# Central Gloucester SWMP

Document: 1 Version: 2

SWMP Report

## Gloucestershire County Council

October 2014

Richard Allitt Associates Ltd
CONSULTING ENGINEERS

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# Document history

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# 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 Central Gloucester SWMP whilst the North and South catchments are considered in separate reports. The Central Gloucester catchment includes the Sud Brook, River Twyver, Matson Brook and Linden Brook.

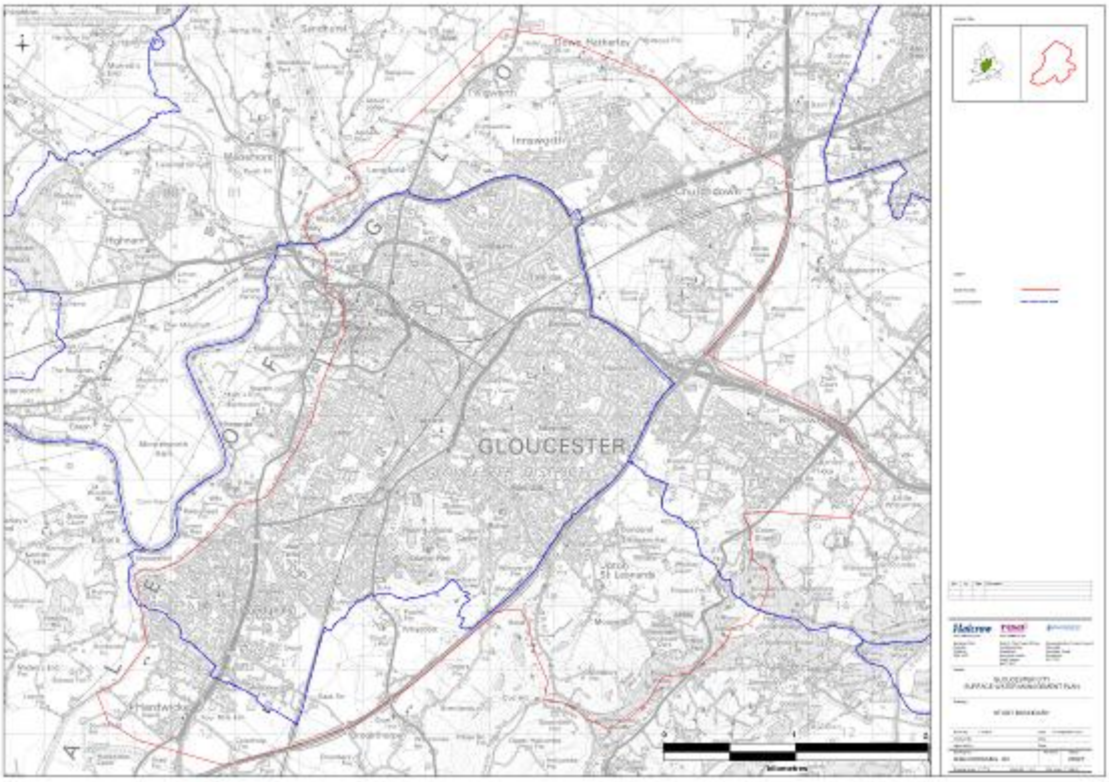


*Figure 1-1 Gloucester SWMP study area*

# 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

There are two major watercourses flowing through the Central Gloucester catchment, the River Twyver and the Sud Brook. The interaction between these watercourses is complex, due to the River Twyver in Glevum Way Park splitting and the manmade Twyver Relief channel draining into the Saintbridge Balancing Pond where it joins the Sud Brook.

These watercourses have previously been modelled within ISIS as far upstream as the M5 motorway. These models have been used to build the watercourses into the InfoWorks ICM model, but have been refined for the urban environment. This has been done by interpolating extra cross sections along the length of the watercourse to increase sinuosity and frequency of calculations.

#### 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.

Inflows to the Sud Brook were modelled entirely in 2D, and the SPRHOST value used for the catchment was 57.75%

**Rural runoff represented as 1D inflows**

For the River Twyver and its tributary 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 GNGLOS011 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 model 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 Sud Brook drains 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 Sud 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 25m$^2$, 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

Based on an understanding of flooding mechanisms from local knowledge by the steering group and the modelling outputs it is evident there are three primary flooding mechanism in the Central Gloucester catchment, some of which operate independently and some which are interlinked, which are discussed in the following sections. The primary flooding locations and mechanisms are illustrated in XXX. To identify flooding mechanisms and hotspot locations we have focussed on areas at risk for a 1 in 30 year rainfall event, because these more frequent flooding incidents will cause greater damage over an appraisal period compared to less frequent (or 'more extreme') flooding incidents (e.g. 1 in 100 year rainfall events). Furthermore, it is difficult to build an economic business case for flooding solely occurring during more extreme rainfall events.

To mitigate flood risk in Central Gloucester there is a need to consider the fluvial catchments holistically, for example considering upstream storage which may mitigate flood risk further downstream. Therefore, the steering group agreed that the Central Gloucester catchment should be considered as a single detailed assessment area. This enables us to consider an over-arching strategy for managing flood risk from different sources in these catchments, and to assess the potential overall costs and benefits of managing flood risk

#### 3.1.3.1 Pluvial runoff entering the urban environment

Runoff from Robinswood Hill presents the biggest flood risk with respect to pluvial flooding. There are three primary flow pathways, which are predicted to cause flooding to properties:

i) runoff which affects properties on Well Cross Road, Robinswood Gardens, Reservoir Road, Finlay Road and Sapperton Road (NB: there was some flooding in November 2012 in this area due to excess surface runoff from Robinswood Hill)

ii) runoff which affects properties on Baneberry Road, Myrtle Close and Badminton Road (NB: properties on these roads were affected during the summer 2007 flooding), and;

iii) runoff which affects properties on Matson Avenue and Winsley Road (NB: there is no historic flooding to properties at this location).

The hydraulic model indicates that over 300 properties could be at risk of flooding during a 1 in 30 year rainfall event, although historic flooding would suggest that the actual nature of flood risk is significantly lower than this. It should be noted that in some of these locations the surface water sewers are also contributing to flooding for the same rainfall event.

#### 3.1.3.2 Fluvial flooding

All of the watercourses except Linden Brook are classified as Main River and therefore are managed by the Environment Agency using their permissive powers. Table 3-1 describes the key flooding issues associated with each of the Main Rivers in the Central Gloucester study boundary. Fluvial flooding presents a significant risk to people and property during extreme rainfall events, but the modelling has indicated that fluvial flooding is not expected during more frequent rainfall events. This makes it more difficult to justify a business case for intervention.

*Table 3-1 Fluvial flood risk in Central Gloucester study boundary*

| Watercourse | Summary of key flooding locations |
|---|---|
| Linden Brook | Linden Brook is culverted along the majority of its length, with surface water sewers discharging into it throughout its course. It is known to be in poor condition in various locations, which means that surface water/combined sewer discharges into the Brook back up and cause flooding. |
| Matson Brook | Pluvial runoff from Robinswood Hill exceeds the capacity of the Matson Brook as it goes into culvert under Cotteswold Road. Once it is out of bank flood water runs down Painswick Road and into The Lampreys |
| Sud Brook (including Twyver relief channel) | There is limited flood risk from the Sud Brook until downstream of Saintbridge balancing pond, which overtopped during 2007, which caused flooding to properties on Cheyney Close, The Lampreys and Malborough Crescent. Property level protection is being offered to 15-20 properties on Cheyney Close and The Lampreys.<br>Downstream of the railway there is predicted flood risk along the length of the culverted sections of the Sud Brook. It should be noted that there is little fluvial flooding from the Sud Brook during more |

| | |
|---|---|
| | frequent rainfall events (e.g. 1 in 10 or 1 in 30 year rainfall events) |
| River Twyver | In Upton St Leonards the River Twyver presents flood risk to isolated properties, which is currently being assessed by GCC and Stroud District Council following flooding in November 2012<br>There is some flood risk from overtopping of the Twyver in Abbeydale upstream of the flow splitter structure, although some properties have implemented property level protection<br>Downstream of the splitter structure there is limited flood risk from the Twyver until the downstream reaches which are influenced by levels in the River Severn (NB: The River Severn can cause backing up of the Twyver as far back as the railway) |

#### 3.1.3.3 Flooding from the urban drainage network (sewer and/or highway)

It should be noted that the performance of the urban drainage network is inter-dependant on the levels in Main Rivers. The modelling demonstrated that the urban Main Rivers in the central Gloucester study area perform a significant urban drainage function. Surface water outfalls occur along the length of the Sud Brook and River Twyver, therefore the capacity of these Main Rivers determines the operation of the sewer network. In some cases lack of capacity in the watercourse causes the sewers to back up with resultant flooding from the sewers rather than from the watercourse. The flooding mechanisms were shown to be highly integrated and the sources of flooding are very difficult to separate. Flooding arises when the flows are greater than the capacities of the watercourses and surface water sewers, with a high degree of interaction between the surface water sewers and the watercourses.

Modelling indicates the following locations are at high risk due to flooding from the sewer network during a 1 in 30 year rainfall event:

- Carmarthen Street;
- Malborough Crescent;
- New Street and Weston Road (which is also at risk due to overtopping of the Sud Brook), and;
- Brook Street.

It is recognised that Severn Trent Water has invested significant money in the Central Gloucester catchment to alleviate flood risk from the combined sewers, and this has been incorporated into the modelling. The locations shown above are not currently on Severn Trent Water's DG5 Register because there has not been historic flooding in these locations, except for properties on New Street which appear on the DG5 Register as flooding due to rainfall events less frequent than 1 in 20 year rainfall event. As a result this is unlikely to trigger investment from Severn Trent Water in the short-term.

## 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 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. The changes made to the model for the detailed risk assessment of the Central Gloucester catchment are described below.

- 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.

### 3.2.3 Quantify current and future flood risk

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. 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. This process found 180 minutes to be the critical duration for the study area.

For these model simulations flood risk management capital and maintenance works which 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 0 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.

## 3.3 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

For the purposes of the options appraisal we have identified and appraised options for each of the key flooding locations in the Central Gloucester study area. Collectively the options will form the short and long term strategy for managing flood risk in the study area. Within the study area measures can be broadly categorised into short-term and long-term, where:

- short-term measures are those which can be funded and delivered within the next 1-5 years and will provide an immediate improvement in flood risk to people and properties, and;
- long-term measures are those which will only be deliverable over a 10-20 year period, and will result in gradual improvements in flood risk.

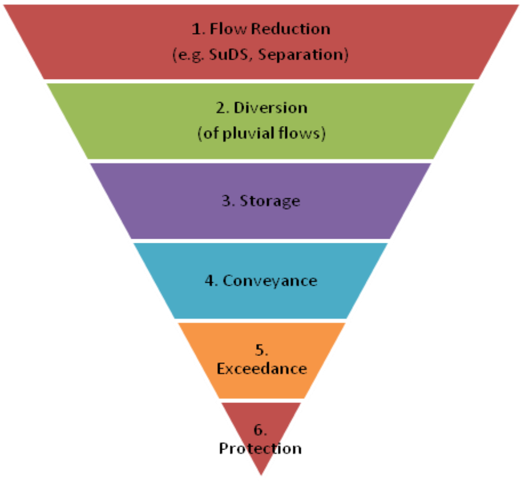
The SWMP Technical Guidance sets out a framework for the options identification and appraisal process which has been followed for the SWMP. This includes:

- identify a range of measures;
- short-list these measures to screen out infeasible measures and determine which ones should be subject to appraisal, and;
- undertake an appraisal (economic, environmental and technical feasibility) of the short-listed measures.

## 4.2 Identify and short-list short-term measures

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 measures 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 determine which measures should be taken forward for options appraisal

The hydraulic modelling identified a significant amount of flooded properties for the 1 in 30 year rainfall event. Many of the properties predicted to flood were isolated properties which may not be at risk in reality because of the presence of kerbs, low lying boundary walls, and/or highway drainage which is not represented in the modelling. Therefore, for the purposes of the options appraisal we have identified the key historic and predicted flooding locations, and focussed on these areas to mitigate flood risk. The short-term measures identified and short-listed for each of the key flooding locations is provided in Table 4-1.

*Table 4-1 Short-term measures identified and short-listed for Central Gloucester catchment*

| ID (in mapping) | Location | Flooding Mechanisms | Measures identified | Short-listed for options appraisal? |
|---|---|---|---|---|
| A | Reservoir Road (and other roads) | Pluvial runoff from Robinswood Hill | A1 – Following flooding in November 2012 Gloucester City Council is investigating land drainage improvements to alleviate flooding in this area | Yes, but no further action in SWMP |
| | | | A2 – Property level protection could be offered in conjunction with A1 | |
| B | Badminton Road (and surrounding roads) | Pluvial runoff from Robinswood Hill | B1 - Upstream storage (storage area P in Appendix E) was considered to manage pluvial flows from Robinswood Hill in public open space to the south of Baneberry Road. This measure was excluded because it would not be cost-beneficial as the storage area would only offer protection to some of the properties at risk | No |
| | | | B2 – Option B1 would also require surface water sewers in the area to be significantly upsized to capture surface water runoff and route it to the storage area. This measure was discounted because it is considered technically infeasible (sewers would need to be upsized to >600mm) and not cost-beneficial | No |
| | | | B3 – Offer property level protection measures to downstream properties | Yes |
| C | Matson Avenue and Winsley Road | Pluvial runoff from Robinswood Hill | No history of flooding in this area, so no pro-active mitigation measures considered | No |
| D | Painswick Road near Wheatway | Pluvial runoff from Upton St Leonards and exceedance from the sewer network | D1 – Storage at Winnycroft Farm (storage area A in Appendix E) was considered to manage pluvial flows and overtopping of the watercourse | Yes |
| | | | D2 – Works at Upton St Leonards to divert pluvial runoff away from Painswick Road (NB: pluvial runoff from Upton St Leonards arrives at this low spot in the catchment). This was found to be ineffective at reducing flood risk so was not considered any further | No |
| | | | D3 – Offer property level protection measures to downstream properties | Yes |
| E | Downstream of Saintbridge balancing pond (Cheyney Close / The Lampreys) | Overtopping of the balancing pond during extreme flows | E1 – Raise embankment of existing Saintbridge wet balancing pond by up to 2m whilst retaining existing water levels to offer additional flood protection | Yes |
| | | | E2 – Extend plan area of Saintbridge wet balancing pond into existing allotments | Yes |
| | | | E3 – Offer property level protection measures to downstream properties | Yes |

| | | | | |
|---|---|---|---|---|
| | Sud Brook, River Tywver and Twyver relief upstream of Saintbridge | Overtopping of Sud Brook during extreme events | There is limited flood risk to properties from the Sud Brook or the Twyver relief upstream of Saintbridge balancing pond, but mitigation measures have been identified to reduce flood flows arriving at Saintbridge, which will improve downstream flood risk. A series of flood storage areas were identified and appraised at locations where there is available green space, as part of an overall strategy to manage flood risk on the Sud Brook and Twyver relief. Potential storage areas identified were (see Appendix E):<br>• A – Winnycroft Farm: taken forward for options appraisal<br>• B – Haycroft Drive: offers little flood protection so **discounted** from further analysis<br>• C – Awebridge Way: not possible to storage sufficient water so **discounted** from further analysis<br>• D – Heron Way: not possible to storage sufficient water so **discounted** from further analysis<br>• E – Curfew Road: not possible to storage sufficient water so **discounted** from further analysis<br>• F – Cotteswold Road (storage in school grounds): existing works on the school grounds means there is no opportunity to implement flood storage in the school grounds so **discounted** from further analysis<br>• J – upsize existing balancing pond at Abbeymead Avenue: taken forward for options appraisal<br>• K – NW Abbeymead Avenue nr Morrisons: storage not effective at all in offering flood protection so **discounted** analysis<br>• L – Football fields nr Glevum Way Park: considered that significant excavation would be required to make this storage area work, so **discounted** from further analysis<br>• M – Osprey Close: being progressed as potential WFD scheme by Gloucester City Council so **not considered** further in SWMP<br>• N – Bittern Avenue: little flood risk benefit as the Twyver is not overtopping at this location so **discounted** from further analysis<br>In addition, we have also considered altering the splitter structure to send more baseflow down the main River Twyver which will reduce sediment loading to Saintbidge balancing pond, and will introduce a self-cleansing regime to the River Twyver | Yes, some storage areas taken forward as was appraisal of splitter structure |
| F | Malborough Rd / Malborough Crescent | Sud Brook (due to backing up from | Fluvial flood risk only affects properties in this area for extreme rainfall events (NB: the affected properties are not in Flood Zone 3). Combined sewer | Yes |

| | | | | |
|---|---|---|---|---|
| | | railway culvert) and combined sewer flooding | flooding affecting properties during more frequent rainfall events, so measures focussed on alleviating flooding from combined sewer network. The short-term measure considered is to offer property-level protection | |
| G | Carmarthen St | Combined sewer flooding | G1 - Offer property level protection measures | Yes |
| H | Brook St / Regent St | Combined sewer flooding and fluvial flood risk from the Sud Brook | H1 - Offer property level protection measures | Yes |
| I | New St / Weston Road | Combined sewer flooding and fluvial flood risk from the Sud Brook | I1 – Provide raised flood wall on left bank of Sud Brook to prevent overtopping of Sud Brook into Weston Road / New Street: only partially effective at reducing flood risk because dominant flooding mechanism is combined sewer flooding | No |
| | | | I2 – Provide a storage area within Trier Way (storage O in Appendix E) to alleviate flood risk from the Sud Brook: only partially effective at reducing flood risk because dominant flooding mechanism is combined sewer flooding | No |
| | | | I3 – Offer property level protection measures | Yes |
| J | Linden Brook (affecting several properties) | Backing up of sewers from the Linden Brook, and failure of STW pumping station | J1 - Failure of the pumping station is currently being investigated by STW and is outside the remit of the SWMP<br>J2 – Investigate the condition of the Linden Brook | |

## 4.3 Appraise short-term measures

### 4.3.1 Appraise measures to manage pluvial runoff from Robinswood Hill (hotspot locations A, B and C)

Gloucester City Council is currently investigating flooding to properties on Reservoir Road and surrounding roads (hotspot A) following flooding in November and December 2012. No further work has been undertaken as part of the SWMP to avoid duplication of activities.

The short-term measure to manage flooding in hotspot B (Badminton Road and surrounding roads) is to implement property level protection to up to 75 properties. The two other measures (storage and upsizing sewers) were discounted as technically and economically infeasible during the short-listing of measures. Based on Environment Agency guidelines about property-level protection the scheme would attract a 'Raw Score' of 78%, and would require local contributions of at least £12k to secure FDGiA funding. This is illustrated in Table 4-2.

*Table 4-2 Property level protection on Badminton Road*

| Whole life costs | Whole life benefits | Benefit-cost ratio | Raw Score | Contribution required (min) to secure FDGiA funding |
|---|---|---|---|---|
| £413k | £2,250k | 5.5:1 | 78% | £90k |

There is no anecdotal evidence of flooding within hotspot area C (Matson Avenue and Winsley Road). Therefore it was agreed that no further work would be undertaken as part of the SWMP.

### 4.3.2 Appraise measures to manage flood risk on Painswick Road near Wheatway (hotspot location D)

Several measures were initially considered to address flooding in this location, which is predicted to affect 10 properties during a 1 in 30 year rainfall event:

- storage at Winnycroft Farm was thought to contribute to a reduction in flood risk;
- managing pluvial runoff from Upton St Leonards which flows down Painswick Road and ponds at the low spot, and;
- property level protection.

It was found that the storage at Winnycroft Farm did not alleviate flood risk at this location. Initially, this was thought to be due to pluvial runoff originating from Upton St Leonards, but when this flow pathway was managed upstream of the M5 it did not improve predicted flood risk to these properties. As a result, property level protection was considered to represent the preferred mitigation measure for these properties. Based on Environment Agency guidelines about property-level protection the scheme would attract a 'Raw Score' of 78%, and would require local contributions of at least £12k to secure FDGiA funding. This is illustrated in Table 4-3.

*Table 4-3 Property level protection on Painswick Road*

| Whole life costs | Whole life benefits | Benefit-cost ratio | Raw Score | Contribution required (min) to secure FDGiA funding |
|---|---|---|---|---|
| £55k | £300k | 5.5 | 78% | £12k |

### 4.3.3 Appraise measures to manage flood risk from the Sud Brook, River Twyver and Tywver relief upstream of Saintbridge balancing pond

Upstream of Saintbridge balancing pond 11 potential locations for flood storage were identified on the Sud Brook, River Twyver and the Twyver relief channel. As outlined in Table 4-1 nine of these flood storage areas were discounted from further analysis because they were considered technically infeasible or did not offer much, if any reduction in flood risk. There is limited flood risk *per se* from the watercourses upstream of Saintbridge balancing pond, so the purpose of providing upstream storage is to reduce flows arriving at the balancing pond during storm events. This will reduce the risk of overtopping of the balancing pond (as happened in July 2007) and reduce flows to the culverted sections of the Sud Brook and River Twyver downstream of the railway. The two flood storage areas taken forward for options were storage areas A and J.

#### 4.3.3.1 Storage A – Winnycroft Farm

For the purpose of modelling this storage for the SWMP the total required storage of 15,000 m3 has been represented as a single storage area, with an estimated discharge rate of 1.0 m3/s. At this stage the storage has been designed with no excavation to reduce overall scheme costs, and would require an embankment in the order of 2m-2.5m high to the south of Corncroft Lane. The technical appraisal of this storage area has identified that:

- there is good access from Corncroft Lane;
- there is potential to design the storage area to continue existing land use;
- the storage would fall under the Reservoir Act and would therefore be subject to additional design requirements, and;
- there is an obvious route for exceedance flows from the storage area over Corncroft Lane and into the open space on Haycroft Drive.

The estimated costs for this storage area are £300k. The economic appraisal has identified that in isolation the storage area does not provide sufficient benefits to justify the costs of intervention. However, this storage area is important as part of an overall strategy of managing flood flows and sediment in the Sud Brook. The cost-benefit analysis indicates that the storage area is unlikely to obtain Flood Defence Grant in Aid, therefore other sources of funding would need to be secured to deliver this scheme. It is noted that there is a SHLAA site in this location, so there is significant potential for work with the developer of this site to provide additional flood attenuation should it come forward for development..

However, even with storage A in place further modelling work has identified an additional flow pathway from Upton Hill (pluvial runoff) which runs down Painswick Road. To resolve this further mitigation was tested by routing flows back into the Sud Brook rather than flowing down Painswick Road. This was found to be ineffective and therefore not included in the final options model runs. It is estimated that the costs of this flood storage area are £300k.

#### 4.3.3.2 Storage J – Abbeymead Avenue

The proposals here are to set levels on the right and left bank sufficiently low to provide additional flood storage (NB: there is potential to lower levels to below bank levels to create wetland habitat). The culvert under Abbeymead Avenue would need to be reduced in size to enable backing up and use of this area. An initial site walkover identified this area for potential landscaping and amenity improvement (in parallel with wetland creation). It is estimated that the storage area would be increased to 9,500 $m^3$. The technical appraisal of this storage area has indicated that:

- there is significant potential for turn this area into an online wetland with associated habitat and possible WFD improvements;
- there is potential to improve public amenity and usage of this area, and;
- access to the site could be difficult.

It is estimated that the costs of undertaking the required works would be in the order of £100k. As with storage area A the flood risk reduction benefits are insignificant, and as a result the storage area is unlikely to obtain FDGiA funding. There is good potential for this storage area to secure WFD funding if it can be demonstrated that the works will make a positive contribution to improve the water body status of the River Twyver.

#### 4.3.3.3 Adjusting splitter structure

It is widely recognised that the existing flow split of the River Twyver near Bittern Avenue could be improved. Currently, the majority of flows go into the Twyver relief channel, ultimately discharging into the Sud Brook via the Saintbridge Balancing Pond. Significantly less flow continues along the main Twyver channel and as a result there is a high degree of sedimentation in the River Twyver downstream (in culverted sections) because there are insufficient velocities in the river to self-cleanse the sediment.

As part of the SWMP we have undertaken an assessment to improve the splitter structure such that more flow passes down the River Tywver. For modelling purposes the structure has been re-designed such that all flow up to 1.0-1.5 m3/s is passed down the main Twyver channel; once flows are greater than this an overflow weir has been modelled to take flows into the Twyver relief channel (NB: it should be noted that currently flow is passed to the relief channel when flows in the Twyver exceed approximately 0.3 m3/s). Initial modelling results for the 1:100 year rainfall event indicate that this revised configuration at the splitter structure does not increase flood risk to the River Twyver downstream. It should be noted that the model has assumed there is no sediment within the River Twyver downstream because velocities in the channel are sufficient to achieve self-cleansing.

In reality some flow would need to be maintained down the Twyver relief channel to maintain the biodiversity and ecology of the watercourse, and further assessment is required to confirm the appropriate ecological balance of flows in the main Twyver channel and the relief channel.

### 4.3.4 Appraise measures to manage flood risk from Saintbridge balancing pond (hotspot location E)

There is significant flood risk to properties downstream of the Saintrbridge wet balancing pond, and in July 2007 the balancing pond overtopped causing deep flooding to properties on Cheyney Close and The Lampreys. Therefore as part of the SWMP we have considered increasing the capacity of the wet balancing pond to manage flows during rainfall events. We have considered two options: raising the existing embankment by up to 2m or extending the plan area into the existing allotments.

Raising the embankment present significant technical challenges associated with the risk category of the existing reservoir. Due to the proposed increase in embankment height the reservoir would increase the risk category from C to A which would require a new larger emergency spillway. Furthermore there may be significant concerns from local residents associated with an increase in stored water depth above ground level and the potential to disturb the existing ecosystem balance of the balancing pond.

The alternative option of extending the plan area is significantly more expensive than increasing the embankment height because of the volume of excavation required (average 4m depth) to achieve a sufficient additional flood volume. Furthermore, encroaching on the existing allotments may result in opposition from local residents around the loss of allotment space.

It is estimated that raising of the embankment would cost £200k-£300k (construction costs) and extending the plan area into the allotments would be in the order of £1m (construction costs). The benefit-cost analysis indicates there is insufficient number of properties benefitting from the works at Saintbridge to justify the investment costs. It is therefore proposed that this option is not taken forward for design and construction due to economic and technical constraints. It is noted that Gloucester City Council has funding to deliver property-level protection to properties on Cheyney Close and The Lampreys, which will provide significant protection to these properties during more frequent flooding incidents.

### 4.3.5 Appraise measures to manage flood risk to Malborough Road and Malborough Crescent (hotspot location F)

Properties on Malborough Road and Malborough Crescent are at risk due to fluvial and sewer flooding. In July 2007 the properties experienced significant fluvial flooding but this was believed to be the result of a blockage in the railway culvert. In addition, the location is not within Flood Zone 3 and is therefore not considered to be at risk up to and including the 1 in 100 year rainfall event (assuming the culvert is not blocked).

The primary source of flood risk during more frequent rainfall events is due to flooding from the sewerage network. It is considered that property level protection could be offered to 5-10 properties at risk of flooding up to and including the 1 in 30 year rainfall event. The costs and benefits of implementing property-level protection are illustrated in Table 4-4, following Environment Agency guidelines.

*Table 4-4 Property level protection on Malborough Rd/Crescent*

| Whole life costs | Whole life benefits | Benefit-cost ratio | Raw Score | Contribution required (min) to secure FDGiA funding |
|---|---|---|---|---|
| £55k | £300k | 5.5 | 78% | £12k |

### 4.3.6 Appraise measures to manage flood risk from the sewer network (hotspot locations G, H and I)

In the short-term property level protection is considered to represent the only mechanism to mitigate flood risk to properties in this area. A longer term strategy of managing surface water has also been considered within the SWMP, and is discussed in Section 4.4.

Based on Environment Agency guidelines about property-level protection the scheme would attract a 'Raw Score' of 78%, and would require local contributions of at least £12k to secure FDGiA funding. This is illustrated in Table 4-5.

*Table 4-5 Property level protection on New St / Weston Rd / Carmarthen St*

| Whole life costs | Whole life benefits | Benefit-cost ratio | Raw Score | Contribution required (min) to secure FDGiA funding |
|---|---|---|---|---|
| £495k | £2,700 | 5.5:1 | 161%* | N/A |

* Properties are within 20% of most deprived in the county and therefore generate a higher Score on Defra's Partnership Funding calculator

### 4.3.7 Appraise measures to manage flood risk from the Linden Brook (hotspot location J)

Flooding to properties adjacent to the Linden Brook appears to be caused by two primary mechanisms:

- There appears to be a capacity issue with the Linden Brook – flooding to properties occurs because of backing up of surface water sewers which connect to the Linden Brook during times of heavy rainfall. It is understood that the Linden Brook may be in poor condition (i.e. collapses) and its exact route is uncertain in some locations, which is likely to exacerbate flood risk.

- During the July 2007 flooding the Severn Trent Water (STW) pumps at Netheridge failed to operate. It is understood that this was because the electrical unit was flooded out causing the pumps to fail, causing significant combined sewer flooding. STW is currently investigating options to mitigate this.

Two hydraulic model scenarios were undertaken of the Linden Brook. First the model was run for a 1 in 200 year rainfall event assuming the Linden Brook was in good condition and the STW pumps were fully operational. A second simulation using the same rainfall event was undertaken with the Brook partially collapsed and the STW pumps switched 'off' (i.e. no pumping). The modelling simulations can only generate the significant flooding of 2007 in this location under the second simulation, which would indicate that the condition of the Brook and the operation of the pumps play a critical role in flood risk in this location. Furthermore, a model simulation (assuming the pumps were operating and the Linden Brook was in good) was also undertaken for a 1 in 30 year rainfall probability event which predicted very little flooding in this area. However in reality parts of the catchment are known to flood frequently (e.g. Bristol Road in 2012) even when the pumps at Netheridge are operational which would again indicate that the condition of the Brook is critical in affecting flood risk.

The recommended mitigation measure is a detailed CCTV survey of the route, capacity and condition of the Linden Brook. Subsequently, works will be required to mitigate defects within the Linden Brook culverted sections. GCC should also liaise with STW about the works at Netheridge pumping station.

## 4.4 Identify and short-list long-term measures

Given the extensive and complex flooding within the Central Gloucester catchment it is evident that there is no single mix of measures which can significantly alleviate flooding in the short-term. The short-term measures identified will offer a reduction in flood risk to people and property within the study area but there are some limitations with the short-term measures:

- there is a reliance on property-level protection which may have limited impact on flood risk due to low uptake by residents and failure to operate the equipment during times of flooding. Furthermore, current Environment Agency guidance states that the duration of benefits for property-level protection measures is 20 years, after which they may need to be replaced which will incur additional capital costs to replace after 20 years;
- flooding from the urban drainage network (highway drains, combined and surface water sewers) is not addressed at source and the measures do not address the issue of high river levels causing backing up and flooding from the urban drainage network;
- the intervention measures will not be effective in the face of climate change[1] which will cause deeper and more extensive flood risk in the catchment as the number of properties at risk of flooding within the catchment is anticipated to rise by nearly 20-30%, and;
- there are limited 'wider benefits' (e.g. water quality, amenity or biodiversity) with the measures, with the exception of works at Winnycroft Farm and Abbeymead Avenue.

In light of these limitations the project steering group agreed to consider an 'alternative' long-term option for the Central Gloucester study area. The long-term option seeks to identify a strategy for how flood risk in Central Gloucester can be managed over the next 20 to 30 years. Principally the long-term strategy is focussed on two areas:

[1] As climate change causes further flooding from the urban drainage network investment will be required, and it is widely recognised that we cannot continue to build bigger and bigger underground drainage networks in the face of climate change

- managing fluvial flood risk by restoring river corridors wherever possible, and;
- undertaking a programme to retrofit green infrastructure within the study area to capture and store surface water runoff from the urban environment.

### 4.4.1 Manage fluvial flood risk by restoring river corridors

Over the long-term, as conditions in the Sud and Tywver catchment change, opportunities should be maximised to restore the river channels and corridors of these urban watercourses. The opportunities are likely to come about as part of development applications or when the current river channels (especially those that have concrete channels) require major capital investment due to erosion or the infrastructure needs replacing.

Specific actions that could be undertaken include:

- naturalising the conveyance of the Sud and Tywver, as both watercourses have long sections where they have been heavily modified, and/or;
- re-connecting the watercourses to natural floodplain through a programme of de-culverting the watercourses (whilst recognising this is only possible in the case of substantial re-design of the urban landscape), and/or;

To achieve a long-term vision of restoring the Sud and Twyver as more natural urban watercourses will require inclusion in Gloucester City Council's Local Plan as a long-term aspiration which can be realised through development. It is highly unlikely that a programme of river restoration could be funded as a pro-active programme, rather it should be done opportunistically through development.

### 4.4.2 Manage surface water through green infrastructure

Conventionally, flooding from drainage (highway or sewer) networks in urban environments have been resolved through provision of larger underground infrastructure. However, there is an increasing recognition that, across the UK, there is a need to think differently about how water is drained in urban environments in the face to climate change, urban creep and development.

One such approach is to seek to manage a greater proportion of runoff generated in urban environments at source through green infrastructure, thereby reducing the flow and volume of runoff that is drained via highway and sewer networks that have a finite capacity.

Therefore, for the SWMP the project steering group agreed to assess the feasibility and effectiveness of utilising green infrastructure to address current and future flooding problems from the drainage network. The details of the approach to this are provided in **Error! Reference source not found.**, and the methodology is broadly outlined below.

Initially, the InfoWorks ICM model was run assuming catchment wide implementation of green infrastructure measures for a range of scenarios including 10%, 25% and 50% impermeable areas managed during a 1 in 30 year rainfall event. Whilst we recognise the management of the entire catchment is not feasible or affordable, the purpose of this screening was to assess whether green infrastructure could be effective at reducing flood risk.

This assessment indicated that with 50% of the catchment area managed flooding could be reduced sufficiently to warrant further investigation. In the Sud and Twyver catchments the drainage network largely contains separate foul and storm water flows to the east of the railway and 'combined' (i.e. foul and surface runoff together) to the west of the railway. Therefore green infrastructure was found to be effective at reducing flooding to properties to the west of the railway and this was selected as an area to focus on. Only a proportion of the area to the west of the railway was selected, focussing on residential properties. Based on the initial modelling it was estimated that flooding would be alleviated to 140 properties at risk up to and including the 1 in 30 year rainfall event.

In order to achieve the reduction in properties flooding during a 1 in 30 year rainfall event, we have calculated the total impermeable area that would need to be managed through green infrastructure (i.e. with 50% of the impermeable area managed in part of the area to the west of the railway). This equates to nearly 150 hectares of green infrastructure within the defined study area. To identify opportunities to implement green infrastructure the following were considered:

- existing hardstanding areas (e.g. car parks)
- roofs with the potential to be retrofitted as green roof;
- residential properties, and;
- roads where the slope was sufficiently flat and there was sufficient width to implement green infrastructure.

The data was aggregated to a model subcatchment scale to identify the total area within each subcatchment where green infrastructure could be applied to hardstanding areas, roofs (for green roofs), residential properties and on the road network. A ranking system was established for roads and roofs and the area of each level this ranking system was calculated. For existing hardstanding and green roofs there was either potential or no potential.

It is recognised that in order to generate a realistic estimate of green infrastructure that could be delivered, an uptake ratio needs to be considered for different surface types. A higher uptake (70%) was applied to the road network recognising it is within the public domain, whereas a lower uptake (30%) was assumed for private residential properties.

Multiplying the total area within each subcatchment where green infrastructure could be applied by the uptake ratio provides a realistic estimate of the area where green infrastructure could be delivered. Based on the assumptions it was estimated that 120 hectares of green infrastructure could be realistically delivered. If uptake ratios were higher there would be opportunities to achieve the 150 hectares required to realise the reduction in flood risk predicted by the model.

A basic cost assessment was undertaken by assigning broad types of measures to each of the surface types considered (hardstanding, commercial roofs, residential properties and roads) and estimating a low, medium and high cost for implementing each measure based on literature research. These costs were based on the costs of implementing the green infrastructure measure, over and above the costs of traditional repairs. Therefore these costs assume an opportunistic approach to retrofitting green infrastructure by implementing measures when repairs are already happening. The types of measures considered were:

- Green roofs
- Rain gardens
- Front garden planter boxes
- Permeable paving
- Disconnection to gardens
- Disconnection to other permeable areas

Annual maintenance and periodic maintenance costs were estimated for each type of measure. The cost assessment was done over a 50 year period, assuming measures would be implemented over 25 years, and the total costs (capital and maintenance) were discounted accordingly.

Wider benefits of green infrastructure were accounted for using literature estimates for the impact of green roofs on energy consumption and enhanced quality of life sue to proximity to stormwater green infrastructure on a house by house basis. These are only 2 of many possible wider benefits that could be included in this assessment.

The results indicate total costs for the duration of the project as between £4.3 million and £8.4 million to achieve flood benefits worth £3.2 million. Quantification of the two possible wider benefits indicates these may be worth up to £34.5 million over the delivery period.

A Monte Carlo-based uncertainty analysis was undertaken using the low to high cost estimates and large error bound estimates for the wider benefits. The results of this show that implementation of the suggested level of green infrastructure will always provide benefits that are worth more than the costs.

The conclusions from this initial research into implementing green infrastructure in Central Gloucester is that it is worth pursuing and further research should be undertaken in the form of pilot studies in a few streets. Pilot studies would provide the opportunity to engage with local communities about the purpose and benefits of green infrastructure as well as providing more information about the effectiveness of the measures and the costs associated with maintenance.

# 5 Action Plan

The SWMP Technical Guidance states that:

*"The final stages of the SWMP study will be to collate the information from the first three phases into a study document, and where appropriate, to prepare an action plan (i.e. the SWMP) for implementing the preferred structural and non-structural option(s). The action plan must be based on the evidence base collated as part of the SWMP study. Contents and format for the action plan will vary depending on local circumstances, but should outline the preferred option, the actions required by each partner and stakeholder, who will pay for the actions, and the timetable for implementation."*

This section of the SWMP report sets out the preferred option, next steps and responsibilities for each of the hotspot areas considered in this SWMP. It also provides an overview of other actions which should be taken across the entire study area.

## 5.1 Short-term actions

In the short-term (0-10 years) it is recommended that the following measures are progressed:

- implement property-level protection across a number of locations within the Central Gloucester catchment;
- further investigation of the Linden Brook;
- investigate the feasibility of adjusting the splitter structure
- build a flood storage area near Winnycroft Farm, and;
- enhance the existing balancing pond near Abbeymead Avenue.

### 5.1.1 Property-level protection

Within the Central Gloucester catchment a range of measures were identified and assessed using the integrated hydraulic model of the catchment. These included: upgrades to the drainage network; additional storage areas; flood embankments, and managing pluvial runoff. A detailed assessment of the technical feasibility, and costs and benefits of these measures indicated that for the most part hard engineering measures would not be suitable in Central Gloucester, either on technical or economic feasibility grounds. Therefore, in the majority of hotspot locations identified it is recommended that property-level protection be progressed as a short-term measure within the catchment. A summary of the key locations where property level protection is indicated in Table 5-1 below. It is estimated that £112k would need to be secured across these locations to achieve a 100% Partnership Funding Score, which would increase the likelihood of securing FDGiA funding.

The next steps to take property level protection in these areas are:

i) submit a FDGiA Application for the scheme in May 2014, for inclusion in the 2016/2016 Medium Term Plan;

ii) undertake consultation with local residents following successful funding application to confirm which residents wish to take up property level protection measures;

iii) appoint a contractor to undertake household surveys to confirm the suitable measures for each property, and;

iv) implement property protection measures.

It is recommended that Gloucester City Council or Gloucestershire County Council act the lead authority for property level protection measures

Table 5-1 Locations recommended for property level protection

| Location | No. properties | Max Cost | PF Score |
|---|---|---|---|
| Badminton Rd | Up to 75 | £412k | 78% |
| Painswick Rd | Up to 10 | £55k | 78% |
| Cheyney Cl / The Lampreys | Being progressed by Gloucester City Council | | |
| Malborough Crescent / Rd | Up to 10 | £55k | 78% |
| New St / Weston Rd / Carmarthen St | Up to 90 | £495k | 161% |

### 5.1.2 Further investigation on Linden Brook

Two hydraulic model scenarios were undertaken of the Linden Brook. First the model was run for a 1 in 200 year rainfall event assuming the Linden Brook was in good condition and the STW pumps were fully operational. A second simulation using the same rainfall event was undertaken with the Brook partially collapsed and the STW pumps switched 'off' (i.e. no pumping). The modelling simulations can only generate the significant flooding of 2007 in this location under the second simulation, which would indicate that the condition of the Brook and the operation of the pumps play a critical role in flood risk in this location. Furthermore, a model simulation (assuming the pumps were operating and the Linden Brook was in good) was also undertaken for a 1 in 30 year rainfall probability event which predicted very little flooding in this area. However in reality parts of the catchment are known to flood frequently (e.g. Bristol Road in 2012) even when the pumps at Netheridge are operational which would again indicate that the condition of the Brook is critical in affecting flood risk.

The recommended mitigation measure is a detailed CCTV survey of the route, capacity and condition of the Linden Brook. Subsequently, works will be required to mitigate defects within the Linden Brook culverted sections. GCC should also liaise with STW about the works at Netheridge pumping station.

### 5.1.3 Investigate adjustments to the splitter structure

As part of the SWMP we have undertaken an assessment to improve the splitter structure such that more flow passes down the River Tywver. For modelling purposes the structure has been re-designed such that all flow up to 1.0-1.5 m3/s is passed down the main Twyver channel; once flows are greater than this an overflow weir has been modelled to take flows into the Twyver relief channel (NB: it should be noted that currently flow is passed to the relief channel when flows in the Twyver exceed approximately 0.3 m3/s). Initial modelling results for the 1:100 year rainfall event indicate that this revised configuration at the splitter structure does not increase flood risk to the River Twyver downstream. It should be noted that the model has assumed there is no sediment within the River Twyver downstream because velocities in the channel are sufficient to achieve self-cleansing.

The immediate next steps is to liaise with the Environment Agency to discuss the ecological implications and appraisal which is required to identify whether the adjustments to the splitter structure would be sustainable. In addition, further flood risk modelling may be required to support a consent application to do works on the splitter structure. Early consultation with the Environment Agency consenting team is required to ensure the sufficient evidence base is required.

### 5.1.4 Flood storage areas at Winnycroft Farm and Abbeymead Avenue

For the purpose of modelling this storage for the SWMP the total required storage of 15,000 m3 has been represented as a single storage area, with an estimated discharge rate of 1.0 m3/s. At this stage the storage has been designed with no excavation to reduce overall scheme costs, and would require an embankment in the order of 2m-2.5m high to the south of Corncroft Lane. The technical appraisal of this storage area has identified that:

- there is good access from Corncroft Lane;
- there is potential to design the storage area to continue existing land use;
- the storage would fall under the Reservoir Act and would therefore be subject to additional design requirements, and;
- there is an obvious route for exceedance flows from the storage area over Corncroft Lane and into the open space on Haycroft Drive.

The estimated costs for this storage area are £300k. The economic appraisal has identified that in isolation the storage area does not provide sufficient benefits to justify the costs of intervention. However, this storage area is important as part of an overall strategy of managing flood flows and sediment in the Sud Brook. The cost-benefit analysis indicates that the storage area is unlikely to obtain Flood Defence Grant in Aid, therefore other sources of funding would need to be secured to deliver this scheme. It is noted that there is a SHLAA site in this location, so there is significant potential for work with the developer of this site to provide additional flood attenuation should it come forward for development..

At Abbeymead Avenue the proposals are to set levels on the right and left bank sufficiently low to provide additional flood storage (NB: there is potential to lower levels to below bank levels to create wetland habitat). The culvert under Abbeymead Avenue would need to be reduced in size to enable backing up and use of this area. An initial site walkover identified this area for potential landscaping and amenity improvement (in parallel with wetland creation). It is estimated that the storage area would be increased to 9,500 $m^3$. The technical appraisal of this storage area has indicated that:

- there is significant potential for turn this area into an online wetland with associated habitat and possible WFD improvements;
- there is potential to improve public amenity and usage of this area, and;

- access to the site could be difficult.

It is estimated that the costs of undertaking the required works would be in the order of £100k. As with storage area A the flood risk reduction benefits are insignificant, and as a result the storage area is unlikely to obtain FDGiA funding. There is good potential for this storage area to secure WFD funding if it can be demonstrated that the works will make a positive contribution to improve the water body status of the River Twyver.

The next steps to take this option forward are:

i) secure funding for these storage areas from developer contributions and/or WFD funding;

ii) undertake consultation with local landowner to understand willingness for their land to be used for the flood storage areas (it is understood that Gloucester City Council are the existing land owner for the storage area at Abbeymead Avenue);

iii) undertake consultation with local residents;

iv) undertake topographic survey and ground investigations 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) secure planning permission for the proposed works, and;

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

The key project risks for both storage areas are highlighted in Table 5-2 below.

*Table 5-2 Project risks for storage at Winnycroft Farm and Abbeymead Avenue*

| Risk | Mitigation |
|---|---|
| Storage of water above natural ground level could result in concern from local residents about increased residual flood risk | Early consultation with local residents |
| Flood storage area would impact existing Public Right of Way, which could result in public opposition | |
| Should excavation be required the costs of the scheme would increase significantly, which could make the scheme unviable economically | Early consultation with local residents will confirm an acceptable embankment height, which will affect the design (and hence costs) of the scheme |
| Landowner unwilling to allow land to be used storage at Winnycroft Farm | Early consultation with the local landowner once funding secured |

## 5.2 Long term actions

### 5.2.1 Implement strategic programme of retrofit green infrastructure

The conclusions from this initial research into implementing green infrastructure in Central Gloucester is that it is worth pursuing and further research should be undertaken in the form of pilot studies in a few streets. Pilot studies would provide the opportunity to engage with local communities about the purpose and benefits of green infrastructure as well as providing more information about the effectiveness of the measures and the costs associated with maintenance.

The next steps to take this forward are:

i) undertake engagement with Gloucester City Council, Gloucestershire Highways and Severn Trent Water to discuss and agree the way forward;

ii) identify two or three streets where a pilot study could be implemented, secure funding for the pilot study, and undertake outline design for the measures;

iii) undertake community engagement within the two/three streets identified as the pilot area;

iv) implement the pilot study and monitor its success;

v) report on the success of the pilot programme and, subject to success, develop a long term plan and vision for implementing green infrastructure in Gloucester City.

### 5.2.2 Restore river corridors on an opportunistic basis

Over the long-term, as conditions in the Sud and Tywver catchment change, opportunities should be maximised to restore the river channels and corridors of these urban watercourses. The opportunities are likely to come about as part of development applications or when the current river channels (especially those that have concrete channels) require major capital investment due to erosion or the infrastructure needs replacing.

Specific actions that could be undertaken include:

- naturalising the conveyance of the Sud and Tywver, as both watercourses have long sections where they have been heavily modified, and/or;
- re-connecting the watercourses to natural floodplain through a programme of de-culverting the watercourses (whilst recognising this is only possible in the case of substantial re-design of the urban landscape), and/or;

To achieve a long-term vision of restoring the Sud and Twyver as more natural urban watercourses will require inclusion in Gloucester City Council's Local Plan as a long-term aspiration which can be realised through development. It is highly unlikely that a programme of river restoration could be funded as a pro-active programme, rather it should be done opportunistically through development. The next steps should be liaison with Gloucester City Council about how this long-term programme can be implemented through the development planning process.

# Appendix A SWMP Process Wheel

# Appendix B Aims and objectives of Central Gloucester SWMP

The aims of the Central 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 and hydrology report

# Appendix E Mapping outputs

# Appendix F Long list of flood storage areas

| Ref | Storage location | Estimate storage volume (max) | Constraints and opportunities | Summary of initial modelling results | Take forward for further assessment? |
|---|---|---|---|---|---|
| A | Winnycroft Farm (Sud Brook trib) | 16,000 | • Potential for future development on site – opportunity to tie in flood storage with development<br>• Existing residential properties downstream low lying<br>• Good access to site<br>• 4 onlinf FSAs – large cut volumes likely to be required | Effective at reducing flood risk downstream on the Sud Brook tributary, but it is likely that only two of the four storage areas identified would be necessary to alleviate flooding | Yes |
| B | Haycroft Drive (by Sud Brook) | 3,000 | • Glos City ownership<br>• Existing residential properties downstream low lying<br>• Good access both sides<br>• Potential for significant cut volumes | The model has placed a low flow restriction in the channel and the channel spills out of the bank naturally. The FSA should be located to the south of the area identified to pick up flooding from the road and be further away from residential properties | Yes |
| C | Awebridge Way (Sud Brook) | 2,000 | • Currently parkland which could be converted to FSA<br>• Residential properties to right and left of channel with low lying properties on the right bank<br>• Limited access through footpaths, and minor roads<br>• Limited construction requirements | These storage areas offer limited reduction in flood risk because there are few properties at risk of flooding between these storage areas and the Saintbridge balancing pond. It is not possible to store sufficient volumes of water within these three areas to negate the need to improve Saintbridge Balancing Pond, therefore these FSAs are not worth pursuing. There may be some scope for a WFD scheme to re-naturalise the channels which may offer some flood benefits, but as a stand alone option for flood mitigation the costs and benefits are not likely to be favourable | No |
| D | Heron Way (Sud Brook) | 8,000 | • Currently parkland with concrete channel<br>• Right and lefty bank properties higher than proposed FSA<br>• Minor road access upstream and downstream<br>• 3 x online FSAs at each footbridge | | No |
| E | Curfew Road (Sud Brook) | 2,500 | • Currently parkland with concrete channel<br>• Left bank residential properties lower than FSA and right bank slightly lower<br>• Limited access<br>• 2 x online FSAs with improved potential in the downstream FSA | | No |
| F | Reservoir Road (Matson Brook) | 7,500 | • Existing football pitch (to remain with FSA in place)<br>• Good access via unsurfaced road<br>• Three sided embankment with large cut and fill volumes | Potentially a very effective FSA to alleviate flooding on the Matson Brook but further work is required to optimise the outlet from the FSA | Yes |
| G | Saintbridge Balancing Pond | Raise water level by max. 2m | • Large existing FSA and nature reserve. Active pressure group may object to changes to existing balancing pond<br>• Residential properties downstream lower than existing FSA<br>• Limited access to site.<br>• Construction works to involve raising of existing embankment | There are two options for the balancing pond: raise the existing embankment to provide greater flood storage or lower the existing water levels to create space for flood storage. Currently modelled with reduced size of sluice at exit of low flow and reduce high level outlet to limit outflow. Embankment raised to create maximum water level of 27.2m. With this in place there is a significant reduction in flood risk downstream | Yes |
| H | Existing allotments nr Birch Avenue | 7,500 | • Existing allotments which would need to be rationalised and improved as part of FSA<br>• Access available via three tracks<br>• Would require large cut volumes to achieve storage | Even with adjustments to the ground levels here only a small section of the proposed FSA would be utilised during a 1:100 year rainfall event. There would be limited flood risk benefit from this FSA | No |
| I | Saintbridge dry balancing pond | 10,000 | • Existing dry balancing pond which would be enlarged<br>• Access available on two sides<br>• Lowering of existing bed by 1m would involve large cut volumes | This existing balancing pond has been lowered by 1m in the model. With the improvements to the Saintbridge balancing pond and the splitter structure there would be no need to improve this balancing pond. | No |
| J | Abbeymead Avenue (River Twyver) | 4,500 | • Existing FSA which would be enlarged by limiting flow through culvert under Abbeymead Avenue<br>• Residential properties higher than FSA | Good scope for improving existing balancing pond by limiting flows into the culvert under Abbeymead Avenue to create an online storage. | Yes |

| | | | | | |
|---|---|---|---|---|---|
| | | | • Access available via minor track to the north only<br>• Limited construction requirements – lowering existing FSA and limiting flow through culvert | | |
| K | NW Abbeymead Avenue nr Morrisons (River Twyver) | 9,000 | • Existing low lying disused ground<br>• Residential properties higher than FSA<br>• Access available via minor road upstream and downstream of car park<br>• Online FSA and bunds required upstream and downstream | This storage is not effective at all and is not offering any reduction in flood risk | No |
| L | Football fields by Glevum Way Park (River Twyver) | 9,000 | • Existing football pitch to remain<br>• Most properties higher than FSA but with low lying commercial properties on the right bank<br>• Limited access via residential road<br>• Offline storage with large cut volumes | FSA J would be preferable to L due to the volume of material which would need to be moved to ensure this FSA would be effective | No |
| M | Osprey Close (Twyver relief channel) | 4,000 | This is being progressed as a WFD scheme by Gloucester City Council. Further liaison required to represent the WFD scheme in the model and optimise flows in the Twyver relief channel | | No |
| N | Bittern Avenue (River Tywver) | 3,000 | • Existing FSA and parkland to remain<br>• Good access on two sides<br>• Offline storage with large cut volumes | There is little benefit of this FSA as the Twyver is not flooding at this location | No |
| O | Trier Way (Sud Brook) | 26,000 | • Existing sports pitches and recreation ground<br>• Good access via A road<br>• Offline storage with very large cut volumes | This FSA would need to be split into two components: 1) in the park to the west of Trier Way and 2) between Trier Way and Park End Road. The former offers little flood risk benefit and should be discounted, but the latter component should be taken forward as it is particularly effective at reducing flooding for the 1:30 year event to properties on Weston Road and New St | Partially |
| P | Near Baneberry Road | 3,000 | • Lower existing recreation fields and Upper Country Park<br>• Church and playing fields surrounding<br>• Access on two side roads<br>• Embankments required to manage pluvial runoff, with some cut and fill required | This FSA is to manage pluvial runoff. Currently, the area identified will only manage one of several pluvial flow pathways, so further work is required to identify how we can manage pluvial runoff from Robinswood Hill | Yes (but adjustments required to initial concept) |
| Q | Tredworth Cemetery | 5,500 | • Existing cemetery although grave stones have been removed – may be highly contentious<br>• Right bank residential properties may be adversely affected<br>• Access via minor road<br>• Likely to be 1m high embankment for FSA | With the improvements in place at Saintbridge balancing pond this FSA would offer limited benefit | No |

# Appendix G Preliminary engineering drawings

# Appendix H Costings

# Appendix I Partnership Funding Calculators

200mm_Central - Opt 1 (Badminton Rd)

200mm_Central - Opt 1 (Painswick Rd)

200mm_Central - Opt 1 (Storage areas+Embankment)

200mm_Central - Opt 1 (Weston Rd)

# Appendix J Retrofit SuDS Technical Note