Bath & North East Somerset Council

River Avon downstream of Churchill Bridge – January 2013

BATH FLOOD RISK MANAGEMENT PROJECT: TECHNICAL SUMMARY

MARCH 2013

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Document Control

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1 Introduction

As part of the proposed Local Development Framework submission for the Bath and North East Somerset area, several new developments are proposed along the corridor of the River Avon in Bath. The proposed development sites are shown in Figure 1.

In order for the developments to satisfy the requirements of the *National Planning Policy Framework (NPPF)*, the developments should be safe from flooding throughout their lifetime, taking climate change into account, they must not have an adverse impact on flood risk to third parties and must have a means of safe access/egress during flood conditions. Where necessary, it is proposed to raise all the development sites so that minimum floor levels are above the 1 in 100 (1%) annual probability flood event (with an additional allowance of 20% on peak river flows for potential impacts of climate change or other uncertainties). Where possible the access/egress routes will also be raised above this level. However in certain locations this will be achieved through raising flood defence walls between the access routes and the river, which will improve the standard of flood protection provided. This will also benefit existing properties which are at risk of flooding.

Black & Veatch Ltd (B&V) has been appointed by B&NES to consider flood mitigation measures that will be required to achieve these objectives, and to identify a scheme that will successfully mitigate any resulting increase in flood risk as a result of excluding flood water from parts of the floodplain. This document sets out the findings of B&V's work, presents proposals for mitigating flood risk, and summarises the further work required to implement the solution.

2 Scheme Requirements

2.1 Mitigating flood risk

The 1960s Bath Flood Defence Scheme was designed to pass flood flows as efficiently as possible through the city. This was achieved by providing a large capacity 'canalised' channel, which effectively acts as a flume to convey a significant volume of flow. When the Avon exceeds its bank-full capacity, water will flow onto its floodplain and return to the river where topography and river levels allow. Ground raising within developments would reduce the extent to which water could flow along the floodplain to add to the total volume conveyed through Bath during extreme floods.

There are some small areas where flood storage volume would be lost. However, the volume lost is negligible compared to the volume of water passing down the river when in flood (up to 400m^3 or 400 tonnes every second). This is demonstrated by the fact that the computer model of the river and floodplain shows no increase in **downstream** flood levels if water is excluded completely from development sites by ground raising.

With all the development sites raised (but no mitigation) there is a maximum increase in level of 20mm in the 1 in 25 (4%), 30mm in the 1 in 50 (2%), 60mm in the 1 in 100 (1%) and 200mm in the 1 in 100 +20% (predicted increase in flows as a result of climate change) annual exceedance probability (AEP)[1] event. These

[1] The chance of a flood of a given size, or larger, occurring in any one year.

increases are to **upstream** levels as a result of the loss of flood conveyance capacity. This is a reflection of the fact that none of the development sites currently flood until a relatively large flood event occurs. However in a 1 in 100 +20% AEP event, large areas of the development sites would be flooded. Flood maps in Appendix A illustrate the estimated current flood extents under a range of annual probability events.

The approaches which have been considered for mitigating the increase in flood risk are discussed beneath the following sub-headings.

2.1.1 Channel Capacity

The intention of the design of the Bath Flood Defence Scheme in the 1960s was that the channel would be 'self cleansing'. This means that any silt that settled within the channel would be remobilised naturally by higher flows. Within the reach of the channel being considered as part of this study, this seems to have been largely successful. The Environment Agency has had a programme of surveying the bed levels of the channel in this area and has seen little change over many years, suggesting that there has been no significant change at all in the standard of protection delivered by the original scheme. An extensive exercise was completed by the Environment Agency in 2012 in which the cross sectional areas were compared against survey data from 1985. This showed that in general the cross sectional areas were actually larger in 2012 than 1985.

It is apparent that, whilst in areas there does appear to have been an accumulation of silt, this has not increased the flood risk as either it would be remobilised in a flood event or is in areas where there is little flow (e.g. Pulteney Boat Dock). Dredging of the channel to increase capacity would not mitigate the increase in flood risk as a result of development.

2.1.2 Compensatory storage

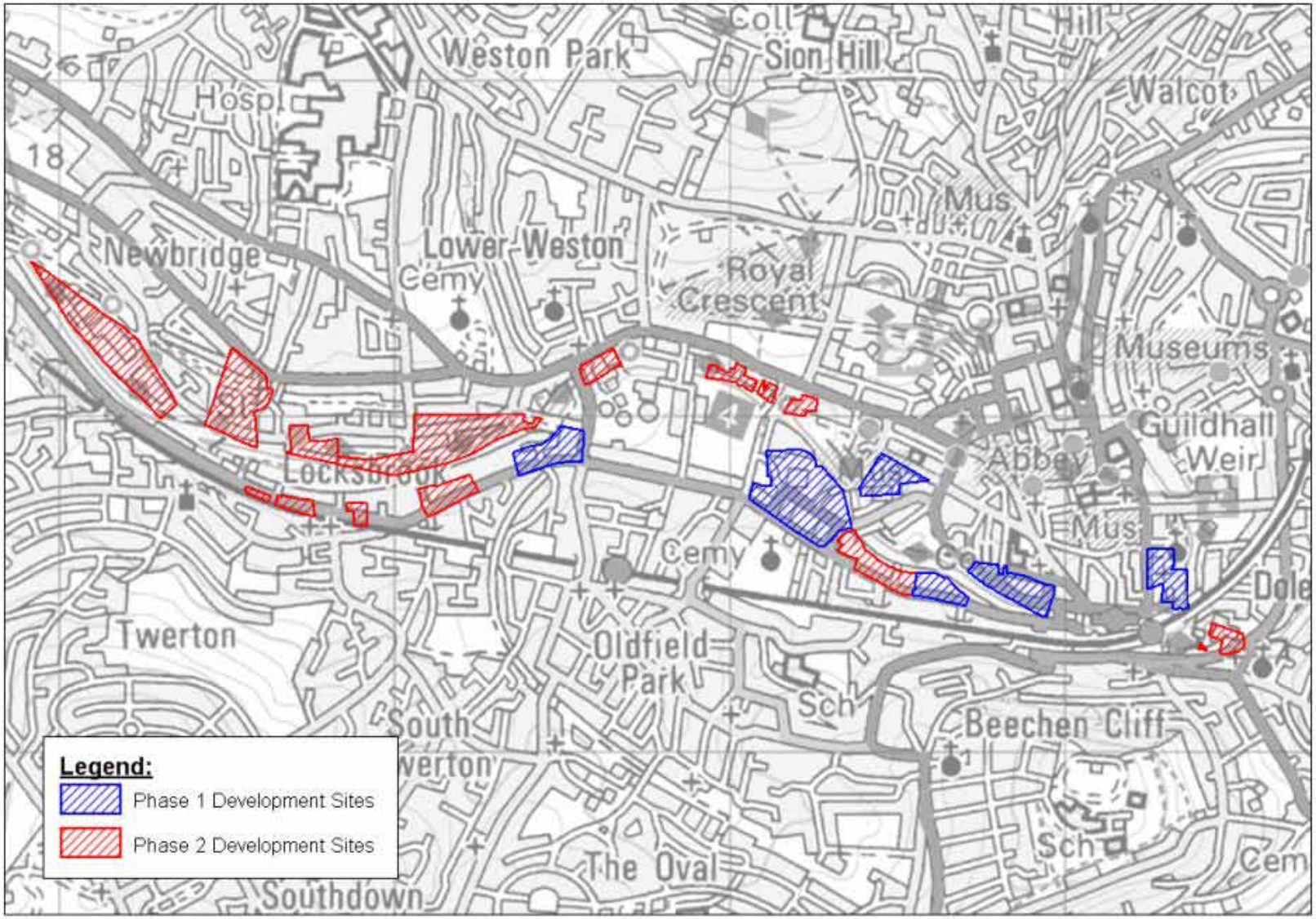
Options to provide compensatory flood storage upstream of Bath have been considered by B&NES as a means of mitigating the increase in flood risk. Previous studies, whilst suggesting upstream storage may be suitable, have all concluded that further more detailed computer modelling should be undertaken to confirm this approach.

This modelling has now been undertaken and confirms that, as stated above, the principal impact of raising developments is a loss of flow conveyance, rather than a loss of flood storage. To provide upstream flood storage that would actually reduce peak flows in Bath would require a volume that is in excess of 10 million cubic metres and it would need to be on land that currently does not flood. No suitable sites of this size are available upstream and therefore upstream storage is no longer being considered as part of any flood mitigation measures for these development sites.

There may be other development sites that come forward in the future which may result in a noticeable effect from loss of flood storage if they were raised above flood level. In previous studies, Batheaston Meadows upstream of Bath has been identified as the most suitable location to provide strategic flood storage mitigation. This is due to the availability of some land above flood levels, its proximity to Bath and the fact that it is owned by B&NES. Whilst this land is not required as part of this phase of works, it would seem sensible to safeguard this land to allow it to be used in the future if required.

The move from the consideration of upstream flood storage to reduce flood risks towards a solution using compensatory flow conveyance (described below) is in part due to a number of local, national and international directives and strategies. These include the B&NES Public Realm and River Corridor strategies as well as the EU Water Framework Directive. These promote greater use of the river corridor for amenity and biodiversity purposes and encourage greater connection between the river and its floodplain.

Figure 1 – Bath development sites



2.1.3 Compensatory flow conveyance

B&V has investigated whether the provision of compensatory flow conveyance along the river corridor is a viable means of mitigating flood risk. The principle of this option is to increase the cross sectional area available to convey flood flows. If this is done at appropriate locations in an efficient way, the effect of this would be to reduce flood levels for given flows and to cancel out any increase in upstream flood levels as a result of raising ground levels on the development sites This option was investigated by adapting the existing computational hydraulic model of the River Avon, which was originally developed for the Environment Agency. The model comprises a 1-dimensional (ISIS Flow) representation of the river channel and structures, and a 2-dimensional (Tuflow) representation of the floodplain. The new developments were represented by raising ground levels within the 2-dimensional component. Model runs were undertaken to estimate the impact of this floodplain loss on river levels during extreme flood conditions. A full description of the hydraulic modelling is included in Appendix B.

The model was then modified to test options for providing additional flow conveyance at strategic locations where it is hydraulically feasible to modify the existing river banks. This was achieved by locally widening river cross sections to provide the additional conveyance.

The modelling concluded that the provision of compensatory flow conveyance at several locations would mitigate the increase in flood risk as a result of the loss of floodplain conveyance by excluding floodplain flow from the development sites in extreme flood events. For conveyance improvements to be successful they must take account of the following constraints:

- The level above which any conveyance improvements are provided is important. If the conveyance is provided at too low a level, flow in the Avon will slow down, causing river levels to rise locally. If the level is too high, conveyance will not be provided when required.
- The width of conveyance improvements is also important. Providing too wide a section will slow the flow down, causing an increase in levels. If insufficient width is provided, it will not be possible to completely mitigate the increase in flood risk.
- The conveyance improvements should be hydraulically continuous. Interruptions along the length of improvements, e.g. retaining existing bank profiles where mature trees are present, will not have the required effect. However, small items within the conveyance improvements, such as seating benches and lamp posts, would be acceptable.
- To fully mitigate the impact on flood risk, it will be necessary to complete the improvements in a phased manner depending on which development sites proceed first.

2.2 Protecting safe access / egress

Lower Bristol Road will form the main access to several of the proposed developments, which will be raised above the floodplain. NPPF requires that safe access to and from the development is maintained in all floods up to the 1 in 100 +20% event.

B&V's modelling has confirmed that the existing flood defences protecting Lower Bristol Road, which comprise flood defence walls and temporary flood barriers across windows fronting the river, would be overtopped during a 1 in 50 (2%) AEP event. In addition, the existing surface water drainage network in Lower Bristol Road has a limited capacity to store storm water when high river levels prevent discharge to the Avon.. Lower Bristol Road is therefore at risk of flooding from both the Avon and surface water. If these issues are not addressed, there would be no safe access to / egress from the development sites when the Avon is in flood. Safe access can be provided to all other development sites through ground raising within the sites.

In order to maintain safe access along Lower Bristol Road, the scheme must comprise the following improvements. These improvements will have the benefit of improving the standard of flood protection provided to existing properties along Lower Bristol Road:

- Overtopping of the existing defences must be avoided in the 1 in 100 +20% event. The conveyance improvements alone will not achieve this objective. B&V has estimated that the existing flood defences would need to be approximately 300 to 500mm higher than their current levels, depending on location. This includes an allowance of 150m for freeboard.
- Surface water flooding could be partly addressed through adding flap valves on the outlets to the River Avon. In addition to this the storage capacity of the drainage system could be increased. However, this is likely to be prohibitively expensive. Therefore it will be necessary to provide a pump station to mitigate surface water flooding during periods of high river flow.

3 Scheme Proposals

The outline proposed improvements are described in this section. B&V has referred to the following information in developing these proposals:

- Recollections of the 1960s Bath Flood Defence Scheme by Trevor Holroyd, who was involved in the development of that scheme. These recollections were assembled by B&V and provided to the Environment Agency in 2005 and form a useful reference.
- Utility service information provided by B&NES, including surface water drainage networks.
- Environmental information provided by B&NES.
- Online resources such as the Environment Agency website, the MAGIC website, the B&NES Adopted Local Plan, previous Environmental Statement for the Bath Riverside Development and the South Quays site.
- Topographical survey of the river banks undertaken by MK Surveys and procured by B&NES.
- 1960s scheme drawings provided by the Environment Agency.

3.1 Flood Conveyance Improvements

The locations of the proposed flood conveyance improvements are summarised on Figure 2 and Figure 3 and described beneath the following sub-headings. All of the improvements shown would be required to offset the net impact of all development sites.

Figure 2 – Locations of proposed flood conveyance improvements between Churchill Bridge and Midland Road Bridge

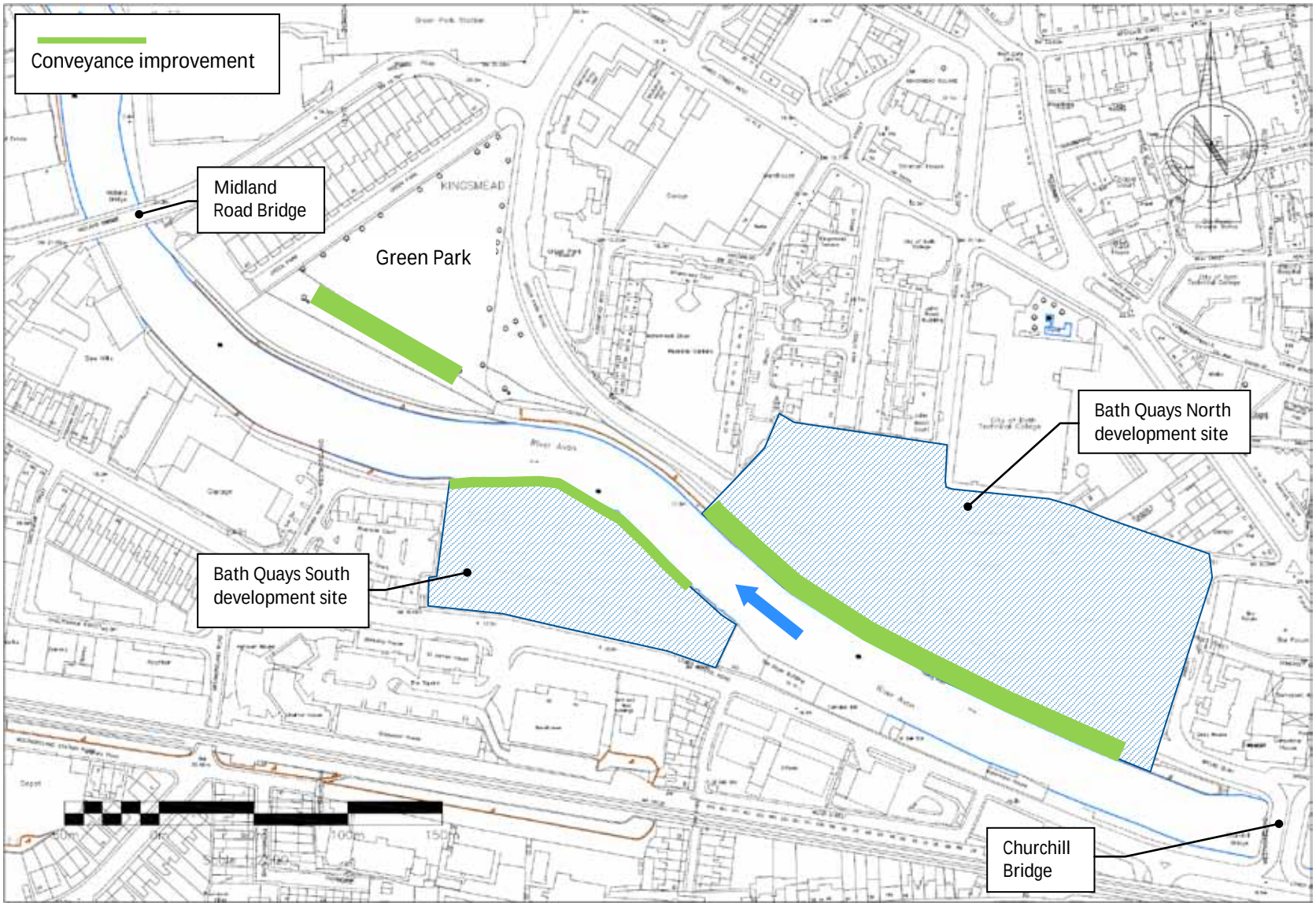
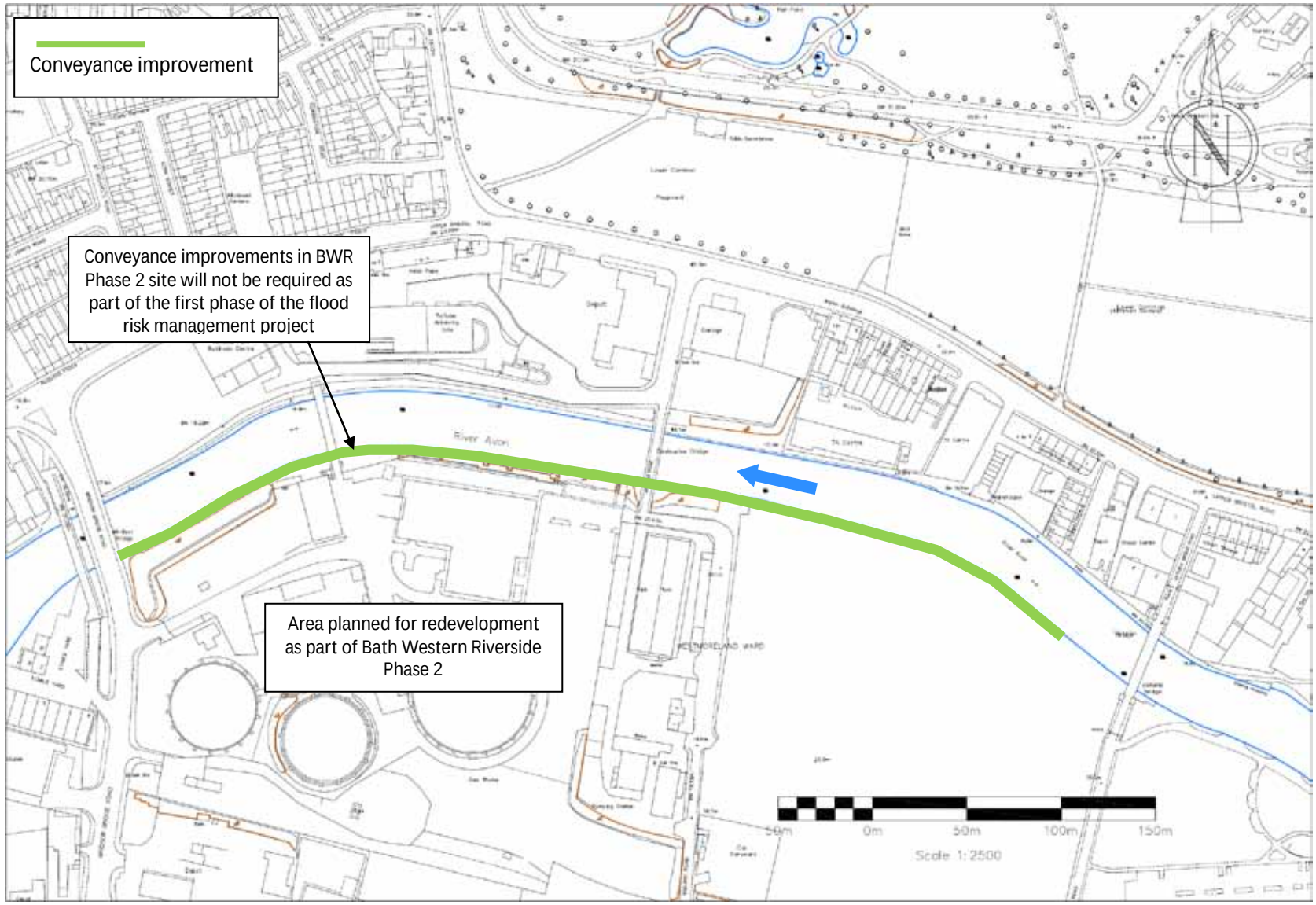


Figure 3 –Locations of proposed flood conveyance improvements upstream of Windsor Bridge



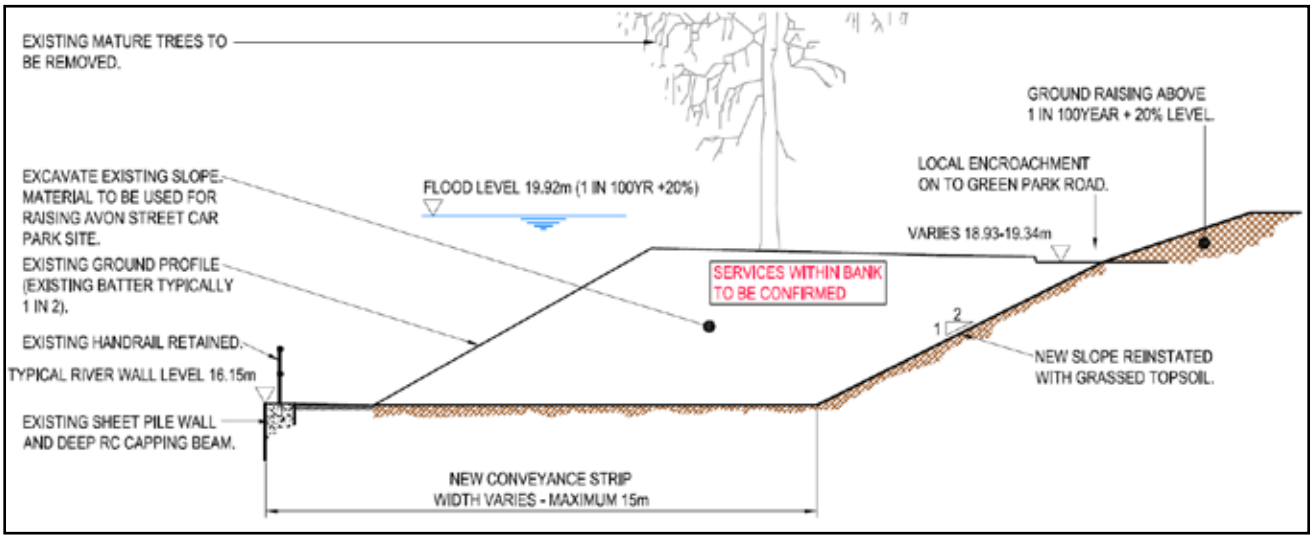
3.1.1 Right bank: Bath Quays North

The existing river bank fronting the proposed Bath Quays North comprises a steel sheet piled wall with a deep reinforced concrete capping beam, which was constructed as part of the Bath Flood Defence Scheme in the 1960s. A 2m wide tow path is located adjacent to the capping beam at a level of approximately 16m Above Ordnance Datum (AOD). There is a 3m high grassed slope adjacent to the tow path, which has a gradient of approximately 1 in 2 (see Figure 4). Green Park Road is located at the top of this slope.

Figure 4 – Existing bank fronting Bath Quays North

It is proposed to provide a conveyance strip at the level of the tow path to offset the increase in flood risk. The conveyance strip would vary in width between 8m and 15m, and would extend for approximately 300m along the River Avon. This would require the excavation of the existing grassed slope, which would be reinstated landward of the conveyance strip. A typical section of the proposal is shown in Figure 5.

Figure 5 –Typical section through proposed conveyance improvements at Bath Quays North



To accommodate the conveyance strip, it would be necessary to remove a number of mature trees which currently line the Green Park Road. This loss would be compensated for by a landscape mitigation scheme, which will be developed with the B&NES environmental planning team.

The improvements may also locally encroach onto Green Park Road. However, it is understood that this road would be locally diverted to accommodate the Bath Quays North development. In the event that it is not diverted, steeper retaining walls would be required in place of the 1 in 2 slope.

This work is required as part of the first phase of the flood risk management scheme.

3.1.2 Right Bank: Green Park

It is understood that Green Park was used as a deposit for construction spoil from the 1960s scheme. This was landscaped to create a raised 'mound' in the centre of the park (see Figure 6).

Figure 6 –Green Park (raised ground to left of picture)

It is proposed to locally excavate into this raised ground to introduce a flood conveyance strip at a level of approximately 18mAOD. This would not require any modification of the existing river bank.

The creation of this conveyance strip may require the removal of some mature trees from within Green Park. These would be compensated for by the landscape mitigation scheme discussed above.

This work is required as part of the first phase of the flood risk management scheme.

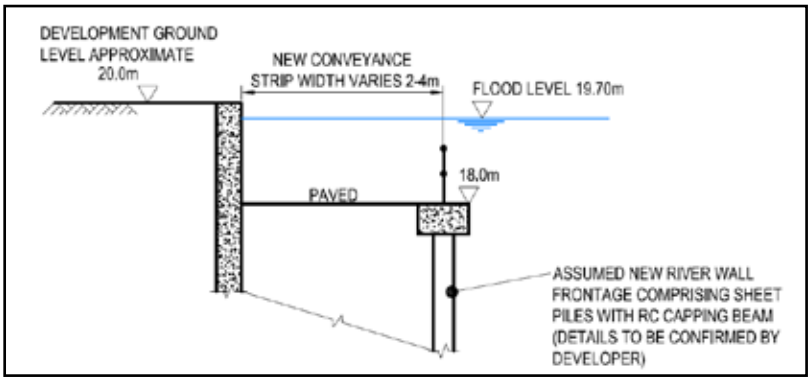
3.1.3 Left bank: Bath Quays South

The existing river frontage along the Bath Quays South development site comprises a mixture of different wall constructions, including timber piled walls, masonry walls, and natural bank. It is understood that this section of river frontage was not improved as part of the 1960s scheme, meaning that the walls are likely to be in excess of 50 years old. Parts of this frontage are in poor condition, particularly the section downstream of the masonry arches adjacent to the Bayer Building, where there are a number of voids visible (see Figure 7).

Figure 7 – River frontage in poor condition at Bath South Quays site

It is envisaged that the river frontage along Bath Quays South would need to be replaced to facilitate construction of the development site. This presents opportunities to provide a more consistent river frontage and to provide a new conveyance strip. The conveyance strip would need to be approximately 4m wide at a level of around 18mAOD, approximately 2m below the proposed ground level in the Bath Quays South development. A cross section through the proposed improvements is shown in Figure 8.

Figure 8 – Section through proposed conveyance strip at Bath Quays South development



It is envisaged that the new river frontage would comprise a steel sheet pile wall, which may need to be anchored, with a concrete capping beam. To maximise the development footprint, it is likely that a vertical retaining wall would be required landward of the flood conveyance strip. Access to the conveyance strip would need to be provided at either end. Assuming this can be accommodated within the development, the provision of a conveyance strip within Bath Quays South would be less complicated than providing one on the opposite bank, where there is limited space between the river and Green Park Road.

This work is required as part of the first phase of the flood risk management scheme.

3.1.4 Left bank: Bath Western Riverside

The first phase of the Bath Western Riverside development included the provision of an 8m wide strip at a level of 16mAOD (see Figure 9). It is proposed to continue this strip throughout the remainder of the Bath Western Riverside development to Destructor Bridge, adopting the same detail. At present a continuation of the conveyance strip at 16mAOD has been considered. The optimum level of this strip will be confirmed as

the proposals are developed. The optimum level would be that it is low enough to provide the required flood conveyance benefits, whilst also being at a high enough level to ensure that flooding of the walkway does not occur too frequently.

This work is required as part of the first phase of the flood risk management scheme. As part of a later phase of the flood risk management scheme it is proposed to continue this walkway through the length of the Bath Western Riverside Phase 2 site (i.e. between Destructor Bridge and Windsor Bridge Road.

Figure 9 – Existing conveyance at Bath Western Riverside

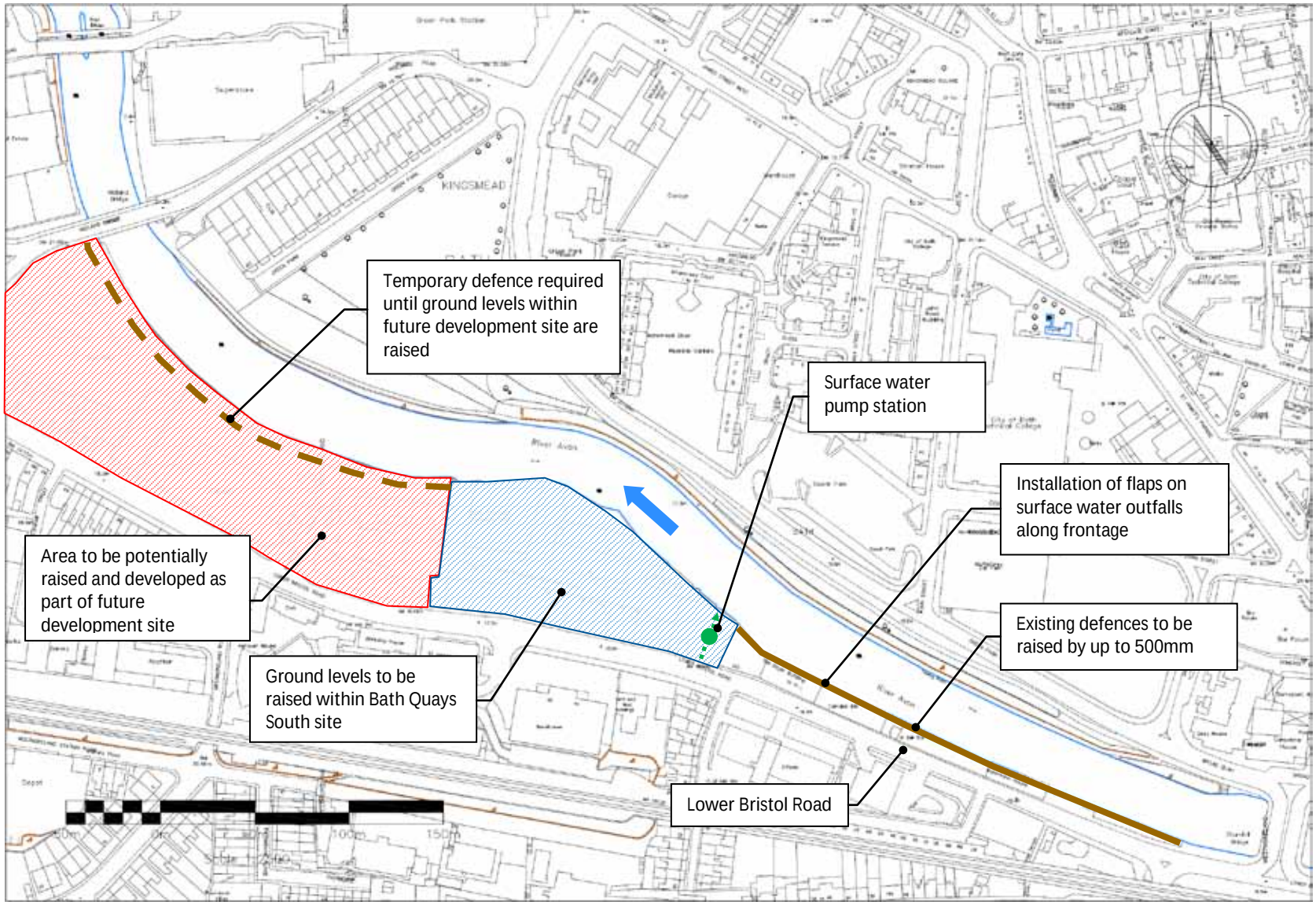
3.2 Flood defence improvements

The locations of the proposed flood defence improvements are summarised on Figure 10. These improvements would secure safe access/egress along Lower Bristol Road from fluvial floods up to the 1 in 100 +20% event. These improvements would also improve the standard of flood protection provided to properties along Lower Bristol Road.

The following improvements are proposed. These details of these improvements will be developed in consultation with landowners and the Environment Agency during the subsequent detailed design stage of this project:

- Raising/replacement of existing flood defence walls along Lower Bristol Road (see Figure 11). These walls were constructed as part of the 1960s flood defence scheme.
- Improvement to existing temporary flood boards across windows at Waterfront House, Camden Mill, Bayer Building (see Figure 12). Where temporary flood boards cannot feasibly be installed across windows (due to the span or access issues), a mutually agreeable solution will need to be identified through consultation with the building owners.

Figure 10 – Locations of flood defence improvements



- Installation of flaps on several large surface water outfalls (see Figure 13). This will prevent fluvial flooding of Lower Bristol Road when the river levels are higher than the road level.
- Provision of a temporary flood defence wall alongside the river within the area proposed for future development to the west of Bath Quays South. Eventually ground levels within this development site will be raised above the flood level, and therefore a temporary flood defence is required to prevent flood water crossing the site in the meantime. Existing shrub vegetation along this frontage will shield the view of the temporary defence from the opposite bank.
- Installation of a new surface water pump station. This would be required to deal with surface water flooding when high river levels prevent discharge of the sewer network to the river. It is anticipated that the pump station could be accommodated within the Bath Quays South Phase 1 development site. Some localised improvements to the drainage network in Lower Bristol Road may be required to accommodate this.

Figure 11 – Existing flood wall protecting Lower Bristol Road

Figure 12 – Existing flood boards in lower windows at Camden Mill

Figure 13 – Unflapped outfall downstream of Churchill Bridge

3.3 Environmental impacts

Table 3.1 provides potential impacts of the proposals at each of the locations. A desk study of the proposals has been undertaken and has identified that generally:

- The whole of Bath has World Heritage Site status. This would not be affected by the proposals which will be sensitively designed to ensure that the character of the riverside is unchanged. A landscape assessment will be required of the proposals in full consultation with the B&NES Landscape Architect.
- During construction there could be negative impacts on the road network from construction traffic which will need to be planned carefully.
- The works to the right bank are within the Bath Conservation Area on the B&NES Adopted Local Plan 2007. Agreement with the B&NES Tree Officer on proposals to remove and replant trees will be required before notification of tree works is provided to them.
- The River Avon is a Site of Nature Conservation Interest (SNCI) and therefore the works must ensure that the river is protected. There are no statutory nature conservation sites within 2km of the proposals apart from Kensington Meadows Local Nature Reserve which is located approximately 1.8km north east and will not be affected.
- Bath has a rich history and therefore the potential for the recovery of buried archaeological deposits or finds is high with any ground breaking activity. Further desk based assessments and a programme of archaeological investigation will be required for any proposals.
- The waterbody classification of the stretch of the River Avon adjacent to the works under the Water Framework Directive is Good Ecological Potential. The proposals will need to be screened to ensure that improving the conveyance during flood events does not adversely affect the ecological potential of the waterbody.

Table 3.1 - Specific Environmental Impacts and Proposed Mitigation

Location	Key Environmental Impacts, Proposed Mitigation and Opportunities
Right Bank: Bath Quays North	· Loss of approximately 20 trees, a tree planting scheme to mitigate for the loss of these trees will be required. · The river side path will be closed for the widening works. A diversion will be required to ensure that the cycle links to National Cycle Network 4 are maintained. Widening the cycle path in this location will improve the accessibility of the path. Other enhancements could be incorporated to the design to improve the amenity of the area. · The design should aim to reuse the material excavated from the slope of find a location where it can be recycled. The material will require testing to ensure that it is not contaminated.
Right Bank: Green Park	· Downstream is the Grade II Listed Victoria Bridge. The proposals will need to be landscaped to complement the bridge. · There are opportunities to enhance the amenity of this area with street furniture and interpretation display materials. · There will be disruption to the users of the park during the works. Advance notice, sensitive programming and phased working will mitigate this impact. · Loss of approximately ten mature trees. A tree planting scheme will be required to mitigate for the loss of trees.
Left Bank: Churchill Bridge to Waterfront House	· No specific impacts have been identified.
Left Bank: Waterfront House	· Users of the affected properties will be disturbed during flood events if they have to install temporary boards · However, improvements will reduce risk internal flooding of buildings. · Waterfront House is a Grade II Listed Building. Any works to the property will require Listed Building Consent.
Left Bank: Waterfront House to Camden Mill	· Temporary use of the car park to construct the wall. Alternative parking provision may need to be provided.
Left Bank: Camden Mill and Bayer Building	· Users of the affected properties will be disturbed during flood events if they have to install temporary boards. · However, improvements will reduce risk internal flooding of buildings. · Camden Mill is a Grade II Listed Building. Any works to the property will require Listed Building Consent.
Left Bank: Bath Quays South	· The proposals and potential environmental impacts of measures to improve conveyance in this section will be detailed by the eventual developers of the site. · A previous application for an educational centre in the development was not granted planning permission. An Environmental Statement was prepared in 2006 which noted that there may be potential impacts on environmental receptors such as archaeology, the Newarks Works, protected species, the River Avon SNCI amongst others. · Any piling to create a new river frontage is likely to need to avoid the salmonids migration periods (15th October 15th April) and may require noise and vibration monitoring.

Location	Key Environmental Impacts, Proposed Mitigation and Opportunities
Left Bank: Bath Western Riverside	An Environmental Statement has been prepared for the development which identified the following, which will be relevant for extending the conveyance improvements downstream: · Impacts on air quality from dust and emissions will be mitigated by measures included in a Construction Environmental Management Plan. · A Bronze Age sword was found on the former gas work site indicating evidence for prehistoric activity in the area; there are also records from the 19th and 20th Century industrial development of the area and the Roman period. A programme of archaeological investigation will be undertaken. · Slow worms have been recorded and the area has interest for invertebrates. There are sightings of otter; although habitats on site are unsuitable. Bat surveys showed no bat roosts. The developer proposed a number of mitigation measures and enhancements in the form of reed rafts in the River Avon. · The previous industrial uses of the site have led to contamination. Further ground investigation would be undertaken to establish a remediation plan. · The development would have effects on microclimate but these effects would be reduced once landscape planting had established. · Noise impacts were considered negligible as the area is also part of a busy road network. · There would be social impacts from the additional accommodation but this is considered to be outweighed by the social benefits from the development. · There will be improvements in the visual realm for near views of the site however, there would be a limited loss of openness which interruption of certain views across the Avon Valley. This would be mitigated with good design.

4 Next Steps

4.1 Screening decision and planning

It will be necessary to obtain a screening decision from B&NES planning officers to determine the consenting requirements for the improvements described in this document.

The proposals will require planning permission. The proposals are listed on Schedule 2 of the Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1999 and are within a 'sensitive site' (i.e. World Heritage Site) as defined in the regulations. However, the nature of the works may preclude the need for a statutory Environmental Impact Assessment (EIA). A comprehensive screening request will be submitted to the planning officers to determine this.

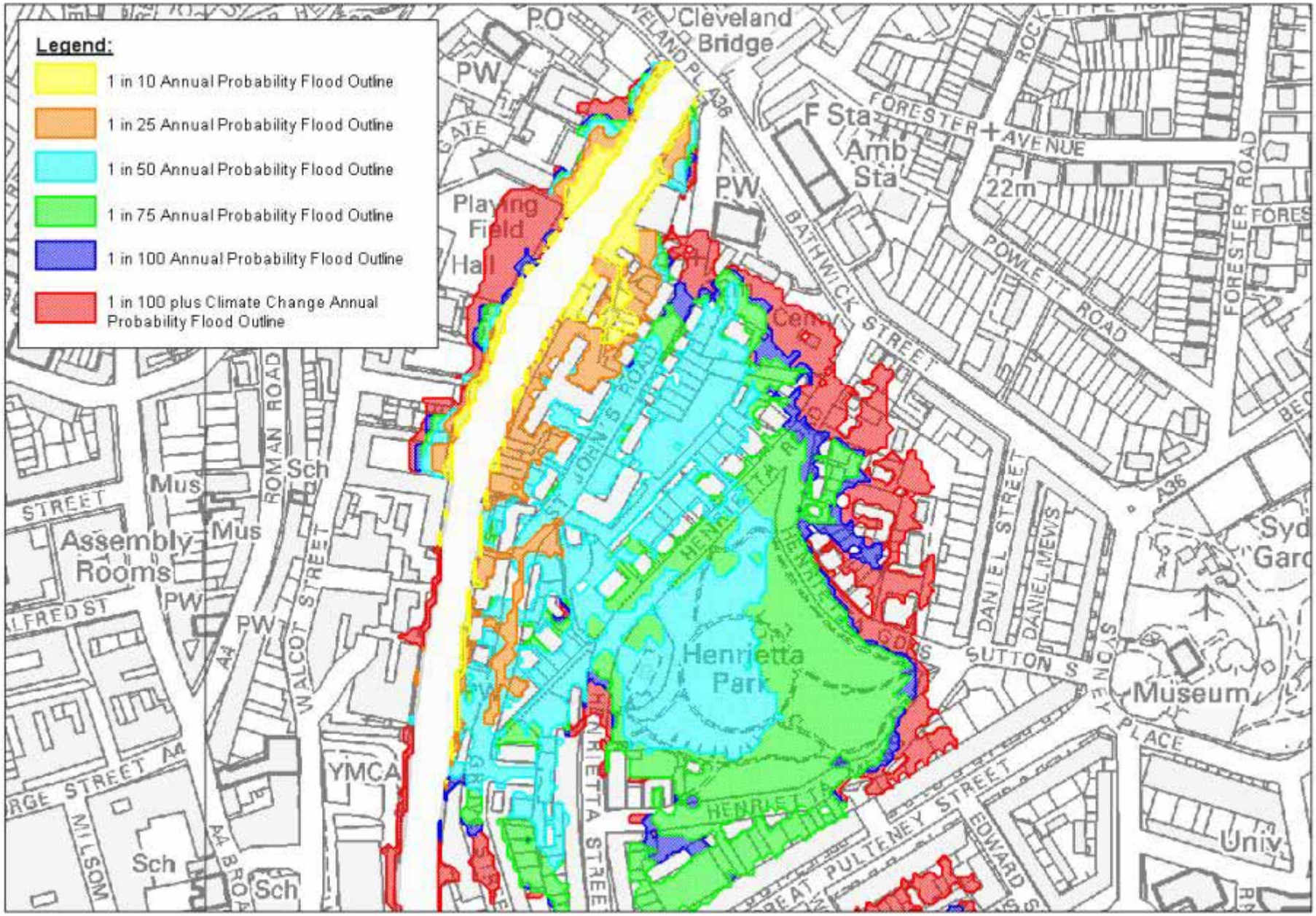
4.2 Design development

It will be necessary to develop the design of the scheme prior to submission of a planning application and Flood Defence Consent application. This would include the following associated work:

- Confirming the alignment, function, depth and size of services affected by the proposed improvements. This is likely to require physical service tracing and mapping. Arrangements would need to be developed to divert or accommodate any services.
- Undertaking ground investigations to inform the foundation design of new flood walls, bank stability, and the risk of ground contamination.
- Obtaining structural cores from the existing flood walls to confirm their construction, and to conclude whether they can be raised or whether they would need to be rebuilt to a higher level.
- Collaboration with B&NES landscape architects to undertake a Landscape Assessment to ensure that the scheme achieves engineering objectives as well as the likely aesthetic requirements raised during the planning process.
- An Extended Phase 1 Habitat Survey to identify any ecological risks of the proposals and an Arboricultural Assessment of any trees to be lost.
- An Archaeological Desk Based Assessment and liaison with the County Archaeologist.
- Consultation with landowners to identify mutually acceptable solutions.
- Consultation with statutory stakeholders to obtain their views on the proposals and to identify risks and mitigation. This will include the Environment Agency and the B&NES Planning Officer.

APPENDIX A

Flood Maps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1 in 100 Annual Probability Flood Outline
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Cleveland Bridge
PO
PW
F Sta
Amb Sta
FORESTER AVENUE
22m
Playing Field
BATHWICK STREET
POWLETT ROAD
FORESTER ROAD
ROMAN ROAD
Sch
Mus
Assembly Rooms
STREET
WALCOT STREET
ST JOHN'S ROAD
HENRIETTA ROAD
Henrietta Park
DANIEL STREET
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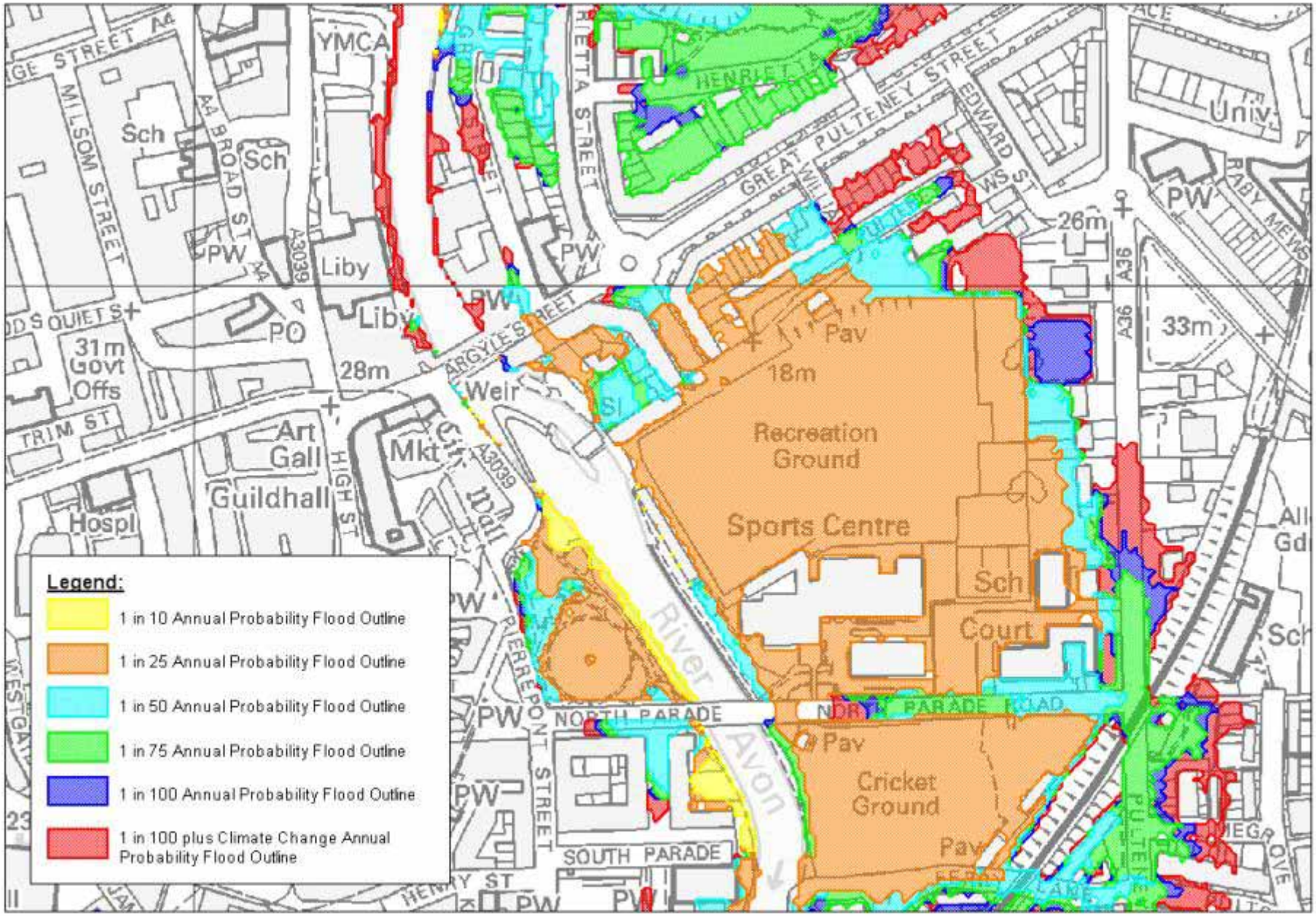
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1 in 100 plus Climate Change Annual Probability Flood Outline
Recreation Ground
Sports Centre
Cricket Ground
River Avon
Weir
NORTH PARADE
SOUTH PARADE
GREAT PULTENEY STREET
ARGYLE STREET
HENRIETTA STREET
MILSOM STREET
HIGH ST
YMCA
Univ
Guildhall
Hospl
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Pav
Court
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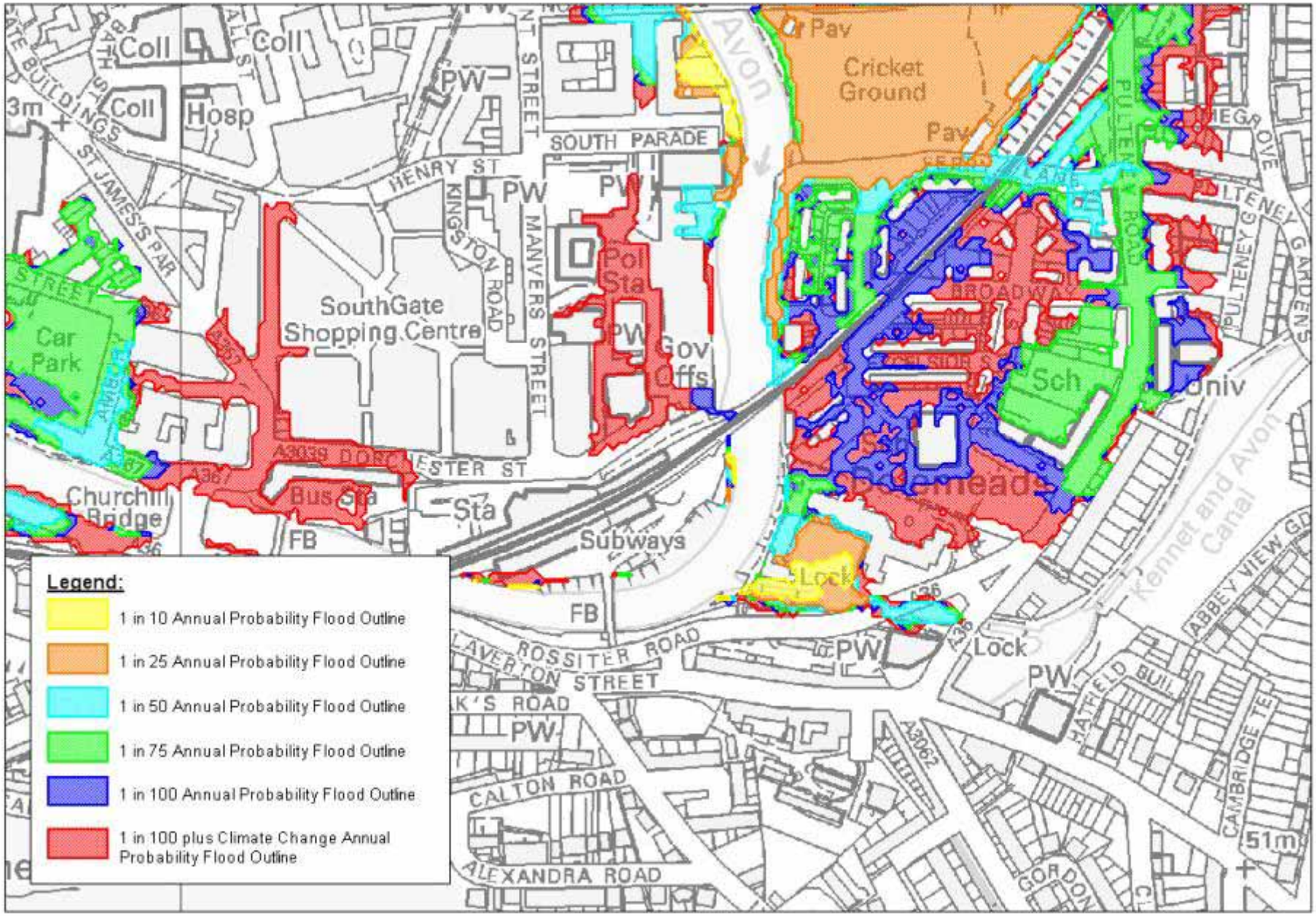
33m
28m
18m
31m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1 in 75 Annual Probability Flood Outline
1 in 100 Annual Probability Flood Outline
1 in 100 plus Climate Change Annual Probability Flood Outline
Avon
Cricket Ground
SouthGate Shopping Centre
Car Park
Churchill Bridge
Subways
Lock
Kennet and Avon Canal
SOUTH PARADE
HENRY ST
MANVERS STREET
KINGSTON ROAD
ST JAMES'S PAR
ROSSITER ROAD
LAVERTON STREET
CALTON ROAD
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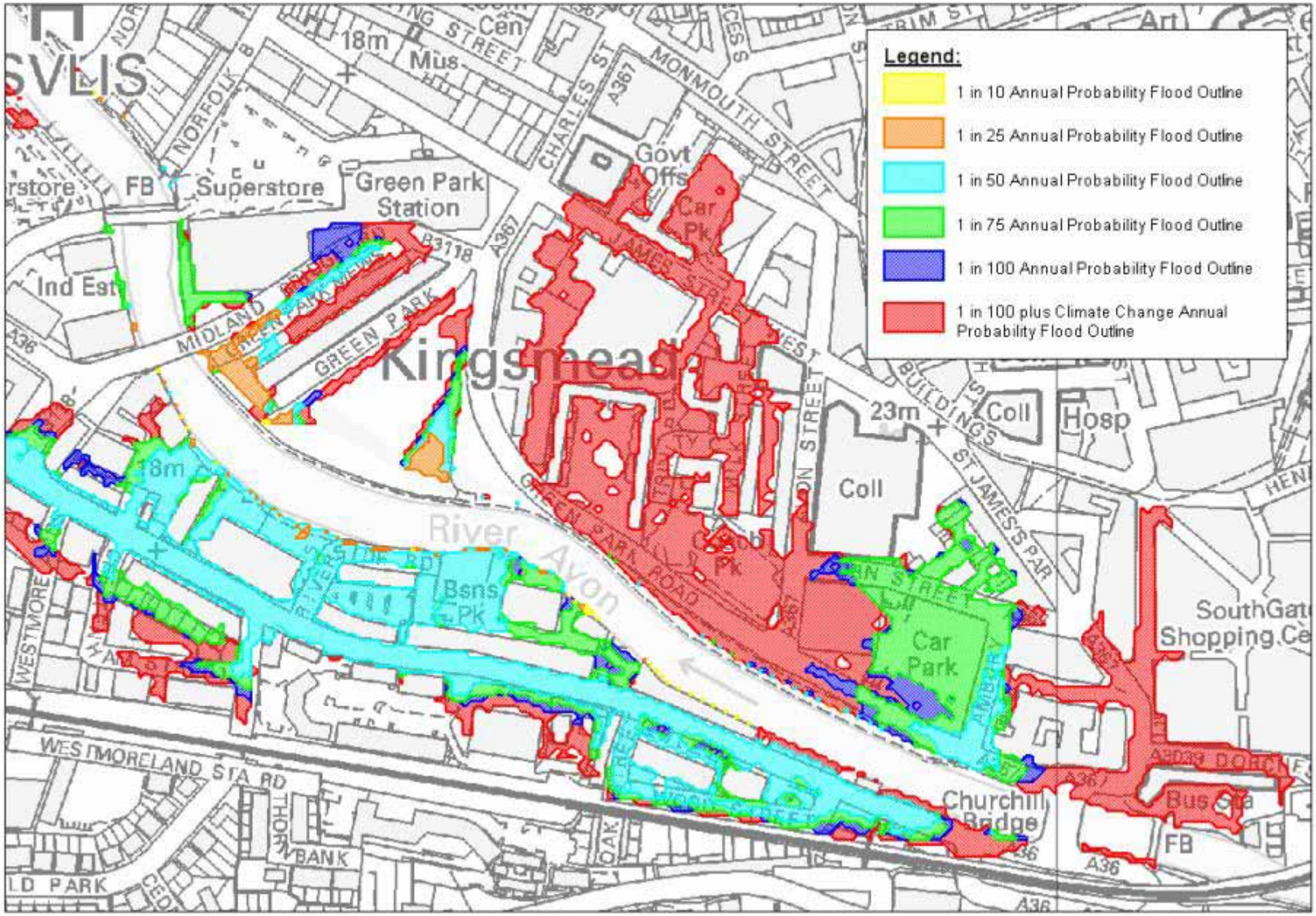
CAMBRIDGE TE
51m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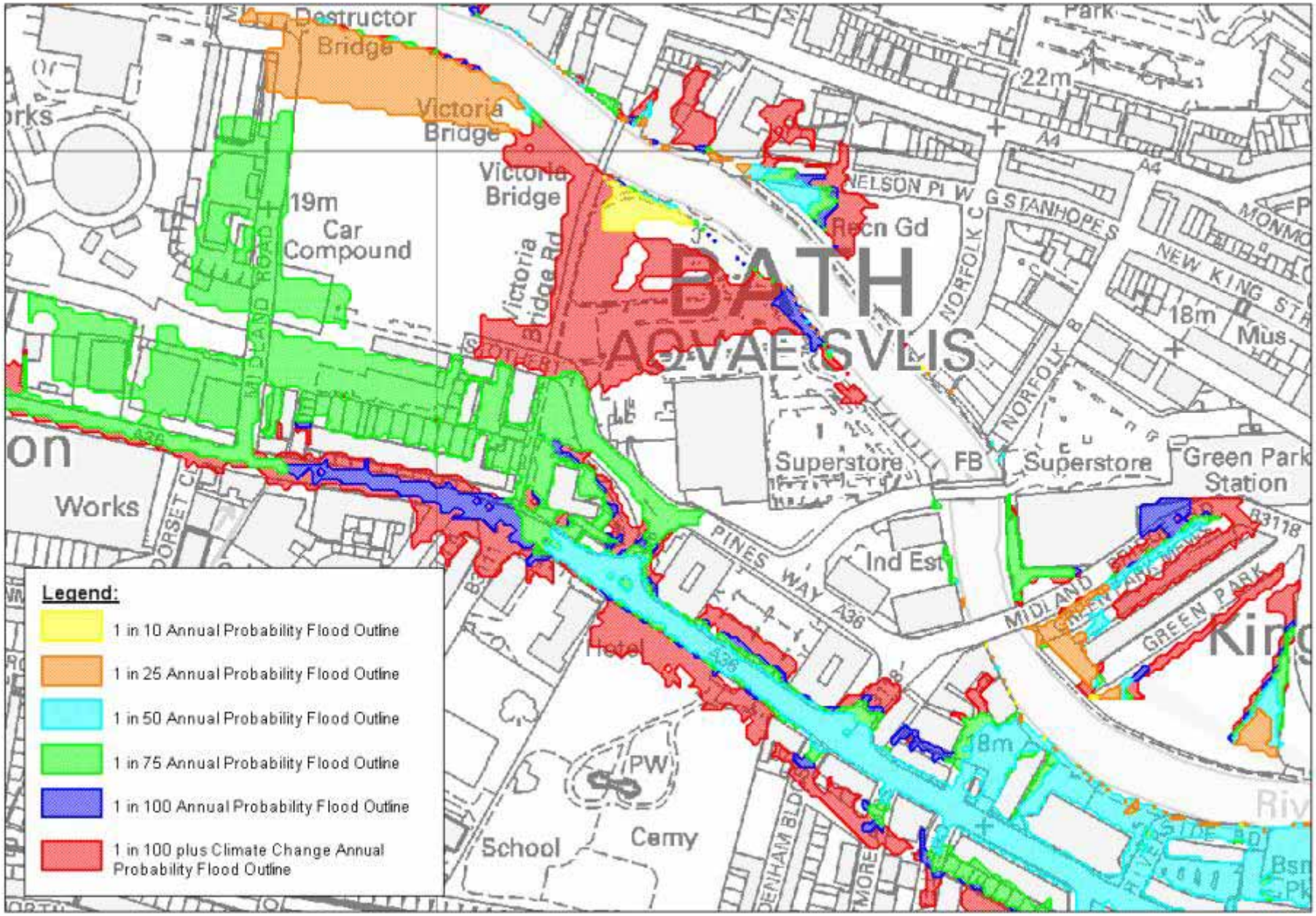
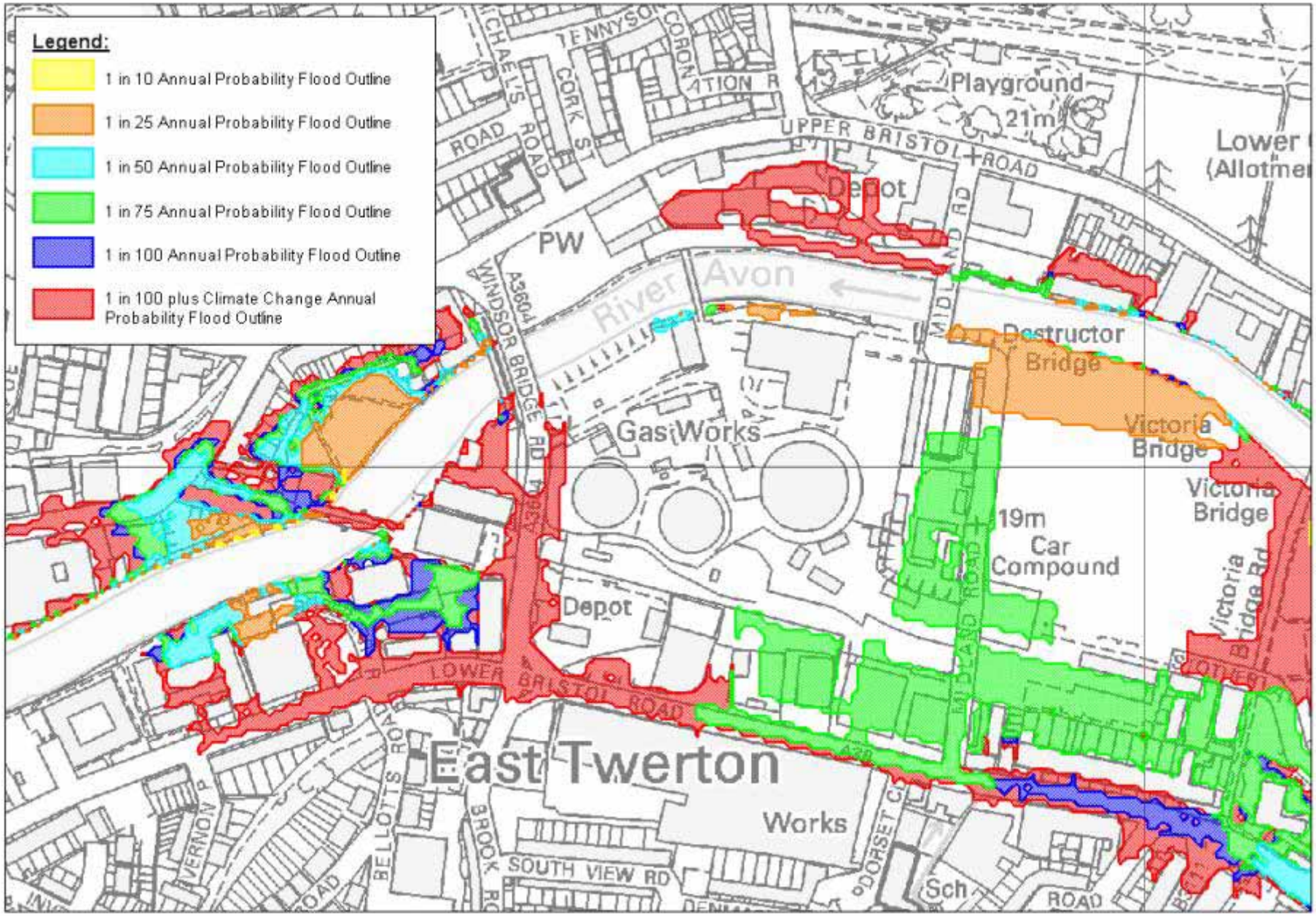
1 in 10 Annual Probability Flood Outline
1 in 25 Annual Probability Flood Outline
1 in 50 Annual Probability Flood Outline
1 in 75 Annual Probability Flood Outline
1 in 100 Annual Probability Flood Outline
1 in 100 plus Climate Change Annual Probability Flood Outline
Kingsmead
River Avon
Green Park Station
Superstore
Ind Est
Govt Offs
Car Pk
Coll
Hosp
Bsns Pk
Car Park
Churchill Bridge
Bus Sta
FB
MONMOUTH STREET
CHARLES ST
NORFOLK
MIDLAND
GREEN PARK
GREEN PARK ROAD
JAMES STREET
ST JAMES'S PAR
BUILDINGS
WESTMORELAND STA RD
WESTMORE
BANK
A367
A36
B3118
18m
23m


Destructor Bridge
Victoria Bridge
Victoria Bridge
19m
Car Compound
Victoria Bridge Rd
Recn Gd
NELSON PL W
G STANHOPES
NORFOLK C
NORFOLK
NEW KING ST
18m
Mus
22m
Park
A4
Superstore
FB
Superstore
Green Park Station
Works
PINES WAY
A36
Ind Est
MIDLAND
GREEN PARK
B3118
Hotel
PW
School
Cemy
18m
Legend:
1 in 10 Annual Probability Flood Outline
1 in 25 Annual Probability Flood Outline
1 in 50 Annual Probability Flood Outline
1 in 75 Annual Probability Flood Outline
1 in 100 Annual Probability Flood Outline
1 in 100 plus Climate Change Annual Probability Flood Outline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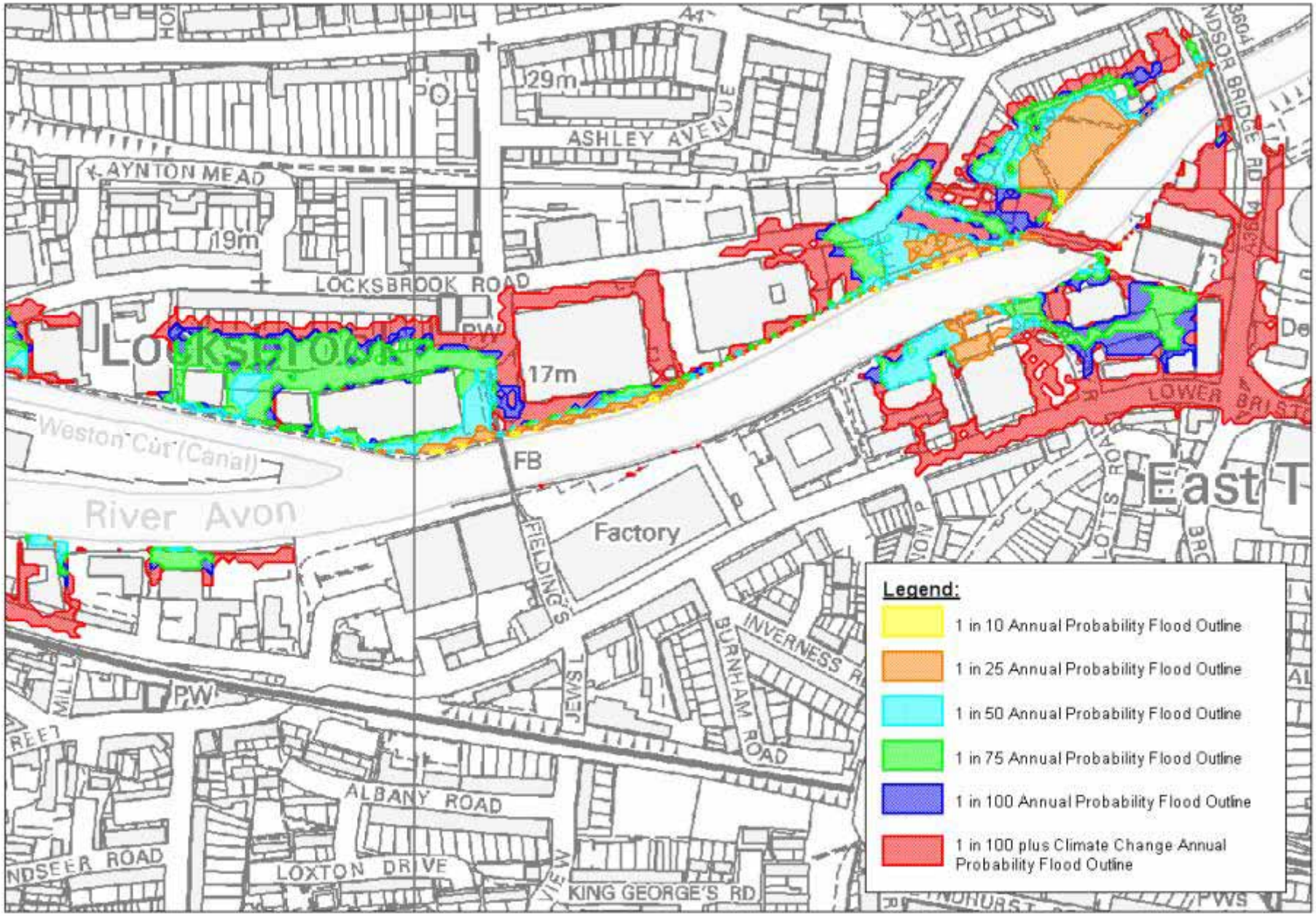
1 in 50 Annual Probability Flood Outline
1 in 75 Annual Probability Flood Outline
1 in 100 Annual Probability Flood Outline
1 in 100 plus Climate Change Annual Probability Flood Outline
Playground
21m
UPPER BRISTOL ROAD
Depot
PW
River Avon
Destructor Bridge
Gas Works
Victoria Bridge
19m Car Compound
Depot
LOWER BRISTOL ROAD
East Twerton
Works
SOUTH VIEW RD
Sch
WINDSOR BRIDGE RD
A3604
CORK ST
CORONATION R
TENNYSON
VERNON
BELLOTTS ROAD
BROOK RD
DORSET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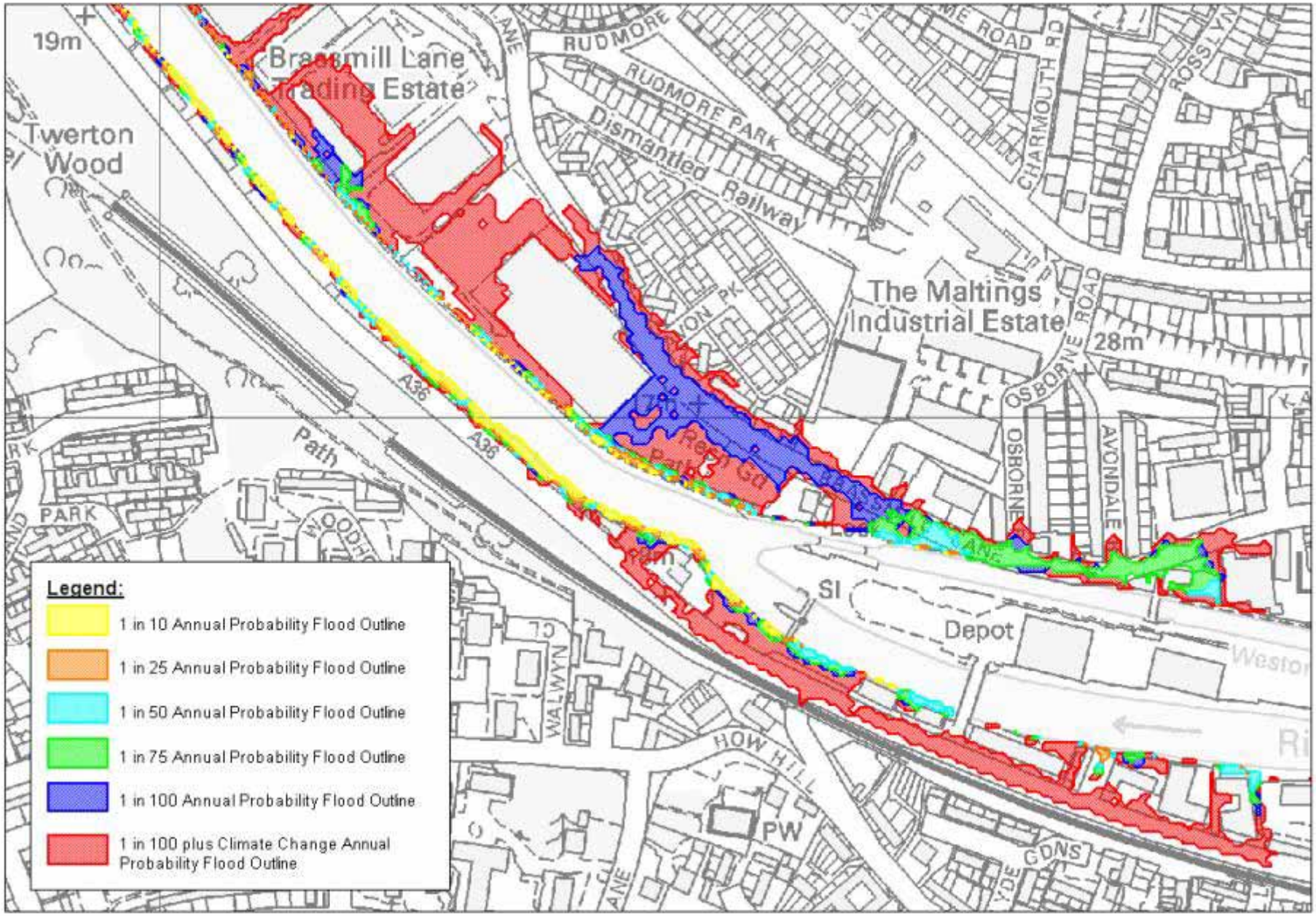
1 in 25 Annual Probability Flood Outline
1 in 50 Annual Probability Flood Outline
1 in 75 Annual Probability Flood Outline
1 in 100 Annual Probability Flood Outline
1 in 100 plus Climate Change Annual Probability Flood Outline
ASHLEY AVENUE
AYNTON MEAD
LOCKSBROOK ROAD
Weston Cut (Canal)
River Avon
Factory
FIELDING'S
JEWSL
BURNHAM ROAD
INVERNESS R
ALBANY ROAD
LOXTON DRIVE
KING GEORGE'S RD
LOWER BRIST
East T
29m
19m
17m
FB
PW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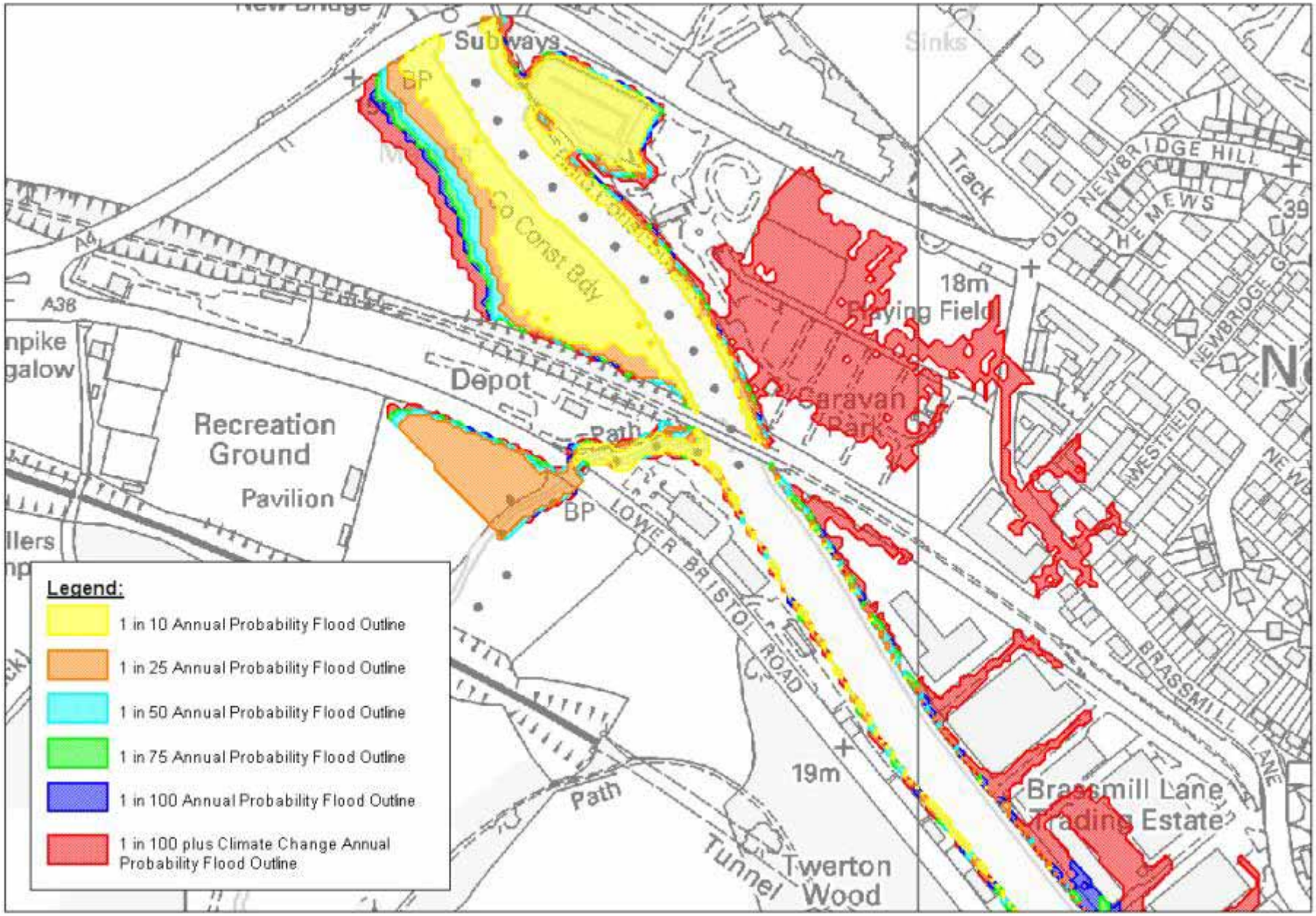
1 in 25 Annual Probability Flood Outline
1 in 50 Annual Probability Flood Outline
1 in 75 Annual Probability Flood Outline
1 in 100 Annual Probability Flood Outline
1 in 100 plus Climate Change Annual Probability Flood Outline
19m
Twerton Wood
Brassmill Lane Trading Estate
RUDMORE
RUDMORE PARK
Dismantled Railway
CHARMOUTH RD
ROSSLYN
The Maltings Industrial Estate
28m
OSBORNE ROAD
OSBORNE
AVONDALE
A36
Path
PARK
SI
Depot
WALWYN
HOW HILL
PW
GDNS


Subways
Sinks
BP
Track
OLD NEWBRIDGE HILL
THE MEWS
NEWBRIDGE G
WESTFIELD
A36
18m
Playing Field
Caravan Park
Depot
Path
Recreation Ground
Pavilion
BP
LOWER BRISTOL ROAD
BRASSMILL LANE
19m
Path
Tunnel
Twerton Wood
Brassmill Lane Trading Estate
Legend:
1 in 10 Annual Probability Flood Outline
1 in 25 Annual Probability Flood Outline
1 in 50 Annual Probability Flood Outline
1 in 75 Annual Probability Flood Outline
1 in 100 Annual Probability Flood Outline
1 in 100 plus Climate Change Annual Probability Flood Outline

APPENDIX B

Hydraulic Modelling

Background

The ISIS-Tuflow model produced by Halcrow Ltd, as part of the Corston to Avonmouth Flood Zone Compliance Project, was provided by the Environment Agency (EA). Two separate models covered the River Avon from the A4 crossing at Bathford to New Bridge Park & Ride titled Bath_us_2005 and Bath_ds_2005. The downstream model (Bath_ds_2005) was of primary interest, covering the reach of the River Avon between Cleveland Bridge and New Bridge Park Ride. The 1D element of the model was based on the B&V ISIS model produced in 2004 as part of the Bath Flood Defence Study, whilst the 2D element of the model was constructed as part of the Corston to Avonmouth Flood Zone Compliance Project.

Updates to the Baseline Model

The 2005 Halcrow model was reviewed during the early stages of this study. In general it was found to be suitable to use for this project. However the following improvements were made to it.

Representation of Bath Western Riverside

As no representation of the development had been made in the Halcrow model, the 1D and 2D elements of the downstream model were updated.

The walkways already constructed as part of the Western Riverside development were included within the ISIS model cross-sections on the left bank between model cross-sections RC035 and RC033, based on Grant Associates drawings: BWR197-AL-A01-GE-2-020, BWR197-AL-A01-GE-2-022 and BWR197-AL-A01-GE-2-024.

The landscaping proposed as part of the Bath Western Riverside Development was represented in the 2D domain through the use of z-shapes. As permission has been granted for the entire Bath Western Riverside development (including the mitigation works) it was decided that any baseline model should assume full development of this site. Proposed ground levels were taken from Section 3.5 of the *Bath Western Riverside Landscape Brief and Masterplan Context for Proposed Replacement of the Destructor Bridge* dated 11 July 2012. The final model configuration and ground levels applied in the 2D domain can be seen below in Figure 1.

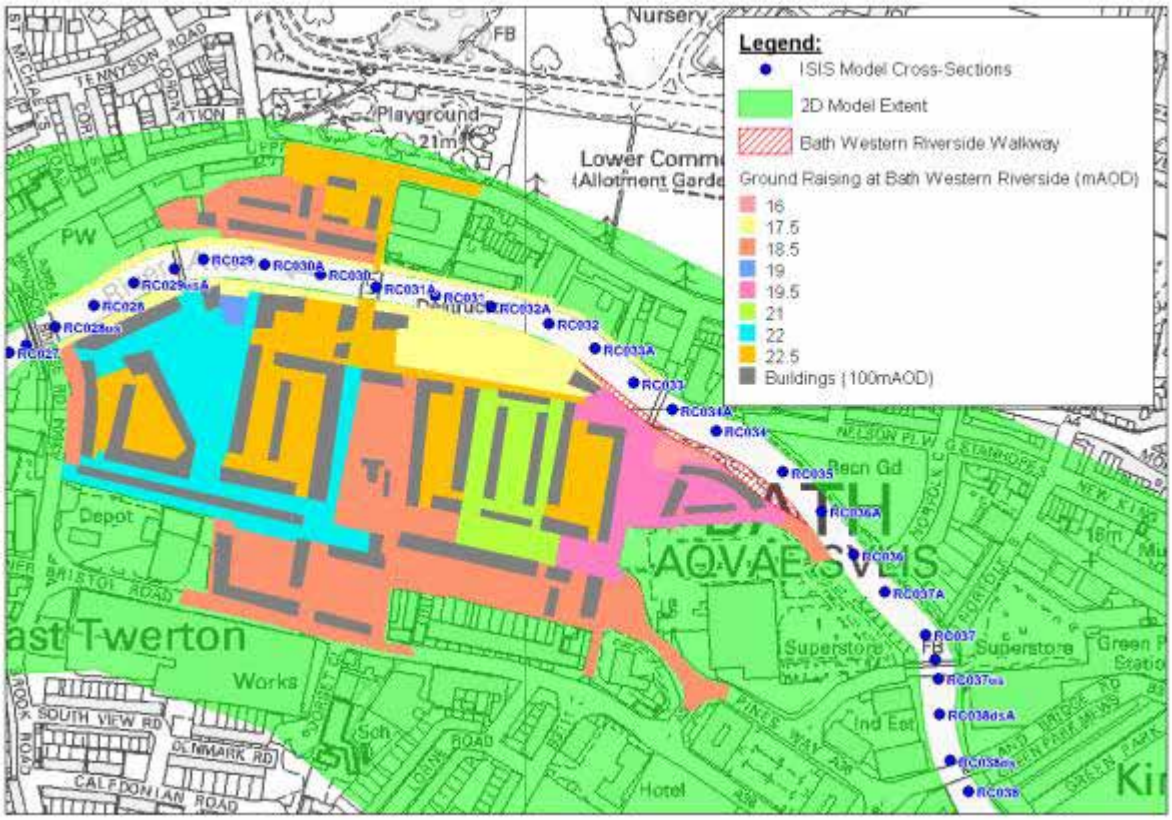


Figure 1: Representation of Bath Western Riverside in the 2D domain

Representation of Buildings

Buildings were represented in the 2D domain by artificially increasing the elevation of z-points within the footprint of each building through the use of z-shapes. This prevented conveyance through buildings, creating a barrier to floodplain flows and can be considered a worst case scenario. An arbitrary elevation of 100mAOD was applied to each building which were defined using OS MasterMap data.

Alteration of the 1D-2D Boundary

Review of the Halcrow ISIS model indicated that the tow path on the right bank of the river between Churchill Bridge and Twerton Sluice had been removed, allowing representation of this area to be included in the 2D domain. As it was considered more accurate to represent this conveyance area in the 1D model, the 1D-2D model boundary was amended (2d_code and 2d-bc layers). This also allowed easier (and more accurate) representation of the mitigation options in this area.

1D Model Cross-Sections

Based on the above change to the 1D-2D model boundary, 1D model cross-sections were reviewed between Henrietta Park and the Weston Cut (Canal) (RC058 to RC021). Where appropriate, cross-sections were amended to extend as far as adjacent buildings and walls and to include the tow path on the right bank. Original cross-section data was obtained from the B&V mode dated 2005 (which was based on topographic survey data). An example of an amended cross-section can be seen below in Figure 2.

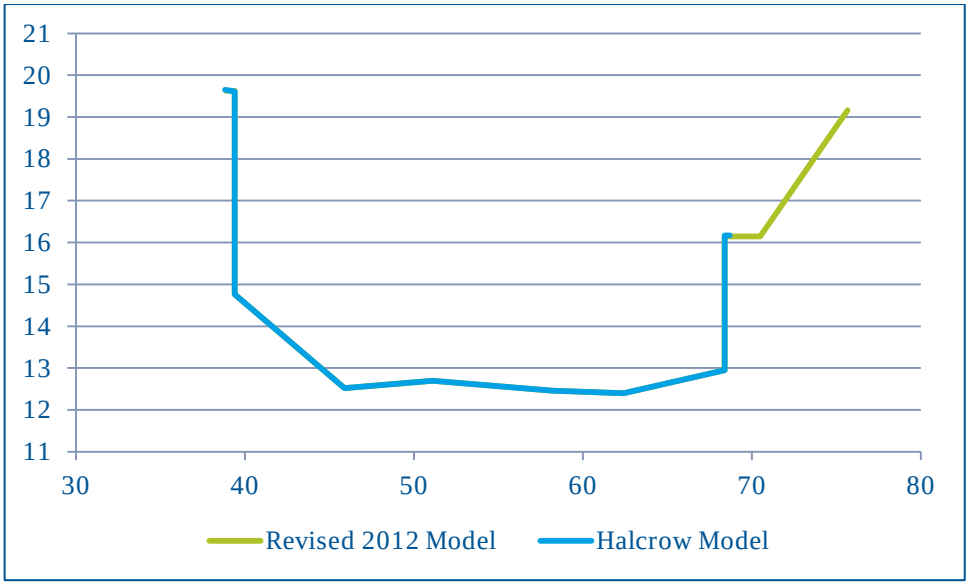


Figure 2: Example of revised 1D model cross-section

Representation of Formal and Informal Defences

In the Halcrow model, the transfer of water between the 1D and 2D domains was dictated by the level (mAOD) of the z-points along the HX boundary (which are based on a 4m grid utilising filtered LiDAR data). No additional z-lines were used to represent bank or defence levels. To ensure the correct flood mechanisms were represented and to ensure that water was not allowed to spill from the 1D to 2D domains until bank/defence levels were exceeded, z-lines were added to the 2D domain to represent informal and formal defences. Levels for these defences were obtained from the December 2012 topographical survey, which provided details of levels along the right bank at the post office, the right bank between Churchill Bridge and Victoria Bridge, and the left bank between Churchill Bridge and Riverside Road. These levels were supplemented with approximate levels detailed on drawings produced as part of the Bath Flood Defence Scheme (2709-ED-394 Rev B through to 2709-ED-402 Rev B), which provided locations and levels of the informal defences on the right and left banks between Victoria Bridge and Brassmill Lane Trading Estate.

The z-lines representing the formal and informal defences were applied to the 2D domain using the 'zig-zag' approach (see Figure 3 below), where the lines passed through all cell centres. This ensured that all z-points along the defences were raised and water was preventing from incorrectly passing across the line, which is a common inconsistency in Tuflow.

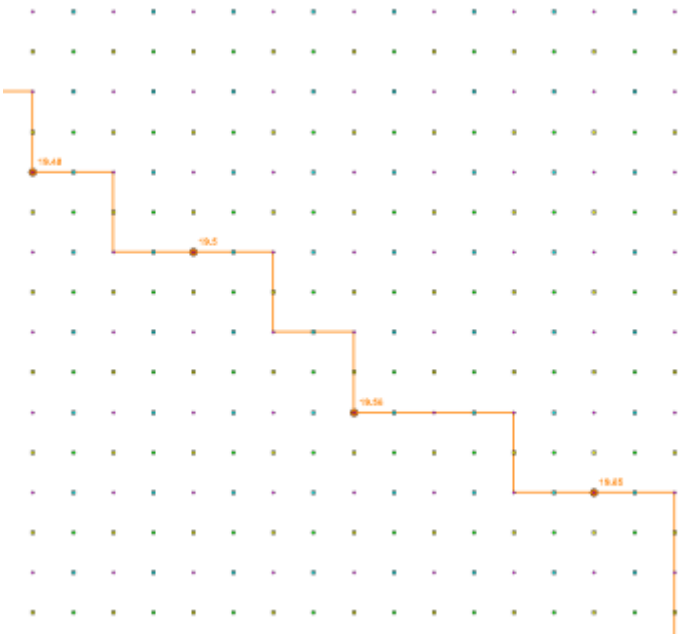


Figure 3: Configuration of z-lines representing formal and informal defences

1D Model Roughness

The review of the Halcrow ISIS model identified that the extremities of the model cross-sections downstream of Churchill Bridge had Manning's 'n' roughness coefficients of 0.07 applied. This was generally along the tow path. These values were considered too high and were reduced to 0.04.

Comparison of Updated Baseline Model to Halcrow Model

Peak water levels in the ISIS model from the 2005 baseline runs were compared to those predicted by the revised 2012 baseline models. Spreadsheet analysis was used for this comparison.

The variation in peak water levels in the ISIS model between the 2005 and 2012 baseline models was generally less than +/-60mm. Within the 2D domain the difference in peak water depths was generally less than +/-200mm. These differences can be considered within the tolerances of the 1D and 2D models respectively.

Modelling the Preferred Option

The preferred option includes the addition of riverside walkways (or widening of existing walkways) between Churchill Bridge and Midland Bridge Road and an extension of the riverside walkway at the Bath Western Riverside Development. These walkways were represented in the 1D model cross-sections. The following cross-sections were altered:

- Widened tow path (by approximately 6-8m) on the right bank downstream of Churchill Bridge (model cross-sections RC044 to RC042);
- Addition of a lowered walkway (approximately 2-4m wide) on the left bank within the footprint of the South Quay development site, at a level somewhere between the 1 in 10 and 1 in25 annual probability flood level (model cross-sections RC042 to RC040);
- Retreat of the embankment in Green Park by approximately 13m (model cross-section RC039B);
- Extension of the existing Bath Western Riverside walkway to Destructor Bridge (model cross-sections RC032 and RC031) for consideration in conjunction with Phase 1 Development Sites only; and
- Extension of the existing Bath Western Riverside walkway to Windsor Bridge Road (model cross-

sections RC032 to RC028) for consideration in conjunction with All Development Sites.

Raising of walls downstream of Churchill Bridge

It is proposed to raise the walls along the left bank between Churchill Bridge and the South Quay Development Site as part of the preferred option. This would prevent flooding onto Lower Bristol Road, preventing property flooding and traffic disruption. The representation of this wall raising in the 2D domain can be seen in Figure 4 below.

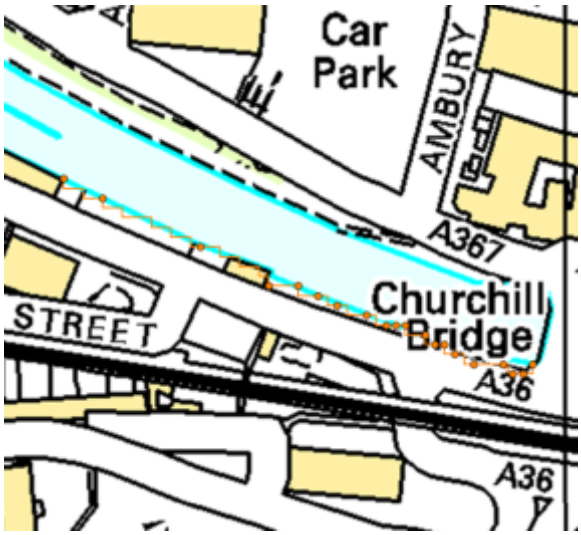
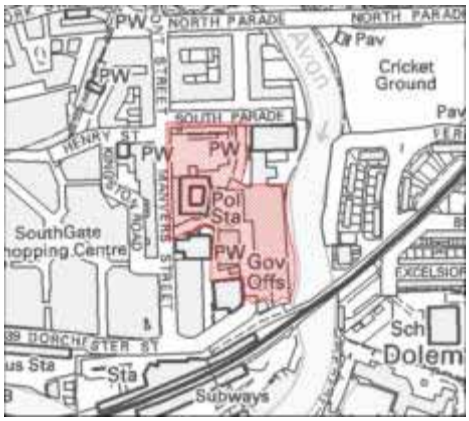


Figure 4: Wall raising along Lower Bristol Road as part of the preferred option

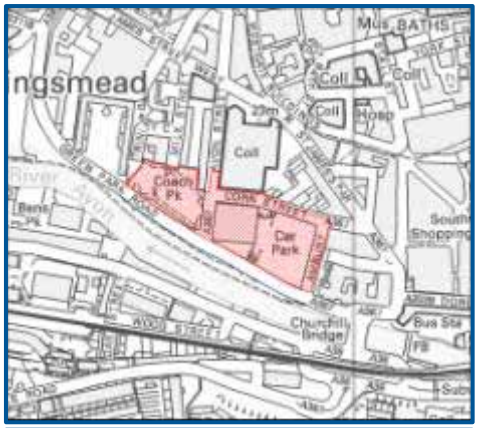
As part of the preferred option, Green Park Road will be raised (or the land in this area following the diversion of Green Park Road as part of the development of the Avon Street Car Park site) between Churchill Bridge and Green Park to prevent flooding. This element of the option was represented in the 2D domain through the use of a z-shape. The elevation of the road raising will be refined during detailed design.

The development sites were represented in the 2D domain by artificially increasing the elevation of z-points within the footprint of each site through the use of z-shapes. This prevented conveyance through each site, creating a barrier to floodplain flows, and can be considered a worst case scenario. The extent of ground raising within each development site boundary was agreed with Bath & North East Somerset Council at a meeting held on Wednesday 24th October 2012. This ground raising within each site can be seen below.

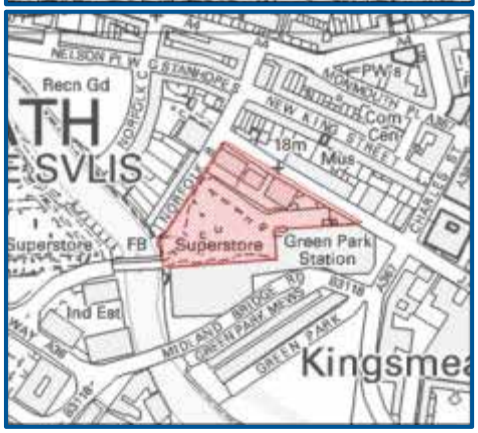
B4 – Manvers Street
100% of site raised



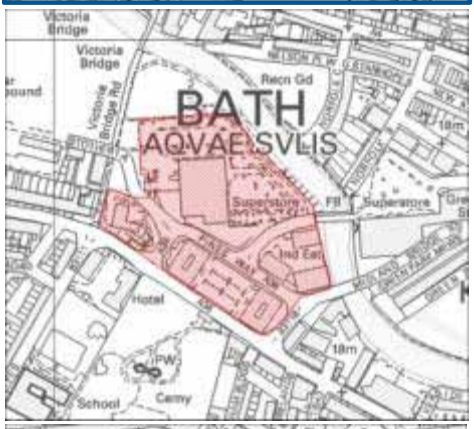
B6 – Avon Street Car Park
100% raising of area not within riverside path widening



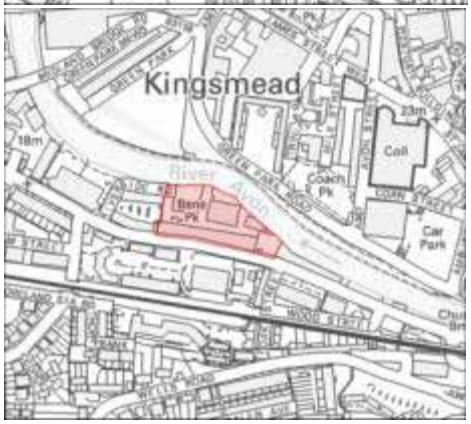
B7 – Green Park
Assuming existing store footprint stays (already above flood levels). Car park to be raised.



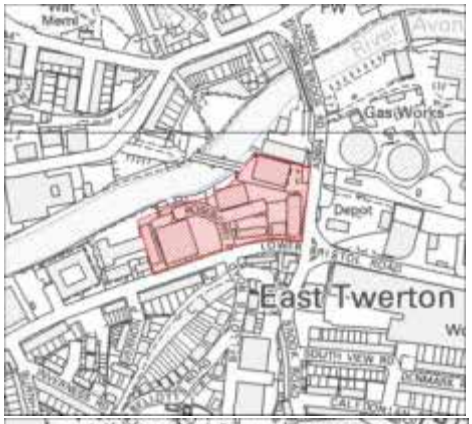
B8 – BWR East
Assumed 8m strip can be left alongside river. Remainder of site raised.



B9a – South Quays
100% of site raised

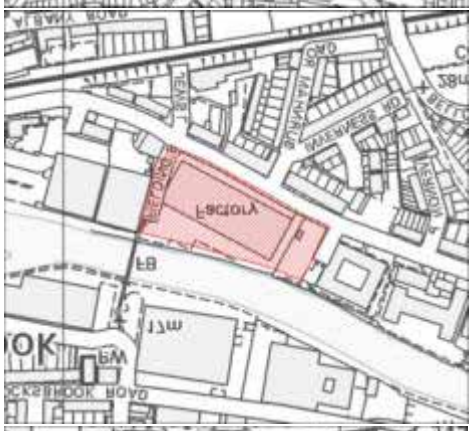


B13a – Stable Yard
Assume Stable Yard itself remains as current. 8m strip left alongside river with remainder of site raised.



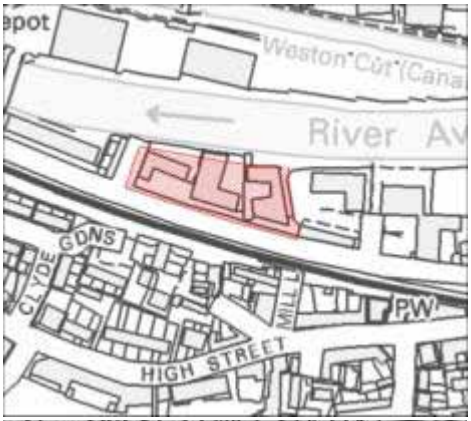
B9b – South Bank
100% of site raised

B13b – Lower Bristol Road
Riverside strip left as existing, remainder of site raised

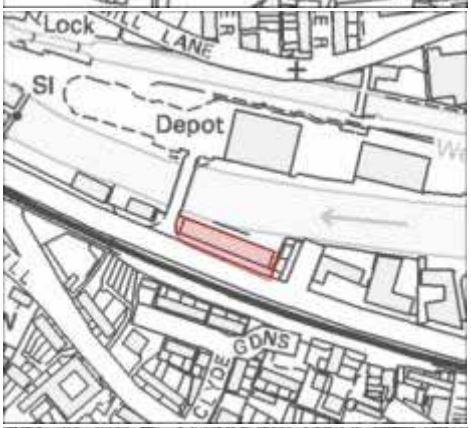


B13c – Cars Mill Phase 1
Riverside strip left as existing, remainder of site raised

B13d - Cars Mill Phase 2
Riverside strip left as existing, remainder of site raised



B13e - Cars Mill Phase 3
Riverside strip left as existing, remainder of site raised

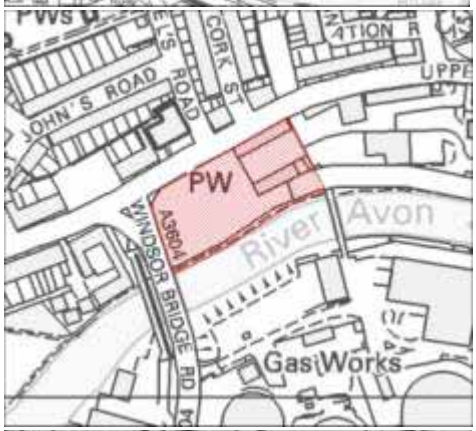


B13f – Brassmill
Riverside strip left as existing, remainder of site raised

B14 – Locksbrook
Riverside strip left as existing, remainder of site raised

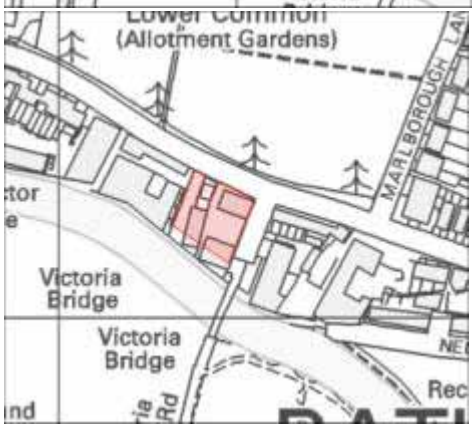
B15 – The Maltings
100% of site raised

B18 – Westmark
100% of site raised



B19 – TA centre
100% of site raised

B20 – Onega Centre
Assumed 8m riverside strip to be left, remainder of site raised



B21 – Hinton Garage
Assumed riverside strip to be left, remainder of site raised

Results of the Preferred Option

Two scenarios were modelled representing the preferred option. The first scenario considered the inclusion of Phase 1 Development Sites only (B4, B6, B7, B8 and B13a) and the second scenario considered the inclusion of All Development Sites.

Table 1 to Table 3 below summarise the change in flood levels at selected key locations at different annual probability events.

	Change in level from baseline (mm)	
Location	**Phase 1 Development Sites**	**All Development Sites**
Pulteney Bridge	-20	-30
St James Railway Bridge	-30	-30
Churchill Bridge	-30	-40
New Windsor Bridge	0	0
Twerton Sluices	0	0
New Bridge	0	0

Table 1: 1 in 50 Annual Probability Event

	Change in level from baseline (mm)	
Location	**Phase 1 Development Sites**	**All Development Sites**
Pulteney Bridge	-80	-60
St James Railway Bridge	-40	-40
Churchill Bridge	-40	-40
New Windsor Bridge	0	+10
Twerton Sluices	0	+10
New Bridge	0	0

Table 2: 1 in 100 Annual Probability Event

	Change in level from baseline (mm)	
Location	**Phase 1 Development Sites**	**All Development Sites**
Pulteney Bridge	+10	+20
St James Railway Bridge	+10	0
Churchill Bridge	0	0
New Windsor Bridge	+10	0
Twerton Sluices	0	+10
New Bridge	0	0

Table 3: 1 in 100 Annual Probability Event Including Climate Change

The main points to draw from this analysis are as follows:

- The proposed works do not show any detrimental impact to third parties even with all development sites raised. This assumes a 20mm tolerance in the model results.
- Flooding of Lower Bristol Road from the left bank immediately downstream of Churchill Bridge is prevented up to a 1 in 100 +20% event.
- The biggest impact on flood levels comes from cutting off the flows to Lower Bristol Road rather than raising of the development sites.