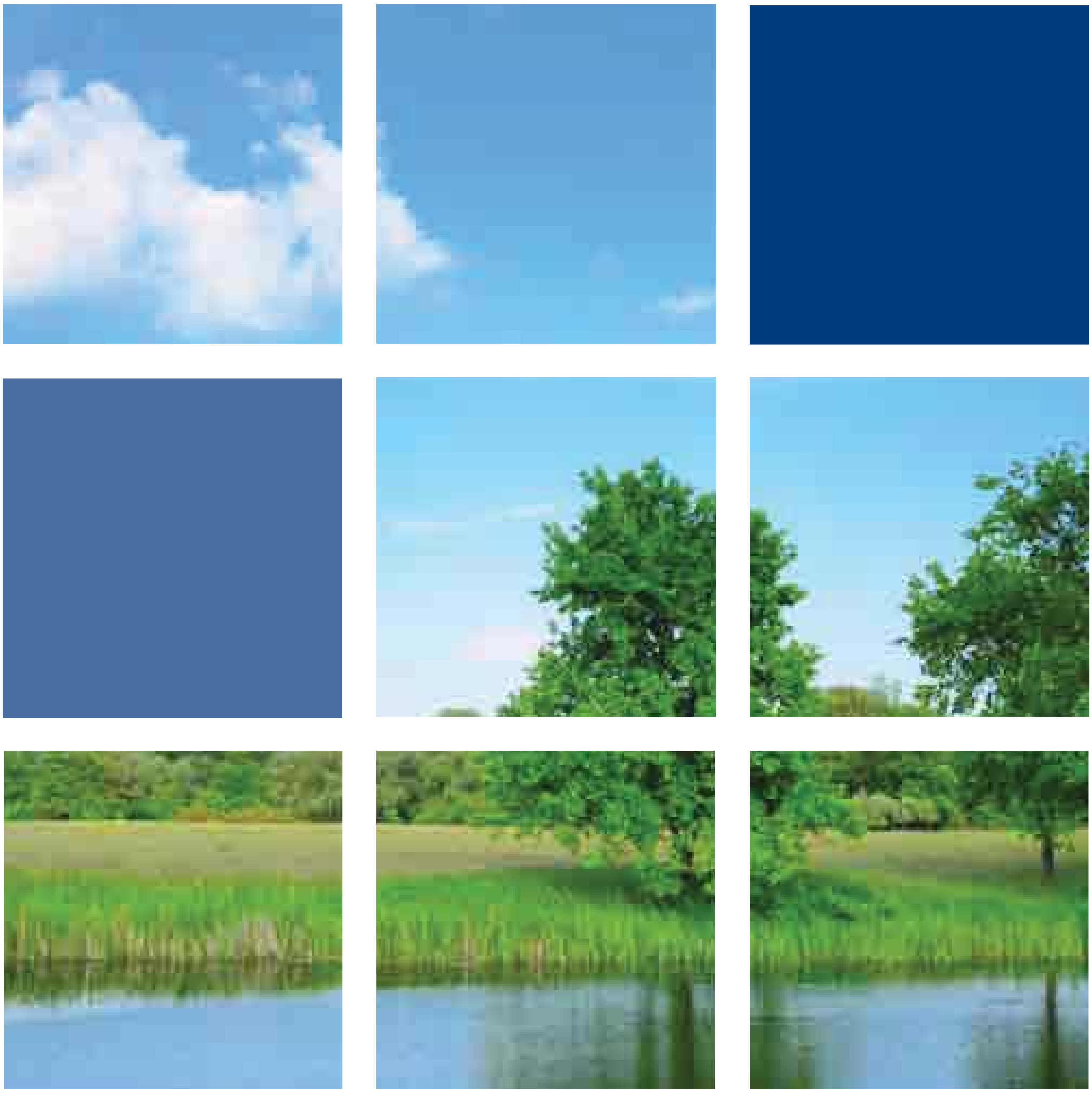
RPS

Langholm

Flood Risk Assessment

IBE0584/June '17



Langholm Flood Risk Assessment

DOCUMENT CONTROL SHEET

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<tr><td rowspan="2">This Document Comprises</td><td>DCS</td><td>TOC</td><td>Text</td><td>List of Figures</td><td>List of Tables</td><td>No. of Appendices</td></tr>
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1 INTRODUCTION

1.1 BACKGROUND

In 2007, Dumfries & Galloway Council commissioned a Strategic Flood Risk Assessment Study to gain a better understanding of the risk of flooding and potential socio-economic consequences across the entire council area. This study used the then recently published indicative River & Coastal Flood Map to identify properties at risk of flooding and estimate the long-term economic costs of flooding. Within the Dumfries & Galloway Council area, a total of 4,537 properties were estimated to be prone to flooding (AEP 0.5%) with long-term Net Present Costs of some £875million.

Langholm is located at the confluence of three rivers the River Esk, Wauchope Water and Ewes Water. The River Esk and the Ewes Water have their confluence to the north of Langholm, and the Wauchope Water joining the main watercourse, from a south westerly direction, in the centre of the town. Figure 1.1 provides a plan of the area indicating the respective routes of the three watercourses.

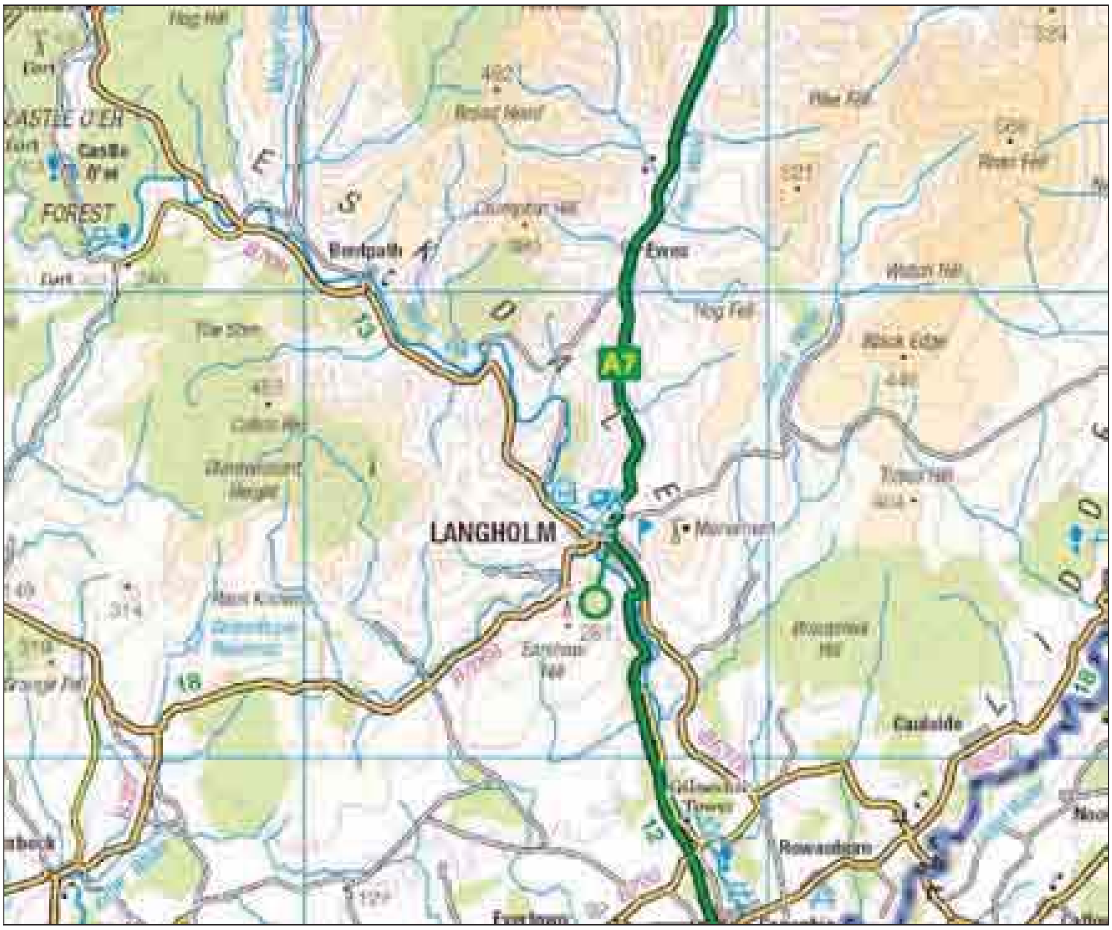

Figure 1.1: Location of Langholm

According to the Strategic Flood Risk Assessment, Langholm has more properties at risk of flooding than any other town in Dumfries & Galloway, with 524 properties within the 0.5% AEP flood inundation zone. The associated long-term Net Present Costs are approximately £100million and are also the highest within the council area. In response to this analysis Dumfries and Galloway Council appointed RPS to undertake a detailed Flood Risk Assessment of the urban area of Langholm.

1.2 AIMS AND SCOPE

To accurately define the flood risk to the area and determine whether a feasible flood alleviation scheme could be developed the study incorporated the following work and analysis:

- Review of historical flooding incidents in Langholm
- Hydrological analysis of the River Esk, Wauchope and Ewes Water
- Detailed 1D/2D hydraulic modelling of 1:10, 1:25, 1:50, 1:100, 1:200 and 1:1,000 year return periods and assessment of climate change impact
- Assessment on the impact of flooding on the urban drainage network
- Revised flood extent and depth mapping for a range of modelled return periods
- Outline Design and assessment of feasible flood protection options to alleviate the risk of flooding.
- Economic Analysis of the proposed flood alleviation scheme in accordance with the Green Book Methodology
- Assessment for the potential for flood forecasting in Langholm
- Assessment of the benefits or otherwise in removing the substantial gravel berms deposited within Langholm.

2 DATA COLLECTION

2.1 METHODOLOGY

Following the initial start up meeting, RPS requested from Dumfries and Galloway Council all information currently held that was useful in the execution of this project. This included:

- LiDAR data
- OS mapping of the area including 1:50,000, 1: 10,000 and 1: 2,500 mapping.
- Scottish Water GIS Data for the urban network within Langholm
- Briefing note on Gravel Extraction 2004.
- Scottish executive IFSAR/Intermap DGM Data
- Any drainage records/data held by Dumfries and Galloway Council

RPS had already retrieved the following documents from the Dumfries and Galloway Council website which were utilised at various stages of the project:

- Biennial Flooding Reports
- Strategic Flood Risk Appraisal (JBA 2007)
- Current Local Plan
- New Local Development Plan

Mastermap building polygon data was also requested to enable quick and accurate representation of flood plain properties within the 2D domain of the computational model for use in the Benefit Cost analysis.

2.2 TOPOGRAPHICAL SURVEY DATA

Following receipt of the above information RPS carried out a detailed walk over survey of the Langholm area and specifically the following reaches of watercourse:

- Wauchope Water - Springhill through to the Esk
- Ewes Water - Whitsheils Bridge to the Esk
- River Esk- Duchess Bridge through to Skipper's Bridge

The detailed walk over survey served a variety of purposes including:

- Identifying structures and the necessary spacing and locations of cross sections so a detailed survey specification could be produced.

- Gaining a thorough understanding of the areas likely to flood based on the strategic flood map. This was necessary at this stage in order that a specification for a property threshold survey could be developed. This was subsequently used for completion of the flood damage assessment later in the project.
- Assessment of roughness values within the watercourses for hydraulic modelling purposes.
- Identify any specific health and safety risks which needed to be included within the survey specification.

Subsequent to the walk over survey RPS produced a survey specification based on the “The EA National Standard Contract for & Specification for Surveying Services v3”, requesting the following data sets:

- required spacing of river cross sections,
- the level of detailed required at each cross section,
- flood plain spot heights for checking LiDAR accuracy,
- hydraulic structure geometry,
- any identified culvert inlet, outlet & manhole details following a review of the Scottish Water Data.
- photographs at each cross section location
- AutoCAD drawings of all bridges and hydraulic structures
- AutoCAD/geo-referenced drawings of cross section locations.
- the data was requested in ASCII (.txt) format to facilitate entry into Infoworks RS1D/2D.

The survey was undertaken by DG Design and Aspect Surveys and was completed in May 2012.

2.3 HYDROLOGICAL DATA

RPS requested from SEPA, data for the Canonbie gauging station and other nearby gauging analysis which was necessary to undertake the hydrological analysis and flood forecasting feasibility element of the project. Canonbie Station is located along the River Esk upstream of the confluence of the Liddel Water, some 12.5 km downstream of Langholm. Annual maximum flow data was provided by SEPA for the station between 1988 and 2011. RPS supplemented this record with data available from the HiFlows-UK database (Environment Agency 2011). The resulting series of annual maximum flows is shown in Figure 2.1 below.

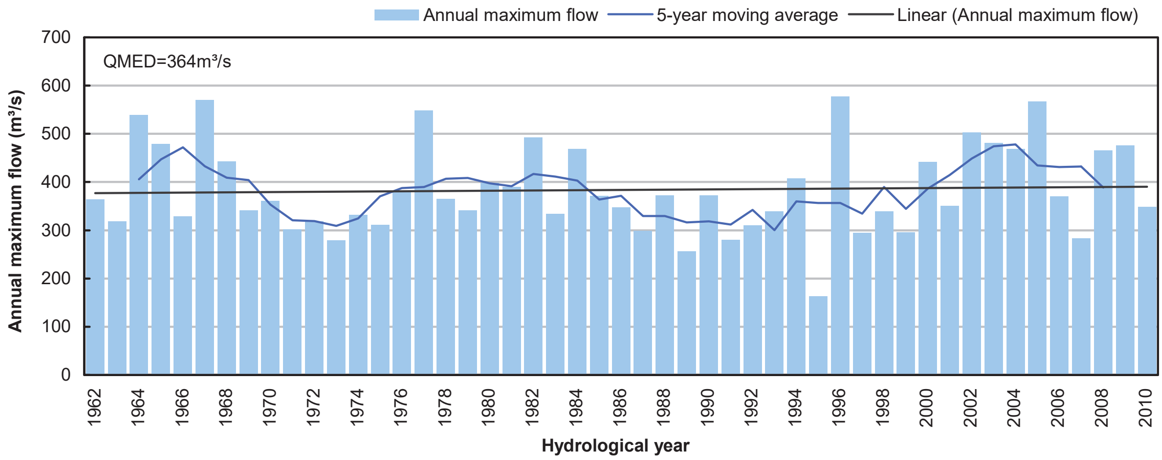

Figure 2.1: Annual maximum flow data at Canonbie gauging station

The graph shows that over time, there is no strong trend in peak flows. However, there are two periods with a sequence of high floods: 1964–1968 and 2000–2008.

The five highest floods on record are shown in Table 2.1 below.

Table 2.1: Highest Floods on Record (River Esk at Canonbie)

Date	Flow (m^3/s)	Multiple of QMED
17/02/1997	577	1.59
09/10/1967	571	1.57
12/10/2005	567	1.56
31/10/1997	549	1.51
06/10/1964	539	1.48

2.4 REVIEW OF HISTORIC FLOODING EVENTS

The flood prevention team at Dumfries & Galloway Council maintains a database of flood incidents. In addition to current flood events directly recorded, the database has been populated with:

- incidents reported in the “Biennial Reports” prepared by the Council between 1997 and 2009; and
- records held by SEPA hydrology teams.

As part of this study, RPS has reviewed the records related to flooding incidents near Langholm. These records are shown on a map in Figure 2.2.

RPS undertook a literature and media search to identify other flood incidents not currently included in the database. As part of the research, RPS interviewed Mr R. Harling, resident of 10 George Street. Mr Harling provided some photographs taken during the flood event of 31 October 1977 and these are shown in Appendix A. Key flood incidents identified are shown in Table 2.2 and are also included in Figure 2.2.

Table 2.2: Additional Flood Incidents

Date	Scale or magnitude	Sources
November 1898	Possibly the highest known flood on the River Esk. Peak river levels were reported as a “few feet” below the arches of the Telford Road bridge	Eskdale & Liddelsdale Advertiser (2010)
31 October 1977	Highest flow since at least 1960 and possibly much longer. Walls adjacent to George Street and Elizabeth Street were overtopped	SEPA river flow data at Canonbie Photos by resident R. Harling (see Appendix A)
8 January 2005	High flow event, water levels reported to reach up to 100 mm below top of wall along George Street and Elizabeth Street	SEPA river flow data at Canonbie Anecdotal evidence by resident R. Harling
19 November 2009	Highest flows during the last 2 years. No flooding occurred within Langholm but river levels reached near the top of the walls along George Street and Elizabeth Street. Similar to January 2005 event	SEPA river flow data at Canonbie Anecdotal evidence by resident R. Harling

Of the highest flows at Canonbie gauging station (Table 2.1), there are a number of records for which no information on flooding or near-flooding can be found at Langholm. Most notably are the highest and second highest flows during February 1997 and October 1967. One of the reasons could be that the Canonbie gauging station is located 12.5km downstream of Langholm with one additional (major) tributary confluence with the River Esk downstream of Langholm. Therefore river flows at Langholm could have been lower than some other events for which a flood incident was reported. However, it is likely that when river flows exceeded 500m^3/s at Canonbie, water levels at Langholm are within 500mm from the top the walls along George Street and Elizabeth Street

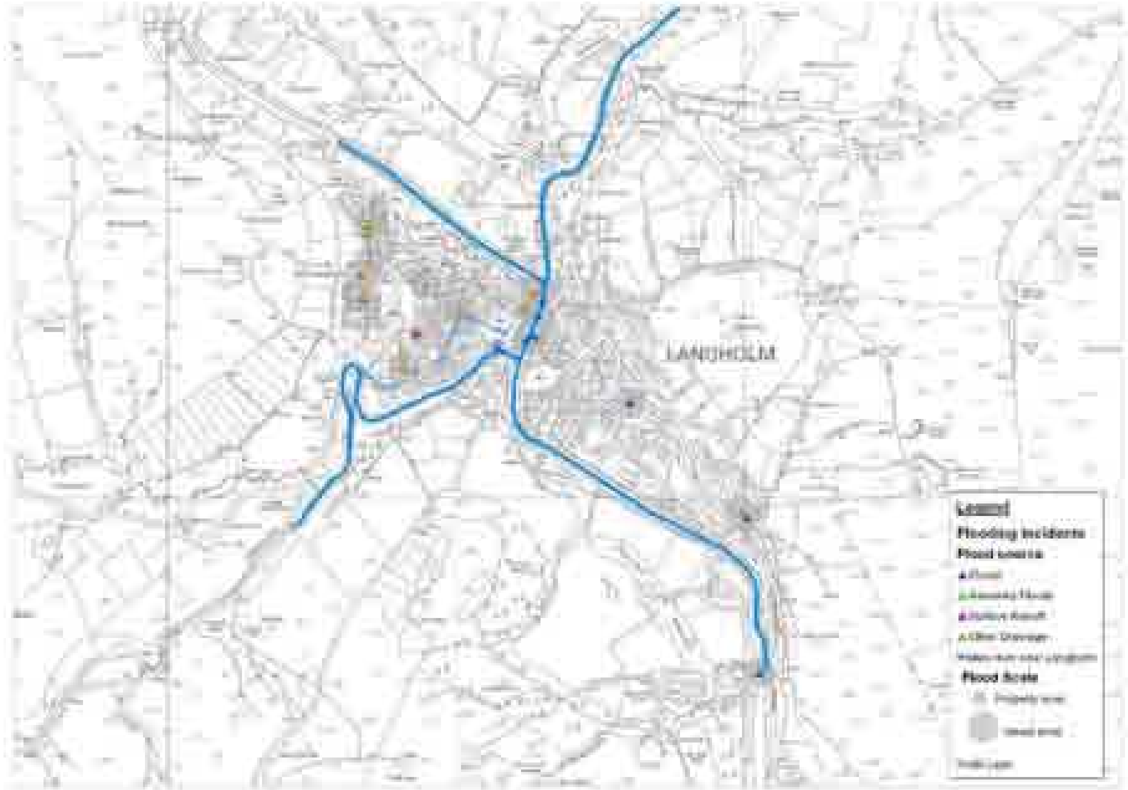

Figure 2.2: Historic Flooding Incidents

3 ASSESSMENT OF RIVER FLOWS

3.1 METHODOLOGY

The assessment of peak river flows and hydrographs follows the methodologies as set out in the Flood Estimation Handbook (FEH) (Centre for Ecology and Hydrology 2008). The following methodologies have been used in this study:

1. Statistical method (single site and pooling group approaches) (Robson & Reed 2008)
2. FEH Rainfall-Runoff method (Reed et al. 2008).

Note that the Revitalised FEH rainfall-runoff method has not been used, as this method has not been validated for Scottish catchments and is therefore currently not accepted by SEPA.

The FEH methods used in the assessment have been undertaken using the FEH CD-ROM 3 (Centre for Ecology and Hydrology 2009) and WINFAP-FEH 3 (Wallingford HydroSolutions Limited 2009).

3.2 CATCHMENTS

River flows were estimated for the three rivers and associated catchments shown in Table 3.1. The catchment boundaries are shown in Figure 3.1.

Table 3.1: Flood Estimation Catchments

River	Location	Drainage area (km^2)	Average elevation (mAOD)	Average annual rainfall (mm)
Esk	Upstream of Ewes Water confluence	291	298	1471
Ewes Water	At confluence with River Esk	80	296	1391
Wauchope Water	At confluence with River Esk	41	239	1279

Figure 3.1: Catchment Boundaries

3.3 FEH STATISTICAL ANALYSES

3.3.1 QMED estimation

The median annual flood (QMED) for each catchment was estimated initially using FEH catchment descriptors. This estimate was then further revised using a suitable donor station. The potential donor stations considered for all three catchments are shown in Table 3.2.

Table 3.2: Potential Donor Stations for QMED Estimation

Location	Catchment Area (km^2)	Comments
River Esk at Canonbie	495	Nearest downstream station
River Esk at Netherby	842	Station downstream of Canonbie
Ettrick Water at Brockhoperig	38	Upland station north of River Esk catchment boundary

In this case, all potential donor stations in Table 3.2 result in very similar adjustments to the QMED based on catchment descriptors. RPS have therefore adopted the gauging station at Canonbie for the following reasons:

- The record length at Canonbie is 49 years and up to date annual maximum flow data was supplied by SEPA for this station. The QMED estimation at this station is therefore highly reliable.
- Canonbie is the nearest downstream station along the River Esk. Using this station ensures that the estimated QMEDs at Langholm are consistent with observations further downstream.

The QMED estimates for all catchments are shown in Table 3.3 below.

Table 3.3: QMED Estimates

River	Location	QMED from catchment descriptors (m^3/s)	QMED adjusted (m^3/s)
River Esk	Upstream of Ewes Water confluence	168	195
Ewes Water	At confluence with River Esk	44	51
Wauchope Water	At confluence with River Esk	32	37

3.3.2 Pooling group development

Pooling groups were constructed for the three catchments in Table 3.1. Each pooling group was reviewed to remove all stations not suitable for QMED estimation or pooling. Subsequently additional stations were added to ensure the total record length was at least 500 years.

Each pooling group was then assessed for homogeneity which indicates how hydrologically similar the pooling group is to the catchment. In line with the recommendations within the FEH, the number of stations in the pooling group has not been reduced when the group was heterogeneous as it is statistically more critical to have a total record length of 500 years or more. Instead, the degree of homogeneity will inform which FEH method (statistical or rainfall-runoff) is adopted.

The degree of homogeneity for each catchment is shown in Table 3.4 below. Full details of the pooling groups are included in Appendix B.

Table 3.4: Pooling Group Characteristics

River	Location	Number of stations	Total record length (years)	Homogeneity
River Esk	Upstream of Ewes Water confluence	14	516	Acceptable homogeneous
Ewes Water	At confluence with River Esk	14	523	Strongly homogeneous
Wauchope Water	At confluence with River Esk	15	525	Heterogeneous

3.3.3 Flood frequency curve estimation

Flood growth curves and frequency curves were constructed for each of the three pooling groups. Both the Generalised Logistic (GL) and Generalised Extreme Value (GEV) distribution functions provided a good fit of the River Esk pooling group's annual maximum flow data. However, the generalised logistic function results in slightly higher flow rates and has therefore been used in the assessment. For the other two catchments, only the Generalised Logistic function resulted in an acceptable fit and has therefore been adopted. Table 3.5 below shows the results for each catchment.

Table 3.5: Pooling Group Results for Selected Probabilities

Annual Exceedence Probability (AEP)	Peak Flow (m3/s)		
	River Esk	Ewes Water	Wauchope Water
50% (QMED)	195	51	37
1%	406	102	81
0.5%	455	112	91
0.2%	528	127	105
0.1%	591	138	118

3.3.4 FEH Rainfall-Runoff method

An FEH Rainfall-Runoff model was set up for each of the catchments as an alternative method of calculating peak flows. Additionally, the rainfall-runoff model can also be used to create a flood hydrograph matching the peak flows estimated using the statistical method.

The model parameters were taken from the catchment descriptors for each catchment. Subsequently, the storm duration was varied to identify the critical storm duration for the catchment.

The results of the analyses are shown in Table 3.6.

Table 3.6: Rainfall-Runoff Results for Selected Probabilities

<table>
<tr><th rowspan="2">Annual Exceedance Probability (AEP)</th><th colspan="2">River Esk</th><th colspan="2">Ewes Water</th><th colspan="2">Wauchope Water</th></tr>
<tr><th>Storm duration (hrs)</th><th>Peak flow (m^3/s)</th><th>Storm duration (hrs)</th><th>Peak flow (m^3/s)</th><th>Storm duration (hrs)</th><th>Peak flow (m^3/s)</th></tr>
<tr><td>50% (QMED)</td><td>25</td><td>124</td><td>9.5</td><td>40</td><td>9.5</td><td>22</td></tr>
<tr><td>1%</td><td rowspan="3">21</td><td>354</td><td>8.5</td><td>128</td><td rowspan="4">7.5</td><td>71</td></tr>
<tr><td>0.5%</td><td>412</td><td rowspan="3">7.5</td><td>151</td><td>84</td></tr>
<tr><td>0.2%</td><td>497</td><td>189</td><td>105</td></tr>
<tr><td>0.1%</td><td>19</td><td>578</td><td>224</td><td>124</td></tr>
</table>

3.3.5 Adopted flood frequency curves and hydrographs

There are discrepancies between the results from the pooling group analysis (Table 3.5) and the FEH rainfall-runoff method (Table 3.6). For each catchment, therefore the most applicable method based on FEH guidance has been utilised. Relevant criteria are whether the pooling group is homogeneous and, to some extent, which method results in the highest flow estimates. Table 3.7 shows the method adopted for each catchment.

For a given catchment, the difference between the two methods is an indicator of the uncertainty associated with the flow estimates. Although this only applies to some extent— both methods share some assumptions as well as input data— it provides a meaningful indicator of the reliability of the estimates. Therefore the percentage difference between the two methods has been calculated for one of the key annual exceedance probabilities, 0.5% (see Table 3.7).

Table 3.7: Method Adopted for Each Catchment

River	Adopted Method	Justification	Percentage difference for 0.5% AEP
River Esk	Pooling group	Pooling group is acceptably homogeneous and also results in higher flows than rainfall-runoff method.	-9%
Ewes Water	Rainfall-Runoff	Pooling group is strongly heterogeneous and results in lower flows than rainfall-runoff method.	-26%
Wauchope Water	Rainfall-Runoff	Pooling group is heterogeneous. Rainfall-runoff method results in similar, although slightly lower flows than rainfall-runoff method up to the 0.5% AEP event.	8%

The final adopted flow rates for each catchment are shown in Table 3.8 and Figure 3.2.

Table 3.8: Adopted Peak Flows

Annual Exceedance Probability (AEP)	Peak Flow (m^3/s)		
	River Esk	Ewes Water	Wauchope Water
50% (QMED)	195	40	22
20%	243	54	30
10%	277	72	40
4%	324	92	51
2%	363	110	61
1%	406	128	71
0.5%	455	151	84
0.2%	528	189	105
0.1%	591	224	124

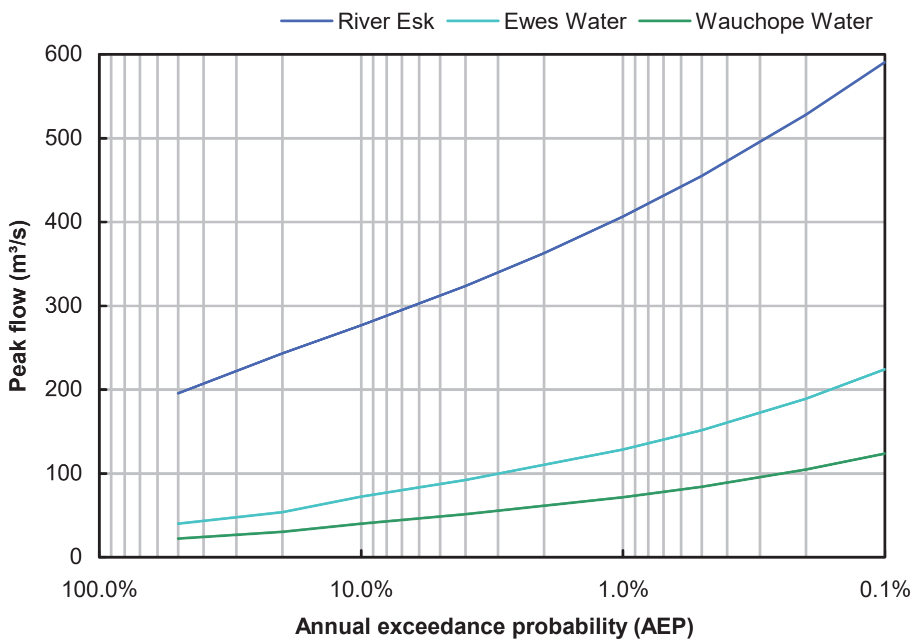

Figure 3.2: Flood frequency curves River Esk (upstream of Ewes Water confluence), Ewes Water and Wauchope Water

3.4 CLIMATE CHANGE PROJECTIONS

Climate change projections indicate a likely increase of precipitation during the winter season and high rainfall events (Defra 2010). This could potentially result in an increase in river flood flows.

In this assessment, RPS has taken the impact as a 20% increase of present day flow rates by the 2080s in line with Dumfries & Galloway Council guidance (2007) and that of SEPA.

Note that the “present day” flow estimates presented above theoretically represent the period between 1960 and 2010 approximately as this assessment is based on data collected during this period.

4 ASSESSMENT OF FLOOD LEVELS

4.1 MODEL CONCEPTUALISATION

For this project RPS used Infoworks ICM to undertake the numerical modelling of the three watercourses in the vicinity of Langholm. Infoworks ICM is an integrated hydrological & hydraulic modelling package developed by Innovyze. It incorporates the well established Infoworks CS hydraulic simulation engine, 2D capabilities and the functionality of a GIS database management system. InfoWorks ICM includes full solution modelling of open channels, below ground drainage networks, floodplains, embankments & hydraulic structures. Additionally, the 2-dimensional areas within Infoworks ICM are modelled through a triangular flexible mesh which allows for high levels of detail in specific areas (for example at river banks and around buildings) and a broader approach in other areas (for example open floodplains). This can give better results compared with a rectangular grid approach utilised in some other packages.

RPS constructed a 1D in bank and 2D out of bank InfoWorks ICM model for the reaches of the three rivers as follows:

- Wauchope Water – Springhill through to the Esk
- Ewes Water - Whitsheils Bridge to the Esk
- River Esk- Duchess Bridge through to Skipper's Bridge

During a site visit undertaken by RPS it was established that the channel immediately upstream of the Skipper's Bridge is a relatively steep reach of the Esk. Subsequently even if the bridge acted as a control point during an extreme event it is extremely unlikely to have a backwater effect on the flood levels in Langholm. RPS therefore determined that just downstream of Skipper's Bridge would be a suitable point for the downstream boundary of the numerical river model.

The model developed provided river flow and water level estimates sufficiently accurate for:

- Assessing the impact of proposed flood risk management options
- updating SEPA's Indicative River & Coastal Flood Map;
- providing real-time river level forecasts; and
- applications for CAR licences, if required.

4.2 MODEL CONSTRUCTION

The in-bank portion of the river models was defined from cross-sectional data, with LIDAR data being used for the floodplain. Bridge, weir, control & defence structures on the river were defined using survey data of their geometry. Calibration coefficients for structures were left as default in line with recommended practice where no specific afflux information is available.

Upstream boundary conditions & input hydrographs for the model were provided from the Hydrological Assessment. Downstream boundary conditions for the River Esk were defined by a normal depth boundary downstream of the Skipper's Bridge thereby ensuring that any backwater effect from this structure was accounted for in the model. The downstream boundary conditions for the Ewes Water and the Wauchope were defined by the River Esk at their confluence.

1D modelling used either extended cross sections and/or 'spills' and storage areas to ensure the full floodplain extent was incorporated in the model and all areas of flood storage were included. For 1D/2D modelling, RPS constructed a 1D in channel model combined with a 2D flood plain model which provides an accurate assessment of both the in channel flow regime and floodplain flow paths. For an accurate assessment of 2D flow paths the bare earth DTM data was used within the modelling package to generate the computational mesh, the mesh was then augmented to include buildings and incidental defences which will affect flow paths. Building footprints were defined by a GIS shape file which was then used to reduce the conveyance through the building in the 2D mesh. All flood receptors were contained within the 2D modelling domain with extended 1D sections only used for the Ewes Water upstream of Whitshiels Bridge and the main River Esk channel downstream of Langholm.

The extent of the integrated hydraulic model of the River Esk, the Ewes Water and the Wauchope Water near Langholm, developed by RPS is shown in Figure 4.1. This model included a 2-dimensional hydrodynamic model of the floodplain with a 1-dimensional or integrated model of the river channel, incorporating all bridges and other hydraulic structures. The maximum mesh size used in the model was $100m^2$ (generally this gives an element size of $75m^2$) which was considered sufficient for modelling the larger open spaces. Within the urban environment the mesh was refined using building polygons which force the mesh to define the building outlines and therefore streets with the result that mesh size in the more urbanised areas ranged between $0.5m^2$ and $40m^2$ depending on the width of streets and density of buildings. A global roughness of 0.06 was applied across the 2D model domain which although high for streets and roads, gives a better representation of other features in the urban environment, including vegetation. Similarly within the 1D model a global roughness of 0.06 was employed on account of the relatively rocky bed and generally lightly vegetated banks.

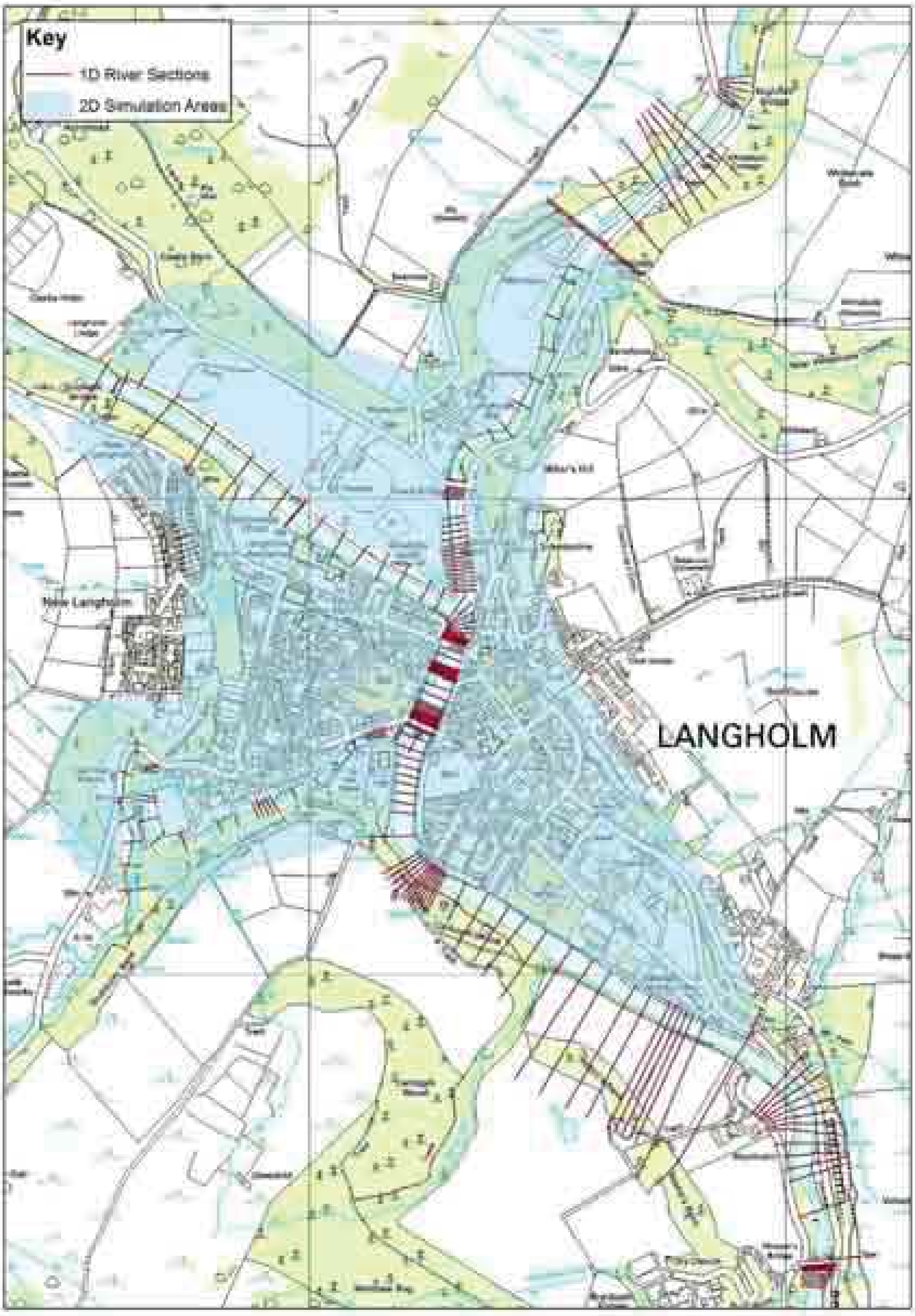

Figure 4.1: Extent of Hydraulic Model

4.3 MODEL CALIBRATION AND VERIFICATION

The computational river models were calibrated by comparing predicted flood levels with field observations. Historical data including photographs and recorded flood data was used, where available, during the calibration and verification of the computational model. Any observed flood levels were used in conjunction with gauging data from the Canonbie Gauging station to estimate the associated flow and return period at Langholm, the estimated flows were then input to the model and various parameters adjusted to replicate the observed levels. Anecdotal evidence collected by RPS from local residents and media was also used to help calibrate and verify the computational models. The model was also calibrated at low flows to ensure the model provides representative water levels for a wide range of events.

A key aspect is verification of 2D flow paths within urban areas. After initial model runs were completed a walk over survey was undertaken to check the accuracy of the predicted flow paths including ascertaining the impact of incidental defences including walls, bridges and underpasses etc. Subsequently further modifications are made to the DTM, the model re-run and the process repeated iteratively until the flood extent is assured. Sensitivity to model roughness was also assessed, indeed this was one of the principal variables used in the validation process to achieve the best fit with the anecdotal records of flooding.

The calibrated river models were run to determine water levels for a range of storm events for both the present day and future scenarios.

4.4 REVIEW OF DRAINAGE NETWORK

From experience RPS recognise that during major fluvial flooding events, urban drainage networks frequently cannot operate as designed because outfalls to the river can no longer drain under gravity. This means that rainwater falling behind flood defences can cause storm drainage pipes to surcharge once capacity within the network is exceeded. This can lead to out of sewer flooding to properties which may have otherwise been protected from direct fluvial flooding. In addition should sewage or storm water pumping stations be directly affected by fluvial flooding this can cause an entire network to surcharge in a relatively short period of time. Pollution of watercourses can also be a major problem environmentally once sewage networks surcharge.

There is no drainage network model available for Langholm and therefore it is not possible to quantify the impact of elevated river levels by numerical modelling. Subsequently, RPS have undertaken a review of the Scottish Water data for the wastewater and drainage network within the vicinity of the town and cross referenced those areas of the network which are deemed to be protected by defences. The primary objective of this exercise was to establish the potential for elevated river levels during an extreme event to have an adverse impact on the ability of the drainage network to function.

The review determined that there are no areas within Langholm where the drainage network is protected by defences. Additionally there was no key infrastructure, such as pumping stations, which are affected by flooding. In areas where the drainage network is affected by fluvial flooding it was confirmed that all manholes will be inundated by fluvial flooding either prior to, or at the same time at which the piped network surcharges. From this high level review it can be concluded that the risk of flooding in Langholm is not exasperated by the influence of elevated river levels on the drainage network.

4.5 INUNDATION MAPPING

Currently, flood extent information is available through SEPA's Indicative River & Coastal Flood Map. As this map is derived from NextMap DTM data only, in contrast to topographic survey or LiDAR data, a more accurate flood extent and flood depth map is required to assess the impacts of flooding at Langholm.

RPS have incorporated the newly acquired survey data and existing LiDAR into the Infoworks hydraulic model. Due to Infowork's GIS based approach, this enables us to display and extract flood extent information without any further post processing. This ensures that all analyses are consistent and that any spurious flood extent results can be directly addressed in the hydraulic models.

Flood maps have been generated for a range of annual exceedance probabilities (AEP):

1. 50% (1/2)
2. 10% (1/10)
3. 4% (1/25)
4. 2% (1/50)
5. 1% (1/100)
6. 0.5% (1/200)
7. 0.5% (1/200), under climate change conditions
8. 0.1% (1/1000)

Flood maps show the following information:

- Potential extent of flood waters (vector polygon data); and
- Depth of water (contoured grid data, and/or vector polyline data).

The flood maps show a high level of detail due to the underlying topographic survey data and 2-dimensional modelling approach. The flood maps are presented in Appendix C. Data has also been provided in CAD/GIS format to the Dumfries and Galloway Council (AutoCAD 2007 and MapInfo

Professional V7) for future use and SEPA (ArcGIS shapefiles) for incorporation into the Indicative River & Coastal Flood Map.

For the Langholm Flood Risk Assessment, these flood depth and flood extent maps form the basis for the outline design of a flood protection scheme and the economic assessment of flood risk and the benefits of such a scheme.

5 OPTION DEVELOPMENT AND ANALYSIS

5.1 OPTIONS

In addition to the flood mapping the main output of the Langholm Flood Study is the outline design and benefit/cost analysis for three flood risk management options. RPS initially considered a wide range of potential flood risk management options including flood storage, flood plain restoration, flood warning and flood protection.

The location of Langholm at the confluence of three rivers makes the practical implementation of effective flood storage difficult. Even when only the River Esk was considered the volume of storage required to significantly reduce flood levels in Langholm was estimated to significantly exceed the potential volume available. For example the difference in volume between the 1:200yr and 1:100yr flood events on the Esk is circa 3 million m^3 a volume that isn't practical to provide within the confined valley of the Esk.

Flood plain reinstatement was also rejected due to the existing highly developed nature of Langholm and the tight constraining valley in which it is situated.

Limited modification of the conveyance capacity of the channel by removing the build up of gravel between the Telford Bridge and the suspension footbridge in Langholm was also considered, see Chapter 7.

The possibility of implementing a flood warning system, see Chapter 6 was also examined and found to be viable with opportunity to create a system with sufficient warning time to allow reactive measures to be implemented, and when combined with some minor improvements to existing structures was considered to be a potential option.

However the RPS review of flood risk management options concluded that the only feasible means of preventing flooding in Langholm during high return period events was the provision of hard defences. The defence structures required for three different scenarios of flood protection- 1:25, 1:50 and 1:200 year return periods, were therefore identified and taken forward for cost/benefit analysis.

Hard defences include the construction of new flood walls or embankments and/or the modification of existing flood walls to the required structural standard and level of protection. Where possible hard defences should be set back from the channel banks to allow space for flood waters and reduce the impact of the flood defence scheme on water levels upstream and downstream of the proposed defence location. Setting defences back from the channel also improves access to rivers and helps minimise the visual impact of a flood defence scheme. The choice of flood defence structure (i.e. flood wall, flood embankment, etc.) along with the alignment of defences is based on space constraints, visual impact and the results of the hydraulic modelling of options.

The do-nothing scenario must also be considered in all option appraisals as the base case against which other options are compared. The base case should generally be the ‘status quo’ option, which should represent the genuine minimum input necessary to maintain services at, or as close as possible to, their current level. In this scenario no action is taken to sustain, maintain or improve existing flood defences. If no works were undertaken, the threat of overtopping of the banks of the River Esk would remain resulting in the possibility of frequent flooding damage to property in addition to causing considerable anxiety to local residents.

The options taken forward for analysis were therefore:

- Option1- Do Nothing
- Option 2- Hard defences to protect against 0.5% AEP flood
- Option3- Hard defences to protect against 2% AEP flood
- Option 4- Hard defences to protect against 4% AEP flood

The locations of the flood defence structures for Options 2 to 4 are presented in Appendix D, together with cross-sections through the defences at a number of locations. The maps also highlight the areas protected by the defences.

5.2 ECONOMIC ANALYSIS

RPS undertook a preliminary benefit-cost analysis to demonstrate the economic case for the identified options. This involved an assessment of the benefits (i.e. reducing flood impact) and the costs of the options over a 100 year design life span. This approach ensures that Dumfries and Galloway Council has a robust economic argument which shows that the preferred option provides best value for money. This approach ensures a clearly identified audit trail which transparently shows how the preferred option would be cost-effective and delivers real value for the community of Langholm.

5.2.1 Assessment of damages

The assessment of the benefits of flood protection measures involves quantifying avoided flood damages over the design life span of the scheme. These avoided flood damages were estimated from the flood inundation maps produced during this project, combined with various spatial data sets of households, business and other economic “receptors”.

Properties/assets identified as at risk were classified according to The Benefits of Flood and Coastal Risk Management: A Handbook of Assessment Techniques (Defra, 2013), also known as “The Multi-Coloured Manual” with property damage figures updated to 2016 values. The Flood Hazard Research Centre recommends a proportional approach in benefit appraisals. This requires quantifying and enumerating only those receptors likely to dominate the benefit assessment. While the road network through Langholm, the monuments and open park areas would be considered assets they are not likely to dominate the benefit assessment. With this said a review of the appraisal process can be carried out in order to consider further assets if the resulting benefit cost ratio (BCR) is marginal.

Properties/assets were grouped in the following categories:

Residential Properties – information detailing the house type, finished floor level and nature of risk to the property will be recorded.

Non-residential Properties (NRP) (commercial/industrial) – A similar database to the residential properties will be prepared but will include the property floor area.

Other Assets – A monetary value will be assigned to emergency service costs as recommended from the Flood and Coastal Defence Project Appraisal Guidance.

Intangibles – The resulting benefits from providing a greater standard of protection in terms of stress and health problems avoided by victims of flooding.

The GIS database showing the classification of properties/assets and depths of flooding for various return periods is presented in Appendix E.

Flood damage was estimated using standard values for flood depths and resulting damages as set out in the Multi Coloured Manual. The values used for the damage assessment are representative of 2016 prices, and therefore did not require any adjustment. The prices were capped for each property type based on data on house prices obtained from Registers of Scotland, and capped for non-residential properties using data on rates obtained from Scottish Assessors Association. Damage values were calculated for as many of the assets identified as being at risk from flooding as possible in order to derive an overall estimate of the potential damage. Emergency costs were derived as a percentage of the residential property damages.

The intangible costs have been calculated based on FCDPAG 3 Supplementary Note: Reflecting socio-economic equality in appraisal and appraisal of human related intangible impacts of flooding. The results of these calculations are presented in Appendix F.

The results of the average annual damage assessment for each of the four options are presented in Appendix G for both residential and industrial/commercial assets. The intangible costs have also been included. Summaries of the costs are also presented. A figure is also included in Appendix G which shows individual properties together with the damage figures.

The estimated damages of the scheme over its lifespan were then evaluated in terms of their Net Present Value. All damages were discounted over the 100 year design lifespan using discount rates as recommended in The Green Book to determine the present value damages. Full details of this is presented in Appendix H.

A full list of assumptions used in the calculation of damages can be found in Appendix I.

5.2.2 Assessment of costs

The whole life costs of the options are made up from several components including the initial capital cost and maintenance costs. The initial capital costs were determined from current market rates and RPS' extensive experience of flood alleviation works. RPS works with a local contractor, on a consultancy basis, to ensure the rates used in the cost assessment are accurate and up to date. To establish maintenance costs RPS have estimated the frequency of maintenance required and then worked with Dumfries and Galloway Council to establish costs based on the predicted maintenance programme.

The detailed costs of each option are presented in Appendix J. These costs were used to calculate the Present Value costs over the lifetime of the scheme (assumed to be 100 years). Details of this are presented in Appendix K. An optimism bias of 60% is usually applied to costs at the pre-feasibility stage, however RPS have reduced this to 56.4% and the reasons for this are presented in Appendix L.

A full list of assumptions used in the calculation of defence costs can be found in Appendix I.

5.2.3 Benefit cost ratio

The costs and benefits as described above are presented in Table 5.1. These values have then been used to calculate the benefit cost ratio for each option. Full details of the summary are presented in Appendix M.

The table shows that the option with the highest benefit/cost ratio is Option 2, hard defences to protect against a 0.5% AEP flood.

Table 5.1: Summary of Economic Analysis

	COSTS & BENEFITS (£)			
Option	**1 Do Nothing**	**2 0.5% AEP**	**3 2% AEP**	**4 4% AEP**
COSTS:				
PV Capital Costs	0	5,090,341	3,180,125	1,865,274
PV Operation & maintenance costs	0	28,813	28,813	28,813
PV Costs	0	5,119,154	3,208,938	1,894,087
Optimism Bias Adjustment	0	2,887,203	1,809,841	1,068,265
TOTAL PV COSTS	0	8,006,356	5,018,778	2,962,351
BENEFITS:				
Total Capped PV Damages	14,031,255	3,166,244	8,766,500	11,757,707
Total PV Intangible Benefits	-	721,057	106,462	2,504
Total Capped PV Benefits	0	11,586,068	5,371,217	2,276,052
DECISION MAKING CRITERIA:				
BENEFIT/COST RATIO	-	1.45	1.07	0.77

6 FLOOD FORECASTING AND WARNING

A new flood warning scheme for the River Esk is to be launched by SEPA in March 2017. The scheme has the potential to benefit 751 properties in Langholm from advance notice of flooding, giving communities and business time to take action to reduce the damage and disruption that flooding can cause. This section has been retained as it was part of the August 2013

6.1 INTRODUCTION

As part of this flood study, a range of flood risk management options were considered, including flood protection measures and other flood risk reduction measures. A flood warning scheme was considered as this could reduce the impact of a flood to communities and business. The key benefits of a flood warning scheme are:

- Individuals and business are able to move valuable items away from a flood risk zone. Flood warning would increase the time available to move property including cars, furniture, equipment, items of emotional value etc.
- Emergency services would be able to have adequate resources on stand-by and mobilise these in a timely manner.
- Temporary flood protection measures (including flood gates, sand bags, pumping equipment, etc) could be prepared and implemented depending on the expected magnitude and timing of a flood. This could be relevant both to Dumfries & Galloway Council and emergency responders (resourcing of staff and equipment) as well as individuals (property level protection measures).
- Flood forecasting and warning would provide detailed information to inform road closures and evacuations to minimise risks to human health.

6.2 ASSESSMENT OF REQUIREMENTS

A flood forecasting and warning system for Langholm and the River Esk would need to meet the following requirements:

- Spatial coverage. Flood warnings are required for all properties and businesses at risk of flooding from the rivers for flood events up to 0.1% AEP conditions. This includes properties along the River Esk, the Ewes Water and the Wauchope Water near Langholm. Optionally, the system should provide warnings for properties in Eskdalemuir along the White Esk and in Longtown along the River Esk.
- Flood types. The forecasting system would only need to provide warnings for flooding from the River Esk and its tributaries. Other flood sources, including overland and groundwater flooding are not included. SEPA currently provides high level flood warnings for different regions in

Scotland which includes the risk due to overland runoff. Site-specific flood warning for overland and groundwater flooding is not considered technically feasible or sufficiently accurate at the present time.

- Forecast accuracy. Flood warnings should be issued based on sufficiently accurate forecasts of river levels and flood extents within the areas at risk of flooding. The accuracy of any flood forecasting system is difficult to assess due to the uncertainty in a large number of sub-systems and input datasets. However, minimum levels of accuracy in water level of ± 300 mm are considered sufficient for flood warning purposes. The development of forecasting systems must consider the likelihood of false alarms versus the likelihood of not predicting floods. Both should be minimised although in reality some trade-off between the two may be required depending on the factors contributing to the forecast uncertainty. The required level of accuracy is also affected by any water level flood warning thresholds and the distance between the thresholds at a particular location.
- Forecasting lead times. Flood warnings will need to be issued at least 3 hours before river levels reach critical levels. Where possible, forecasting lead times should be more than 3 hours and ideally 6 hours or even longer. Although forecasts can be produced for longer periods in advance, for example 24 hours, forecasts will become less and less accurate primarily due to the uncertainty in rainfall predictions.
- Operation of flood protection structures. If applicable, flood forecasts should be adequate for the operation of flood gates and other flood protection temporary works. For example, water level forecasts at the location of a flood gate must be timely and sufficiently accurate to enable a timely closure while also avoiding unnecessary closures.
- Embedded in existing structures. Where possible, the forecasting and warning system should be integrated in existing organisational and technical structures. This is to prevent unnecessary duplication of efforts, minimise costs and maximise the potential for improvements and lessons learnt from an integrated approach. For example, both the Met Office and SEPA run various forecasting and warning schemes across Scotland which may be suitable for providing flood warnings in Langholm.
- System improvements. The system should be relatively easy to adapt and improve depending on changing needs. Additionally, it should be possible to integrated newly acquired data and improved modelling techniques without a complete re-development of the system.
- Flood warnings dissemination. Flood warnings should be issued to Category 1 and 2 responders (including emergency services, Dumfries & Galloway Council and transport and utility companies). Additionally, residents and business should be able to receive flood warnings directly.
- Community acceptance. The flood warning system should be accepted and supported by the local community, including residents, businesses and others community groups. A widely accepted and well communicated flood warning system could increase the preparedness for flooding and resilience during and after a flood.

6.3 REGULATORY AND INSTITUTIONAL FRAMEWORK

In Scotland, flood risk management is undertaken by a number of authorities and public agencies. While legislation and key guidance is provided by the Scottish Government, other duties are devolved to Local Authorities, SEPA and emergency services.

SEPA has provided flood warning and forecasting services since the agency was established in 1996. Over the last decade, however, it has expanded its flood warning services, including the development of a hydrometric network and real-time flood forecasting modelling.

SEPA's role as a flood warning authority was formalised with the Flood Risk Management (Scotland) Act in 2009. The agency has now a statutory duty in providing flood warning and forecasting services.

- Implementation of a river and coastal flood forecasting software framework, "Flood Early Warning System (FEWS) Scotland" (see next section).
- Implementation of a flood warning dissemination programme, "Flood Warning Direct".
- Implementation of a joint SEPA and Met Office flood forecasting service covering all areas in Scotland, "Scottish Flood Forecasting Service".

Flood emergency response is a joint responsibility between SEPA and other Category 1 and 2 Responders (including Local Authorities, police and fire & rescue services). All Category 1 Responders have direct access to SEPA's and the Met Office's flood forecasts allowing for a timely and targeted incident management. Local residents and business also can sign-up to receive flood warnings through the Flood Warning Direct service.

6.4 FLOOD EARLY WARNING SYSTEM (FEWS) SCOTLAND

In 2006, SEPA implemented a real-time flood forecasting platform known as the "Flood Early Warning System (FEWS) Scotland". Initially, the platform was developed to integrate real-time hydrometric data, hydrological models and hydraulic models for the Rivers Clyde, Kelvin and Irvine. Since then the system has expanded and currently includes hydrometric data from all of SEPA's telemetered hydrometric stations and forecasting models for rivers in Glasgow, Edinburgh, Aberdeenshire and Moray. Additionally, tidal forecasts are available within the system for key locations along the Scottish coast.

FEWS Scotland is an implementation of the Delft-FEWS software by Deltares. Delft-FEWS is based on "open" software principles and standards and allows, in principle, any dataset, model or reporting method to be integrated. FEWS Scotland is linked with SEPA's hydrometric telemetry system (raingauge, river level and river flow data) and also receives Met Office radar rainfall data (actuals and forecasts). These data are automatically fed into a range of hydrological and hydraulic model which are run automatically or when initiated by the user. Models used within FEWS Scotland include primarily Probability Distributed Model (PDM) rainfall-runoff models, ISIS river hydraulic models and Delft-3D Flow estuary models. Forecasts can be readily interpreted by SEPA's flood warning duty officers to prepare and issue flood warnings. Additionally, Category 1 and 2 responders have direct access to the forecasts through web-based reports.

6.5 HYDROMETRIC DATA AVAILABILITY

To assess the feasibility of a flood warning scheme for the Langholm area, we have assessed the extent of the existing hydrometric network. Relevant data include rainfall (raingauge and radar), river levels and river flows.

6.5.1 Raingauge data

For flood warning we assume that rainfall data would be used from SEPA's network of raingauges only. Although the Met Office also operates a large number of raingauges, these are not considered as these are not directly integrated with SEPA's telemetry system. All nearby raingauges are shown in Table 6.1 below. The locations of the raingauges are also shown Figure 6.1.

Table 6.1: Overview of nearby SEPA and Met Office raingauges

Location	Operator	Easting (m)	Northing (m)	Approximate elevation (mAOD)	Telemetry
Braidlie	SEPA	347670	596673	190	yes
Solway Bank	SEPA	330717	577413	130	yes
Eskdalemuir Observatory	Met Office	323502	602731	240	not in SEPA systems

6.5.2 Rainfall radar data

Weather radar data is available from a number of radar stations across Scotland. The nearest radars are shown in Table 6.2 below. Note that although these stations are operated by the Met Office, the data from these stations is currently available within FEWS Scotland.

Table 6.2 suggests that the radars are too far from the catchment to provide detailed rainfall data. At a distance of more than 75 to 100 km the radar resolution is reduced to 5 km. Typically for flood forecasting radar data with a resolution of 2 km or 1 km preferably is required.

Table 6.2: Nearest MetOffice rainfall radar locations

Location	Easting	Northing	Distance to Langholm	Comments
Holehead	261790	682835	120 km	Radar resolution at this distance is 5 km which may not be sufficiently accurate for flood forecasting
Munduff Hill	318820	703225	120 km	
High Moorsley	433873	545572	105 km	

6.5.3 River flow and level data

There are currently two river gauging stations within the River Esk catchment. Key details for these stations are shown in Table 6.3. The locations of the gauging stations are also shown Figure 6.1.

Table 6.3: River gauging stations information

Station location	NGR	Relation to required flood warning locations	Flow rating information
River Esk at Canonbie	339695, 575108	12 km downstream of Langholm 9 km upstream of Longtown	Natural channel hydraulic control. The river bed is thought to be eroding, however, and the station's rating curves has been reviewed twice since the start of the records in 1962 (Environment Agency, 2011). Spot gaugings have been taken up to the median annual flood (QMED) approximately which indicates that high flow estimates may be inaccurate.
Liddel Water at Rowanburnfoot	341450, 575950		Velocity-area station on straight gravel bedded reach. High flows may bypass the station and are not gauged. Spot gaugings have been taken up to 0.7 × QMED which indicates that high flow estimates may be inaccurate.

Table 6.3 indicates that the existing river gauging stations could be used for flood warning at Longtown. The stations have little benefit for flood warning at Langholm as they are located downstream of the town.

6.5.4 Catchment and river models

As far as we are aware, no hydrological or hydraulic models of the River Esk catchment have been previously been prepared for or made available to Dumfries & Galloway Council or SEPA.

As part of the current study, a detailed integrated 1D-2D hydrodynamic models has been developed for the River Esk, the Ewes Water and the Wauchope Water at Langholm. This model would be available for flood forecasting. The model would need to be adapted to enable integration into FEWS Scotland. Alternatively, if unique stage-discharge relationships exist at the locations required for flood warning, these relationships may be used to provide water level forecasts.

No hydraulic models are presently available for the river reaches at Eskdalemuir and Longtown.

6.6 PRELIMINARY DESIGN

A flood forecasting and warning scheme for Langholm and optionally Eskdalemuir and Longtown should be integrated into FEWS Scotland and operated by SEPA. The main reasons area:

- SEPA is the statutory flood warning authority and operates in partnership with the Met Office an end-to-end system of hydrometric data collection, real-time flood forecasting and flood warning.
- Hydrometric data and catchment models for the River Esk can be directly integrated in FEWS Scotland.

In addition to these key reasons, FEWS Scotland and SEPA’s wider flood warning capabilities meet all requirements as set out above.

To develop a flood forecasting system the existing hydrometric network may need to be expanded. This could include one or more additional raingauges, and in particular within the upper parts of the Esk catchment. Additional river flow gauges would be beneficial within the upstream catchments of the White Esk and Ewes Water. A river level gauge would be beneficial along the River Esk in Langholm.

Real time flood forecasting for Langholm (and Eskdalemuir and Longtown) can be achieved through a combination of hydrological rainfall-runoff models and river hydraulic models.

Rainfall-runoff models would be required to predict the river runoff as a result of current or future rainfall. Here the Probability Distributed Model is a well-proven modelling packages that can be used to model the Upper or White Esk, the Ewes Water and the Liddel Water (see Figure 6.1). Both raingauge data and radar rainfall data could be used for real-time input into the models. Currently there are no gauging stations in these catchments which could be used for calibration of the models. Initially, the models could be developed relying on a number of catchment characteristics including topography and land use. In time, when the hydrometric network is further developed, newly acquired data can be used to improve the model accuracy by calibration.

Runoff from other sub-catchments could be modelled in real-time by scaling of the hydrographs modelled through the rainfall-runoff models. Here the most suitable donor catchments and scaling factors could be estimated by comparison of the modelled flows with recorded flows at the Canonbie gauging station.

Real-time river hydraulic modelling would be required to forecast the routing of the hydrographs through the catchment. Here a simple hydraulic routing model can be developed for the River Esk between Eskdalemuir and Langholm. For the locations where flood warnings are required, river levels will need to be estimated. This could be achieved either through a hydraulic model run in real-time or alternatively through an offline assessment of a stage-discharge relationship at these locations. These relationships could then be used in real-time to estimate levels from river flow forecasts modelled through the hydraulic routing models. At Langholm, the hydraulic model developed as part of this study could be used. Some model modifications will be required if the hydraulic model itself needs to be run in real-time.

Note that all the above forecasting activities, including data collection, hydrological and hydraulic modelling are all automated and integrated within the FEWS Scotland software.

At each flood warning location, Eskdalemuir, Langholm and Longtown, three flood warning thresholds will need to be established corresponding with SEPA's "Flood Alert", "Flood Warning" and "Severe Flood Warning" status levels. The thresholds would be based on different water levels and flood extents at each location. For example a suitable "Flood warning" threshold may be defined at the threshold at which properties start being inundated.

6.6.1 Likely achievable lead-times

An indication of the likely forecasting lead times that may be achieved, are shown in Table 6.4. Table 6.4 shows that a minimum lead time of 3 hours may be achieved for Langholm. For Eskdalemuir, this minimum lead time may not be possible without relying on rainfall forecasts. Rainfall forecasts would be required at this location due to the quick responding upper catchment. Operationally, rainfall forecasts are available through the rainfall radar network. As indicated above, the spatial resolution of the radar data is however not likely to be sufficiently small to provide accurate rainfall forecasts and therefore water level forecasts.

Table 6.4: Indicative lead times

Flood warning location	Time-to-peak in rainfall-runoff modelled catchment (hrs)	Additional flood wave travel time to location (hrs)	Estimated lead-time without rainfall forecasts (hrs)	Likely to achieve target of 3 hrs?
Eskdalemuir	2.2	0.0	2	Would require rainfall forecasts
Langholm	2.2	4–8	6–10	Yes, target of 6 hrs feasible.

6.6.2 Implications of infrequent flood events

The effectiveness of a flood warning scheme depends highly on the perception and awareness of residents and businesses. Flood warnings may not be received by all individuals whose properties are at risk of flooding. If flood warnings are received, some may not take any action or may take ineffective actions.

In Langholm, flooding of large numbers of properties is not expected for flood magnitudes below the 4% AEP flood conditions. However the rarity of significant flooding, in itself, may not affect how people respond to a flood warning. More important is the accuracy of the forecasts both in terms of correctly forecasted flood incidents (hit) and in terms of correctly forecasted absence of significant flooding (correct negative). It is essential to minimise the number of false alarms as this may lead to a reduced response to future flood warnings.

Infrequent flooding may, however, require additional awareness raising to ensure that individuals and businesses are aware of the flood warning scheme and know how to act in the case of a warning being issued. Additionally, different means of disseminating flood warnings should be considered. For example, in the long term fewer people may actively sign up to receive direct flood warnings and therefore issuing flood warnings through loudhailers etc may be beneficial.

6.7 IMPLEMENTATION ACTIVITIES

6.7.1 Flood Warning Infrastructure

To implement a flood warning scheme for Langholm, Eskdalemuir and Longtown the following programmes of work are recommended:

1. Improvements to SEPA's hydrometric network in the River Esk catchments. This is likely to require at least one new raingauge and one new river flow gauging station in the upper parts of the catchment, which would be integrated within the existing network. A rain gauge is relatively easy to install and maintain. A flow gauging station requires more planning and design. As a minimum, a cableway and gauging hut with stilling well would need to be installed, and in some cases also an in-bank flow control structure. Maintenance and ongoing calibration would need to be undertaken by SEPA's local hydrology team. Additionally, water level recorders should be installed at Langholm, Eskdalemuir and Longtown.
2. Development and calibration of real-time rainfall runoff models for the White Esk, Ewes Water and Liddel Water catchments.
3. Development and calibration of river routing and hydrodynamic models as required between the rainfall-runoff modelled catchments and flood warning locations. Existing models may be adapted to be able to run under real-time conditions.
4. Assessment of flood warning thresholds (Flood Alert, Flood Warning and Severe Flood Warning) at each flood warning location.
5. Integration of all forecasting models into FEWS Scotland.
6. Consultation and awareness raising with stakeholders including local residents and training of local emergency responders.

It is envisaged that any implementation plan would be lead by SEPA as the flood warning authority supported by Dumfries and Galloway Council.

Implementation costs would include one-off hydrometric network and model development costs, and ongoing data collection and maintenance costs. Assuming that the system would be implemented and owned by SEPA, a large proportion of these costs may be subsumed within current flood warning operations budgets. Additional costs may include any expansion of the hydrometric network (capital and maintenance costs) and the development of hydrological and hydraulic models for the Esk catchment.

Further consultation with SEPA would be required to agree the approach to funding and implementation of a flood warning scheme.

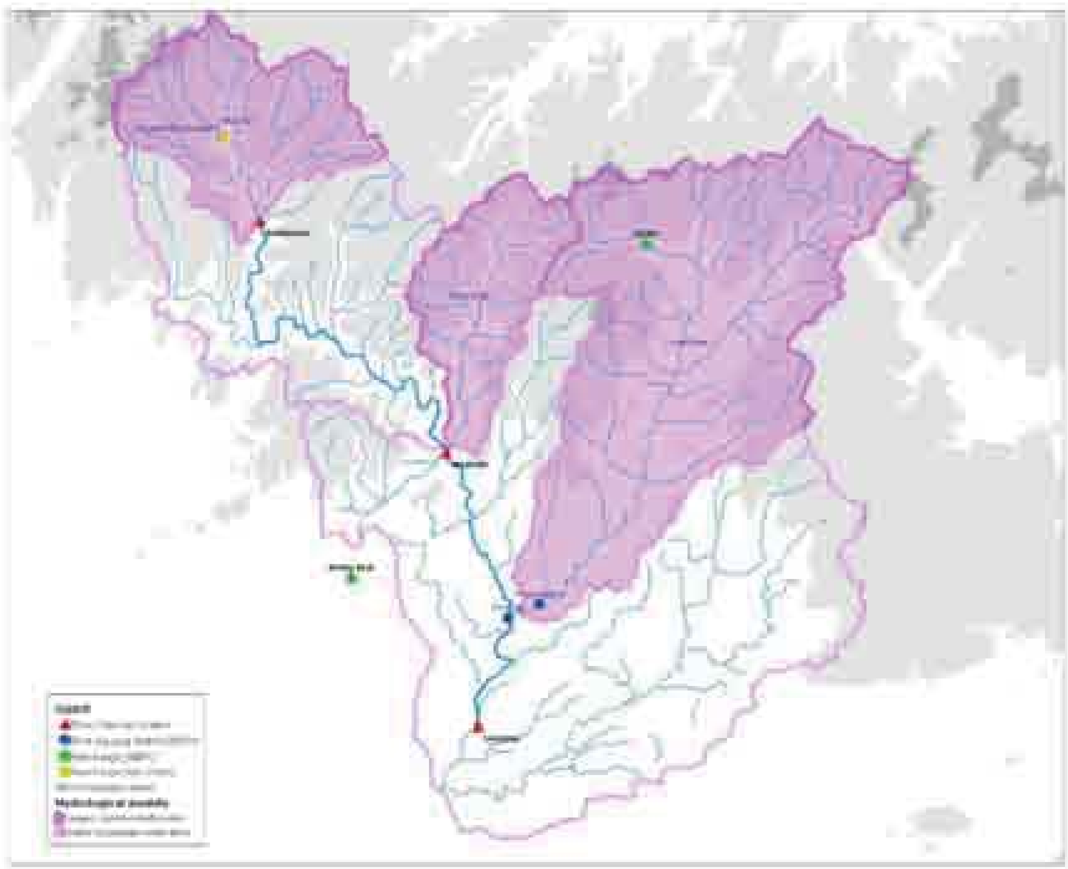

Figure 6.1: Hydrometric Data & Indicative Forecasting Model Components

6.7.2 Flood Resilience Improvements

In addition to consideration of the infrastructure required to implement a flood warning system an assessment of the potential for minor flood protection improvement works to improve the effectiveness of flood warning was also undertaken. This involved examining the flood outlines for the more frequent events (≥4% AEP) to identify those locations with a low flooding threshold. This assessment indicated that the first onset of property flooding occurs at Langholm Mill upstream of Ewes Bridge during a 1:5yr event however no flooding of properties within the town of Langholm is anticipated until at least the 1:10yr event. During this event the principal areas of flood impact are along the main River Esk between the Telford Bridge and the suspension footbridge, principally at Elizabeth Street and George Street. Flooding was also identified at Francis Street, Mary Street and from Waterside down to the Wastewater Treatment Works. Some flooding from the Wauchope Water was also identified to the rear of properties at Caroline Street.

A detailed site walkover was undertaken to determine if the indicated flooding was likely to affect properties and identify the scope for minor works to be undertaken to improve flood protection in these areas. This identified that whilst gardens on the river side of the road and the road at Mary Street/Francis Street will flood it is unlikely that water would actually enter the properties. Similarly the properties at Waterside appear to be sufficiently elevated, Figures 6.2 and 6.3, that inundation would be restricted to roads, paths and open spaces.

Figure 6.2 Typical Property Entrance at Waterside

Figure 6.3 Typical Properties at Waterside

At the Mill on Glenesk Road, some minor works to the rear wall, pointing and the provision of a watertight flood gate where there is presently a pedestrian gate as shown in Figure 6.4 would improve flood protection at this site.

Figure 6.4 Pedestrian Gate at Mill (Note Gap below door)

The properties at Caroline Street also appear to be sufficiently elevated as shown in Figure 6.5, that actual flooding of residential property would not be anticipated, some sheds, garages and gardens would however be affected.

Figure 6.5 View from River towards Caroline Street

At Elizabeth Street the top of the Kerb is generally above the 1:10yr flood level however there are a few locations, such as that shown in Figure 6.6, where some form of flood gate is required to maintain this level of protection. Improving the integrity of the flood protection along Elizabeth Street would protect 3-4 properties from direct flooding during a 1:10yr event. However it should be noted that these measures would not necessarily provide the normal 300mm freeboard above the flood level.

Figure 6.6 Access Gate at Elizabeth Street

Similarly the wall at George Street, Figure 6.7, should provide protection from at least a 1:10yr flood event, however the integrity of this defence is compromised by unsealed outlets and river access as shown in Figures 6.8 and 6.9.

Figure 6.7 Wall at George Street

Figure 6.8 Unsealed Drainage Outlet at George Street

Figure 6.9 Open access to river at George Street

Consequently it is recommended that all uncontrolled outlets through the wall are either removed or fitted with appropriate non-return valves and that the river access is fitted with a suitable flood gate to maintain the integrity of this structure during high flow events. Completing these works would have the effect of protecting additional properties from direct flooding during a 1:10yr flood event, although again the freeboard may be less than 300mm.

7 GRAVEL BERM ASSESSMENT

cbec was sub-contracted by RPS to model the River Esk, Ewes Water and Wauchope Water at Langholm using a fully 2D hydraulic method to investigate potential changes to water level, channel velocities and bed shear stress resulting from removal and modification of gravel bars upstream and downstream of the Thomas Telford Road Bridge. The full report of this assessment is contained in Appendix N with the main conclusions detailed below.

Removal of gravels on the right bank of the Esk upstream of the Telford Road Bridge down to the confluence with the Wauchope Water has a very slight beneficial effect on water levels through the left and middle bridge openings, but produces very little difference in levels through the right opening. Levels upstream of the bridge on the Esk and Ewes Water are reduced slightly, but levels downstream of the bridge are not significantly changed.

If the right hand bar from the bend on the Esk upstream of the Telford Bridge down to the confluence of the Wauchope Water is reduced in size by gravel removal, it will likely re-form due to sediment supply from the Esk and from the large bar at the confluence of the Ewes Water and the Esk. In turn, if this large bar is removed, it will likely reform from sediment supply from the Ewes Water.

Figure 7.1: Gravel bar, looking upstream

8 SUMMARY AND RECOMMENDATIONS

Langholm is located along the River Esk at the confluence of two of its tributaries: the Ewes Water and the Wauchope Water, therefore Langholm effectively lies at the junction of three rivers, each carrying significant discharges. The Dumfries & Galloway Council Strategic Flood Risk Appraisal, August 2007, indicated that Langholm had more properties at risk of flooding than any other town in Dumfries & Galloway. Consequently the Council commissioned RPS to undertake a detailed assessment of the flood risk within Langholm and identify potential measures to address this risk.

A computational river model of the River Esk from Duchess Bridge through to Skipper's Bridge, including the Wauchope Water from Springhill through to the Esk, and the Ewes Water from Whitsheils Bridge to the Esk, was developed in order to predict water levels for a range of design storm events. The model was used to produce accurate flood extent and flood depth maps required to inform and assessment of the impacts of flooding at Langholm. The results of this detailed assessment indicate that the flood risk in Langholm (268 properties within the 1:200yr flood extent) is not as great as was indicated by the earlier Strategic Assessment (524 properties).

Currently, flood extent information for development planning is available for the whole of Scotland through SEPA's Indicative River & Coastal Flood Map. Using local topographic surveys and LiDAR data, RPS has produced more accurate flood extent and flood depth maps for Langholm in order to understand local flooding mechanisms and provide more accurate estimates flood levels, flood extents and the number of properties at risk. The information can be used by Dumfries & Galloway Council in preference to the SEPA Indicative River & Coastal Flood Map outputs to secure floodplains against future development and provide detailed flood risk advice in relation to Langholm.

The Flood Risk Management (Scotland) Act 2009 requires the production of Flood Risk Management Plans covering each Local Plan District. Two sets of complementary plans will be produced, Flood Risk Management Strategies produced by SEPA, and Local Flood Risk Management Plans produced by lead local authorities, both of which will be at the heart of efforts to tackle flooding in Scotland. Langholm lies within the Solway Local Plan District and the flood maps produced for the Langholm Flood Risk Assessment can therefore be used to inform the Local Flood Risk Management Plan for Solway.

RPS has considered possible flood management options for Langholm and concluded that the only feasible type of defence is the provision of hard defences. Hard defence schemes were developed for three different scenarios of flood protection- 1:25, 1:50 and 1:200 year return periods. The financial feasibility of providing the proposed defence schemes was investigated by a cost benefit analysis and the option that produced the highest benefit/cost ratio was for hard defences to protect against a 1:200yr or 0.5% AEP flood.

As part of the study, RPS also considered the development and implementation of a flood warning scheme for Langholm and potentially Eskdalemuir and Longtown. This included assessing whether such a scheme was suitable, in terms of both its likely benefits and technical feasibility. The programme of works to implement a flood warning scheme was presented, along with a summary of minor works to enhance protection up to a 1:10yr event. It is envisaged that any implementation plan for a flood warning system would be lead by SEPA as the flood warning authority, supported by Dumfries and Galloway Council. Further consultation with SEPA is required to agree the funding mechanism and implementation approach for a flood warning scheme.

RPS sub-contracted cbec to undertake an assessment of impacts to water levels and velocities from the removal of gravel bars in the study area. The assessment concluded that there would be minimal flood risk benefit gained by the removal of the existing gravel bars which are likely to reform due to sediment from the Ewes Water.

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