South Gloucester SWMP

Document: 1 Version: 2

SWMP Report

Gloucestershire County Council

October 2014

Halcrow

raa
Richard Allitt Associates Ltd
CONSULTING ENGINEERS

South Gloucester SWMP

Document: 1 Version: 2

SWMP Report

Gloucestershire County Council

October 2014

Halcrow

raa Richard Allitt Associates Ltd
CONSULTING ENGINEERS

Document history

South Gloucester SWMP

SWMP Report

Gloucestershire County Council

This document has been issued and amended as follows:

Version	Date	Description	Created by	Verified by	Approved by
1.1	Sept 2013	First draft	Ali Cotton	Derek Carter	Derek Carter
1.2	Oct 2014	FINAL	Ali Cotton	Ali Cotton	Derek Carter

Contents

Appendix

1 Introduction

1.1 Project background

During the summer 2007 flooding Gloucester City was severely affected, with over 1,100 properties estimated to have flooded. Based on work completed during the First Edition SWMP it is evident that flooding mechanisms in Gloucester are highly complex, with significant interactions between fluvial and surface water systems. Areas in Gloucester affected by the summer 2007 flooding included:

- Gloucester City Centre – significant flooding occurred throughout Gloucester City Centre (it is estimated that 518 residential properties flooded) due to overtopping of the watercourses and surcharging of the surface water drainage as outfalls to watercourses were blocked due to high levels.
- Hucclecote – there were multiple sources of flooding in Hucclecote, including overtopping of Horsbere Brook and Wotton Brook, surface runoff from King George V playing field and backing up of drains. Over 50 residential properties are estimated to have flooded.
- Longlevens – in Longlevens the predominant flooding mechanism was overtopping of the Horsbere Brook, but surface runoff and surcharging of storm water drains also contributed. Over 270 residential properties are estimated to have flooded.
- Quedgeley – flooding occurred due to overtopping of Daniel's Brook, Dimore Brook and Whaddon Brook, surface runoff from Robin Hill Wood and sewer flooding. 238 residential properties are estimated to have flooded.

In April 2012 Gloucestershire County Council commissioned Halcrow and Richard Allitt Associates to undertake a Surface Water Management Plan (SWMP) for Gloucester. The purpose of the SWMP is to:

- develop a comprehensive understanding of all sources of flood risk (including flood hazards);
- work together and be inclusive of partner and stakeholder views throughout;
- support spatial and emergency planning by disseminating information from the SWMP,
- identify and appraise (through benefit-cost analysis) a range of potential options to mitigate flooding;
- raise the awareness amongst riparian owners of the existence of watercourses and their responsibilities, and;
- identify the flood risk associated with the blockage of major trash screens and culverts (i.e. the performance of key assets).

1.2 Surface Water Management Plans (SWMP) in context

A SWMP is described as a framework through which key local partners with a responsibility for surface water and drainage in their area work together to understand the causes of surface water flooding and agree the most cost effective way of managing that risk. The purpose is to make sustainable surface water management decisions that are evidence based, risk based, future proofed and inclusive of stakeholder views. The SWMP process is illustrated in Appendix A (taken from Defra's SWMP Technical Guidance).

A SWMP should establish a long-term action plan to manage surface water in an area and should influence; future capital investment, drainage maintenance, public engagement and understanding, land-use planning, emergency planning and future developments. The following benefits should be achieved through undertaking a SWMP study:

- increased understanding of the causes, probability and consequences of surface water flooding;
- increased understanding of where surface water flooding will occur, which can be used to inform spatial and emergency planning functions;
- a co-ordinated action plan, agreed by all partners and supported by an understanding of the costs and benefits, which partners will use to work together to identify measures to mitigate surface water flooding;
- identifying opportunities where SuDS can play a more significant role in managing surface water flood risk;
- increased awareness of the duties and responsibilities for managing flood risk of different partners and stakeholders;
- improved public engagement and understanding of surface water flooding, and;
- significant contribution made towards meeting the requirements of the Flood Risk Regulations (2009) and Flood and Water Management Act (2010).

Box 1 – Definition of surface water flooding for Gloucester SWMP

For the purposes of this study, surface water flooding is defined as:

- surface water runoff; runoff as a result of high intensity rainfall when water is ponding or flowing over the ground surface before it enters the underground drainage network or watercourse, or cannot enter it because the network is full to capacity, thus causing flooding (known as pluvial flooding);

- flooding from groundwater where groundwater is defined as all water which is below the surface of the ground and in direct contact with the ground or subsoil;

- sewer flooding*; flooding which occurs when the capacity of underground systems is exceeded due to heavy rainfall, resulting in flooding inside and outside of buildings. Note that the normal discharge of sewers and drains through outfalls may be impeded by high water levels in receiving waters** as a result of wet weather or tidal conditions;

- flooding from open-channel and culverted watercourses which receive most of their flow from inside the urban area and perform an urban drainage function;

- overland flows from the urban/rural fringe entering the built-up area, and;

- overland flows resulting from groundwater sources.

* Consideration of sewer flooding in 'dry weather' resulting from blockage, collapse or pumping station mechanical failure is excluded from SWMPs as this is for the sole concern of the sewerage undertaker

**Interactions with larger rivers and tidal waters can be important mechanisms controlling surface water flooding

1.3 Study area

Gloucestershire County Council commissioned the Gloucester SWMP to cover the whole of Gloucester City's administrative boundary, as well as the towns and villages adjacent to Gloucester including: Brockworth, Churchdown, Innsworth, Longford and Twigworth. The overall study area is illustrated in Figure 1-1.

The study area was split into three areas: North, Central and South, for the purposes of the hydraulic modelling. This report considers the South Gloucester SWMP whilst the North and South catchments are considered in separate reports. The South Gloucester catchment covers Black Ditch, Daniels Brook, Dimore Brook, Shorn Brook and Whaddon Brook.

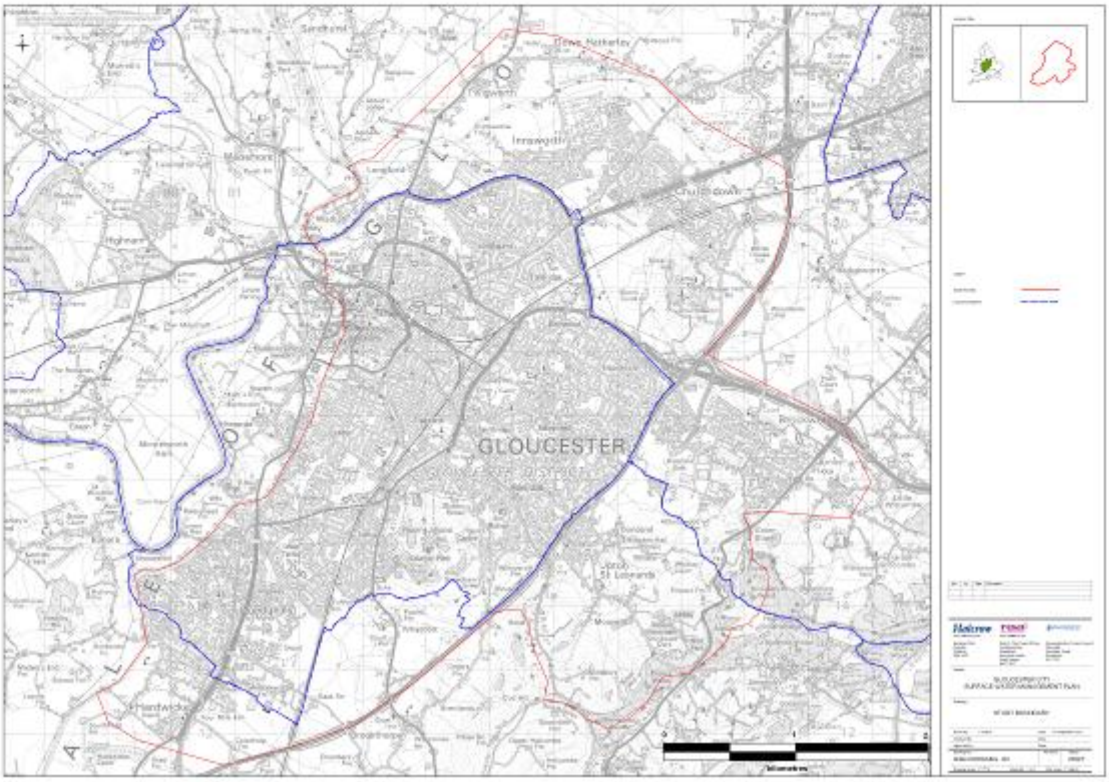

Figure 1-1 Gloucester SWMP study area

2 Phase 1 - Preparation

2.1 Scope the need for the SWMP study

The need for a SWMP study was identified as part of the First Edition SWMP in 2009, due to the nature of flood risk in the catchments.

2.2 Establish partnership

The first stage of the SWMP process is to establish a partnership to help deliver the SWMP. For the Gloucester SWMP a Project Steering Group has been established comprising of: Gloucestershire County Council, Gloucester City Council, Tewkesbury Borough Council, Environment Agency, Severn Trent Water, Lower Severn Internal Drainage Board, Joint Core Strategy planner, Gloucestershire Highways, Halcrow and Richard Allitt Associates. There are a range of other stakeholders who need to be involved in the development of the SWMP at various stages of the process; these are discussed in Section **Error! Reference source not found.**.

Members of the Project Steering Group attended the project inception meeting on 9th May 2012. At the inception meeting the study area, project aims, data requirements, and how to engage with wider stakeholders was discussed and agreed.

2.3 Scope the SWMP study

2.3.1 Set aims and objectives

Draft aims and objectives were produced for discussion and agreement by the Project Steering Group at the Inception Meeting. Partners were encouraged to review and enhance the aims and objectives as necessary, and once finalised, provide confirmation that they agree with the aims and objectives. The final aims and objectives are provided in Appendix B.

2.3.2 Identify availability of information

To undertake the modelling approach used for the Gloucester SWMP information was requested from the Project Steering Group and wider stakeholders. A summary of the data obtained for the SWMP is provided in Table 2-1, and a full data register is included in Appendix C. In addition to the data listed in Table 2-1, site visits were undertaken to gather:

- culvert information where no data exists;
- information on the current condition of some culverts where data does exist, and;
- information on small watercourses and drains (and associated structures) that do not have existing models.

The collection of asset data will supplement GCC's asset register (a requirement of the Flood and Water Management Act). Photos for each asset visited will be supplied to GCC and can be used in the asset register.

The data was reviewed and it was confirmed that the anticipated level of assessment (as set out in section 2.4) can be achieved with the existing data available.

Data provider	Description of data	Comments
Gloucestershire County Council (via EA GeoStore)	Locally Agreed SW Information	Surface Water Flood Maps for 1:200 year rainfall event. The Locally Agreed SW Information is a composite map of different SW mapping sources
Gloucestershire County Council (via EA GeoStore)	Areas Susceptible to Groundwater Flooding	
Gloucestershire County Council	Historical Flooding	GIS layer showing recorded property flooding in July 2007, and EA wrack mark data
Gloucestershire County Council	Environmental constraints	GIS layers showing locations of Ancient Woodland, AONB, Nature Reserves, RAMSAR, SAC and SSSI which will be used to help inform the options assessment
Gloucestershire County Council (via EA GeoStore)	EA Fluvial Flood Zones	Flood Zones 2 and 3
British Waterways	Asset data	Location of culverts, locks, sluices and weirs. In addition data on breach and overtopping of canals has been provided
Severn Trent Water	SMP models of Gloucester with AMP5 improvements	STW have provided their sewer models of the study area, which include committed and completed improvements during the AMP5 period
Severn Trent Water	LiDAR data and photogrammetric DTM	This data was subsequently used for the modelling
Environment Agency	LiDAR data	The LiDAR was 'stamped' to represent the Horsbere Brook flood storage area, as the LiDAR had been flown in advance of this scheme being built
Environment Agency	EA fluvial models	EA fluvial models available for: Tidal Severn, Hatherley, Horsbere, Wotton, Sud, Tywver, Whaddon, Daniels, Dimore
Environment Agency	Culvert survey data	EA data provided for a range of culverts in Gloucester on various watercourses
Environment Agency	Engineering drawings of flood defence schemes	Drawings of Horsbere Brook and Daniels Brook flood alleviation schemes were provided for use in the modelling
Highways Agency	Drainage assets and flood hotspot data	HA data included locations of assets, and flooding hotspots from the HA maintained network in Gloucester (A40, A417, M5)
Gloucestershire Highways	Drainage data	Data on catchpits, gullies, manholes, outfalls, and pipe network provided
Network Rail	Location of asset data	Network Rail provided a spreadsheet to GCC (as part of co-operation under the FWMA) indicating the locations of their assets.

Table 2-1 Summary of data provided for SWMP

2.4 Identify level of assessment for SWMP study

The technical process for the Gloucester SWMP is summarised below.

- Skip the strategic assessment phase, which was completed as part of the First Edition SWMP.
- Begin the modelling at the Intermediate stage, developing a Level II ICM model. This will consist of the existing modelling from the First Edition SWMP, watercourses and culverts; thus producing a single integrated model (divided into three sub study boundaries: North, Central and South). This model will allow all flooding mechanisms to be simulated in an integrated way. It should be noted that this model will be built to represent 'current day' catchment conditions, which includes the Horsbere Brook flood storage area, Daniels Brook flood alleviation scheme and Severn Trent Water capital investment (NB: the STW works include committed capital investment for 2012/13).
- Run the intermediate model for two current day and two future (to account for climate change and urban creep) rainfall events. Use this model to identify flooding mechanisms in Gloucester, identify flood hotspots, and provide information for spatial and emergency planners.
- In the flood hotspots the Project Steering Group will agree the areas to be taken forward to detailed assessment. Focus will be on areas which are at risk from local sources of flooding, or where flooding sources are integrated (e.g. Main River and surface water). In the detailed assessment areas a Level III ICM model ('detailed') will be built to improve the resolution of the modelling
- The detailed model will be run for a for a range of storm events (1 in 5, 10, 30, 50, 75, 100, 1 in 30 + climate change, and 1 in 100 + climate change) to identify the properties and infrastructure affected by flooding, and the damages due to flooding (known as the 'Annualised Flood Damage Costs').
- In each detailed assessment area a long-list of potential mitigation measures will be identified, which will subsequently be short-listed by the Project Steering Group against an agreed set of criteria. This process will identify up to three options for each detailed assessment area and detailed modelling will be undertaken to identify the reduction in flood risk with the options in place. The costs of each option will also be calculated, which will enable a 'cost-benefit assessment' to be undertaken.
- Based on the cost-benefit assessment, the engineering feasibility and a preliminary environmental assessment ('Strategic Environmental Assessment') of the options, a preferred option(s) will be selected for each detailed assessment area and an action plan will be developed.

3 Phase 2 – Risk Assessment

3.1 Undertake intermediate assessment

3.1.1 Modelling approach

The modelling approach used for the Level II ICM modelling is outlined, and discussed in more detail below:

- import the existing Severn Trent Water public sewer model into InfoWorks ICM;
- add the watercourses to the ICM model from existing ISIS models, river survey data, culvert surveys, or LiDAR data;
- incorporate buildings, kerbs and other features to the model which will affect the depth and routing of surface water flooding;
- determine hydrological approach, and;
- build above ground (2D) model to route overland flows.

3.1.1.1 Import existing intermediate model into InfoWorks ICM

The sewer system used in the InfoWorks ICM model was imported from the Severn Trent Water (STW) InfoWorks CS model of the network. The STW sewer model has a high level of verification and has been used in developing a number of capital schemes within the sewer network. For a fair representation of the catchment in its current state, it was decided to include the capital schemes which are currently either under construction or programmed to go into the ground in the next couple of years in the catchment. This gives the best representation of the catchment at a time when any investment or scheme may be implemented.

3.1.1.2 Import ISIS models and river survey into InfoWorks ICM

The four main watercourses are Daniels Brook, Dimore Brook, Shorn Brook, Whaddon Brook and there is also the Black Ditch and an unknown watercourse running through the catchment, as shown in Figure 3-1.

The majority of these watercourses have been modelled with full integration between the 1D river channels and the 1D sewer network with coupling to a 2D representation of the floodplain. The Whaddon Brook, the Daniels Brook and the Dimore Brook had all been previously modelled in ISIS, and these models were used as the basis of the InfoWorks ICM model. For the SWMP, it was required to model these reaches further upstream than the existing model. For these stretches the river reaches were built using the digital terrain model (DTM). The Black Ditch and the unknown watercourse were not previously modelled these have also been modelled from the DTM. Survey data was used to adjust the levels taken from the DTM to match those surveyed to give the most accurate representation possible. The Shorn Brook has been modelled solely in 2D.

The Daniels Brook has been subject to course alteration as a housing development has been constructed on the former RAF Quedgeley. The existing flood relief channel has been improved and a new raised bed and a sluice gate on the Daniel’s Brook restrict flow into the original channel and diverts most flow to the flood relief channel. The cross sections of the modified Daniel's Brook have been taken from design drawings. The bank separating the two channels was raised as part of the flood relief work. Two mesh zones in the model raised the ground level in the DTM to represent the higher ridge.

The Shorn Brook was modelled solely in 2D. The simulated flow was routed down the channel as it was represented by the DTM, and therefore the mesh. One of the tributaries of the Daniels Brook was also modelled using this method until its confluence with the Daniels Brook.

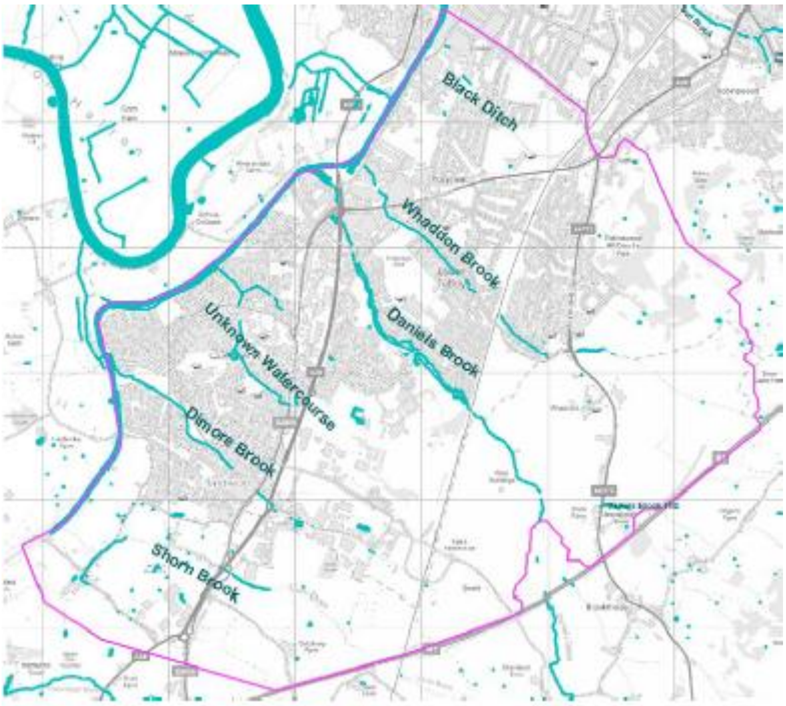

Figure 3-1 Watercourses in South Gloucester SWMP

3.1.1.3 Undertake additional survey

Where necessary, surveys were undertaken of the bridges and culverts in the catchment and this data was used in preference of data with lower confidence. The channels built using the DTM were also adjusted to match the surveyed inverts to give the most accurate representation possible.

There were lengths of watercourse within the study area that were not previously modelled. For these stretches the river reaches were built using the digital terrain model (DTM). Again the survey data was used to adjust the levels taken from the DTM to match those surveyed to give the most accurate representation possible

3.1.1.4 Hydrology

There are three different aspects to the hydrology used in the modelling, as follows:

- urban hydrology used for the areas which drain to the foul, combined of surface water sewer networks;

- pluvial runoff from permeable surfaces within the urban area and areas downstream of the location of the 1D fluvial inflows, and;
- 1D inflows for the watercourses.

Sewer hydrology

The hydrology used by Severn Trent Water in their sewer models differs from the rest of the UK Water Industry. Severn Trent Water uses a fixed 100% runoff from all surfaces irrespective of whether they are impermeable or permeable; the only difference between the different surfaces is the initial losses which are allowed for. This approach may be considered unduly conservative but based on past experience Severn Trent Water have found that the flows generated are not particularly unreasonable; this might be because the contributing areas are carefully defined following property boundaries so that large permeable surfaces are excluded which is reasonable as they generally do not contribute flows to the sewers.

Pluvial hydrology

The 2D mesh generates direct (2D) runoff for areas outside of the sewer network contributing areas. The percentage runoff for each catchment was calculated from FEH independently, as described below. In all the catchments the SPRHost value identified was increased by 50% to allow for catchment wetness. This was done to bring the design criteria in line with the design standards used for the Cheltenham, Tewkesbury and Bishops Cleeve SWMPs. This value was originally calculated during the Cheltenham SWMP which utilised data from the Dowdeswell Reservoir for the July 2007 event which was used for verification of the model.

Pluvial hydrology (including the Dimore Brook catchment) was modelled with a SPRHOST of 64.5%, based on 50% uplift in the FEH parameter.

Rural runoff represented as 1D inflows

For the Whaddon Brook, Daniel's Brook and Shorn Brook 1D inflow hydrographs were produced to represent fluvial inflows to the model and prevent the need to model the entire upstream catchments in 2D. The location of the 1D inflow hydrographs are shown in GSGLOS 002 in Appendix E.

Inflow hydrographs were produced at each location following the FEH rainfall/runoff methodology and catchment descriptors. The possible use of donor catchments was reviewed. Whilst the FEH CD identifies three National River Flow Archive (NRFA) gauging stations on Shorn Brook, information about these stations is neither available on the NRFA web pages nor in Appendix A of FEH volume 4. Donor adjustments were therefore not made to Tp (time to peak), SPR (standard percentage runoff) and BF (baseflow).

The catchment descriptors for each subcatchment were obtained from FEH CD-ROM version 3. These were checked as outlined below.

- The digitised catchment boundaries were checked visually against background Ordnance Survey open data mapping. The digitised catchment boundaries appear correct and so were not adjusted. No alternations were made to Standard Percentage Runoff values which were reviewed against soil information within Landis (www.landis.org.uk/services/soilscapes.cfm).

- The URBEXT values indicate that all catchments are rural (or moderately urbanised) other than Hatherley brook which has an URBEXT of 0.178. The URBEXT values were adjusted to the 2012 value using the Urban Expansion Factor calculation as outlined in FEH volume 5.

Design storm durations were calculated for each of the sub catchments between 1.25 and 7.25 hours using a data interval of 0.25 hours.

Whilst the majority of the subcatchments being assessed within this hydrology note are predominantly rural, the study area as a whole (including the area downstream of these 12 inflow locations) is urban. Therefore a summer storm profile was used.

A single FEH catchment does not cover the study area, therefore depth-duration-frequency (DDF) parameters are taken from a catchment central to the study area and applied to all inflows. This establishes a consistent design storm over each subcatchment which is applied to the study area of 138km^2.

Downstream levels for the rivers which discharge to the River Severn (Dimore Brook, Black Ditch and unknown watercourse) were provided from an existing River Severn tidal interface. These levels correspond to the 5 year return period calculated within the River Severn model. A relatively low return period was required for the Severn to provide downstream conditions without causing fluvial flooding which would mask the impact of surface water flooding being investigated as part of the South Gloucester SWMP.

The Daniel's Brook and Whaddon Brook drain into the Gloucester and Sharpness Canal, therefore dictating the downstream conditions of the watercourse. From gauging data on the Canal it is known there is no significant response in the water level from rainfall events. The standard recorded level from the Canal was applied to the downstream end of the Daniel's and Whaddon Brook as a level file to restrict flows.

3.1.1.5 Build above ground 2D model

For each catchment, a 2D mesh was created from the DTM to cover the study area. A new feature of version 2.5 of InfoWorks ICM is 'terrain sensitive meshing'. This identifies steep areas within the DTM and can reduce the triangle size in these areas to more accurately represent the terrain. This also removes the need for break lines. Some sensitivity testing was undertaken to identify the best triangle and element sizes and height variation values to use. It was identified that the most suitable values were a maximum triangle size of 100m2, a minimum element area of 5m2 and a maximum height variation of 0.75m.

Buildings, greater than a plan area of 25m2, were identified and cut out of the 2D mesh as voids to replicate their obstruction of flow paths.

Mesh zones were used for two purposes. The first was to remove any false blockages in the mesh. These occur where there are embankments, such as for motorways or railways, which have underpasses or subways which provide flow routes that have not been cut out of the DTM. In these situations mesh zones were added to alter the ground level to be the same as the ground levels either side of the embankments, enabling the flow paths. The second use of mesh zones was only required in the Northern catchment and is described in the North Gloucester SWMP report.

3.1.2 Model simulations

At the inception meeting for these projects it was identified that there have been a number of major changes in the catchment since the last major storm (July 2007), specifically the Environment Agency schemes on the Horsbere Brook and Daniels Brook, and numerous Severn Trent Water sewerage schemes. For this reason it was decided that it was inappropriate to attempt to verify the models against the 2007 event. It was decided that the recorded flooded properties would be used to identify whether the models were replicating flooding in known locations. This was used in conjunction with local knowledge to ensure that the flooding mechanisms and depths were realistic.

The model results were generated for 1 in 30 and 1 in 200 year events (0.033 and 0.005 AEP) to aid spatial and emergency planning. The intermediate models were also used to identify flooding hot spots to be taken forward to detailed modelling and optioneering.

3.1.3 Identify hotspot locations for detailed risk assessment

An assessment of anecdotal records of flooding and the intermediate modelling resulted in several potential hotspot locations being identified. Initially five hotspot locations were identified, and the steering group determined to take forward two of the areas for detailed risk assessment. The two areas taken forward to detailed risk assessment were:

- Whaddon Brook – modelling and historical flood records indicate a significant flood risk issue along this watercourse, with flood risk to properties and people on Stroud Road, Grange Road, Holmleigh Road and into Lower Tuffley;
- Milton Avenue and Black Ditch – this area is predominantly experiencing flooding due to pluvial runoff, and includes known locations which have suffered historic flooding including Shakespeare Avenue and Milton Avenue. This area also includes the Black Ditch watercourse.

A plan of these two areas is provided in **Error! Reference source not found.**.

Three further areas were initially proposed for detailed risk assessment, but were discounted by the steering group.

- Tuffley Avenue – the intermediate model indicated several properties to be at risk of flooding due to pluvial runoff, but there is no anecdotal evidence to support this.
- Abootswood Close – the intermediate model indicated several properties to be at risk of flooding due to pluvial runoff, but there is no anecdotal evidence to support this.
- Dimore Brook – there are a number of isolated clusters of flooded properties along this watercourse. The steering group agreed to utilise the intermediate model to help identify these clusters and provide information to support future Property-Level Protection, but that no further modelling should be undertaken.

3.2 Undertake detailed risk assessment

3.2.1 Collate information for detailed assessment

The data needed for the Level III ICM was identified and gathered early on during the project. A full data register is provided in Appendix C.

3.2.2 Approach

Develop modelling approach

The detailed model build process begins from the basis of the intermediate models. It was done in version 3 of the InfoWorks ICM software. For each of the hotspot locations a separate network was created, and the models were pruned as described below.

The sewer model was left largely as it was in the intermediate models as the sewerage network is so complex with the capacity of the main trunk sewers being a key factor. Some minor areas of surface water network that did not contribute to the individual hotspot locations were removed as these had no impact in the areas of interest and this improved simulation times.

The 2D simulation areas were reduced to cover only the study area and other areas that may be contributing overland flow into the study areas. Given the difference in hotspot size different 2D parameters were used in the different detailed models. The 2D mesh parameters used are shown in the modelling report in Appendix D.

Roads have been represented within the detailed models by use of mesh zones. These have been given a reduced maximum triangle size of $4m^2$ and minimum element size of $1m^2$ and have also been lowered by 125mm. This lowering represents the way kerbs constrain the flow within the carriageway and the value of 125mm is used as this is standard kerb height.

Property boundaries can affect flow paths, depending on style and height. The intermediate model was used to identify areas where flow paths cross property boundaries and these areas were then assessed using photographs to find the style of the boundaries. Where the boundaries were found to be impermeable (e.g. Walls), they were represented in the model using porous walls, given a height based on estimates from photographs. This gave the best representation available.

For all the detailed models the river reaches within the hotspot areas were modelled in line with the intermediate modelling. The downstream boundary conditions for the watercourses that drain into the River Severn were given a 'free outfall', so the effects from the River Severn were removed from the model. This meant that level files were only required for those watercourses draining into the Gloucester and Sharpness Canal.

Method to calculate flood damages

The purpose of quantifying flood risk is to identify the annualised damages that occur to people and property due to flooding. This can subsequently be used to justify the costs and benefits of mitigation measures to alleviate the flooding.

The first step in quantifying the current and future flood risk is to establish the baseline modelling conditions, which includes: the design rainfall events and the critical duration; the boundary conditions of the model, and; the model receptors to be included in the calculations. Six design storms were run using 'present' day rainfall and two design storms were run using 20% uplift for climate change:

- 1 in 5 (20%) probability of occurring in any given year;
- 1 in 10 (10%) probability of occurring in any given year;
- 1 in 30 year (3.33%) probability of occurring in any given year;
- 1 in 30 (3.33%) probability of occurring in any given year + a 20% uplift in rainfall to account for future climate change;
- 1 in 50 (2%) probability of occurring in any given year;
- 1 in 75 (1.33%) probability of occurring in any given year;
- 1 in 100 (1%) probability of occurring in any given year, and;
- 1 in 100 (1%) probability of occurring in any given year + a 20% uplift in rainfall to account for future climate change.

The suite of design storms were run for the 'critical duration' event. The critical duration event is the design storm duration which gives the greatest volume of flooding. The suite of design storms were run for the 'critical duration' event. The critical duration event is the design storm duration which gives the greatest volume of flooding. This was done by running 60, 120, 180, 240, 300 and 360 minute duration storms for the 1 in 10 year (10%AP) return period. For each of these different storm durations the total flooding, the number of flooded manholes and the extent of flooding were determined.

For these model simulations flood risk management capital and maintenance works that have been built or proposed since 2007 were included in the model (e.g. clearance of blockages, upsizing of pipes).

The model receptors included in the annualised damages were residential properties, non-residential properties and critical services (e.g. schools), using the Environment Agency's National Receptors Dataset (NRD). The NRD assigns each 'property' centre point with a MCM (Multi-Coloured Manual) code which is in turn used to calculate the damage to the property based on modelled depth of flooding.

Once the baseline model conditions are established and the model simulations have been completed, the outputs from the model are used to quantify the current and future risk.

The 2D flood depth results from the simulations were converted into ASCII grid files and these were subsequently interrogated to identify whether a residential or non-residential property was considered to suffer from internal flooding.

This data was then used in conjunction with flood depth/damage curves to calculate the flood damage cost for that storm return period. The standardised spreadsheet developed by Defra and used for cost-benefit assessments for fluvial flooding projects was used; this spreadsheet automatically calculates the annualised flood damage costs. It is particularly important with this process that the full range of storm return periods are included. Property thresholds of 200mm were used for all properties in the study area as agreed with the Project Steering Group.

The annualised damages are further discussed in Section 4.2 alongside the benefits and costs of options. Subsequently Defra's Partnership Funding calculator was completed for each option to identify the benefit-cost ratio and the level of Partnership Funding likely to be required to secure FDGiA.

3.2.3 Flood risk in hotspot locations

Milton Avenue and Black Ditch

The upstream extent of this catchment is the Gloucester Ahtletics Club and sports fields to the south and east of Laburnum Road. Pluvial runoff flows overland primarily into two ditches which converge to form a watercourse near Poplar Close. The watercourse then goes into culvert for the remainder of its length before re-emerging at the western end of Milton Avenue before flowing into the Black Ditch. There is an existing balancing pond near Milton Avenue which drains the remainder of the Black Ditch catchment to the north. There is no history of overtopping of this balancing pond. Downstream of the balancing pond the Black Ditch is in culvert as it flwos through the industrial estate east of Bristol Road before emerging as an open channel downstream of a siphon under the canal. The Black Ditch continues to flow north-westerly in an open channel (except through culverts under the A38 and Rea Lane) before joining the River Servern west of Rea Lane. Modelling suggests that the Black Ditch backs up when levels in the River Severn floodplain are high, but there is no anecdotal evidence of this occurring so the influence of the Severn was removed from further analysis for this catchment.

There is anecdotal and modelling evidence that the watercourse near Poplar Close overtops at the culvert inlet during times of heavy rainfall which causes flood to the hosues immediately downstream. In addition direct pluvial runoff from the Gloucester Athletics Club runs onto and across Podsmead Road causing flooding to properties. In addition, the surface water sewer network in this catchment is under stress, which causes flooding to properties and infrastructure. The surface water sewer on Podsmead Road is exceeded during frequent rainfall events causing water to pond on the low spot of the road near the junction with Woodpecker Road.

In addition, exceedance from the surface water and pluvial runoff has caused flooding to properties on Scortt Avenue, Masefield Avenue and Shakespeare Avenue. Finally, properties on Milton Avenue are at risk of flooding due to pluvial runoff and exceedance from the surface water sewer network.

A summary of the predicted numbers of properties and expected annual damage is shown in Table 3-1. As illustrated 55 residential properties are at risk from a 1 in 30 year probability rainfall event, with a further 83 at risk from a 1 in 100 year probability rainfall event. This equates to an expected annual damage of £6.4million.

Table 3-1 Properties at risk for Milton Avenue and Black Ditch catchment

Criteria	No. residential properties at risk	No. commercial properties at risk
1 in 10 year rainfall probability event	36	3
1 in 30 year rainfall probability event	55	3
1 in 50 year rainfall probability event	74	6
1 in 75 year rainfall probability event	125	7
1 in 100 year rainfall probability event	138	7
Expected damage over a 100 year appraisal period (£)	**£7.6 million**	

Whaddon Brook

The primary source of flood risk in this catchment is overtopping of the Whaddon Brook and pluvial runoff. There was significant flooding in this area in July 2007. At least 50 properties are recorded to have flooded although this is believed to be a significant under-representation of actual flooding. Furthermore, flooding is regularly experienced at the low spot on Stroud Road near the junction with Grange Road, and there was property flooding in November 2012 north of Grange Road.

At the upstream of the catchment (to the east of Stroud Road) the Whaddon Brook flows in a westerly direction in an open channel. At the point it enters into culvert under Stroud Road (and Grange Road) there is anecdotal and modelled evidence that the watercourse overtops the Brook at this point causing ponding on Stroud Road. When flood depths on Stroud Road are deep enough, they overtop onto Grange Road, causing flood water to flow down Grange Road and flood properties on Grange Road, Bybrook Road, Whaddon Way and Harwell Close. In addition to flooding from the watercourse, there is also evidence of runoff flowing both north and south on Stroud Road, and ponding at the low spot. This additional runoff contributes to flooding downstream.

As the watercourse flows through the urban area there is also evidence of overtopping of the Brook on Holmleigh Road which causes flood risk to properties. Furthermore, there is anecdotal and modelled evidence of flooding to properties along the entire section of the watercourse, including the industrial estate to the north of Cole Avenue.

In addition to flood risk from the Whaddon Brook pluvial runoff south of Grange Road is also known to cause flooding to properties on Grange Road, Bybrook Road, Whaddon Way and Harwell Close.

A summary of the predicted numbers of properties and expected annual damage is shown in Table 3-2. As illustrated 70 residential properties are at risk from a 1 in 30 year probability rainfall event, with a further 98 at risk from a 1 in 100 year probability rainfall event. This equates to an expected annual damage of £28.25 million.

Table 3-2 Properties at risk for Whaddon Brook catchment

Criteria	No. residential properties at risk	No. commercial properties at risk
1 in 10 year rainfall probability event	36	18
1 in 30 year rainfall probability event	70	29
1 in 50 year rainfall probability event	99	36
1 in 75 year rainfall probability event	140	42
1 in 100 year rainfall probability event	168	43
Expected damage over a 100 year appraisal period (£)	**£28.25 million**	

3.3 Map and communicate risk

3.3.1 Map surface water flooding

Outputs from the Level II ICM model was provided to the project steering group, and spatial and emergency planners at Gloucestershire County Council and Gloucester City Council. The outputs were provided using an interactive PDF format, which allows users to view a series of model outputs within one document, and toggle layers on and off. These outputs should be used to inform spatial and emergency planning in the catchment.

4 Phase 3 - Options

4.1 Introduction

The SWMP Technical Guidance sets out a framework for the options identification and appraisal process which has been followed for the SWMP. This process is described below. Section XX to XX describe how this process has been adopted for the Whaddon Brook and Milton Avenue detailed assessment areas.

4.1.1 Identify and short-list measures

Identify a range of measures which could be taken to reduce flood risk – at this stage thinking shouldn't be constrained by funding routes and a range of structural and non-structural measures should be considered which may have a range of costs and benefits associated with them. To identify options for each detailed assessment area a hierarchical approach was adopted based on the diagram in Figure 4-1. This diagram provides a useful framework to consider options, starting with flow reduction (SUDS and separation) and working through the hierarchy.

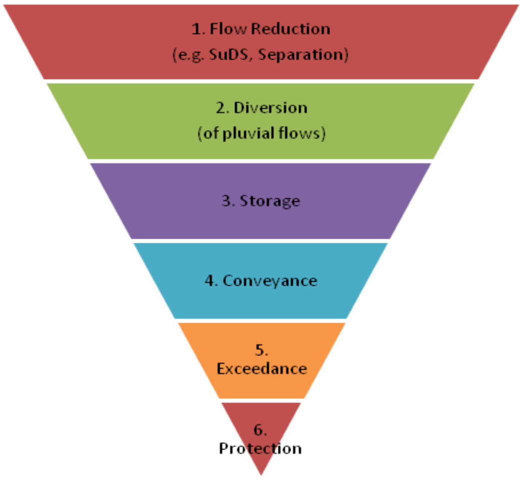

Figure 4-1: Hierarchy to consider appropriate surface water management measures (courtesy of Richard Allitt Associates)

The measures set out in this hierarchy were assessed in terms of their potential feasibility for the study area.

Once the measures have been identified a process is undertaken short-list the range of measures through a high-level appraisal to screen out measures which are not feasible and identify up to three options for each detailed assessment area to take forward for detailed appraisal (benefit-cost analysis).

4.1.2 Assess measures

For the short-listed options undertake detailed options appraisal for up to three options for each detailed assessment area to identify a preferred option/s. The SWMP technical guidance states that the 'first step in the options assessment process is to determine which benefits and costs are to be included in the analysis.' For the SWMP there are two distinct sets of options for the options assessment:

- options which have been taken forward to detailed modelling appraisal and benefit-cost analysis, and;
- options which have not been taken forward for detailed modelling appraisal but will be considered as part of the SWMP action plan (these include options for protecting the homes affected by groundwater flooding in Moreton Close).

4.1.2.1 Options taken forward to detailed modelling appraisal and benefit-cost analysis

The process for assessing the options which have been taken forward to outline design and detailed benefit-cost analysis is set out below:

- calculate baseline annualised average damages (AAD) to property, businesses and critical services for the 'Do Nothing' scenario over a 100 year period, and discount[1];
- calculate AAD for the 'Do Minimum' and flood alleviation options to identify the residual damages under different scenarios over a 100 year period, and discount (NB: the baseline damages – the residual damages = benefits of intervention);
- calculate approximate capital and operational costs of the 'Do Minimum' and flood alleviation options over a 100 year period[2], and discount;
- calculate the benefit-cost ratio (BCR)[3] for each option;
- consider other factors which influence the decision about which options should be taken forward, including engineering feasibility and project risks, and socio-political acceptability;
- using the BCR and assessment of un-monetised benefits and costs determine the preferred option/s to take forward for the action plan[4], and;
- refine the preferred option and develop the SWMP action plan.

The outputs from this assessment are provided in Section 4.2.

4.1.2.2 Options not taken forward for detailed modelling appraisal but considered as part of SWMP action plan

There are a range of measures which can be taken within the study area to manage the risk of flooding, but which have not been subject to detailed modelling as part of the SWMP. These include:

- Property level protection measures

---

[1] Discounting is a technique used to compare the costs and benefits that occur in different time periods. It is based on the principle that, generally, people prefer to receive benefits now rather than later and all costs and benefits should be discounted in the analysis. The SWMP has used the standard Green Book methodology for discounting: 3.5% for 0-30 years, 3.0% for 31-75 years, and 2.5% for 76-125 years into the future.

[2] Construction costs were calculated based on daily labour rates, time to complete activities, and volumes of earth to be cut and filled. Operational costs included annual maintenance and periodic refurbishment of the structures.

[3] A ratio of the benefits and costs of an option over the whole life (in this case 100 years). A BCR of >1 indicates that the benefits exceed the costs.

[4] Remaining options screened out and decision-making process documented.

- Community resilience measures such as local flood response plans and improved communication networks for flood warning (e.g. trained flood wardens);
- Mobilising local communities to undertake ditch clearance and maintenance of watercourses (possibly through flood wardens), and;
- 'Green streets' – retrofitting sustainable drainage systems (SuDS) into the existing urban environment whenever opportunities arise, e.g. highway improvements, traffic calming measures, regeneration.

These measures are considered in greater detail in the SWMP action plan.

4.2 Whaddon Brook catchment

4.2.1 Identify and short-list measures

The dominant flooding mechanisms in this catchment are:

- overtopping of the Whaddon Brook to the east of Stroud Road which causes water to pond on Stroud Road and then flow down Grange Road
- runoff on Stroud Road from the north and south to the 'low spot' at the junction of Stroud Road/Grange Road which causes water to pond on Stroud Road and then flow down Grange Road;
- pluvial runoff to the south of Grange Road which flows onto the highway and floods residential properties, and;
- overtopping of the watercourse to the east of the railway which causes flooding on Holmwood Road.

To mitigate flood risk in this area a range of measures were initially identified, as illustrated in Table 4-1.

Measures	Consideration	Short-listed for further assessment?
Flow reduction	Flow reduction in the urban area will not reduce flood risk because flooding is dominated by overtopping of watercourses and pluvial runoff. No options for flow reduction were identified.	No
Diversion	To alleviate flooding due to pluvial runoff south of Grange Road the existing embankment could be increased in height by 200-300mm	Yes for detailed modelling
Storage	Several areas were identified as being potentially suitable for storage: • utilising St Peter's school rugby pitch as a temporary storage area • creating two online storage areas on the right bank of Whaddon Brook to the east of Stroud Road (NB: currently unused land) • creating a storage area south of Grange Road near the junction with Bybrook Road to intercept pluvial runoff • creating an online storage pond on the left bank of Whaddon Brook immediately to the east of the railway • creating a storage area to the south of Grange Road immediately to the east of the railway • utilising the football pitches at Holmleigh Park as a temporary storage area	Utilising St Peter's school rugby pitch was discounted because there were other more favourable locations Utilising football pitches at Holmleigh Park was discounted because existing ground levels did not lend themselves to storage.

Conveyance	It may be possible to add an additional culvert in the footpath along Grange Road to increase conveyance. This has been tested in the model as does alleviate flood risk, as long as the additional culvert discharges to the storage area to the south of Grange Road	Yes
Exceedance	Re-profiling of Grange Road was considered to enable exceedance flows to be managed to a storage area to the south of Grange Road. However, this would increase the flood hazard (and potential risk to life) which was considered unacceptable	No
Property level protection	Property-level protection will be required at the businesses to the north-west of Cole Avenue to alleviate flood risk, as there are no other suitable mitigation measures	Yes, but not for detailed modelling

Table 4-1 Measures identified and short-listed for Whaddon Brook

Based on the initial measures identified and short-listed through a technical appraisal, and in agreement with the project steering group, it was agreed that a two composite options would be represented in the detailed modelling, which comprised of some or all of the following:

- creating online storage areas on the right bank of Whaddon Brook to the east of Stroud Road (NB: currently unused land)
- creating a storage area south of Grange Road near the junction with Bybrook Road to intercept pluvial runoff
- creating an online storage pond on the left bank of Whaddon Brook immediately to the east of the railway
- creating a storage area to the south of Grange Road immediately to the east of the railway, and;
- increase existing embankment existing in the field to the south of Grange Road by 200-300mm.

Preliminary engineering drawings which illustrates these options are provided in Appendix F.

4.2.2 Assess measures

Both options investigated for this catchment involve significant engineering works to address the different sources of flooding. With respect to the flood storage areas the key technical challenges associated with these flood storage areas are: the level of storage above natural ground level; the volume of excavation, landowner negotiations and compensation; potential for contaminated land within the study area, and; managing exceedance flows. Based on the technical feasibility assessment we have not identified any show stoppers to delivery of this option.

However, the storage options all rely on provision of storage in private land. Therefore early engagement and consultation with affected landowners will be critical in establishing the willingness to allow land for flood storage in times of heavy rainfall. In addition, one of the key issues associated with this option is that the storage areas would result in water being above natural ground level during significant rainfall events. There may be concern from local residents about storage being provided above natural ground level in close proximity to residential properties, and these concerns will need to be considered during the next stages of the scheme development. Storage east of Stroud Road is in close proximity to St Peter's School, and school children need to access the playing fields to the south of the Brook via a footbridge. Therefore, health and safety of school children will be a key consideration as part of further design work, to ensure safe access to the playing fields can be maintained and the storage areas will not present a risk.

The economic appraisal clearly favour option 2 as the preferred option. Option 1 has a benefit-cost ratio of 8.5, and a Partnership Funding Score of 65%. Therefore, it is estimated at this stage that approximately £650k of contributions would need to be raised locally to enable the scheme to progress. This is considered to be unrealistic at this stage, and therefore option 1 has been discounted on economic grounds. Option 2 has a benefit-cost ratio of 10.9, and a Partnership Funding Score of 84%. Approximately £230k of local contributions would need to be secured in order to achieve a PF Score of 100% which would increase the likelihood of progressing this scheme.

Name of option	Brief description	Advantages / Opportunities	Disadvantages / Constraints	Economic Appraisal
Baseline	Existing system working as designed with no additional improvement measures other than basic maintenance regime and known blockages removed.	✓ No additional capital costs ✓ Continue basic maintenance programme to ensure system is clear from blockages.	✗ Flooding will continue in the area causing damage to properties and infrastructure, and 'risk to life' because of the fast flowing water within the study area. ✗ Flood risk will increase over time due to climate change and urban creep. ✗ In a major rainfall event it is probable that debris will block parts of the drainage system regardless of how clear it was prior to the event.	
Option 1 – Composite	Composite option consisting of new flood storage areas and some localised embankments. The composite option consists of: - Online storage on the Whaddon Brook east of Stroud Road (total volume = 15,000 m^3) - Storage to the south of Grange Road (nr junction with Bybrook Road) to intercept runoff from fields (volume = 5,000 m^3) - Storage to the south of Grange Road (immediately east of railway line) to intercept surface runoff (volume = 500 m^3) - Online storage on left bank of Whaddon Brook to the north of Grange Road (immediately east of railway line) (volume = 4,000 m^3) - Increase embankment height in fields running parallel to Grange Road by 200-300mm to provide additional protection from surface runoff - Low-level embankments/walls on	✓ Storage area could be designed to enhance habitat and biodiversity ✓ Option addresses both fluvial and pluvial runoff issues and eases burden on surface water sewer network ✓ Subject to design, some of the storage areas could be built to enable existing land use to continue	✗ Significant engineering works over a sizeable area ✗ Storage area east of Stroud Road in close proximity to school with associated health and safety concerns ✗ Would require storage c.2m above natural ground level to the east of Stroud Road, which would be expensive due to need for sheet piling ✗ Storage above natural ground level in close proximity to residential properties could lead to residents concerns ✗ Additional complexities in design (e.g. geotechnical risks) due to need for auxiliary spillway and construction of raised embankment as part of storage ✗ Access to Public Rights of Way would be affected during and after construction ✗ Poor access to some of the storage locations ✗ Does not resolve all flooding to commercial properties near Cole Avenue	Whole Life Costs = **£1.8m** Whole Life Benefits = **£15.6m** Benefit-Cost Ratio = **8.6** PF Score = **65%** Contributions needed for 100% PF Score = **£639k**

Name of option	Brief description	Advantages / Opportunities	Disadvantages / Constraints	Economic Appraisal
	eastern side of Stroud Road near junction with Grange Road to ensure surface runoff goes to storage area			
Option 2 – Revised Composite	Composite option consisting of new flood storage areas and some localised embankments. The composite option consists of: - Online storage on the Whaddon Brook east of Stroud Road (total volume = 18,000 m^3) - Storage to the south of Grange Road (nr junction with Bybrook Road) to intercept runoff from fields (volume = 6,000 m^3) - Embankment to the south of Grange Road (immediately east of railway line) to intercept surface runoff - Online storage on left bank of Whaddon Brook to the north of Grange Road (immediately east of railway line) (volume = 5,500 m^3)	✓ Similar advantages / opportunities to option 1	✗ Similar disadvantages and constraints to option 1, although the scope of engineering works is reduced	Whole Life Costs = **£1.4m** Whole Life Benefits = **£15.6m*** Benefit-Cost Ratio = **10.9** PF Score = **84%** Contributions needed for 100% PF Score = **£230k** * Assumed benefits are the same as option 1 as it offers similar standard of protection. To be confirmed during PAR

4.3 Milton Avenue

4.3.1 Identify and short-list measures

Based on the initial assessment of the measures identified it was agreed that a single composite option would be represented in the detailed modelling, including:

- low-level embankment adjacent to eastern edge of Podsmead Road near running track to capture pluvial runoff;
- low-level embankment adjacent to the western edge of the playing fields to capture pluvial runoff, and;
- small storage area between Masefield Avenue and Scott Avenue (surface water sewers will be diverted to the storage area.

A preliminary drawing to illustrate the option is provided in Appendix F.

Measures	Consideration	Short-listed for further assessment?
Flow reduction	Flow reduction in the urban area will not reduce flood risk because flooding is dominated by pluvial runoff. No options for flow reduction were identified.	No
Diversion	Low-level embankment adjacent to eastern edge of Podsmead Road near running track to capture pluvial runoff Embankment along the western boundary of the playing fields to capture runoff from the playing fields and the upstream catchment	Yes for detailed modelling
Storage	Yes, storage between Masefield Avenue and Scott Avenue	Yes for detailed modelling
Conveyance	No conveyance measures identified	No
Exceedance	Exceedance measures not considered to alleviate flooding in this area	No
Property level protection	Provide property level protection for all properties identified as being at risk of flooding. This does not reduce flood hazard, but would provide protection against damages to properties.	Yes, but not for detailed modelling

Table 4-2 Measures identified and short-listed for Milton Avenue

4.3.2 Assess measures

The composite option is recommended to be taken forward as the preferred option for Milton Avenue and Black Ditch. The proposed composite option would provide protection to 60 properties at very significant (1 in 20 year) and significant (1 in 75 year) flood risk. It is estimated that the scheme would fully qualify for Partnership Funding, as the PF Score is 123%, assuming the properties are in the top 21%-40% of most deprived communities in the country. The preferred option would mostly involve construction within the public realm which would simplify the issues associated with land acquisition, although some negotiation will be required with Gloucester Athletics Club and Sport England (who maintain the playing fields).

In addition, the preferred option involves limited storage (except for at Scott Avenue and Masefield Avenue). It is not proposed that water is stored behind the embankments to the east of the study area for any significant length of time.

One of the key issues associated with this option is that the storage area and embankment would result in water being above natural ground level during significant rainfall events. In addition, the storage area at Scott Avenue and Masefield Avenue would result in a reduction in the informal playing area within this area. Both of these issues could result in concerns from local residents and therefore early engagement and consultation with local residents will be important to ensure buy-in from the community.

Name of option	Brief description	Engineering characteristics & issues	Other considerations	Economic appraisal
Baseline	Existing system working as designed with no additional improvement measures other than basic maintenance regime and known blockages removed.	✓ No additional capital costs	✗ Flooding will continue in the area causing damage to properties and infrastructure, and 'risk to life' because of the fast flowing water within the study area. ✗ Flood risk will increase over time due to climate change and urban creep. ✗ In a major rainfall event it is probable that debris will block parts of the drainage system regardless of how clear it was prior to the event.	
Option 1 – Composite	Composite option consisting of: • 1.4m embankment to east of Laburnum Road and along western edge of playing fields • 1.4m bund east of Podsmead Road to intercept runoff from playing fields • Offline storage area between Masefield Avenie/Scott Avenue to store flows currently in surface water sewers	✓ Makes use of land mostly within the public realm which will reduce issues of land acquisition ✓ Limited storage which simplifies design of scheme ✓ Potential to secure external funding as a result of any future regeneration of the playing fields	✗ Embankments will hold water above natural ground level ✗ Storage on Scott Avenue and Masefield Avenue is within close proximity to properties and a playing area so will need appropriate health and safety considerations. Storage will also be above natural ground level which will need to be considered during design ✗ Possible residents concern about flood storage in close proximity to properties ✗ Potential concern about embankment within Gloucester Athletics Club ✗ Public rights of way may need diverting during and after construction	Whole Life Costs = **£514k** Whole Life Benefits = **£3,910** Benefit-Cost Ratio = **7.5:1** PF Score = **123%** Contributions needed for 100% PF Score = **N/A** NB: 100 yr assumed design life (TBC during PAR preparation)

Name of option	Brief description	Engineering characteristics & issues	Other considerations	Economic appraisal
Option 2 – Property level protection	Property level protection to 55 properties within the hotspot area at risk of flooding during a 1 in 30 year flood event	✓ Limited construction activities ✓ Suitable in this location because shallow flood depths; property protection would be effective	✗ Reluctance of householders to install measures could reduce efficiency of scheme to reduce flood risk ✗ No opportunity for environmental enhancements	Whole Life Costs = **£231k** Whole Life Benefits = **£1,260** Benefit-Cost Ratio = **5.5:1** PF Score = **111%** Contributions needed for 100% PF Score = **N/A** NB: 20 yr assumed design life

5 Action Plan

5.1 Whaddon Brook

5.1.1 Summary of flood risk

The primary source of flood risk in this catchment is overtopping of the Whaddon Brook and pluvial runoff. There was significant flooding in this area in July 2007. At least 50 properties are recorded to have flooded although this is believed to be a significant under-representation of actual flooding. Furthermore, flooding is regularly experienced at the low spot on Stroud Road near the junction with Grange Road, and there was property flooding in November 2012 north of Grange Road.

At the upstream of the catchment (to the east of Stroud Road) the Whaddon Brook flows in a westerly direction in an open channel. At the point it enters into culvert under Stroud Road (and Grange Road) there is anecdotal and modelled evidence that the watercourse overtops the Brook at this point causing ponding on Stroud Road. When flood depths on Stroud Road are deep enough, they overtop onto Grange Road, causing flood water to flow down Grange Road and flood properties on Grange Road, Bybrook Road, Whaddon Way and Harwell Close. In addition to flooding from the watercourse, there is also evidence of runoff flowing both north and south on Stroud Road, and ponding at the low spot. This additional runoff contributes to flooding downstream.

As the watercourse flows through the urban area there is also evidence of overtopping of the Brook on Holmleigh Road which causes flood risk to properties. Furthermore, there is anecdotal and modelled evidence of flooding to properties along the entire section of the watercourse, including the industrial estate to the north of Cole Avenue.

In addition to flood risk from the Whaddon Brook pluvial runoff south of Grange Road is also known to cause flooding to properties on Grange Road, Bybrook Road, Whaddon Way and Harwell Close.

Based on the integrated modelling undertaken in this study 70 residential properties are at risk from a 1 in 30 year probability rainfall event, with a further 98 at risk from a 1 in 100 year probability rainfall event. This equates to an expected annual damage of £28.25 million.

5.1.2 Preferred option

Based on the options appraisal it was determined that a composite option would be the preferred option to take forward to apply for funding:

- storage to the east of Stroud Road with an estimated volume of 18,000 m^3;
- storage to the south of Grange Road near the junction with Bybrook Road with an estimated volume of 6,000 m^3;
- storage on the left bank of Whaddon Brook immediately to the east of the railway with an estimated volume of 5,500 m^3, and;
- an embankment to the south of Grange Road immediately to the east of the railway.

It should be noted that the current design is seeking to manage flood risk to most properties up to and including a 1 in 100 year rainfall event. During the development of the Project Appraisal Report differing standards of protection will need to be assessed to optimise the costs and benefits of the scheme, and the technical design. For example, a lower standard of protection would result in reduced volume of storage required which may be more publicly acceptable.

5.1.2.1 Technical feasibility

This scheme involves a significant amount of engineering works, and there are therefore a number of technical challenges to be overcome. None of the technical challenges are considered to be insurmountable, but will need to be considered in greater detail during the development of the Project Appraisal Report, and outline and detailed design.

The storage options all rely on provision of storage in private land. Therefore early engagement and consultation with affected landowners will be critical in establishing the willingness to allow land for flood storage in times of heavy rainfall. In addition, one of the key issues associated with this option is that the storage areas would result in water being above natural ground level during significant rainfall events. There may be concern from local residents about storage being provided above natural ground level in close proximity to residential properties, and these concerns will need to be considered during the next stages of the scheme development. Storage east of Stroud Road is in close proximity to St Peter's School, and school children need to access the playing fields to the south of the Brook via a footbridge. Therefore, health and safety of school children will be a key consideration as part of further design work, to ensure safe access to the playing fields can be maintained and the storage areas will not present a risk.

5.1.2.2 Costs and benefits

As part of the SWMP an assessment of the construction and maintenance costs of the preferred option, and the potential benefits (with respect to reductions in flood risk) was undertaken.

The estimated design, construction and maintenance costs for the preferred option are:

- Planning and Design = £80k
- Construction = £1250k
- Maintenance = £100k

Over a 100 year period the total estimated Present Value costs are estimated to be £1438k.

The benefits of this measure can be quantified by comparing the total damages due to flooding for a baseline scenario with the preferred option. The Present Value benefits are estimated to be £15,610k, which gives a benefit cost ratio of 10.9. It should be noted that it is not possible to alleviate flooding to all properties in the area, but the option does reduce flood risk for 140 properties.

5.1.2.3 Partnership Funding Score

In May 2011, the way that Government funding is allocated to flood and coastal erosion risk management projects in England changed with immediate effect. Funding levels for each scheme now relate directly to the number of households protected, the damages being prevented, plus the other benefits a scheme would deliver. The principle of Partnership Funding is that Central Government will be prepared to pay a certain percentage of the costs towards a flood scheme, depending on the benefits provided. Where there is a shortfall in how much Central Government is prepared to give towards a scheme there are two primary options for the promoting risk management authority: 1) secure additional funding from local sources, or; 2) reduce the costs of the scheme.

The Partnership Funding Score for Whaddon Brook is illustrated in Table 5-1. The PF Score is 84% which means that additional funding (or reduction in scheme costs) would need to be secured in order to progress this scheme

Table 5-1 Partnership Funding information for Whaddon Brook

Criteria	Outcome
PV Costs	£1.44m
PV Benefits	£15.6m
Benefit-Cost Ratio	10.9
PF Score	84%
Res. Properties at risk before the scheme	Very Significant = 53 Significant = 60 Moderate = 73
Res. Properties at risk after the scheme	Very Significant = 25* Significant = 6 Moderate = 14 * There are a number of commercial properties which flood and are not currently addressed by this scheme. Further work will be undertaken as part of the PAR to confirm whether these properties can be protected.

5.1.3 Next steps and responsibilities

The next steps to take this option forward are:

i) submit a FDGiA Application for the scheme for inclusion in the Medium Term Plan;

ii) undertake consultation with local landowners, the school and Network Rail to confirm the proposed location of the storage areas.

iii) undertake consultation with the local residents to confirm acceptability of the proposals;

iv) undertake topographic survey, ground investigations and auxiliary spillways as part of the outline design;

v) undertake an environmental assessment of the proposed option – it is recommended that an Environment Agency low risk file note will be sufficient for this option;

vi) prepare a Project Appraisal Report and secure funding from the Project Appraisal Board (assuming the application for FDGiA is successful);

vii) secure planning permission for the proposed works, and;

viii) undertake detailed design, prepare drawings for contractors and appoint contractors to undertake the necessary works.

It is recommended that Gloucester City Council act as the lead authority for this scheme, although close liaison with Gloucestershire County Council will be critical to successful delivery. The timescales for action will be dependant on securing funding for the preferred option.

5.1.4 Project Risks

The key project risks and potential mitigation measures are identified at this stage are identified in Table 5-2.

Table 5-2 Project risks for Whaddon Brook

Risk	**Mitigation**
Storage above natural ground level could lead to concerns from local residents	Early and ongoing communication and engagement with local residents to ensure buy-in for the scheme and to enable design changes to be incorporated early on if required to secure public buy-in Storage volumes could be reduced to alleviate residents concerns, but this will need to be considered during the PAR
Lack of willingness from landowners to allow flood storage on their land	Early and ongoing engagement with landowners. Alternative for IPP if storage is not feasible.
Ground conditions unsuitable for excavation and low embankment	Early ground investigation to identify suitability of ground for proposed works
Storage near school could present risks to school children	Need to fully consider health and safety concerns early on, and engage with the school about the design
FDGiA funding not secured	Seek alternative contributions for the scheme
Public Right of Way (PROW) affected by storage	Early consultation with PROW team in GCC to confirm proposed design of storage area and required mitigation.

5.2 Milton Avenue and Black Ditch

5.2.1 Summary of flood risk

Pluvial runoff flows overland primarily into two ditches which converge to form a watercourse near Poplar Close. The watercourse then goes into culvert for the remainder of its length before re-emerging at the western end of Milton Avenue before flowing into the Black Ditch. There is an existing balancing pond near Milton Avenue which drains the remainder of the Black Ditch catchment to the north. There is no history of overtopping of this balancing pond. Downstream of the balancing pond the Black Ditch is in culvert as it flwos through the industrial estate east of Bristol Road before emerging as an open channel downstream of a siphon under the canal. The Black Ditch continues to flow north-westerly in an open channel (except through culverts under the A38 and Rea Lane) before joining the River Servern west of Rea Lane. Modelling suggests that the Black Ditch backs up when levels in the River Severn floodplain are high, but there is no anecdotal evidence of this occurring so the influence of the Severn was removed from further analysis for this catchment.

There is anecdotal and modelling evidence that the watercourse near Poplar Close overtops at the culvert inlet during times of heavy rainfall which causes flood to the hosues immediately downstream. In addition direct pluvial runoff from the Gloucester Athletics Club runs onto and across Podsmead Road causing flooding to properties. In addition, the surface water sewer network in this catchment is under stress, which causes flooding to properties and infrastructure. The surface water sewer on Podsmead Road is exceeded during frequent rainfall events causing water to pond on the low spot of the road near the junction with Woodpecker Road.

In addition, exceedance from the surface water and pluvial runoff has caused flooding to properties on Scortt Avenue, Masefield Avenue and Shakespeare Avenue. Finally, properties on Milton Avenue are at risk of flooding due to pluvial runoff and exceedance from the surface water sewer network.

5.2.2 Preferred option

Based on the options appraisal it was determined that a composite option would be the preferred option to take forward to apply for funding:

- low-level embankment adjacent to eastern edge of Podsmead Road near running track to capture pluvial runoff;
- low-level embankment adjacent to the western edge of the playing fields to capture pluvial runoff, and;
- small storage area between Masefield Avenue and Scott Avenue (surface water sewers will be diverted to the storage area.

5.2.2.1 Technical feasibility

There are no major technical feasibility issues associated with the preferred option. The preferred option would mostly involve construction within the public realm which would simplify the issues associated with land acquisition, although some negotiation will be required with Gloucester Athletics Club and Sport England (who maintain the playing fields).

In addition, the preferred option involves limited storage (except for at Scott Avenue and Masefield Avenue). It is not proposed that water is stored behind the embankments to the east of the study area for any significant length of time.

One of the key issues associated with this option is that the storage area and embankment would result in water being above natural ground level during significant rainfall events. In addition, the storage area at Scott Avenue and Masefield Avenue would result in a reduction in the informal playing area within this area.

Both of these issues could result in concerns from local residents and therefore early engagement and consultation with local residents will be important to ensure buy-in from the community.

5.2.2.2 Costs and benefits

As part of the SWMP an assessment of the construction and maintenance costs of the preferred option, and the potential benefits (with respect to reductions in flood risk) was undertaken.

The estimated design, construction and maintenance costs for the preferred option are:

- Planning and Design = £52k
- Construction = £369k
- Maintenance = £93k (over 100 years including discounting: includes £3k per annum for annual maintenance and £10k every 25 years for structural repairs)

Over a 100 year period the total estimated Present Value costs are estimated to be £514k

The benefits of this measure can be quantified by comparing the total damages due to flooding for a baseline scenario with the preferred option. The Present Value benefits are estimated to be £3,910, which gives a benefit cost ratio of 7.6. It should be noted that it is not possible to alleviate flooding to all properties in the area, but the option does reduce 'very significant' (1 in 20 year rainfall probability event) and 'significant' (1 in 75 year rainfall probability event) flood risk to 59 properties.

5.2.2.3 Partnership Funding Score

> In May 2011, the way that Government funding is allocated to flood and coastal erosion risk management projects in England changed with immediate effect. Funding levels for each scheme now relate directly to the number of households protected, the damages being prevented, plus the other benefits a scheme would deliver. The principle of Partnership Funding is that Central Government will be prepared to pay a certain percentage of the costs towards a flood scheme, depending on the benefits provided. Where there is a shortfall in how much Central Government is prepared to give towards a scheme there are two primary options for the promoting risk management authority: 1) secure additional funding from local sources, or; 2) reduce the costs of the scheme.

The Partnership Funding Score for Milton Avenue and Black Ditch is illustrated in Table 5-3. The PF Score is 123% which means there is a high potential that Central Government would be prepared to fund the entire scheme.

Table 5-3 Partnership Funding information for Milton Avenue and BlackDitch

Criteria	Outcome
PV Costs	£514k
PV Benefits	£3,910k
Benefit-Cost Ratio	7.6:1
PF Score	123%
Properties at risk before the scheme	Very Significant = 36

	Significant = 36 Moderate = 9
Properties at risk after the scheme	Very Significant = 3 Significant = 10 Moderate = 33

5.2.3 Next steps and responsibilities

The next steps to take this option forward are:

ix) submit a FDGiA Application for the scheme for inclusion in the Medium Term Plan;

x) undertake consultation with Gloucester Athletics Club and Sport England to understand willingness for proposed embankments;

xi) undertake consultation with the local residents to confirm acceptability of the proposals;

xii) undertake topographic survey, ground investigations and auxiliary spillways as part of the outline design;

xiii) undertake an environmental assessment of the proposed option – it is recommended that an Environment Agency low risk file note will be sufficient for this option;

xiv) prepare a Project Appraisal Report and secure funding from the Project Appraisal Board (assuming the application for FDGiA is successful);

xv) secure planning permission for the proposed works, and;

xvi) undertake detailed design, prepare drawings for contractors and appoint contractors to undertake the necessary works.

It is recommended that Gloucester City Council act as the lead authority for this scheme, although close liaison with Gloucestershire County Council will be critical to successful delivery. The timescales for action will be dependant on securing funding for the preferred option.

5.2.4 Project Risks

The key project risks and potential mitigation measures are identified at this stage are identified in Table 5-4

Table 5-4 Project risks for Milton Avenue and Black Ditch

Risk	Mitigation
Gloucester Athletics Club and Sport England unwilling to allow proposed embankments	Early consultation required once funding secured Pursue property level protection as the preferred option if the landowner is unwilling to allow land to be used
Storage above natural ground level could lead to concerns from local residents	Early and ongoing communication and engagement with local residents to ensure buy-in for the scheme and to enable design changes to be incorporated early
Loss of open space in Scott Avenue /	

Masefield Avenue could lead to residents concern	on if required to secure public buy-in
Ground conditions unsuitable for excavation and low embankment	Early ground investigation to identify suitability of ground for proposed works
FDGiA funding not secured	Seek alternative contributions for the scheme

Appendix A SWMP Process Wheel

Appendix B Aims and objectives of South Gloucester SWMP

The aims of the South Gloucester SWMP will be to identify cost effective and affordable measures to alleviate flooding to residents and businesses in Gloucester by:

- developing a comprehensive understanding of all sources of flood risk (including flood hazards);
- working together and being inclusive of partner and stakeholder views throughout;
- supporting spatial and emergency planning by disseminating information from the SWMP,
- identifying and appraising (through benefit-cost analysis) a range of potential options to mitigate flooding;
- raise the awareness amongst riparian owners of the existence of watercourses and their responsibilities, and;
- identify the flood risk associated to the blockage of major trash screens and culverts (i.e. the performance of key assets).

The objectives of the SWMPs are as follows:

i) build an 'intermediate' InfoWorks ICM model of the respective catchments including all sewers, watercourses and culverts;

ii) by means of sensitivity analysis and historical records verify the 'intermediate' models,

iii) run the 'intermediate' models for two current day storm events (to be agreed) and prepare plans showing predicted depths and velocities for each storm event;

iv) for Gloucester North only, the flood risk assessment must also consider the risk from reservoir inundation (data supplied by EA subject to security and confidentiality arrangements),

v) for Gloucester South only, the flood risk assessment must also consider the risk from a break in the canal bank (subject to discussions with British Waterways),

vi) run the 'intermediate' models for two 'future' storm events (e.g. with climate change and/or future development) to understand how flooding might change in the catchment over time;

vii) use the 'intermediate model' to identify the flooding mechanisms in the catchments;

viii) in areas of highest flood risk the steering group will agree areas to be studied in more detail ('detailed assessment areas');

ix) build and verify a series of discrete sub-models to a 'detailed' level (in InfoWorks ICM) for each detailed assessment area;

x) using the 'detailed' sub-models, identify the flood risk for a range of storm events (1 in 5, 10, 30, 50, 75, 100, 1 in 30 + climate change, and 1 in 100 + climate change);

xi) using the 'detailed' sub-models identify the properties affected by flooding for each return period and calculate the 'Annualised Flood Damage Costs';

xii) identify a long-list of potential mitigation measures (referred to as 'options') for each detailed assessment area and undertake workshop with partners to enhance options and shortlist accordingly, against agreed criteria, for each detailed assessment area;

xiii) for a limited number (up to 3) of possible options for each detailed assessment area, prepare a detailed model including the required works and run each 'options' model for the agreed range of storm return periods and for each option determine the Annualised Flood Damage Costs;

xiv) calculate the construction costs for each option and calculate the Cost Benefit ratio for each option;

xv) for each detailed assessment area identify the preferred option(s) to be taken forward for the development of the action plan;

xvi) prepare action plans for each detailed assessment area, which includes a summary of the agreed actions, potential funding routes, responsibilities and timescales for implementation;

xvii) prepare an engagement plan which outlines who, when and how stakeholders (outside the project steering group) should be engaged, and carry out engagement in accordance with the plan, and;

xviii) agree the format of modelling outputs with the project steering group, and disseminate information to the project steering group and any stakeholders identified in the engagement plan.

Appendix C Data Register

C.1 Tables

Table C.1 – Data register

Appendix D Hydraulic modelling report

Appendix E South Mapping outputs

GSGLOS 001 - Study boundary

GSGLOS 002 - Hotspot areas

GSGLOS 003 - Intermediate model 1_30yr Depth

GSGLOS 004 - Intermediate model 1_30yr Hazard

GSGLOS 005 - Whaddon Bk baseline 1_30yr Depth

GSGLOS 006 - Whaddon Bk baseline 1_100yr Depth

GSGLOS 007 - Whaddon Bk option 1_30yr Depth

GSGLOS 008 - Whaddon Bk option 1_100yr Depth

GSGLOS 009 - Black Ditch baseline 1_30yr Depth

GSGLOS 010 - Black Ditch baseline 1_100yr Depth

GSGLOS 011 - Black Ditch option 1_30yr Depth

GSGLOS 012 - Black Ditch option 1_100yr Depth

Appendix F Preliminary engineering drawings

Black Ditch Composite Option

Whaddon Brook Option 1

Whaddon Brook Option 2

Appendix G Costings

Whaddon Brook - Option 1

Whaddon Brook - Option 2

Black Ditch - Composite Option

Appendix H Partnership Funding Calculators