MILESTONE 5 – TECHNICAL NOTE

JBA Project Code	2017s6293
Contract	Bristol SWMP Model - Review and Update - Phase 2
Client	Bristol City Council
Day, Date and Time	6 July 2018 (updated 12 September 2018)
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Subject	Updated model summary

1 Introduction

Following a review of the existing Bristol SWMP model JBA Consulting was commissioned by Bristol City Council to develop a new model to help improve the understanding of surface water flood risk across the city. The new model has been developed in the InfoWork-ICM software and combines the existing Wessex Water network model of the Avonmouth STW catchment with a 2d ground model.

This technical note outlines the model development and key assumption and data inputs to the model.

2 Technical Summary

Item	Comments
What software & reason for choice:	InfoWorks ICM v8.0 InfoWorks ICM was chosen due to its suitability to simulate direct rainfall, sewer networks and river channels simultaneously. Version 8.0 was used as this was the latest release of InfoWorks ICM at project commencement.
General Schematisation:	The updated Bristol SWMP model represents the foul, combined and surface water Wessex Water sewer network, watercourses and topographic catchment. The Wessex Water InfoWorks CS model of the Avonmouth Catchment was used as the basis of 1d network model. The Brislington Verified Model (2014) is an Urban Pollution Management (UPM) model for the Bristol area and includes 16 DAP catchments that ultimately drain to the Avonmouth STW to the west of Bristol. The original DAP catchment models have been developed over a long period of time and include a range of modelling methodologies, which has been taken into consideration during the development of the SWMP model. The river network has not been explicitly modelled as part of the SWMP; however key structures and culverted reaches have been reproduced in InfoWorks ICM using data from the existing Bristol City Council CaFRA ISIS model. The hydrology of the study area uses direct rainfall across the whole model combined with sub-catchments in the areas that are positively drained 2D zones representing the surface of each hydrological catchment in the city have been generated. The boundary of the 2D zones is based on the topographic catchment within the BCC boundary and these have then been extended to ensure that a reasonable overlap exists between catchments and at the topographic boundary particularly to the south of the city. It is acknowledged that for the larger catchments, the River Frome and River Trym the full catchment extends well beyond the city boundary, however the flood risk associated with these larger catchments is primarily fluvial. The topographic levels of the 2D domain are based on a DTM composite of 1m LIDAR data and 2m LIDAR data. This was the best available topographic data at the time of model build that provided suitable coverage for the whole city. The 2D zone mesh represents a bare earth scenario. In addition, buildings have been represented by porous polygons. These polygons limit the through flow and present an obstacle to overland flow routes. Studies have shown that roads can be a significant conveyance route for surface water in an urban environment. Therefore, the infiltration zones have been used to represent the roads have been included in the 2d mesh to provide improved representation of the roads. The different surface roughness's have been represented as roughness zones.
Design Events	The following pluvial design events have been run: 1 in 2 year, 5 year, 10 year, 30 year, 50 year, 75 year, 100 year, 200 year and 1000 year. In addition, three epochs have been run with climate change uplifts for rainfall. To test the risk in a range of storm events the model has been run of the 30, 60, 180 and 360 minute summer storms

Item	Comments
Rainfall	The ReFH Rainfall Generator was used with a summer rainfall profile. DDF catchment descriptors have been derived for each catchment across the city

Table 2-1: DDF catchment descriptors

Catchment	C	D1	D2	D3	E	F	SAAR	BFIHOST	PROPWET
Ashton	-0.026	0.376	0.418	0.288	0.292	2.468	882	0.448	0.350
Avonmouth	-0.026	0.339	0.443	0.294	0.292	2.426	790	0.614	0.350
Brislington	-0.026	0.360	0.410	0.289	0.291	2.469	892	0.518	0.350
Frome	-0.025	0.368	0.427	0.242	0.289	2.454	793	0.363	0.350
Malago	-0.026	0.360	0.410	0.289	0.291	2.469	892	0.518	0.350
Redfield	-0.025	0.381	0.403	0.231	0.287	2.484	789	0.410	0.350
Trym	-0.026	0.339	0.442	0.276	0.291	2.450	795	0.325	0.350

The previous SWMP modelling used a depth duration approach to rainfall and the table below shows the average rainfall depths for each return period and storm duration for comparison.

Table 2-2: Average rainfall for each modelled storm event

Return period / 1 in x years	Rainfall depth / mm			
	30-minute storm	60-minute storm	180-minute storm	360-minute storm
2	10	13	19	24
5	14	18	26	32
10	18	22	31	39
30	26	31	42	51
50	30	36	48	58
75	34	41	54	64
100	38	44	58	69
200	47	54	70	81
1000	76	87	106	121

Item	Comments
Downstream boundary – Tide Level	Outfall 2d units have been used for sewer outfalls to the fluvial watercourses to allow the 1d network to discharge to the 2d zone surface; however in order to account for the impact of potential tide locking within the tidal Avon estuary a Mean High Water Spring (MHWS) tide level has been used at the outfalls to the Avon. The MHWS tide has been selected to provide a conservative estimate of the tidal influence on flood risk in Bristol. The time to concentration of the modelled catchments and drainage networks varies across Bristol, therefore it the tidal peak has been timed to coincide with the peak rainfall. The tide level has been taken from 4 locations along the estuary, at Avonmouth, Sea Mills, Ashton and within the Bristol Harbour, with the closest estimate applied to each outfall.

Rainfall Runoff	A default fixed rainfall runoff value matching the catchment SPRHOST value has been applied for each modelled catchment. This represents the natural ground surface for the catchment. Infiltration zones have then been applied to model to update the runoff for areas of hard standing to 80% runoff and general surfaces to 30% runoff. Where 1d subcatchments have been included to route runoff into the 1d sewer network the percentage runoff from the 2D Zone has been updated to account for the additional runoff "lost" in the 1d model. While this value varies across the model extent due to differences in the type of drainage present (combined / separate systems) or modelling methodology included in the original Wessex Water CS model an average of 25% has been selected across the full model extent. This could be refined further should more detailed local assessments of flood risk be required.
Coefficients:	Standard Manning's n and Colebrook White roughness coefficients are used to represent hydraulic roughness in the 2D Zone and surface and waste water drainage network respectively. Roughness zones have been used across the 2D Zone based on OS Mastermap data The Manning's n roughness values range from 0.02 for roads to 0.3 for buildings, with the base 2D Zone roughness set to 0.06, which is representative of general surfaces. The Colebrook-White value has been retained from the original Wessex Water model. For the foul / Combined network the roughness has been set to 1.5 mm for the bottom roughness and 1.5 mm or 3.0 mm for the top roughness. For the surface water network the default value has been set to 0.6 mm. Where new network has been added this has been used, however where the original model includes alternative values these have been retained. Headloss coefficients for additional conduits added in were inferred using the InfoWorks ICM inference tool.
Structures	**1D** The 1d sewer network includes both foul/combined and surface water sewers. As the base model has been developed as a UPM model attention has previously been on areas where the two systems interact. For each modelled catchment the extent of the modelled surface water network has been review against the GIS records to identify area for update and extension. Where required the surface water network has been extended to reach the true discharge location e.g. where a CSO has been modelled discharging to a nominal outfall rather than a true watercourse. Where the surface water network hasn't previously been modelled pipes greater than 450mm have been incorporated, with smaller branch network included as required. Wessex Water have recently undertaken a Bifurcation survey across the Bristol area. The survey has been provided as part of this study and the information has been used to update the 1d sewer network. **2D** Key structures, such as river culvert, embankments and flow controls within the 2D Zones for each catchment have been incorporated using data from the exiting BCC CaFRA model and design drawings where appropriate.
Model Proving:	The Wessex Water sewer model had previously been verified and no significant changes were made to it within the integrated model. No flow survey has been undertaken as part of this study, however it is understood that the Wessex Model is currently being updated to include the New-UK runoff model and this will include a reverification of the 1d model. The SWMP model has been developed

	to allow the future integration of this updated model should it be required 2d results have been compared with the existing SWMP outputs that form part of the RoFSW mapping for England. The results show a general reduction in the modelled flood depth in areas that have previously been identified to be at risk of flooding. Increased flood risk has been predicted in areas associated with the watercourses in Bristol, however this is to be expected with a full catchment model and is consistent with the Flood Map for Planning. Further details are include in Section 4 of this report.

Item	Comments
Modelling assumptions and limitations	The representation of any complex system by a model requires a number of assumptions to be made. In the case of the one dimensional element of the model it must be assumed that: - Network model provided by Wessex Water is an accurate representation of the local drainage system. - Controls on the variable sluice gates and pumps remain as per the Wessex Water model - The units used to represent the hydraulic structures within the model represent the situation accurately - A stable numerical solution can be achieved In terms of the two dimensional element of the model, the assumptions include: - LIDAR is representative of the land surface and no errors have been introduced through the filtering algorithms - ReFH design rainfall inflows accurately represent rainfall for a given return period storm event - OS MasterMap is an accurate representation of ground cover - Where roughness zones have not been implemented, a Manning's n value of 0.06 is representative Whilst the accuracy of a hydraulic model depends largely on the accuracy of the hydrological, topographical and structural data some assumptions and uncertainty can be introduced as part of the modelling process. These could include: - Estimates of model parameters such as roughness, structure coefficients and percentage runoffs are representative - SPRHOST provides a reasonable percentage runoff representation of the natural land surfaces in Bristol that aren't covered by sub-catchments - Decisions made during model proving It should be noted that the model has been built to understand the interaction between rainfall, overland flows and the sewer networks. The model does not explicitly model the river network as this is represented in alternative models.

3 Modelling Approach

3.1 Available Data

Item	Comments
Models	The InfoWorks ICM model was developed from the following existing models: • Avonmouth InfoWorks CS network model – Wessex Water • CaFRA ISIS-Tuflow model – Bristol City Council
Survey data	No new survey of assets or river channel sections were undertaken for this project. Network model – Bifurcation survey (2017) – Wessex Water
LIDAR & other Topographic Data	1m filtered LIDAR data (EA Geostore) covering the majority of the study area with 2m filtered LIDAR data (EA OpenData) covering missing areas.
Map Data	OS MasterMap and OS Open Data
Gauging station flows / levels	Tide levels • 523 - Port of Bristol (Avonmouth) • 523B – Avon at Sea Mills • Cumberland Basin

3.2 Overview of 1d model

Sewers	Model Description	
	Nodes	**Pipes**
Surface water system	6609 manholes or outfalls modelled. Flood Type: • Gully 2D for manholes within the 2D Zone, • Stored / Lost for manholes outside the 2D zone (based on existing WW model)	6647 sewers modelled 292 km 1D sim engine
Foul / Combined	26847 manholes or outfalls modelled. Flood Type: • Gully 2D for manholes within the 2D Zone, • Stored / Lost for manholes outside the 2D zone (based on existing WW model)	26820 sewers modelled 1,050 km 1D sim engine

Sewer Network:	The sewer network has been imported from Wessex Water's InfoWorks CS Brislington Verified (2014) model into the InfoWorks ICM model. The sewer network within Bristol includes both separate foul and surface water system as well as area of older combined sewers. Outfalls from the surface water network drain into the watercourses and were connected to the 2d Zone where appropriate. InfoWorks ICM calculates in-sewer flows by solving the Saint-Venant equations using a 4-point Preissmann scheme.
Inflows:	Inflows to the surface water network model are generated using 1d subcatchments. The existing InfoWorks CS model contained combined and surface water subcatchments covering the residential and urban areas. These designated runoff areas for different runoff surface type (roads, roofs, permeable) and were not altered. The default infiltration surface of the 2D Zone is set to permeable based on the SPRHOST value for each catchment and varies from 0.3 for Ashton to 0.39 for

	Brislington to the south of the Avon and 0.3 for Trym to 0.4 for the Frome catchment. To improve the representation of the rainfall response across the 2D Zones infiltration zones have been used for roads and areas of hardstanding with a higher fixed runoff value (0.8) where no 1d subcatchments exist and 0.25 for areas with routing via the 1d network. Manholes in the 2D zone were coupled to the surface. Therefore, additional inflow could be made if surface water ran over a node. Due to the extent of the model road gullies were not explicitly modelled in the SWMP update. These could be added to a more detailed model of specific risk locations.
Pipe Inverts:	Pipe inverts have been taken from the original Wessex Water model. Where data was missing or outfall connections inferred, model pipe inverts were either taken from GIS data or assumed by interpolating between known data points or estimating.
Pipe Dimensions:	Pipe dimensions have been taken from the original Wessex Water model, Wessex Water GIS network data, Bifurcation survey or where data was missing, dimensions were inferred from the upstream or downstream connection.
Length of Model (km):	1,340km
Labelling/ Numbering System Used:	Node ID's have been defined based on WW modelling guidance and reference to the BCC CaFRA model where appropriate
Hydraulic roughness values used	Colebrook-White values remained as per the Wessex Water CS model. In most cases: **Foul / Combined** Bottom roughness Colebrook-White value = 1.5mm Top roughness Colebrook-White value = 1.5mm **Surface water** Bottom roughness Colebrook-White value = 0.6mm Top roughness Colebrook-White value = 0.6mm
Amendments to existing model	The flood type of the nodes was changed from stored to Gully-2D where the manholes fell within the 2D zone. This has been done to allow direct interaction between the 1d network and the 2d model surface.

3.3 Overview of 2D Model

Triangular mesh:	The 2D domain has been constructed internally within InfoWorks ICM using the Delaunay Triangulation Algorithm. This creates a triangular mesh of ground elevation.
Overland flow:	The 2D domain solves the Shallow Water Equations (SWEs) across the triangular mesh.
Area of 2D domain:	See table below
Boundary condition:	The boundary condition of the 2D Zone is set to be 'normal condition'. Depth and velocity are kept constant when water reaches the boundary, so water can flow out without losses.

Catchment	Area / ha
Ashton	2,784
Avonmouth	2,812
Brislington	2,904
Frome	4,081
Malago	2,750
Redfield	1,335
Trym	3,700

DTM data source:	Filtered LIDAR (1m from EA Geostore, 2m from EA OpenData).	**DTM resolution:**	1m
Mesh Modifications			
Watercourse	The watercourses within the 2D zones have been included as mesh zone to improve the routing of flows discharged from the surface water network or via overland flows to the main river channels. Key structures have been included using 2d outfall and conduit links and, where the DTM filtering has failed to remove bridges and river crossing they have been removed from the 2d surface using Mesh zones.		
Roads	Roads are of key flow paths for surface water and have been represented within the 2D Zone using infiltration zones in the mesh process as a break in the mesh. As the mesh resolution was fine within Bristol and the DTM data was LIDAR it was not necessary to lower roads, as the mesh picked up the curb drop in the LIDAR. As the roads are well defined in the mesh, it would be double counting to also lower the roads by an additional 0.15 m – which is UK standard curb height. The use of the boundary of infiltration zones on the boundary of the road ensures that triangles are snapped to the road outline - best representing the shape.		
Buildings	Buildings have been represented as porous polygons. A porosity of 0.05 has been assigned representing a restriction to flow but allowing a small amount of water to infiltrate. A value of 0.05 is assumed to be the likely percentage of the building where water could enter, for example doors or airbricks. Representing the buildings as porous polygons also means the ground model tin is meshed to the outlines. Due to variability of building types across the city the building threshold level has been set to the DTM throughout. A threshold survey of the whole area was not feasible for this study, however local surveys could be completed to improve the understanding of local risk in the future and added to model as required		
Infiltration Zones	As set out above the 2D Zone for each catchment was set to a permeable infiltration surface with fixed runoff set to the SPRHOST for the individual catchments. This provides a better local representation of runoff compared with a blanket value across the city as a whole Infiltration zones have been applied for roads and roadside areas as defined by OS MasterMap. These were defined a fixed runoff coefficient of 0.8 for un drained areas, with the value updated to 0.25 for areas that have been positively drained.		
Roughness Zones	The default roughness of the 2D Zone was set to 0.06 which is typical of a rural area. However roughness zones have been used across the majority of the study area with surface types informed from OS MasterMap. Table 3-1 lists the hydraulic roughness values used for the 2D domain.		

Table 3-1: Hydraulic roughness values used

Land Cover	Manning's n
Roads	0.020
Natural general surface	0.080
Buildings	0.300
Water	0.040

Terrain Sensitive Meshing	Terrain sensitive meshing has been used to better represent changes in gradient in the DTM. It allows smaller triangles to be generated where there is greater difference in height between triangle vertices. The cost is that more triangles are created – which increases run time, but it is a valuable addition to identify surface water flow routes, particularly in coarser meshes.

Maximum triangle size (m^2):	64
Minimum element area (m^2):	16
Terrain sensitive meshing:	Yes
Maximum height variation (m):	1
Minimum angle (degrees):	5
Roughness (Manning's n)	0.060

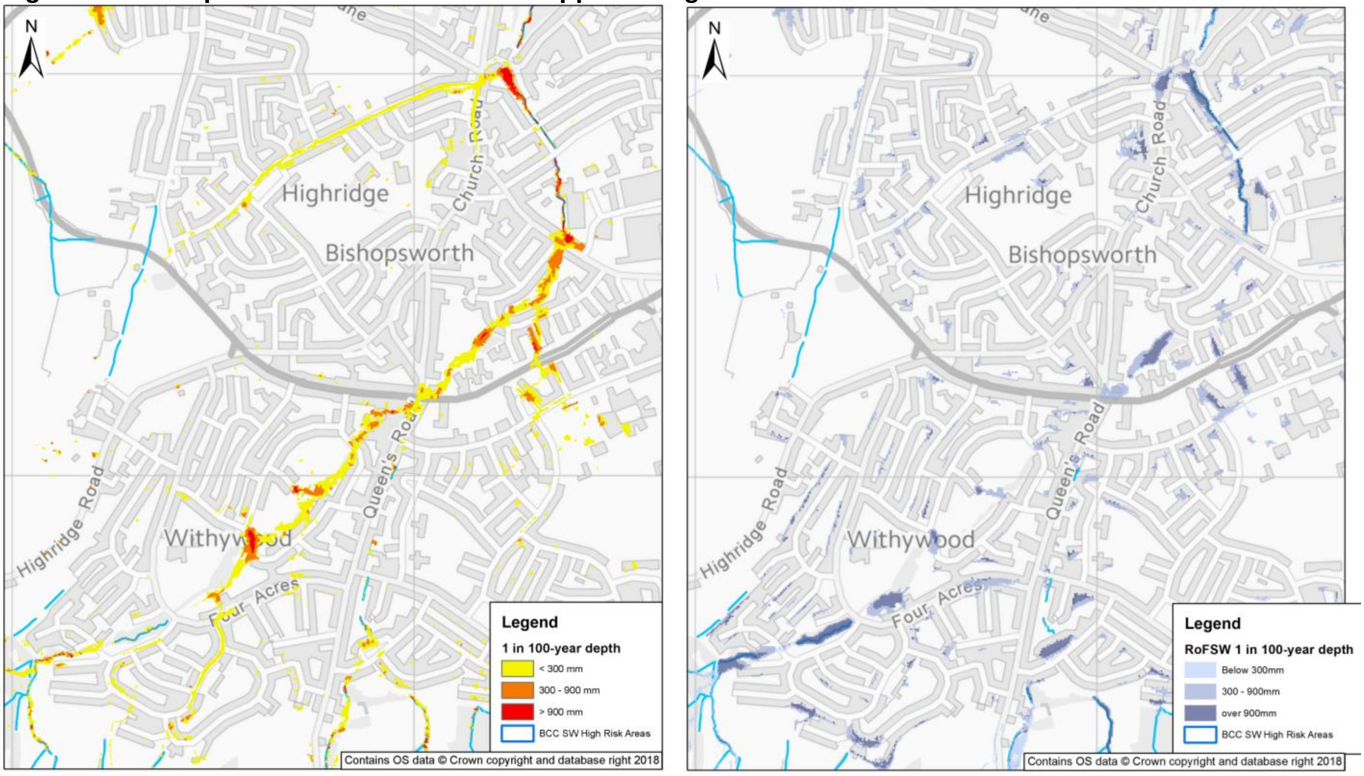
4 Model results

Surface water flood risk is largely driven by topography and in an urban area is also influenced by key features of the urban environment such as buildings, roads and the drainage network. In Bristol the modelling shows that the surface water risk is closely associated with the valleys and watercourses that drain from both the north and south towards the Avon.

The updated model results show increased flood risk associated with the main river channels. This is due to the increased size of the model catchments and subsequently the potential flow paths in the updated model. The updated model also shows increased flow paths along culverted sections of watercourses, this is particularly present in south Bristol such as the upper Malago, shown in Figure 4-1 and Pigeonhouse Stream. These areas represent surcharged, or bypassing flow and help to identify areas at potential risk.

The use of porous polygons to represent buildings within the model results in reduced ponding immediately adjacent to buildings compared with the existing SWMP model. Porous polygons allow limited flow to pass through building while the majority of the flow is routed between or around the structures in the mesh. This gives an improved understanding of potential areas of risk and helps to identify the source and pathways of flooding.

Figure 4-1: Comparison of SW flood risk – Upper Malago



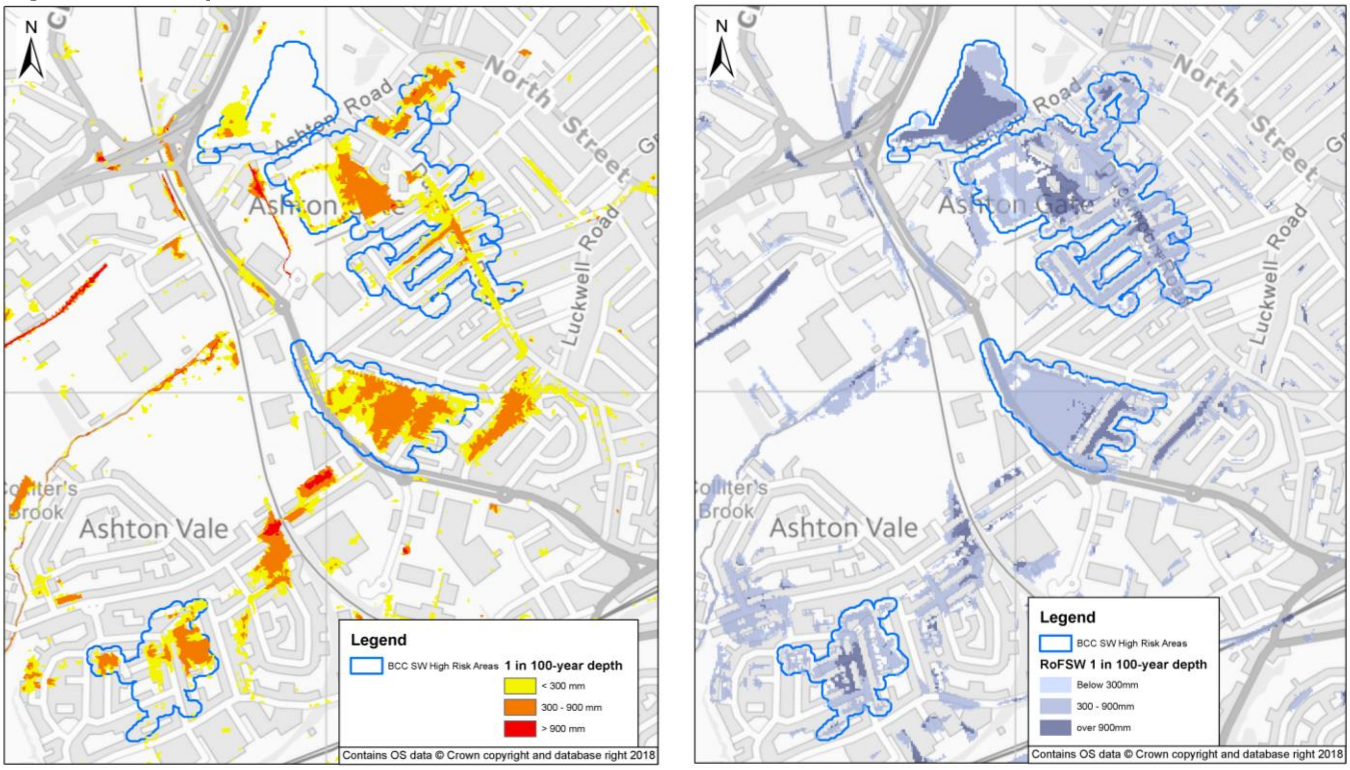
4.1 High Surface Water Flood Risk Areas

The existing SWMP model results were used to identify key areas of high surface water across the city including Ashton, Henbury and St Agnes. A comparison between the updated model outputs and existing RoFSW mapping is set out below.

4.1.1 Ashton

Surface water flooding in the Ashton area is predominantly associated with surface runoff from the south and east draining towards the lower areas around Duckmoor Road and Gore's Marsh. The updated model outputs show a general reduction in the modelled flood extent and depth in the high risk areas previously identified in the Ashton catchment. This is particularly apparent in the Duckmoor Road area close to the Ashton Gate stadium.

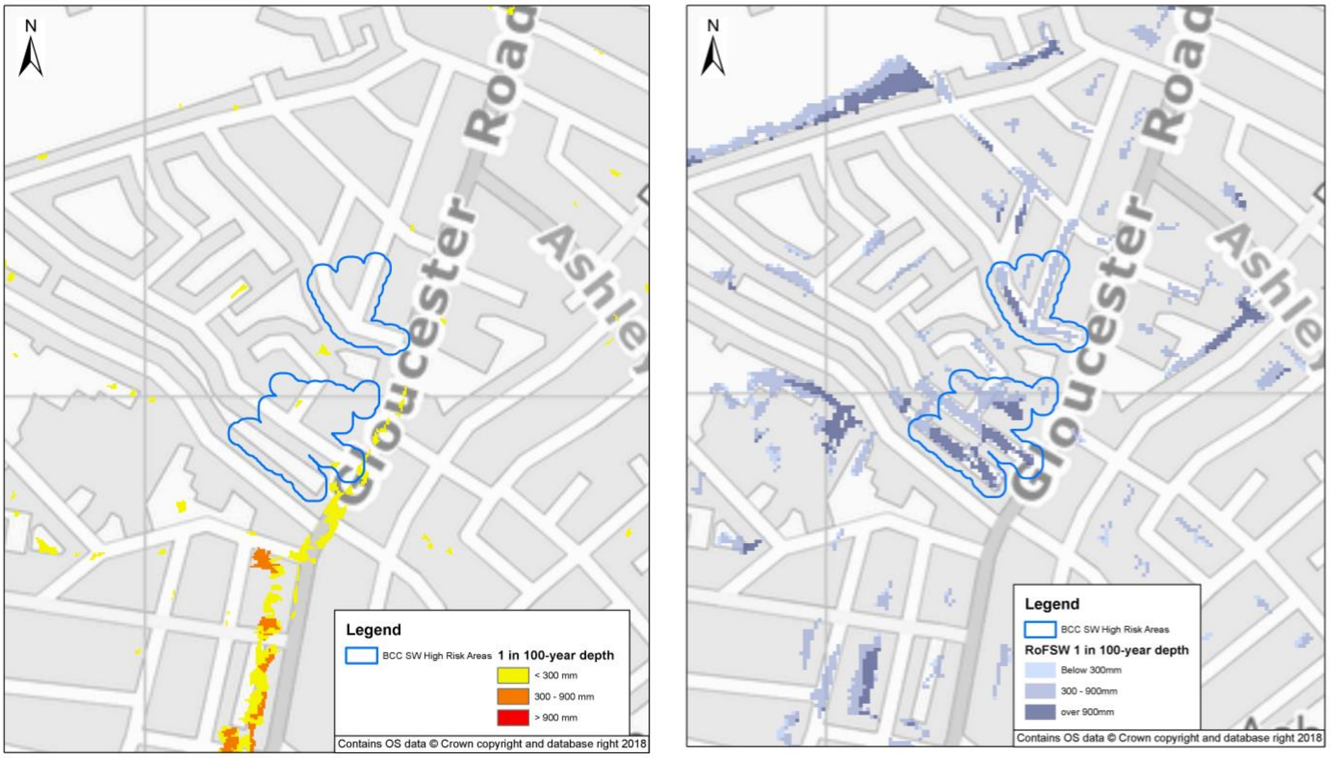
Figure 4-2: Comparison of SW flood risk - Ashton



4.1.2 Gloucester Road

The updated model outputs show reduced ponding of surface water in the Gloucester Road area. This is in part due to the use of porous polygons in the model rather than stamped buildings that permanently obstruct flow. The updated model predicts shallow flows along the roads and at buildings in this area and increased flows to the south and from the west results in the updated model predicting increased ponding and surface water risk in the Montpelier area of the city.

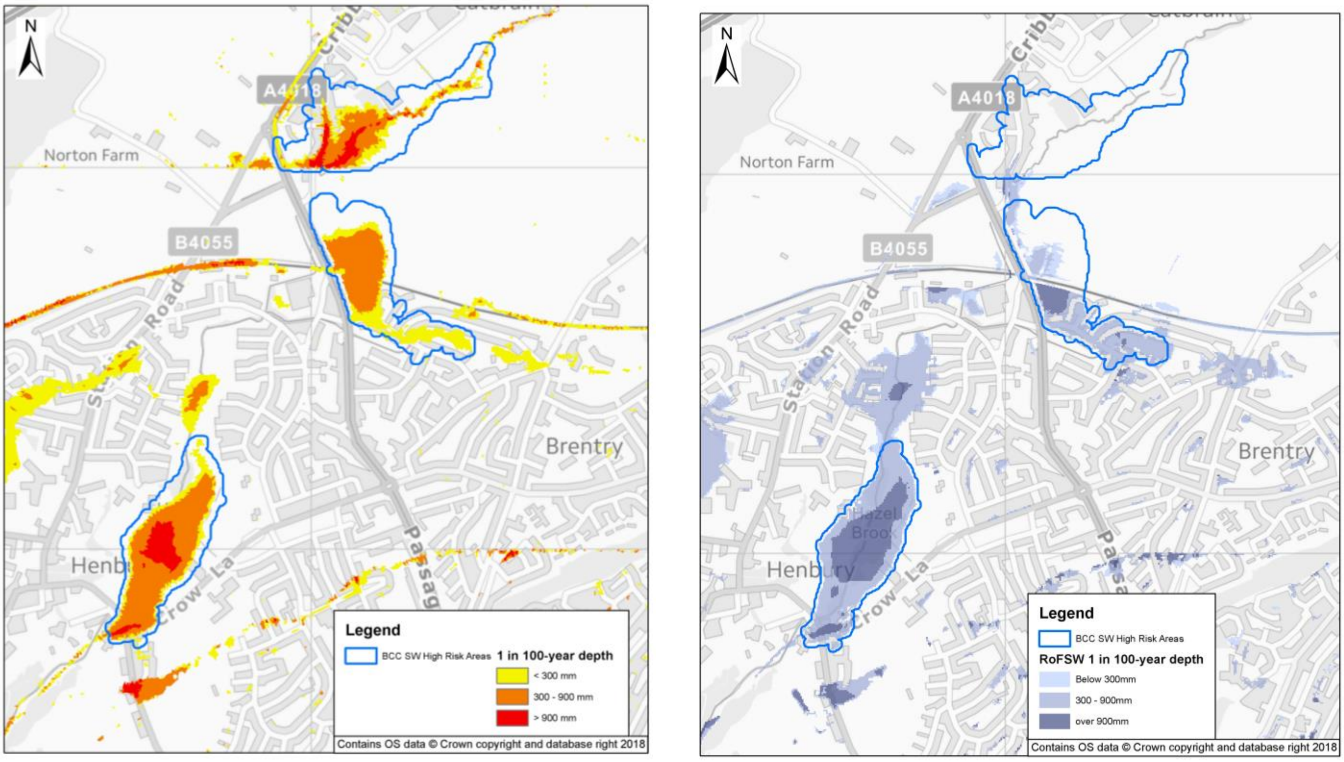
Figure 4-3: Comparison of SW flood risk – Gloucester Road



4.1.3 Henbury

Surface water flood risk in the Henbury area is closely associated with flooding from the upper reaches of the Hazel Brook, a tributary of the River Trym. The updated SWMP model includes limited representation of the fluvial structures in this area and therefore increased ponding at the upstream end of the culverted sections of the watercourse is modelled, but reduced flood depths are predicted downstream of the railway.

Figure 4-4: Comparison of SW flood risk – Henbury

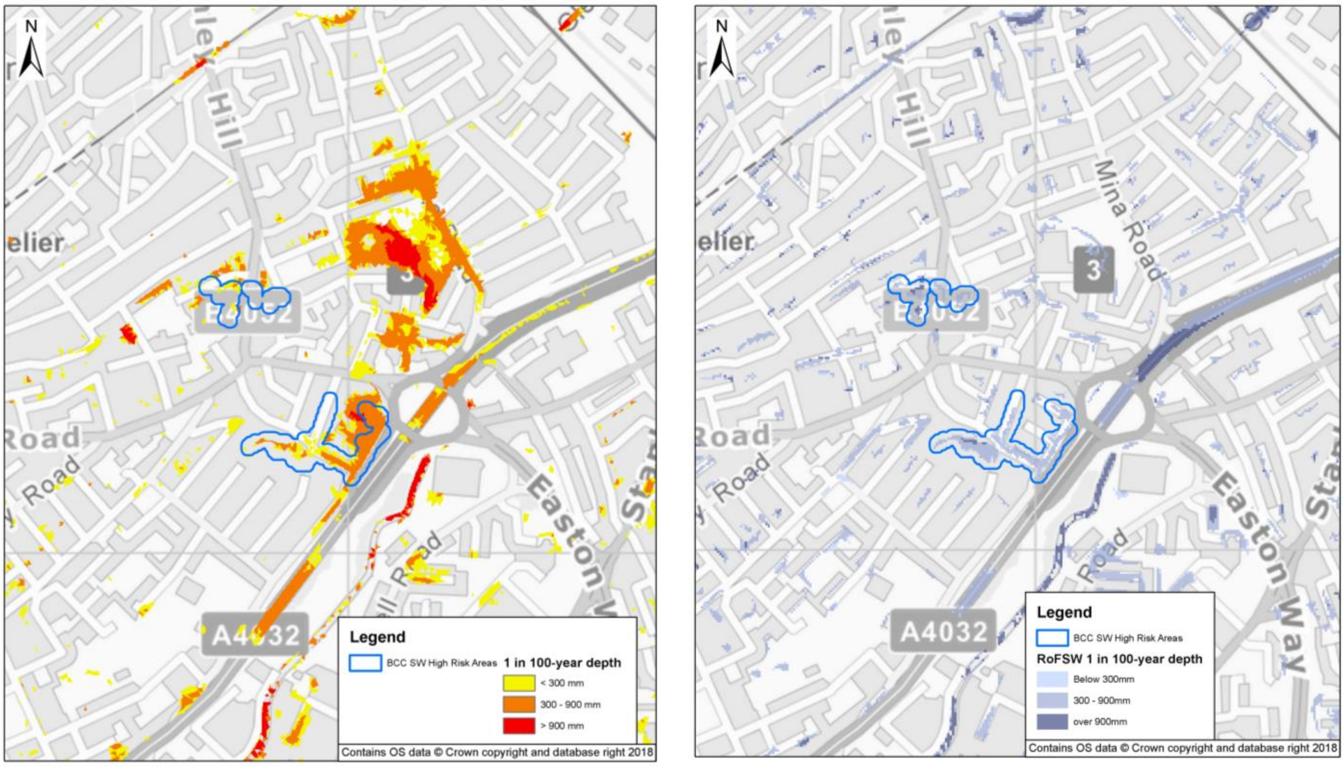


4.1.4 St Agnes

The updated modelling indicates an increase in the surface water flood risk in the St Agnes area as shown in Figure 4-5 below. The increase in flooding at Mina Road is as a result of increased representation of the culverted watercourses in this area and flooding associated with the open channel section of the watercourse through Mina Road Park.

In the existing modelling the use of amendments to the ground model to represent buildings results in patchy areas of the flooding as shown in the figure below. As previously mentioned the use of porous polygons to represent buildings limits effect.

Figure 4-5: Comparison of SW flood risk – St Agnes



4.2 Southmead

Southmead is located in the upper catchment of the River Trym and flood risk in this area is closely associated with runoff from the golf course and urban areas of the upper catchment that cannot enter the culverted sections of the river at Stanton Road. While the culvert is represented in the model, an updating the representation of the inlet structure could improve the understanding of how flows interact with the pipe network in this area.

The existing model results in this area indicate very limited flow beyond Felstead Road due to ponding at buildings in the area. The updated model outputs show reduced risk in the area upstream of Felstead Road due to increased flows along the roads and within gardens, but subsequently increased risk downstream at Pen Park Road.

The update model shows reduced flood depths in the Trowbridge Road / Charfield Road area. As noted above this is in part due to the representation of buildings as porous polygons, which reduces ponding and allows for better representation of flows between and around buildings.

Figure 4-6: Comparison of SW flood risk – Southmead