Bishop’s Cleeve, Woodmancote & Southam Surface Water Management Plan

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Bishop’s Cleeve SWMP Report

Gloucestershire County Council

October 2014

Halcrow

raa Richard Allitt Associates Ltd
CONSULTING ENGINEERS

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Document history

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1.2	01/04/2014	Revised draft	Ali Cotton	Ali Cotton	Elliot Gill
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Bishop's Cleeve SWMP Report

Contents

Bishop’s Cleeve SWMP Report

Appendix

Bishop's Cleeve SWMP Report

1 Introduction

1.1 Project background

During the summer floods of 2007 the Bishop's Cleeve urban area (including Woodmancote and Southam) was severely affected by flooding, and it is estimated that approximately 90-100 properties were flooded. It is known that surface water flooding occurred throughout Bishop's Cleeve due to excess surface water runoff (pluvial flooding) and exceedance from surface water drainage networks. During the first edition SWMP for Gloucestershire undertaken in 2009, Bishop's Cleeve was identified as one of several priority areas for more detailed investigation. The findings of the first edition SWMP regarding this area are set out in the following paragraph.

Anecdotal evidence indicates that various locations within Bishop's Cleeve are reported to be affected by surface water flooding. In addition, there are a large number of reported incidents of flooding within the Cleeve Hill area resulting from runoff from Cleeve Hill. Intermediate surface water mapping has indicated that over 12% of the Bishop's Cleeve urban area is affected by surface water flooding and 4.5% of the Southam area. This equates to a total of 11% of the two urban areas combined. Both residential and commercial properties are located within the two areas with approximately 614 properties shown to lie within the intermediate surface water maps. This is relatively high given the size of the urban area.

It is recommended that Southam, Cleeve Hill and Bishop's Cleeve are combined into one SWMP, given the interactions between watercourses within the area and the surface water runoff from Cleeve Hill. This would enable an improved understanding of surface water risk to be obtained and better surface water management plans within the area.

As a result of this recommendation Gloucestershire County Council commissioned Halcrow and Richard Allitt Associates to undertake a Surface Water Management Plan (SWMP) for Bishop's Cleeve (including Woodmancote and Southam) in July 2011. The purpose of the SWMP was to:

- develop a comprehensive understanding of all sources of flood risk;
- work together and be inclusive of partner and stakeholder views throughout;
- support spatial and emergency planning by disseminating information from the SWMP, and;
- identify and appraise (through benefit-cost analysis) a range of potential options to mitigate flooding, focussing on areas which were primarily at risk from surface water flooding.

For the purposes of this report the project will be referred to as the 'Bishop's Cleeve SWMP'.

1.2 Surface Water Management Plans (SWMPs) 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

Bishop's Cleeve SWMP Report

management decisions that are evidence based, risk based, future proofed and inclusive of stakeholder views.

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 are 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 Bishop's Cleeve 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.

Bishop's Cleeve SWMP Report

* 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

1.3.1 Overview of Bishop's Cleeve

Bishop's Cleeve, Woodmancote and Southam are historic villages located towards the north east of the Borough of Tewkesbury, dating back at least to the 8th Century. They lie to the west of the Cotswold Escarpment at the foot of Cleeve Hill, which at 1,083 feet (330 m) is the highest point both of the Cotswolds and in Gloucestershire. The villages have expanded rapidly over the past 20 years, having together a total population in excess of 13,000, and consequently the urban area has extended up the lower slopes of the hill.

There are several watercourses in the study area, including Glebe Farm Brook, Dean Brook & various unnamed minor watercourses. Where these run through the urban area these watercourses have been culverted and diverted in places, and development has over time encroached on their natural flow paths. The position of the urban area in relation to Cleeve Hill puts it at risk of high surface water runoff from the steep escarpment. There is no form of interception or delay before runoff from the escarpment reaches the urban area.

1.4 Approach for Bishop's Cleeve SWMP

The approach for this project follows the SWMP process wheel (see Figure 1-1 and 0) very closely and builds upon the lessons learnt from the First Edition SWMP and the Cheltenham SWMP.

Bishop’s Cleeve SWMP Report

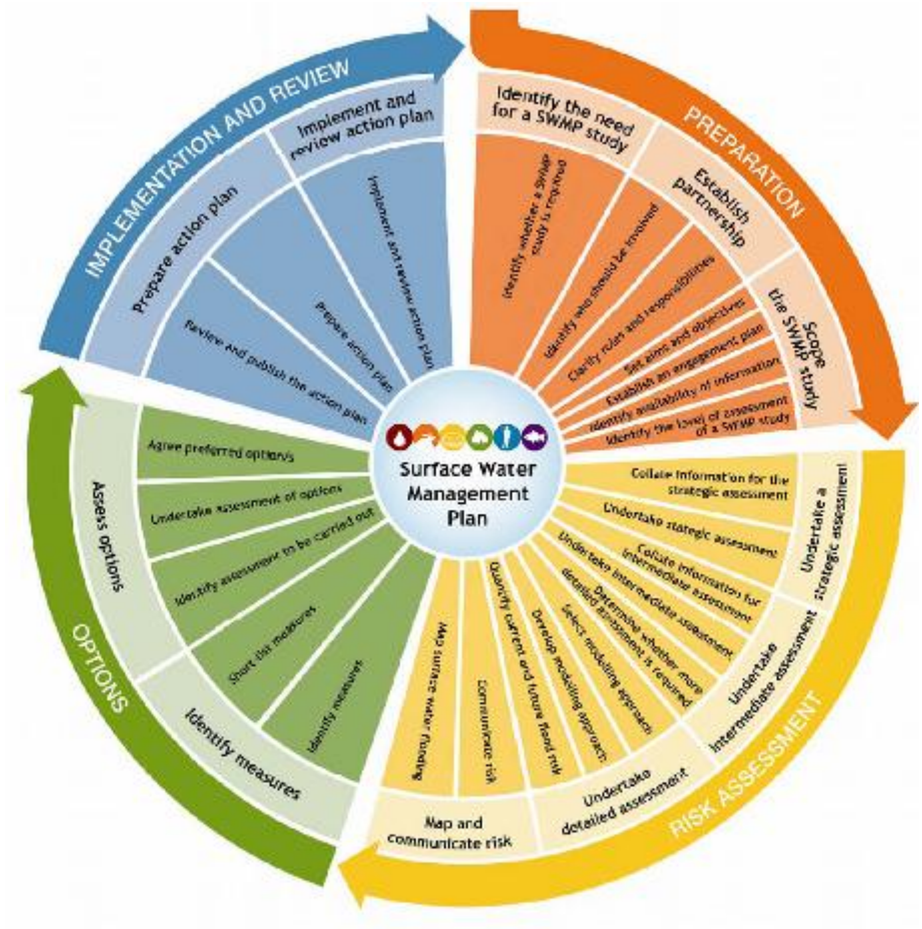

Figure 1-1 SWMP Process Wheel

1.4.1 Technical approach for Bishop’s Cleeve SWMP

The technical process for the Bishop’s Cleeve SWMP is summarised below.

- Skip the strategic assessment phase, which was completed as part of the First Edition SWMP.
- Begin the modelling at the Detailed stage, developing a Level III ICM model[1]. This will consist of the existing modelling from the First Edition SWMP, watercourses and culverts; thus producing a single integrated model. This model will allow all flooding mechanisms to be simulated in an integrated way.
- Run the detailed model for the July 2007 rainfall event, to ensure that the model is able to represent the known flooding locations from 2007.

[1] NB: For other SWMPs in Gloucestershire an intermediate Level II ICM model has initially been developed, and a detailed Level III ICM model developed in ‘hotspot’ locations. However, due to the relatively small size of the study boundary it is possible to undertake a detailed modelling approach straight away.

Bishop's Cleeve SWMP Report

- In partnership with the steering group identify the flood hotspots with the study area. In selecting the flood hotspots focus will be on areas which are at risk from local sources of flooding, or where flooding sources are integrated.
- 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 hotspot location a long-list of potential mitigation measures will be identified, which will subsequently be short-listed by the steering group against an agreed set of criteria. This process will identify up to three options for each hotspot and 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 hotspot area and an action plan will be developed.

1.5 Overview of this report

This report describes Phases 1-3 of the SWMP process wheel, and is structured in the following way:

- chapter 2 – outlines Phase 1 of the SWMP, which includes establishing a partnership, setting aims and objectives, identifying the approach for the SWMP, establishing an engagement plan;
- chapter 3 – outlines Phase 2 of the SWMP, which includes the intermediate and detailed risk assessment, as well as the approach to mapping and communicating surface water flood risk, and;
- chapter 4 – outlines Phase 3 of the SWMP, which includes identifying and testing options to reduce surface water flooding in the hotspots.

Phase 4 of the SWMP process wheel outlines the need to develop, implement and review action plans to reduce surface water flood risk. An action plan for the Bishop's Cleeve SWMP has been developed as a separate document to this report.

Bishop's Cleeve SWMP Report

2 Phase 1 - Preparation

2.1 Scope the need for the SWMP study

The need for the Bishop's Cleeve SWMP was identified as part of the First Edition SWMP. The findings of the first edition SWMP regarding this area are set out in the following paragraph.

Anecdotal evidence indicates that various locations within Bishop's Cleeve are reported to be affected by surface water flooding. In addition, there are a large number of reported incidents of flooding within the Cleeve Hill area resulting from runoff from Cleeve Hill. Intermediate surface water mapping has indicated that over 12% of the Bishop's Cleeve urban area is affected by surface water flooding and 4.5% of the Southam area. This equates to a total of 11% of the two urban areas combined. Both residential and commercial properties are located within the two areas with approximately 614 properties shown to lie within the intermediate surface water maps. This is relatively high given the size of the urban area.

It is recommended that Southam, Cleeve Hill and Bishop's Cleeve are combined into one SWMP, given the interactions between watercourses within the area and the surface water runoff from Cleeve Hill. This would enable an improved understanding of surface water risk to be obtained and better surface water management plans within the area.

2.2 Establish partnership

A partnership approach is the most efficient approach to co-ordinate local flood risk management activities. Strong local partnerships will enable effective, efficient and integrated flood risk management activities, also allowing for co-ordinated investments. Local flood risks can be complex in nature (i.e. multiple sources and pathways managed by multiple organisations) therefore working in partnership is essential to achieving optimum understanding of the risks, as well as developing integrated and efficient mitigation measures where multiple organisations are involved

After the 2007 floods, GCC acted quickly to establish the Gloucestershire Flood Risk Management Group; a multi-agency group that includes representatives from GCC (including Emergency Management Services [EMS], Planning, Development Co-ordination and GH representatives), the Environment Agency, Severn Trent Water, Thames Water, the Lower Severn Internal Drainage Board and all the local Districts.

For the Bishop's Cleeve SWMP a steering group was created, which builds upon the existing successful relationships established since 2007. The steering group consisted of representatives from GCC (Flood Risk Management Officers), Tewkesbury Borough Council (Drainage Engineer), the Environment Agency and Severn Trent Water.

At the inception meeting the partners were provided with an overview of the project and an indicative programme, so that resource inputs could be planned. A partnership agreement was also produced and has been signed by all partners.

Bishop's Cleeve SWMP Report

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 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 are provided below; a full list of the aims and objectives are provided in Appendix B.

The aim of the Bishop's Cleeve SWMP is to identify cost effective and affordable measures to alleviate flooding to residents and businesses in the study area by:

- developing a comprehensive understanding of all sources of flood risk;
- working together and being inclusive of partner and stakeholder views throughout;
- supporting spatial and emergency planning by disseminating information from the SWMP, and;
- identifying and appraising (through benefit-cost analysis) a range of potential options to mitigate flooding.

2.3.2 Establish an engagement plan

For the Bishop's Cleeve SWMP an engagement plan was drawn up in partnership with the communication team at GCC, and was discussed and agreed by the steering group. The full engagement plan can be accessed separately to this report, but a summary is provided below.

The engagement plan identified a number of key positive messages which should be achieved through engagement. These are illustrated in Table 2-1.

Table 2-1: Key positive messages from engagement plan

Headline	Message	Benefit
Partnership working	Gloucestershire County Council is working in partnership with a range of stakeholders and local communities	Flooding in urban areas is complex and by working together with all organisations we can better understand flood risk and ways to mitigate the risk
Personal resilience	We will be working in partnership with local residents and businesses to identify ways of reducing the risk of flooding including looking at how residents and businesses can help themselves	Local communities and businesses will recognise the importance of personal resilience measures and will take action to reduce the risk of flooding to their property or business
Funding	Progress of flood alleviation schemes will be dependant on securing the necessary funding; in accordance with the new funding arrangements it is likely that 'local contributions' would be required to gain access to national funding	Expectations within the local community will be managed
Multiple use of SWMP outputs	Outputs from SWMPs will be distributed to spatial and emergency planning departments	Surface water flood risk better accounted for in spatial and emergency plans

Bishop's Cleeve SWMP Report

The engagement plan identified four key stages of engagement.

Stage 1 – Raising awareness

The principal purpose of stage 1 was to raise awareness of the SWMP. To this end an information sheet about the SWMP was produced and distributed to the key stakeholder and wider stakeholder groups.

Stage 2 – After initial modelling is completed

The purpose of stage 2 was to allow the key stakeholder group to view and comment on the initial modelling results, and their validity against the July 2007 flooding. Once the models had been simulated for the July 2007 rainfall event, and reviewed by the steering group, a meeting was held with the key stakeholder group to demonstrate the outputs from the modelling work, and receive feedback on their appropriateness.

Stage 3 – During identification and appraisal of options

The purpose of this stage was to allow the key stakeholder group to understand the process of identifying, short-listing and appraising options, and to provide input to the options process.

After the initial modelling work had been undertaken a steering group meeting was held to: identify a range of potential measures to alleviate flooding; screen out infeasible measures, and; short-list measures to be taken forward to detailed appraisal. Following this, a meeting was held with the key stakeholder group to provide an overview of the options selection, short-listing and appraisal stage, and also to provide an opportunity for the key stakeholder group to feedback into the options stage of the SWMP. In addition, three evening meetings were held with Bishop's Cleeve and Woodmancote Parish Councils to discuss and agree which options should be taken forward.

Stage 4 – Dissemination of findings

The purpose of this stage will be to disseminate the findings from the SWMP. This will primarily be achieved through engagement with the relevant parish councils, who can help to engage the wider community.

2.3.3 Identify availability of information

Following on from the inception meeting a period of data gathering ensued, resulting in consultation with each partner and gathering the data required for the analysis. A data register is provided in Appendix C.

Once the data had been gathered, an assessment was made of where site visits were needed to supplement the data. Site visits were conducted, to gather:

- culvert information where no information exists;
- information on the current 'state of play' of culverts where information does exist (to check siltation and debris etc.), and;
- information on small watercourses and drains (and their structures) that do not have models.

Bishop’s Cleeve SWMP Report

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

Bishop's Cleeve SWMP Report

3 Phase 2 – Risk Assessment

3.1 Introduction

For other SWMPs in Gloucestershire a two stage modelling approach had been adopted:

- Stage 1 – build and verify a Level II ICM 'intermediate' model of the entire catchment to identify hotspot locations for further analysis, and provide outputs for spatial and emergency planners, and;
- Stage 2 – in hotspot locations build and verify a Level III ICM 'detailed' model (which include finer mesh zones, buildings, kerbs and highway drainage where available) to identify and appraise mitigation measures.

For the Bishop's Cleeve SWMP it was possible to build and verify a Level III ICM model from the outset as the study area is relatively small. Therefore model simulation times were acceptable with the Level III ICM model for the whole study area.

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 modelling approach used for the Level III 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;
- build above ground (2D) model to route overland flows, and;
- verify the InfoWorks ICM model.

Import Severn Trent Water public sewer model

Severn Trent Water was undertaking a Sewerage Management Plan at the same time as the SWMP and therefore an adequate sewer model was obtained which included all the sewers in the town. The foul and combined sewer networks within the model were verified to within the tolerances specified by Severn Trent Water. Unfortunately the surface water sewer network had not been verified by Severn Trent Water following their normal practice, which reduces confidence in the surface water sewer

Bishop's Cleeve SWMP Report

component of the model. The Severn Trent Water model was imported into InfoWorks ICM for the purposes of the SWMP.

Add watercourses to the ICM model

There were no previous models of any of the watercourses within the study area. Therefore the geometry of the watercourses for the modelling was built using the Digital Terrain Model (DTM) combined with culvert survey data to achieve accurate results at the upstream and downstream river reach extents. Approximately 80 culverts were surveyed to obtain GPS co-ordinates, dimensions and invert levels, and the data for these were considered to be of the highest quality. Some culverts could not be surveyed due to access problems, and the data for these were estimated based on engineering judgement.

Incorporate additional features into the ICM model

The presence of buildings, kerbs, walls and other features (including highway drainage) can significantly affect how overland flows are routed in urban areas. Therefore, the Level III ICM model needed to replicate these features as far as possible to improve the precision and accuracy of model outputs. The key features are described below.

- **Buildings –** Buildings were imported from the MasterMap data and added to the model as 'voids'. This effectively means that overland flows will be routed around the edges of buildings.
- **Kerbs** - Representation of the kerb lines was achieved by taking the regions within the MasterMap data which represented the roads and converting them to 'mesh zones[2]' with their elevation lowered by 125mm. The maximum triangle sizes within the mesh zones were reduced to $12m^2$ instead of the normal $40m^2$ in order to give a finer resolution on the roads.
- **Walls** - The walls to be included in the model were identified from a walk round the relevant area of the catchment and from oblique aerial photographs. Within InfoWorks ICM these features can be added as 'porous walls' and different attributes (e.g. height) can be assigned to them.
- **Break lines** - Also important in 2D modelling is the delineation of the tops and bottoms of cut slopes and embankment slopes (e.g. at the top and bottom of the railway cutting side slopes). This was achieved by adding 'Break lines' which have no properties other than requiring the triangles within the 2D mesh to be formed along them.
- **Highway drainage** - Highway Drainage was found to be a limitation in the study as there was no data available. This was a limitation in areas such as New Road, Woodmancote where there is an extensive road drainage network

[2] Mesh zones are a facility within InfoWorks to define areas which can be modelled with a finer or a coarser 2D simulation mesh than the main model. These areas can also be raised or lowered in relation to the Digital Terrain Model.

Bishop’s Cleeve SWMP Report

(rather than surface water sewers). Road gullies are part of the highway drainage network, as such they are not included in the sewer model as the water company is not responsible for them. Highway drainage will have an influence on surface water exceedance during storm conditions. An initial pluvial runoff simulation revealed the primary flow routes through the town and the road gullies along these flow routes were surveyed. The whole catchment could not be surveyed due to time and budget constraints. Road gullies were added to the InfoWorks ICM model. Each gully surveyed was identified by type (specified by the Design Manual for Roads and Bridges, vol 4 Geotechnics and Drainage) and an assessment was also made on site of the crossfall and the /longitudinal gradient.

Determine hydrological approach

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

- urban hydrology used for the areas which drain to the foul, combined and surface water sewer networks, and;
- pluvial runoff from the upstream catchment and permeable surfaces within the urban area.

The hydrology used by Severn Trent Water in their AMP5 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 to be unduly conservative but the experiences which Severn Trent Water have are 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.

Runoff from the upstream catchment and permeable surfaces within the urban area was applied to the model as direct (2D) runoff, where the rainfall is applied to the above ground mesh and allowed to be routed overland based on topography. The rainfall to be applied was generated using FEH catchment descriptors, but it should be noted that in accordance with the Cheltenham SWMP the standard runoff coefficient (SPRHOST) was increased to 47%[3]. This represents a conservative approach to the hydrology, and assumes that the catchment is saturated prior to intense rainfall applied for the design storms.

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[3] The Cheltenham SWMP utilised information from Dowdeswell Reservoir to identify that the catchment runoff in July 2007 was substantially increased above the norm by the preceding heavy rainfall in June 2007. It was considered that the same would have applied to Bishop’s Cleeve given its close proximity and similarities to the Cheltenham catchment. This increase amounted to 50% on the SPRHOST value. The final SPRHOST value used for the modelling was 47%; therefore 47% of direct rainfall onto the surface was generated as ‘runoff’.

Bishop's Cleeve SWMP Report

Build above ground 2D model

To successfully represent the conveyance and ponding of flood water requires the use of a ground model within the Level III ICM model. A LiDAR (Light Detection and Radar) survey was specially commissioned for the Bishop's Cleeve SWMP covering the whole of the catchment including all of the area up to the watershed on the eastern side of the town. The quality of the LiDAR was within specified tolerances but it should be noted that this survey captured the topography as it existed in 2011 rather than as it existed at the time of the July 2007 flood event. The principal differences were that after the 2007 flood event several of the ditches were deepened and widened.

Once the watercourses, sewers and LiDAR data was brought into the InfoWorks ICM model and checked, a 2D mesh was created. In InfoWorks ICM the 2D mesh is represented as a series of triangles based on ground level data from the LiDAR data. When sewers or watercourses are at capacity water is placed onto the 2D mesh and is routed above ground. Water on the 2D mesh can re-enter sewers or watercourses where there is available capacity. This allowed 2D runoff to be simulated for the whole catchment.

A 2D mesh was created over the entire Bishop's Cleeve and Southam region at a very detailed resolution using 40m^2 maximum triangle size. The 2D boundary included the area up to the catchment ridge line so that all runoff from the steep escarpment was captured. In order to gain a more accurate representation of runoff paths, roads were added into the 2D zone as mesh zones, as previously described.

3.2.3 Verify Level III ICM model

The July 2007 flood event was considered to the best event to verify the model against as the return period of the event is sufficiently high for it to be a fair test of the model. Furthermore, there were reasonably good records of the properties and areas which flooded, and rainfall data is available for this event.

Initially, rainfall data from the July 2007 event was obtained from a number of rain gauges and weather radar data. The weather radar recorded significantly less rainfall and was discounted as being representative of rainfall in the catchment in July 2007. The nearest rain gauge to Bishop's Cleeve was Langley which is east of the study area and is in the rain shadow of Cleeve Hill. It is therefore believed that this rain gauge may well have under-estimated rainfall which actually fell on the study area catchment in July 2007. This is because the steep topography of Cleeve Hill faced by the south-westerly storm is likely to have caused significant and intense rainfall on Cleeve Hill as air was forced upwards.

When the Level III ICM model was simulated using the data from the Langley rain gauge for July 2007 the model did not predict flooding in all recorded locations. It is most likely that this is because the Langley rain gauge does not account for the intensity of rainfall on Cleeve Hill, as discussed. Therefore, in addition to the observed rainfall from the Langley rain gauge a 1 in 100 year 60 minute synthetic

Bishop’s Cleeve SWMP Report

storm was also simulated in the model to support the verification stage[4]. Both the Langley rain gauge and the 1 in 100 year 60 minute synthetic storm were used to verify the model against the July 2007 flood event.

As far as possible, the model needed to be able to replicate catchment conditions (e.g. blockages) at the time of the July 2007 flood event. Working with Tewkesbury Borough Council the modelling team identified known blockages and other catchment conditions from July 2007 for the verification purposes. The modelled blockages are illustrated in Appendix E.

Outputs from the model verification (for both simulations) are provided in Figure 3-1 and Figure 3-2 below. The red buildings represent recorded flooding locations collected by Tewkesbury Borough Council following the July 2007 event, although it is uncertain whether these are internal or external flooding, or the associated depths. The results indicate that the model is successfully replicating the flow pathways and key flooded areas from July 2007. With a 1 in 100 year 60 minute event the model predictions are better aligned with the recorded flooded properties, and this is a reflection of the sensitivity of the study area to high intensity rainfall. Overall, the model was considered to provide a satisfactory verification against known flooding locations in the study area.

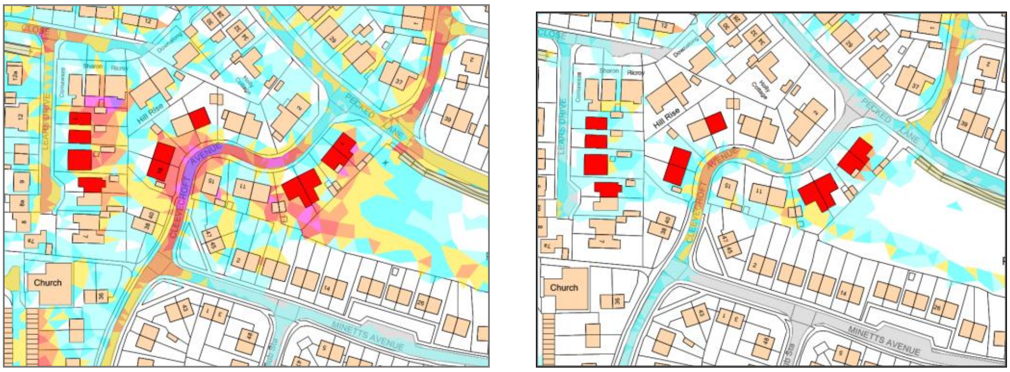

Figure 3-1: Comparison of flood predictions between July 2007 rainfall (right) and 1 in 100 year 60 minute storm (left)

[4] The return period of the July 2007 event was estimated as 1 in 120 years, so using a 1 in 100 year synthetic storm is a similar return period. A 60 minute storm is more intense than the rainfall recorded at Langley rain gauge, and is more likely to be representative of the intensity of rainfall experienced on Cleeve Hill in July 2007.

Bishop’s Cleeve SWMP Report

Figure 3-2: Verification of flooding using 1 in 100 year 60 minute event

3.2.4 Undertake model simulations

Once the model was satisfactorily verified against the summer 2007 flood events, the model was run for a series of storm events to:

- identify flooding mechanisms and all sources of flood risk across Bishops Cleeve;
- identify areas where surface water flood risk is highest – in these areas detailed options will be identified to mitigate the flooding (discussed in Section 3.2.5);
- quantify current and future flood risk (discussed in Section 3.2.6), and;
- provide mapping to support spatial and emergency planners (discussed in Section 3.3).

3.2.5 Identify flooding hotspot locations

Based on the recorded flooding from July 2007 and the Level III ICM model a number of hotspot locations were identified in the study area. These hotspots will be the locations where options will be identified and appraised to mitigate flood risk. Table 3-1 provides an overview of the hotspot locations.

Table 3-1: Hotspot locations for SWMP

Hotspot ref.	Locations affected	No. of properties affected in July 2007	Comments
A	Millham Road and Woodmancote Park Homes	30-40	Flooding primarily caused by surface runoff exceeding capacity of local watercourses
B	Stockwell Lane, Chapel Lane, Pecked Lane, Cleevecroft Avenue, Lears Drive, Church Road, Evesham Road	10-20	Flooding primarily caused by surface runoff exceeding capacity of local watercourses. Rapid runoff from escarpment causes fast flowing runoff on Stockwell Lane, which continues through the town centre of Bishop’s Cleeve
C	SE Cleeve – Hillside	10-15	Flooding primarily caused by surface runoff

Bishop's Cleeve SWMP Report

	Gardens, Denham Close, Potters Field Road		exceeding capacity of local watercourses
D	Moreton Close	10	Flooding caused by groundwater levels or runoff from school playing fields, but risk is unclear and no options have been proposed at this stage
E	GE Factory and A4019	1 commercial property and highway	Runoff ponds to the eastern embankment of the A4019 and subsequently overtops the road causing deep flooding on the road (0.5m) and to the GE factory. Maintenance and additional culvert since 2007 is believed to have reduced the risk significantly here, and no further options have been identified.

3.2.6 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.[5]

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

[5] For the options simulations the 1 in 50 and 1 in 75 probability rainfall events were not simulated. The remainder of the simulations were used to understand the benefits of any intervention.

Bishop's Cleeve SWMP Report

flooding were determined. This process found 60 minutes to be the critical duration for the study area for the baseline options.

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 were 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[6]. Property thresholds of 200mm were used for the majority of properties based on a walk-over survey undertaken in June 2012, except for the Woodmancote Caravan Park Homes where a property threshold of 500mm. Depth-damage curves from the Multi-Coloured Manual were used to estimate damage at each property based on the depth of flooding. 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. The annualised damages are further discussed in Section 4.3.2 alongside the benefits and costs of options. Subsequently Defra's Partnership Funding calculator was completed for each option to identify the benefit-cost ratio and the level of Partnership Funding likely to be required to secure FDGiA.

3.3 Map and communicate risk

3.3.1 Communicate risk

Three evening meetings were held with Bishop's Cleeve and Woodmancote Parish Councils to confirm flood risk in the study area, and to seek feedback on proposed options to alleviate flooding.

3.3.2 Map surface water flooding

Outputs from the Level III ICM model was provided to the project steering group, and spatial and emergency planners at Gloucestershire County Council and Tewkesbury Borough 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 Bishop's Cleeve.

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[6] Where a flood outline intersected with a building outline the maximum depth of flooding at the property boundary was used for the damage calculations

Bishop's Cleeve SWMP Report

4 Phase 3 - Options

4.1 Introduction

The SWMP Technical Guidance sets out a framework for the options identification and appraisal process which has been followed for the Bishop's Cleeve SWMP. This process is described below:

1. identify a range of measures which could be taken to reduce flood risk – at this stage thinking shouldn't be constrained by funding routes and a range of structural and non-structural measures should be considered which may have a range of costs and benefits associated with them;

2. short-list the range of measures through a high-level appraisal to screen out measures which are not feasible and identify up to three options for each detailed assessment area to take forward for detailed appraisal (benefit-cost analysis), and;

3. undertake detailed options appraisal for up to three options for each detailed assessment area to identify a preferred option/s (some options may not require detailed appraisal through modelling but will be considered as part of the action plan, e.g. promoting flood resilience and resistance).

4.2 Identify and short-list measures

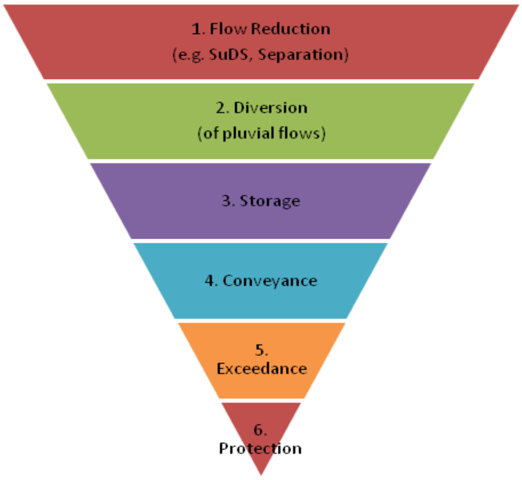

Figure 4-1: Hierarchy to consider appropriate surface water management measures (courtesy of Richard Allitt Associates)

To identify options for each detailed assessment area a hierarchical approach was adopted based on the diagram in Figure 4-1. This diagram provides a useful framework to consider options, starting with flow reduction (SUDS and separation) and working through the hierarchy.

The measures set out in this hierarchy were assessed in terms of their potential feasibility for the study area. Following initial modelling assessment these measures were discussed at a steering group meeting and through two evening meetings with Bishop's Cleeve and Woodmancote parish councils. Table 4-1 summarises the options and outcomes from this initial screening stage.

Bishop's Cleeve SWMP Report

Table 4-1: Overview of initial screening stage

Option ID	Type of measures	Brief description of measure	Recommendation
Hotspot A: Woodmancote Park Homes and Millham Road			
1	Diversion	Northern diversion routed north along the eastern boundary of Bishop's Cleeve starting at Bushcombe Lane and running north-west to the bridge underneath the railway and into existing open space (need to further understand linkages with potential development to north and south of Cleeve as identified by the joint Core Strategy.	Taken forward for further consideration
1a	Storage	There is potential for an upstream attenuation area to be constructed immediately upstream Butt's Lane around Braemar residence and Poplin Piece field, upstream of the new residential development (397136,227792).	Taken forward for further consideration
2	Conveyance	The swale starting approximately between Knapps Crescent and Jennings Orchard (397056, 227712) runs alongside Rosewood Walk leading toward the play park adjacent and upstream of Collyberry Road does not connect with the underground concrete attenuation tank underground the play park (396833, 227722). This option would be to connect the swale into the attenuation tank.	Do not take this option forward as it is likely to be uneconomical to divert flows from the swale into the existing storage tank without upsizing, and flows in the swale are only likely to contribute a small amount of total flow in the catchment.
3	Conveyance	There is a second drain which converges with the open channel just downstream of Collyberry Road and flows under Station Road to a boundary ditch along the western edge of Woodmancote Primary School via a pond (396736, 227658) in the school grounds. It may be useful to locate the source and route of the second channel upstream of the school. If the catchment area and thus flows of this channel are large enough to merit attenuation, there may be scope to increase the attenuation capacity of the school pond. There would be potential safety concerns about attenuating storm water within a school, so there may be scope for a covered tank or fenced open device.	In isolation this would be ineffective at reducing flood risk because the upstream catchment is small, but the option could be taken forward for further consideration in combination with options 6 and 7.
4	Storage	Downstream of Collyberry Road, the watercourse is a small dog- legging ditch and part culvert, tightly constrained alongside the boundary of and within Woodmancote Park Homes and south of Willow Drive. There is a small wooded area between the toe of the roadway embankment and just west of the bend of Willow Drive (396695,227832). This is the only available area upstream of the railway and is on the leftbank of the watercourse and there could be some potential space for attenuating flood flows.	Do not take this option further as it is unlikely to have much, if any, flood risk benefit
5	Protection	Offer property level protection to residents of Woodmancote Park Homes and Millham Road	Do not take forward because depths of flooding are too high for property level protection at the park homes

Bishop's Cleeve SWMP Report

6	Conveyance	Increasing conveyance through the railway embankment may be an option, however this must be assessed to determine what benefit it provides upstream and increase in risk to properties downstream of the railway. It may be possible to improve the inlet arrangements on the culvert to improve conveyance without upsizing or duelling the culvert under the railway, but this would need to be confirmed by hydraulic modelling.	Take this forward for further consideration alongside option 7 (NB: it would only function in combination with option 7)
7	Storage	Downstream of the railway embankment, it is understood the right bank fields beyond the recreational ground are to be developed for residential properties. All of or part of recreational ground is at a similar level to the housing and may be a potential site for attenuation. This is a viable option but would only be effective if upstream measures can ensure that storm water arrives into the attenuation area rather than flooding homes upstream of the railway.	Take this forward for further consideration alongside option 6
Hotspots B & C: Stockwell Lane/Chapel Lane through to town centre & south-east Cleeve			
8	Storage	There are two former mill ponds adjacent to Stockwell Lane which could be re-instated as attenuation areas. Due to constrictions from the road and surrounding buildings, they may not be able to be enlarged significantly, and would need to be subject to a topographic survey to better assess the potential to increase their. Access would require co-operation from the resident in The Mill.	Unlikely to offer much, if any, flood risk benefit. However, agreed with parish council to take this forward
9	Conveyance	The road drainage on Stockwell Lane could be improved to allow the surface runoff which runs down Stockwell Lane to discharge into the adjacent watercourse. This can be achieved by removing the existing kerbs and drainage points for dropped kerbs, re-cambering of the roads, and/or providing a cattle grid or 'cross drain' device	Take this forward for further consideration
10	Conveyance	Upszie the culverted watercourse along Stockwell Lane. Between the mill ponds and The Apple tree Pub on Stockwell Lane, the watercourse is mostly open, however downstream of this point the road rises, and the watercourse is covered for access to roadside properties. The culverted watercourse then runs alongside or under Stockwell Lane. This option would seek to increase the size of the culverted section of watercourse to improve the conveyance of flows within the culvert.	Do not take this forward as it is considered technically infeasible and would not be affordable
11	Conveyance	At the corner of Chapel Lane and Station Road, (397140, 227245), overland flow from Stockwell Lane diverges and flows down both Chapel Lane, New Road and Station Road, with some ponding at Station Road. It is proposed the road is re-cambered at this junction such that levels are adjusted to allow water to flow down Chapel Lane (thereby using Chapel Lane as a dedicated exceedance flood route), reducing the flood risk to the property adjacent and immediately downstream the junction	Take this forward for further consideration
12	Storage	It is proposed that watercourse channel and field drainage improvements are investigated to reduce the risk of overland flows, and a storage is considered in the area alongside Hillside Gardens where the watercourse is culverted (397513, 227212).	Take this forward for further consideration
13	Conveyance	It is possible that the culvert under Britannia Way is being overtopped due to lack of conveyance through the culvert, although we need to confirm if there is anecdotal evidence to confirm this. It is	Take this forward for further

Bishop's Cleeve SWMP Report

		recommended that the need to upgrade the culvert at Britannia Way is reviewed in light of anecdotal evidence and upstream improvement works.	consideration
14	Storage	Increase the capacity of the existing balancing pond at Honeybourne Meadow. It is proposed the option of increasing the storage capacity of the ponds be undertaken and potentially subsequent adjustment to the existing control structure to increase storage.	Take this forward for further consideration
15	Conveyance	It is also proposed that the option of formally utilising the existing railway reserve exceedance route be explored further. The storage pond outlet could be modified to divert excess water to the ±2km long rail reserve exceedance route	Do not take this option forward, it is considered technically and economically infeasible
16	Storage	A recreation ground including play park and soccer field, on the leftbank adjacent Pecked Lane at (396334, 227352) was reviewed for potential storage. Pecked Lane recreational ground is considered as a suitable site for potential on-line storage. . Observations from the site visit would suggest that the land is already low lying and any excavation works may end up with the recreation ground being lower than the watercourse.	Do not take this option forward as it will provide little, if any, flood risk benefit
17	Storage	Existing green space adjacent to the watercourse at the corner of Evesham Road and Finlay Way at (395709, 227848) was considered as a storage area. It is not considered that this area be used as storage. Any apart of the area would require a large depth of lowering in the order of 1.0m to 1.5m to channel bottom depth. In addition, the flood receptors at risk are predominantly upstream, therefore there would be little benefit from storage at this location	Do not take this forward because it will offer limited additional flood protection benefits

Bishop's Cleeve SWMP Report

For the Woodmancote Park Homes and Millham Road area the following options have been taken forward for options appraisal:

- option 1 (upstream diversion) although this may not be economical, or;
- a combination of options 1a, 3, 6 and 7.

For the Stockwell Lane/Chapel Lane through to the town centre (including Hillside Gardens) the following composite option is being progressed for this area:

It is recommended that the following composite option is progressed for this area:

- investigate potential improvement works to the existing mill ponds to allow them to offer some flood storage (option 8);
- undertake highway drainage improvement works (option 9) on Stockwell Lane near Box Farm to enable surface water to get into the watercourse, and;
- re-profile the road junction at The Green (option 11) to ensure a continuous flow pathway along Stockwell Lane and Chapel Lane, and;
- construct a flood storage area upstream of Hillside Gardens (option 12) or offer the residents property-level protection, and;
- enlarge the Honeybourne Meadow balancing pond (option 14).

These composite options were tested in the hydraulic model, forming two primary options:

- Option A – option 1, plus options 8, 9, 11, 12 and 14, and;
- Option B – a combination of options 1a, 3, 6 and 7, plus options 8, 9, 11, 12 and 14.

4.3 Assess options

4.3.1 Identify assessment to be carried out

The SWMP technical guidance states that the 'first step in the options assessment process is to determine which benefits and costs are to be included in the analysis.' The process for assessing the options which have been taken forward to outline design and detailed benefit-cost analysis is set out below:

- calculate baseline annualised average damages (AAD) to property, businesses and critical services for the 'Do Nothing' scenario over a 100 year period, and discount[7];

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

Bishop's Cleeve SWMP Report

- calculate AAD for the 'Do Minimum' and flood alleviation options to identify the residual damages under different scenarios over a 100 year period, and discount (NB: the baseline damages – the residual damages = benefits of intervention);
- calculate approximate capital and operational costs of the 'Do Minimum' and flood alleviation options over a 100 year period[8], and discount;
- calculate the benefit-cost ratio (BCR)[9] for each option;
- consider other factors which influence the decision about which options should be taken forward, including engineering feasibility and project risks, and socio-political acceptability;
- using the BCR and assessment of un-monetised benefits and costs determine the preferred option/s to take forward for the action plan[10], and;
- refine the preferred option and develop the SWMP action plan.

The outputs from this assessment are provided in Section 4.3.2.

4.3.2 Undertake assessment of options

4.3.2.1 Option A

Hotspot A: Woodmancote Park Homes / Millham Road

Under this option a diversion channel would be built from Bushcombe Lane to the railway line to the north of Woodmancote Park Homes. The diversion channel would run in a north-westerly direction. The diversion channel would run along contour lines and would be approximately 1.0-1.5m and up to 2m wide (at bed level), with two box culverts as the channel passed under a track adjacent to Butt's Lane and Butt's Lane itself. In addition, for this option to be effective a cross drain or similar structure would be required on Bushcombe Lane into the diversion channel. This is because during a 1 in 100 year rainfall event up to 1.2 m^3/s will flow down Bushcombe Lane and would cause flooding to the Park Homes. With the diversion channel and flows captured from Bushcombe Lane the scheme shows a large reduction in flood risk up to the 1 in 100 year rainfall event as nearly all runoff is captured and diverted away from the Park Homes.

However, this option would require significant engineering works, including 2 culverts, scour protection, and downstream compensatory storage. There may also be significant land owner issues, which have not been considered to date. It is estimated that up to 7,000 m^3 of downstream compensatory storage would be required to ensure that downstream flood risk did not increase. A potential site has been

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

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

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

Bishop's Cleeve SWMP Report

identified immediately to the west of the railway line, but this is subject to future development of Homelands Phase 2. It is understood that the S.106 contributions for Homelands has already been agreed so there is no mechanism for securing additional contributions towards the scheme

Hotspot B & C: Stockwell Lane/Chapel Lane to town centre & south-east Cleeve

A composite option has been tested for the Stockwell Lane/Chapel Lane through to the town centre area. At the upstream end the potential for utilising the two mill ponds as attenuation during rainfall events. Potential combined storage at the mill ponds is estimated at 1,240 m3, whereas flows which could be diverted off the road and through the ponds is 6,900 m3 for a 1 in 5 year rainfall event. Therefore, even during a small rainfall event runoff far exceeds the potential capacity of the ponds and they would offer little, if any, flood risk benefit downstream. Utilising the mill ponds has therefore been excluded from further analysis at this stage.

Further down Stockwell Lane a cross-drain type structure has been modelled outside the entrance to the Apple Tree Pub, where flow would be passed directly to the culverted watercourse. Placing the drainage at this location will pick up additional flow paths which would otherwise be missed by drainage placed at the top of the mill ponds. The current modelled option demonstrates that this would be effective at reducing the depth of flow along the road up to a 1 in 10 year event. For higher rainfall events there is insufficient capacity within the watercourse, and flows would continue down Stockwell Lane.

At the junction of Chapel Lane and Station Lane the option is seeking to stop flood water pooling on New Road, making this section impassable. This would require lowering of the exceedance route by up to 350mm, and raising the ground level along the bottom of New Road to approximately 80.6m AOD (or raised by 150mm). This has been effective at significantly reducing the flood risk to this area and reducing the level of pooled water thus making the road passable. However in larger return period storms a second flow path exists which brings flow across from Denham Close, the road should be suitably profiled to allow these flows to pass down New Road and on to Chapel Lane. In addition, it is unknown what services are under the road at this area, which would affect whether the road could be lowered. Utisiling this area as a dedicated exceedance route would require buy-in from Gloucestershire Highways and the local community. Signage would be required to ensure the risks to local community would be managed.

Further downstream, there is a 1.6m wide by 1.0m high culvert under Britannia Way. The model shows that the culvert in Britannia Way would be over-topped or very close to being over-topped on a 1 in 30 year event. The exceedance route along Chapel Lane would require some additional work to ensure that the flow enters the watercourse at this point and does not flow along the footpath, as is shown by the model. The maximum current capacity is 6.0 m^3/s. Substantial upsizing would be required to enable this culvert to pass forward a 1 in 100 year flow of approximately 12 m^3/s. The feasibility of this has not been assessed in detail.

At Honeybourne Meadow the proposed scheme is to expand the balancing pond to the north and south, with the entire area being levelled to 68.5m AOD. A bund has been placed around the low points of the balancing pond to 70.3m AOD. Pass forward flow is provided via a 1m wide x 0.5m high culvert to match the capacity in the downstream network. A relief weir has been provided at 70.0mAOD which is

Bishop's Cleeve SWMP Report

currently 3.0m wide (5.0m wide may be more appropriate to alleviate the flood risk to the properties bordering the meadow). This scheme is demonstrated to be effective at significantly reducing the flood risk to the downstream properties up to a 1 in 30 year event. Above this return period the storage becomes fully utilised and the additional flow has to spill onto the railway, but the reduction in flow has been shown to reduce the flow that continues onto Pecked Lane. However due to the increase in water level in extreme storm events risk to properties adjacent to the meadow may be increased. The increase in flood water level may also cause problems for the surface water sewers that currently discharge into the watercourse. These issues will need to be addressed during design to ensure no increase to surrounding properties.

At Hillside Gardens 1.7m high bunded storage area to east of Hillside Gardens, providing 2,800 m^3 of storage has been modelled. The storage area would be drained via a 150mm pipe which connects into the surface water system on Hillside Gardens. Storage at this location would be above natural ground level which could raise local concerns about the risk of exceedance and overtopping. Property level protection could be considered in this area as an alternative to upstream storage.

Economic Appraisal

The reduction in flood risk for different rainfall events is presented in Table 4-2, and shows that for a 1 in 30 year rainfall event the scheme would reduce flood risk to nearly 100 properties. For a 1 in 100 year rainfall event 170 properties would benefit from reduced flood risk.

This equates to a monetary reduction in flood risk over a 100 year period of £6.37 million (expressed as a Present Value). The cost of the scheme over the same time period is estimated to be £1.64 million (Present Value). Option A therefore has a benefit cost-ratio of 3.88.

Table 4-2: Properties at risk with Option A

Rainfall event	Residential properties at risk		
	Do Nothing	**Option A**	**Reduction in risk**
Residential properties at risk (excluding Woodmancote Park Homes)			
1 in 30 year rainfall event	93 properties	32 properties	61 properties
1 in 100 year rainfall event	181 properties.	56 properties	125 properties
Woodmancote Park Homes properties at risk			
1 in 30 year rainfall event	45 properties	10 properties	35 properties
1 in 100 year rainfall event	57 properties.	14 properties	43 properties

4.3.2.2 Option B

Hotspot A: Woodmancote Park Homes / Millham Road

Option B has a different suite of measures to manage flood risk to Woodmancote Park Homes and Millham Road. Upstream a storage area has been represented to the east of Butt's Lane. The storage would comprise of a 2m high storage bund with a

Bishop's Cleeve SWMP Report

225mm outlet pipe that connects into the swales that runs along Knapps Crescent. Approximately 1,000 m^3 could be stored, and the model evidence suggests the storage would be overtopped during a 1 in 30 year rainfall event. The storage is technically feasible, but would require storage above natural ground level. There may be concerns from residents downstream of the storage about overtopping, which would need to be managed during design

Further storage was also proposed on the north-west boundary of Woodmancote Primary School (option 3). However, this has excluded from option B for the reasons outlined. Only one known flow path, a surface water sewer, could be found upstream which fed into the watercourse and the flow peaked at 100 l/s for a 1 in 30 year event. This does not warrant attenuation when compared with the pluvial runoff along Station Road (900 l/s peak) which is causing the majority of the flooding. Flow passes along Station Road until the junction with Britannia Way where part of the flow diverges northwards, then again outside Woodmancote Primary School part of the remaining flow diverges northwards through the properties to Collyberry Road. By the time the overland flow reaches the location of the potential storage the majority of the flow has already left the road. Capturing the overland flow at this point would provide a negligible reduction in flood risk.

Improved conveyance under the railway to the west of Woodmancote Park Homes has been included in this option. Improvements to the culvert inlet were initially tested but found to be ineffective. Therefore a duplicate 960mm diameter culvert is proposed under the railway. This scheme has been effective at reducing the flood risk to some of the properties surrounding the culvert inlet as it has meant that the depth of pooled water has not risen as high. However little has been done to alleviate the pluvial runoff routes which funnel flow to this point so the flood risk still exists, but the likelihood of internal flooding has been reduced. However, in order for a new railway culvert to be installed it is possible that two park homes would need to be moved. In addition, there are significant technical challenges of constructing a new culvert under the railway, and would require significant engagement with British Heritage Railway who manage this section of the railway.

An additional culvert under the railway can only be feasible if sufficient compensatory downstream storage is provided to mitigate any increase in flood risk downstream. The recreation area to the north of Millham Road is proposed as an area to provide storage. The proposed scheme would be lower the right bank of the watercourse to ensure flows would flood onto the recreation area, and then lower to recreation area by up to 0.4m. This scheme has been shown to be effective at reducing the flood risk to those properties that run along the southern border of the recreational ground. However, there is a risk of increasing flood risk to properties downstream of Millham Road. As part of the design of this option the change in downstream risk will need to be assessed in further detail. If there is an increase in downstream risk then additional mitigation works may be required, or a reduced second culvert could be installed to limit additional peak flows from east of the railway.

Hotspot B & C: Stockwell Lane/Chapel Lane to town centre & south-east Cleeve

The suite of measures for this area are the same as for option A, and have been discussed in Section 4.3.2.1.

Bishop's Cleeve SWMP Report

Economic Appraisal

The reduction in flood risk for different rainfall events is presented in Table 4-3, and shows that for a 1 in 30 year rainfall event the scheme would reduce flood risk to 85 properties. For a 1 in 100 year rainfall event 150 properties would benefit from reduced flood risk. Under Option B a similar number of properties would be protected Woodmancote Park Homes and Millham Road for the 1 in 30 year rainfall event compared to Option A. However, at the 1 in 100 year rainfall event more properties would continue to flood under Option B compared to Option A. The scheme offers a reduced standard of protection for Woodmancote Park Homes and Millham Road compared to Option A.

This equates to a monetary reduction in flood risk over a 100 year period of £6.05 million (expressed as a Present Value). The cost of the scheme over the same time period is estimated to be £1 million. The scheme is nearly £600,000 cheaper than Option A over the whole life of the scheme, and this primarily because the lengthy diversion channel is not part of Option B. Option B has a cost-benefit ratio of 6.01, which makes it significantly more economically viable than Option A.

Table 4-3: Properties at risk with Option B

Rainfall event	Residential properties at risk		
	Do Nothing	Option A	Reduction in risk
Residential properties at risk (excluding Woodmancote Park Homes)			
1 in 30 year rainfall event	93 properties	37 properties	56 properties
1 in 100 year rainfall event	181 properties.	61 properties	120 properties
Woodmancote Park Homes properties at risk			
1 in 30 year rainfall event	45 properties	18 properties	27 properties
1 in 100 year rainfall event	57 properties.	29 properties	28 properties

4.3.3 Summary and conclusions

Option B is recommended as the preferred option based on technical and economic assessment of the two composite options. Economically, Option B offers a far more attractive cost-benefit ratio of 6:1, compared to 3.9:1 for Option A. As a result Option B can attract significantly more contribution towards the scheme from Central Government through Flood Defence Grant in Aid[11]. Based on the Partnership

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

Bishop's Cleeve SWMP Report

Funding Calculator Option B has a Partnership Funding Score of 82% and therefore the likely shortfall in funding is in the region of £160,000. Comparatively Option A has a Partnership Funding Score of 53% and the likely funding shortfall is in the region of £700,000.

Technically, the scope of engineering works associated with Option B is reduced because the diversion channel is not included as part of the option. There are some significant technical and political constraints associated with the diversion channel, which would affect the feasibility of this approach:

- consultation, agreement and possible compensation with multiple landowners;
- significant costs to construct the diversion channel;
- requirement for large downstream compensatory storage within the vicinity of Homelands Phase 2, and;
- health and safety considerations given the scale of the diversion channel;

Option B offers a lower standard of protection to properties in Woodmancote Park Homes and Millham Road, but the construction works are less complex involving two smaller flood storage areas and an additional culvert under the railway. These would still present challenges during construction (e.g. working underneath railway), but the complexities and issues are lower compared to Option A.

Bishop's Cleeve SWMP Report

Table 4-4: Summary of findings options appraisal

Name of option	Brief description	Advantages / Opportunities	Disadvantages / Constraints	Economic Appraisal
Do Nothing	No measures taken to improve existing situation – assumes all culverts are 70% blocked.	✓ No engineering works required.	✗ Flooding will continue in the area causing damage to properties and infrastructure, and 'risk to life' because of the fast flowing water within the study area. ✗ Flood risk will increase over time due to climate change and urban creep. ✗ In a major rainfall event it is probable that debris will block parts of the drainage system regardless of how clear it was prior to the event.	-
Do Minimum	Existing system working as designed with no additional improvement measures other than basic maintenance regime and known blockages removed.	✓ No additional capital costs ✓ Continue basic maintenance programme		
Option A	Woodmancote Park Homes/Millham Road: • Diversion 1.0 to 1.5m high from Bushcombe Lane to railway • Plus cross-drains on Bushcombe Lane to capture flow on the road into the diversion channel • Up to 7,000 m^3 of compensatory storage would be required downstream of the railway (depending on outlet controls) Stockwell Ln/Chapel Ln through to town centre: • Provision of cross drain type device outside entrance to Apple Tree Pub (capacity up to a 1 in 10 year event) • Re-profiling of road junction Stockwell Ln / Station Ln – involves lowering of Stockwell Ln by up to	✓ Diversion of flows around Woodmancote Park Homes offer significant reduction in flood risk to properties up to and including a 1 in 100 year rainfall event ✓ Significant reduction in hazard to people and road users along Bushcombe Lane and Stockwell Lane as flows would be taken off to the diversion channel ✓ Increasing storage at Honeybourne Meadow will significantly enhance standard of protection downstream ✓ Opportunities to expand and enhance Honeybourne Meadow as a public amenity asset	✗ Diversion channel around Woodmancote Park Homes involves significant engineering works, including 2 culverts, scour protection, and downstream compensatory storage. There may also be significant land owner issues, which have not been considered to date ✗ Diversion channel would be 1.0-1.5m above natural ground level and there may be some concerns about the risk of overtopping ✗ It is unclear if downstream compensatory storage is possible given the Homelands Phase 2 development ✗ Re-profiling of the road at Stockwell Ln/Station Ln may not be possible because of the presence of services close to the road surface ✗ Managing exceedance flows on the road would require significant community	Whole Life Costs = £1.6m Whole Life Benefits = £6.37m Benefit-Cost Ratio = 3.88 PF Score = 53% Contributions needed for 100% PF Score = £700,000

Bishop's Cleeve SWMP Report

Name of option	Brief description	Advantages / Opportunities	Disadvantages / Constraints	Economic Appraisal
	350mm, and raising New Road by up to 150mm • 1.7m high bunded storage area to east of Hillside Gardens, providing c.2,800 m³ of storage • Expanding Honeybourne Meadow to the north and south to a level of 68.5m AOD and a bund to a level of 70.3m AOD		education and signage ✗ Storage at Hillside Gardens would be above natural ground level may raise concerns about risk of overtopping ✗ Additional storage at Honeybourne needs to be carefully designed to avoid increasing flood risk to adjacent properties through overtopping or limiting surface water sewers discharging ✗ There would be significant disposal of materials from excavation which is difficult given access in an out of Bishop's Cleeve	
Option B	Woodmancote Park Homes/Millham Road: • Provision of c.1,000 m³ storage to east of Butt's Lane • Additional 960mm culvert under the railway • Lowering the right bank of the watercourse downstream of the railway and lowering recreational area by 0.4m Stockwell Ln/Chapel Ln through to town centre as per Option A	✓ For Woodmancote Park Homes and Millham Road option B will be lower cost because the diversion channel is not included ✓ Opportunity to utilise the recreational ground downstream of the railway line as a dual use space ✓ Significant reduction in hazard to people and road users along Stockwell Lane as flows would be taken off to the diversion channel ✓ Increasing storage at Honeybourne Meadow will significantly enhance standard of protection downstream	✗ Providing an additional culvert under the railway will be technically difficult and costly ✗ The suite of measures for Woodmancote Park Homes and Millham Road result in a lower standard of protection compared to option A ✗ Initial modelling suggests it may be difficult to provide sufficient compensatory storage downstream of the railway to avoid increased flood risks to properties near Millham Road ✗ Does not manage the flow pathway along Bushcombe Lane which is a significant source of flooding ✗ Re-profiling of the road at Stockwell Ln/Station Ln may not be possible because of the presence of services close	Whole Life Costs = £1.0m Whole Life Benefits = £6.05m Benefit-Cost Ratio = 6.01 PF Score = 82% Contributions needed for 100% PF Score = £165,000

Bishop's Cleeve SWMP Report

Name of option	Brief description	Advantages / Opportunities	Disadvantages / Constraints	Economic Appraisal
		✓ Opportunities to expand and enhance Honeybourne Meadow as a public amenity asset	to the road surface ✗ Managing exceedance flows on the road would require significant community education and signage ✗ Storage at Hillside Gardens and Butt's Lane would be above natural ground level and may raise concerns about risk of overtopping ✗ Additional storage at Honeybourne needs to be carefully designed to avoid increasing flood risk to adjacent properties through overtopping or limiting surface water sewers discharging	

Bishop's Cleeve SWMP Report

5 Action Plan

5.1 Summary of flood risk

Bishop's Cleeve and Woodmancote suffered major flooding during the summer of 2007, and it is estimated that 90-100 properties flooded during this extreme event. Key flooded locations were:

- Millham Road and Woodmancote Park Homes;
- Stockwell Lane, Chapel Lane, Pecked Lane, Cleevecroft Avenue, Lears Drive, Church Road and Evesham Road;
- Hillside Gardens, Denham Close, Potters Field Road;
- Moreton Close - flooding caused by groundwater levels or runoff from school playing fields, and;
- GE Factory and the A4019.

In Millham Road and Woodmancote Park Homes flooding was primarily caused by surface runoff from Cleeve Hill to the east exceeding the capacity of natural (watercourses) or manmade (highway gullies or surface water sewers) drainage. Flows from Cleeve Hill run down the highway network (e.g. Bushcombe Lane) and flow through Woodmancote Park Homes, causing flooding to properties. There is a 960mm culvert under the railway but this was believed to be blocked during 2007, exacerbating the flooding. Downstream, near Millham Road, flooding was caused by overtopping of the watercourse. Overtopping was caused by lack of capacity in the watercourse, plus poor maintenance of the watercourse. Since 2007 the watercourse has been cleared to maximise conveyance.

Surface runoff from Cleeve Hill also runs down Stockwell Lane before ponding at the junction of Chapel Lane/Station Lane or continuing down Chapel Lane. It does not cause property flooding on Chapel Lane because properties are elevated from the road. Exceedance flows continue down Chapel Lane, passing under the culvert at Britannia Way before arriving at Honeybourne Meadow balancing pond. In 2007 the balancing pond overtopped causing large flows down the railway and onto Pecked Lane. Downstream of Pecked Lane there was severe flooding to properties on Cleevecroft Avenue, Lears Drive, Church Road and Evesham Road.

At Hillside Gardens surface runoff from Cleeve Hill also exceeds the capacity of the natural and manmade drainage, causing water to flow onto Hillside Gardens, Denham Close, Potters Field Road.

At Moreton Close flooding is believed to be caused by high groundwater levels or runoff from the school playing fields, but this risk remains unclear

In 2007 there was also flooding to the GE Factory and thr A4019 which is a main route in and out of Bishop's Cleeve. Runoff from Cleeve Hill ponds to the east of the road, and subsequently overtops the road causing deep flooding on the A4019 (0.5m deep) and to the GE Factory. Maintenance and additional culvert since 2007 is believed to have reduced the risk significantly here

Bishop's Cleeve SWMP Report

5.2 Preferred option to manage flood risk

Based on the options appraisal a composite option is the preferred option to take forward for Bishop's Cleeve and Woodmancote:

- storage upstream of Butt's Lane with an estimated volume of 1,000 m^3;
- providing an additional 960mm culvert under the railway near Woodmancote Park Homes, alongside compensatory storage downstream in the recreation ground near Millham Road;
- provision of a cross-drain type structure on Stockwell Lane to convey additional flows into the watercourse;
- alter the road levels at the junction of Chapel Lane and Station Lane to ensure exceedance flows onto Chapel Lane;
- stoage upstream of Hillside Gardens with an estimated volume of 2,800 m^3;
- upsizing the box culvert under Britannia Way, and;
- upsizing the current storage at Honeybourne Meadow to a level of 70.3m AOD (an additional 5,000 m^3 of storage).

5.2.1 Technical feasibility of options

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

Storage upstream of Butt's Lane and Hillside Gardens rely on storing water on private land. Therefore early engagement and consultation with affected landowners will be critical in establishing the willingness to allow land for flood storage in times of heavy rainfall. In addition, both storage options would result in stored water above natural ground level, which may be a concern for local residents. Early and ongoing engagement will be critical to ensure buy-in to the proposed approach.

Upstream of Honeybourne Meadow the proposed option relies on maximising the conveyance capacity of the existing culverted watercourse and managing exceedance flows away from properties. Proposed works to the highway on Stockwell Lane (cross-drain), Chapel Lane/Station Lane (road re-profiling) and Britannia Way (culvert upsized) will need to be subject to services search to ensure the works would not affect existing services or pipelines. Managing exceedance flows on the road surface would require community buy-in from the outset, and provision of appropriate signage. Gloucestershire Highways would also need to be engaged as the proposed works affect the function and operation of the highway.

Additional storage at Honeybourne Meadow appears to be an attractive option to reduce downstream flood risk. No assessment of the current ecological value of the existing balancing pond has been undertaken, and this will be critical during preparation of the Project Appraisal Report. There is a risk that increasing the level of storage could adversely affect adjacent properties through overtopping or limiting

Bishop's Cleeve SWMP Report

the discharge of surface water sewers; this will need to be addressed during the next stage of design to ensure this risk does not materialise.

In Woodmancote Park Homes the proposed works are to provide an additional 960mm culvert under the railway. This will be technically challenging because the culvert goes under an operational railway and given the limited space available on site. Downstream compensatory storage would be required to mitigate downstream flood risk. Initial work undertake indicates it may be difficult to provide sufficient compensatory storage, and during design the flows from the culvert would need to be optimised against available storage in the recreation area.

5.2.2 Costs and benefits

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

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

- Planning and Design = £95k
- Construction = £799k
- Maintenance = £109k

Over a 100 year period the total estimated Present Value costs are estimated to be £1,002k.

The benefits of this measure can be quantified by comparing the total damages due to flooding for a baseline scenario with the preferred option. The Present Value benefits are estimated to be £6,038k, which gives a benefit cost ratio of 6.02.

5.2.2.1 Partnership Funding Score

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

The Partnership Funding Score for is illustrated in Table 5-1. The PF Score is 82% which means that additional funding (or reduction in scheme costs) would need to be secured in order to progress this scheme

Table 5-1 Partnership Funding information for Bishop's Cleeve and Woodmancote

Criteria	Outcome
PV Costs	£1,002k
PV Benefits	£6,038k

Bishop's Cleeve SWMP Report

Benefit-Cost Ratio	6.02
PF Score	82% (£165k contribution required to achieve a PF Score of 100%
Res. Properties at risk before the scheme	Very Significant = 105 Significant = 60 Moderate = 38
Res. Properties at risk after the scheme	Very Significant = 22 Significant = 33 Moderate = 148

5.3 Next steps and responsibilities

The next steps to take this option forward are:

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

ii) undertake further engagement with parish councils once funding is in place;

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

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

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

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

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

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

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

5.4 Project Risks

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

Table 5-2 Project risks for Bishop's Cleeve and Woodmancote

Risk	**Mitigation**
Storage above natural ground level could lead to concerns from local residents	Early and ongoing communication and engagement with local residents to ensure buy-in for the scheme and to enable design changes to be incorporated

Bishop’s Cleeve SWMP Report

	early on if required to secure public buy-in Storage volumes could be reduced to alleviate residents concerns, but this will need to be considered during the PAR Property level protection could be an alternative option
Lack of willingness from landowners to allow flood storage on their land	Early and ongoing engagement with landowners. Property level protection could be an alternative option
Ground conditions unsuitable for excavation and low embankment	Early ground investigation to identify suitability of ground for proposed works.
Compensatory storage at recreation ground insufficient to mitigate any increase in risk to Millham Road	Reduce the scope and size of an additional culvert under the railway to ensure flows are adequately balanced
FDGiA funding not secured	Seek alternative contributions for the scheme
Honeybourne causes increase in risk	Reduce the increase in water level to ensure NO increase in risk to surrounding properties
Health and Safety concerns associated with exceedance flows	Appoint CDM co-ordinator during design to ensure all health and safety concerns are addressed. Engage with residents to ensure they understand purpose of scheme, and ensure adequate signage warning risk of exceedance flows

Bishop's Cleeve SWMP Report

Appendix A SWMP Process Wheel

Bishop's Cleeve SWMP Report

Appendix B Aims and objectives of Bishop's Cleeve SWMP

The aim of the Bishop's Cleeve SWMP is to identify cost effective and affordable measures to alleviate flooding to residents and businesses in Bishop's Cleeve, Woodmancote & Southam by:

- developing a comprehensive understanding of all sources of flood risk;
- working together and being inclusive of partner and stakeholder views throughout;
- supporting spatial and emergency planning by disseminating information from the SWMP, and;
- identifying and appraising (through benefit-cost analysis) a range of potential options to mitigate flooding.

Specific objectives of the Bishops Cleeve, Southam and Woodmancote SWMP are as follows:

i) build and verify a 'detailed' InfoWorks ICM model of the Bishops Cleeve, Woodmancote and Southam catchment;

ii) using the 'detailed' model, 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);

iii) using the 'detailed' model calculate the 'Annualised Flood Damage Costs';

iv) identify a long-list of potential mitigation measures (referred to as 'options') for the catchment and undertake workshop with partners to enhance options and shortlist accordingly, against agreed criteria;

v) for a limited number (up to 3) of possible options for the catchment, 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;

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

vii) identify the preferred option(s) to be taken forward for the development of the action plan;

viii) prepare an action plan for the catchment, which includes a summary of the agreed actions, potential funding routes, responsibilities and timescales for implementation;

ix) 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;

Bishop's Cleeve SWMP Report

x) 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.

Bishop's Cleeve SWMP Report

Appendix C Data Register

Bishop's Cleeve SWMP Report

Appendix D Hydraulic modelling and hydrology report

Appendix D1 – Hydraulic Modelling and Hydrology Report.pdf

Appendix D2 – Options Report.pdf

Bishop's Cleeve SWMP Report

Appendix E Mapping outputs

GBSWMP001 - StudyBoundary

GBSWMP002 - 2007 modelled blockages

GBSWMP003 - Do Nothing 1_30yr (Depth)

GBSWMP004 - Do Nothing 1_100yr (Depth)

GBSWMP005 - Do Minimum 1_30yr (Depth)

GBSWMP006 - Do Minimum 1_100yr (Depth)

GBSWMP007 - Diversion (Opt. A) 1_30yr (Depth)

GBSWMP008 - Diversion (Opt. A) 1_100yr (Depth)

GBSWMP009 - Composite (Opt.B) 1_30yr (Depth)

GBSWMP010 - Composite (Opt.B) 1_100yr (Depth)

GBSWMP011 - Rev. Composite (Opt.C) 1_30yr (Depth)

Bishop’s Cleeve SWMP Report

Appendix F Preliminary engineering drawings

Appendix F1 - Option A Prelim Drawing

Appendix F2 - Option B Prelim Drawing

Bishop’s Cleeve SWMP Report

Appendix G Costings

Appendix G1 – Option A Costing.pdf

Appendix G2 – Option B Costing.pdf

Bishop's Cleeve SWMP Report

Appendix H Partnership Funding Calculators

Appendix H1 – PF Calculator – Option A.xls

Appendix H2 – PF Calculator – Option B.xls