, schemes and strategies.
- *Flood risk assessments: climate change allowances, EA, May 2022*. This guidance is to be used for strategic flood risk assessments and flood risk assessments (FRAs) for planning applications, and development consent orders for nationally significant infrastructure projects. This includes FCERM schemes that need planning permission.

Review of the above guidance documents showed there is no difference in the fluvial flow allowances between the two guidance documents (see Table 2).

There is a small difference in the sea level rise allowances between the two guidance documents. The sea level rise allowances were found to be slightly different – for 2030 and 2069 epochs the maximum difference was only 10mm and for the 2130 epoch the difference was 24mm for the higher central allowance and 92mm for the upper allowance (see Table 2). In all cases, the FRA climate change allowances were slightly higher than the FCERM allowances. Given this result, it was agreed that the sea level rise allowances specified in the FRA climate change guidance as opposed to the FCERM climate change guidance could be used for all modelling to be undertaken in the BAFS OBC.

It was agreed with the EA that the above climate change guidance should be followed using the central fluvial and higher central tidal allowances for flood defence levels, and the higher central fluvial and upper end tidal allowances for assessing residual risk.

Table 2: Climate change allowances.

	Fluvial flow allowance (%)		Sea level rise allowance (m) based on 2017 baseline year			
Epoch year	**FCERM+FRA central**	**FCERM+FRA higher central**	**FCERM higher central (not used)**	**FCERM upper (not used)**	**FRA higher central**	**FRA upper**
2030	10	15	0.074	0.090	0.075	0.091
2065 **	12	19	0.364	0.466	0.368	0.468
2069	12	19	0.405	0.522	0.415	0.532
2070	26	39	0.416	0.536	0.427	0.548
2125 **	26	39	1.089	1.419	1.111	1.498
2130 *	26	39	1.153	1.498	1.177	1.590

* Allowances calculated based on method agreed with EA (see Section 4.4.1).
** 2065 and 2125 used in SOC but not in OBC: included in table for comparison.

4.4.1 Allowances for 2130

As the above guidance documents only provide allowances up to year 2125, allowances for 2130 needed to be agreed with the EA given the need for modelling this epoch. During the inception stage of the BAFS OBC modelling, the EA agreed the following:

Fluvial flows:

Use the same allowance as for 2125 given there are only 5 years between 2125 and 2130. Note the allowance for 2125 is taken from the ‘2080s’ category which represents the period 2070 to 2125.

Sea level rise:

The current FCERM climate change guidance for sea levels states “*To perform an extra assessment for the lifetime of the scheme after 2125, use the sea level rise projections to 2300 for RCP 8.5. You can get sea level rise projections for the appropriate location and year from the UKCP18 user interface.”* This is referring to the ‘extended projections’ dataset, which go up to 2300 but are slightly different from the ‘21st century projections’ dataset where they overlap. Four methods were considered to determine sea level rise allowances for 2130 and the following method, which was slightly more conservative than the other methods, was agreed: ‘Take the FRA allowance for 2125 and then add on 5 years of sea level rise calculated using the millimetres per year value given in the guidance for the last epoch (2096 to 2125).’

5. Baseline 'Do Minimum' option model results

The baseline 'Do Minimum' option model results are presented as a series of flood extent figures within this chapter. The following figures are presented:

- Figure 4: 2030 Fluvially dominated events.
- Figure 5: 2030 Tidally dominated events.
- Figure 6: 2069 Fluvially dominated events.
- Figure 7: 2069 Tidally dominated events.
- Figure 8: 2130 Fluvially dominated events.
- Figure 9: 2130 Tidally dominated events.

In all the above cases, the climate change allowances applied are the design allowances used for impact assessment and scheme design, which is the 'central' allowance for fluvial and 'higher central' allowance for tidal.

The flood extent figures show:

- Frequent flooding to areas of St Philips Marsh in all epoch years for both fluvial and tidal dominated events.
- Onset of flooding to most areas outside of St Philips Marsh is 1:200yrs in 2030 and is generally fluvially driven.
- Significant increase in flood extent between 2030 and 2069 for tidally dominated events. The increase is much smaller for fluvially dominated events.
- Significant increase in flood extent between 2069 and 2130 for both fluvially and tidally dominated events.

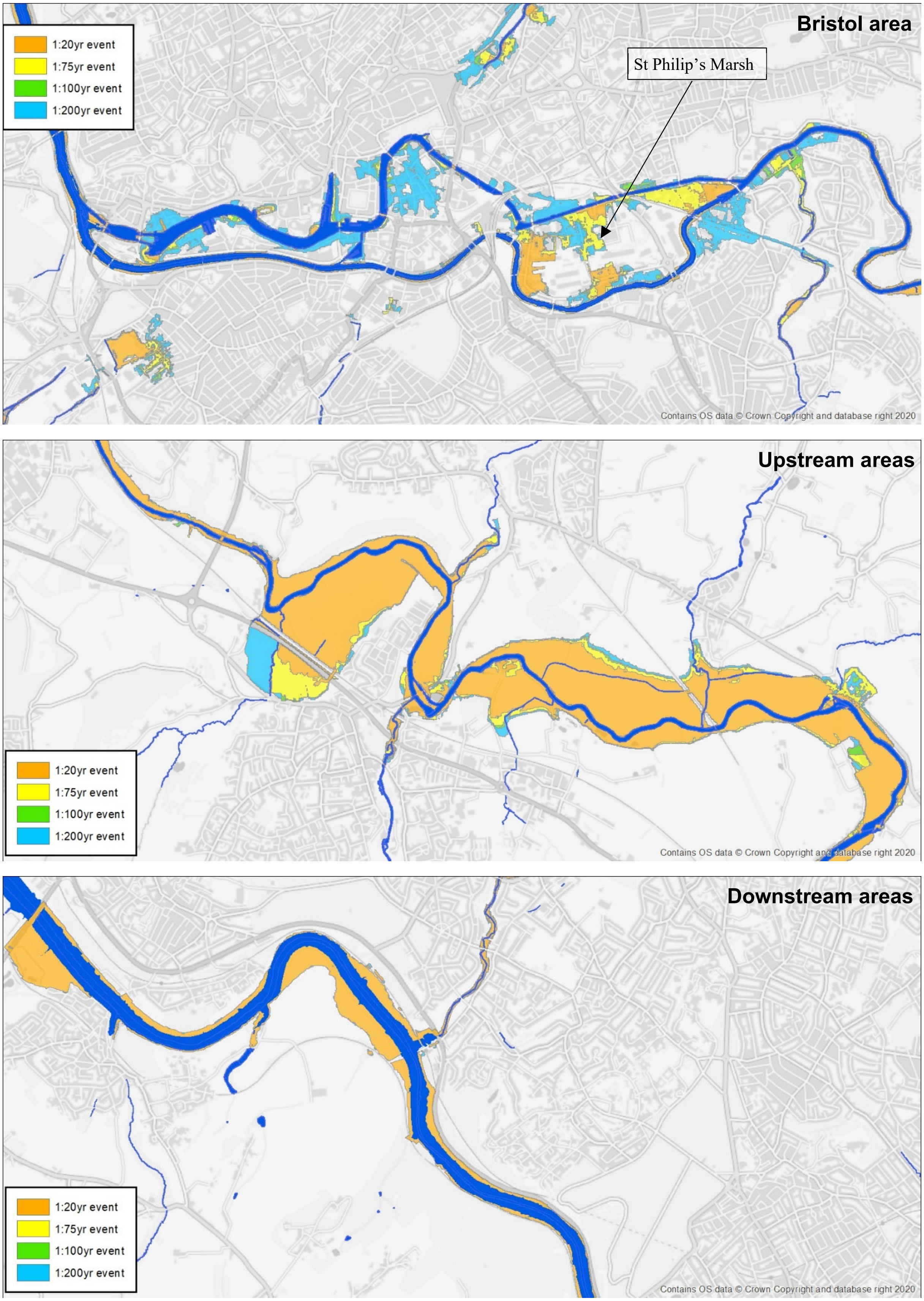


Figure 4: Flood extents for 2030 fluvial dominated events.

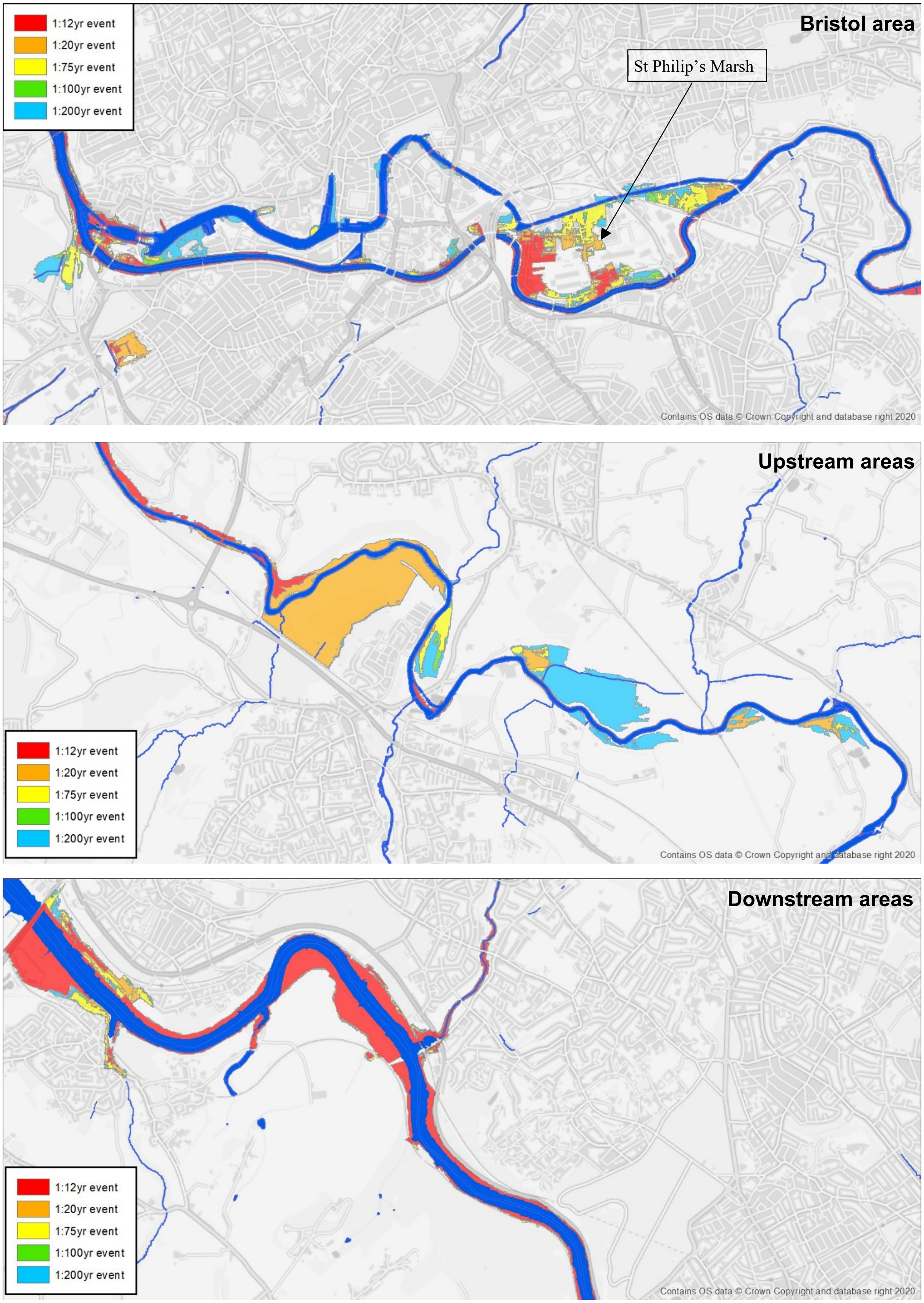


Figure 5: Flood extents for 2030 tidal dominated events.

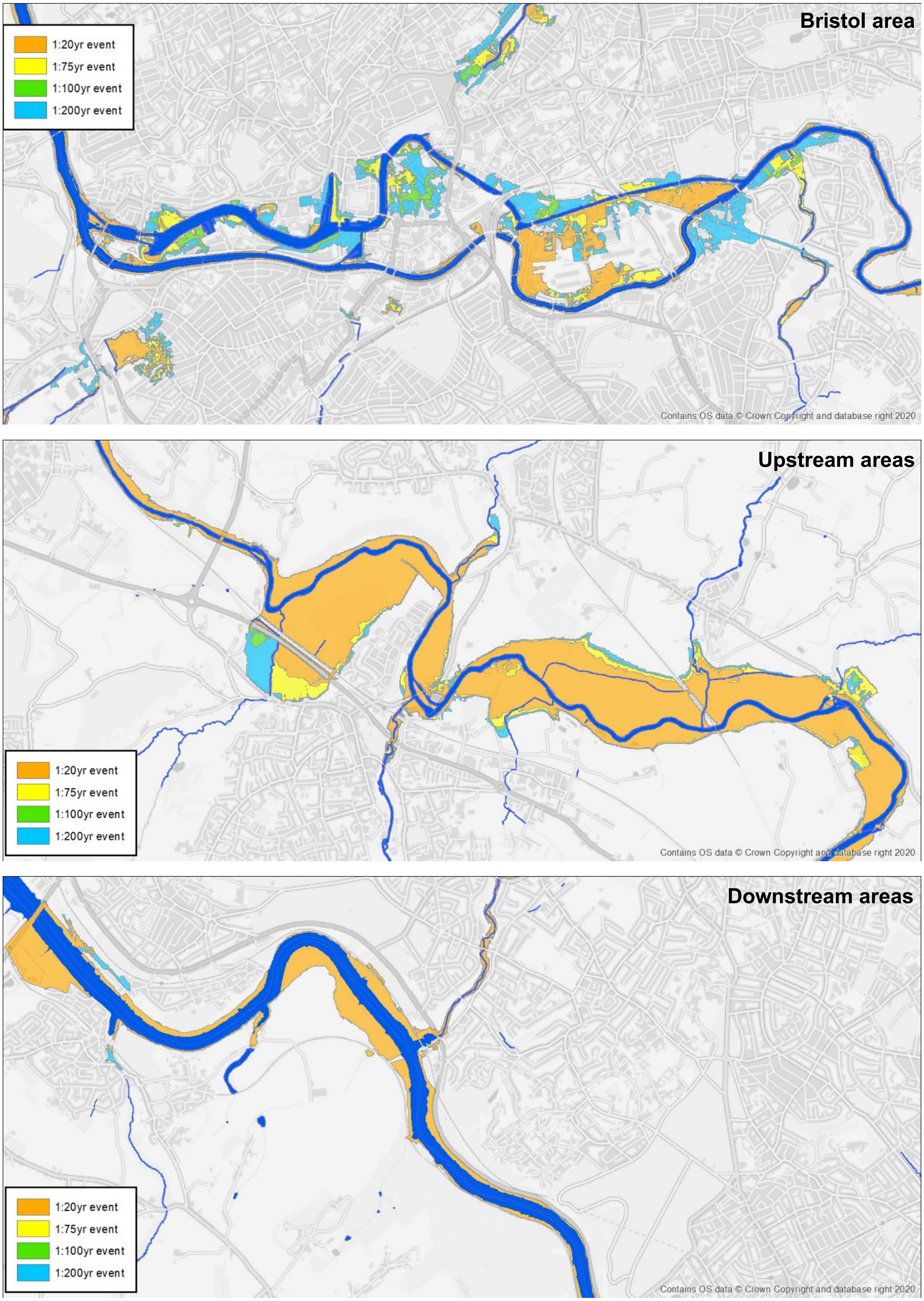


Figure 6: Flood extents for 2069 fluvial dominated events.

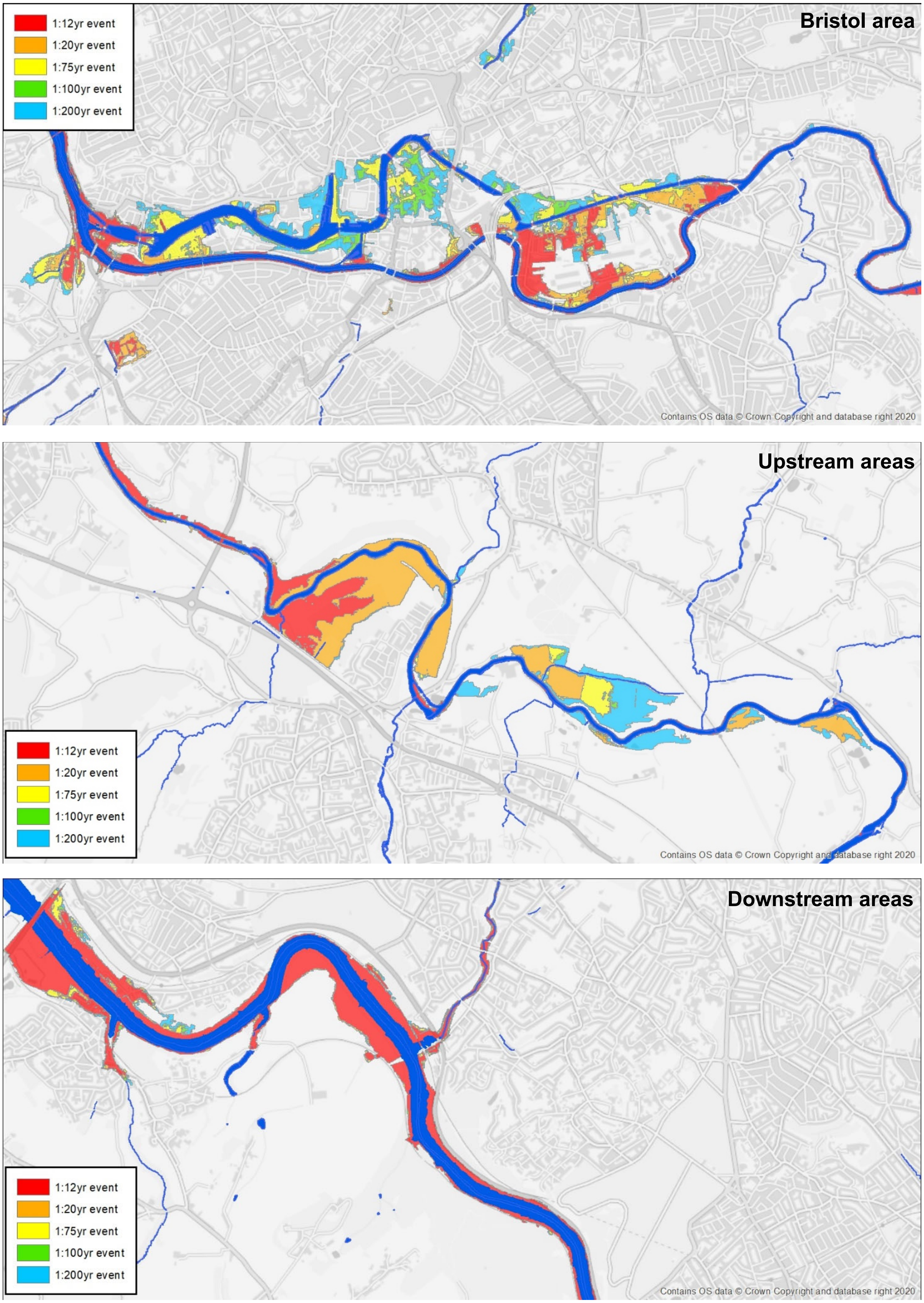


Figure 7: Flood extents for 2069 tidal dominated events.

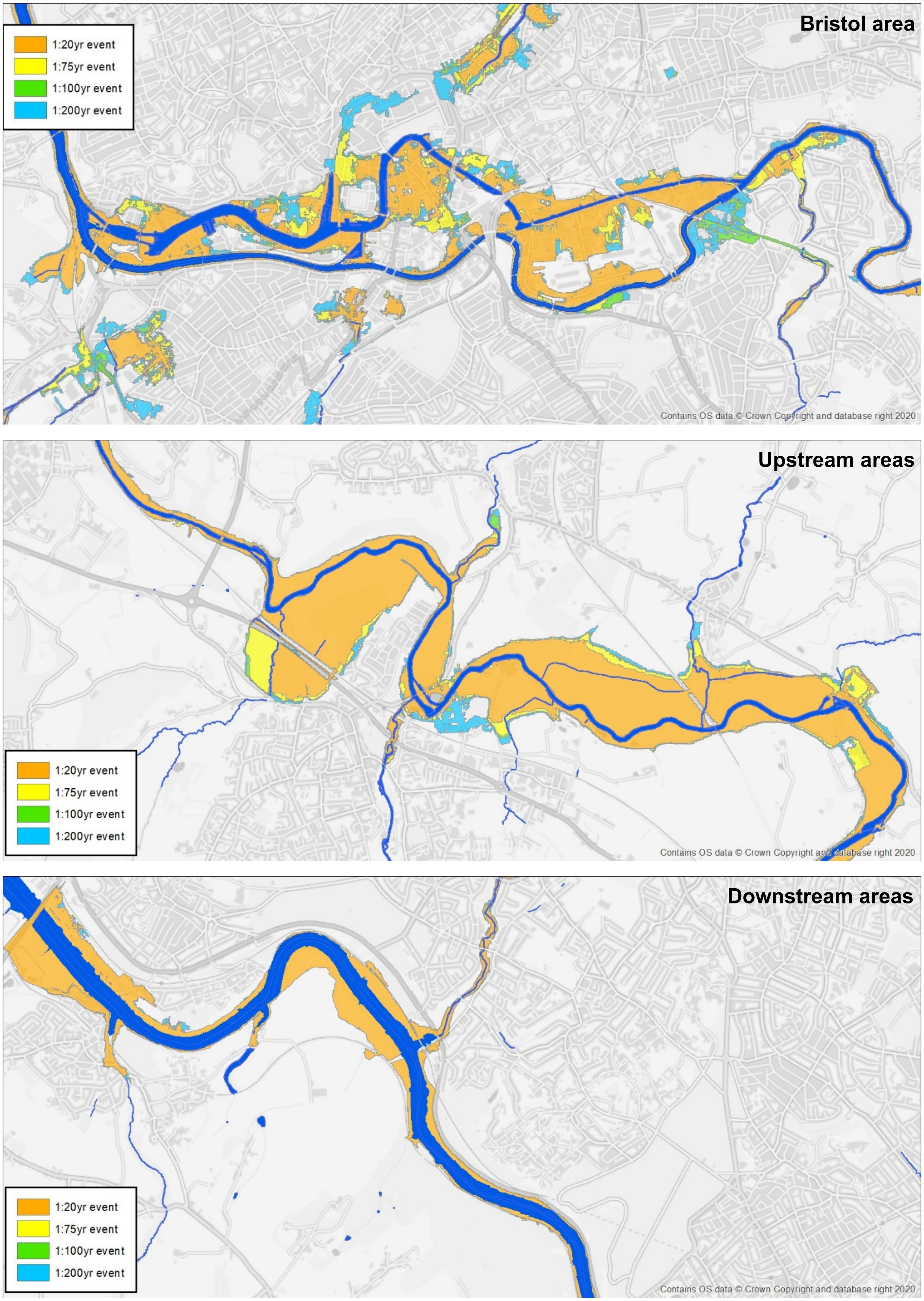


Figure 8: Flood extents for 2130 fluvial dominated events.

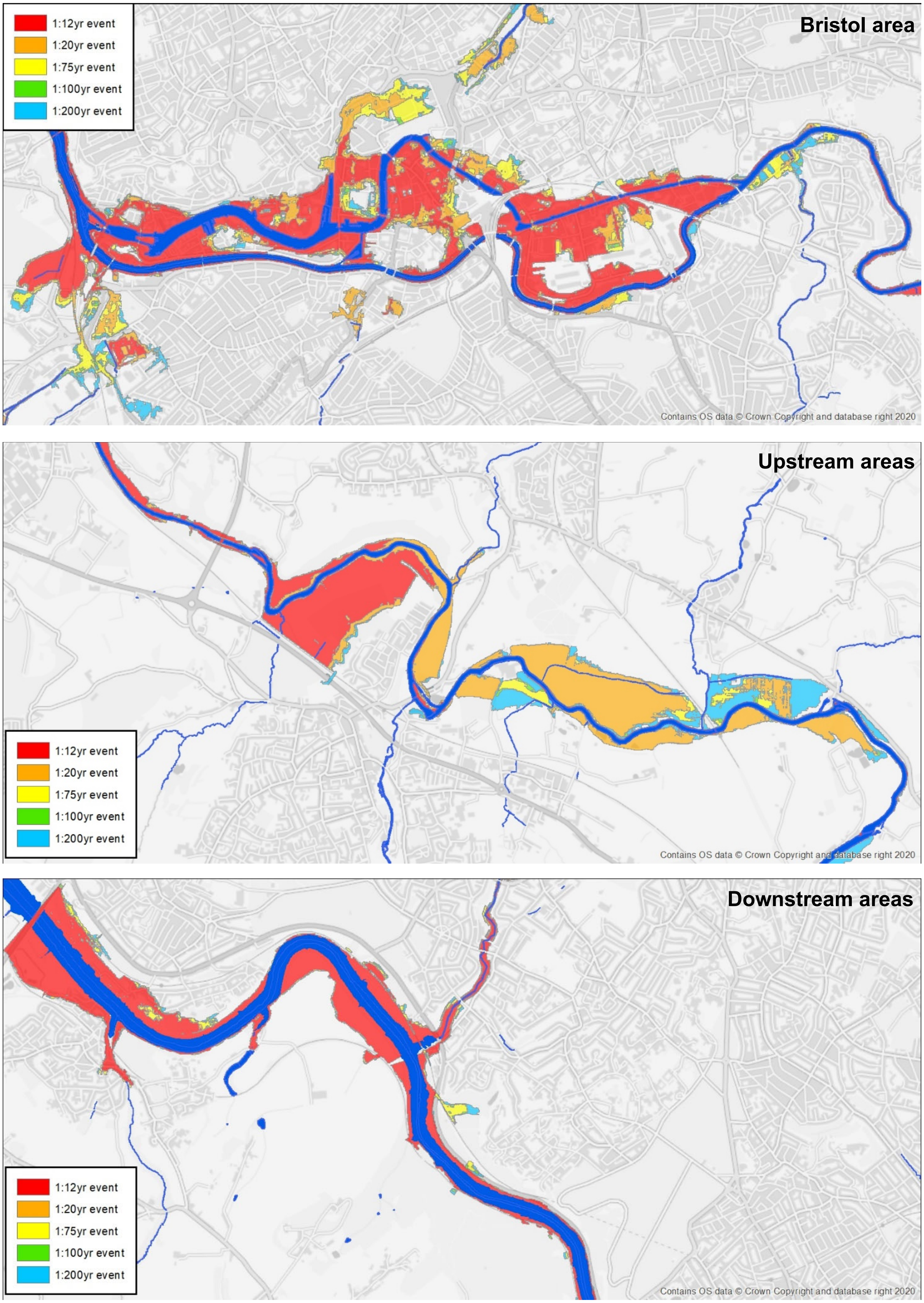


Figure 9: Flood extents for 2130 tidal dominated events.

Flood depth maps for the baseline ‘Do Minimum’ option are presented in Appendix A. These maps show peak flood depths results from the model across the main areas of interest for the following flood events:

- 2069 Fluvially dominated 1:100yr event (1:100yr fluvial and 1:1yr tidal)
- 2069 Tidally dominated 1:200yr event (1:2yr fluvial and 1:200yr tidal)
- 2130 Fluvially dominated 1:100yr event (1:100yr fluvial and 1:1yr tidal)
- 2130 Tidally dominated 1:200yr event (1:2yr fluvial and 1:200yr tidal)

In all of the above cases, the climate change allowance applied is the design allowance used for impact assessment and scheme design, which is the ‘Central’ allowance for fluvial and ‘Higher Central’ allowance for tidal.

6. Phase 1 and 2 scheme development

Iterative modelling was undertaken to support the development of both the Phase 1 and Phase 2 scheme design. Although the focus of the current OBC is Phase 1, it is necessary to develop the Phase 2 scheme design in order to:

- Enable the Phase 1 scheme to be designed in such a way as to enable the defences to be raised in the future (Phase 2). A key aspect of this is the required flood defence level for the Phase 2 flood defences – this dictates the form of construction and design requirements for the Phase 1 flood defences.
- Support the overall business case, including the FCERM economic appraisal, for the full scheme.
- Demonstrate that the full scheme, including both Phase 1 and Phase 2, is consentable and that there are no unacceptable flood risk impacts.

The three key aspects of the iterative modelling undertaken are:

1. To test and refine the alignment of the proposed flood defences. This aspect is described in Chapter 7.
2. To determine the flood defence crest levels, including freeboard allowances where these are required. This aspect is described in Chapter 8.
3. To assess flood risk impacts from the scheme and demonstrate that these are acceptable. This aspect is described in Chapter 9.

There is interaction between the above three aspects. Where there is interaction / iteration between these three aspects, Chapters 7 to 9 make reference to the relevant sections in other Chapters.

Figure 10 shows the approximate flood modelling process and how outputs from the modelling have been used in the scheme design. The red items are the modelling tasks, purple are engineering tasks, orange are inputs / decisions, and green are outputs.

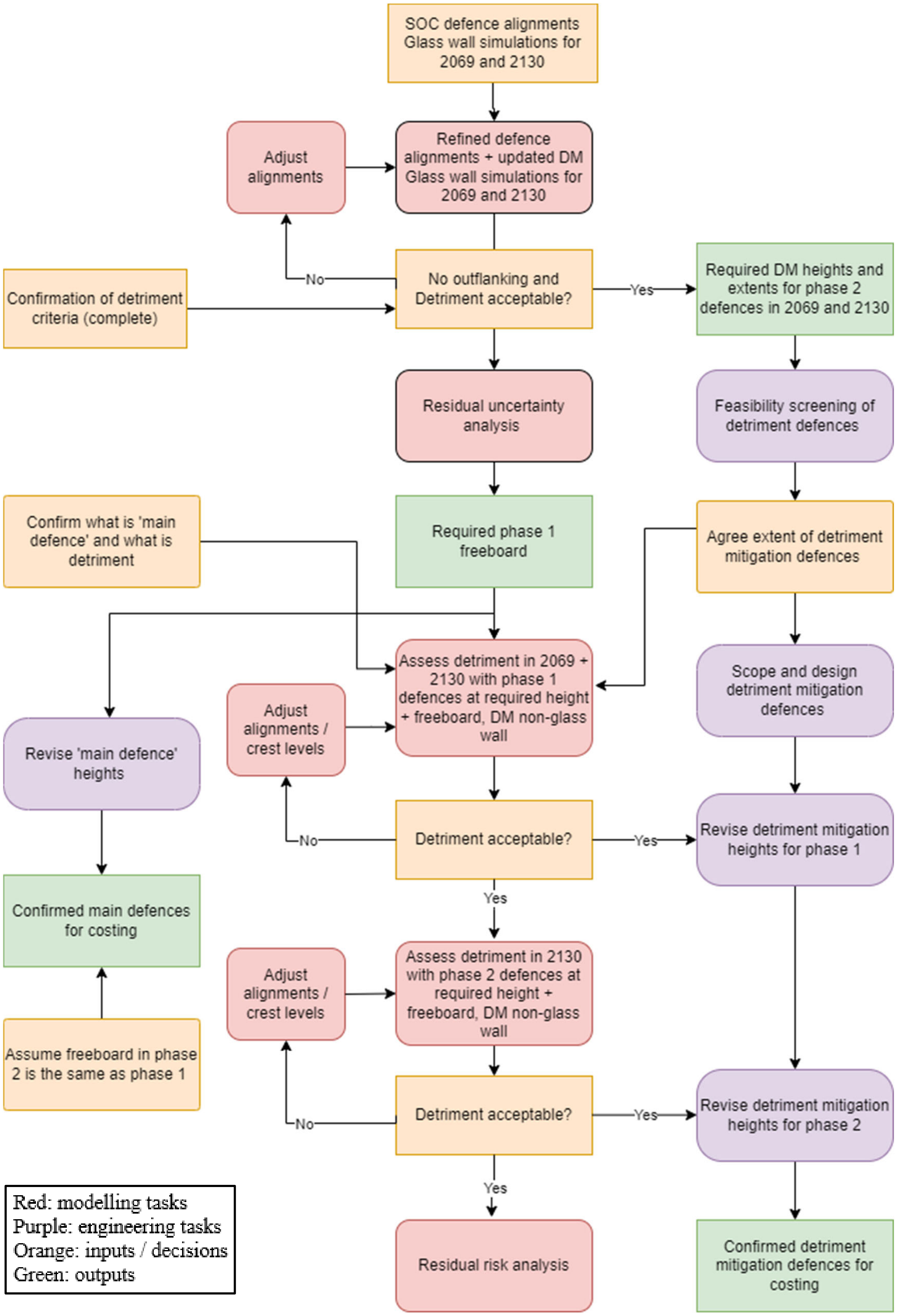


Figure 10: Approximate modelling process showing interaction with the engineering tasks. Note "DM" refers to 'Detriment Mitigation'.

7. Flood defence alignments

This chapter summarises how the flood defence alignment for the proposed scheme was derived.

7.1 Defence alignments from SOC

For the initial defence alignment tests described in the following section, the initial flood defence alignments were taken from the BAFS SOC study. The rationale for these alignments is explained in the SOC reporting. In summary, the defence alignments comprise:

- Main scheme flood defences required along the Avon through Netham and Bristol to prevent overtopping in the design flood events.
- Raised lock gates required at Entrance Lock and Netham Lock to manage flood risk to the Floating Harbour from the Avon.
- Main scheme flood defence required along the south bank of the Feeder Canal adjacent to the St Philips Marsh strategic growth and regeneration area to prevent overtopping in the design flood events. In this case the flooding mechanism is fluvial flows entering the Floating Harbour and Feeder Canal from the River Frome causing elevated water levels which overtop at Feeder Road.
- Additional flood defences are required elsewhere to mitigate detrimental impact on flood risk from the main scheme flood defences. These are termed ‘detriment mitigation defences’ and are located in areas between Swineford and Pill / Shirehampton.

The overall Phase 1 Avon flood defence alignments in the SOC are very similar to the Phase 2 flood defence alignments. There are a few areas where the SOC identified that flood defences were not required in Phase 1 but would be required in Phase 2, these were:

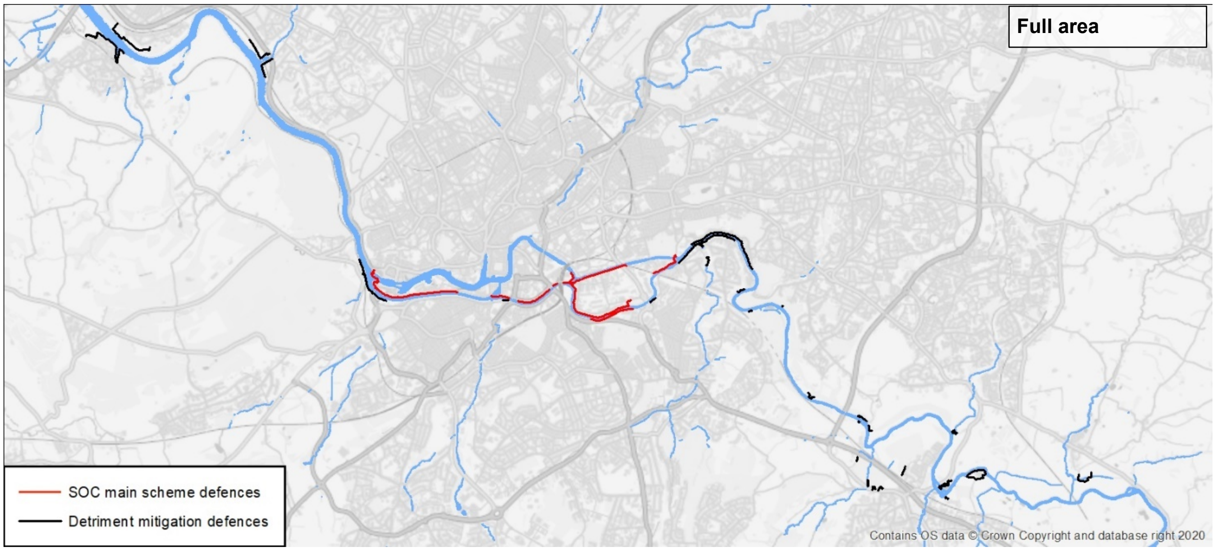
1. The Paintworks site where there are existing defences present.
2. The following detriment mitigation measures:
    a. The upstream part of Crew’s Hall Road (right bank of Avon).
    b. A 100m length flood defence on the left bank of the Avon adjacent to Whitby Road.
    c. A 100m length flood defence on the left bank of the Avon adjacent to New Charlotte Street.
    d. The downstream part of the flood bank at Pill (left bank of Avon).
    e. Detriment mitigation measures identified for the Malago (raising of bank levels upstream of Parson Street and adding a flood storage area at 'Marksbury Open Space').

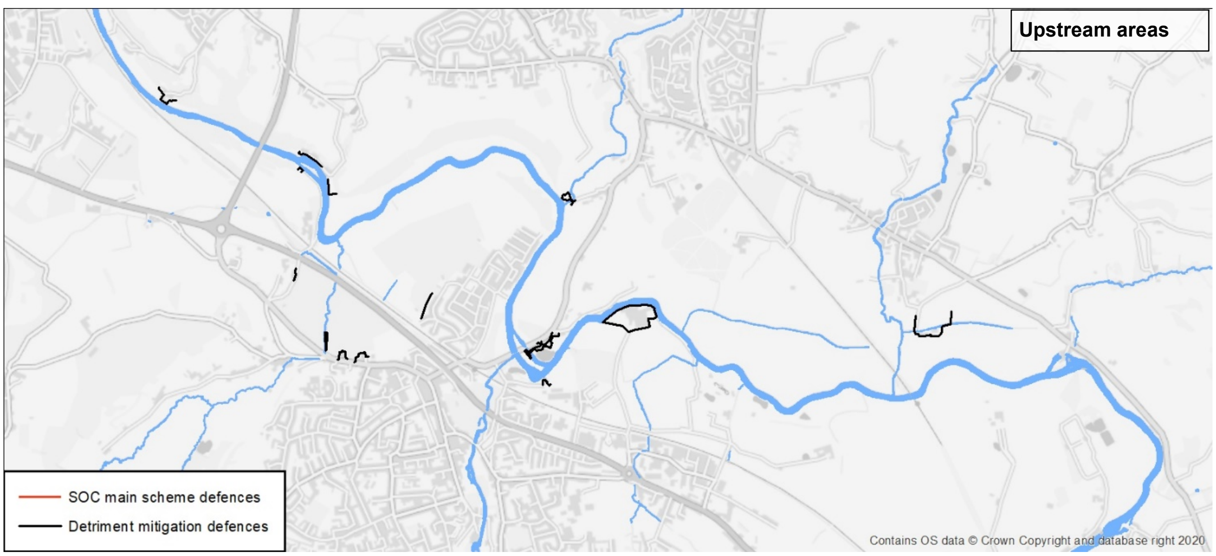
7.2 Initial flood defence alignment tests

The initial flood defence alignment tests were undertaken using the updated baseline hydraulic model but prior to some final updates being made to this model. These final updates to the baseline model, which were made after the initial defence alignment tests, are summarised below and are explained in more detail in the baseline modelling report[1].

- Adjusted phasing of the Malago flow peak relative to the Avon flow peak.
- 2D model extended at Shirehampton to prevent glass-walling near the rail line.
- Refined representation of Brislington Brook Chapel Way culvert.

A test was initially undertaken to assess the SOC main scheme defence alignment without detriment mitigation. The SOC main scheme flood defences, i.e. excluding detriment mitigation defences, were incorporated into the updated hydraulic model with flood defence levels set very high to prevent overtopping – this is termed “glass-wall” defences in modelling terminology. The alignment of these flood defences is shown as the red lines in Figure 11 and this corresponds to the Phase 2 defence alignment, which is only marginally greater in extent than the Phase 1 defence alignment identified in the SOC (see Section 7.1). The detriment mitigation measures identified in the SOC (the black lines in Figure 11) were excluded from this model. For the purposes of this initial test, the Avon left bank defences at St Anne's and Ashton were assumed to be detriment mitigation defences as opposed to main scheme defences. This model was run for the Phase 1 and Phase 2 design events, namely the 1:100yr fluvially dominated and 1:200yr tidally dominated events for the 2065 and 2130 epoch years. Note this initial stage of modelling used 2065 instead for Phase 1 design events; this was subsequently revised to 2069. Results showed significant outflanking in the areas where the detriment mitigation defences were excluded from the model. The flood depths from the test were compared against the baseline (pre-scheme) flood depths for the same flood event to assess the impact (betterment and detriment) of the scheme. This showed significant detriment in the areas where the detriment mitigation defences were excluded from the model. Further information on detriment assessment is included in Chapter 9.





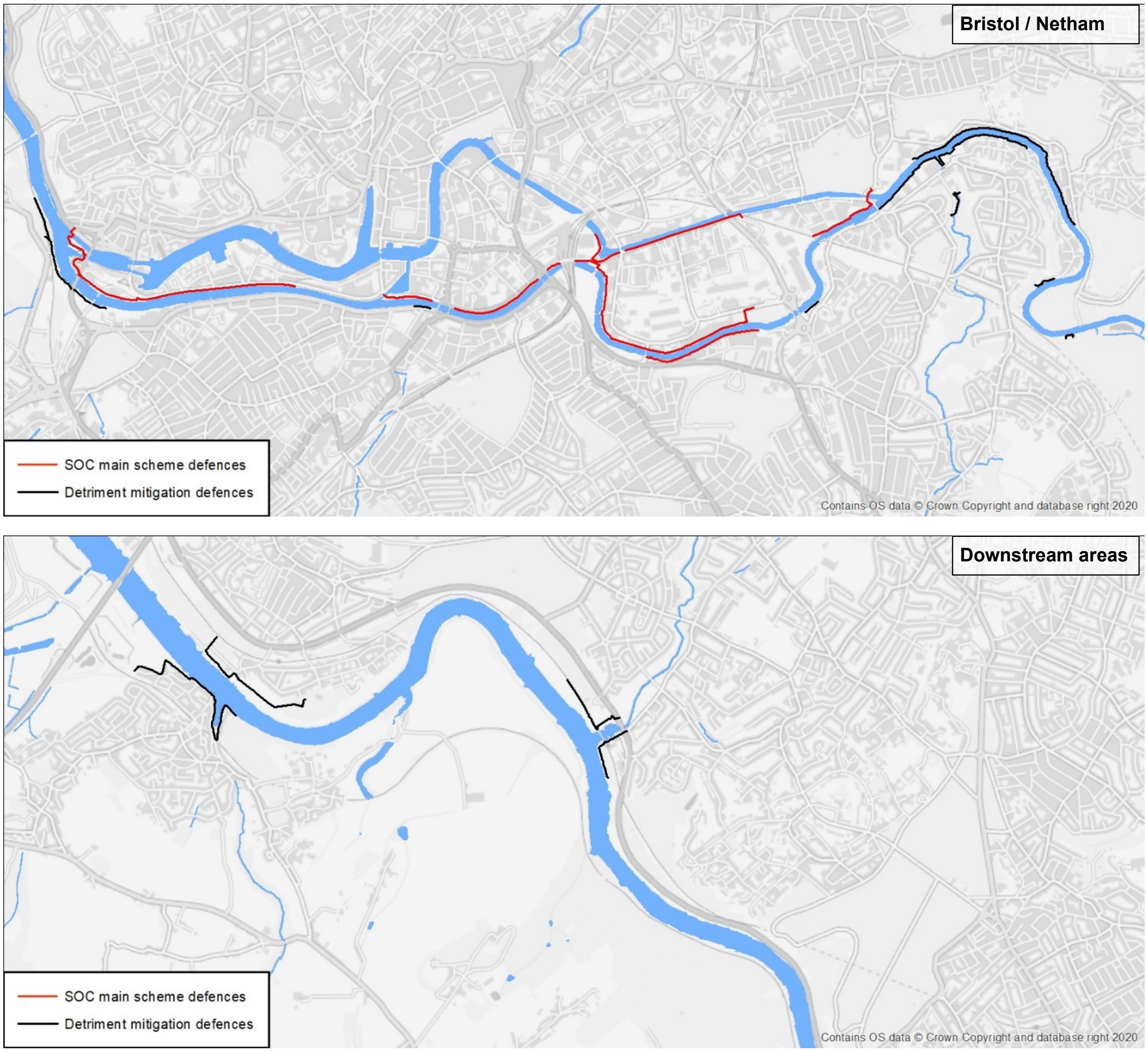


Figure 11: Flood defence alignment from SOC: Full area, upstream areas, Bristol / Netham area, downstream areas.

A second test was undertaken with the detriment mitigation defences identified in the SOC added to the above model. All detriment mitigation defences were set to "glass-wall" to prevent overtopping except for the Chapel Way flood defence on Brislington Brook which was set to have crest level of 13.4m AOD as per the SOC design. This test model excluded the detriment mitigation measures identified for the Malago in the SOC, which comprised raising of bank levels upstream of Parson Street and adding a flood storage area at 'Marksbury Open Space'. The results from this test showed no outflanking of flood defences within the extent of the main scheme. However, the results showed some areas of detriment remained where properties are located, such as at Hotwells Road, Freeland Place, Whitby Road and in some upstream areas such as Swineford.

The alignments of the SOC main scheme defences and detriment mitigation defences were taken forward to the next stage of modelling as described in the next section.

7.3 Update to scheme definition

In the SOC, the proposed scheme included both 'main scheme defences' and 'detriment mitigation defences' along the Avon between Crew's Hall Road and Pill / Shirehampton. The defence crest levels for these two categories of Avon defences were based on different design basis. The main scheme defences needed to include freeboard whereas the detriment mitigation defences did not. Also, at the time of the SOC, different climate allowances were applicable to each category of defence (FCERM vs NPPF). During the OBC options modelling stage, it was agreed with BCC and the EA that the design basis of all flood defences between Crew's Hall Road and Pill / Shirehampton should be made consistent and should be as follows:

- All Phase 1 flood defences to provide the required SoP based on 2069 epoch year and include freeboard allowance.
- All Phase 2 flood defences to provide the required SoP based on 2130 epoch year and include freeboard allowance.
- Phase 1 and Phase 2 flood defences to be sufficiently high to prevent detriment to properties based on the criteria given in Chapter 9.

The rationale for this updated design basis is:

- The updated climate change guidance available at the time of the current OBC study means that the climate allowances for FCERM and NPPF are now consistent.
- Freeboard has been included for all the above flood defences to enable the flood risk benefits behind the proposed flood defences to be fully accounted for in the economic appraisal.
- In many cases, the crest levels of the Phase 1 flood defences that were previously termed 'detriment mitigation defences' are required to be similar or higher than the Phase 1 design level including freeboard allowance.
- Provides a more equitable approach across the extent of the scheme.

7.4 Refinement of flood defence alignment

Following the initial flood defence alignment tests described above and following the final updates to the hydraulic model, refinements were made to the flood defence alignments as summarised below and explained in the following sub-sections. More detail on the flood defence alignments, design and constraints can be found in the Options development report[4] and supporting appendices.

- Additional flood defences in the Bristol area were incorporated to mitigate impacts from the scheme where properties are present.
- Design refinements were implemented to flood defence type and/or alignments based on an assessment of constraints. This was undertaken for the flood defences at Shirehampton, Sea Mills, Ashton, Cabot Way, and in areas upstream of Bristol.
- Reduction in the upstream extent of the Crew's Hall Road flood defence: Property threshold survey in this area showed that the threshold level of properties behind the upstream part of this flood defence were above maximum flood level for the design events. Therefore, the flood defence was able to tie into high ground 250m downstream of the original point.

7.4.1 Additional flood defences

Further flood defences were added to the model to prevent detriment where properties are located. Flood defences were added at the locations listed below, which are shown in Figure 12 and Figure 13.

- Hotwells Road: This needs to be included in Phase 1 to prevent detriment to 3 properties.
- Freeland Place: This needs to be included in Phase 1 to prevent detriment to 3 properties.
- Payne's Shipyard: Detriment occurs to 2 properties in the 2130 epochs but no detriment occurs in 2069. However, this flood defence needs to be included in Phase 1 in order to satisfy the detriment acceptability criteria given in Section 9.1, notably the requirement for there to be no unacceptable detriment from Phase 1 in 2130, i.e. to consent Phase 1, there must be no detriment for the design life of the scheme, without relying on the future delivery of Phase 2. Note there is currently a planning

[4] Bristol Avon Flood Strategy, Options development report, December 2023.

application for redevelopment of this site (status as of January 2024 is "pending consideration") which may negate the need for a flood defence to be included in the BAFS scheme at this location.

- Whitby Road: This comprises (a) a flood defence along the Avon left bank and (b) a lower flood defence along the Whitby Road pavement to prevent detriment to the Boc Gas & Gear site from increased overland flow along Whitby Road from the north. This needs to be included in Phase 2.

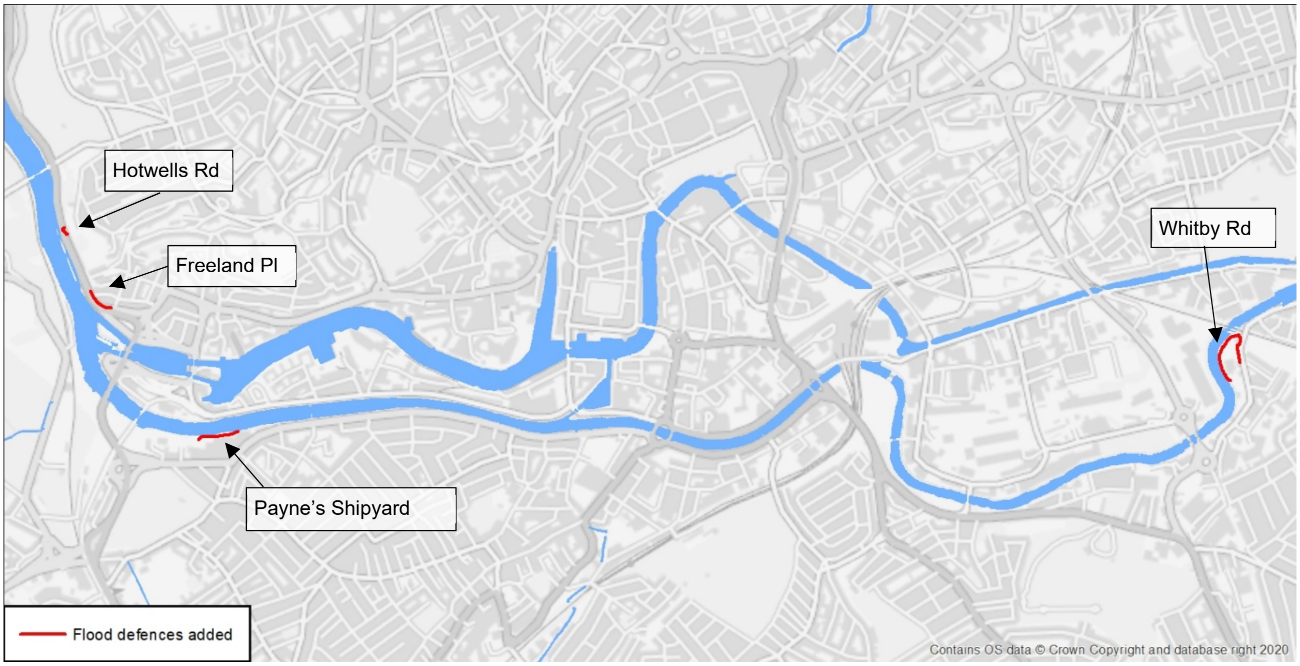


Figure 12: Flood defences added in Bristol during refinement.

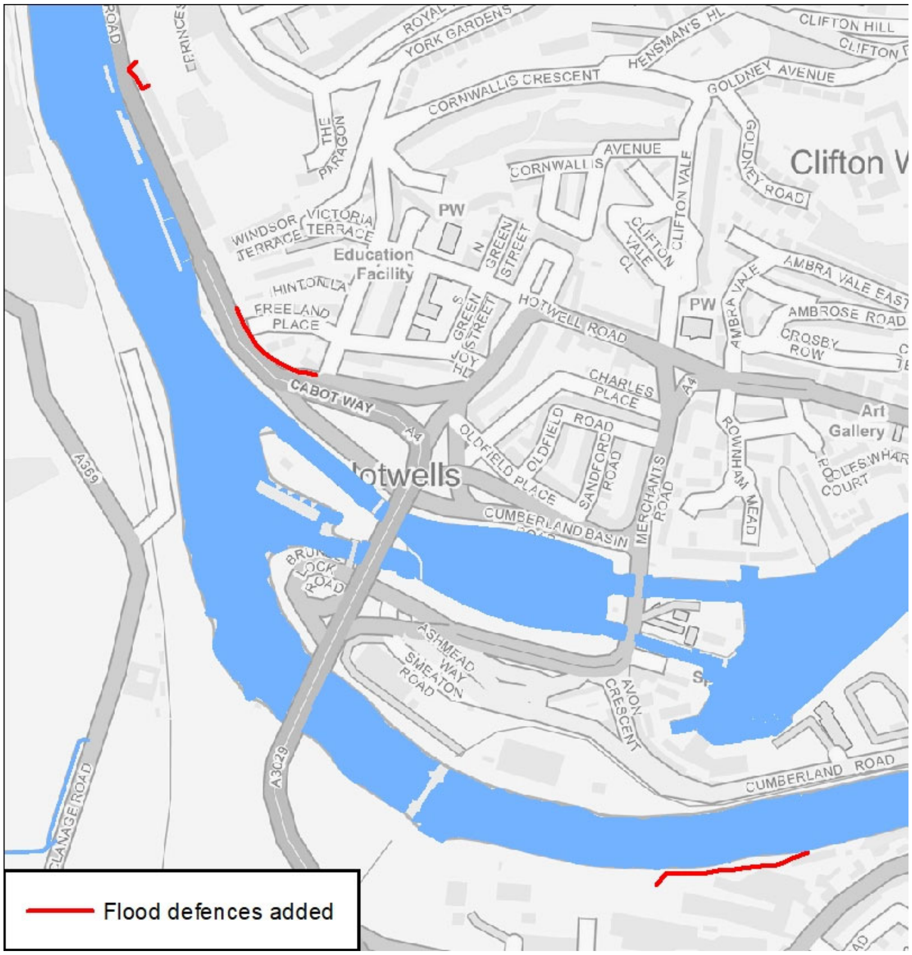


Figure 13: Flood defences added in Bristol during refinement (zoomed-in).

7.4.2 Design refinements – Shirehampton

The alignment of flood defences at Shirehampton were refined based on consideration of constraints and buildability. The refined alignment is shown against the original alignment in Figure 14.

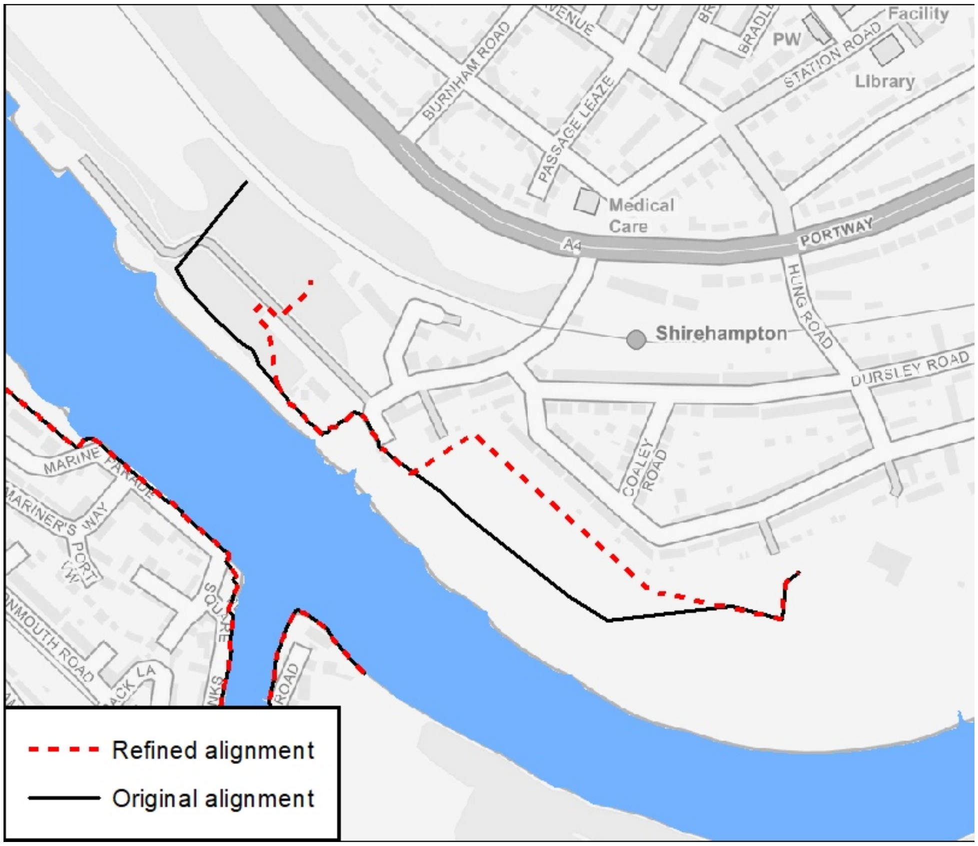


Figure 14: Refined vs original alignment - Shirehampton.

7.4.3 Design refinements – Sea Mills

The alignment of flood defences at Sea Mills were refined based on consideration of constraints and buildability. The refined alignment is shown against the original alignment in Figure 15. The main driver for the refinement here is the constraint imposed by a Scheduled Ancient Monument (SAM) comprising a burial ground to the south of Sea Mills train station. The refined alignment ties the main flood defence into the rail bridge parapet and the high ground south of the rail bridge and would incorporate flood gates to maintain access to the properties to the west of the train station. The refined alignment includes new / raised flood defences around the two properties to the west of the train station – these would increase the standard of protection to these properties but would not provide the design standard of the BAFS scheme due to buildability constraints.

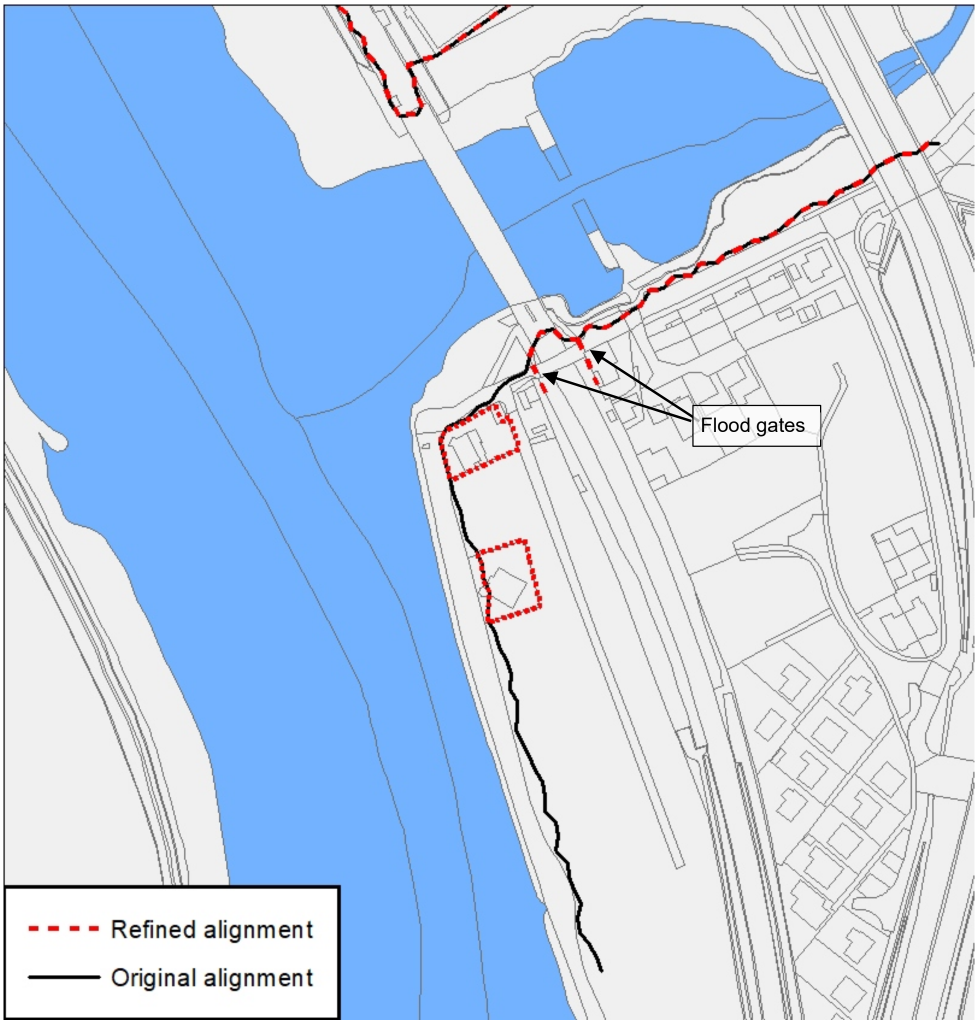


Figure 15: Refined vs original alignment - Sea Mills.

7.4.4 Design refinements – Ashton

The alignment of flood defences at Ashton were refined based on consideration of constraints and buildability. The refined alignment is shown against the original alignment in Figure 17. The main driver for the refinements here are buildability, making use of high ground, and maintaining amenity value such as reducing obstruction of views of the river and surrounds. This alignment would require a flood gate or road raising on Ashton Avenue.

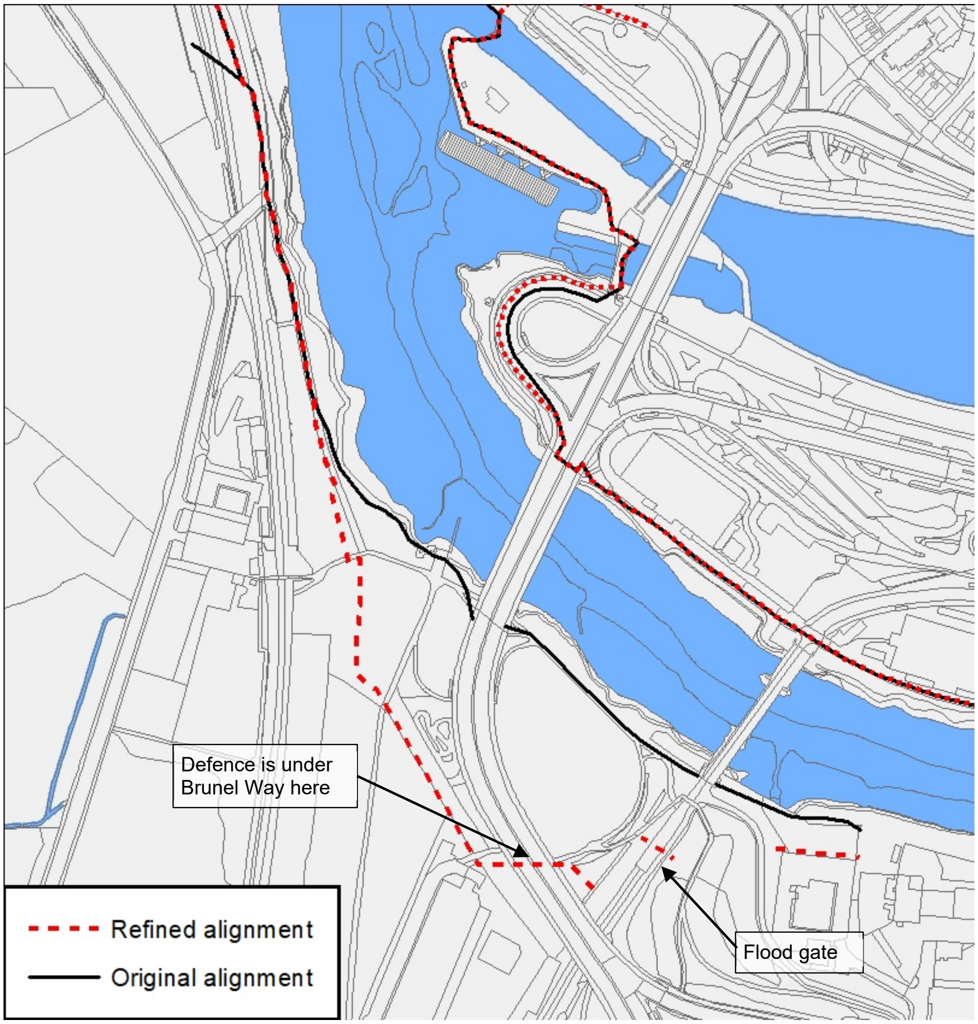


Figure 16: Refined vs original alignment – Ashton.

7.4.5 Design refinements – Cabot Way

The alignment of flood defences at Cabot Way were refined based on consideration of constraints and buildability. The refined alignment is shown against the original alignment in Figure 17. The main driver of this refinement at Cabot Way to the north of Entrance Lock is to enable the flood defence to tie into high ground while reducing impact / access issues to the road. The refined alignment would require road raising or a flood gate to maintain access along the single lane carriageway immediately adjacent to Entrance Lock.

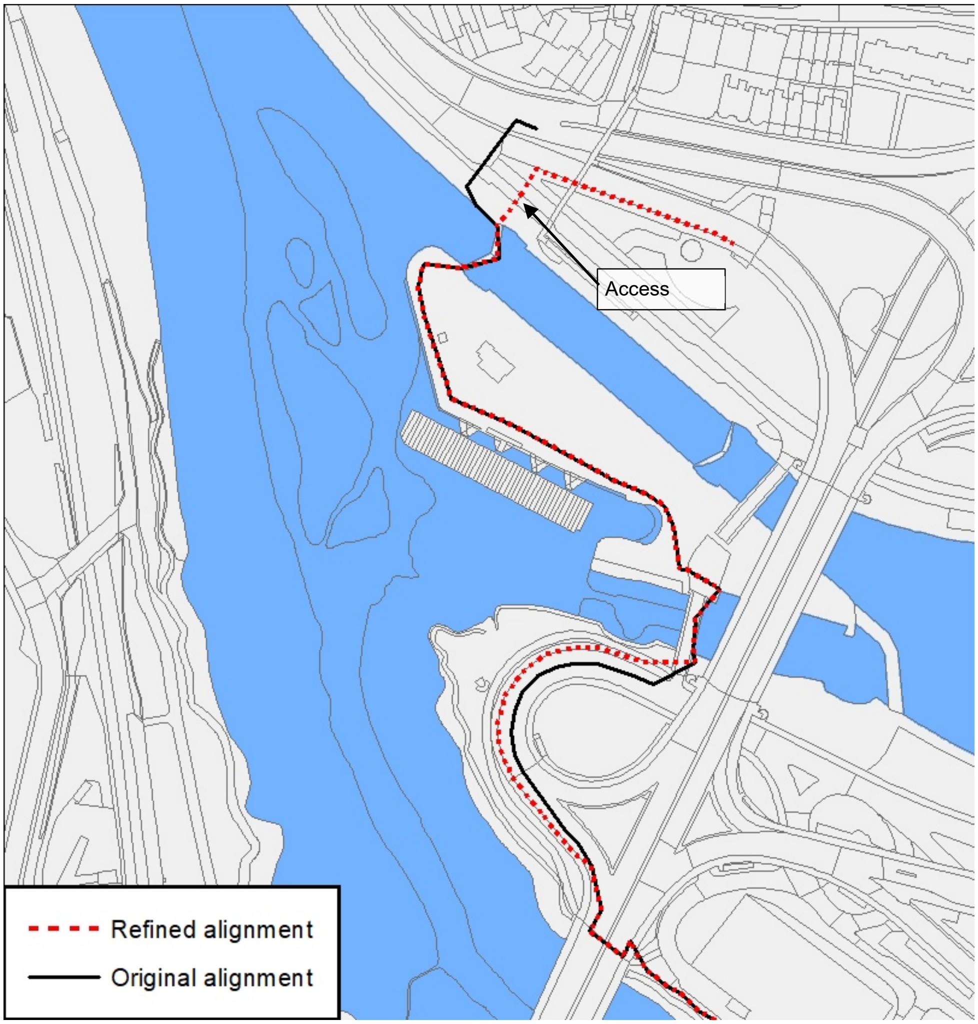


Figure 17: Refined vs original alignment – Cabot Way.

7.4.6 Design refinements – Areas upstream of Bristol

The alignment of flood defences upstream of Bristol were refined based on buildability / amenity constraints. The refined alignment is shown against the original alignment in Figure 18. Some sections of defence were lowered from the full height where it was considered impractical to construct at the full height, e.g. at riverside cottages – these are termed practical betterment defences as they will reduce flood frequency compared to baseline, though won't provide the full defence standard of the wider scheme. In some other locations, property flood resilience measures were identified as being more practical to implement than flood defences; these are also shown in Figure 18.

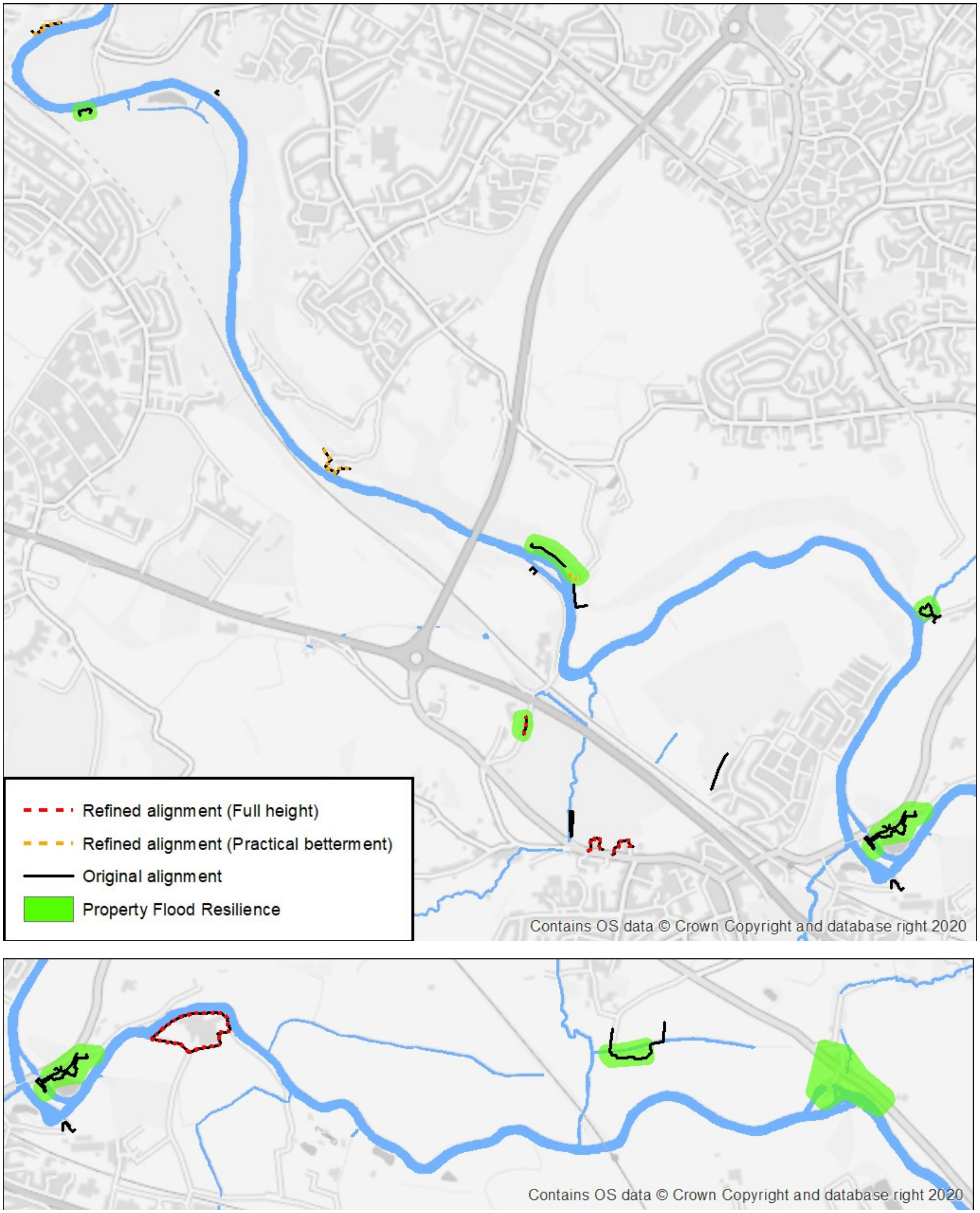


Figure 18: Refined vs original alignment – Upstream areas.

7.5 Phase 1 vs Phase 2 flood defence alignment

The overall Phase 1 Avon flood defence alignments in the SOC are very similar to the Phase 2 flood defence alignments / extents – the differences are listed in Section 7.1. Following refinements and updated impact assessment undertaken during the OBC, the only difference between the Phase 1 and Phase 2 flood defence alignments / extents is at the Paintworks site where approximately 50% of the length of the proposed new flood defence would not need to be constructed until Phase 2. The differences identified in the SOC that are listed in Section 7.1 no longer apply for the following reasons:

1. The remaining part of the Paintworks site flood defence: This needs to be constructed in Phase 1 to prevent detriment in 2130. This is because to consent Phase 1, there must be no detriment for the design life of the scheme, without relying on the future delivery of Phase 2 (see Section 8.4).
2. Detriment mitigation measures:
    a. The upstream part of Crew's Hall Road (right bank of Avon): Threshold survey showed this was no longer required (see Section 7.4).
    b. A 100m length flood defence on the left bank of the Avon adjacent to Whitby Road: This needs to be constructed in Phase 1 to prevent detriment in 2130. This is because to consent Phase 1, there must be no detriment for the design life of the scheme, without relying on the future delivery of Phase 2 (see Section 8.4).
    c. A 100m length flood defence on the left bank of the Avon adjacent to New Charlotte Street: Same reason as above.
    d. The downstream part of the flood bank at Pill (left bank of Avon). Same reason as above.
    e. Detriment mitigation measures identified for the Malago: The updated detriment assessment identified that these measures are no longer required as there is no unacceptable detriment on the Malago system here.

8. Flood defence crest levels and freeboard allowances

8.1 Freeboard

Freeboard is an allowance that is incorporated into the height of flood defences to account for uncertainties in the modelling and for physical process, such as waves, that are not accounted for in the modelling. This freeboard allowance is effectively added on to the peak water level from the 'with scheme' modelling to give a flood defence level for use in the design. This is illustrated in Figure 19.

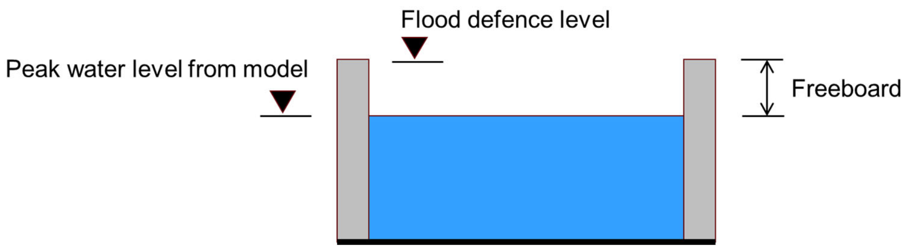


Figure 19:Illustration of freeboard allowance.

8.2 Flood defence levels excluding freeboard

Flood defence crest levels excluding freeboard allowance were determined using a 'glass-wall' version of the Phase 2 scheme model. In this model, the proposed flood defences, including the detriment mitigation flood defences, were set very high to prevent overtopping. This model was run for the Phase 1 and Phase 2 design events, namely the 1:100yr fluvially dominated and 1:200yr tidally dominated events for the 2069 and 2130 epoch years. The peak water level results were then extracted and used to determine the flood defence levels excluding freeboard. This was done simply by taking the maximum water level from the fluvially dominated event and the 1:200yr tidally dominated event at the nodes adjacent to the flood defence. The Phase 1 flood defence levels were determined using the 2069 event results while the Phase 2 flood defence levels were determined using the 2130 event results.

8.3 Residual uncertainty assessment

The flood defence levels excluding freeboard, which are based on the raw water level results from the modelling, do not account for any residual uncertainties such as uncertainties within the modelling and physical processes that are not captured in the modelling. Residual uncertainties must be considered in the design where the flood defence is to provide a defined standard of protection and where flood risk benefits associated with the flood defence are to be claimed up to the design standard. This is applicable to all 'main scheme' flood defences, i.e. all River Avon flood defences from Crew's Hall Road to Pill / Shirehampton including the proposed new / raised lock gates at Netham Lock and Entrance Lock. Some additional works have been identified for areas upstream of Crew's Hall Road and on Brislington Brook to reduce / offset impacts on flood risk from the main scheme flood defences – there is no requirement for freeboard (except for settlement allowance) for these additional works.

For the main scheme flood defences, the response / measures to be considered for managing residual uncertainties for the proposed scheme is:

1. Adjusting the estimated defence levels by adding a "freeboard" allowance to account for residual uncertainties.
2. Routine maintenance of the channel and water retaining assets.

Freeboard allowances have therefore been derived for the proposed main scheme Phase 1 flood defences. These freeboard allowances are to be added to the flood defence levels estimated from the hydraulic modelling to define design crest levels for the proposed main scheme flood defences. The freeboard allowances are based on an identification and estimation of residual uncertainties including physical processes but excluding settlement allowance. Settlement allowance is not included; this should be calculated separately by a qualified geotechnical engineer.

Residual uncertainty allowance has been estimated using the methodology outlined in the current EA guidance on uncertainty estimation[5]. In accordance with this guidance, residual uncertainty allowance has only been estimated for present day conditions. The guidance states *"Future uncertainties are better addressed through precautionary allowances, for example, for climate change. The appraisal process is the point at which to agree the amount of adaptive capacity that should be embedded into the present-day actions to account for future risks and uncertainties."*

To provide an appropriate level of granularity and accuracy, the proposed flood defences were subdivided into shorter sections to account for the variation in one or more of the following:

1. Required defence level excluding freeboard: Where the required defence level excluding freeboard varies by more than 0.1m, the flood defence has been divided into sections.
2. Proposed defence type: The defence type influences the wave allowance.
3. Orientation: The orientation influences the wave allowance, e.g. when it results in a large difference in fetch.

The resultant flood defence sections used for residual uncertainty assessment are summarised and shown in Chapter 2 of the Residual uncertainty assessment[6], which is included as Appendix B to this report.

Freeboard allowances were calculated for each defence section. The freeboard includes two main components that are summed:

1. Uncertainty in modelled river water levels: This considers uncertainty and influence of secondary variables including model type and construction, software version, hydrology, tidal conditions, river channel and floodplain geometry and roughness, representation of key structures, impact of blockages.

2. Allowance for physical processes: This includes wind-generated waves, and super-elevation.

The derivation of each component of the above is described in the Residual uncertainty assessment[6] in Appendix B. The Residual uncertainty assessment also provides a summary of freeboard values and design levels for all flood defence sections based on the assessment undertaken in August 2023. Since this assessment, some further refinements have been made to flood defence levels – these are described in the following two sections.

8.4 Flood defence levels required to prevent detriment

For consents and planning approvals to be granted for the proposed scheme, it must be demonstrated that the flood risk impacts from the scheme are acceptable in the context of the overall benefit of the scheme. The assessment of flood risk impacts, focussing on detrimental impacts, and the associated acceptability criteria, are described in Chapter 9. One key acceptability criterion is repeated here as it has a significant influence on the proposed scheme flood defence levels: There should be no unacceptable detriment to properties from the Phase 1 flood defences for flood event magnitudes up to the design standard of the scheme (1:100yr fluvial and 1:200yr tidal) for both 2069 and 2130 epoch years. The key item to note here is that Phase 1 impacts must be acceptable in 2130, i.e. to consent Phase 1, there must be no detriment for the design life of the scheme, without relying on the future delivery of Phase 2.

A model test was set up with the main scheme flood defences set to the Phase 1 flood defence level including freeboard (the detriment mitigation flood defences were also included). This was run for a suite of return periods (both fluvial and tidal) for both 2069 and 2130 epoch years. The model results showed unacceptable detriment due to overtopping of the Phase 1 flood defences in several locations for the 2130 epoch for one or more flood events due to overtopping of the Phase 1 flood defences. Although the flood defence level for Phase 1 is higher than the effective flood defence level for the baseline 'Do Minimum' option, detriment still occurs in these locations. This is because the proposed scheme increases river water levels and the area behind the flood defence fills up with floodwater due to the overtopping, in most cases the flood level is the same or very similar to the peak river level. The proposed approach for preventing this detriment is to raise

[5] Accounting for residual uncertainty: updating the freeboard guide" (EA FCERM R&D programme, report SC120014, Environment Agency, February 2017).

[6] Bristol Avon Flood Strategy OBC, Technical Note: Residual uncertainty assessment, Arup, August 2023.

sections of flood defences associated with this overtopping – these sections are listed below with a description of the approach taken. The flood defence sections below that are located in Bristol, i.e. excluding Sea Mills, Pill and Shirehampton, are shown in Figure 20.

- Left bank at Whitby Road: This occurred over a small area behind the flood defence in the 2130 tidal 1:200yr and fluvial 1:100yr events. The crest level was raised to the Phase 2 flood defence level excluding freeboard.
- Left bank at Paintworks: This occurred over a small area behind the middle part of this flood defence in the 2130 tidal 1:75yr event. This occurs because the Phase 1 defence level plus freeboard is 0.05m below the peak Avon water level in the 75yr fluvial event, therefore there is a very small amount of overtopping (and this does not occur in the baseline model for this event). The crest level for the middle part of this defence was raised to the Phase 1 model peak water level for the 2130 1:75yr event, which is 0.06m higher than the Phase 1 flood defence including freeboard.
- Right bank at Clarence Road: This occurred over a small area behind the flood defence in the 2130 tidal 1:75yr and 1:100yr events. This is due to local topography trapping the water that overtops the Avon defence – the flood level is effectively the same as the peak river water level, which is higher than the baseline ‘Do Minimum’ water level. The crest level was raised to the Phase 1 model peak water level for the 2130 1:100yr event, which is 0.12m higher than the Phase 1 flood defence including freeboard.
- Right bank at parts of Cumberland Road and the Chocolate Path: This occurred over a small area behind sections of these flood defences in the 2130 tidal 1:200yr event. This is due to local topography trapping the water that overtops the Avon defence – the flood level is effectively the same as the peak river water level, which is higher than the baseline ‘Do Minimum’ water level. The crest levels were raised for these sections of defence to the Phase 1 model peak water levels for the 2130 1:200yr event, which are 0.18 to 0.23m higher than the Phase 1 flood defence including freeboard.
- Left bank at Ashton: The crest level was raised to the Phase 2 flood defence level excluding freeboard.
- Payne’s Shipyard: The crest level was raised to the Phase 2 flood defence level excluding freeboard.
- Freeland Place: The crest level was raised to the Phase 2 flood defence level excluding freeboard.
- Hotwell Road: The crest level was raised to the Phase 2 flood defence level excluding freeboard.
- Sea Mills (all): The crest level was raised to the Phase 2 flood defence level excluding freeboard.
- Shirehampton (all): The crest level was raised to the Phase 2 flood defence level excluding freeboard.
- Pill (all): The crest level was raised to the Phase 2 flood defence level excluding freeboard.

An updated version of the Phase 1 flood defence level model that incorporates the raising of selected flood defence sections, as described above, was run for the 2130 design flood events. The results showed the proposed raising successfully prevented unacceptable detriment in all locations. Chapter 9 gives more detail on the assessment of detriment and associated detriment maps.

It is recommended that the subsequent full business case and detailed design considers further optimisation of flood defence levels as there may be opportunity to reduce the amount of raising applied to the above flood defence sections for Phase 1, particularly where this is significant floodplain volume behind the flood defence such as at Ashton and Pill.

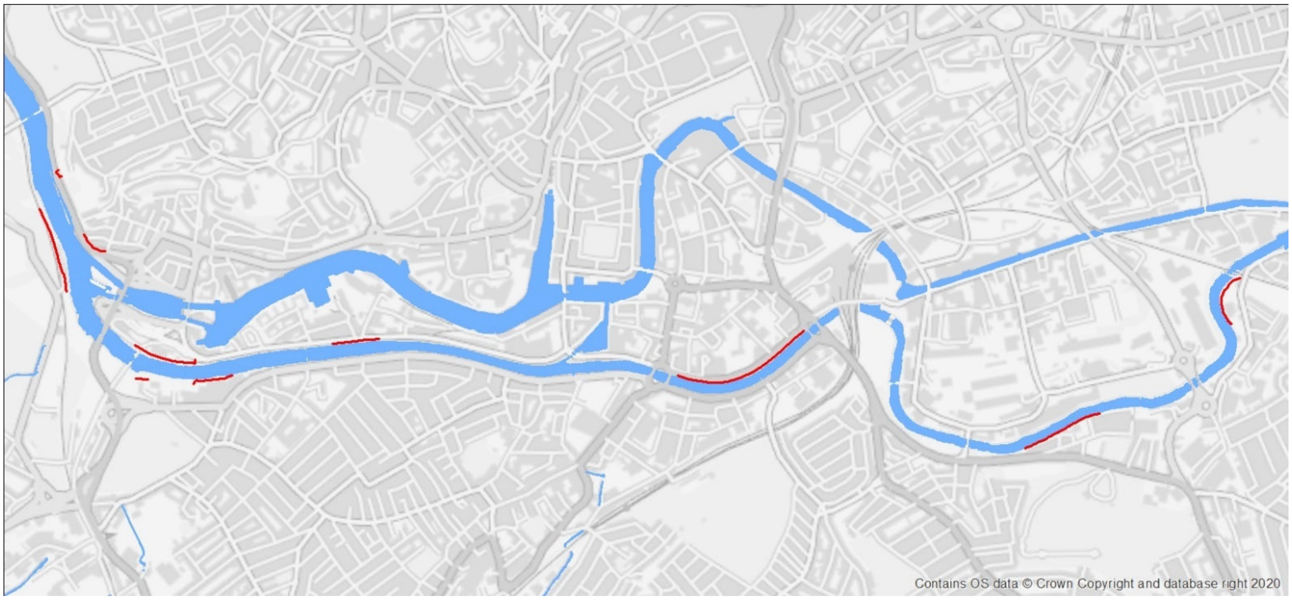


Figure 20: Sections of Phase 1 flood defence in Bristol that are raised to prevent detriment in 2130.

8.5 Final Avon main scheme flood defence levels (Crew's Hall Road to Pill / Shirehampton)

The residual uncertainty assessment described in the previous section is based on 'glass-wall' modelling and analysis undertaken between June and August 2023. Following this work, further refinements were made to the proposed flood defence alignments as described in Section 7.4. One final round of 'glass-wall' modelling was then undertaken in October 2023 based on the refined flood defence alignment to determine updated flood defence levels.

The updated flood defence levels for Avon main scheme flood defences (Crew's Hall Road to Pill / Shirehampton) are tabulated in Appendix C, which includes the following information:

- Updated flood level for 2069: This is based on the updated option modelling (October 2023) and values are slightly different to the values presented in the residual uncertainty assessment reporting (August 2023) due to changes in proposed flood defence alignment and rounding up to the nearest 0.01m. All values are within +/-0.02m of the values in the residual uncertainty assessment reporting.
- Updated nominal flood defence level for 2069: This is calculated as the updated flood level for 2069 plus the Total Freeboard excluding settlement allowance.
- Change in nominal flood defence level for 2069: This is the updated value (from October 2023) minus the original value (from August 2023). All values are within +/-0.02m as per the first bullet point above.
- Flood level for 2130. Note this was not provided in the residual uncertainty assessment reporting.
- Nominal flood defence level for 2130: This is calculated as the updated flood level for 2130 plus the Total Freeboard excluding settlement allowance that has been calculated for the Phase 1 defences. This calculation assumes that the freeboard allowances for Phase 2 flood defences will be the same as those used for the Phase 1 flood defences.

Appendix C also includes a column titled 'Level to use for Phase 1'. This is either:

- 2069 level with freeboard.
- 2069 level with freeboard plus some additional raising for all or part of the flood defence section: This is needed to prevent detriment behind these flood defences in some 2130 flood events and is required for Phase 1 to be consentable without relying on future delivery of Phase 2, as per Section 8.4.

- 2130 level without freeboard: This is needed to prevent detriment in 2130 and is required for Phase 1 to be consentable without relying on future delivery of Phase 2, as per Section 8.4.

8.6 Chapel Way detriment mitigation flood defence

In the baseline 'Do Minimum' option, which is used to represent the existing situation, the Brislington Brook overtops at Chapel Way (upstream of where it becomes culverted) during fluvial events. This overtopping causes overland flows to travel north contributing to flooding in the St Anne's Road area. The proposed scheme includes a flood defence at Chapel Way (Figure 21) to reduce overtopping and overland flooding from Brislington Brook to help prevent detriment in the St Anne's Road area caused by the proposed Avon flood defences.

In the SOC, a high flood defence (crest level 13.4m AOD) was proposed at Chapel Way, which posed potential issues with buildability and had implications under the 1975 Reservoir Act. During the OBC, iterative modelling was undertaken to optimise the crest level of the proposed Chapel Way flood defence. This identified an optimal crest level of 11.00m AOD for the headwall section and 11.15m AOD for the rest of the flood defence. This would be sufficient, when combined with flapped outfalls in the Avon defences (see Chapter 9) to prevent detriment for both 2069 and 2130 epochs regardless of whether Phase 2 is implemented. The crest level of 11.15m AOD is only 0.1m higher than that of the existing wall at the back of the car park at the upstream end of the proposed flood defence. Analysis of LIDAR ground level data shows that the volume of water retained above existing ground level at the flood defence (10.2m AOD) is 8,720m^3, which is less than 10,000m^3 and therefore the proposed flood defence would not fall under the 1975 Reservoir Act.

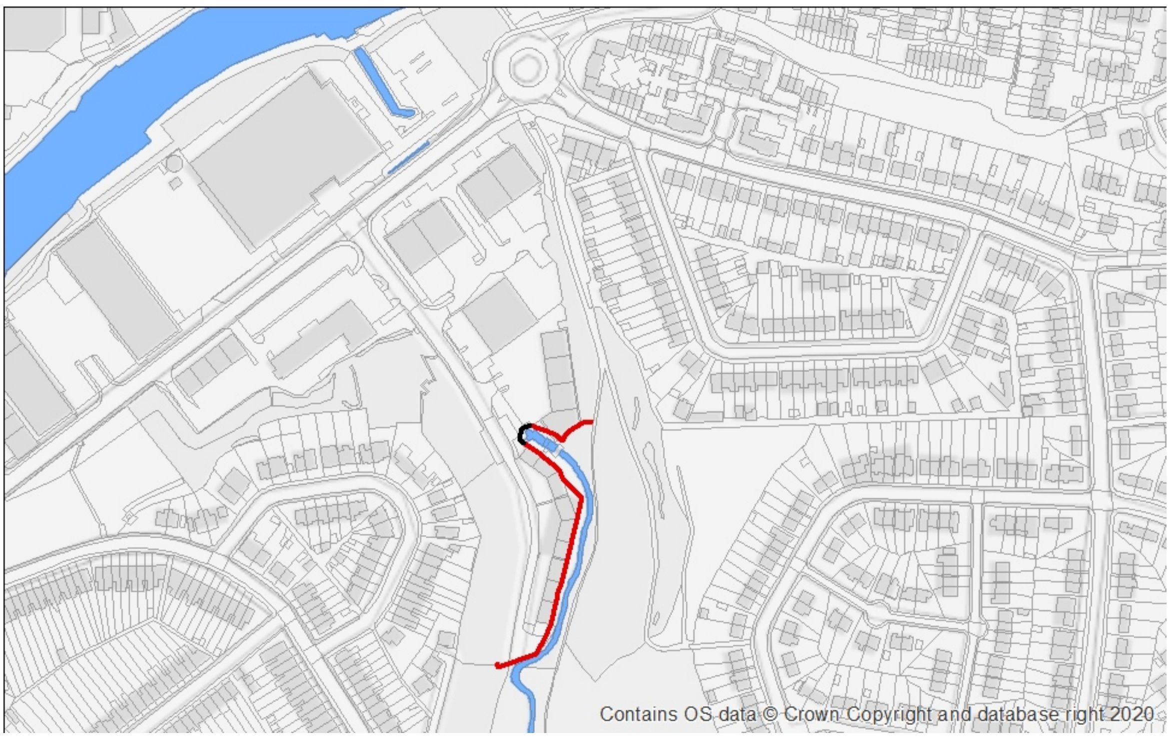


Figure 21: Chapel Way proposed flood defence alignment (black = headwall section, red = rest of flood defence).

8.7 Upstream detriment mitigation defences

The proposed scheme includes some detriment mitigation measures in areas upstream of Crew's Hall Road to reduce / offset impacts on flood risk from the main scheme flood defences. For these measures, which include flood defences, there is no requirement for freeboard (except for settlement allowance) to be incorporated into the design as these measures do not need to provide a specific standard of protection.

The assessment of constraints, including buildability and amenity considerations, for these measures is described in the OBC report and supporting appendices. This assessment identified that some sections of flood defence upstream of Crew's Hall Road would need to be lowered from the full height. This was proposed where it was considered impractical to construct at full height, e.g. at riverside cottages. In these cases, these flood defences have been termed 'practical betterment' defences as they will reduce flood frequency compared to baseline, though won't provide the full defence standard of the wider scheme. It was agreed with the EA that practical betterment measures could be assumed at this stage; however, this is subject to public consultation and will need to be agreed with landowners at the next stage.

There are three locations where practical betterment is proposed; these are shown by the orange dashed lines in Figure 18 and are listed below.

- The Pump House, Pump House Lane: Flood defence level set to 10.5m AOD compared to full height defence level of 10.8m AOD for 2069 and 11.45m AOD for 2130.
- Riverside Cottages, Hanham: Flood defence level set to 10.5m AOD compared to full height defence level of 11.32m AOD for 2069 and 11.89m AOD for 2130.
- Ferry Road at Chequers Inn, Hanham: Flood defence level set to 10.0m AOD compared to full height defence level of 11.32m AOD for 2069 and 11.89m AOD for 2130.

9. Impact assessment and mitigation

9.1 Detriment criteria

Detriment is defined as the increase in water levels and flood depths caused by the proposals, compared against the baseline Do Minimum option, which represents the existing situation.

It was agreed with BCC and the EA that the same criteria used in the SOC detriment assessment and mitigation requirements should be adopted for the current OBC study and this should be applied to both Phase 1 and Phase 2. The criteria agreed is:

1. A figure of 25mm should be used as the threshold for classifying any increase of flood water level due to the proposed raised defences as this is considered indicative of the tolerance of the hydraulic model results.
2. Detriment must be mitigated for return periods up to the design standard, e.g. if the proposed scheme has a 1:100yr SoP than detriment must be mitigated for flood event magnitudes up to and including the 1:100yr event. Detriment mitigation is not required for flood event magnitudes that exceed the SoP.
3. Detriment should be assessed for a range of return periods for fluvially dominated and tidally dominated events.
4. Detriment should be assessed and mitigated for present day and future climate up to 2130 based on NPPF climate change allowances.
5. Detriment to properties (buildings only) and key transport infrastructure (active rail lines and the resilient road network) requires mitigation to achieve the above criteria.

It was agreed that there should be no unacceptable detriment to properties from both Phase 1 and Phase 2 up to the design standard of the scheme. It was agreed that there should be no unacceptable detriment to properties from the Phase 1 flood defences for both 2069 and 2130 epoch years. The key item to note here is that Phase 1 impacts must be acceptable in 2130, i.e. to consent Phase 1, there must be no detriment for the design life of the scheme, without relying on the future delivery of Phase 2.

9.2 Initial testing

Initial impact assessment was undertaken towards the start of the OBC option development work. This assessment was based on the SOC scheme flood defence alignments prior to any refinements.

Testing was initially undertaken to assess impact from the SOC main scheme defence alignment without detriment mitigation, as described in Section 7.2. For this testing the defences were set to “glass-wall” to prevent overtopping. Impact maps for this initial testing are presented in Appendix D.1 for the Phase 1 and Phase 2 design events, namely the 1:100yr fluvially dominated and 1:200yr tidally dominated events for the 2065 and 2130 epoch years. Note this initial stage of modelling used 2065 instead for Phase 1 design events; this was subsequently revised to 2069. These impact maps show significant detriment in the areas where the detriment mitigation defences were excluded from the model, including areas upstream and downstream of Bristol and within Bristol at Ashton and Netham in the St. Anne’s Road area and Crew’s Hall Road area. Figure 22 shows detriment in the Netham area for the 2065 and 2130 fluvial events.

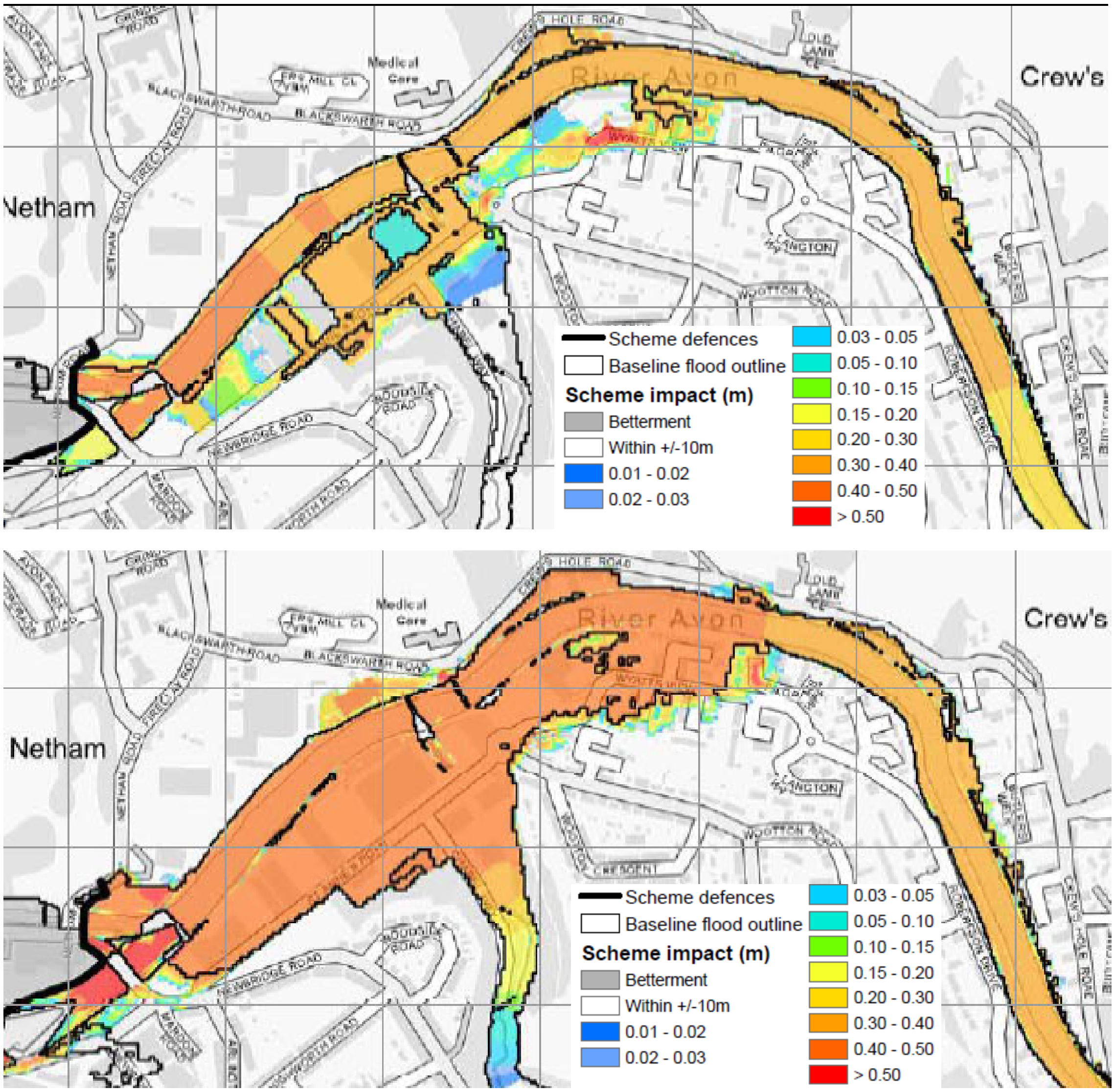


Figure 22: Example of detriment from SOC defences without detriment mitigation, fluvial 1:100yr event in 2065 (top) and 2130 (bottom).

A second test was undertaken with the detriment mitigation defences identified in the SOC added and set to "glass-wall" to prevent overtopping except for the Chapel Way flood defence on Brislington Brook which was set to have crest level of 13.4m AOD as per the SOC design. This test model excluded the detriment mitigation measures identified for the Malago in the SOC, which comprised raising of bank levels upstream of Parson Street and adding a flood storage area at 'Marksbury Open Space'. Impact maps for this test are presented in Appendix D.2 for the same flood events as above. These maps show some areas of detriment remained where properties are located, such as at Hotwells Road, Freeland Place, Whitby Road and in some upstream areas such as Swineford.

9.3 Iterative impact assessment

Following the initial tests described in the previous section, impact assessment was undertaken for the design events during the development of the OBC scheme design in order to determine the flood defence alignments and crest levels required to achieve the detriment criteria described in Section 9.1. This included assessing impacts for both the Phase 1 and Phase 2 flood defence levels. Phase 1 was assessed for 2069 and 2130 while Phase 2 was assessed for 2070 and 2130.

The resultant refinements to flood defence alignment and crest levels required to achieve the detriment criteria are described in the following sections:

- Section 7.4.1: Additional flood defences added in the Bristol area.

- Section 7.4.6: Refined approach / alignment for mitigation measures upstream of Bristol. More information on the level of flood defences is given in Section 8.7.
- Section 8.4: Adjustment of flood defence levels to prevent detriment (various flood defences between Whitby Road to Pill / Shirehampton).

In addition to the above flood defence alignment and crest level refinements, modelling identified that flapped outfalls are required for the proposed Avon left bank flood defence between the Brislington Brook outfall and Feeder Road Bridge (approx 450m). This is to reduce the depth of flood water that ponds in the St. Anne's Road behind the proposed flood defence here in order to prevent detriment to properties here. Note that this floodwater originates from Brislington Brook where it overtops at Chapel Way. In the baseline Do Minimum option, this floodwater is able to discharge into the River Avon where the river bank is sufficiently low. Without flapped outfalls, overland flows from Brislington Brook are not able to discharge into the Avon. Model tests identified the following flapped outfalls would be required:

- Phase 1: A total of 14 flapped outfalls of 300mm diameter.
- Phase 2: In additional to the above, a further 17 flapped outfalls of 300mm diameter.

In reality, it is likely to be more practical to incorporate all required outfalls into the Phase 1 flood defences rather than incorporate the additional outfalls needed for Phase 2 in the Phase 2 works. It is recommended that future stages of this project, such as the full business case and detailed design stages, undertake further assessment of the requirement for flapped outfalls, including optimisation of position, size and number of outfalls.

9.4 Final impact assessment

Model setups representing the final iteration of Phase 1 and Phase 2 were used to undertake a final assessment of flood risk impact to third parties. These model setups increase all proposed flood defences including detriment mitigation defences and include freeboard allowance where required.

The final impact assessment for Phase 1 and Phase 2 was undertaken for the flood events listed in Table 3. In all cases, the design climate change allowances were used, namely Central for fluvial flows and Higher Central for tidal.

Table 3: Flood events used for the final impact assessment.

Model setup	Event type	Return period (years)	2030	2069	2070	2130
Phase 1	Fluvial	1:20	✓	✓		✓
		1:75	✓	✓		✓
		1:100	✓	✓		✓
		1:200	✓	✓		✓
	Tidal	1:20	✓	✓		✓
		1:75	✓	✓		✓
		1:100	✓	✓		✓
		1:200	✓	✓		✓
Phase 2	Fluvial	1:20			✓	✓
		1:75			✓	✓
		1:100			✓	✓
		1:200			✓	✓
	Tidal	1:20			✓	✓
		1:75			✓	✓
		1:100			✓	✓
		1:200			✓	✓

The final impact maps for Phase 1 are presented in Appendix D.3 while the final impact maps for Phase 2 are presented in Appendix D.4.

9.5 Investigation at Ashton

The impact mapping shows some small / isolated areas of detriment in the Ashton area in some specific flood events for Phase 1 in 2030 and 2069. These were investigated and more detailed mapping showing the flood depths and detriment in this area relative to the location of property is presented in Appendix D.5.

For all but the last page in Appendix D.5, the impact shown on the mapping is considered to be false and due to anomalies in the LIDAR resulting in artificial ponding within parts of properties. On the last page there are two buildings showing more than 25mm detriment (in the 2069 1:100yr fluvial event) where the detriment does not appear to be due to LIDAR anomalies. These buildings appear to be outbuildings based on review of the photography available at the time of this assessment. There is no threshold survey for these buildings so it is not possible to determine whether the modelled water levels would cause internal flooding. Given the uncertainty associated with impacts at these buildings, it is recommended that threshold survey is collected for these buildings in future stages of this project.

9.6 Other detriment

In addition to the areas in Ashton, described above, the impact maps also show a small area of detriment on the left bank of the Avon immediately upstream of Netham Weir. This appears to affect one property, namely the ‘Bristol Car Group’ building, in fluvial flood events of 1:75yr or greater in 2130. The 1:100yr fluvial flood depth in 2130 at this property is approximately 0.3m. It is proposed that Property Flood Resilience measures are provided for this property to mitigate detriment in 2130.

10. Flood modelling for economic assessment

Model simulations were undertaken to determine flood depths and flood hazard associated with overtopping. The results have been used to determine flood damages in the economic analysis for the OBC (reported separately) to calculate the benefits of each option. The option benefits and option costs are used to aid selection of a preferred option and to determine funding requirements.

Flood damage simulations were undertaken for the following five options, which are described in greater detail in the options appraisal report:

- Do Minimum: This represents the current situation and assumes current maintenance regime will continue into the future. This uses the baseline model described in Chapter 2 and Do Minimum option assumptions described in Section 3.1.
- Do Nothing: This is a hypothetical baseline against which all other options should be compared. This option represents a 'walk away' scenario where all maintenance and operation of flood risk assets would cease immediately. The option assumptions are outlined in Section 3.2.
- Proposed scheme flood defences. For the economic analysis, it is assumed that Phase 1 is constructed and operational by 2030 and that Phase 2 will be constructed and operational by 2070. Three different SoPs were modelled to enable application of the FCERM decision rule in the economic analysis:
  - Flood defences based on design standard of 75yr SoP (both fluvial and tidal).
  - Flood defences based on design standard of 100yr SoP (both fluvial and tidal).
  - Flood defences based on design standard of 200yr SoP (both fluvial and tidal).

10.1 Proposed scheme option models

A 'glass-wall' version of the model (flood defences set artificially high) was used to derive flood defence levels for each of the three proposed scheme option SoPs. For each of the three SoPs, four flood events were modelled and in each case, the return period modelled is equal to the SoP to be represented:

- 2069 fluvial event
- 2069 tidal event
- 2130 fluvial event
- 2130 tidal event

For each SoP option, two models were set up: one model to represent Phase 1 and one model to represent Phase 2. The maximum water level of the 2069 fluvial and tidal water level results was to define the Phase 1 flood defence crest levels. The maximum of the 2130 fluvial and tidal water level results was used to define the Phase 2 flood defence crest levels.

All flood defence crest levels used in the flood damage modelling exclude freeboard, as required by FCERM Appraisal Guidance. The freeboard allowance is excluded from flood damage assessment because it is used in the design to manage uncertainty in modelled water levels as opposed to intentionally providing a higher design standard. For the River Avon Phase 1 flood defences that are proposed to be set to 2130 level excluding freeboard (see Section 8.5), the water level uncertainty allowance has been subtracted from the proposed Phase 1 defence level – in all cases the resultant crest level is still greater than the 2069 level excluding freeboard so the design standard is still being provided within the model.

10.2 Flood events simulated

For each option, a range of flood event magnitudes were simulated for several points in time during the 100yr appraisal period. This was required to provide sufficient detail in the flood damage assessment. The epoch years selected are 2030, 2065, 2070 and 2130 and this is explained in Section 4.3. The climate change allowances applied for each epoch year are given in Section 4.4. For each of the three proposed scheme flood defences options, the Phase 1 model was used for the 2030 and 2069 epochs and the Phase 2 model was used for the 2070 and 2130 epochs.

The 13 flood events listed in Table 1 in Section 4.2 were simulated for each epoch year. A total of 56 simulations were run for each option (4 epoch years x 13 flood events). A total of 280 simulations were run in total (5 options x 56 simulations).

10.3 Model results

Maximum water level, maximum flow velocity and maximum flood hazard results were extracted from the 2d model for each simulation for use in the flood damage assessment (reported separately). Flood extent polygon files were also created.

10.3.1 Checks

Model results were checked to ensure results were as expected based on option, epoch year, return period, and the SoP modelled for the proposed scheme flood defences options. The following minor inconsistencies were identified in the proposed scheme flood defences option results. These were flagged up to the economic analysis team and are explained / justified below.

The Floating Harbour water levels for the 2070 fluvial 1:200yr event are slightly lower than those for the fluvial 1:100yr event, which results in marginally less flooding in the 1:200yr event than the 1:100yr event around the Floating Harbour (Figure 23). Inspection of 1d timeseries results shows this is due to the control rules for Entrance and Junction Lock gates. In the 1:200 event, the Floating Harbour water levels before the main fluvial peak just about exceed the prescribed trigger level of 7m AOD which causes the gates to open and lower water levels in the harbour while the tide level is still low enough. Conversely, in the 2070 1:100 event, the water levels in the Floating Harbour don't exceed the trigger level until it's too late (due to the tide level being too high). Note there is a 0.5hr time delay built into the rules to account for mobilisation of control structure operation. The Floating Harbour water level vs time results for the 2070 fluvial 1:100yr and 1:200yr events for the 75yr SoP scheme model are shown in Figure 24.

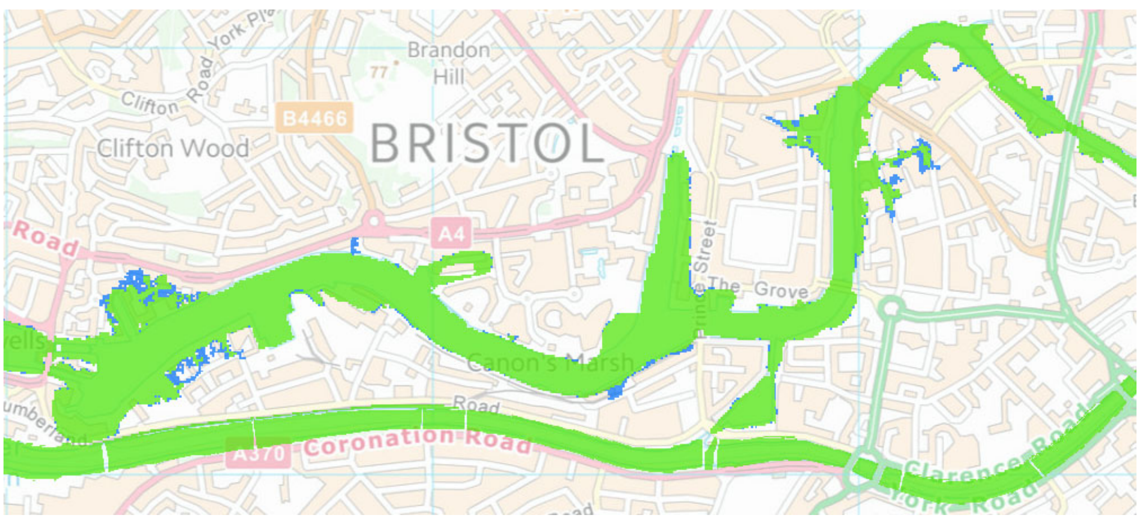


Figure 23: Flood extent for fluvial events in 2070: blue = 1:100yr, green = 1:200yr.

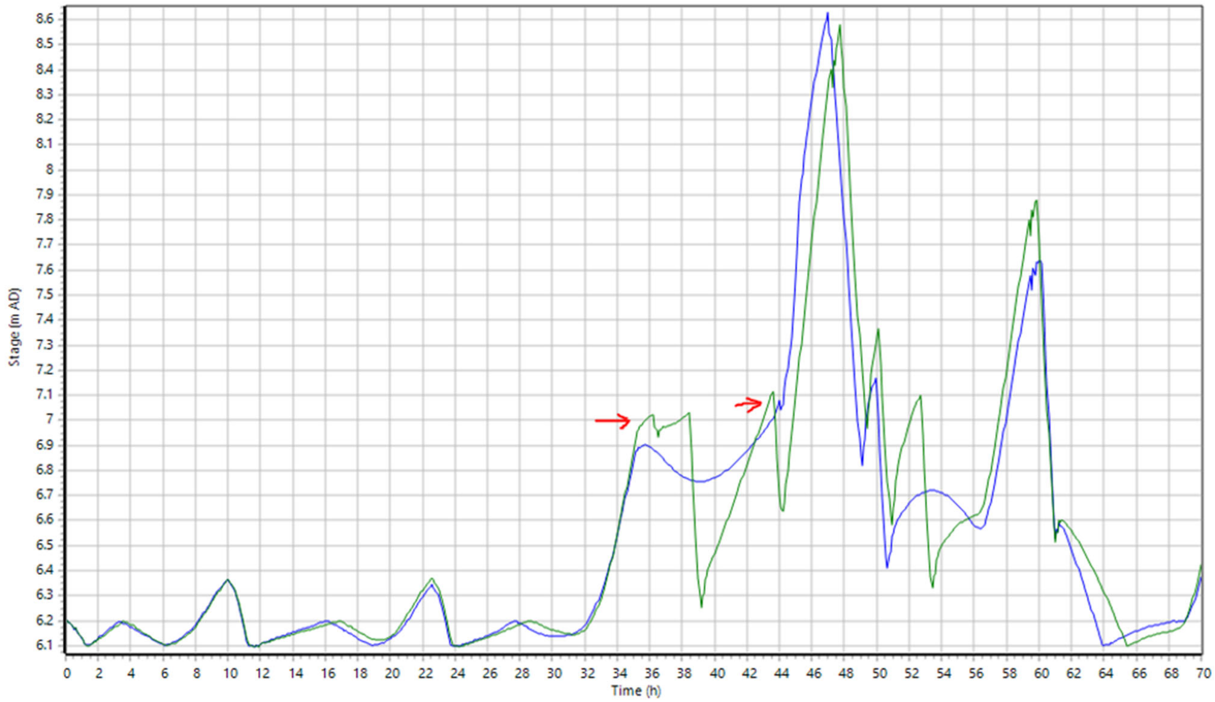


Figure 24: Water level vs time in Floating Harbour for fluvial events in 2070: blue = 1:100yr, green = 1:200yr.

Some slight overtopping at Cumberland Road was observed to occur in the 2130 tidally dominated event that has the same magnitude as the SoP being modelled. The flood depths are less than 0.1m and are generally less than 0.01m and flooding only gets to edge of buildings. The greatest overtopping occurs for the 200yr SoP scheme model for the 1:200yr tidal event in 2130 (see Figure 25). This minor overtopping appears to be due to the fact that the defence line is slightly set back from the 1d-2d HX link line in the model so there is a line of 2d grid cells on the riverside of the flood defence and the TUFLOW 2d modelled water levels in these grid cells are slightly greater than the water level in the river adjacent to these grid cells (note that flood defence levels were derived from the 1d results not 2d results). This effect doesn't appear to occur at other locations where the defence line is slightly set back from the 1d-2d HX link line so this may be due to minor instability in the 2d model. The economic analysis team confirmed this minor overtopping would not impact on the flood damage assessment.

Figure 25: Flood depths for 1:200yr tidal event in 2130 for 200yr SoP scheme model.

10.3.2 Impact of proposed scheme

Flood extents in Bristol for the Do Minimum option and proposed scheme flood defences option are compared in Figure 26 to Figure 29 for the fluvial 1:100yr and tidal 1:200yr events in 2069 and 2130. These return periods correspond to those that are used to define Flood Zone 3. For the proposed scheme flood defences option, the 2069 results shown are for before the second phase is constructed in 2069. Note that for the 1:100yr fluvial event, the 100yr SoP and 200yr SoP options give the same model results in Bristol.

For all figures, the smaller flood extent is placed on top of the next smallest flood extent. Therefore, the green areas show the additional flooding from the 75yr SoP option compared to the 100yr SoP option and the light blue areas show the additional flooding from the 100yr SoP option compared to the 200yr SoP option.

The results show significant areas of Bristol would benefit from the proposed scheme even if a 75yr SoP was selected. While there is significant benefit for fluvial events, there is greater benefit in tidal events. The benefit in 2130 is significantly greater than in 2069 due to the significant increase in flooding between 2069 and 2130 for the baseline Do Minimum option.

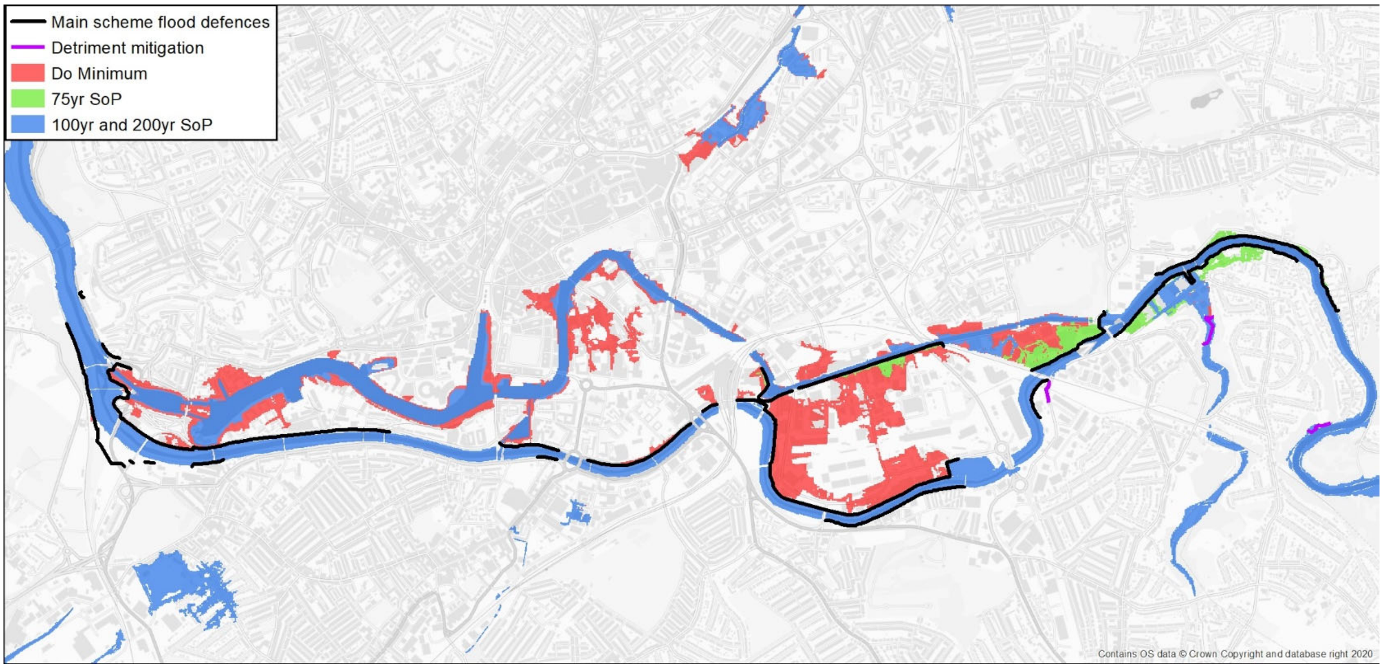


Figure 26: Flood extents of flood defences options vs Do Minimum option for 2069 fluvial 1:100yr event.

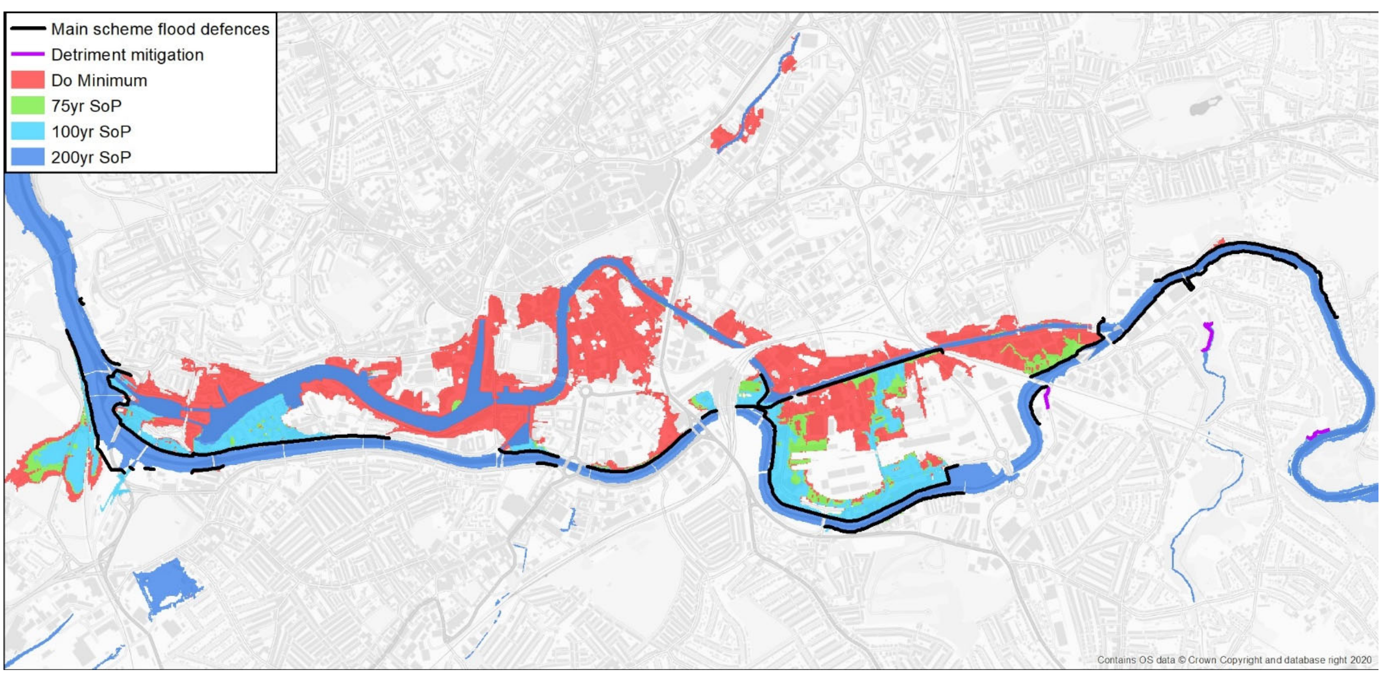


Figure 27: Flood extents of flood defences options vs Do Minimum option for 2069 tidal 1:200yr event.

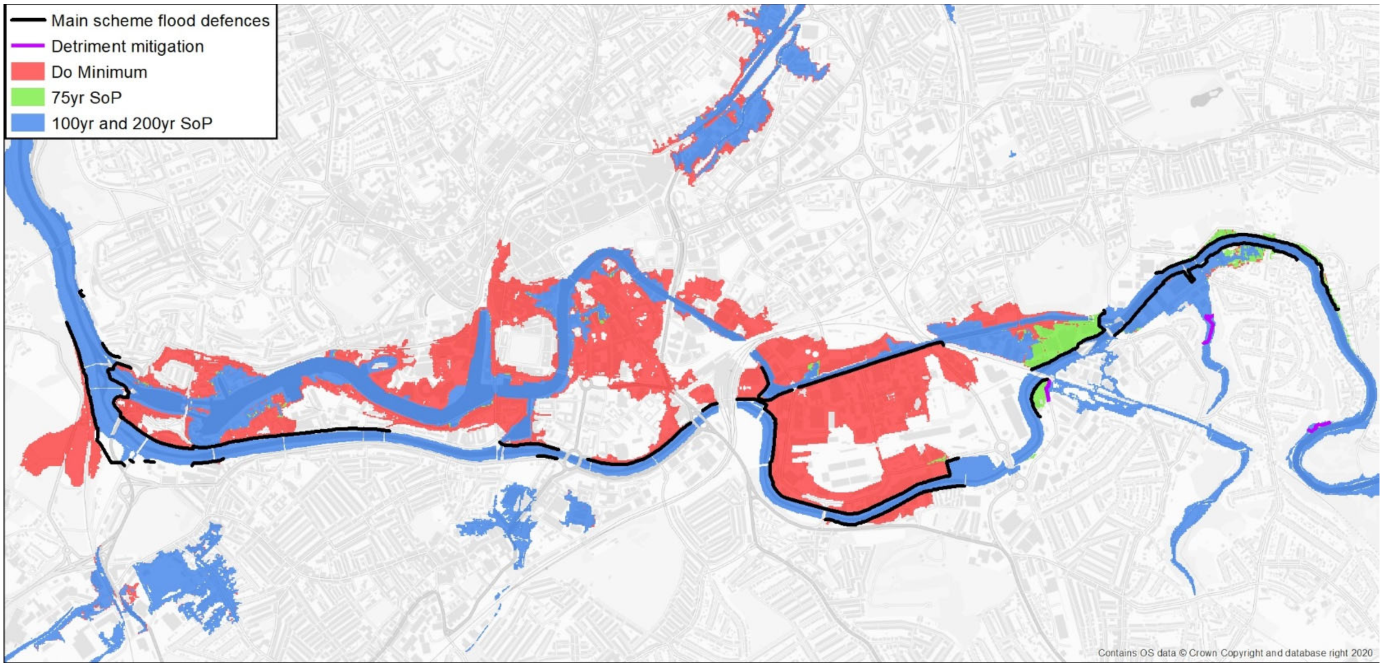


Figure 28: Flood extents of flood defences options vs Do Minimum option for 2130 fluvial 1:100yr event.

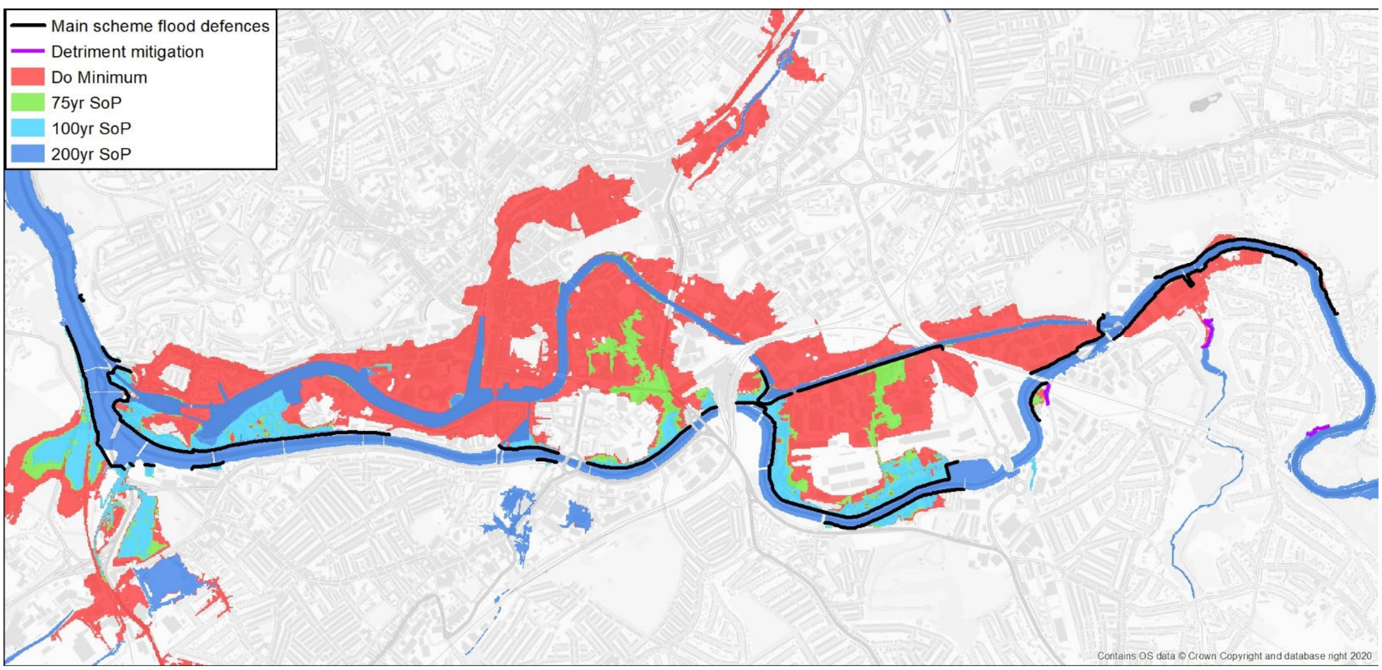


Figure 29: Flood extents of flood defences options vs Do Minimum option for 2130 tidal 1:200yr event.

11. Assessment of residual flood risk for Phase 1

As assessment of the residual risk associated with overtopping of the Phase 1 flood defences has been undertaken. Overtopping of the Phase 1 defences will occur when the flood conditions exceed the design standard of the flood defences. The design standard of the Phase 1 flood defences is:

- Fluvially dominated 1:100yr and tidally dominated 1:200yr events.
- Flood conditions based on the 2069 epoch year (the Phase 1 defences are to provide the above design standard up to 2069).
- Flood conditions based on the central allowance for fluvial and the higher central allowance for tidal.

The ten residual risk flood event scenarios listed in Table 4 were agreed with the EA. Note that the first two scenarios in this table are based on the Phase 1 design standard and therefore no overtopping of the Phase 1 flood defences occurs in this scenario – these are included to help provide context, particularly for areas where there are no flood defences proposed such as around the Floating Harbour and on tributaries.

Table 4: Residual risk flood event scenarios modelled.

ID	Freeboard included	Epoch year)	Climate change allowance (fluvial)	Climate change allowance (tidal)	Flood event type	Return period (years)
1	No	2069	central	higher central	Fluvially dominated	100
2		2069	central	higher central	Tidal dominated	200
3		2069	higher central	upper end	Fluvially dominated	100
4		2069	higher central	upper end	Tidal dominated	200
5		2130	central	higher central	Fluvially dominated	100
6		2130	central	higher central	Tidal dominated	200
7		2130	higher central	upper end	Fluvially dominated	100
8		2130	higher central	upper end	Tidal dominated	200
9	Yes	2130	central	higher central	Fluvially dominated	100
10		2130	central	higher central	Tidal dominated	200

The above scenarios were set up and modelled using the Phase 1 defences model. As per column 2 in Table 4, two versions of the Phase 1 model were used: one version with freeboard excluded and another version with freeboard included for the 'main scheme' flood defences, where required. For the version of the model with freeboard excluded, the following adjustment has bene applied: Where the Phase 1 design levels exclude freeboard (defences required to be set to 2130 level, and detriment mitigation flood defences – see Chapter 8), the water level uncertainty allowances has been subtracted from the flood defence crest level as per the approach used for the economic assessment modelling described in Chapter 10.

The maximum flood depth results were used to create the suite of residual risk maps presented in Appendix E. The residual risk maps show flood extents and flood depths due to overtopping. The maps also show the location of the 'main scheme' flood defences, detriment mitigation flood defences and proposed areas of Property Flood Resilience (PFR). The residual risk maps for scenario based on the design climate change allowances (IDs 1, 2, 5, 6, 9 and 10) can also be compared against the baseline flood depth maps presented in Appendix A to see the impact of Phase 1 on flood extents and flood depths.

Key observations from review of the residual risk maps are given below:

- For the Phase 1 design standard flood events (ID 1 and 2 in Table 4), there is no overtopping of the Phase 1 'main scheme' flood defences, as expected. However, overtopping does occur at:
  - locations around the Floating Harbour in the 1:100yr fluvial event (see Figure 30) due to fluvial flows entering from the River Frome;

– areas of the Avon where no flood defences are proposed, either because there are no properties or because there is no unacceptable detriment;

– tributaries, such as the Frome, Malago, Brislington Brook and tributaries in the Ashton area: the BAFS scheme does not extend to cover tributaries.

- Some Phase 1 ‘main scheme’ flood defences are set to 2130 level excluding freeboard to prevent unacceptable detriment from Phase 1 in 2130. This is needed for Phase 1 to be consentable without relying on future delivery of Phase 2 (see Chapter 8). These include flood defences at Sea Mills, Pill and Shirehampton. The residual risk maps show that these flood defences do not overtop in 2069 under the more severe climate change allowance tested (ID 3 and 4 in Table 4).

- The residual flooding in 2069 under the more severe climate change allowance tested (ID 3 and 4 in Table 4) results in generally relatively shallow flooding in the Bristol area with slightly deeper flooding in areas of St Philips March and the St. Anne’s Road area upstream of Netham Weir.

- There is significant residual flooding in the Bristol and Netham areas in all the 2130 flood scenarios. In the Bristol area and in St Philip’s Marsh, there is significantly greater flooding from tidally dominated events compared to fluvially dominated events, upstream of this flooding in dominated by fluvial events.

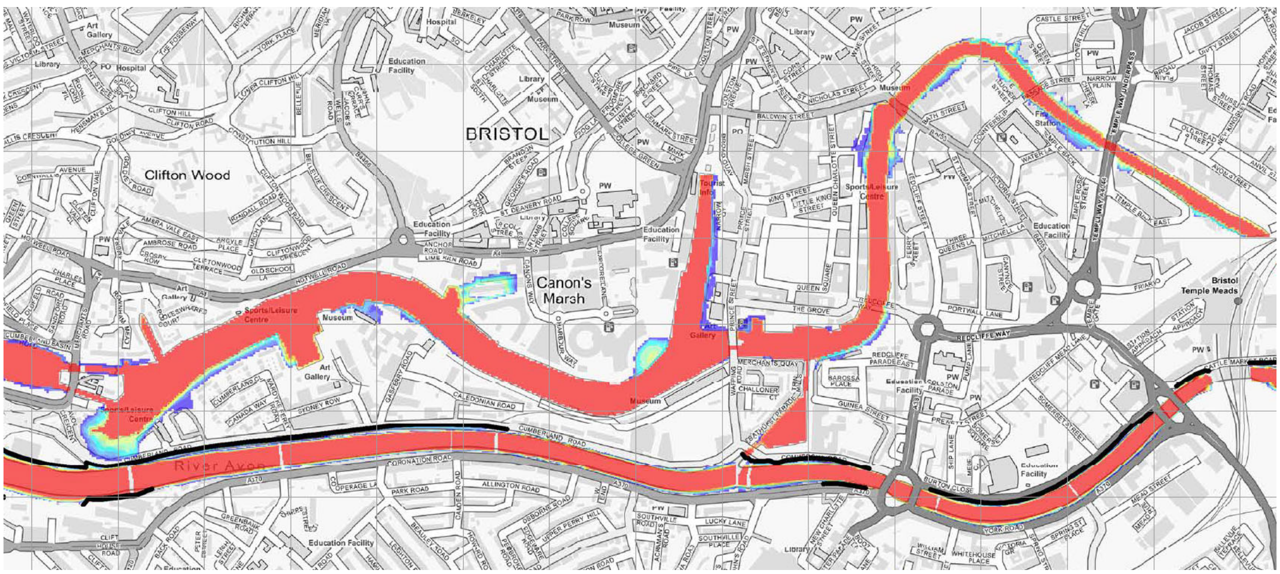


Figure 30: Residual overtopping of the Floating Harbour in the Phase 1 design fluvial event.

Comparing the residual risk maps for Phase 1 excluding freeboard in the 2130 design events (IDs 5 and 6) to the equivalent baseline flood depth maps shows:

- Sea Mills, Shirehampton and Pill: Phase 1 residual flood depths are virtually the same as baseline flood depth, i.e. the Phase 1 flood defences do not provide flood risk benefit in 2130.

- Bristol and St Philips Marsh areas: Phase 1 residual flood depths are significantly lower than baseline flood depths for both fluvially and tidally dominated flood events. This shows the Phase 1 flood defences would still provide significant flood risk benefit in 2130.

- Netham area: No significant difference.

- Areas upstream of Bristol: Phase 1 residual flood depths are slightly greater than baseline flood depths for fluvially dominated events.

12. Impact on surface water

The hydraulic model used for the OBC represents flooding from the main rivers but excludes:

- ordinary watercourses (non-main river);
- surface water flooding arising directly from rainfall before the water gets into watercourses;
- the below ground surface urban drainage network or the flooding that may arise from this.

Given these limitations, the hydraulic model does not explicitly show whether the proposed scheme and/or the increases in River Avon water levels as a result of the proposed scheme, would affect surface water (pluvial) flood risk associated with rainfall and urban drainage systems and ordinary watercourses that discharge into the Avon. An assessment has therefore been undertaken using existing datasets to understand whether / how the proposed scheme could impact surface water flood risk and to identify potential mitigation measures where appropriate.

Note that surface water flood risk is considered within the economic analysis, which is reported separately. The OBC report and relevant appendices give more information.

12.1 Impact of elevated River Avon water levels

The proposed scheme causes an increase in peak water levels on the River Avon. An assessment of the potential impacts of elevated River Avon water levels on surface water flood risk has been undertaken.

The phasing of the River Avon water level peak vs the rainfall peak was assessed by analysing rain gauge and river gauge data. The two closest rain gauges to the study area are Keynsham and Clifton Oakfield (Figure 31).

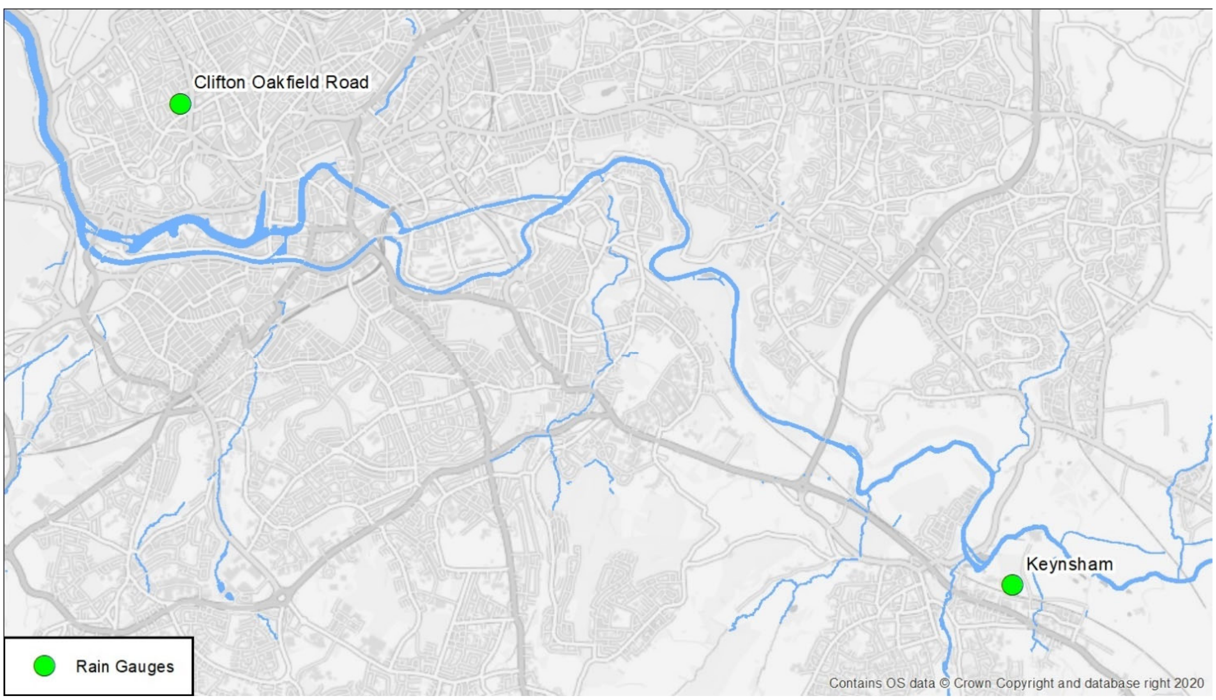


Figure 31: Location of closest rain gauges.

Rain gauge data was downloaded for the above two rain gauges and compared. Figure 32 shows a comparison of the 24hr rolling rainfall totals for a recent series of heavy rainfall events (17th December 2022 to 17th January 2023). This shows that although there is some difference in rolling rainfall totals between the two gauges, there is no significant difference in the timing of the peaks of the rolling rainfall totals. This means that the analysis of rainfall vs river level peak timing should be insensitive to the selection of rain gauge. For the purposes of this assessment, the River Avon water levels will be compared against the Keynsham rain gauge data.

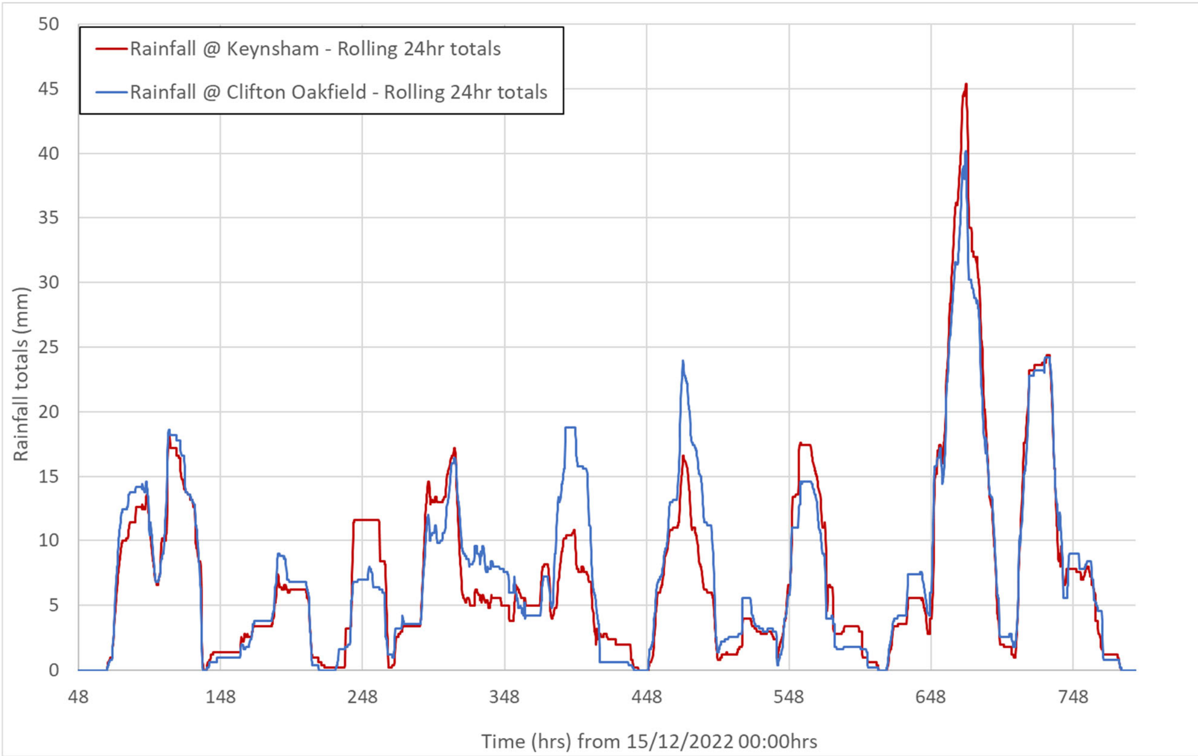


Figure 32: 24hr rolling rainfall totals for Keynsham and Clifton Oakfield Road rain gauges.

The closest River Avon water level gauge to the study area that is not significantly influenced by tide levels is the Keynsham river level gauge. The Keynsham river gauge water levels are compared against the 6hr and 24hr rolling rainfall totals from the Keynsham rain gauge (Figure 33). This shows a clear and consistent lag between the peak of the rainfall totals and the peak of the river water levels. The average lag was calculated to be 21hrs. Based on this significant lag, the fluvial response of the River Avon will be much slower than that of surface water flooding resulting from rainfall. The flood peaks for these two sources of flooding will therefore be significantly desynchronised with the River Avon fluvial peak occurring significant later than the surface water flood peak.

The flood model results show that the proposed scheme would only start to affect River Avon water levels 1 to 2hrs before the fluvial flood peak. As such, the increase in peak River Avon water levels due to the proposed scheme would occur significantly later than the surface water flood peak.

The model results show there is no detriment >25mm on ordinary watercourses and drains that discharge into the River Avon in Bristol via flapped outfalls. For example, the detriment maps show no detriment for Colliters Brook, which is included in the hydraulic model. This is because the increase in River Avon water levels does not cause a material increase in the duration that the outfall is locked closed by River Avon water levels.

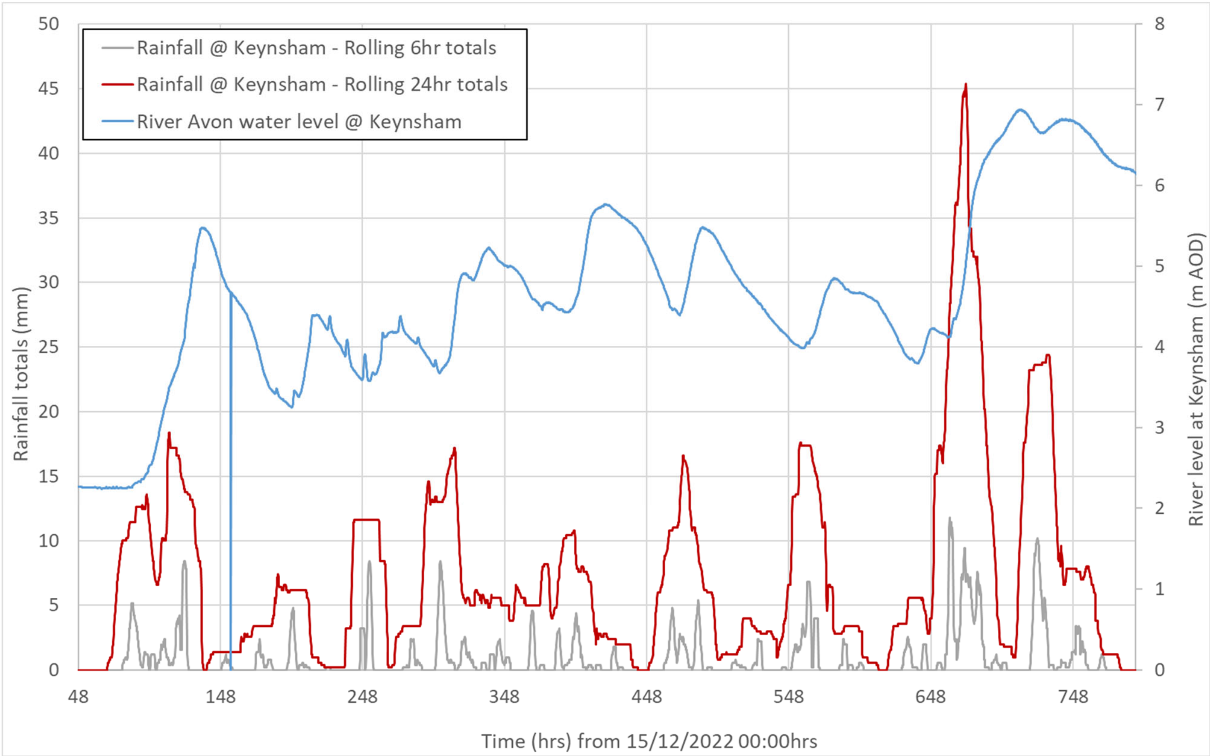


Figure 33: River Avon water level vs rolling rainfall totals at Keynsham.

12.2 Impact of proposed flood defences

The proposed scheme flood defences have the potential to reduce overland discharge of surface water runoff into the River Avon. An assessment has therefore been undertaken to identify areas where surface water flood risk may be impacted by the proposed flood defences and to identify potential mitigation measures where appropriate.

The most relevant existing datasets for surface water flood risk are:

- EA national 'Risk of Flooding from Surface Water' (RoFfSW) mapping dataset, which was created in 2013. The data is derived from national scale surface water modelling supplemented with data from more detailed local models where available. For Bristol, the data has been supplemented with outputs from the Bristol Surface Water Management Plan (SWMP) integrated modelling from 2011, which includes representation of the subsurface drainage and overland flow. Model outputs such as flood extents and flood depths are provided for the 1:30yr, 1:100yr and 1:1000yr present day climate rainfall events.

- Modelling undertaken by JBA for the updated Bristol SWMP, dated 2019, which has not been incorporated into any EA national surface water mapping dataset. Model outputs such as flood extents and flood depths are provided for the 1:30yr, 1:100yr and 1:1000yr present day climate rainfall events.

For this current assessment, the most recent of the above two datasets (2019) has been used. The 1:100yr results have been used – the 1:100yr surface water flood extents are very similar to those for the 1:30yr event but the flood depths are greater.

Locations where the proposed flood defence could potentially impact on surface water flood risk have been recognised by identifying locations where surface water mapping shows surface water flow paths effectively cross through the proposed flood defences, e.g. where surface water runoff is currently directed into the river. The extent and depth of surface water at these locations has also been considered.

12.2.1 Netham

The 1:100yr surface water flood depths at Netham and locations where the proposed flood defences have potential to impact on surface water flood risk are shown in Figure 34.

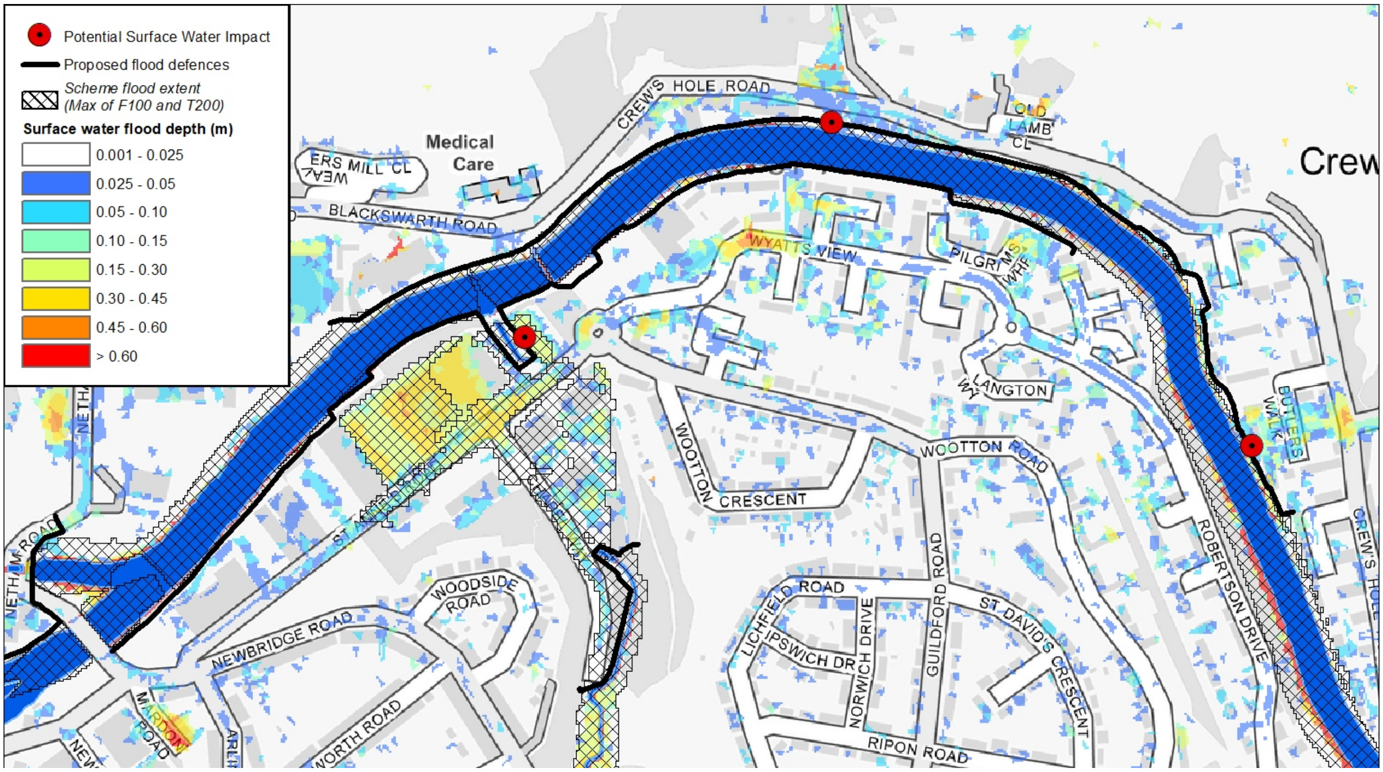


Figure 34: Surface water flood depths at Netham.

During the scheme development and modelling, it was identified that overland flows from Brislington Brook could become trapped behind the proposed River Avon flood defences in the St. Anne's Road area. To mitigate the resultant impact of this, the proposed scheme includes flapped outfalls in the River Avon flood defences here (see Section 9.3). The final detriment assessment demonstrated that this would prevent any increases in flood depths in this area. Given the topography and similarity in overland flow paths, the proposed flapped outfalls here will also mitigate impact on surface water runoff from rainfall.

Two additional locations have bene identified where the proposed flood defences may impact on surface water flood risk – these are both in the Crew's Hall Road area. The surface water flood depths are low at less than 0.07m at both of these locations. It is recommended that flapped outfalls through the defence are considered to mitigate impact on surface water flood risk here.

12.2.2 St Philips Marsh

The 1:100yr surface water flood depths at St Philips Marsh and the locations where the proposed flood defences have potential to impact on surface water flood risk are shown in Figure 35.

There is one area of surface water adjacent to the proposed River Avon flood defences but this appears to be from water overtopping the depression immediately to the north as opposed to surface water flow paths being directed to the proposed flood defence. Nevertheless, it is recommended that a flapped outfall is considered at this location.

There is also one area adjacent to the proposed Feeder Road flood defence where surface water flood depths are around 0.15m at the proposed flood defence. At Atlas Street and Glass House, the surface water flood depths are greater – the LIDAR shows ground levels here are around 0.25m lower than Feeder Road and therefore experience a greater depth of ponding. It is assumed that the existing highway drainage is sufficient to enable ponded surface water to drain following a flood event but it is recommended that a flapped outfall is included here to mitigate any potential increase in surface water flood risk. Note that in the baseline 'pre-scheme' situation, this area and much of St Philip's Marsh is at flood risk from the Feeder Canal overtopping; the proposed scheme would prevent this overtopping for flood event magnitudes up the design event.

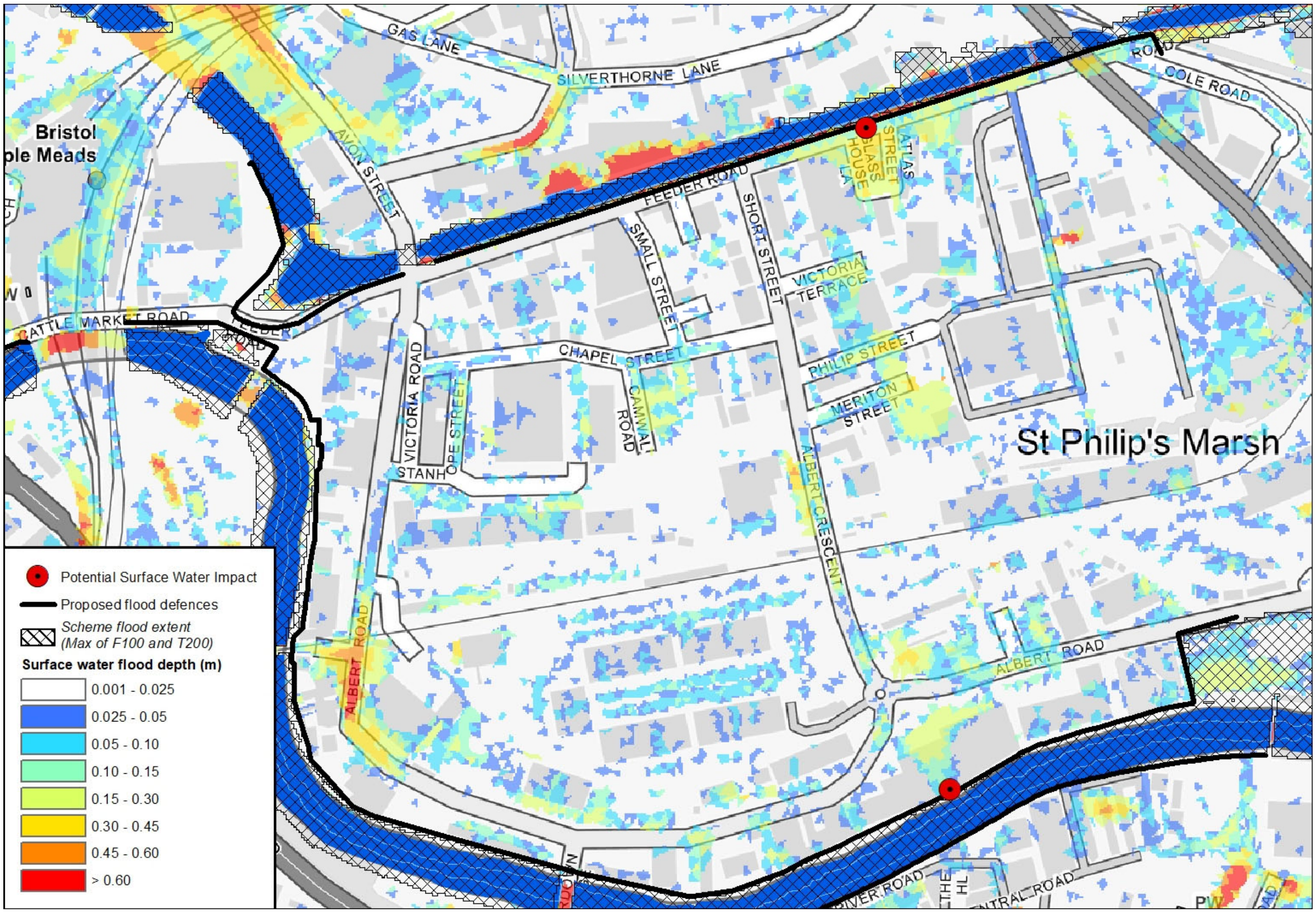


Figure 35: Surface water flood depths at St Philip's Marsh.

12.2.3 Ashton

The 1:100yr surface water flood depths in the Ashton area and the locations where the proposed flood defences have potential to impact on surface water flood risk are shown in Figure 36.

The location to the north is at the disused rail line. The surface water flood depths show that in the baseline 'pre-scheme' situation, surface water is already being held back by the high ground next to the rail line. There is only very marginal surface water flow extending beyond this towards the river and this is very shallow (around 0.03m). Therefore, the proposed scheme is unlikely to materially affect surface water flood risk at this location.

The location to the south is due to an isolated depression in the LIDAR data at one property; this may be partly due to filtering anomalies in the LIDAR data across the building footprint. Given the topography, it is assumed that this property already has some form of surface water drainage but further investigation is recommended at detailed design stage.

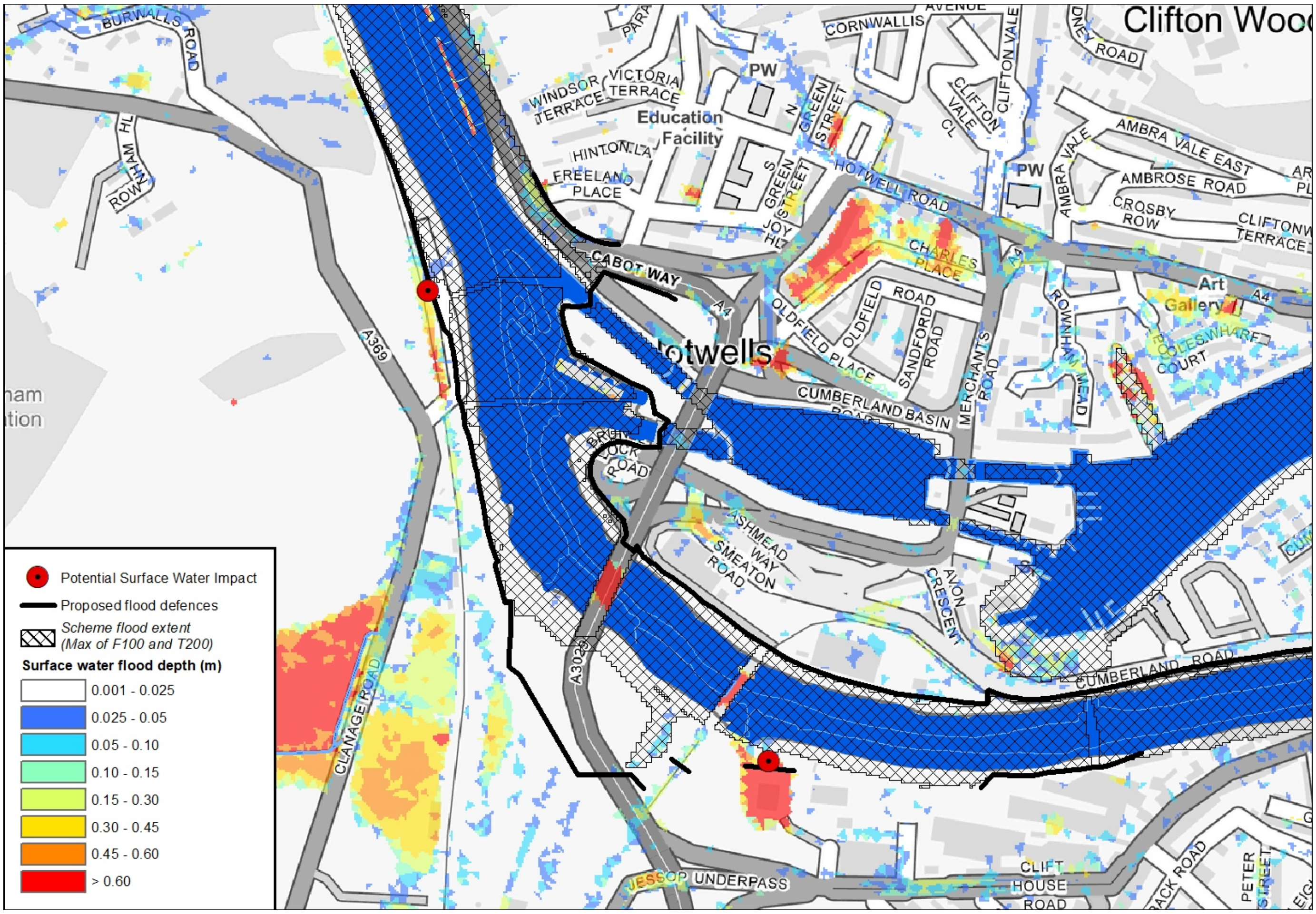


Figure 36: Surface water flood depths at Ashton.

12.2.4 Wider surface water drainage implications

Wessex Water is the regulated Water and Sewerage Company providing sewerage and wastewater treatment services in Bristol. They own and maintain the sewerage network which comprises a mixture of separate storm and foul, and combined sewerage, including some 32 surface water drainage and Combined Sewer Overflow outfalls within the currently defined extents of the Bristol Flood Alleviation Scheme (BFAS) defences. In addition to these, Wessex Water is also responsible for at least 51 other outfalls to the River Avon between Keynsham and Avonmouth which could be indirectly affected by the BFAS flood defence proposals.

Outfall assets generally have non-return flap valves to protect the upstream network against flooding from high river levels and tidal surge, however these cannot guarantee total isolation and it is known that saline ingress can occur during high tide conditions. Furthermore, these valves cannot provide protection against flooding when heavy rainfall coincides with high tides, due to the risk of self-flooding behind a closed valve; this is particularly the case in low-lying locations such as St Phillips, where ground level is lower than the current peak river level during tidal / fluvial extremes.

BCC shared information supporting scoping feasibility studies in 2022. During 2025 to 2030, subject to the outcome of the 2024 Price Review, Wessex Water plans to conduct further detailed investigations into the condition and operation of these outfalls and to make the case for investment to improve the drainage and sewerage networks' long-term resilience to tidal surges and River Avon flood levels.

13. Recommendations

13.1 General recommendations

The following general recommendations should be considered for future modelling work undertaken to support the development of the proposed scheme:

- Whether any changes to ground levels or river channels / structures have occurred since the current study.
- Whether there is new LIDAR data or topographic survey available to refine the model.
- Whether any new / updated information such as topographic survey is available that could be incorporated into the model.
- Whether new hydrometric data is available to refine the hydrology.
- Whether new design tide levels or national guidance are available to refine the downstream tidal boundary.
- Whether new climate change guidance is available.
- Consider updating the Frome culvert representation to better match available topographic survey or undertake sensitivity analysis to demonstrate model results in the area of interest are not sensitive to this.

13.2 Options specific recommendations

As the preferred option is developed and the scheme progresses from Outline Business Case to Full Business Case and Detailed Design, it is recommended that hydraulic modelling is undertaken to test future design refinements that may materially impact on flood risk, e.g. realignments of flood defence, changes in crest levels.

If proposed flood defence alignments are refined in future, it is recommended that wave and super-elevation allowances are re-checked and the freeboard values refined if and where required. It is also recommended that the permissible overtopping flow used in the wave allowance calculation is reviewed and potentially tested / refined as the scheme design progresses, particularly where receptors are set back from the flood defence. Future studies should also consider whether additional information or analysis is available that will enable refinement of the level uncertainty component of the freeboard allowance.

A significant length of the proposed Phase 1 flood defences have proposed crest level set to the Phase 2 flood defence level excluding freeboard in order to mitigate unacceptable detrimental impacts. This crest level is higher than the Phase 1 flood defence level including freeboard. It is recommended that future stages of this project consider further optimisation of flood defence levels as there may be opportunity to reduce the height of these flood defences for Phase 1 without leading to unacceptable detrimental impacts, particularly where this is significant floodplain volume behind the flood defence such as at Ashton and Pill.

Future stages of this project should undertake further assessment of the requirement for flapped outfalls through the proposed flood defences, including optimisation of position, size and number of outfalls. This is most relevant for the River Avon left bank flood defence upstream of Netham Weir in the St. Anne's Road area, but should also be considered where the proposed flood defences have been identified to potentially impact on surface water flood risk.

The impact assessment shows some small / isolated areas of detriment in the Ashton area in some specific flood events for Phase 1 in 2030 and 2069. In the majority of cases this appeared to be due to LIDAR filtering issues at building footprints but there are two buildings where this does not appear to be the case. Given the uncertainty associated with impacts at these buildings, it is recommended that threshold survey is collected for these buildings in future stages of this project to determine whether these buildings would be impacted and the scale of impact.

14. Summary

Bristol City Council (BCC) have worked with the Environment Agency (EA) and other partners to create a long-term Strategy for managing flood risk from the River Avon. The resultant Bristol Avon Flood Strategy (BAFS) Strategic Outline Case (SOC) outlines action to be taken in phases to reduce the chance and impact of flooding from the River Avon, and how each phase will be funded. The Strategic Outline Case (SOC) was presented to the EA's Large Project Review Group (LPRG) and assured in January 2021. Following a public consultation, the Strategy was endorsed by BCC cabinet in March 2021.

The preferred option comprises raised flood defences along the River Avon including new tidal stop gates for the Floating Harbour. The initial phase of construction (Phase 1) is assumed to be completed in the 2030s and a subsequent phase of constructing additional defences and raising defences (Phase 2) is assumed for the 2060s.

Hydraulic modelling has been undertaken to support the OBC. This includes updating the baseline modelling to reduce uncertainties and subsequent modelling to support the development of the preferred option comprising the following:

- Identification and refinement of required flood defence alignments.
- Derivation of flood defence crest levels and freeboard allowances.
- Assessment of flood risk impacts (detriment) to third parties and identification of mitigation measures.
- Modelling to support the economic assessment.
- Assessment of residual flood risk.
- Assessment of impact on surface water and identification of potential mitigation measures.

A set of recommendations for future modelling work and freeboard assessment have also been provided that should be considered in future stages to support the development of the proposed scheme.

Appendix A

Baseline 'Do Minimum' option flood depth maps

Appendix B

Residual uncertainty assessment

Appendix C

Final flood defence levels

Appendix D

Impact maps

D.1 SOC defences without detriment mitigation

D.2 SOC defences with SOC detriment mitigation

D.3 Phase 1 (final)

D.4 Phase 2 (final)

D.5 Investigation of impacts in Ashton area

Appendix E

Residual risk maps for Phase 1