Outer Hope Feasibility Report

South Hams District Council

August 19 2013

Plan Design Enable

Notice

This document and its contents have been prepared and are intended solely for South Ham District Council's information and use in relation to Outer Hope Flood Study.

Atkins Ltd assumes no responsibility to any other party in respect of or arising out of or in connection with this document and/or its contents.

This document has 40 pages including the cover.

Document history

Job number: 5112137			Document ref: Outer Hope Feasibility Report			
Revision	Purpose description	Originated	Checked	Reviewed	Authorised	Date
Rev 1.0	Draft for client comment	AMC	AM	LW	AMC	20/02/13
Rev 2.0	Final Issue	AMC	AM	LW	AMC	19/08/13

Client signoff

Client	South Hams District Council
Project	Outer Hope Flood Study
Document title	Outer Hope Feasibility Report
Job no.	5112137
Copy no.	
Document reference	Outer Hope Feasibility Report

Table of contents

Tables

Figures

Executive summary

Following a number of flooding incidents in Outer Hope, South Hams District Council commissioned Atkins in March 2012 to complete a flood risk study of the catchment, identifying the key flood risk mechanisms, and appraising potential flood alleviation measures.

A hydrological and hydraulic model was constructed to represent the Outer Hope Brook and floodplain areas. Three flood events were tested in the hydrological and hydraulic models and the results compared to the observed flooding. The hydrological and hydraulic models were shown to perform well, and predict flood extents and depths similar to that observed in the three events. The study model is therefore considered robust and appropriate for assessing potential flood risk management options.

The hydraulic modelling has shown upstream flood storage to be the most viable option hydraulically and is able to provide a 1% AEP (Annual Exceedance Probability) standard of protection. The technical feasibility of this option needs to be further explored during the next stage of assessment including discussions with landowners, ground investigation and further detailed hydraulic modelling, including the opportunity to include an allowance for climate change.

The preferred option would cost approximately £268k, and provide approximately £1.4 million in benefits, giving a benefit-cost ratio of 5.2. The Flood Defence Grant in Aid (FDGiA) score of 50% indicates that approximately £134k could be provided by FDGiA funding.

As part of any further assessment consideration should be given to:

- Management of surface water flows from the Outer Hope bypass to divert it into greenfield areas;
- Formalising inspection and maintenance regime of the channel and structures; and
- Resilience measures such as property level protection and a formal flood management plan.

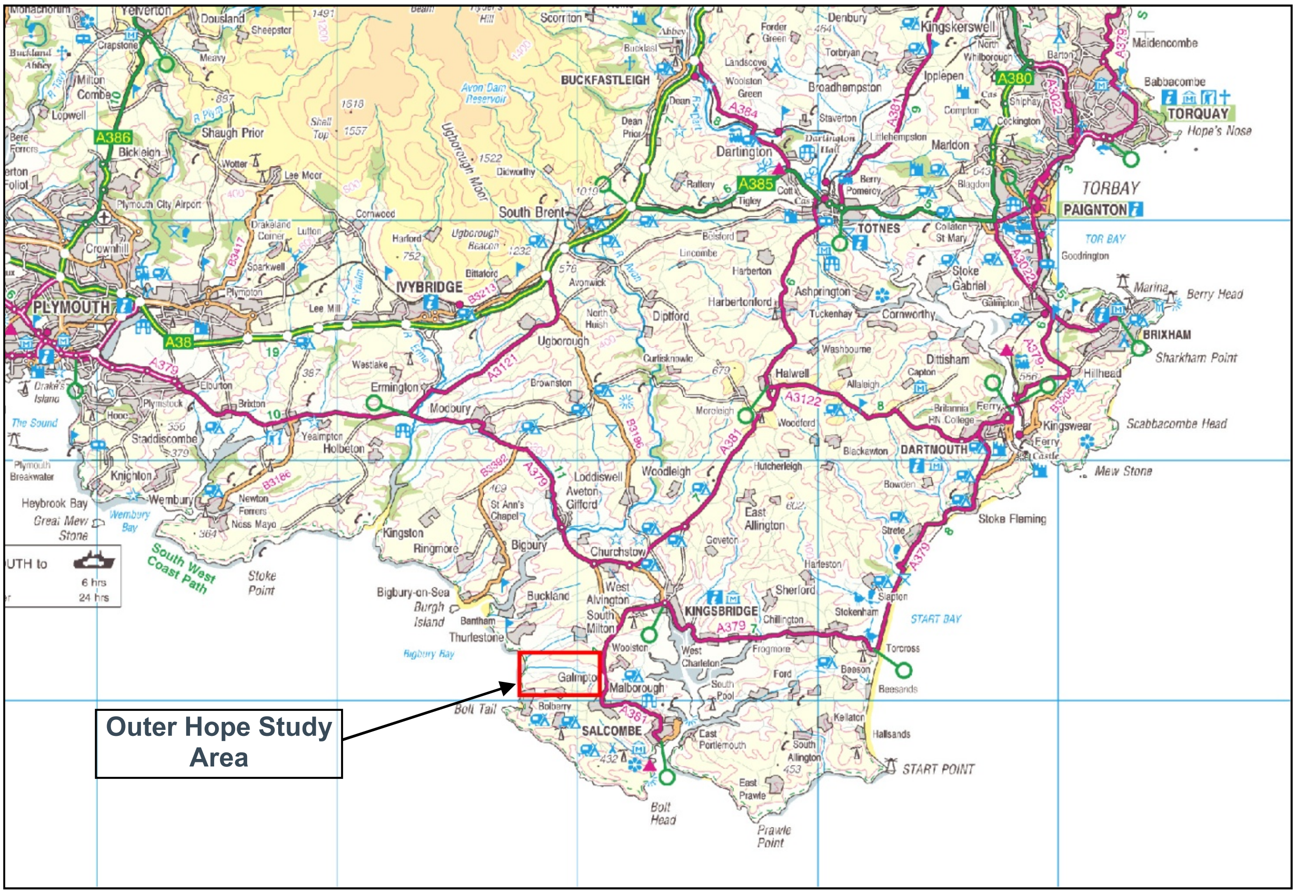
It is therefore recommended that the preferred option is subject to further, more detailed assessment to refine the scheme, its costs and benefits, and undertake consultation with the residents and landowners.

1. Introduction and Background

1.1. Introduction

Following a number of flooding incidents in Outer Hope, South Hams District Council commissioned Atkins in March 2012 to complete a flood risk study of the catchment, identifying the key flood risk mechanisms, and appraising potential flood alleviation measures.

Outer Hope is located on the south coast of Devon, approximately 7km west of Salcombe and 8km south-west of Kingsbridge. Outer Hope, along with Inner Hope forms the village of Hope Cove. The village lies within the parish of South Huish and within the South Devon Area of Outstanding Natural Beauty (AONB). Figure 1 shows the location of the study area.



This map is reproduced from the Ordnance Survey material with the permission of Ordnance Survey on behalf of the Controller of Her Majesty's Stationery Office © Crown copyright. Unauthorised reproduction infringes Crown copyright and may lead to prosecution or civil proceedings. South Hams District Council, 100022628, 2012.

Figure 1. Study Area Location

1.2. The Problem

In order to understand the flooding problem fully a site visit, a meeting with residents and a review of historical flooding information was undertaken. These sources all indicated that the principal source of flood risk for the village was from the Outer Hope Brook. Although groundwater flooding, surface water flooding and/or exceedance of the drainage network were also reported to be problems the main source was clearly from Outer Hope Brook.

Flooding photos and records from the residents clearly show the culvert and channel capacity of the brook being exceeded, leading to overtopping on the left bank (looking downstream) with water spilling into the original course of the brook at the bottom of the valley; records indicate that the brook was diverted from its original course in the 1930’s to feed a watercress farm in the village. Flood flows then pass through the Hope Cove bypass road culvert, leading to flooding of properties downstream.

Figure 2 and Figure 3 demonstrate this flood flow route in the April 1999 flood, and clearly show flood water flowing along the valley floor and through the bypass road culvert, and flooding the garden of Holbeche House. This appears to be the most significant source of flood water, although additional spills from the brook downstream of the Hope Cove bypass also occur.

Figure 2. April 1999 flood event looking upstream from Hope Cove bypass road

Figure 3. April 1999 flood event at the outlet from the Hope Cove bypass road culvert

1.3. Site Visit and Stakeholder Engagement

A site visit was undertaken on the 09 May 2012. The site visit was combined with a visit to South Hams District Council to collect data and discuss the flooding issues experienced.

The site visit consisted of a site walkover and a meeting with local residents to record their experiences of flooding and collect photographs and descriptions of flood flow routes through Outer Hope.

During the site walkover the upper catchment was visited and a storage pond noted close to Burton Farmhouse. However, this is not expected to have a hydrological influence on the catchment, particularly not downstream in Outer Hope.

The river channel was inspected and photographs taken to note the condition of the river channel and floodplains to inform the hydraulic modelling.

The meeting with local residents was extremely useful and enabled us to document primary flood mechanisms, flood flow routes and receive a number of photographs and videos of the flooding. These photographs and videos have been used to verify the hydrological and hydraulic model.

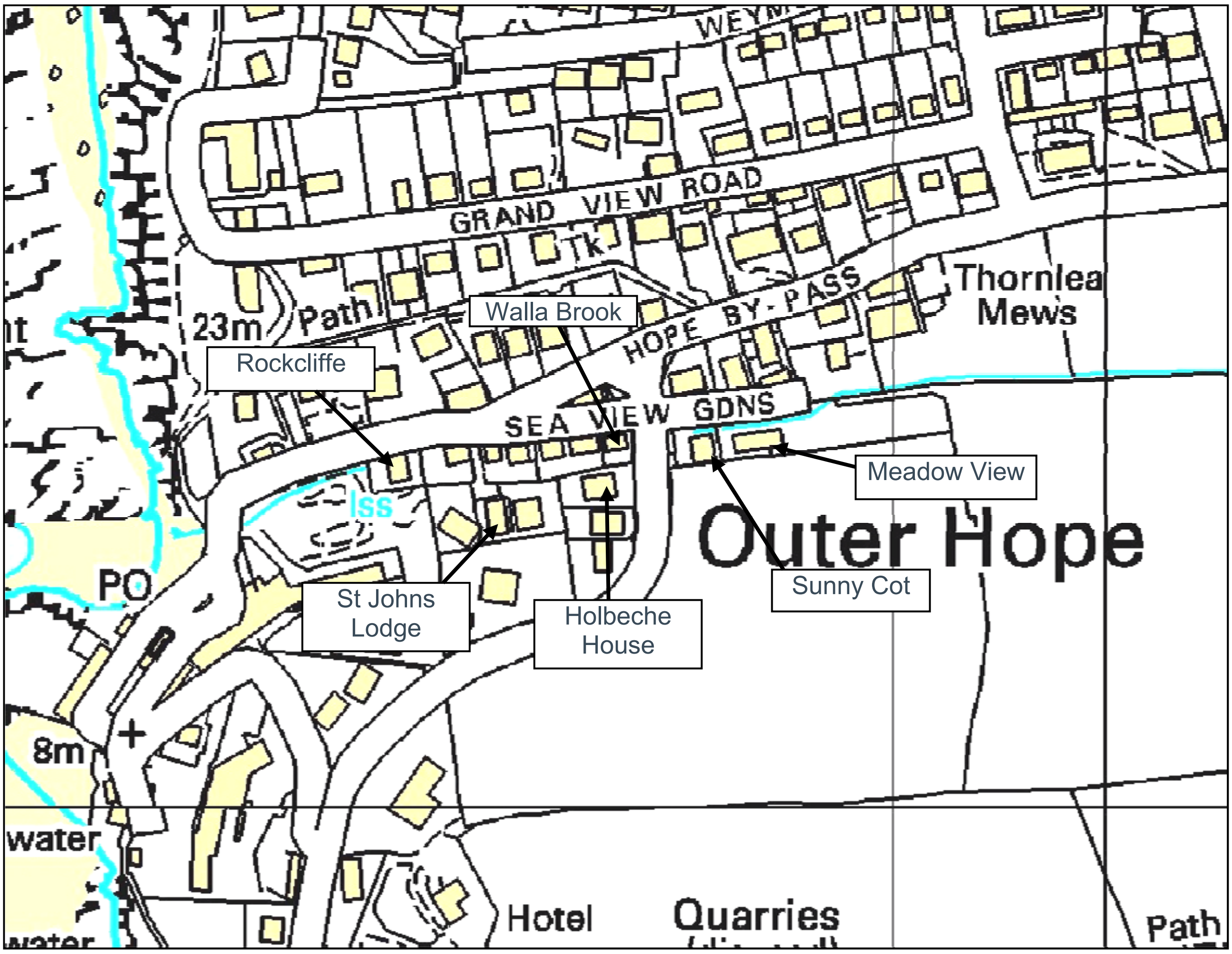
1.4. Study Objectives

The objectives of the Outer Hope Flood Risk Study are as follows:

- To gather evidence of historical flood events in the catchment;
- To undertake a topographical survey of the watercourse;
- Produce a hydrological and hydraulic model of the watercourse to understand flood risk mechanisms and define the floodplain;
- Complete a high level options appraisal to identify potential flood alleviation options (such as increasing culvert size, storage, improved maintenance);
- Use the hydrological and hydraulic model to test potential flood alleviation options;
- Undertake high level benefit-cost assessment for proposed flood alleviation options; and
- Produce a Feasibility Report documenting the above and recommending viable flood alleviation options for the community.

1.5. Property Location Plan

The location of the properties discussed in Sections 2 to 4 are shown in Figure 4.



This map is reproduced from the Ordnance Survey material with the permission of Ordnance Survey on behalf of the Controller of Her Majesty's Stationery Office © Crown copyright. Unauthorised reproduction infringes Crown copyright and may lead to prosecution or civil proceedings. South Hams District Council, 100022628, 2012.

Figure 4. Property Locations

2. Hydrological Modelling

2.1. Introduction

Two hydrological methods have been used to estimate the flows for the Outer Hope catchment, namely the Flood Estimation Handbook (FEH) Statistical method, and the FEH Revitalised Flood Hydrograph (ReFH) method. The Statistical method uses statistical techniques to estimate peak flows at different return periods, in relation to an index flood that is defined as the median annual flood (QMED). The ReFH method can be used to generate hydrographs, which can then be scaled to achieve the desired peak flow at a particular key assessment point.

Small catchment methods such as the Rational Method and Institute of Hydrology 124 have not been applied as recent research has indicated that the ReFH provides more reliable flow estimates.

The impacts of climate change will be assessed in line with the Environment Agency guidance note “Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities”. This suggests a 20% increase in flows for the 2050’s and a 30% increase for the 2080’s, for South-West England.

2.2. Catchment Description

The catchment of the Outer Hope Brook is rural in nature with the majority given over to agriculture, (predominantly grazing). It has steep valley sides, particularly on the southern slope.

The brook has been diverted from its natural course approximately 200m upstream of the village, downstream of the Sewage Treatment Works. Therefore, instead of running along the valley floor the brook now runs at a higher point in the valley, before entering a series of culverts adjacent Sea View Gardens, then running through the village. The channel diversion was thought to have been undertaken to feed watercress farms and fish cleaning stations prior to the Second World War. The brook discharges through a 0.6m diameter culvert beneath the Sea Road, and then cascades down onto the beach.

Figure 5 shows the extent of the catchment area draining to Outer Hope.

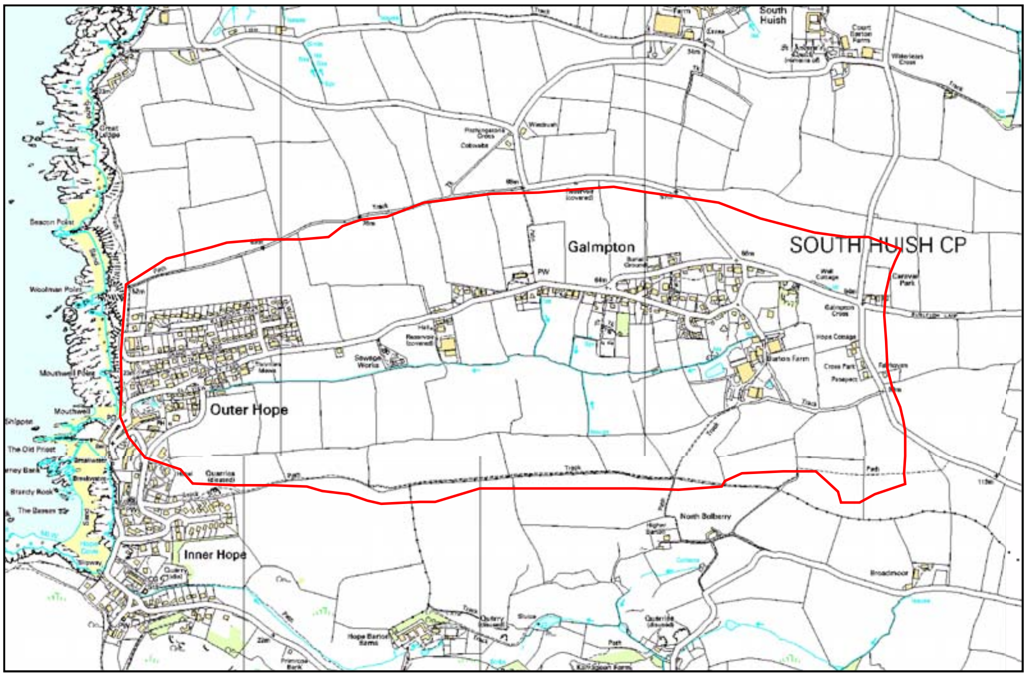


Figure 5. Outer Hope catchment area

Catchment descriptors were derived from the FEH CD-ROM. Small changes to the catchment area were made to more accurately represent the catchment draining to Outer Hope; otherwise the catchment descriptors were unadjusted from that defined by the FEH CD-ROM. Table 1 illustrates the key catchment descriptors for the Outer Hope Brook.

Catchment Descriptor	Description	Value
Area	Catchment drainage area	1.56 km²
FARL	Index of flood attenuation due to reservoirs and lakes (1 indicates no attenuation)	1
PROPWET	Proportion of time when SMD <6mm	0.47
BFIHOST	Baseflow Index derived using the HOST classification	0.618
DPLBAR	Mean of distances along drainage paths between 50m grid node and the outlet	1.34
DPSBAR	Mean of all inter-nodal slopes along drainage slopes	122
SAAR	Standard period (1961-90) average annual rainfall (mm)	884
SPRHOST	Standard Percentage Runoff derived using HOST	26.49
URBEXT (2000)	Extent of urban and suburban cover	0.0778

Table 1. Key Catchment Descriptors

2.3. Flood events assessed

The following table describes the range of flood return period events for which flow estimates were estimated.

Return Period (% AEP)	Return Period (Years)
20% AEP	5-year
5% AEP	20-year
2% AEP	50-year
1.33% AEP	75-year
1% AEP	100-year
1% AEP + 20% Climate Change	100-year + 20% Climate Change
1% AEP + 30% Climate Change	100-year + 30% Climate Change
0.1% AEP	1000-year

Table 2. Return Period Definitions

2.4. FEH Assessment

2.4.1. FEH Statistical Approach

The results from the FEH Statistical assessment are in Table 3. No adjustment to QMED has been undertaken using donor stations as local gauged catchments were not considered similar enough to the Outer Hope catchment for inclusion.

2.4.2. ReFH Approach

The results from the ReFH assessment are shown in Table 3. The critical storm duration was calculated for the catchment based on the equation in FEH (using SAAR and Tp).

Return Period	ReFH Peak Flow (m^3/s)	FEH Statistical Peak Flow (m^3/s)	Difference (m^3/s)
20% AEP	1	0.7	0.3
5% AEP	1.5	1	0.5
2% AEP	1.9	1.3	0.6
1.33% AEP	2.1	1.5	0.6
1% AEP	2.2	1.6	0.6
1% AEP + 20% CC	2.7	1.9	0.8
1% AEP + 30% CC	2.9	2	0.9
0.1% AEP	4.2	2.9	1.3

Table 3. ReFH and FEH Statistical Peak Flows

2.5. Summary

In summary a hydrological assessment has been completed using standard FEH guidance, the preferred method for deriving flows for this catchment was the ReFH methodology. The final design flows applied in the hydraulic model are displayed in Table 4.

Return Period	ReFH Peak Flow (m^3/s)
20% AEP	1
5% AEP	1.5
2% AEP	1.9
1.33% AEP	2.1
1% AEP	2.2
1% AEP + 20% CC	2.7
1% AEP + 30% CC	2.9
0.1% AEP	4.2

Table 4. Final Design Event Flows

3. Hydraulic Modelling

3.1. Introduction

Ground levels at the upstream extent of the model are around 55-56mAOD, falling to 9-10mAOD at the downstream extent of the model. The hydraulic model was developed using ISIS. The following data was used to develop the ISIS hydraulic model:

- Centreline topographic survey (2001);
- Centreline topographic survey 2012); and
- Light Detecting and Ranging (LiDAR) data provided by the Environment Agency in October 2012.

It should be noted that the Centreline surveys (2001 and 2012) were appointed directly by South Hams District Council and the survey was not completed to Environment Agency specification, and is therefore not as detailed as typical Environment Agency modelling studies. The survey was sufficient for hydraulic modelling for options appraisal, but should the preferred option be taken forward to detailed design further survey may be required.

3.2. Methodology

3.2.1. Hydraulic Model Build

The following assumptions were applied in the development of the ISIS hydraulic model:

- Mannings 'n' values have been set using Chow (1959), at 0.040 for in-channel (representative of minor streams, some winding and shoals) and 0.050 for the floodplains (representative of representative of light brush and trees, or scattered brush on floodplains), with the exception of the floodplain channel (the original natural course of the brook), where they were set to a universal 0.040;
- Structure spill (i.e. bridge or culvert decks) coefficients were set to 1.2 (representative of road surface and limited hindrance to the passage of flow), whereas spill coefficients linking the main brook channel to the floodplain channel were set to 0.5 to represent the higher roughness values along the lengths of the spills (representative of tree lined banks);
- LiDAR data was the predominant source of information for the floodplain channel, where possible this was supplemented with surveyed levels from Centreline Surveys;
- A normal depth boundary was applied as the downstream boundary for both the main brook channel and the floodplain channel;
- An inflow of 0.35 m^3/s was used as the upstream boundary of the floodplain channel to solve model instability issues. However, since the floodplain channel follows the valley bottom, water will naturally drain to this point, so it is likely that a proportion of the catchment flows would reach the floodplain channel without having first spilled from the Outer Hope Brook; and
- Due to the steep nature of the watercourse, the system of culverts and bridges and the floodplain channel it was necessary to use higher than normal initial conditions to enable the model to run. This limitation will need to be taken into account when assessing potential flood alleviation options.

The key features of the ISIS hydraulic model are displayed in Table 5.

Feature	Number / Description
Total number of nodes	68
Total length	1.6 km
Spill coefficients	1.2 for structures and 0.5 for spills between the Outer Hope Brook and the secondary floodplain channel
Number of river cross sections	38
Number of structures	4
Number of boundaries	4; upstream inflows for the Outer Hope Brook and secondary floodplain channel, and a Normal Depth boundary for the downstream extents.

Table 5. Key ISIS Hydraulic Model Features

3.2.2. Model Verification

The hydrological and hydraulic model was verified using the following flood events:

- 23 April 1999;
- 07 April 2001; and
- 09 February 2009.

Whilst no flood level information was available for these events to verify the model, anecdotal evidence and photographs taken during the flood event have been used to compare against that predicted by the hydrological and hydraulic model. Rainfall data for the three events were routed through the hydrological and hydraulic model and the results compared to that recorded in Outer Hope.

The daily rainfall gauge at Hope Cove (NGR SX6816 4028) was supplemented with information from the closest Tipping Bucket Rainfall (TBR) gauge at Harbertonford (SX 79180 55988) to provide more detail on storm durations and rainfall profiles. It should be noted that this gauge is over 15km from the study area, but in the absence of better available data this is a suitable proxy. Information provided by residents indicated that the community floods during short duration, high intensity storms, typical of the Devon and Cornwall region. It is therefore likely that the majority of the daily rainfall total recorded at the Hope Cove station fell in a considerably shorter time period; this is supported by the storm durations recorded at Harbertonford.

For the rainfall to be routed through the ReFH hydrology unit it requires the total rainfall to be distributed across a given storm duration. The rainfall distribution recorded at Harbertonford was therefore applied to the Hope Cove rainfall totals.

The key features of the three verification events are shown in Table 6. This indicates that the rainfall totals between the two gauges are broadly similar for the three flood events.

Rainfall Event	Rainfall Totals (mm)		Rainfall Duration (Harbertonford)	Return Period (FEH CD-ROM)	
	Hope Cove	Harbertonford		Hope Cove	Harbertonford
23 April 1999	30.9	27	7	2.9	1.3
07 April 2001	17.9	11	4	1.3	< 1 month
09 February 2009	42.2	49.2	17	3	2.4

Table 6. Verification Events Key Features

The three flood events (23 April 1999, 07 April 2001 and 09 February 2009) were tested in the hydrological and hydraulic models and the results compared to the observed flooding. The hydrological and hydraulic models were shown to perform well when compared to the three flood events, and predict flood extents and depths similar to that observed. Further details can be found in the Technical Note in Appendix A.

The nature of the hydraulics present, namely the low capacity of the river channel and culverts within the village will mean the same flood flow routes will operate for a wide range of flows. However, the depths of flow observed and modelled do correlate in most cases.

The following table summarises the performance of the model for the three events, with '+' representing a model overestimate, '✓' a correlation, and '-' a model underestimate.

Location	23 April 1999	07 April 2001	09 February 2009
	Performance (+,✓,-)	Performance (+,✓,-)	Performance (+,✓,-)
Upstream of bypass road	+	N/A	+
Meadow View / Sunnycot	N/A	N/A	-
Holbeche House / St Johns Lodge	✓	✓	-
Outer Hope Car Park	✓	N/A	✓ / +

Table 7. Summary verification results

3.2.3. Sensitivity Assessment

The following sensitivity tests were run to assess the impact of changes in the model assumptions on results for the 1% AEP event:

- Mannings 'n' values were increased and decreased by 10%; and
- Structure and floodplain spill coefficients increased and decreased by 50%.

The results of these tests are summarised in Table 8.

Model Node	Location	1% AEP event Baseline Peak Water Level (mAOD)	Mannings +10% Difference (m)	Mannings -10% Difference (m)	Spill Coefficients +50% Difference (m)	Spill Coefficients -50% Difference (m)
XS1_CH0000	Upstream model extent	55.72	-0.02	0.02	0.00	0.00
XS11_CH0944	Adjacent Sewage Treatment Works	27.36	-0.04	0.04	0.00	0.00
XS13_CH1127	Adjacent field boundary	23.53	-0.04	0.04	0.00	0.00
XS16_CH1376	Adjacent Meadow View	18.54	0.00	0.01	0.02	-0.04
XS16_CH1407	Adjacent Sunnycot	17.26	-0.04	0.04	-0.03	-0.04
XS16_CH1443	Adjacent Wallabrook	16.77	0.00	-0.01	0.07	-0.12
XS17_CH1573	Downstream Rockcliffe	13.10	-0.01	0.01	0.01	-0.05

XS18_CH1637	Downstream Extent of Model	10.15	-0.01	0.01	0.01	-0.05
FPCH_0249	Floodplain channel - Meadowview	17.24	-0.03	0.02	-0.03	0.03
FPCH_0275	Floodplain channel - Sunnycot	17.24	-0.03	0.02	-0.03	0.03
FPCH_0285U	Immediately upstream of bypass road culvert	17.24	-0.03	0.02	-0.03	0.03
FPCH_0290	Floodplain channel – Holbeche House	15.31	-0.01	0.02	0.00	0.01
FPCH_0362	Floodplain channel – St Johns Lodge	12.86	-0.01	0.01	0.00	0.00
FPCH_0427	Floodplain channel – Car Park	11.36	-0.03	0.03	-0.01	0.02

Table 8. Sensitivity assessment results

These results demonstrate that peak water levels are insensitive to changes in the key model parameters tested. This suggests that the model is robust as the results do not change significantly when changing key model assumptions.

3.3. Model Results

3.3.1. Design Events

Having verified the hydrological and hydraulic models a series of design events were run to assess the level of flood risk in Outer Hope, these design events are:

- 20% AEP event;
- 5% AEP event;
- 2% AEP event;
- 1.33% AEP event;
- 1% AEP event;
- 1% AEP + 20% Climate Change event, and + 30% Climate Change event; and
- 0.1% AEP event.

3.3.2. Baseline Levels and Flows

The table below displays the peak water levels and flows in the baseline hydraulic model for the 1% AEP flood event. Appendix B contains the full results for all model nodes.

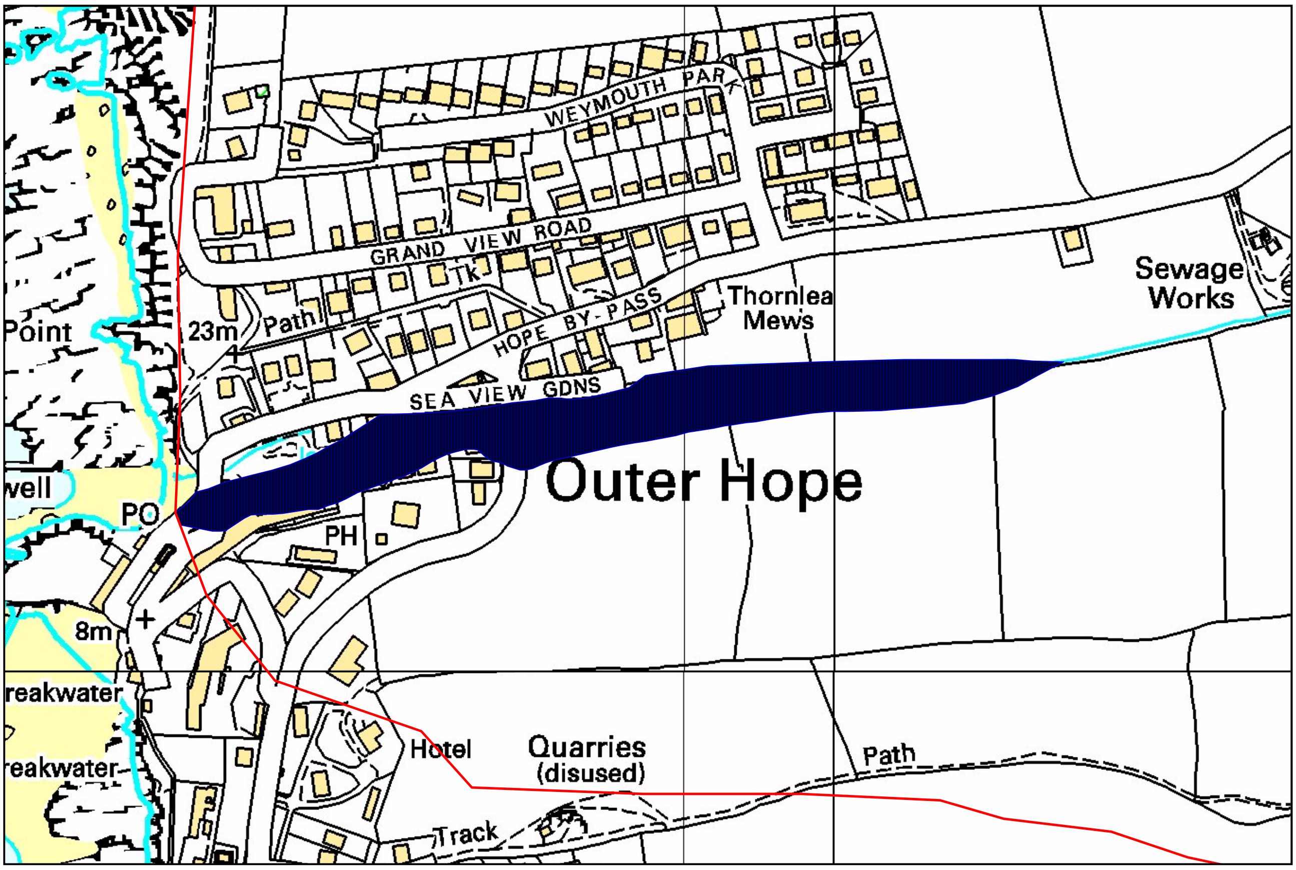
Model Node	Location Description	1% AEP event peak water level (mAOD)	1% AEP event peak flow (m^3/s)
XS1_CH0000	Upstream model extent	55.72	2.2
XS11_CH0944	Adjacent Sewage Treatment Works	27.36	2.2
XS13_CH1127	Adjacent field boundary	23.53	2.2
XS16_CH1376	Adjacent Meadow View	18.54	1.6
XS16_CH1407	Adjacent Sunnycot	17.26	1.1
XS16_CH1443	Adjacent Wallabrook	16.77	0.2
XS17_CH1573	Downstream Rockcliffe	13.10	0.2
XS18_CH1637	Downstream Extent of Model	10.15	0.2

FPCH_0249	Floodplain channel - Meadowview	17.24	0.7
FPCH_0275	Floodplain channel - Sunnycot	17.24	0.9
FPCH_0285U	Immediately upstream of bypass road culvert	17.24	1.3
FPCH_0290	Floodplain channel – Holbeche House	15.31	1.8
FPCH_0362	Floodplain channel – St Johns Lodge	12.86	1.8
FPCH_0427	Floodplain channel – Car Park	11.36	1.8

Table 9. Baseline 1% AEP event peak water levels and flows

3.3.3. Floodplain Outline

A floodplain outline was generated for the 1% AEP event; this is displayed in Figure 6.



This map is reproduced from the Ordnance Survey material with the permission of Ordnance Survey on behalf of the Controller of Her Majesty's Stationery Office © Crown copyright. Unauthorised reproduction infringes Crown copyright and may lead to prosecution or civil proceedings. South Hams District Council, 100022628, 2012.

Figure 6. 1% AEP flood event outline

3.4. Summary

In summary, a 1D ISIS hydraulic model was constructed to represent the Outer Hope Brook and floodplain areas, based on Centreline Surveys of 2001 and 2012, and supplemented by LiDAR data. Three flood events were tested in the hydrological and hydraulic models and the results compared to the observed flooding. The hydrological and hydraulic models were shown to perform well, and predict flood extents and depths similar to that observed in the three events. The study model is therefore considered robust and appropriate for assessing potential flood risk management options.

A range of design events were tested in the hydrological and hydraulic model and a floodplain outline for the 1% AEP flood event produced.

4. Options Appraisal

4.1. Introduction

The options appraisal has been completed in line with guidance from the Environment Agency's Flood and Coastal Erosion Risk Management – Appraisal Guidance (FCERM-AG) document released in 2010.

The first stage of this process is to undertake a high level appraisal of potential flood risk management measures to ensure a wide range of measures are considered, and allow detailed assessment to be focused on those measures which are considered to be most effective. Those measures considered to be viable were then taken forward for assessment in the hydrological and hydraulic model.

After assessing the effectiveness of flood risk management options we analysed the economic benefits of each individual option by comparing the monetary value of damages avoided if the option is implemented with the cost of implementing and maintaining the option. Finally the preferred option (s) will be subject to the Flood Defence Grant in Aid (FDGiA) scoring assessment to determine the likelihood of securing central government funding.

4.2. High Level Options Appraisal

This initial stage in the identification and appraisal of flood risk management measures (high level options) involves a qualitative 'first pass' assessment of the various measures. Each measure is assessed in terms of its benefits and disadvantages under a range of categories affecting its suitability as a flood risk management tool; these include cost, environment/heritage impacts, risks, community acceptance, health and safety and maintenance requirements.

This high level appraisal allows for a robust and rational analysis of a large range of conceivable and logical flood risk management options. Those options found to be disadvantageous or unfeasible at this early stage will not be considered further, whilst all other options are progressed for further consideration. A range of measures were considered as part of this study, including: do nothing, flood storage, increasing size of key structures, flood walls or embankments and increase in channel capacity.

The following measures were also considered, these will not in isolation solve the flooding issues but may help reduce the severity and speed of flooding such as: source control, individual property protection and inspection and maintenance of key structures.

The results of the high level appraisal are displayed in Table 10.

Category	Option	Comments	Taken Forward for further assessment	Hydraulically Modelled
Source control	Afforestation/Agricultural practices	Effectiveness of this measure in reducing flood risk, particularly for such a "flashy" catchment is not well proven. This would require extensive landowner negotiation, and a regular maintenance regime to ensure that debris did not block the downstream channel and structures. This option is not therefore considered feasible; however it will be assessed in the model to understand the potential impact.	✗	✓
	Use of Green	The majority of the study area is rural / greenfield thus there is not a	✗	✗

	Infrastructure	need to convert these areas to green infrastructure. There is no, or limited opportunity to convert the existing urban / brownfield areas into green infrastructure.		
Flood storage	Floodplain storage or wetland creation/river restoration	This is a viable option upstream of the village.	✓	✓
	SUDS - new/retrospective	This is a viable option to reduce the surface water runoff within the village, but will not impact on the main flood risk source which is the brook. Whilst this option is viable it is considered that funds would be better spent on options which seek to reduce the flooding from the brook.	✓	✗
Channel conveyance	Formalise maintenance regime	This is a viable option for both the open channel and structures along the brook.	✓	✓
	Increase culvert size	Due to the increase in size likely to be required, and the cost and disruption to the community this is unlikely to be a viable option. Model runs will however be undertaken to assess the culvert sizes required.	✗	✓
	River engineering i.e. channelisation	This would not reduce flood risk since the watercourse in the village is generally either culverted or in a man-made channel following the diversion in the early/mid 1900's. Further channelisation is unlikely to reduce flooding.	✗	✗
	Diversion channels	This is not a technically feasible option as no alternative diversion routes are available due to the location of properties in the “natural” floodplain.	✗	✗
	Raised Defences	This is a viable option for the river reach in the village.	✓	✓
Other infrastructure improvements	Pumping	This would be costly and technically challenging given the volumes of water involved, lack of flood warning available and distances over which flood water would need to be pumped.	✗	✗
	Green Roofs	The predominant flood risk source is fluvial; therefore retrospective fitting of green roofs would not help manage the principal source of flooding. Any new developments should give consideration to including this.	✗	✗
	Improve capacity of piped networks	This may provide some betterment, but given the cost and technical challenges associated	✗	✗

		with this option, and given that the principal flood source is fluvial it is considered that resources would be better spent on other options.		
	On-line storage (existing/new)	There is no capacity for online storage within the existing drainage network.	✗	✗
	Off-line storage (existing/new)	There is potential for this option within the study area, but is unlikely to offer a tangible benefit for Outer Hope as the available locations within the drainage network for this option would be outside of the village. Furthermore the primary flooding mechanism is fluvial rather than surface water runoff.	✗	✗
	Increased maintenance regime for networks / gullies	This is a viable option but is unlikely to result in an appreciable reduction in flood risk, at least for significant events (such as the 1% AEP event); less extreme events may see greater benefits.	✗	✗
Planning activities	Development Control	This is already in place but should be continued; any further development in the catchment, particularly upstream on the agricultural land is likely to result in increased flood risk in the village.	✓	✗
	SUDS Strategy	This may be beneficial if pursued as part of the Local Flood Risk Management Strategy, but would not be necessary to develop such a strategy at the community level.	✓	✗
	Blue Development Corridors	This is not necessary/cost effective in a community of this size.	✗	✗
Resilience	Flood awareness	The community is extremely aware of the flood risk and has an informal system in place.	✓	✗
	Emergency & disaster planning/response	A formal emergency plan would be beneficial	✓	✗
	Property level protection / Building Resilience	This is a viable option and warrants further consideration.	✓	✗
Monitoring / Advise / Survey	Asset inspection	Detailed survey and inspection of the culverts through the village may help identify particular "pinch points" or structural risks/weaknesses.	✓	✗
	Flood warning and forecasting	This is a viable option and warrants further consideration, although given the "flashy" nature of the catchment the community may be subject to extremely short lead times and/or false warnings.	✓	✗
	Improve Hydrometric network	This would be essential if a flood warning service is provided.	✓	✗

Further assessment	Further study into potential options and funding sources	This would be required if this Feasibility Study indicates that there is a viable option (s) to manage flood risk for the community.	✓	✗

Table 10. High Level Options Appraisal Summary

The options identified as potentially viable and therefore requiring further assessment will be discussed in the subsequent sections. Not all of the flood risk management measures considered as potentially viable in Outer Hope were modelled in the hydrological and hydraulic model, as the impacts of some measures, such as flood warning cannot be represented in the model. However, the effectiveness of measures can still be considered in a qualitative manner as part of the appraisal process.

4.3. Modelled Options

Following this preliminary assessment the options described in Table 10 are considered alongside the Do Nothing and Do Minimum options. The Do Nothing option has been carried forward as a baseline against which all other options can be assessed. Similarly, the Do Minimum option has been included for completeness. Flood risk would remain the same in the short term, but could be expected to increase in the longer term due to climate change.

The effectiveness of the potential mitigation measures was tested using the 1% AEP event. Table 11 describes how each of the measures taken forward for modelling was represented in the hydrological and hydraulic model.

Option Number	Description	Representation in hydrological and hydraulic model
0	Do Nothing (baseline)	No change from baseline model
1	Do Minimum (improved maintenance)	Channel Mannings ‘n’ value reduced to 0.03, and floodplain Mannings ‘n’ to 0.04 to represent regular maintenance regime reducing channel and floodplain roughness.
2	Increase capacity of existing culverts	Main channel culverts increased in capacity as follows: Meadow View Access culvert from 0.513m² to 3m², Hope bypass road culvert from 0.318m² to 3m², and culvert alongside access drive from minimum size of 0.2m² to 1.6m².
3	Raised defences	Raised left bank levels upstream of Meadow View to 19-22mAOD, adjacent Sunnycot to 18mAOD, and adjacent Wallabrook to 17.5mAOD.
4	Land management	Reduced percentage runoff in ReFH unit by 20% to represent land management practices, designed to slow runoff rates and attenuate rainfall at source.
5	A) Upstream Storage	Pond modelled in the upper catchment, upstream of the Sewage Treatment Works. Bank lowering on the left bank but no excavation required. Localised bank raising downstream of the bypass road culvert outlet.
	B) Upstream storage	Pond modelled adjacent to the Sewage Treatment Works. Bank lowering on the left bank and excavation works required. Localised bank raising downstream of the bypass road culvert outlet.

Table 11. Modelled option descriptions

4.3.1. Model Results

The model results of the five modelled options are shown in the following tables, and the results summarised in section 4.5. Appendix C displays the full option model results.

4.3.1.1. Option 1 (Do Minimum)

Table 12 displays the results from the Option 1, Do Minimum option which shows that this option has a minimal impact on peak water levels, reducing them by a maximum of 0.1m. The marginal change in water levels means water will still spill from the main channel into the floodplain and flood Outer Hope; since the change in levels and flow paths is so slight there will be no impact on the flood extents compared to the Do Nothing scenario. This option in isolation will not therefore reduce flood risk to Outer Hope, but a formal maintenance regime may form part of another option to ensure scheme performance is maintained.

Model Node	Location	1% AEP event Baseline peak water level (mAOD)	1% AEP event Option 1 peak water level (mAOD)	Difference (m)
XS1_CH0000	Upstream model extent	55.72	55.66	-0.06
XS11_CH0944	Adjacent Sewage Treatment Works	27.36	27.26	-0.11
XS13_CH1127	Adjacent field boundary	23.53	23.43	-0.09
XS16_CH1376	Adjacent Meadow View	18.54	18.49	-0.05
XS16_CH1407	Adjacent Sunnycot	17.26	17.18	-0.08
XS16_CH1443	Adjacent Wallabrook	16.77	16.79	+0.02
XS17_CH1573	Downstream Rockcliffe	13.10	13.08	-0.02
XS18_CH1637	Downstream Extent of Model	10.15	10.12	-0.02
FPCH_0249	Floodplain channel - Meadowview	17.24	17.17	-0.07
FPCH_0275	Floodplain channel - Sunnycot	17.24	17.17	-0.07
FPCH_0285U	Immediately upstream of bypass road culvert	17.24	17.17	-0.07
FPCH_0290	Floodplain channel – Holbeche House	15.31	15.27	-0.04
FPCH_0362	Floodplain channel – St Johns Lodge	12.86	12.84	-0.02
FPCH_0427	Floodplain channel – Car Park	11.36	11.28	-0.07

Table 12. Option 1 (Do Minimum) change in peak water levels (1% AEP event)

4.3.1.2. Option 2 (upsize culverts)

Table 13 shows the change in peak water levels with Option 2, increasing the size of the culverts on the main channel, and demonstrates notable reductions in water level in the floodplain upstream of the bypass road as less water spills out of bank. However, elsewhere water levels remain the same or increase. As stated in Table 10 upsizing the existing culvert network would have significant challenges, both technically and in terms of stakeholder and landowner considerations, especially given the scale of the upsizing necessary to offer any betterment. As the modelling has indicated that the reduction in levels and flood extents even with a significant increase in culvert size is minimal, this option is not considered to be a viable.

Model Node	Location	1% AEP event Baseline peak water level (mAOD)	1% AEP event Option 2 peak water level (mAOD)	Difference (m)
XS1_CH0000	Upstream model extent	55.72	55.72	0.00
XS11_CH0944	Adjacent Sewage Treatment Works	27.36	27.36	0.00
XS13_CH1127	Adjacent field boundary	23.53	23.53	0.00
XS16_CH1376	Adjacent Meadow View	18.54	18.61	+0.07
XS16_CH1407	Adjacent Sunnycot	17.26	17.20	-0.06
XS16_CH1443	Adjacent Wallabrook	16.77	16.84	+0.07
XS17_CH1573	Downstream Rockcliffe	13.10	13.17	+0.07
XS18_CH1637	Downstream Extent of Model	10.15	10.21	+0.06
FPCH_0249	Floodplain channel - Meadowview	17.24	16.91	-0.33
FPCH_0275	Floodplain channel - Sunnycot	17.24	16.91	-0.33
FPCH_0285U	Immediately upstream of bypass road culvert	17.24	16.91	-0.33
FPCH_0290	Floodplain channel – Holbeche House	15.31	15.31	0.00
FPCH_0362	Floodplain channel – St Johns Lodge	12.86	12.86	0.00
FPCH_0427	Floodplain channel – Car Park	11.36	11.36	0.00

Table 13. Option 2 (upsize culverts) change in peak water levels (1% AEP event)

4.3.1.3. Option 3 (raised defences)

Table 14 displays the change in peak water levels for Option 3, raised defences along the main brook channel, and shows that whilst in some locations peak water levels are reduced in the floodplain as less water spills from the main channel, peak water levels in the brook are increased significantly in locations such as adjacent to Meadow View and Wallabrook. As a result, whilst floodplain channel water levels are reduced (but not removed entirely) main channel levels are increased markedly; this option is not therefore considered viable.

Model Node	Location	1% AEP event Baseline peak water level (mAOD)	1% AEP event Option 3 peak water level (mAOD)	Difference (m)
XS1_CH0000	Upstream model extent	55.72	55.72	0.00
XS11_CH0944	Adjacent Sewage Treatment Works	27.36	27.36	0.00
XS13_CH1127	Adjacent field boundary	23.53	23.53	0.00
XS16_CH1376	Adjacent Meadow View	18.54	18.80	+0.26
XS16_CH1407	Adjacent Sunnycot	17.26	18.31	+1.05
XS16_CH1443	Adjacent Wallabrook	16.77	17.74	+0.97
XS17_CH1573	Downstream Rockcliffe	13.10	13.23	+0.13
XS18_CH1637	Downstream Extent of Model	10.15	10.28	+0.14
FPCH_0249	Floodplain channel -	17.24	17.11	-0.14

	Meadowview			
FPCH_0275	Floodplain channel - Sunnycot	17.24	17.11	-0.14
FPCH_0285U	Immediately upstream of bypass road culvert	17.24	17.11	-0.14
FPCH_0290	Floodplain channel – Holbeche House	15.31	15.28	-0.03
FPCH_0362	Floodplain channel – St Johns Lodge	12.86	12.85	-0.01
FPCH_0427	Floodplain channel – Car Park	11.36	11.31	-0.05

Table 14. Option 3 (raised defences) change in peak water levels (1% AEP event)

4.3.1.4. Option 4 (land use management)

Table 15 compares the impact of Option 4, land use management on peak water levels for the 1% AEP event. This option shows marked reductions in floodplain channel levels, of up to 0.47m, but limited changes in the main channel. This demonstrates that there may be some benefits derived from this option. However, given the uncertainty in firstly gaining agreement from the landowner for changes to the land use, and secondly the uncertainty in the affect of land use management changes on runoff and flows on such a small, steep catchment such as this, it is considered that this option as a stand-alone scheme would not be viable. It may however be beneficial to pursue this measure as part of a wider option.

Model Node	Location	1% AEP event Baseline peak water level (mAOD)	1% AEP event Option 4 peak water level (mAOD)	Difference (m)
XS1_CH0000	Upstream model extent	55.72	55.67	-0.05
XS11_CH0944	Adjacent Sewage Treatment Works	27.36	27.27	-0.09
XS13_CH1127	Adjacent field boundary	23.53	23.45	-0.08
XS16_CH1376	Adjacent Meadow View	18.54	18.52	-0.02
XS16_CH1407	Adjacent Sunnycot	17.26	17.17	-0.09
XS16_CH1443	Adjacent Wallabrook	16.77	16.75	-0.02
XS17_CH1573	Downstream Rockcliffe	13.10	13.10	0.00
XS18_CH1637	Downstream Extent of Model	10.15	10.14	0.00
FPCH_0249	Floodplain channel - Meadowview	17.24	16.78	-0.47
FPCH_0275	Floodplain channel - Sunnycot	17.24	16.78	-0.47
FPCH_0285U	Immediately upstream of bypass road culvert	17.24	16.78	-0.47
FPCH_0290	Floodplain channel – Holbeche House	15.31	15.29	-0.02
FPCH_0362	Floodplain channel – St Johns Lodge	12.86	12.85	-0.01
FPCH_0427	Floodplain channel – Car Park	11.36	11.32	-0.04

Table 15. Option 4 (land use management) change in peak water levels (1% AEP event)

4.3.1.5. Option 5 (upstream storage)

Table 16 compares the baseline peak water levels and those from Option 5, upstream storage (A and B). This option includes localised bank raising on the left bank immediately downstream of the bypass road culvert outlet to prevent water spilling into the floodplain at this point. Both Options 5A and 5B provide the same betterment downstream, providing a 1% AEP standard of protection. Option 5A provides approximately 13,500m³ of storage and Option 5B approximately 7,500m³ of storage.

This option provides the greatest reductions in peak water level, and should be taken forward for further study to assess issues such as the optimum size and location of the storage area, landowner acceptance, and climate change impacts.

Model Node	Location	1% AEP event Baseline peak water level (mAOD)	1% AEP event Option 5 peak water level (mAOD)	Difference (m)
XS1_CH0000	Upstream model extent	55.72	55.70	-0.02
XS11_CH0944	Adjacent Sewage Treatment Works	27.36	26.86	-0.50
XS13_CH1127	Adjacent field boundary	23.53	23.05	-0.48
XS16_CH1376	Adjacent Meadow View	18.54	18.05	-0.49
XS16_CH1407	Adjacent Sunnycot	17.26	16.96	-0.30
XS16_CH1443	Adjacent Wallabrook	16.77	16.88	+0.11
XS17_CH1573	Downstream Rockcliffe	13.10	13.13	+0.02
XS18_CH1637	Downstream Extent of Model	10.15	10.17	+0.03
FPCH_0249	Floodplain channel - Meadowview	17.24	16.37	-0.87
FPCH_0275	Floodplain channel - Sunnycot	17.24	15.80	-1.45
FPCH_0285U	Immediately upstream of bypass road culvert	17.24	15.80	-1.45
FPCH_0290	Floodplain channel – Holbeche House	15.31	15.10	-0.21
FPCH_0362	Floodplain channel – St Johns Lodge	12.86	12.78	-0.09
FPCH_0427	Floodplain channel – Car Park	11.36	11.01	-0.34

Table 16. Option 5 (upstream storage A or B) change in peak water levels (1% AEP event)

4.4. Options not modelled

The remaining measures not modelled but identified as having potential to reduce flooding in Outer Hope are discussed below:

- Surface water runoff / SuDs: a scheme to take water from the Outer Hope bypass and divert it into the storage areas or greenfield areas is potentially feasible and should be investigated as part of the proposed storage scheme;
- Formalising inspection and maintenance: local residents undertake maintenance and inspection activities; however these should be formalised into a maintenance plan and agreed with South Hams District Council;
- Flood warning: due to the small, steep catchment and flashy nature of the storms described by residents as causing flooding of the village, it is unlikely flood warning would provide adequate lead times for the community and would not provide sufficient benefits compared to the costs;

- Resilience: measures such as property level protection and a formal flood management plan should be investigated as part of the preferred option in the next stage of assessment; and
- Development Control: the National Planning Policy Framework (NPPF) and associated Technical Guidance should be adhered to for any future development and no further run-off than currently contributing to the catchment should be allowed. Development should show a net benefit to current catchment conditions using SuDs systems etc.

4.5. Summary

The options listed in Table 11 have been included in the hydrological and hydraulic model which has shown that the majority of the options tested have almost no impact on peak water levels and flood extents at the 1% AEP event. Since the peak flows between the less severe, more frequent events such as the 20% AEP event are broadly similar to the more extreme 1% AEP event tested in the model, it is considered unlikely that these options would have a significant improvement in performance for the lower return period events.

As the channel and structure capacity within the main channel is the key constraint causing flooding, it could be expected that these options would have limited impact. The flood risk management option which has a significant impact on water levels and flood extents is upstream flood storage which is shown to be able to provide a 1% AEP standard of protection.

Option 5A has a flood storage pond upstream of the Sewage Treatment Works, whereas Option 5B has a pond adjacent to the Sewage Treatment Works. Both of these options would need further study to assess if they are technically feasible, which option is most efficient and if permission from landowners would be granted. It should be noted that further modelling and / or excavation of the storage areas would be required to assess the performance of this option with the impact of climate change.

5. Economic Appraisal

5.1. Introduction

The first step in the economic analysis of investment options is to develop a benchmark against which economic performance will be compared. In the case of flood alleviation schemes, this is the 'do-nothing' option.

Do Nothing damages are those damages that would occur if nothing was done to manage flood risk. This is a scenario in which the Environment Agency or Lead Local Flood Authority, and all other persons or organisations undertake no maintenance of any assets contributing to flood alleviation. For example, Do Nothing would normally mean:

- Maintenance of existing defences is abandoned and that with time there would be an increasing risk of failure of all flood defence assets as a result;
- Flood embankments and channels will become overgrown and impede flow. Erosion and vegetation growth would lead to an increased risk of embankment breaches; and
- Siltation in the channel and thick vegetation on the banks will reduce the channel conveyance in places and result in an increase in water levels.

As there are no flood defences along the Outer Hope Brook, or a formal maintenance regime in place the Do Nothing scenario is identical to the current situation.

5.2. Damage Assessment

The Multi Coloured Manual (MCM, Flood Hazard Research Centre 2005 and 2010) outlines methods for carrying out an assessment of flood alleviation benefits at varying levels of detail depending on the requirement of the study being undertaken. These range from a basic approach, used for strategy level studies, through to a more detailed method for full-scale feasibility or project appraisal studies. The object of a strategy level study is to identify where more detailed investigations are required. In line with this need the basic level Benefit-Cost Assessment (BCA) method should be robust enough to identify areas where it is likely to be economically beneficial to develop a scheme for improved flood risk management. This ensures that time and money is not spent unnecessarily investigating areas where schemes are not likely to be beneficial.

Once a strategy level study has shown that improved flood risk management might be economically beneficial a Feasibility Study such as this is normally undertaken. A Feasibility Study will better estimate the benefits of possible flood mitigation options and identify, more specifically, the areas where the overall benefits of a scheme are likely to be highest.

The final stage, prior to any work being undertaken, is a full-scale Feasibility Study and Project Appraisal Report (PAR). This study will highlight the preferred flood mitigation option from a number of possible options, always including the 'do-nothing' option.

5.2.1. Flood Damages

It is recommended by FCERM-AG that the economic appraisal covers the life of the longest lasting scheme; it is proposed that a 100-year time horizon is adopted for this appraisal.

The depth-damage statistics provided in the MCM (2010) are quoted at 2010 prices and therefore need to be adjusted for inflation using the Consumer Price Index (CPI) to the most recent quarter for which data is available (up to December 2012).

LiDAR data was used to define property ground levels, with an allowance of 150mm to take account of property threshold levels (as confirmed during the site visit), with the exception of the terraced Anchor Cottages where Centreline Survey information was applied due to the position of the NRD point being incorrect.

Following MCM guidance, damages in the Outer Hope catchment are made up from the following component costs:

- Direct Damages to Residential Properties;
- Direct Damages to Non Residential Properties (NRP);
- Temporary Accommodation costs; and
- Emergency Service Costs.

Damages can also include a number of other components such as traffic delay losses and recreational impacts, but these are normally low; no other components were considered applicable at this stage, although it is recognised that the impact on tourism in the study area could be considered at a later stage.

5.2.1.1. Residential Properties

Flood damages for residential properties have been taken from the Flood Hazard Research Centre's (FHRC) MCM. The MCM contains depth-damage data for a range of residential and non-residential property types. This enables specific depth-damage calculations to be made according to the type and age of a property.

Residential property types were defined based on that provided in the National Receptors Database (NRD), and have been classified as either flat, terrace, bungalow, semi-detached and detached. As a Feasibility level study it was not felt appropriate to define residential properties by age.

Socio-economic equity issues have not been taken into account by applying Distributional Impact factors since a large proportion of the properties are holiday lets and/or second homes, applying the locally derived socio-economic classification would not therefore be appropriate.

5.2.1.2. Non-Residential Properties

The depth-damage data for the NRP's is based on the figures published in the MCM. MCM data for NRP's is provided in damages per m². It should be noted that basement flood damages have been removed from the damage assessment; this will under-estimate flood damages since it assumes that no properties have basements when in reality this is unlikely to be the case.

5.2.1.3. Other

The MCM 2010 recommends using a variable factor to account for the costs of emergency services, with 5.6% being used for dense, urban areas, and 10.7% for dispersed, rural areas. For Outer Hope the 10.7% factor has been applied.

Following guidance from the FHRC temporary accommodation costs have been included at £6,695 for residential properties and £5,461 for non-residential properties, each time the property is flooded. Where properties have been written off no temporary accommodation costs are incurred to ensure Average Annual Damages (AAD) from temporary accommodation costs are not overestimated.

5.2.2. Calculation of Average Annual Damages, Write-off and Capping

The AAD's were used to determine Present Value damages (PVd) over the 100-year appraisal period for Outer Hope. Where properties are shown to have flood damages above their capital value, based on the discounted value of the property specific AAD over the 100-year time horizon, it has been assumed that the property should be abandoned and has been written off. As the frequency of flooding is >20% AEP event the year of write-off has been taken as year 9 as it was not considered realistic to write off properties any earlier (i.e. year zero).

The detailed breakdown of how each of the damage components contribute to the Annual Average Damage (AAD) and therefore the (PVd) can be seen in the calculation spreadsheets included in Appendix D.

5.2.3. Discounting

Damages were discounted using the HM Treasury recommended rates, as published in the Green Book and given in Table 17. Discounting will have the effect of reducing the value of damages that are incurred in the future.

Year	Discount Rate (%)
0-30	3.5
31-75	3.0
76-100	2.5

Table 17. Variable discount rate

5.2.4. Do nothing damages

The following table summarises the ‘Do-nothing’ or baseline economic damages for Outer Hope.

Damage Source	AAD (£k)
Residential (AAD)	£5
Non-residential (AAD)	£0
Temporary Accommodation Costs (AAD)	£1
Emergency Services (AAD)	£1
Total Write Off Value	£1,744
PVd	£1,473
PVd (no capping)	£5,626

Table 18. Summary Do-nothing damages

5.2.5. Sensitivity Assessment

A range of sensitivity tests were undertaken to assess the impact on the PVd’s following a change in key assumptions and data sources, namely:

- Property threshold levels were increased and decreased by 150mm;
- Local Outer and Inner Hope property values were applied rather than County average values; and
- The year of write off was changed from year 9 to year 0 and 19.

Table 19 summarises the impact of these changes on PVd in Outer Hope.

Scenario	PVd (£k)	Difference from baseline (£k)	% Difference
Do Nothing baseline	£1,473	N/A	N/A
Property thresholds +150mm	£1,373	-£100	-7%
Property thresholds -150mm	£1,987	+£514	+35%
Capital write off Year 0	£1,937	+£464	+31%
Capital write off Year 19	£1,100	-£373	-25%
Local (Outer and Inner Hope) capital values applied	£3,014	+£1,541	+105%

Table 19. Sensitivity assessment results

This indicates that PVd's are sensitive to the assumptions concerning year of write off and capital values, which is to be expected since the majority of the damages (>85% of Do Nothing PVd) are incurred from capital write off of residential properties.

This assessment has adopted a conservative approach in estimating PVd's to ensure damages are not overestimated, for example by assuming the year of write off is year 9 rather than year zero, applying Devon County average capital values rather than locally derived higher values, and by including an allowance for property threshold levels. This will ensure that a robust comparison of benefits and costs can be undertaken, and provide more certainty in the potential viability of any preferred option.

5.3. With Scheme Damages and Benefits

With scheme damages are the residual flood damages that remain after flood mitigation measures are put in place. These damages are the damages that could occur over and above the level of service offered by a flood risk management scheme.

Flood risk management measures to be taken forward are described in Section 4. For this Feasibility Study we have a 1% AEP event design standard of protection, although for comparison purposes we have included the 2% AEP event standard of protection also. It is not thought worthwhile or appropriate to test incremental standards of service in this Feasibility Study, this would be investigated further if taken forward to a more detailed study.

Option	PVd (£k)	PVd Avoided and PV Benefits (£k)
Do Nothing baseline	£1,473	£0
2% AEP Standard of Protection	£234	£1,239
1% AEP Standard of Protection	£86	£1,388

Table 20. With scheme damages and benefits

5.4. High Level Costs

A cost estimate for each viable option has been made by reference to the Environment Agency Flood Risk Management Estimating Guide – Unit Cost Database (2007). Costs from this database have been increased to take account of inflation using the CPI. Costs for the storage options have been estimated based on recent local schemes. Since the only option which is able to provide a 1% AEP standard of protection is upstream storage, costs for other options have not been estimated; however an indicative estimate for raised walls through the village would be approximately £330k.

An Optimism Bias of 60% has been included in line with DEFRA and HM Treasury guidance, and an allowance of 20% for detailed design and site supervision in line with that applied in recent studies completed in the south-west. The unit costs and number of units used to produce the cost estimates for this review are detailed in Appendix E. The costs are summarised in Table 21. No allowance for maintenance works have been made at this stage.

Option Element	Costs (£k)
Upstream storage (A or B) capital cost	£103
Localised bank / wall raising capital cost	£46
20% allowance for detailed design / supervision	£30
60% Optimism Bias	£89
Total	**£268**

Table 21. Option 5A or 5B Scheme Costs

5.5. Benefit – Cost Ratios and FDGiA Scores

The benefits of any flood alleviation option are calculated by subtracting the residual PVd with a scheme from the PVd under the Do Nothing situation.

The benefit cost ratio and FDGiA for the preferred flood risk management option is summarised in Table 22. It should be noted that at less than unity the benefit cost ratios show that there would not be economic benefit in undertaking the flood risk management options.

Option	Benefit-Cost Ratio	FDGiA Score
Option 5A or 5B (upstream storage)	5.2	50%

Table 22. Benefit-cost ratios and FDGiA Scores

5.6. Summary

An economic appraisal in line with guidance from DEFRA, the Environment Agency and the MCM has been completed and indicates that the PVd's under the Do Nothing scenario are £1.5 million, the bulk of the damages are from write-off of residential properties. A flood risk management option that provides a 1% AEP standard of protection would generate benefits of £1.4 million.

A high level cost has been developed for the preferred Option (Option 5A or 5B), upstream storage, estimated at £268k, giving a benefit-cost ratio of 5.2. The FDGiA score for this scheme is 50%, indicating that the proposed scheme could receive approximately £134k from FDGiA funding.

6. Conclusions and Recommendations

Following a number of flooding incidents in Outer Hope, South Hams District Council commissioned Atkins in March 2012 to complete a flood risk study of the catchment, identifying the key flood risk mechanisms, and appraising potential flood alleviation measures.

A hydrological assessment has been completed using standard FEH guidance; the preferred method for deriving flows for this catchment was the ReFH methodology.

A 1D ISIS hydraulic model was constructed to represent the Outer Hope Brook and floodplain areas. Three flood events were tested in the hydrological and hydraulic models and the results compared to the observed flooding. The hydrological and hydraulic models were shown to perform well, and predict flood extents and depths similar to that observed in the three events. The study model is therefore considered robust and appropriate for assessing potential flood risk management options.

The hydraulic modelling has shown upstream flood storage to be the most viable option hydraulically and is able to provide a 1% AEP standard of protection. The technical feasibility of this option needs to be further explored during the next stage of assessment including discussions with landowners, ground investigation and further detailed hydraulic modelling, including the opportunity to include an allowance for climate change.

The preferred option would provide approximately £1.4 million in benefits and have a benefit-cost ratio of 5.2. The FDGiA score of 50% indicates that approximately £134k could come from FDGiA for this scheme.

As part of any further assessment the following aspects should be considered in more detail:

- Surface water runoff / SuDs: a scheme to take water from the Outer Hope bypass and divert it into the storage areas or greenfield areas is potentially feasible;
- Formalising inspection and maintenance: local residents undertake maintenance and inspection activities. However, these should be formalised into a maintenance plan and agreed with South Hams District Council; and
- Resilience: measures such as property level protection and a formal flood management plan should be considered in more detail.

It is therefore recommended that the preferred option is subject to further, more detailed assessment to refine the scheme, the costs and benefits, and to undertake consultation with the residents and landowners.

Appendices

Appendix A. Modelling Technical Note

Technical note

Project:	Outer Hope Flood Risk Study	**To:**	South Hams District Council
Subject:	Flood study	**From:**	Atkins
Date:	5 Feb 2013	**cc:**	

1. Introduction

Following a number of flooding incidents in Outer Hope, South Hams District Council commissioned Atkins in March 2012 to undertake a flood risk study of the catchment, identifying the key flood risk mechanisms, and appraising potential flood alleviation measures.

2. Aims

The aims of the Outer Hope Flood Risk Study are as follows:

- To gather evidence of historical flood events in the catchment;
- to undertake a topographical survey of the watercourse;
- produce a hydrological and hydraulic model of the watercourse to understand flood risk mechanisms and define the floodplain;
- complete high level options appraisal to identify potential flood alleviation options (such as increasing culvert size, storage, improved maintenance);
- use the hydrological and hydraulic model to test potential flood alleviation options;
- undertake high level benefit-cost assessment for proposed flood alleviation options; and
- produce a Feasibility Report documenting the above and recommending viable flood alleviation options for the community.

This Technical Note outlines the hydrological and hydraulic modelling undertaken, which will form the basis for flood risk management option testing.

3. Approach

A site visit, meeting with residents and review of the historical flooding information indicated that the principal source of flood risk for the village was from the Outer Hope Brook. Although, groundwater flooding, surface water flooding and/or exceedance of the drainage network were also reported to be problems the main source was clearly from Outer Hope Brook.

Flooding photos and records from the residents show the culvert and channel capacity of the Brook being exceeded, leading to overtopping on the left bank with water spilling into the original course of the Brook at the bottom of the valley. Flood flows then pass through the Outer Hope bypass road culvert, leading to flooding of properties downstream. Records indicate that the Brook was diverted from its original course in the 1930's to feed a watercress farm located where the present day car park is, and to provide water for fish cleaning stations.

Figure 3-1 and Figure 3-2 demonstrate this flood flow route during the April 1999 event, and clearly show flood water flowing along the valley floor and through the bypass road culvert, resulting in flooding of the garden of Holbeche House. This flood flow route appears to be the most significant source of flood water, although additional spills from the Brook downstream of the Outer Hope bypass also occur.

Figure 3-1: April 1999 flood looking upstream from the Outer Hope bypass

Figure 3-2: April 1999 flood Outer Hope bypass culvert downstream face

Since the principal source of flooding is the fluvial system it was decided to develop a river model (hydrological and hydraulic) to represent the Outer Hope Brook and associated flooding mechanisms, rather than a surface water or drainage model. This model would be used to assess the existing flooding situation (the “baseline”) and test the effectiveness of potential flood alleviation options.

4. Hydrology

4.1. Introduction

Two methods were used to estimate the flows for the Outer Hope catchment, namely the Flood Estimation Handbook (FEH) Statistical method, and the FEH Revitalised Flood Hydrograph (ReFH) method. The Statistical method uses statistical techniques to estimate peak flows at different return periods, in relation to an index flood that is defined as the median annual flood (QMED). The ReFH method is used to generate hydrographs based on rainfall runoff techniques, which can then be scaled to achieve a desired peak flow (perhaps the statistical peak) at a particular key assessment point.

Small catchment methods such as the Rational Method, and Institute of Hydrology 124, have not been applied as recent research has indicated that the ReFH provides more reliable flow estimates for such watersheds.

The impacts of climate change are assessed in line with the Environment Agency guidance note “Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities”. This suggests a 20% increase in flows for the 2050’s and a 30% increase for the 2080’s, for South-West England.

4.2. Catchment Description

The catchment of the Outer Hope Brook is rural in nature with the majority given over to agriculture, (predominantly grazing), and has a steep valley sides, particularly on the south slope.

The Brook has been diverted from its natural course approximately 200m upstream of the village, just downstream of the Sewage Treatment Works. Hence, instead of running along the valley floor the Brook now runs at a higher point in the valley, before entering a series of culverts adjacent Sea View Gardens, then running under the village. The channel diversion away from the valley bottom was thought to have been undertaken to feed watercress farms and fish cleaning stations prior to the Second World War. The Brook finally discharges through a 0.6m diameter culvert beneath the Sea Road, and then cascades down onto the beach. Figure 4-1 shows the extent of the catchment area draining to Outer Hope.

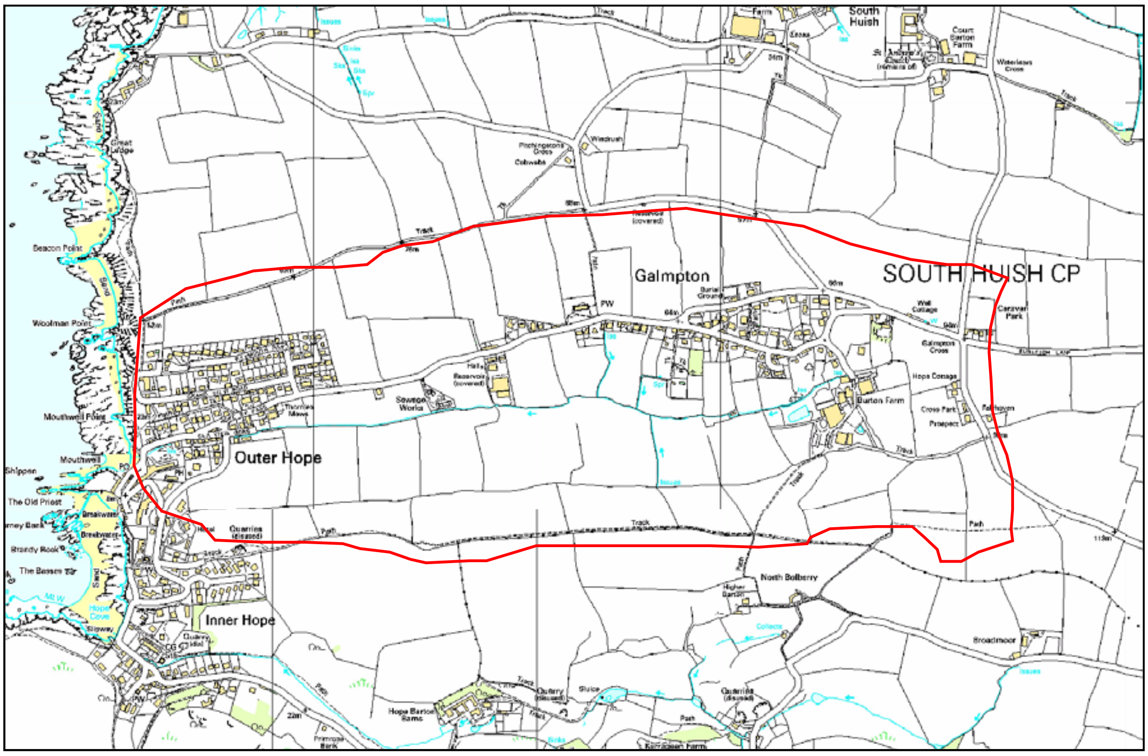


Figure 4-1: Outer Hope catchment boundary

Catchment descriptors were obtained from the FEH CD-ROM. Small changes to the catchment area were made to more accurately represent the catchment draining to Outer Hope, as derived from the Ordnance Survey mapping. With this exception, the catchment descriptors were unadjusted from that defined by the FEH CD-ROM. Table 4-1 illustrates the key catchment descriptors for the Outer Hope Brook.

Catchment Descriptor	Description	Value
Area	Catchment drainage area (adjusted)	1.56 km²
FARL	Index of flood attenuation due to reservoirs and lakes (1 indicates no attenuation)	1
PROPWET	Proportion of time when SMD <6mm	0.47
BFIHOST	Baseflow Index derived using the HOST classification	0.618
DPLBAR	Mean of distances along drainage paths between 50m grid node and the outlet	1.34
DPSBAR	Mean of all inter-nodal slopes along drainage slopes	122
SAAR	Standard period (1961-90) average annual rainfall (mm)	884
SPRHOST	Standard Percentage Runoff derived using HOST	26.49
URBEXT (2000)	Extent of urban and suburban cover	0.0778

Table 4-1: Key Catchment Descriptors

4.3. FEH Assessments

The following table describes the range of flood return period events for which flow estimates were estimated.

Return Period (% AEP)	Return Period (Years)
20% AEP	5-year
5% AEP	20-year
2% AEP	50-year
1.33% AEP	75-year
1% AEP	100-year
1% AEP + 20% Climate Change	100-year + 20% Climate Change
1% AEP + 30% Climate Change	100-year + 30% Climate Change
0.1% AEP	1000-year

Table 4-2: Return Period Definitions

4.3.1. Statistical assessment

The results from the FEH Statistical assessment are shown below. No adjustment to QMED has been undertaken using donor stations, as local gauged catchments were not considered similar enough to the Outer Hope catchment for inclusion. The results from the Statistical assessment are shown in Table 4-3 below.

4.3.2. FEH Revitalised Flood Hydrograph

The results from the ReFH assessment are shown in Table 4-3. The critical storm duration was calculated for the catchment at 1.5-hours, based on the equation in FEH (using SAAR and Tp).

Return Period	ReFH Peak Flow (m^3/s)	FEH Statistical Peak Flow (m^3/s)	Difference (m^3/s)
20% AEP	1.0	0.7	0.3
5% AEP	1.5	1.0	0.5
2% AEP	1.9	1.3	0.6
1.33% AEP	2.1	1.5	0.6
1% AEP	2.2	1.6	0.6
1% AEP + 20% CC	2.7	1.9	0.8
1% AEP + 30% CC	2.9	2.0	0.9
0.1% AEP	4.2	2.9	1.3

Table 4-3: ReFH and FEH Statistical Design Flows

4.4. Final Design Flows

The final design flows applied in the hydraulic model are displayed in Table 4-4. The ReFH flows were used in preference to the Statistical flows as these were higher estimates, and hence precautionary for any design testing.

Return Period	ReFH Peak Flow (m^3/s)
20% AEP	1
5% AEP	1.5
2% AEP	1.9
1.33% AEP	2.1
1% AEP	2.2
1% AEP + 20% CC	2.7
1% AEP + 30% CC	2.9
0.1% AEP	4.2

Table 4-4: Final Design Flows

5. Hydraulic Modelling

5.1. Hydraulic Model Build

5.1.1. Introduction

The computational hydraulic model was developed using ISIS software. The following data was used to develop the model:

- Centreline topographic survey (2001);
- Centreline topographic survey (2012); and
- Light Detecting and Ranging (LiDAR) data provided by the Environment Agency in October 2012.

It should be noted that the Centreline surveys (2001 and 2012) were appointed directly by South Hams District Council and were not completed to Environment Agency specification, and are not therefore as detailed as similar studies. The following assumptions were applied in the development of the ISIS hydraulic model:

- Mannings 'n' values have been set using Chow (1959), at 0.040 for in-channel (representative of minor streams, some winding and shoals) and 0.050 for the floodplains (representative of representative of light brush and trees, or scattered brush on floodplains), with the exception of the floodplain channel (the original natural course of the Brook), where they were set to a universal 0.040;
- Structure spill (i.e. bridge or culvert decks) coefficients were set to 1.2 (representative of road surface and limited hindrance to the passage of flow), whereas spill coefficients linking the main Brook channel to the floodplain channel were set to 0.5 to represent the higher roughness values along the lengths of the spills (representative of tree lined banks);
- LiDAR data was the predominant source of information for the floodplain channel, where possible this was supplemented with surveyed levels from Centreline Surveys;
- A normal depth boundary was applied as the downstream boundary for both the main Brook channel and the floodplain channel;
- An inflow of 0.35 m^3/s was used as the upstream boundary of the floodplain channel to solve model instability issues. However, since the floodplain channel follows the valley bottom, water will naturally drain to this point, so it is likely that a proportion of the catchment flows would reach the floodplain channel without having first spilled from the Outer Hope Brook; and
- Due to the steep nature of the watercourse, the system of culverts and bridges and the floodplain channel it was necessary to use higher than normal initial conditions to enable the model to run. This limitation will need to be taken into account when assessing potential flood alleviation options.

5.1.2. Baseline Model

Ground levels at the upstream extent of the model are around 55-56m AOD, falling to 9-10m AOD at the downstream extent of the model some 1600m away. The key features of the ISIS hydraulic model are displayed in Table 5-1.

Feature	Number / Description
Total number of nodes	68
Total length	1.6 km
Spill coefficients	1.2 for structures and 0.5 for spills between the Outer Hope Brook and the floodplain channel
Number of river cross sections	38
Number of Structures	4
Number of boundaries	4; upstream inflows for the Outer Hope Brook and floodplain channel, and a Normal Depth boundary for the downstream extents.

Table 5-1: ISIS model key features

The ISIS model schematic is shown in Figure 5-1, showing the split between the main Brook channel and the flood channel.

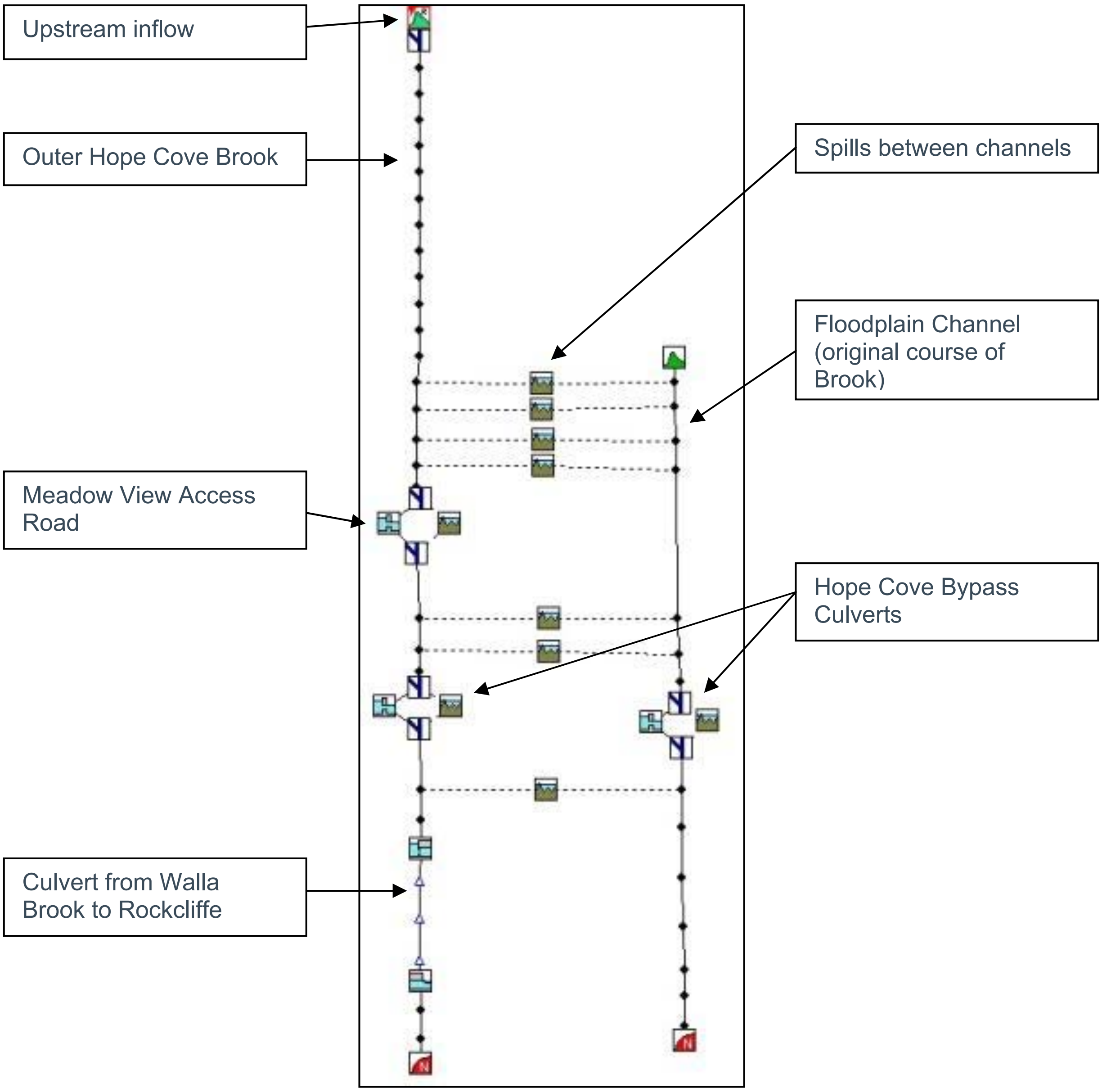


Figure 5-1: ISIS model schematic

5.2. Model Verification

The hydrological and hydraulic model was compared against observations from the following flood events to generate confidence in its predictions, in lieu of the ability to calibrate against recorded data

- 23 April 1999;
- 07 April 2001; and
- 09 February 2009.

Whilst no flood level information was available for these events to calibrate the model, anecdotal evidence and photographs taken during the flood event have been used to compare against that predicted by the hydrological and hydraulic model. Rainfall data for the three events was routed through the hydrological and hydraulic model and the water level results compared to those recorded in Outer Hope.

The daily rainfall gauge at Hope Cove (NGR SX6816 4028) was supplemented with information from the nearest Tipping Bucket Rainfall (TBR) gauge at Harbertonford (SX 79180 55988) to provide more detail on storm durations and rainfall profiles. It should be noted that this gauge is over 15km from the study area, but in the absence of better available data this is a suitable donor. Information provided to the study, by local residents, indicated that the community floods during short duration, high intensity storms, typical of the Devon and Cornwall region. It is therefore likely that the majority of the daily rainfall total recorded at the Hope Cove station fell in a considerably shorter time period; this is supported by the storm profiles recorded at Harbertonford.

For the rainfall to be routed through the ReFH hydrology unit it requires the total rainfall to be distributed across a given storm duration. The rainfall profile recorded at Harbertonford was therefore applied to the Hope Cove rainfall totals.

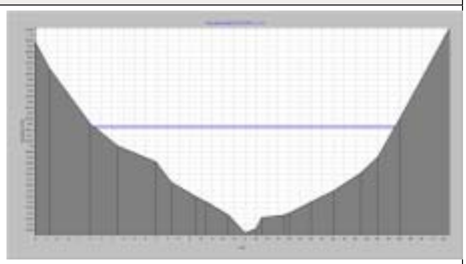
The key features of the three verification events are shown in Table 5-2. This indicates that the rainfall totals and event return periods for the two gauges are broadly similar for all three flood events. The rainfall return periods, calculated using the event rarity tool in the FEH CD-ROM (depth-duration frequency) indicates that all three flood events could be expected on a relatively frequent basis (i.e. less than 3-years). However, it should be noted that the return period varies significantly dependent on the storm duration, for which we are reliant on durations from the Harbertonford rain gauge. For example, if the storm duration for 23 April 1999 event is reduced to 4-hours (from 7-hours) the return period increases from 3-years to 6-years. As the residents indicate that the storms causing flooding at Outer Hope are intense, short duration events the actual event return periods may be higher than those stated below.

Rainfall Event	Rainfall Totals (mm)		Rainfall Duration (Harbertonford)	Approximate Return Period (years)	
	Hope Cove	Harbertonford		Hope Cove	Harbertonford
23 April 1999	30.9	27	7	2.9	1.3
7 April 2001	17.9	11	4	1.3	< 1 month
9 February 2009	42.2	49.2	17	3	2.4

Table 5-2: Verification events

5.2.1. 23 April 1999 Flood Event

The following table compares event photographs with the outputs from the hydraulic model for the 23 April 1999 flood event.

Location	Event Photograph	Model Results
Looking upstream from Outer Hope bypass road; cross section FPCH_0285U		 The model indicates depths of up to 0.9m deep and approximately 30m wide, this would appear to slightly overestimate the flood extents.

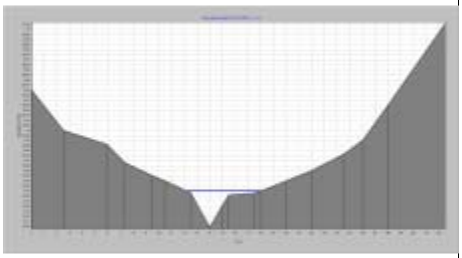
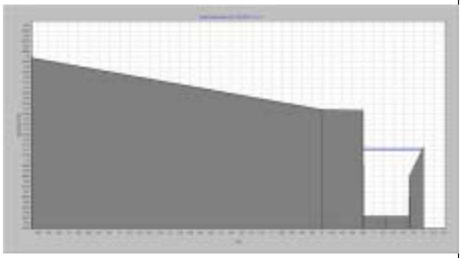
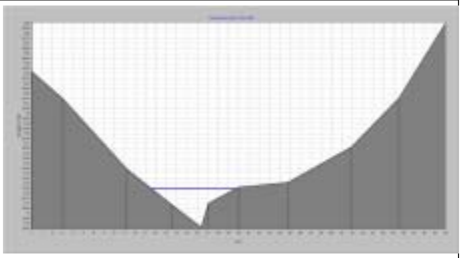
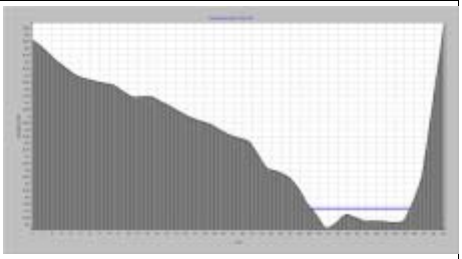
Culvert outlet from the Outer Hope bypass road; cross section FPCH_0285D		 The model indicates flood extent approximately 6m in width, similar to that indicated in the photograph.
Culvert outlet from the Meadow View access road; cross section XS16_CH1407 D		 The model has peak water levels equal to that indicated in the photograph.
Looking downstream from Outer Hope bypass road towards Walla Brook and Holbeche House; cross sections FPCH_0290 and FPCH_0312		 The model indicates a flood extent approximately 9m in width and depths <0.4m, which is in agreement with the site observations.
Exit point from the car park at the downstream end of the model; cross section FPCH_0491		 The model indicates shallow water depths of <0.2m, over a wide area approximately 20m in width, similar to that in the event photograph.

Table 5-3: 23 April 1999 event comparison with model outputs

5.2.2. 07 April 2001 Flood Event

The following table compares event photographs with the outputs from the hydrological and hydraulic model for the 7 April 2001 flood event.

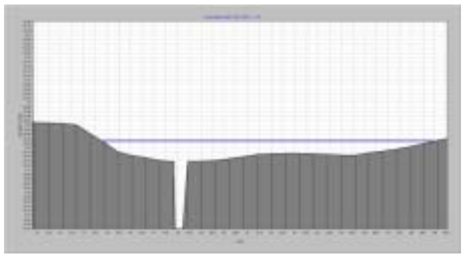
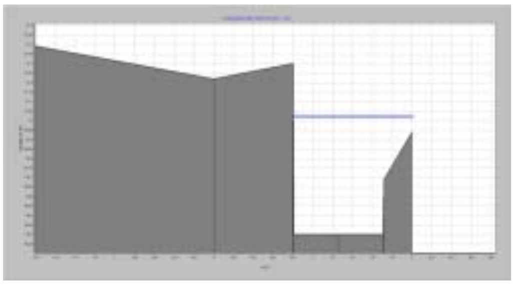
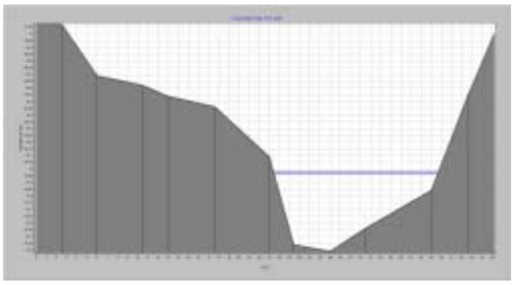
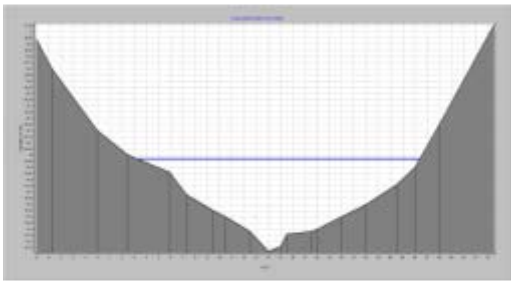
Location	Event Photograph	Model Results
Looking downstream towards the car park from St Johns Lodge; cross section FPCH_0362		 The model indicates a flood extent of approximately 15m in width, with depths of <0.2m; this appears to be similar to that in the event photographs.
Looking upstream from The Lodge; cross section FPCH_0362		

Table 5-4: 07 April 2001 event comparison with model outputs

5.2.3. 9 February 2009 Flood Event

The following table compares event photographs with the outputs from the hydrological and hydraulic model for the 09 February 2009 flood event.

Location	Event Photograph	Model Results
Adjacent Sunny Cot; cross section XS16_CH1418		 The model indicates out of bank flows at this section from the left bank, but not the right bank. The photo clearly shows the right bank being overtopped, suggesting that the model is under-estimating water level (or flow).
Looking down to the bottom of the valley through the garden of Sunny Cot; cross section FPCH_0280		 The model shows a flood extent approximately 17m wide, with a depth of <0.5m; this appears to be higher than that indicated in the event photograph.
Looking upstream from Outer Hope bypass road; cross section FPCH_0285U		 The model shows a flood extent approximately 24m wide, with a depth of <0.5m; this appears to be higher than that indicated in the event photograph.

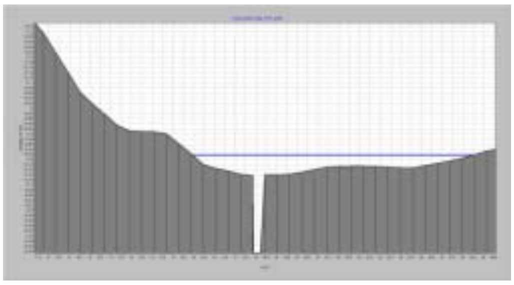
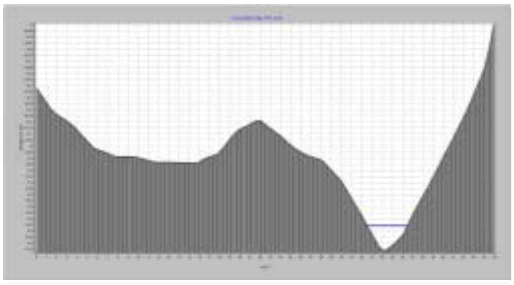
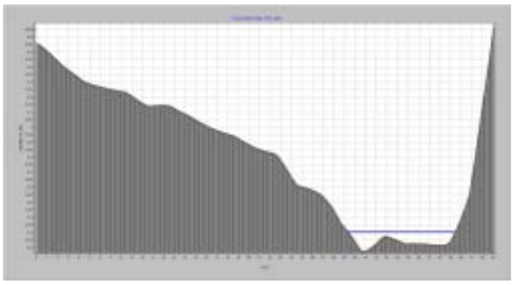
Lodge House and St Johns Lodge access road looking upstream; cross section FPCH_0362		 The model indicates a flood extent approximately 14m wide at a depth of <0.2m; whilst the extents are similar the model has underestimated depths marginally.
Outer Hope car park, looking upstream; cross section FPCH_0476		 The model indicates flood extents of approximately 4m width at a depth of <0.3m; this appears to be a slight overestimate to that shown in the photograph.
Exit point from the car park at the downstream end of the model; cross section FPCH_0491		 The model indicates flood extents of approximately 10m width at a depth of <0.2m, very similar to that shown in the photograph.

Table 5-5: 09 February 2009 event comparison with model outputs

5.2.4. Verification Summary

The hydrological and hydraulic models were shown to perform well when compared to the three flood events, and predict flood extents and depths similar to that observed. The following table summarises the performance of the model for the three events, with '+' representing a model overestimate, '✓' a correlation, and '-' a model underestimate.

Location	23 April 1999	07 April 2001	09 February 2009
	Performance (+,✓,-)	Performance (+,✓,-)	Performance (+,✓,-)
Upstream of bypass road	+	N/A	+
Meadow View / Sunnycot	N/A	N/A	-

Holbeche House / St Johns Lodge	✓	✓	-
Outer Hope Car Park	✓	N/A	✓ / +

Table 5-6: Model Verification Summary

5.2.5. Sensitivity Testing

The following sensitivity tests were run to assess the impact of changes in the model assumptions on results for the 1% AEP event:

- Mannings 'n' values were increased and decreased by 10%; and
- Structure and floodplain spill coefficients increased and decreased by 50%.

The results of these tests are summarised in Table 5-7.

Model Node	Location	1% AEP event Baseline PWL (mAOD)	Mannings +10% Difference (m)	Mannings -10% Difference (m)	Spill Coefficients +50% Difference (m)	Spill Coefficients -50% Difference (m)
XS1_CH0000	Upstream model extent	55.72	-0.02	0.02	0.00	0.00
XS11_CH0944	Adjacent Sewage Treatment Works	27.36	-0.04	0.04	0.00	0.00
XS13_CH1127	Adjacent field boundary	23.53	-0.04	0.04	0.00	0.00
XS16_CH1376	Adjacent Meadow View	18.54	0.00	0.01	0.02	-0.04
XS16_CH1407	Adjacent Sunnycot	17.30	-0.03	0.05	-0.02	0.03
XS16_CH1443	Adjacent Wallabrook	16.78	0.00	0.00	0.07	-0.10
XS17_CH1573	Downstream Rockcliffe	13.11	-0.01	0.01	0.01	-0.05
XS18_CH1637	Downstream Extent of Model	10.15	-0.01	0.01	0.01	-0.05
FPCH_0249	Floodplain channel - Meadowview	17.28	-0.02	0.03	-0.01	0.03
FPCH_0275	Floodplain channel - Sunnycot	17.28	-0.02	0.03	-0.01	0.03
FPCH_0285U	Immediately upstream of bypass road culvert	17.28	-0.02	0.03	-0.01	0.03
FPCH_0290	Floodplain channel – Holbeche House	15.45	0.00	0.00	0.00	0.00
FPCH_0362	Floodplain channel – St Johns Lodge	12.87	-0.01	0.01	0.00	0.01
FPCH_0427	Floodplain channel – Car Park	11.36	-0.03	0.03	-0.01	0.03

Table 5-7: Sensitivity assessment results

These results demonstrate that peak water levels are insensitive to changes in the key model parameters tested.

5.2.6. Modelling Summary

The process of verifying the hydrological and hydraulic model can be summarised as follows:

- A simple comparison process using three known flood events was undertaken. Due to the lack of available hydrological (e.g. flow gauges) and hydraulic (e.g. recorded flood levels) data a full model calibration and verification exercise has not been completed. The approach is considered appropriate for this level of study;
- A series of sensitivity tests were undertaken which indicate that the model is not sensitive to changes in key parameters;
- During the verification tests no changes were made to hydrological (e.g. Time to Peak) or hydraulic (e.g. Mannings roughness) parameters to improve the correlation between recorded and modelled results. This is partly due to the model's generally good performance: in some locations and events it was underestimating; and in others overestimating; there was not, therefore, a consistent pattern with which to change the parameters. The key reason for not adjusting any parameters was the uncertainty in inflows, due to the lack of available flow gauges and the application of a remote TBR to provide a rainfall profile for the study area. The cause of differences between the observed and modelled results may be either hydrological or hydraulic parameters, or both, and without further data it would be prudent not to 'fix' the model; and
- Despite such uncertainties the verification tests indicated that the hydrological and hydraulic models represented flood risk mechanisms within Outer Hope well, producing flood extents and depths similar to those experienced during the three events tested. The model is therefore considered to be robust and suitable for generating flood outlines and options testing.

5.3. Design Runs

Having verified the hydrological and hydraulic models, a series of design events were simulated to assess the level of flood risk in Outer Hope, these design events were:

- 20% AEP event;
- 5% AEP event;
- 2% AEP event;
- 1.33% AEP event;
- 1% AEP event;
- 1% AEP + 20% Climate Change event, and + 30% Climate Change event; and
- 0.1% AEP event.

6. Floodplain Outlines

A floodplain outline was generated for the 1% AEP event; this is displayed in Figure 6-1.

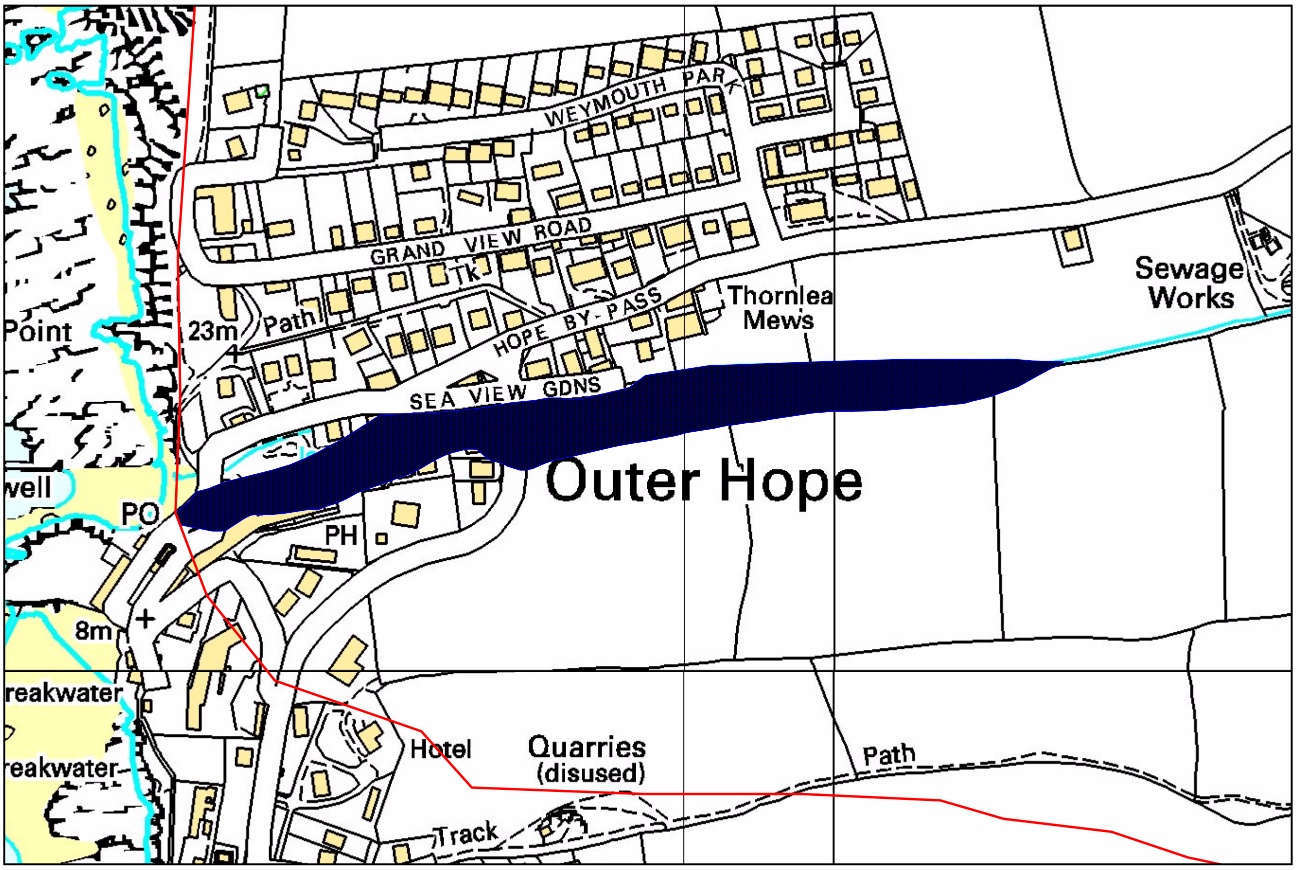


Figure 6-1: 1% AEP flood event outline

7. Conclusion

The following conclusions can be drawn from this hydrological and hydraulic modelling Technical Note:

- Discussions with SHDC and the residents of Outer Hope indicated that the principal flooding mechanism in the village was from the Outer Hope Brook, largely through out of bank flows returning to the natural valley bottom;
- A hydrological assessment has been completed using standard FEH guidance, the preferred method for deriving flows for this catchment was the ReFH methodology;
- A hydraulic model was developed based on Centreline Surveys of 2001 and 2012, supplemented by LiDAR data. A 1D ISIS hydraulic model was constructed to represent the Outer Hope Brook and floodplain areas;
- Three flood events (23 April 1999, 07 April 2001 and 09 February 2009) were tested in the hydrological and hydraulic models and the results compared to the observed flooding. The hydrological and hydraulic models were shown to perform well, and predict flood extents and depths similar to that observed in the three events;
- The sensitivity assessment indicates that the model is not sensitive to changes in key parameters;
- A suite of design events were tested in the hydrological and hydraulic model, and a floodplain outline for the 1% AEP flood event produced; and
- The hydrological and hydraulic models are considered robust and appropriate for assessing potential flood risk management options.

Appendix B. Baseline model results

Modelled Peak Water Levels

		Do Nothing Peak Water Level (mAOD)							
Model Node	**Location**	**20%**	**5%**	**2%**	**1.33%**	**1% AEP event**	**1%+20%**	**1% +30%**	**0.1%**
XS1_CH0000	Upstream model extent	55.58	55.64	55.69	55.70	55.72	55.76	55.78	55.89
XS11_CH0944	Adjacent Sewage Treatment Works	27.13	27.23	27.31	27.34	27.36	27.43	27.47	27.64
XS13_CH1127	Adjacent field boundary	23.33	23.42	23.48	23.51	23.53	23.59	23.62	23.77
XS16_CH1376	Adjacent Meadow View	18.43	18.50	18.53	18.53	18.54	18.55	18.56	18.57
XS16_CH1407	Adjacent Sunnycot	17.15	17.17	17.17	17.17	17.26	17.40	17.43	17.52
XS16_CH1443	Adjacent Wallabrook	16.74	16.75	16.76	16.76	16.77	16.82	16.83	16.85
XS17_CH1573	Downstream Rockcliffe	13.10	13.10	13.10	13.10	13.10	13.11	13.11	13.12
XS18_CH1637	Downstream Extent of Model	10.14	10.14	10.14	10.14	10.15	10.15	10.15	10.16
FPCH_0249	Floodplain channel - Meadowview	16.39	16.60	16.94	17.11	17.24	17.39	17.42	17.52
FPCH_0275	Floodplain channel - Sunnycot	16.15	16.60	16.94	17.11	17.24	17.39	17.42	17.52
FPCH_0285U	Immediately upstream of bypass road culvert	16.15	16.60	16.94	17.11	17.24	17.39	17.42	17.52
FPCH_0290	Floodplain channel – Holbeche House	15.25	15.28	15.30	15.30	15.31	15.36	15.38	15.46
FPCH_0362	Floodplain channel – St Johns Lodge	12.83	12.85	12.86	12.86	12.86	12.89	12.90	12.94
FPCH_0427	Floodplain channel – Car Park	11.25	11.30	11.33	11.34	11.36	11.46	11.49	11.63

Appendix C. Option model results

Modelled Peak Water Levels

Model Node	Location	Options (1% AEP) Peak Water Level (mAOD)					
		Do Minimum	Upsize Culverts	Raised Defences	Land Management	Upstream Storage A	Upstream Storage B
XS1_CH0000	Upstream model extent	55.66	55.72	55.72	55.67	55.70	55.72
XS11_CH0944	Adjacent Sewage Treatment Works	27.26	27.36	27.36	27.27	26.86	26.87
XS13_CH1127	Adjacent field boundary	23.43	23.53	23.53	23.45	23.05	23.06
XS16_CH1376	Adjacent Meadow View	18.49	18.61	18.80	18.52	18.05	18.06
XS16_CH1407	Adjacent Sunnycot	17.18	17.20	18.31	17.17	16.96	16.93
XS16_CH1443	Adjacent Wallabrook	16.79	16.84	17.74	16.75	16.88	16.82
XS17_CH1573	Downstream Rockcliffe	13.08	13.17	13.23	13.10	13.13	13.14
XS18_CH1637	Downstream Extent of Model	10.12	10.21	10.28	10.14	10.17	10.18
FPCH_0249	Floodplain channel - Meadowview	17.17	16.91	17.11	16.78	16.37	16.37
FPCH_0275	Floodplain channel - Sunnycot	17.17	16.91	17.11	16.78	15.80	15.80
FPCH_0285U	Immediately upstream of bypass road culvert	17.17	16.91	17.11	16.78	15.80	15.80
FPCH_0290	Floodplain channel – Holbeche House	15.27	15.31	15.28	15.29	15.10	15.10
FPCH_0362	Floodplain channel – St Johns Lodge	12.84	12.86	12.85	12.85	12.78	12.78
FPCH_0427	Floodplain channel – Car Park	11.28	11.36	11.31	11.32	11.01	11.01

Appendix D. Benefit assessment

Project Summary Sheet

Client/Authority				Prepared (date)	08/02/2013
South Hams District Council				Printed	18/07/2013
Project name				Prepared by	AMC
Outer Hope Flood Study				Checked by	PJC
Project reference				Checked date	08/02/2013
Base date for estimates (year 0)	Dec-2012				
Scaling factor (e.g. £m, £k, £)	£k	(used for all costs, losses and benefits)			
Year	0	30	75		
Discount Rate	3.5%	3.00%	2.50%		
Optimism bias adjustment factor	60%				

Costs and benefits of options

	Costs and benefits £k				
Option number	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**
Option name	Do Nothing	2% AEP SoP	1% AEP SoP	0	0
AEP or SoP (where relevant)					
COSTS:					
PV capital costs	0	268	268		
PV operation and maintenance costs	0	0	0		
PV other	0				
Optimism bias adjustment	0	0	0		
PV negative costs (e.g. sales)					
PV contributions					
Total PV Costs £k excluding contributions	0	268	268	0	0
Total PV Costs £k taking contributions into account	0	268	268	0	0
BENEFITS:					
PV monetised flood damages	1,473	234	86		
PV monetised flood damages avoided		1,239	1,388	1,473	1,473
PV monetised erosion damages					
PV monetised erosion damages avoided (protected)		0	0		
Total monetised PV damages £k	1,473	234	86	0	0
Total monetised PV benefits £k		1,239	1,388	1,473	1,473
PV damages (from scoring and weighting)					
PV damages avoided/benefits (from scoring and weighting)					
PV benefits from ecosystem services					
Total PV damages £k	1,473	234	86	0	0
Total PV benefits £k		1,239	1,388	1,473	1,473

DECISION-MAKING CRITERIA:

excluding contributions

Based on total PV benefits (in cludes benefits from scoring and weighting and ecosystem services)

	Option 1	Option 2	Option 3	Option 4	Option 5
Net Present Value **NPV**		972	1,120	1,473	1,473
Average benefit/cost ratio **BCR**		4.6	5.2		
Incremental benefit/cost ratio **IBCR**			-		
			Highest bcr IBCR>1		

Based on monetised PV benefits (ex cludes benefits from scoring and weighting and ecosystem services)

	Option 1	Option 2	Option 3	Option 4	Option 5
Net Present Value **NPV**		972	1,120	1,473	1,473
Average benefit/cost ratio **BCR**		4.6	5.2		
Incremental benefit/cost ratio **IBCR**			-		
			Highest bcr		

including contributions

Taking account of contributions (in cludes benefits from scoring and weighting and ecosystem services)

	Option 1	Option 2	Option 3	Option 4	Option 5
Net Present Value **NPV**		972	1,120	1,473	1,473
Average benefit/cost ratio **BCR**		4.6	5.2		
Incremental benefit/cost ratio **IBCR**			-		
			Highest bcr		

Based on monetised PV benefits (ex cludes benefits from scoring and weighting and ecosystem services)

	Option 1	Option 2	Option 3	Option 4	Option 5
Net Present Value **NPV**		972	1,120	1,473	1,473
Average benefit/cost ratio **BCR**		4.6	5.2		
Incremental benefit/cost ratio **IBCR**			#DIV/0!	-0.3	-
			Highest bcr #DIV/0!		
Best practicable environmental option (WFD)					

Brief description of options:

Option 1	Do Nothing
Option 2	2% AEP SoP
Option 3	1% AEP SoP
Option 4	
Option 5	

Comments and assumptions:

Summary Annual Average Damage

Sheet Nr.

Client/Authority
South Hams District Council

Project name
Outer Hope Flood Study

Option:
Do nothing - Year of Write off yr 9 (base case)

Project reference	0
Base date for estimates (year 0)	Dec-2012
Scaling factor (e.g. £m, £k, £)	£k
Discount rate	Variable
Applicable year (if time varying	2012

Prepared (date)	08/02/2013
Printed	18/07/2013
Prepared by	AMC
Checked by	PJC
Checked date	11/02/2013

Average waiting time (yrs) between events/frequency per ye

	0.5	1	5	20	50	75	100	1000	Infinity	
	2.000	1.000	0.200	0.050	0.020	0.013	0.010	0.001	0	
Damage category	Damage £k									
Residential property	0	0	3	8	58	89	99	132	135	5
Ind/commercial (direct)	0	0	0	0	0	0	0	0	0	0
Temp Acc	0	0	0	0	27	27	27	39	40	1
Traffic related									0	0
Emergency services	0	0	0	1	6	10	11	14	14	1
Agricultural									0	0
									0	0
									0	0
Total damage £k	0	0	3	8	91	126	136	185	190	6
Area (damagexfrequency		0	1	1	1	1	0	1	0	

AAD	**6**	£k
Write off (Year 9)	**1,280**	£k
PVd	**1,473**	£k

Notes
Area calculations assume drop to zero at maximum frequency.
Default value for the highest possible damage assumes continuation of gradient for last two points, an alternative value can be entered, if appropriate.
One form should be completed for each option, including 'without project', and for each representative year if profile changes during scheme life (e.g. sea-level rise)
Residential property, Industrial / commercial (direct), and Other damages are itemised in Asset AAD sheet and automatically linked to this sheet

Summary Annual Average Damage

Sheet Nr.

Client/Authority
South Hams District Council

Project name
Outer Hope Flood Study

Option:
Do nothing - 2% SoP

Project reference	0		
Base date for estimates (year 0)	Dec-2012	Prepared (date)	08/02/2013
Scaling factor (e.g. £m, £k, £)	£k	Printed	18/07/2013
Discount rate	Variable	Prepared by	AMC
		Checked by	PJC
Applicable year (if time varying	2012	Checked date	11/02/2013

	Average waiting time (yrs) between events/frequency per ye									
	0.5	1	5	20	50	75	100	1000	Infinity	
	2.000	1.000	0.200	0.050	0.020	0.013	0.010	0.001	0	
Damage category	Damage £k									
Residential property	0	0	0	0	0	325	337	383	389	6
Ind/commercial (direct)	0	0	0	0	0	0	0	0	0	0
Temp Acc	0	0	0	0	0	80	80	92	94	1
Traffic related									0	0
Emergency services	0	0	0	0	0	35	36	41	42	1
Agricultural									0	0
									0	0
									0	0
Total damage £k	0	0	0	0	0	440	454	517	524	8
Area (damagexfrequency		0	0	0	0	1	1	4	1	

AAD	**8**	£k
Write off (Year Zero)	**-**	£k
PVd	**234**	£k

Notes
Area calculations assume drop to zero at maximum frequency.
Default value for the highest possible damage assumes continuation of gradient for last two points, an alternative value can be entered, if appropriate.
One form should be completed for each option, including 'without project', and for each representative year if profile changes during scheme life (e.g. sea-level rise)
Residential property, Industrial / commercial (direct), and Other damages are itemised in Asset AAD sheet and automatically linked to this sheet

Summary Annual Average Damage

Sheet Nr.

Client/Authority
South Hams District Council
Project name
Outer Hope Flood Study

Option:
Do nothing - 1% SoP

Project reference	0		
Base date for estimates (year 0)	Dec-2012	Prepared (date)	08/02/2013
Scaling factor (e.g. £m, £k, £)	£k	Printed	18/07/2013
Discount rate	Variable	Prepared by	AMC
		Checked by	PJC
Applicable year (if time varying	2012	Checked date	11/02/2013

Average waiting time (yrs) between events/frequency per ye	0.5	1	5	20	50	75	100	1000	Infinity	
	2.000	1.000	0.200	0.050	0.020	0.013	0.010	0.001	0	
Damage category	Damage £k									
Residential property	0	0	0	0	0	0	0	383	426	2
Ind/commercial (direct)	0	0	0	0	0	0	0	0	0	0
Temp Acc	0	0	0	0	0	0	0	92	103	1
Traffic related									0	0
Emergency services	0	0	0	0	0	0	0	41	46	0
Agricultural									0	0
									0	0
									0	0
Total damage £k	0	0	0	0	0	0	0	517	574	3
Area (damagexfrequency		0	0	0	0	0	0	2	1	

AAD	**3**	£k
Write off (Year Zero)	**-**	£k
PVd	**86**	£k

Notes
Area calculations assume drop to zero at maximum frequency.
Default value for the highest possible damage assumes continuation of gradient for last two points, an alternative value can be entered, if appropriate.
One form should be completed for each option, including 'without project', and for each representative year if profile changes during scheme life (e.g. sea-level rise)
Residential property, Industrial / commercial (direct), and Other damages are itemised in Asset AAD sheet and automatically linked to this sheet

Appendix E. Scheme Costs

Outline Scheme Costs

Option	Description	Length/Volume	Unit	Approx. Height (m)	Approx. Cost
A) Flood Storage	Upstream storage A or B				£ 102,773.16
	PAR / Detailed Design / Supervision Costs (consultant, EA)	20%			£ 20,554.63
	Optimism Bias	60%			£ 61,663.90
	Total				**£ 184,991.69**
B) Raised Defences - Walls	Walls along left bank of Outer Hope Brook	100	m	1.2	£ 183,554.92
					£ -
					£ 183,554.92
	PAR / Detailed Design / Supervision Costs (consultant, EA)	20%			£ 36,710.98
	Optimism Bias	60%			£ 110,132.95
	Total				**£ 330,398.85**
C) Infill low spots	Infill low spots adjacent Wallabrook	25	m	1	£ 45,888.73
					£ -
					£ -
	PAR / Detailed Design / Supervision Costs (consultant, EA)	20%			£ 9,177.75
	Optimism Bias	60%			£ 27,533.24
	Total				**£ 82,599.71**
Total Preferred Option (A+C)					**£ 267,591.40**

Atkins Ltd,
The Hub,
500 Park Avenue,
Aztec West,
Almondsbury,
Bristol,
BS32 4RZ

Email: andrew.cox@atkinsglobal.com
Telephone: 01454 662289