SCARBOROUGH BOROUGH COUNCIL

Church Becks, Scalby

Flood Alleviation Scheme – Phase 2

FINAL REPORT

Notice

This document has been produced by ATKINS for Scarborough Borough Council solely for the purpose of the Church Beck, Scalby project appraisal report.

It may not be used by any person for any other purpose other than that specified without the express written permission of ATKINS. Any liability arising out of use by a third party of this document for purposes not wholly connected with the above shall be the responsibility of that party who shall indemnify ATKINS against all claims costs damages and losses arising out of such use.

Document History

JOB NUMBER: 5002531			DOCUMENT REF: 5002531/98/DG/41			
Revision	Purpose and Description	Originated	Checked	Reviewed	Authorised	Date
D-1	Draft for Review	E Ainsworth	O Drieu	T Ishaq	TI	18.2.04
D-2	Draft for Review	E Ainsworth	O Drieu	T Ishaq	-	21.3.04
D-3	Draft for Issue	E Ainsworth	M Timmins	TAI / JW	TI / KAT	25.3.04
D-4	Final Report	E Ainsworth	J Fisher	J Wright	J Wright	August 2004

CONTENTS

Glossary of terms

Term	***Meaning / Definition***
AAD	Average Annual Damages
AOD	Above Ordnance Datum
BF	Base Flow (an FEH term)
Defra	Department for Environment, Food and Rural Affairs (formerly MAFF)
EA	Environment Agency
FAS	Flood Alleviation Scheme
FEH	Flood Estimation Handbook
FSR	Flood Studies Report
ISIS	Mathematical one-dimensional hydrodynamic model for open channel flow
LiDAR	Light Detection And Ranging (ground levels from aerial survey)
MAFF	Ministry of Agriculture, Fisheries and Food (now Defra)
MCM	Multicoloured Manual (for deriving costs of flooding)
NPV	Net Present Value
PAG3	Project Appraisal Guidance Volume 3
PAR	Project Appraisal Report
Phase 1 Report	Critical Watercourse Study – Church Beck, (Atkins July 2002)
PR	Percentage Runoff
PV	Present Value
Q100	1 in 100 year return period
Q_{MED}	(Q 'med') Median Annual Flood
SAAR	Standard Annual Average Rainfall (an FEH term)
SBC	Scarborough Borough Council
SoP	Standard of Protection
T_P	Time to peak (an FEH term)
URBEXT	Urban Extent (an FEH term)
WINFAP-FEH	FEH Windows software package

Executive Summary

A phase 1 (scoping report) on the flooding issues was undertaken in 2003 for the Church Beck catchment. At that stage it was determined that a more detailed options appraisal report was justified. This report represents an in-depth study that has been undertaken to determine the causes, extents and frequency of flooding. Mitigation options have also been assessed and costed.

General Conclusions

Flooding to the properties around Carr Lane, Hackness Road and Scalby Beck Road is frequent and extensive and justifies the designation of Church Beck as a Critical Ordinary Watercourse. The most recent severe flood occurred in October 2000 when flooding was experienced on roads and by approximately 24 residential properties to a depth of up to 1m. This event has been estimated to have a return period of 15-20 years.

Hydrological assessments have determined that the flow along Church Beck is 4.9 m^3/s for the 100 year return period event and 5.8 m^3/s for the 200 year event. Coldgill Beck contributes 1.5m^3/s and 1.8 m^3/s respectively to these flows.

Hydraulic modelling predicts that flooding is first experienced by 3 properties for a 1 in 10 year return period. Church Beck Cottage and Brook View flood as a result of culvert incapacity under Carr Lane and 113 Hackness Road floods as a result of channel incapacity along the stretch that had been restricted by the recent piling works. This rises to 28 properties for the 25 year event and 35 properties for 100 year event. Flood depths of up to 1.55m are predicted for some properties for the 1 in 100 year event as confirmed by recent flooding incidents.

Specific Causes of Flooding

The hydraulic analyses have revealed that there are a number of contributing factors to flooding in the area caused by various mechanisms. The table below summarises the causes, extents and locations of the flooding and these are described in more detail in subsequent paragraphs.

Summary of the locations, causes and mechanisms of flooding in the study area

Location	No. of Properties affected	Causes	Return Period for Start of flooding
Hackness Road	7	Limited capacity of Low Hill footbridge (CHU_00282) and incapacity of channel along Hackness Road	10 – 50 years
Properties around the Church Beck and Coldgill Beck confluence	6	Limited capacity of small weir and ornamental bridge at Church Beck Cottage (CHU_00427) and the twin arched Carr Lane culvert around the confluence of Church Beck and Coldgill Beck (CHU_00423)	10 years
Scalby Beck Road	22	Limited capacity of channel along Hackness Road with flooding from left bank across field	25 years
Carr Lane		Incapacity of culvert under Carr Lane	10 years
Hackness Road		Low Hill footbridge obstruction to flow and general channel incapacity	10 years
Field adjacent to Hackness Road		General channel incapacity	5-10 years

The incapacity of key structures is a direct cause of flooding. The small weir and ornamental bridge at Church Beck Cottage (CHU_00427) and the twin arched Carr Lane culvert around the confluence of Church Beck and Coldgill Beck (CHU_00423) both limit flow capacity and thus act as hydraulic controls leading to flooding. The properties affected at both these locations (that occur in close proximity) are Church Beck Cottage, Brook View School House, Dainton, Homestead and Toad Cottage.

The capacity of the channel at Low Hill footbridge (CHU_00282) is also limited as the footbridge acts as an obstruction to the flow. This causes flooding of the footpath and Hackness Road.

The reach of Church Beck along Hackness Road has limited channel capacity as a result of bank subsidence and stabilisation works. Even with the recent piling works undertaken on the right bank the channel still cannot accommodate flows greater than a return period of 10-25 years. Flooding originates in the field adjacent to Hackness Road due to the lower elevation of the left bank compared to the right bank over much of the beck's length along the road. The field slopes down away from the channel providing a flow path towards the properties on Scalby Beck Road. Flooding also occurs along Hackness Road by this mechanism.

Mitigation Measures Proposed

A number of mitigation measures were assessed, tested and costed as summarised in the table below. (Options 1 and 2 represent do nothing and do minimum but have been rejected.) A range of return periods were also assessed and the 200 year Standard of Protection was considered to be the most cost-beneficial for the preferred scheme.

Summary of mitigation measures and cost benefit assessments

<table>
<tr><th>Option</th><th>3 (Flood Storage)</th><th>4 (Channel Widening)</th><th>5 (Options 3&4)</th></tr>
<tr><td>Protecting properties at Coldgill/Church Beck confluence</td><td colspan="3">1. Replace culvert under Carr Lane with larger capacity culvert, incorporating wildlife ledge. (Appx. 15m length.)
2. Extend culvert upstream a distance of appx. 20m to counter channel incapacity along this stretch.
3. Undertake scour protection works to right bank along Church Beck to counter increased storm flows out of culvert under Carr Lane.</td></tr>
<tr><td>Protecting Properties along Hackness Road</td><td>Re-design Low Hill Road footbridge to facilitate storm flows.
Channel stabilisation works will remove most serious constriction that currently causes flooding. (Already undertaken by SBC.)</td><td rowspan="2">Re-design Low Hill Road footbridge to facilitate storm flows.
Undertake channel widening of Church Beck along Hackness Road (appx. 200m length), using adjacent field to accommodate wider 2-stage channel.
Replace existing hedge with new species rich hedgerow.
Enlarge outfall to Sea Cut, incorporating steps for wildlife access.</td><td>Re-design Low Hill Road footbridge to facilitate storm flows.
Construct embankments along Church Beck to contain the flow in-bank.
Undertake limited widening of channel along Hackness Road (appx. 200m length).
Replace existing hedge with new species rich hedgerow.</td></tr>
<tr><td>Protecting Properties along Scalby Beck Road</td><td>Allow flooding to field and contain floodwaters as storage.
Construct flood bund to protect Scalby Beck Road flooding from the field.</td><td>Construct flood bund to protect properties along Scalby Beck Road.</td></tr>
<tr><td>Church Beck Channel Stabilisation along Hackness Road</td><td>Drive steel sheet piling along right bank (length 100m).</td><td>Undertaken as part of channel widening.</td><td>Undertaken as part of channel widening.</td></tr>
<tr><td>Cost Benefit Ratio range (200 yr SoP)</td><td>2.6 – 3.4</td><td>4.0 – 5.1</td><td>4.0 – 5.1</td></tr>
<tr><td>Defra Priority Score (200 yr SoP)</td><td>10.1 - 11.6</td><td>12.5 – 14.7</td><td>13.6 – 15.8</td></tr>
</table>

Ecological considerations

The ecological benefits of the three schemes have been considered in order to make a decision on the preferred option. For Option 3 and 5 the flood storage in the improved grassland field could increase the diversity of species within the sward and create areas of marshy grassland that would benefit both invertebrates and birds. Options 4 and 5 will widen the watercourse enabling the colonisation of limited aquatic and some marginal flora. Option 4 will include an enhancement to an enlarged Sea Cut Outfall by means of a stepped structure which will be beneficial to wildlife, e.g otters.

There is little to separate the options from an ecological viewpoint as channel widening and flood storage are both able to enhance the ecology.

Selection of Proposed Scheme

There is little to separate the schemes (especially options 4 and 5) in terms of costs. Therefore cost benefit ratios and a consideration of the risks associated with the schemes have been considered in order to make a decision on the preferred option.

In conclusion, option 4 is the preferred scheme based on the higher cost benefit ratio, the fewer risks associated with the scheme and the greater ecological benefit. This scheme designs flooding out of the system by widening (replacing) the existing culvert under Carr Lane and extending it upstream by a distance of approximately 20m. It also widens the channel from its current 1.5-2m to 5-6m and includes the construction of flood banks. The new channel is proposed as a two-stage system accommodating normal and storm flows without detriment. Channel stabilisation is inherent in the shallowing of the slopes of the left and right banks and a larger outfall structure can be designed to be more sympathetic to wildlife. It is recommended that a 200 year standard of protection is adopted throughout this scheme.

Recommendations

In terms of the selection of freeboard and factors of safety regarding channel design, a manning's n of 0.08 (to simulate a highly vegetated channel) indicated increased water levels of 200-300mm for the 100 year design event. It is recommended that this robustness should be accommodated for in the design as freeboard along the proposed floodbanks.

Note that High water levels in Sea Cut have been considered in this assessment but these are required to be confirmed and re-assessed once final design levels have been determined by the EA.

It is also recommended that a series of trash screens be constructed along the watercourse and at all culvert entrances and that a strict maintenance regime is adopted to ensure that the design remains .

It should be noted that the model has not been calibrated although it has been verified. As the watercourse is considered to be small with a rocky/gravely bed, a higher Manning's n than would normally be utilised should be assigned in design and that robust and adequate factors of safety considered.

The major risks associated with the proposed solution are the ecological constraints (presence of otters) and the requirement to purchase land adjacent to Church Beck along Hackness Road. Consultations with all relevant bodies will also be a requirement. There is, therefore, a risk that the preferred option could be subject to change.

Finally, it should be noted that the indicative flood plain maps indicate that Scalby Beck Road is within the floodplain for the Sea Cut. It is understood that the EA are currently undertaking a flood plain mapping exercise for Sea Cut and so it is critical that consideration must be made for that work otherwise Scalby Beck Road may still be at risk of flooding from Sea Cut.

1 Introduction

1.1 Background

WS Atkins Consultants Limited (Atkins) were commissioned by Scarborough Borough Council (SBC) to prepare a project appraisal report (PAR) for Church Beck critical ordinary watercourse. The aim of this report is to assess and justify the implementation of a flood alleviation scheme (FAS) for the town of Scalby. It is intended that this report would be submitted to Defra for grant aid on capital expenditure.

This report represents phase 2 of the Church Beck project. Phase 1 consisted of a brief assessment of the flooding problem using a limited ground survey, a hydrological assessment, the collation and population of a flood history table and the initial costings and economic appraisal of potential solutions. The Phase 1 report concluded (Atkins, July 2002) that the project was economically and technically viable to proceed to wards a m ore detailed modelling and option assessment stage.

1.2 General Description of Church Beck

Scalby is a small town on the outskirts of Scarborough and the area around Church Beck is towards the western extent of the town. A general location plan is shown in Appendix A.1 and a detailed description of the catchment is presented in Section 4.1.

In summary, Church Beck and Coldgill Beck combine at Carr Lane where the watercourse flows alongside properties and Hackness Road before discharging into Sea Cut. Flooding of various properties occurs along the watercourse, along Hackness Road and numerous properties have flooded in Scalby Beck Road. These locations are presented in Appendix A.2. Flooding has occurred over a number of years with numerous properties (greater than 15) inundated in February 1999, June 2000 and October/November 2000.

1.3 Report Structure

This report outlines the work undertaken as part of this study. This includes a summary of:

- An ecological survey and an assessment of the impact of the preferred option on the ecology and environment.
- The hydrological modelling of Church Beck and Coldgill Beck.
- The hydraulic modelling of both watercourses.
- The proposal of options for a FAS.
- An economic assessment.
- Full details of the recommended option for a FAS.

2 Flooding History

Following discussions with long-term residents of the Church Beck area and data collected during phase 1 of this study, several flooding events from Church Beck were identified. These occurred in 1967 and 1980 (exact dates unknown), in February 1999, June 2000, and late October/early November 2000. The numbers and locations of properties affected during these events are summarised in Table 2.1 (from the phase 1 report). No reports of flooding have been received prior to the 1967 event although this does not imply that no flooding occurred before this date.

Table 2.1 - Effects of Historical Flooding from Church Beck and Coldgill Beck

Flood Event	No. of Properties Affected (internal and external)
October/November 2000	*Overtopping at entrance to culvert near Toad Cottage; overtopping of twin arched bridge at Church Becks Cottage; overtopping of wooden footbridge on Hackness Road; overbank flow along Hackness Road and into the field.*
Residential Properties	6 properties on Carr Lane 4 properties on Hackness Road 14 properties on Scalby Beck Road
June 2000	*Overtopping at entrance to culvert near Toad Cottage; overtopping of twin arched bridge at Church Becks Cottage; overtopping of wooden footbridge on Hackness Road; overbank flow along Hackness Road and into the field.*
Residential Properties	6 properties on Carr Lane 4 properties on Hackness Road 14 properties on Scalby Beck Road
February 1999	*Overtopping of wooden pedestrian footbridge on Hackness Road; overbank flow along Hackness Road and into the field.*
Residential Properties	1 property on Carr Lane 1 property on Hackness Road 14 properties on Scalby Beck Road
1980	Flooding of roads
1967	Flooding of roads

Five sources of flooding have been identified in the table above, namely:

1) at the entrance to the culvert near Toad Cottage

2) the entrance to the twin arched bridge near to Church Becks Cottage

3) overtopping of the wooden footbridge on Hackness Road

4) overbank flow from the channel along Hackness Road onto the road

5) overbank flow from the channel along Hackness Road into the field

These sources are shown on Appendix A.2. Photographs of the October 2000 flooding event and resident questionnaires can be found in the Phase 1 report and have not been reproduced in this report.

3 Previous Reports and Data Available

3.1 Previous Reports

Apart from the Phase 1 report, no previous reports are known to exist for the Church Beck flooding situation.

3.2 Topographic Survey

Survey Operations Limited were commissioned to provide topographic survey data for Church Beck and Coldgill Beck. This included:

- levels and contours around the pond on Upper Church Beck, and details of weir outlet structures for the pond;
- threshold and road levels through parts of Scalby known to be recently affected by flooding from the Church Beck catchment;
- spot levels within the field between Hackness Road and Scalby Beck Road;
- cross sections through the open watercourses of Church Beck and Coldgill Beck,
- culvert inlet and outlet units and upstream and downstream sections of bridges including deck levels.
- photographs of the channel and structures (see Appendix B)

LiDAR data for the area surrounding Scalby was also obtained and utilised. The LiDAR data was flown in 2003 and the heights were checked against Atkins topographical survey at key locations. As with most LiDAR surveys, there appeared to be a discrepancy between the heights from the two sources of data, which was not consistent throughout the whole study area. A greater confidence was placed on the accuracy of the topographical survey and the LiDAR data was thus used with caution.

3.3 Other Data Obtained

In addition to the above, the following information was obtained and reviewed as part of this study:

- various newspaper cuttings reporting on historical flooding events in Scalby;
- recorded levels on the Sea Cut and recorded rainfall at Keld Head for the June 2000 and October 2000 flood events;
- photos provided by residents following the floods of June 2000 and October 2000;
- photos of the subsidence of the channel banks along Hackness Road in early February 2004;
- site visits were undertaken to assess the various flooding mechanisms and flood mitigation options.

3.4 List of References Used

A list of the references used in this study is given below:

- *FCDPAG3 Economic Appraisal Supplementary Note to Operating Authorities - Revisions to Economic Appraisal Procedures Arising from the new HM Treasury "Green Book"*, Defra, March 2003.

- *The Benefits of Flood and Coastal Defence: Techniques and Data for 2003 (the Multi-Coloured Manual)*, Middlesex University and the Flood Hazard Research Centre, January 2003.

- *Flood Estimation Handbook – Procedures for Flood Frequency Estimation*, Duncan Reed, Institute of Hydrology, 1999.

- *Critical Watercourse Study, Church Becks, Atkins, July 2002 (the Phase 1 report)*

- *Ecological Report of Critical Watercourse, Atkins, March 2004.*

4 Ecological Assessment of Church Beck

Atkins have produced a separate, full ecological report for a number of watercourse in Scarborough, namely, Church Beck, Long Plantation Watercourse and Burniston and Cloughton Becks. A summary of the Church Beck findings are presented in the following sections.

4.1 Introduction

Church Beck and Coldgill Beck are two watercourses that meet at a culverted confluence under Carr lane in the village of Scalby. The courses of both becks are sinuous at the upper reaches before converging in the culvert. Where Church Beck retains its more natural profile the banks form a shallow 'U' shape within mixed plantation woodland. The substrate comprises cobbles and shingle with some fine sands and silt. Further downstream, through Scalby village, Church Beck is culverted and subsequently flows through a narrow channel. Here it is bordered by Hackness Road before entering a piped culvert outfall into Sea Cut.

4.2 Flora and Fauna (general)

Flora and fauna is limited within the beck. Diverse fisheries are unlikely, however 3 spined stickleback (*Gasterostreus aculeatus)* are present. It is possible that several species of dragonfly (Odonata) and other invertebrates populate these watercourses. Southern Hawker dragonfly *(Aeshna cyanea)* has been recorded in the vicinity.

Aquatic and marginal vegetation was mostly absent upstream. Common plants along the lower course of Church Beck included water parsnip *(Berula erecta)*, watercress (*Rorippa- nasturtium aquaticum*) and brooklime (*Veronica beccabunga)*. Marsh marigold (*Caltha palustris)* was occasionally recorded amongst the marginal vegetation.

4.3 Protected Species

<u>Watervole (*Arvicola terrestris)*</u>

It is unlikely that water voles are present on this watercourse. The species will certainly be absent from the lower reaches of Church Beck due to its engineered concrete bank structure and the absence of suitable burrowing habitat and forage. It is therefore unlikely that this species will be affected by the proposals.

<u>Great crested newt (*Triturus cristatus)*</u>

There are no potential breeding ponds within the area surveyed and terrestrial habitat to support the species is minimal. It is unlikely that this species (if present) will be affected by the proposals.

<u>Badger (*Meles meles)*</u>

Although no evidence of badger has been recorded through recent survey, this species should be considered where works are to affect the upper reaches of the becks. This is because suitable habitat is present and English Nature has provided records of badger in the vicinity. The lower reaches do not offer suitable habitat for this species and therefore badger is unlikely to be affected by any proposals in this area.

White-clawed crayfish (*Austrpotamobius pallipes*)

The substrate of Coldgill Beck offers some suitability for the for white-clawed crayfish, supporting refuges and some forage interest. However, water chemistry (including pH, quality, BOD and turbidity) is an important factor when determining suitable habitat for the species. These factors have not been determined at this stage. Downstream on Church Beck the habitat is far less favourable and therefore the species is unlikely to be affected by flood alleviation proposals at this location.

Otter (*Lutra lutra*)

The otter has far ranging inland territories with regard to rivers and streams and is not restricted to larger tributaries often preferring smaller streams and becks for forage and laying up. These waters are often essential for dispersal of young enabling expansion of the population.

Church Beck is linked via culvert to Sea Cut which provides good otter habitat and is believed to support the species (with anecdotal evidence of introductions further downstream). In addition, English Nature has provided otter records on the upstream reach of Church Beck in consultation (November 2002).

It is plausible that this watercourse may act as a dispersal route for juveniles and foraging, with individuals working up-stream from Sea Cut. But it is likely that the use of the beck is low with activity centred in the less disturbed reaches, wooded areas of Coldgill Beck or the un-surveyed section of Church Beck.

However, it is likely that the culverts downstream (on Sea Cut, under Church Hill road and Carr Lane) and the intermediate stretches of Church Beck may discourage and inhibit otter use. This is due to the difficult passage through the steeply sloped concrete shelving into the piped culvert at Sea Cut and the exposed and engineered narrow sections of watercourse through the village. Passage through the culverts would not be possible during spate flows. It is recommended further information is sourced, with regard to the local population and otter casualties within the Scalby area at the next stage. Further consultation, especially with local otter recorders/groups should be conducted together with additional surveys.

Otters are strictly protected by the Wildlife and Countryside Act (1981) as amended and cannot be killed, kept or sold except under licence. In addition the otter is listed as a European protected species under Schedule 2 of The Conservation (Natural Habitats etc.) Regulations1994. This legislation creates the offence of deliberately capturing, killing or disturbing an otter or damaging its breeding or resting sites.

It is unlikely that flood alleviation proposals will directly affect otter breeding or resting sites, it is also unlikely that the proposals will have any adverse effect on otter dispersal. Conversely the scheme could improve dispersal routes by facilitating movement and improving passage through culverts and outfalls.

4.4 Nesting Birds

Nesting birds are legally protected and any vegetation clearance in which birds are nesting should be undertaken outside the breeding season to avoid damage or destruction of nests. The bird breeding season is dependant on local variation but runs from approximately mid-February to mid-September. All birds, their nests and eggs are protected by the Wildlife and Countryside Act 1981 (as amended).

4.5 Invasive Species

Japanese knotweed was not recorded during the survey of either Church or Coldgill Beck.

Giant hogweed was encountered in two locations along Coldgill Beck and Church Beck however, at the time of survey the plants were dying back and smaller individuals may be present along the becks that were undetected.

Giant hogweed is listed on Schedule 9 and subject to section 14 of the Wildlife and Countryside Act 1981, which creates the offence of planting or causing the plant to grow in the wild. In addition giant hogweed is injurious to human health causing burn-like blisters and lesions, photosensitivity, scarring and contact with the eyes can lead to temporary or possibly permanent blindness.

4.6 Mitigation and/or Enhancements

Based on existing ecological information the following measures are recommended to maintain or enhance existing features of nature conservation value:

- provision of flood storage and ecological enhancement of the downstream reach of Church Beck;
- improvements to the piped culvert outfall at the convergence with Sea Cut to allow the passage of wildlife.
- improvements and incorporation of wildlife ledges to the culverts under Church Hill and Carr Lane;
- retention of existing hedgerow where possible or reinstatement of a species rich replacement hedgerow if the existing one is removed;
- measures to reduce potential impacts to Sea Cut, including turbidity, water quality etc.

Potential Constraints (based on current information):

- presence of invasive/injurious plant species; giant hogweed;
- records of otter in the vicinity of works, possible presence of a European protected species;
- Work should be undertaken outside of the bird breeding season which extends from mid-February to mid-September (depending on local variations)

5 Hydrological Modelling

5.1 Catchment Definition

Church Beck is a tributary of the Sea Cut (Scalby Beck) and is a small, critical ordinary watercourse flowing in a southerly direction to the west of Scalby. In its upper reaches Church Beck is split into two becks: the tributary Coldgill Beck (flowing in a south easterly direction) and Church Beck (flowing in a south westerly direction). The tributaries combine at Carr Lane near to Church Beck Cottage, and the beck then flows in a south easterly direction towards the Sea Cut. Church Beck is correctly classified as a Critical Ordinary Watercourse.

The uppermost reaches of Church Beck and Coldgill Beck are relatively steep (1:70 approximately), and the surrounding area is characterised by a mixture of farmland and woodland. On both of the becks there are "ornamental" ponds within the upper reaches that are small and therefore attenuation of flow is minimal. Around the confluence of Coldgill Beck and Church Beck, the beck gradient flattens (1:250 approximately) and the catchment is characterised by a mixture of residential area and fields. As the becks runs alongside Hackness Road the gradient starts to increase (1:70 approximately) towards the outfall to Sea Cut. The invert level of outfall structure is located approximately 2.5m above the normal flow water level of Sea Cut.

Church Beck drains a total catchment area of 4.5km^2 and using the Flood Estimation Handbook (FEH) URBEXT parameter as a guide, is approximately 3% urbanised. The underlying geology of the catchment is Jurassic sandstone, limestone and shales overlain predominantly by a cover of boulder clay.

The Church Beck catchment is depicted in Appendix A.3 along with the sub-catchments of Upper Church Beck and the tributary Coldgill Beck. Table 5.1 summarises some of the hydrological and hydraulic characteristics of the Church Beck and Coldgill Beck catchments.

Table 5.1 - Catchment Characteristics

	Coldgill Beck	Upper Church Beck	Church Beck (whole catchment)
Catchment Area (km^2)	1.87	2.52	4.47
Length of Watercourse	1 km	1 km	2.4 km
URBEXT	0.006	0.04	0.029

5.2 FEH Methodology

The primary aim of the hydrological assessment is to derive design flows for input into the hydrodynamic model (ISIS) of the Church Beck open channel flow system. Design flow estimates have been derived for the, 5, 10, 25, 50, 75, 100 and 200 year return periods for the catchments of Coldgill Beck and Church Beck upstream of the confluence, and for the whole of the Church Beck catchment upstream of its confluence with Sea Cut. Design inflow hydrographs have been generated for the Church Beck catchment in accordance with the FEH.

Church Beck is an ungauged catchment, and therefore FEH procedures for ungauged ('no-data') catchments have been used to model catchment hydrology. The key stages in the FEH analysis are as follows:

1. Use of FEH CD-ROM 1999 to determine catchment descriptors;
2. Application of WINFAP-FEH (FEH software package) to derive a pooling group of hydrologically similar catchments;
3. Estimate of Q_{MED} (the median annual flood) from catchment descriptors, and adjustment using analogue catchments;
4. Statistical estimation of peak flows for different return periods from the product of Q_{MED} and growth curves obtained from the pooling group;
5. Application of FEH rainfall-runoff method to derive hydrographs for the various return periods using synthetic unit hydrographs;
6. Reconciliation of the two methods for the purpose of design flows.

5.2.1 Statistical Analysis

The statistical derivation of flows for Church Beck catchment is summarised in Appendix C.1 (Section 4).

As the Church Beck catchment is ungauged, an estimate of the median annual flood (Q_{MED}) is derived initially from digital catchment descriptors. Estimating Q_{MED} for an ungauged catchment by catchment descriptors alone can be inaccurate. The FEH therefore recommends that, for an ungauged site, a method to improve Q_{MED} is to adjust the estimated Q_{MED} on the basis of data collated from a 'donor' or 'analogue' catchment, which has an extensive flow record. A donor catchment is a local catchment with gauged data particularly relevant to flood estimation at the subject site. The ideal donor catchment is one sited just upstream or downstream of the subject site. An analogue catchment is a more distant gauged catchment which is sufficiently hydrologically similar to the subject site to make the data relevant.

It was deemed that there is no appropriate donor gauge for Church Beck and therefore sites within the pooling group that are geographically close to the subject site (ie: within the North East) have been adopted as analogue catchments. The adjustment ratio using the analogue catchments varied, with the average value approximately equal to 1.2. The average ratio derived from the relevant analogue catchments was subsequently used to adjust the catchment descriptor estimates of Q_{MED} (refer Appendix C.1, Table 4.2).

It is noted that an alternative method of calculating Q_{MED} is deriving an approximation on the basis of a typical bankfull width for a natural watercourse (determined based upon cross sections throughout a reach). In this instance, Q_{MED} values derived on this basis are generally larger than those derived using the catchment descriptor method (refer Appendix C.1, Table 4.3). These values suggest, therefore, that the adjustment ratios derived from analogue catchments may give a more representative Q_{MED}.

The initial selection of a pooling group for an ungauged catchment is automated by WINFAP-FEH. The WINFAP database is queried to identify gauging records relating to catchments that may be considered 'hydrologically similar' to the subject site which are determined on the basis of catchment descriptors. Sufficient data is collated initially to provide '5T' station years of data, where 'T' is the target return period - in this case 100 years. These sites are subsequently reviewed and tested for discordance and heterogeneity, and the pooled data is then used to produce growth curve estimates that, in conjunction with Q_{MED}, determine the statistically derived peak design flow estimates for the catchment. The derivation and adoption of the Church Beck pooling group is summarised in Appendix C.1 (Table 4.7).

5.2.2 Rainfall-Runoff Method

The derivation of the rainfall-runoff model is summarised in Appendix C.1 (Section 5).

The rainfall-runoff method predicts flows by relating rainfall and the hydrological response of a catchment to a storm event. Three key parameters are used by the rainfall-runoff model to define the hydrological characteristics of a catchment, and since Church Beck is ungauged these have been determined from catchment descriptors (FEH CD-ROM). These parameters are:

(i) Catchment response to rainfall (time-to-peak, T_p);

(ii) Proportion of rainfall which directly contributes to river flow (percentage runoff, PR);

(iii) Quantity of flow in the river prior to the storm event (baseflow, BF).

Rainfall is defined in terms of duration, depth and distribution (over time), and may relate to either a probabilistic design event, eg: 1 in 100 year return period, or an observed storm event (for calibration purposes). Where a design event is to be analysed, the storm duration (D) is determined as a function of catchment response (time-to-peak, T_p) and Standard Annual Average Rainfall (SAAR). The derivation of rainfall depth is automated using the FEH Rainfall-Runoff module within ISIS for a particular return period of a given storm. An aerial reduction factor is subsequently applied, and the rainfall hyetograph (rainfall distribution over time) is defined using a standard profile. For the Church Beck catchment the FEH 75% winter profile was used together with a catchment wide storm.

5.3 Rational Method

The Rational Method provides an alternative means of estimating peak flows for all of the Church Beck sub-catchments.

The Rational Method uses runoff coefficients and rainfall intensity to calculate peak flows for a given catchment area. The runoff coefficients are dependent on land use, rainfall intensity and return period, and for a 100 year event, the coefficients are approximately 0.2 for the sub-catchments. Lower return period events have slightly lower runoff coefficients.

Further details of the Rational Method, the runoff coefficients used and the results can be found in the calculation record in Appendix C.1.

5.4 Design Flows - Discussion

Peak flows have been calculated for the hydrological assessment locations using statistical pooling analysis, rainfall-runoff and the Rational Method. These flow estimates for various return period events are presented graphically in Appendix C.8 to C.10 and in Table 5.2.

Table 5.2 - Peak Flow Estimates (m^3/s)

Return Period (years)	Coldgill Beck			Upper Church Beck			Entire Church Beck		
	Statistical	Rainfall-Runoff	Rational	Statistical	Rainfall-Runoff	Rational	Statistical	Rainfall-Runoff	Rational
Q_{MED}	0.3	0.4	-	0.7	1.0	-	1.2	1.4	-
5	0.4	0.5	1.0	1.2	1.5	1.3	1.9	2.0	2.2
10	0.5	0.6	1.3	1.5	1.8	1.7	2.3	2.4	2.8
25	0.6	0.9	1.8	2.0	2.4	2.3	3.1	3.3	3.7
50	0.7	1.2	2.3	2.4	2.9	3.0	3.7	4.1	4.8
75	0.8	1.4	2.5	2.7	3.2	3.3	4.2	4.5	5.3
100	0.8	1.5	2.7	2.9	3.5	3.6	4.5	4.9	5.8
200	0.9	1.8	3.3	3.6	4.2	4.3	5.4	5.8	6.9

The rainfall runoff flow estimates are considerably higher than the statistical flow estimates for Coldgill Beck and to a lesser extent for Upper Church Beck, but there is a good comparison for the whole of the Church Beck catchment. The validity of the FEH statistically derived flow regime is heavily dependent upon how suitably the adopted pooling group represents the catchment of interest. As all catchments within the pooling group are gauged, invariably this means that the majority are generally sizeable river systems. It has been assumed that the response mechanisms of these larger catchments are not strictly representative of the characteristics inherent in the smaller Church Beck catchment. It is also reasonable to assume that localised topographic factors (e.g the steep upper parts of the Coldgill and Church catchments) may result in a localised weather pattern. This would mean the localised frequency, duration and severity of storm events in the Scalby area may vary from adjacent gauged catchments and, therefore, may not be accurately predicted by FEH statistical method.

The flows estimated using the Rational Method are generally larger than the rainfall runoff method and the statistical method, apart from Upper Church Beck where there is a close similarity between the Rational Method and rainfall runoff method. The Rational Method is generally used for small uniform urban catchments as a crude first estimate and may, therefore, not be the most appropriate method to represent the flows in the small rural catchments of Church Beck.

For these reasons, the rainfall runoff model flows have been adopted in this instance for design purposes.

6 Hydraulic Modelling

6.1 General

The primary aim of the hydraulic modelling is to predict peak design water levels throughout the Church Beck system to derive flood depths for input into the Cost Benefit Analysis. The model also serves to assess flood alleviation options.

The hydraulic analysis of Church Beck has been undertaken using ISIS (Version 2.0), a one-dimensional hydrodynamic model. The hydrodynamic facility is particularly prevalent in the context of the Church Beck system where a considerable proportion of the catchment is low lying within the lower reaches (ie: Hackness Road and surrounds). During larger events, the design flows exceed bankfull conditions, spilling into these floodplain areas. As this occurs, the ability to accurately assess floodplain storage effects and channel interaction becomes critical, and this can simply not be achieved within the confines of a simple steady-state (peak flow) regime.

Peak design water levels have been assessed for the 5, 10, 25, 50, 75, 100 and 200 year return periods. As an ungauged catchment with limited rainfall and no recorded water levels, a definitive calibration of the Church Beck ISIS model has not been possible but verification of the model for the recent flooding in June and October 2000 has been undertaken.

The Cross section locations and the adopted ISIS representation of the Church Beck system are presented in Appendix A.4 and Appendix A.5 respectively.

It is emphasised that the Church Beck model has been developed based upon current catchment conditions (in December 2003). Following subsidence of the channel along Hackness Road in early February 2004, emergency works have been undertaken along the right bank. The hydraulic model is based on the detailed topographic survey of the channel prior to these works and so does not fully represent the existing situation. Future development and/or capital works within the study area may alter catchment response, and therefore it is recommended that subsequent reviews of the model are undertaken prior to utilisation to ensure that the predicted flooding regime remains representative of physical catchment conditions. However, it is fair to sate that the stabilisation works undertaken will not have a significant impact on the work undertaken and the proposed solutions.

6.2 Flooding Flow Routes

Because of the steep topography within certain parts of Scalby (e.g Carr lane), flood waters escaping from the watercourses will flow through the town with minimal pooling within it. These flow routes were assigned in Mapinfo by analysing data from the following sources:

- topographic survey, including spot levels on roads and threshold levels of properties;
- LiDAR data;
- historical records of flooding within Scalby (see Table 2.1); and,
- an assessment of potential flow routes during site visits.

Appendix A.6 shows the flood fow routes that have been determined and incorporated into the hydraulic model.

6.3 Schematisation of the River System

6.3.1 River Channel

The schematisation of the Church Beck system was undertaken on the basis of the topographic survey (refer Section 3.1) and collated in order to describe the physical properties of the channel and overbank areas. (This is presented in Appendix A.5)

Typically cross sections are spaced at intervals of approximately 50-75 metres along the length of the channel, positioned on the basis of their surveyed chainage and forming the basis of the computational model. To model the roughness of the channel, Manning's 'n' values have been adopted on the basis of survey photography (refer Appendix B) and site reconnaissance visits, defined in accordance with appropriate values as depicted in 'Open Channel Hydraulics' (Chow, 1959). The design roughness regime for the Church Beck system has been adopted as 0.040 and 0.060 for the channel and overbank areas respectively. This relates to the channel being relatively free of dense vegetation.

6.3.2 Hydraulic Structures

A total of eleven (11) bridges and culverts were identified along the Church Beck model reach, in addition to three (3) weir structures. Each structure was assessed individually and modelled appropriately (see Table 6.1). The wooden footbridge at COL_00092 was not modelled as the bridge is rotten and is likely to be washed away during high flows.

Table 6.1 – Hydraulic Structures (refer to Appendix A.4)

Model Chainage	Name of Structure	ISIS Unit
CHU_00880	Pond Weir 1	Spill
CHU_00866	Pond Weir 2	Spill
CHU_00770	Wynbrook Footbridge	Orifice
CHU_00550	St. Laurence Footbridge	Orifice
CHU_00458	Toad Cottage Culvert	Orifice
CHU_00427	Church Beck Cottage Small structure	Orifice
CHU_00423	Beck Confluence Twin Arched culvert	Twin Orifices
CHU_00343	Church Hill Twin Arched Bridge	Twin Orifices
CHU_00282	Low Hill Footbridge	Bridge with Piers
CHU_00020	Sea Cut Outfall	Orifice
COL_00069	Stables Weir	Spill
COL_00028	Church Beck Cottage Footbridge	Orifice
COL_00016	Ivy Cottage Bridge	Orifce
COL_00009	Dainton Bridge	Orifice

6.3.3 Floodplain Areas

Where initial model results suggested that the predicted peak water levels exceeded the extent of the cross sections surveyed, floodplain areas were delineated using additional topographic survey and LiDAR data, and then incorporated into the ISIS model at appropriate locations.

The fields to the east of Hackness Road act as a localised retention ‘basin’ that is much lower than the surrounding topography. For this reason, the floodplain was best represented in the form of an offline reservoir unit rather than the more simplistic extended section approach. A depth area relationship of the ‘basin’ was derived from a detailed topographical survey and the approximate capacity is approximately 160,000 m^3. This existing floodplain is the field between Hackness Road and Scalby Beck Road and the houses on Scalby Beck Road. The volume has been calculated using LiDAR and represents an existing typical amount. This reservoir was connected to Church Beck in the form of lateral spills.

6.3.4 Catchment Storage

The pond in the upper reaches of Church Beck acts as a storage area for flow from the upper catchment of Church Beck. The pond has been modelled as an online reservoir and outflow into Church Beck is controlled by a weir structure. A depth area relationship of the pond was derived from a detailed topographical survey and the approximate capacity is 2,080 m^3. This pond has a very limited capacity and hence minimal impact on the attenuation of flows from the upstream catchment.

6.4 Boundary Conditions

6.4.1 Catchment Hydrology

Design flow hydrographs have been derived for Church Beck for the 5, 10, 25, 50, 75, 100 and 200 year return periods respectively in accordance with procedures outlined in the Flood Estimation Handbook (FEH). Adopted peak design inflows for the Church Beck catchment are summarised in Table 6.2 below, however the hydrological analyses undertaken as part of this investigation are summarised in detail in Section 5 of this report.

Table 6.2 - Adopted Peak Design Inflows (m^3/s)

Return Period (years)	Peak Design Flow Estimate (m^3/s)	
	Church Beck only	Coldgill Beck
5	1.5	0.5
10	1.9	0.7
25	2.5	1.0
50	3.1	1.2
75	3.4	1.4
100	3.6	1.5
200	4.3	1.9

The Church Beck inflow represents the catchment area upstream of the confluence with Coldgill Beck and also the catchment downstream of the confluence to the outfall into the Sea Cut. The catchment area for the combined watercourse is only 0.08 km^2 and so for simplicity this area was added onto the Upper Church Beck inflow and URBEXT was adjusted accordingly.

6.4.2 Downstream Conditions

Church Beck is a minor tributary of the Sea Cut. The Church Beck catchment is relatively small in area and steep in gradient, and therefore will respond to a rainfall event considerably faster than the larger Sea Cut catchment. However, there is the possibility of a coincident flooding event (ie: a flood peak in Church Beck coinciding with elevated water levels in the Sea Cut). The governing downstream boundary adopted for design purposes has been defined as a Discharge-Height (Q-H) relationship, determined on the basis of normal flow depth conditions. A sensitivity analysis has subsequently been undertaken to ascertain the impact upon upstream water levels in Church Beck associated with a variation in this downstream condition. The result of this sensitivity analysis shows that a raised water level in the Sea Cut has a minimal impact at high flows as the size of the outfall structure is as much a control to the outfall into the Sea Cut as the water level in the Sea Cut.

6.5 Model Verification

No calibration data is available for Church Beck, so the model has only been verified and not calibrated. Verification of the hydraulic model involves the input of a recorded rainfall event and comparing the resulting stage with those levels recorded by residents through questionnaires and photographs. Calibration involves checking the predicted water levels from the model to actual levels recorded in the field.

The events selected for verification were the June 2000 and October 2000 events for which rainfall data was obtained from the Environment Agency. There is only one tipping bucket rain-gauge within the vicinity of the catchment, which is at Keld Head. The Percentage Runoff and the Catchment Wetness Index were adjusted for the event based on the previous 5 days of rainfall. The June 2000 event (estimated return period 10-15 years) was a shorter duration event than the October 2000 event (estimated return period 15-25 years) and it resulted in lower levels of flooding. From the collected residents' questionnaires and photographs the level of flooding appears to compare well with that predicted by the model.

6.6 Sensitivity Analysis

A sensitivity analysis has been undertaken to ascertain the impact upon peak design flood levels of variations in critical design parameters, which is particularly crucial for an uncalibrated model. The following sensitivity analyses have been undertaken based upon 1 in 100 year design event flow estimates.

6.6.1 Roughness Regime

Manning's 'n' included in the Church Beck model is based solely upon visual inspection. On this basis, an assessment of the sensitivity of predicted peak water levels to variations in channel and over-bank roughness is imperative. The impact upon peak design flood levels resulting from a variation in Manning's 'n' of +20% (ie: $n_{channel}$ 0.040 (design) to 0.048; $n_{overbank}$ 0.055 (design) to 0.66 has been considered. This resulted in a 50mm (maximum) increase in peak water level along the modelled river system around Carr Lane, but a minimal impact of less than 25mm throughout the rest of the catchment. It should be noted that this choice of Manning's 'n' is assuming that the channel is relatively clear of vegetation. If not maintained and the vegetation allowed to become dense then all the modelling undertaken will be unrepresentative. A highly vegetated channel would flood much sooner and more frequently but would not significantly change the severity of a 100 year return period flood.

6.6.2 Summer Rainfall Profile

The Church Beck Catchment is a rural catchment (based on URBEXT of 0.125) and FEH suggests that the design rainfall profile applicable to Church Beck is a winter profile, which has been applied to the hydraulic model. The winter profile is a symmetrical bell shaped profile unlike the summer profile which has a characteristic peaked shape. Church Beck has experienced summer flooding events, e.g. June 2000 and so it was deemed appropriate to undertake a sensitivity of the rainfall profile used. The impact of a summer profile is a 120mm (maximum) increase in peak water level around Carr Lane, with a lower (approximately 50mm) impact on water levels elsewhere.

6.6.3 Coincidental Flooding

Church Beck is a tributary of the Sea Cut. The Church Beck catchment is relatively small and steep in nature, and therefore will respond to a rainfall event considerably faster than the Sea Cut. The possibility of a coincident flooding event (ie: a flood peak in Church Beck coinciding with elevated water levels in the Sea Cut), though improbable, cannot be entirely discounted. For this reason, the impact upon peak design flood levels associated with a coincident flooding event in the Sea Cut has been considered. This has been modelled as an elevated downstream boundary of 39.5mAOD (0.05m above the soffit of the Sea Cut Outfall on Church Beck). The result is a 110mm (maximum) increase in peak water level for a reach of approximately 50 metres upstream of the outfall structure.

6.6.4 Climate Change

It is recommended that climate change be considered via a 20% increase in design flow over the next 50 years. To this end, a sensitivity assessment has been undertaken to provide some indication of the potential impacts that climate change (assuming a 20% increase in the 100 year design flow) may have upon flood levels throughout the Church Beck catchment. The result is a 150mm (maximum) increase in peak water level around Carr Lane and only 20mm within the channel along Hackness Road.

6.7 Flood Extents

The hydraulic model was run for the existing situation for the 5, 10, 25, 50, 75, 100 and 200 year design flows. It was found that in a 5 year event flooding was predicted in Carr Lane. Flooding is predicted to occur where there is a significant constriction in flow as a result of undersized structures. The structures that are significantly undersized are the small structure (CHU_00427) near Church Beck Cottage (i.e the ornamental bridge and weir); the twin arched bridge just downstream of the confluence between Coldgill Beck and Church Beck (CHU_00423); and the twin arched road bridge under Church Hill (CHU_00343). The capacity of the culvert (CHU_00458) at Toad Cottage is affected by high tailwaters caused by the backing up from the structures at CHU_00427 and CHU_00423. The flooding extents for various return periods are outlined in Appendix A.7.

7 Discussion of Measures to Mitigate Flooding

In this section, various flood defence measures are discussed to address specific flooding problems around the catchment. Some of these measures are then combined to form a set of three solutions.

7.1 Measure 1 - Increased Upstream Storage

It is always necessary to consider options from a strategic point of view to ensure that the catchment is assessed holistically. Upstream flood storage is becoming increasingly important and is already utilised on both large and small catchments. The limitations of this method should also be noted, namely the large area of suitable land that is required and the inherent susceptibility to sustained and frequent events. For assessment purposes, locations of potential storage areas were not considered here, only the impact and value that upstream storage may have in possible solutions.

Coldgill Beck and Upper Church Beck flow through “ornamental ponds” within their upper reaches and the outflow on both becks is controlled by a weir structure. The pond on Church Beck (See Appendix A.4) is included within the model extents whilst the pond on Coldgill Beck is upstream of the model reach. For a 1 in 100 year return period event (Q100) the land surrounding the pond on Upper Church Beck is flooded and it was assessed that enlarging the pond does not have a significant impact on reducing flows downstream. Instead, offline storage within the upper reaches of Church Beck has been assessed. In order to model the option of offline storage in Church Beck, the inflow hydrograph peak flow was reduced from 3.6m^3/s to 1.6m^3/s (for Q100 event. The reduction in peak flow represents a reduction in the volume of water for the design Q100 flood event from 74,000m^3 to 32,500m^3. The difference in the volume of water (41,500m^3) represents the minimum volume of offline storage required. (In reality, due to the natural inefficiencies of a flood storage solution, this volume could easily be 2-5 times the minimum required). The result was a reduction in water levels of 250mm around Toad Cottage and at the beck confluence, with a lower impact (150–200mm reduction) impact downstream along Hackness Road. However, flooding still occurs around Church Beck cottage, Carr Lane, and along Hackness Road and the adjacent field.

In order to model the option of increased offline storage on Coldgill Beck, the inflow hydrograph peak flow was reduced from 1.5m^3/s to 0.5m^3/s (for Q100 event) such that the flow within Coldgill Beck was within the banks. The reduction in peak flow represents a reduction in the volume of water for the design Q100 flood event from 24,000m^3 to 3,600m^3. The difference in the volume of water (20,400m^3) represents the minimum volume of offline storage required. (In reality, due to the natural inefficiencies of a flood storage solution, this volume could easily be 2-5 times the minimum required). The impact of reducing flow on both Coldgill Beck and Church Beck is a reduction in water level of 100-150mm around the confluence but a minimal impact on Hackness Road and further downstream.

As the flooding around Carr Lane is due to the confluence of the two becks an assessment of the impact of storage within the upper part of Coldgill Beck and Church Beck was assessed. The same storages were assumed as above and the impact was a reduction in levels around the beck confluence of 450mm but flooding still occurs around Church Beck Cottage and Carr Lane. Downstream of the confluence of the two becks flow is contained within the channel of Church Beck.

It is concluded that increasing storage within the upper catchments in itself is not going to alleviate the flooding problem around the confluence of the 2 becks, but may alleviate flooding further downstream along Hackness Road.

7.2 Measure 2 - Localised Defences

In this option the following defences are considered:

(i) Constraining Church Beck and Coldgill channels with embankments/floodwalls.

(ii) Using the field adjacent to Hackness road as flood storage to defend properties along Scalby Beck Road..

No channel widening work is assumed and no changes to structures allowed for.

The water levels from the hydrodynamic model were compared with the bank levels of both Church Beck and Coldgill Beck, and channel bank levels were altered within the model such that water was contained within the channel. A 300mm freeboard level (considered low) was also added onto the required bank levels to take into account, for example, climate change, modelling uncertainty and construction errors. For each of the nodes in the model the height of embankment required is tabulated in Table 7.1 and 7.2. The locations of these nodes and the length of the embanking are shown in Appendix A.8.

Table 7.1 - Height of Embanking required at selected nodes in the model along Church Beck and Coldgill Beck (including 300mm freeboard) for Q100 (see Appendix A.4 for model node location)

Model Chainage	Description	Required Height of Embanking	
		Left Bank (mm)	Right Bank (mm)
CHU_00834	Upper Church Beck section	800	0
CHU_00803	Upper Church Beck section	950	0
CHU_00770	Wynbrook Footbridge	850	0
CHU_00481	Upper Church Beck section	0	700
CHU_00458	Toad Cottage Culvert inlet	0	1150
CHU_00443	Toad Cottage Culvert outlet	0	750
CHU_00427	Church Beck Cottage Small structure	0	1050
CHU_00423	Beck Confluence Twin Arched culvert	0	750
CHU_00282	Low Hill Footbridge	500	500
CHU_00262	Hackness Road section	650	650
CHU_00242	Hackness Road section	0	650
CHU_00125	Hackness Road section	0	500
CHU_00075	Hackness Road section	0	550
COL_00016	Ivy Cottage Bridge	500	0
COL_00009	Dainton Bridge	450	0

Table 7.2 - Height of Embanking required at selected nodes in the model along Church Beck (including 300mm freeboard) for Q25

Model Chainage	Description	Height of Embanking	
		Left Bank (mm)	Right Bank (mm)
CHU_00834	Upper Church Beck section	700	0
CHU_00803	Upper Church Beck section	750	0
CHU_00770	Wynbrook Footbridge	550	0
CHU_00458	Toad Cottage Culvert inlet	0	450
CHU_00443	Toad Cottage Culvert outlet	0	450
CHU_00427	Church Beck Cottage Small structure	0	850
CHU_00423	Beck Confluence Twin Arched culvert	0	450
CHU_00262	Hackness Road section	150	0
CHU_00075	Hackness Road section	0	350

As well as embanking along Church Beck and Coldgill Beck, in order to prevent the flooding of properties within Scalby Beck Road, a flood bund is recommended within the field. The location of the proposed flood bund is shown in Appendix A.8 being close to Scalby Beck Road. This ensures that the field is utilised to its full capacity as a flood storage basin during a flood event but remaining dry during other periods. The height of the flood bund required for various return periods is shown in Table 7.3. The length of the flood bund is determined by the surrounding heights within the fields and will be approximately 130m in length.

Table 7.3 - Height of Flood bund required to protect properties in Scalby Beck Road and maintain a reservoir in the field.

Return Period (years)	Height of Flood Bund (mm)	Height of Flood Bund including 600mm freeboard (mm)
25	500	1100
50	700	1300
75	800	1400
100	900	1500

Tables 7.1 to 7.3 show that the level of embanking required along Church Beck and Coldgill Beck, and within the field adjacent to the field is substantial. Some of the embanking required is along Hackness Road (e.g between model nodes CHU_0282 and CHU_00242, and between CHU_00125 and CHU_00020). Church Beck runs very close alongside Hackness Road and the space available to construct floodwalls along the right bank is limited. The height of the flood walls required are above 0.5m which would be potentially dangerous to traffic on Hackness Road. The measure of flood embanking in itself is not thought to be an optimum solution and thus it was necessary to consider improvements to the structures and to increase conveyance in the channel itself.

7.3 Measure 3 - Improvements to Structures

The structures that are significantly undersized for events larger than Q25 are:

- Church Beck Cottage small weir structure and bridge (CHU_00427);
- twin arched bridge just downstream of the confluence between Coldgill Beck and Church Beck underneath Carr Lane (CHU_00423);
- twin arched road bridge under Church Hill (CHU_00343).

Note: Although the twin arched road bridge under Church Hill is surcharged at high flows the bridge parapets and the channel banks are sufficiently high enough to prevent overtopping. The focus for the improvements to structures is, therefore, concentrated on the structures around Carr Lane.

Downstream of the culvert (CHU_00458) at Toad Cottage there is a 20 m length of open channel which has the small structure (CHU_00427) erected by local residents, and downstream of this there is the twin arched stone bridge (CHU_00423) underneath Carr Lane which outfalls into Church Beck at the confluence with Coldgill Beck. These two structures are a constriction to flow and water spills out into Carr Lane and affects the surrounding properties. The constriction to flow at these two structures also causes backing up to the Toad Cottage culvert (CHU_00458) such that there is significant flooding at the culvert inlet.

It is proposed that the box culvert (approximately 1.6m wide x 1m high) at Toad Cottage is extended 35m downstream under Carr Lane so that it outfalls directly into the combined Church Beck/Coldgill Beck (see Appendix A.9).

7.4 Measure 4 - Channel and Bank Stabilisation

Instability of the right bank along the lower part of Hackness Road in the past has resulted in works to stabilise the banks. These stabilisation works resulted in narrowing the channel up to approximately 1m in bed width along a stretch of 50-100m. Subsequently, the stabilised banks experienced severe slumping (as per communications and photographs from Scarborough Borough Council). Emergency works have now been carried out to rectify this. Despite these works, the channel capacity within this reach along Hackness Road is limited and further slumping of the right bank may occur increasing the potential for flooding of surrounding properties on Hackness Road.

The proposed works in this measure are a combination of stabilisation of the banks and localised widening of the channel bed from the left bank by approximately 1m, with the depth of the channel remaining the same. Widening of the channel will reduce the sharpness of the two bends in the current channel which have undergone significant undercutting and slumping of the banks, and will ensure that the channel capacity is sufficient and is constant throughout the reach. These works would require the removal of part of the hedge and the channel would take up part of the nearby field for a length of approximately 100m. The location of the bank stabilisation and channel widening along Hackness Road is illustrated in Appendix A.10.

7.5 Measure 5 – Channel Widening

The channel downstream of the wooden footbridge has insufficient capacity to contain the flow within the banks for events greater than a 1 in 5 return period. The proposed works are a widening of the channel for approximately 250 m along Hackness Road such that the flow is maintained within the banks for higher return periods. The depth of the channel along this reach will remain the same. The banks of the widened channel will be gentle slopes reducing the risk of bank instability and the height of banks will be designed including 600mm freeboard. For higher return periods, the capacity of the outfall structure into Sea Cut becomes critical. For a higher standard of protection, increasing the capacity of the outfall structure is required to carry the flow within the widened channel. The location of the channel widening along Hackness Road and the outfall structure is illustrated in Appendix A.11. Table 7.4 summarises the widening of the channel and the alterations to the capacity of the outfall structure required for various return periods. Table 7.5 summarises the heights of the banks (both left and right) required for the various chainages in the model where there is proposed channel widening (refer to Appendix A.4 for model node locations).

Table 7.4 – Width of channel widening and enlargement of Sea Cut outfall structure

	Q25	Q50	Q100	Q200
Channel widening (m)	2	3	4	4
Outfall – increase in capacity	-	50%	100%	100%

Table 7.5 – Elevation of banks for various return periods along Hackness Road

Model Node	Height of banks (mAOD including 600mm freeboard)			
	Q25	Q50	Q100	Q200
CHU_00262	41.1	41.1	41.1	41.15
CHU_00242	41.0	41	41	41
CHU_00216	40.8	40.8	40.8	40.9
CHU_00190	40.7	40.7	40.65	40.8
CHU_00174	40.6	40.6	40.6	40.75
CHU_00158	40.55	40.55	40.55	40.7
CHU_00141	40.5	40.5	40.5	40.7
CHU_00125	40.5	40.5	40.5	40.7
CHU_00075	40.45	40.5	40.5	40.7
CHU_00020	40.4	40.45	40.45	40.65

8 Description of Flood Mitigation Options

The following options have been considered to alleviate flooding within Scalby from the watercourses of Church Beck and Coldgill Beck. These options have been taken forward for detailed cost benefit analysis.

8.1 Option 1 - Do Nothing

Under the 'Do Nothing' option, the present maintenance scheme would cease and no additional or maintenance works would be undertaken. Flooding would occur on a regular basis due to blockage of and silting of the culverts and parts of the channel, resulting in regular flooding and damage to a large number of residential properties. Certain stretches of Church Beck along Hackness Road will experience bank collapse as has occurred in the past which would be detrimental to the footpath and the road and cause channel blockage.

It should be noted that the 'Do Nothing' case is the baseline against which all other schemes are measured and would require the Council to effectively 'walk away' from the problem. A portion of the damages associated with this case then become the benefits of providing a scheme as some of these damages are avoided.

8.2 Option 2 - Do Minimum

A 'do minimum' option is considered to be the minimum required to maintain the status quo or to undertake cost-effective measures that may increase the standard of protection sensibly. These measures are not emergency works, but could be a combination of maintenance and enhancement and are not intended to involve significant capital works.

In this case, the 'do minimum' option would be to ensure that the potential capacity of the watercourses is not reduced through silting and weed growth or through blockages at structures. The channel along Hackness Road which is susceptible to slumping (see Option 6) would be stabilised as necessary following the emergency works undertaken in February 2004. No additional engineering work would take place, but the present maintenance regime would be continued and enhanced.

This option (and others) could be combined with the introduction of flow and rainfall gauges, whereby future assessments could be undertaken to deal with the current uncertainty relating flow predictions and observed historical flooding data. In this scenario further assessments would be carried out after a reasonable length of data has been collected, after at least 5 years. However, it should be noted though that the quality and length of data required before reliable conclusions could be made is uncertain.

Under this option, flooding would still occur in the Toad Cottage area as no capital work is proposed for the existing culvert which is considered under-capacity. Flooding would also still occur further down Church Beck along Hackness Road and Scalby Beck Road.

8.3 Option 3 –Culvert Extension, Channel Stabilisation, Flood Embankments and Flood Storage

Apart from Measure 2 (Localised Embanking) the measures discussed in Section 7 in themselves are not likely to provide a full solution to the flooding issues in Scalby from Church Beck. A combination of measures is the preferred solution to preventing flooding in Scalby. This combined option will incorporate the culvert extension (Measure 3), channel stabilisation (Measure 4) and flood embankments (Measure 2). Works to the culvert and the channel stabilisation mean that the amount and level of embanking is limited only to upstream of the Toad Cottage extended culvert (at model node CHU_00458), and around the wooden Low Hill footbridge (at model node CHU_00282). The level of the flood bund within the field is the same as for Measure 2. The level of embanking for various return periods is summarised in Table 8.1 and the location of the works for Q100 standard of protection are illustrated in Appendix A.12.

Table 8.1 - Height of flood embankments and flood bund for various return periods

Location of Embanking		Return Period (years)			
		25	50	100	200
Height of Flood Embankment at CHU_00458 with 300mm freeboard (mm)	Left Bank	0	50	200	650
	Right Bank	0	150	300	750
Height of Flood Embankment at CHU_00282 with 300mm freeboard (mm)	Left Bank	0	500	550	600
	Right Bank	0	500	550	600
Height of Flood Bund including 600mm freeboard (mm)		1100	1300	1500	1750

Flood storage in the field adjacent to Hackness Road would provide various ecological benefits for the area by diversifying the habitats present. Flood storage in the improved grassland field could increase the diversity of species within the sward and create areas of marshy grassland that would benefit both invertebrates and birds.

The scheme could also incorporate the formation of varied a topography with the inclusion of shallow excavated scrapes which would encourage a series of ecological niches. Where possible this should be accompanied by seeding with a species rich wildflower mix tailored to the wetter environment.

8.4 Option 4 - Culvert Extension, Channel Widening, Flood Embankments

This combined option will incorporate the culvert extension (Measure 3), channel widening (Measure 5) and flood embankments (Measure 2). The amount of widening and heights of embankments along the widened channel for various standards of protection are in Tables 7.4 and 7.5 respectively. The location of the works is illustrated in Appendix A.13 and details of channel widening are presented in Appendix A.14. Works to the culvert only offers a 1 in 25 year standard of protection and so for higher return periods embanking is required upstream of the Toad Cottage extended culvert (at model node CHU_00458). The height of embanking at CHU_00458 is summarised in Table 8.1.

For high return periods the channel widening in itself is not sufficient to convey all the flow due to the constriction of the outfall structure which causes backing up of flow in the lower reaches of Church Beck. For return periods of Q50 and above enlargement of the outfall structure is required (see Table 7.4 for required increases in capacity for various return periods). The sloping culvert outfall into Sea Cut should be redesigned to enable the passage of wildlife. This may involve reducing the angle of slope and/or providing a series of steps to facilitate otter movements through the outfall and the replacement to incorporate a wildlife ledge.

The existing channel at Hackness Road is narrow and constrained by vertical stone and concrete walls and piling. This existing structure inhibits the growth of vegetation and therefore the beck is at present species poor with little invertebrate interest. This option will widen the watercourse to approximately 5m and enable the colonisation of limited aquatic and some marginal flora, however the management of the beck is likely to necessitate the periodic clearance of vegetation to maintain the channel and prevent blockage and flooding. Bank side flora should be retained wherever possible and only the right bank should be managed.

Widening the channel will require the removal of the existing hedgerow and this should be reinstated with a species mix of local provenance. In this instance the hedge could be accompanied by features such as a hedgebank and wide verge to maximise species and structural diversity.

8.5 Option 5 – Culvert Extension, Channel Widening, Flood Embankments, Flood Storage

This option combines the culvert extension (Measure 3), channel widening (Measure 5) and flood embankments (Measure 2). This option differs from Option 3 by incorporating a smaller amount of widening of the channel and utilising the field for some flood storage during higher flows. Widening of the channel will be from the left bank and the height of the right bank will remain the same. Various combinations of channel widening and flood bund heights were considered. Widening the channel to 2m results in only a 50mm reduction in the height of the flood bund for all standards of protection compared to that with a 1m widening. It was considered that a 1m widening is the optimum and the flood bund heights for this option are summarised in Table 8.4. The location of the works are illustrated in Appendix A..15 and details of flood storage and channel widening are detailed in Appendix A.16.

Works to the culvert only offers a 1 in 25 year standard of protection and so for higher return periods embanking is required upstream of the Toad Cottage extended culvert (at model node CHU_00458). The height of embanking at CHU_00458 is summarised in Table 8.1.

Table 8.4 - Width of channel widening and height of flood bund

	Q25	Q50	Q100	Q200
Channel widening (m)	1	1	1	1
Height of Flood Bund including 600mm freeboard (mm)	400	600	800	1050

This option would widen the channel to approximately 3m and provide flood storage in the field adjacent to Hackness Road. This scheme will enhance the corridor of the existing channel and provide the benefits associated with the creation of a flood storage area as described in Section 8.3.

9 Economic Appraisal Methodology

9.1 Objectives

The economic appraisal of various options presented in Section 6 was conducted in accordance with the PAG3, (DEFRA 2003). The purpose of conducting this appraisal was to test the economic feasibility of the proposed schemes to alleviate flooding in Scalby from Church Beck and Coldgill Beck.

9.2 Estimation of Flooding Depths

Flooding depths have been estimated from the water levels calculated by the ISIS model and the threshold levels of properties within the flood risk area. Appendix D summarises the depths of flooding for each property for various return periods. These depths of flooding have been utilised in the economic appraisal.

9.3 Depth Damage Data

There are no commercial properties, only residential properties at risk of flooding within Scalby from Church Beck. Costs were attributed to each property based on the depth of internal flooding (see Section 9.2). Damage costs were estimated using the Flood Hazard Research Centre's "The Benefits of Flood and Coastal Defence: Techniques and Data for 2003" (also known as the Multi-coloured Manual or MCM) and figures were updated for inflation using RPI Index. The Type and Age and Social Class classifications were used to determine the appropriate table to be used for each residential property type. Three property types were assumed to be at risk within Scalby; pre-1919 detached houses, 1975-1985 detached houses, and 1975-1985 detached bungalows. The damages associated with flooding in each property type are summarised in Section 10.1 and detailed fully in Appendix E, including extracts from the MCM.

The duration of flooding of properties varies with location within the Church Beck catchment. Whilst the upper part of the catchment around Carr Lane is likely to experience flooding of less than 12 hours, the properties within Scalby Beck Road, where the flood water is likely to pond with no natural means of escape, the flood duration is likely to be greater than12 hours. For this reason both scenarios of greater and less than 12 hours flood duration were analysed to determine the associated damages to properties.

The flood depth for each property, or group of similar properties, was used to determine the correct column to be used in the tables of Chapter 4, annexe 4.1 from the MCM. From the tables only the row providing Total Damage was used to calculate residential losses (See Appendix E).

Residential losses for each residential property or group of similar properties, for each return period flood event were entered into FCDPAG3 spreadsheet in the Asset AAD tab and from this the Present Value of losses was estimated for each property.

9.4 Write-off Values

FCDPAG3 states 'Care should be exercised where the total present value of losses exceeds the current write-off value of the asset. In the case of domestic or commercial property it will usually be prudent to assume that the long-term economic loss cannot exceed the current capital value of the property'. Property write-off values have been estimated using a number of sources. The write-off value for the residential properties was determined from the HM Land Registry – Residential Property Report found on the internet for July-September 2003. Table 9.1 shows the write off values that have been adopted for the various property types at risk.

Table 9.1 – Property write-off values

Property Type	Unit write-off (£k)	No. of units	Total (£k)
Pre 1919 Detached House	180	11	1,980
1975-1985 Detached House	140	12	1,680
1975-1985 Detached Bungalow	130	12	1,560
		Total	**5,220**

9.5 Options Analysed

The Options which were analysed as part of the economic appraisal are as follows:

1) Do Nothing
2) Do Minimum
3) Option 3
4) Option 4
5) Option 5

For each of these options the benefits were estimated from the damages, along with the costs of implementing the scheme.

10 Assessment of Benefits

10.1 'Do Nothing' Damages

The 'Do Nothing' damages are used to provide a cost baseline for the economic appraisal of the various options. They are calculated assuming no maintenance, repairs or improvements are made to the existing channel and structures and that the Council effectively 'walks away' from the problem. The structures may become blocked and eventually collapse, damaging the property and roads above them and resulting in frequent flooding and the eventual loss of parts of the town. Along Hackness Road the banks would collapse further along with the footpath resulting in frequent flooding of adjacent properties and affecting the integrity of the road.

10.1.1 Identification of Properties at Flood Risk

Flood outlines (see Appendix A.7) and flood depths for each event return period were determined by hydraulic modelling. Table 10.1 summarises the number of properties of each type that are at risk of flooding for the various return periods.

Table 10.1 - Number of properties at risk for various return periods

Return period (years)	No. of properties affected	Properties
5	1	Carr Lane (1)
10	3	Carr Lane (2), Hackness Road (1)
25	28	Carr Lane (4), Hackness Road (2), Scalby Beck Road (22)
50	33	Carr Lane (5), Hackness Road (6), Scalby Beck Road (22)
75	35	Carr Lane (6), Hackness Road (7), Scalby Beck Road (22)
100	35	Carr Lane (6), Hackness Road (7), Scalby Beck Road (22)
200	35	Carr Lane (6), Hackness Road (7), Scalby Beck Road (22)

10.1.2 Residential Property Losses

Table 10.2 summarises the average damage for each property type for the upper and lower limits based on flood duration. The damage associated with each individual property for the various return periods are summarised in Appendix E.

Table 10.2 - Damages Assigned to Various Property Types

Property Type	Damages – Lower Estimate	Damages – Upper Estimate
Pre-1919 Detached House	£62.7k average per property	£97.8k average per property
1975-1985 Detached House	£78.2k average per property	£91.4k average per property
1975-1985 Detached Bungalow	£98.6k average per property	£117.0k average per property
Total for 35 properties	£2,811k	£3,577k

10.1.3 Adopted losses

The Present Value (PV) loss calculated in the FCDPAG3 spreadsheet for each property, or group of similar properties, was compared with the write-off value for the property and they are summarised in Table 10.3. The number of properties used in the write-off calculation was based on the number of properties at risk for the 1 in 100 year return period event. The combined write off values are greater than the combined PV damages for each property type for both the upper and the lower limits that have been estimated. Therefore, the PV damages have been used to estimate the losses without a flood defence scheme.

Table 10.3 – Adopted Loss Values

Property Type	PV damages (£k)		Write-off value (£k)	Adopted Loss (£k)	
	Lower	Upper		Lower	Upper
Pre 1919 Detached House	690	1,076	1,980	690	1,076
1975-1985 Detached House	938	1,097	1,680	938	1,097
1975-1985 Detached Bungalow	1,183	1,404	1,560	1,183	1,404
Total	**2,811**	**3,577**	**5,220**	**2,811**	**3,577**

10.2 'Do Minimum' Damages

The 'Do Minimum' option seeks to maintain the status quo with the structures and channel by implementing a regime of urgent repairs and regular maintenance. The modelled culvert and structure capacities have been calculated assuming they are free from silt. The channel has been modelled assuming that they are not heavily vegetated or constricted due to the slumping of banks. Annual Average Damage (AAD) has been calculated using these assumptions.

It is, therefore, reasonable to assume that the damages that will occur for the 'Do Minimum' option are equal to the AAD calculated for the 'Do Nothing' option, and will occur evenly over the economic design life.

10.3 Assessment of Option 3

10.3.1 Q25 Standard of Protection Damages

The results of the hydraulic modelling reveal that the extension of the culvert on Upper Church Beck, channel and bank stabilisation along Hackness Road and the construction of a flood bund within the field adjacent to Hackness Road is sufficient to protect all properties from the 1 in 25 year flood event. This scheme also offers a greater protection (up to Q100) for properties around Carr Lane and Hackness Road. For events greater than the 1 in 25, floodwaters will overtop the flood bund causing damage to properties within Scalby Beck Road. Flooding will also occur around the wooden footbridge on Hackness Road causing damage to several properties within the vicinity. Table 10.4 summarises the number of properties of each type that are at risk of flooding for events greater than the Q25 return period. The damage associated with each individual property for the upper and lower limits (based on flood duration) for the various return periods are summarised in Appendix E.

Table 10.4 - Properties at Risk

Return period (year)	No. of properties affected	Properties
5	0	-
10	0	-
25	0	-
50	26	Hackness Road (4), Scalby Beck Road (22)
75	27	Hackness Road (5), Scalby Beck Road (22)
100	27	Hackness Road (5), Scalby Beck Road (22)
200	32	Hackness Road (5), Scalby Beck Road (22)

For each of the properties at risk, the adopted loss is determined by comparing the write off value with the present value damages. The number of properties used in the write-off calculation was based on the number of properties at risk for the 1 in 200 year return period event. Table 10.5 summarises the combined adopted losses for the properties at risk.

10.3.2 Q50 Standard of Protection Damages

The scheme that offers at least a Q50 standard of protection to all properties is everything included within the Q25 scheme with the addition of:

- Increasing the height of the flood embankment around the low-lying area of the wooden footbridge;
- Increasing the height of the flood bund within the field to a Q100 standard of protection.

For events greater than the 1 in 100, flood waters will overtop the flood embankment and flood bund causing damage to properties. The number of properties of each type that are at risk of flooding for events greater than the Q50 return period are the same as in Table 10.4. The number of properties used in the write-off calculation was based on the number of properties at risk for the 1 in 200 year return period event. The combined adopted losses for the properties for the Q50 scheme are summarised in Table 10.5.

10.3.3 Q100 Standard of Protection Damages

The scheme that offers at least a Q100 standard of protection to all properties is everything included within the Q25 scheme with the addition of:

- Increasing the height of the flood embankment around the low-lying area of the wooden footbridge;
- Increasing the height of the flood bund within the field to a Q100 standard of protection.

For events greater than the 1 in 100, flood waters will overtop the flood embankment and flood bund causing damage to properties. The number of properties of each type that are at risk of flooding for events greater than the Q100 return period are the same as in Table 10.4. The number of properties used in the write-off calculation was based on the number of properties at risk for the 1 in 200 year return period event. The combined adopted losses for the properties for the Q100 scheme are summarised in Table 10.5.

10.3.4 Q200 Standard of Protection Damages

The scheme that offers at least a Q200 standard of protection to all properties is everything included within the Q25 scheme with the addition of:

- Increasing the height of the flood embankment around the low-lying area of the wooden footbridge;
- Increasing the height of the flood bund within the field to a Q200 standard of protection.

For events greater than the 1 in 200, flood waters will overtop the flood embankment and flood bund causing damage to properties. The number of properties of each type that are at risk of flooding for events greater than the Q100 return period are the same as in Table 10.4. The number of properties used in the write-off calculation was based on the number of properties at risk for the 1 in 200 year return period event. The combined adopted losses for the properties for the Q200 scheme are summarised in Table 10.5.

Table 10.5 – Adopted Loss Values for Option 3, for various Return Periods

Return Period	Property Type	PV damages (£k)		Write-off value (£k)	Adopted Loss (£k)	
		Lower	Upper		Lower	Lower
Q25	Total	1,116	1,354	3,880	1,116	1,354
Q50	Total	715	868	3,880	715	868
Q100	Total	370	457	3,880	370	457
Q200	Total	137	172	3,880	137	172

10.4 Option 4

10.4.1 Q25 Standard of Protection Damages

The results of the hydraulic modelling reveal that the extension of the culvert on Upper Church Beck, channel widening by 2m along Hackness Road and localised embanking can protect all properties from the 1 in 25 year flood event. This scheme also offers a greater protection (up to Q100) for properties around Carr Lane. For events greater than the 1 in 25, floodwaters will overtop the banks causing damage to properties along Hackness Road and within Scalby Beck Road. Table 10.4 summarises the number of properties of each type that are at risk of flooding for events greater than the Q25 return period. The damage associated with each individual property for the upper and lower limits (based on flood duration) for the various return periods are summarised in Appendix E.

For each of the properties at risk, the adopted loss is determined by comparing the write off value with the present value damages. The number of properties used in the write-off calculation was based on the number of properties at risk for the 1 in 200 year return period. The combined adopted losses for the properties at risk are the same as for Combined Option 3 and are summarised in Table 10.5.

10.4.2 Q50 Standard of Protection Damages

The scheme that offers at least a Q50 standard of protection to all properties is everything included within the Q25 scheme with the addition of:

- Increasing the widening of the channel along Hackness Road to 3m;
- Enlarging the capacity of the Sea Cut outfall structure by 50%;

- Increasing the height of the embanking to a Q50 standard of protection.

For events greater than the 1 in 50, flood waters will overtop the banks and causing damage to several properties. The number of properties of each type that are at risk of flooding for events greater than the Q100 return period are the same as in Table 10.4. The number of properties used in the write-off calculation was based on the number of properties at risk for the 1 in 200 year return period event. The combined adopted losses for the properties for the Q50 scheme are the same as for Combined Option 3 and are summarised in Table 10.5.

10.4.3 Q100 Standard of Protection Damages

The scheme that offers at least a Q100 standard of protection to all properties is everything included within the Q25 scheme with the addition of:

- Increasing the widening of the channel along Hackness Road to 4m;

- Enlarging the capacity of the Sea Cut outfall structure by 100%;

- Increasing the height of the embanking to a Q100 standard of protection.

For events greater than the 1 in 100, flood waters will overtop the banks and causing damage to several properties. The number of properties of each type that are at risk of flooding for events greater than the Q100 return period are the same as in Table 10.4. The number of properties used in the write-off calculation was based on the number of properties at risk for the 1 in 200 year return period event. The combined adopted losses for the properties for the Q100 scheme are the same as for Combined Option 3 and are summarised in Table 10.5.

10.4.4 Q200 Standard of Protection Damages

The scheme that offers at least a Q200 standard of protection to all properties is everything included within the Q25 scheme with the addition of:

- Increasing the widening of the channel along Hackness Road to 4m;

- Enlarging the capacity of the Sea Cut outfall structure by 100%;

- Increasing the height of the embanking to a Q200 standard of protection.

For events greater than the 1 in 200, flood waters will overtop the banks and causing damage to several properties. The number of properties of each type that are at risk of flooding for events greater than the Q200 return period are the s ame as in Table 10.4. The number of properties used in the write-off calculation was based on the number of properties at risk for the 1 in 200 year return period event. The combined adopted losses for the properties for the Q100 scheme are the same as for Combined Option 3 and are summarised in Table 10.5.

10.5 Option 5

10.5.1 Q25 Standard of Protection Damages

The results of the hydraulic modelling reveal that the extension of the culvert on Upper Church Beck, channel widening along Hackness Road and the construction of a flood bund within the field adjacent to Hackness Road can protect all properties from the 1 in 25 year flood event. This scheme also offers a greater protection (up to Q100) for properties around Carr Lane. For events greater than the 1 in 25, floodwaters will overtop the flood bund causing damage within Scalby Beck Road. Table 10.4 summarises the number of properties of each type that are at risk of flooding for events greater than the Q25 return period. The damage associated with each individual property for the upper and lower limits (based on flood duration) for the various return periods are summarised in Appendix E.

For each of the properties at risk, the adopted loss is determined by comparing the write off value with the present value damages. The number of properties used in the write-off calculation was based on the number of properties at risk for the 1 in 200 year return period event. The combined adopted losses for the properties at risk are the same as for Combined Option 3 and are summarised in Table 10.5.

10.5.2 Q50 Standard of Protection Damages

The scheme that offers at least a Q50 standard of protection to all properties is everything included within the Q25 scheme with the addition of:

- Increasing the height of the flood bund;
- Increasing the height of the embanking to a Q50 standard of protection.

For events greater than the 1 in 50, flood waters will overtop the banks and flood bund causing damage to several properties. The number of properties of each type that are at risk of flooding for events greater than the Q100 return period are the same as in Table 10.4. The number of properties used in the write-off calculation was based on the number of properties at risk for the 1 in 200 year return period event. The combined adopted losses for the Q50 scheme are the same as for Combined Option 3 and are summarised in Table 10.5.

10.5.3 Q100 Standard of Protection Damages

The scheme that offers at least a Q100 standard of protection to all properties is everything included within the Q25 scheme with the addition of:

- Increasing the height of the flood bund;
- Increasing the height of the embanking to a Q100 standard of protection.

For events greater than the 1 in 100, flood waters will overtop the banks and causing damage to several properties. The number of properties of each type that are at risk of flooding for events greater than the Q100 return period are the same as in Table 10.4. The number of properties used in the write-off calculation was based on the number of properties at risk for the 1 in 200 year return period event The combined adopted losses for the Q100 scheme are the same as for Combined Option 3 and are summarised in Table 10.5.

10.5.4 Q200 Standard of Protection Damages

The scheme that offers at least a Q200 standard of protection to all properties is everything included within the Q25 scheme with the addition of:

- Increasing the height of the flood bund;
- Increasing the height of the embanking to a Q200 standard of protection.

For events greater than the 1 in 200, flood waters will overtop the banks and causing damage to several properties. The number of properties of each type that are at risk of flooding for events greater than the Q100 return period are the same as in Table 10.4. The number of properties used in the write-off calculation was based on the number of properties at risk for the 1 in 200 year return period event. The combined adopted losses for the Q200 scheme are the same as for Combined Option 3 and are summarised in Table 10.5.

10.6 Present Value Damages

The damages incurred are spread over the 50 year economic life of the project and discounted at a rate of 3.5% for the first 30 years and 3.0% after that, to give the present value damages incurred. These are summarised below in Table 10.6 for each of the options (full details of these calculations are provided in Appendix E). For the combined options various standards of protection (SoP) are considered.

Table 10.6 - Summary of Present Value Damages

Option		Present Value Damages	
		Lower	Upper
Do Nothing		£2,811k	£3,577k
Do Minimum		£2,811k	£3,577k
Option 3	Q25 SoP	£1,116k	£1,355k
	Q50 SoP	**£715**	**£868**
	Q100 SoP	£370k	£458k
	Q200 SoP	**£137**	**£172**
Option 4	Q25 SoP	£1,116k	£1,355k
	Q50 SoP	**£715**	**£868**
	Q100 SoP	£370k	£458k
	Q200 SoP	**£137**	**£172**
Option 5	Q25 SoP	£1,116k	£1,355k
	Q50 SoP	**£715**	**£868**
	Q100 SoP	£370k	£458k
	Q200 SoP	**£137**	**£172**

10.7 Loss of Life

The potential for the loss of human life during a flood event has not been considered explicitly in the assessment of 'Do Nothing' damages. However, it is thought that there is a risk to life if no action is taken, e.g. through being swept off their feet by flood water flowing along the roads. A large proportion of the properties at risk are bungalows owned mainly by elderly people, and therefore there may be a greater potential loss of life. The behavioural characteristics of people during a flood are very unpredictable, so the risk to life is difficult to quantify. If loss of life was to be included in the economic analysis, the benefit cost ratio of each of the 'Do Something' options would increase as would the general priority of the scheme. Although loss of life has not been included in the economic analysis it has been considered when calculating the Defra priority score through selecting a very high risk to public safety, which reflects the age of the residents and the number of bungalows in the area.

10.8 Traffic Disruption

Hackness Road is an important through road for access for local residents from the west of Scalby to Scarborough. There is no traffic survey data available so it was not possible to include costs incurred from the closure of the road (e.g. through increased distance travelled following diversions) in the assessment for 'Do Nothing' damages. However, if detailed breakdown of journey costs were to be included in the economic analysis, the benefit cost ratio of each of the 'Do Something' options would increase as would the general priority of the scheme.

10.9 Assessment of Risks

The risks associated with each scheme are summarised in Table 10.7. For Option 3 the main risk is acquiring permission to flood the land and build the flood bund. For Option 4 the main risk is the need to purchase part of the field alongside Hackness Road to enable the channel to be widened. In purchasing the field the hedgerow will be lost which may be an issue if it has a protection order associated with it. Option 5 has more risks associated with it because it has the combined risks of options 3 and 4.

Table 10.7 – Risks associated with the schemes for the three Combined Options

Risk	Option 3	Option 4	Option 5
Permission to flood land within storage area alongside Hackness Road	Yes	No	Yes
Permission to build flood bund within field adjacent to Scalby Beck Road	Yes	No	Yes
Land Purchase of field alongside Hackness Road	May be required	Mandatory	Mandatory
Loss of hedgerow alongside Hackness Road	No	Yes but will be replaced	Yes but will be replaced
Works remote from Church Beck channel	Yes – flood bund	No	Yes – flood bund

11 Assessment of Costs

A breakdown of the estimated costs for each option is shown in Appendix F. Land purchase and compensation costs are covered separately along with any site investigation works required. Contingencies are assumed to be 20%.

Costs for each option are broken down into three components: capital (plus contingencies), maintenance and fees. The 'Do Minimum' improvements are also required for all the other options and so these costs are also incorporated into each option.

The costs incurred are then spread over the 50 year design life of the project and discounted (at a rate of 3.5% for the first 30 years and then 3.0% for the next 20 years) to give the present value costs incurred. These are summarised below in Table 11.1. Full details of all the calculations are presented in Appendix F. The costs of the combined schemes are very similar but Option 4 has the lower costs associated with the higher return periods of Q100 and Q200.

Analysis of costs have been undertaken using CESMM3 (Civil Engineering Standard Method of Measurement, Martin Barnes, 1992) and experience from similar construction works. Assumptions regarding land purchase, site investigation costs and contingencies have been made and these will need to be checked.

Table 11.1. Summary of Present Value Option Costs for preferred scheme

Option		Present Value of Costs (£k)
Do Nothing		-
Do Minimum (Maintenance)		94
Option 3 (Culvert extension, channel stabilisation and flood bund and embankments)	Q25 SoP	764
	Q50 SoP	865
	Q100 SoP	950
	Q200 SoP	1,016
Option 4 (Culvert extension, channel widening and flood embankments)	Q25 SoP	512
	Q50 SoP	627
	Q100 SoP	654
	Q200 SoP	668
Option 5 (Culvert extension, channel widening, flood bund and embankments)	Q25 SoP	594
	Q50 SoP	623
	Q100 SoP	642
	Q200 SoP	664

12 Benefit Cost Analysis

An incremental benefit cost analysis has been undertaken following the guidelines given in PAG3. Present value benefits are calculated by subtracting the present value 'Do Something' damages from the present value 'Do Nothing' damages. The benefit cost ratio is then calculated by dividing these benefits by the present value option costs.

Damages and costs have been estimated for all the options outlined in Section 8. Benefit cost ratios have, therefore, been estimated for each standard of protection. The results from this analysis are summarised in Table 12.1 for the Upper and Lower PV Damages, and full details are provided in Appendix G.

Table 12.1 It may be seen that the highest benefit cost ratio of 4.0 to 5.1 is given by Option 4 and Option 5 with a Q200 standard of protection. The Combined Option 3 has much lower cost benefit ratios than either Option 4 or 5 which are both similar. However, Combined Option 5 has much higher incremental benefit cost ratios than Combined Option 4 (for Standards of protection up to Q100).

Defra[1] have set up a priority scoring system which "attempts to ensure the equitable distribution of funding supporting the provision of flood and coastal defence solutions. It recognises that whilst it should be possible to undertake a broad brush economic analysis at an early stage in project development, it is not reasonable to undertake a full project appraisal. In addition to economics, it provides a simplified approach to weighting projects to take account of the intangible impacts on people and the natural environment." The calculations for the priority scoring for each of the schemes are in Appendix H and the scores for a Q200 standard of protection are summarised in Table 12.1. The highest Defra priority scores are given by Option 5.

[1] Defra Website – Annex B The Priority Scoring System

Table 12.1 - Summary of Incremental Benefit Cost Analysis for Lower (L) and Upper (U) estimates for PV Damages, and Defra Priority Scores

	Do Nothing	Do Minimum	Cost Benefis for Option 3								Cost Benefis for Combined Option 4								Cost Benefis for Combined Option 5							
			Q25 Standard of Protection		Q50 Standard of Protection		Q100 Standard of Protection		Q200 Standard of Protection		Q25 Standard of Protection		Q50 Standard of Protection		Q100 Standard of Protection		Q200 Standard of Protection		Q25 Standard of Protection		Q50 Standard of Protection		Q100 Standard of Protection		Q200 Standard of Protection	
PV costs (PVc) (£k)		94	764		865		950		1,016		512		627		654		668		594		623		642		664	
			L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U
PV damage (PVd) (£k)	2,811		1,116	1,354	715	868	370	457	137	172	1,116	1,354	715	868	370	457	137	172	1,116	1,354	715	868	370	457	137	172
PV damage avoided (£k)			1,694	2,223	2,096	2,709	2,441	3,119	2,674	3,405	1,694	2,223	2,096	2,709	2,441	3,119	2,674	3,405	1,694	2,223	2,096	2,709	2,441	3,119	2,674	3,405
Total PV benefits (PVb) (£k)			1,694	2,223	2,096	2,709	2,441	3,119	2,674	3,405	1,694	2,223	2,096	2,709	2,441	3,119	2,674	3,405	1,694	2,223	2,096	2,709	2,441	3,119	2,674	3,405
Net Present Value (NPV) (£k)		94	931	1,459	1,230	1,844	1,490	2,169	1,658	2,389	1,182	1,710	1,469	2,082	1,787	2,466	2,005	2,737	1,101	1,629	1,473	2,086	1,799	2,478	2,009	2,741
Average Benefit/Cost Ratio			2.2	2.9	2.4	3.1	2.6	3.3	2.6	3.4	3.3	4.3	3.3	4.3	3.7	4.8	4.0	5.1	2.9	3.8	3.4	4.4	3.8	4.9	4.0	5.1
Incremental Benefit/Cost Ratio			2.5	3.3	4.0	4.8	4.0	4.8	3.6	4.4	4.0	5.3	3.5	4.3	12.9	15.3	15.7	19.3	3.4	4.5	13.8	16.7	18.1	21.5	10.3	12.7
Defra Priority Scores			-	-	-	-	-	-	10.1	11.6	-	-	-	-	-	-	12.5	14.7	-	-	-	-	-	-	13.6	15.8

13 Conclusions & Recommendations

An in-depth options assessment and hydraulic study has been undertaken to determine the causes, extents and frequency of flooding in the Church Beck catchment. Mitigation options have been assessed and costed and the following conclusions determined.

Flooding causes, extents and mechanisms

(i) Flooding within the properties around Carr Lane, Hackness Road and Scalby Beck Road is frequent and extensive and justifies the designation of Church Beck as a Critical Ordinary Watercourse.

(ii) Hydraulic modelling predicts that flooding is first experienced by 3 properties for a 1 in 10 year return period, namely, Church Beck Cottage, Brook View and 113 Hackness Road. This rises to 28 properties for the 25 year event and 35 properties for the 100 year event. Flood depths of up to 1.55m are predicted for some properties for the 1 in 100 year event as confirmed by recent flooding incidents.

(iii) There are three main stretches of flooding and specific flooding mechanisms associated with these areas as summarised below:

1	Hackness Road (7 properties affected)	Limited capacity of Low Hill footbridge (CHU_00282) and incapacity of channel along Hackness Road. (Flooding starts at a return period of between 10 and 50 years.)
2	Church Beck and Colgill Beck confluence (6 properties affected)	Limited capacity of small weir and ornamental bridge at Church Beck Cottage (CHU_00427) and the twin arched Carr Lane culvert around the confluence of Church Beck and Coldgill Beck (CHU_00423). (Flooding starts at a return period of 10 years)
3	Scalby Beck Road (22 properties affected)	Limited capacity of channel along Hackness Road with flooding from left bank across field. (Flooding starts at a return period of 25 years)

(iv) The incapacity of key structures is a direct cause of flooding. The small weir and ornamental bridge at Church Beck Cottage (CHU_00427) and the twin arched Carr Lane culvert around the confluence of Church Beck and Coldgill Beck (CHU_00423) both limit flow capacity and thus act as hydraulic controls leading to flooding. The properties affected at this location are Church Beck Cottage, Brook View School House, Dainton, Homestead and Toad Cottage.

Preferred flood mitigation option

A number of mitigation measures were assessed, tested and costed. Option 4 is the preferred scheme based on the slightly higher cost benefit ratio (3.3 – 4.1 caclulated), the fewer perceived risks associated with the scheme and the greater ecological benefit. This scheme designs flooding out of the system by widening (replacing) the existing culvert under Carr Lane and extending it upstream by a distance of approximately 20m. It also widens the open channel along Hackness Road from its current 1.5-2m to 5-6m. The new channel is proposed as a two-stage system accommodating normal and storm flows without detriment. Channel stabilisation is inherent in the shallowing of the slopes of the left and right banks and a larger outfall structure can be designed to be more sympathetic to wildlife.

The preferred option (option 4) is summarised below.

Protecting properties at Coldgill/Church Beck confluence

(i) Replace culvert under Carr Lane with larger capacity culvert, incorporating a wildlife ledge. (Appx. 15m length).

(ii) Extend culvert upstream by a distance of appx. 20m to counter channel incapacity along this stretch.

(iii) Undertake scour protection works to right bank along Church Beck to counter increased storm flows out of culvert under Carr Lane.

Protecting Properties along Hackness Road abd Scalby Beck Road

(i) Undertake channel widening of Church Beck along Hackness Road (appx. 200m length), using the adjacent field to accommodate wider 2-stage channel.

(ii) Replace existing hedge with new species-rich hedgerow.

(iii) Enlarge outfall to Sea Cut, incorporating steps for wildlife access.

(iv) Re-design Low Hill footbridge to facilitate storm flows.

Maintenance Measures

(i) A number of trash screens are required to be constructed and maintained along the watercourse. These should also be designed to be accessed and cleaned during flood conditions.

(ii) The channel is required to be kept relatively free of vegetation and debris.

Consideration of risks

The main risk associated with the preferred option is considered to be the purchasing of the land required to widen the channel. Associated with this are the presence of otters and as such, the selection of the preferred option and detailed design has to be undertaken with strict consultation and with the agreement of English Nature. Consultations with the residents are also required, although a wider channel would become an ecological feature and enhance the area. It should then be noted that the preferred option could be subject to change.

Recommendations

(i) Church Beck and Colgill Beck are both considered to be critical ordinary watercourses and this status should be maintained.

(ii) In terms of the selection of freeboard and factors of safety regarding channel design, a manning's n of 0.08 (to simulate a highly vegetated channel) increased water levels of 200-300mm for the 100 year design event. It is recommended that this robustness should be accommodated for in the design as freeboard along the floodbanks.

(iii) This Project Appraisal Report has revealed that there is a strong economic case to advance this project and present it to DEFRA for grant aid assistance.

(iv) The flooding mechanisms are complex and the solutions impacting on numerous stakeholders. Therefore, consultations should be initiated to facilitate agreements before detailed design is initiated.

(v) As part of the detailed design phase, a comprehensive site investigation would be required. This will consist of a full services search, and relevant boreholes to determine ground conditions. This will enable a greater level of confidence to be placed in the scheme costs which could then be revisited. The issue of land purchase and/or permission to do works on land will also need to be further investigated.

(vi) The progression of this study will need to incorporate a carefully designed consultation strategy to ensure that all stakeholder opportunities are maximised.

(vii) Updating of the hydraulic model with the recent emergency works on Church Beck along Hackness Road will need to be undertaken so that the flood alleviation options can be tested for the current channel conditions. However, this is not expected to change the findings significantly.

(viii) It is recommended that consideration be given to local rainfall and water level monitoring such that a calibration of the hydraulic model can be undertaken at a future date. However, it is not suggested that the project is delayed for this requirement.