SCARBOROUGH BOROUGH COUNCIL

Long Plantation Watercourse, Filey

Flood Alleviation Scheme – Phase 2

Final including Client comments

Notice

Document History

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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 – The Dams Area, (Atkins July 2002)
PR	Percentage Runoff
PV	Present Value
Q100	1 in 100 year return period
Q_{MED}	(Q 'med') Median Annual Flood
RPI	Retail Price Index
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 Dams area of Filey. At that stage it was determined that a more detailed options appraisal report was justified. This, current report represents a detailed mathematical modelling exercise 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 in the Wharfedale housing estate is frequent justifies the designation of Long Plantation Watercourse as a Critical Ordinary Watercourse. The most recent flood occurred in 10th August 2002 when flooding was experienced to 47 properties in Wharfedale estate. The flooding was from a combination of Long Plantation Watercourse and sewer incapacity. This event has been estimated to have a return period of 15-20 years.

Hydrological assessments have determined that the flow along Long Plantation Watercourse is 1.1 m^3/s for the 100 year return period event and 1.3 m^3/s for the 200 year event. The existing bank-full capacity of the channel is estimated to be approximately 0.5m3/s, or a 10 year return period event. This excludes any allowance for debris or culvert blockages that would reduce this capacity significantly.

Hydraulic modelling predicts that flooding is first experienced by 3 properties for a 1 in 10 year return period. The 3 properties at the end of Fewston Close flood as a result channel incapacity along the stretch and low bank levels. This rises to 6 properties for the 25 year event and 22 properties for 100 year event. Flood depths of up to 300mm are predicted for some properties for the 1 in 100 year event.

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 (100 yr event)	Causes	Return Period for Start of flooding
Fewston Close Wharncliffe Place Barden Place Rivelin Way	22	Limited capacity of channel Run-off from school fields.	10 years
Allotment Gardens Culvert		Surcharged culvert with potential to cause flooding when blocked	
Pasture Crescent Culvert		Surcharged culvert with potential to cause flooding when blocked	
New Development Culvert		Surcharged culvert with potential to cause flooding when blocked	

The incapacity of the channel upstream of the Dams area is a direct cause of flooding. The uneven gradient of the channel and dense vegetation are the main problems. The gradient causes the flow to back up and flooding the Wharfedale housing estate.

The three culverts are surcharged for events greater than 1 in 10 year, but the channel has the capacity to contain the flow. However, if the culvert inlet is blocked by debris this will lead to flooding of the surrounding area.

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 respectively but have been rejected.) A range of return periods were also assessed and the 100 year Standard of Protection was considered to be the most cost-beneficial for the preferred scheme.

Summary of mitigation measures and cost benefit assessments

Option	3 (Flood Embankment)	4 (Storage)	5 (Channel widening & re-profiling)
General Maintenance	1. Installation of new trash screen to all culverts 2. Regular maintenance to remove any debris from channel which may cause blockages 3. Maintenance of channel to control the growth of vegetation		
Protecting Properties in Wharfedale Housing Estate	Construct embankments along the right bank from Wharncliffe Place to Rivelin Way (approx 200m) to alleviate flooding of the housing estate.	Construct bunds along the left hand bank to attenuate the run-off across the school fields. The school fields will act as storage.	Undertake channel widening along Long Plantation Watercourse from Wharncliffe Place to Rivelin Way (approx 200m) to obtain a wider 2-stage channel. Also re-profiling of the channel bed.
Cost Benefit Ratio (100 yr SoP)	2.4	1.44	3.2
Defra Priority Scores (100 yr SoP)	12.5	7.9	15.4

Ecological considerations

The presence of Great Crested Newts in the Dams Lakes is likely to have a considerable impact on the type, extent and timing of work in this channel and a licence would probably be required. As the preferred option proposes works at least 100m from the lakes, it may be that extensive works would be permitted, following an ecological survey to ascertain the exact extent of habitat required by the Great Crested Newts.

Selection of Proposed Scheme

There is little to separate the schemes for options 3 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 5 is the preferred scheme based on the higher cost benefit ratio and the greater ecological benefit, once the scheme is complete. This scheme designs flooding out of the system by widening and re-profiling the existing channel. The new channel is proposed as a two-stage system accommodating normal and storm flows without detriment. Before the channel is widened, re-profiling is required as the channel gradient is uneven, causing some ‘pinch’ points that result in the flows backing up and flooding.

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 a minimum freeboard for the proposed works.

It is also recommended that a series of trash screens be constructed along the watercourse and at all culvert entrances (downstream of the Dams area) and that a strict maintenance regime is adopted to ensure that the channel bed and sides remain essentially free from dense vegetation.

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 heavy vegetation, 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 associated with close proximity of the Dams area and presence of great crested newts. Consultations with all relevant bodies will also be a requirement combined with a habitat survey. There is, therefore, a risk that the preferred option could be subject to change.

1 Introduction

1.1 Background

WS Atkins Consultants Limited (Atkins) was commissioned by Scarborough Borough Council (SBC) to prepare a flood alleviation scheme phase 2 study for Long Plantation critical ordinary watercourse. The aim of this report is to assess and justify the implementation of a flood alleviation scheme (FAS) for the Long Plantation Watercourse catchment. It is intended that this report would be submitted to Defra for grant aid on capital expenditure.

This report represents phase 2 of the Dams 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 towards a more detailed modelling and option assessment stage.

1.2 General Description of Long Plantation Watercourse

Filey is a traditional English seaside resort and fishing town on the North East coast of England. The Dams area and Long Plantation Watercourse are situated to the north west of the Wharfedale housing estate in the west of Filey. 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, the Dams are composed of a total of six small lakes of various sizes. The inflow to the lakes appears mainly from the Long Plantation Watercourse to the north and the outflow leaves The Dams at its north east side flowing in an easterly direction. The watercourse enters into a culvert system under the allotment gardens and eventually discharges to the sea at Coble Landing. Flooding of properties occurs along Long Plantation Watercourse. These locations area presented in Appendix A.2. Flooding has occurred on at least two occasions recently in November 2000 and August 2002.

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 Long Plantation and The Dams.
- The hydraulic modelling of the watercourse.
- 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 Wharfedale housing estate area and data collected during phase 1 of this study, three recent flooding events from Long Plantation Watercourse were identified. These occurred in late October and early November 2000 and 10th August 2002. 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 2000 event although this does not imply that no flooding occurred before this date.

Table 2.1 - Effects of Historical Flooding from Long Plantation Watercourse

Flood Event	No. of Properties Affected (internal and external)
October 2000	*Insufficient channel capacity caused flooding around the footbridge and adjacent land. No records of properties affected.*
November 2000	*Insufficient channel capacity and channel blockages caused flooding.*
	6 properties on Rivelin Way, Fewston Close & Ewden Close (gardens including solum) 1 property flooded internally
August 2002	*Insufficient channel capacity and intense rainfall (3 inches in 3 hours)*
	47 properties on Wharfedale estate were affected by flooding. This was caused by a combination of flooding from Long Plantation Watercourse and sewer incapacity

(Note: 'solum' represents average ground level and indicates that flood water would affect property foundations without any actual internal flooding. The EA defines a property as being flooded when water levels reach 150mm below ground floor level)

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

1) Channel incapacity along Long Plantation Watercourse

2) Blockages in the channel

3) Land drainage during intense rainfall

4) Incapacity of sewer system

These sources are shown on Appendix A.2. A detailed investigation into the issues of sewer incapacity has been completed by Atkins. For further details see the Filey Town flood investigation report (5002531/98/dg/42). 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 Long Plantation Watercourse and The Dams flooding situation.

3.2 Topographic Survey

Survey Operations Limited were commissioned to provide topographic survey data for Long Plantation Watercourse. This included:

- threshold and road levels through parts of Wharfedale housing estate known to be recently affected by flooding from the Long Plantation Watercourse catchment;
- spot levels within the allotment gardens to the east of Pasture Crescent;
- cross sections through the open watercourses,
- culvert inlet and outlet units and upstream and downstream sections of bridges including deck levels.
- photographs of the channel and structures (see Appendix B)

There was no LiDAR data available for the area surrounding. During the first phase study a limited survey was completed by North Engineering Survey. The survey consisted of spot heights for the school playing field, The Dams area and the proposed development area to the north east of The Dams. From the spot heights, 0.5m contour lines were calculated.

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;
- photos provided by residents following the floods;
- 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, The Dams, Filey, Atkins, January 2003 (the Phase 1 report)*
- *Filey Town Flooding Investigation, Atkins, March 2004*

4 Ecological Assessment of Long Plantation Watercourse

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 Long Plantation Watercourse findings are presented in the following sections.

4.1 Introduction

The narrow watercourse at Long Plantation borders Wharfedale housing estate and Filey Dams Nature Reserve. This inflow drain is fed by surface water from the adjacent agricultural land and a school playing field before passing into the Dams.

The outflow exits the Dams before passing through a culvert under Pasture Crescent and eventually entering the sea at Coble Landing.

Filey Dams Nature Reserve is a Site of Importance for Nature Conservation (SINC) managed by Yorkshire Wildlife Trust. The reserve (Dams Goit) is sited in the parish of Filey to the north of Wharfedale housing estate.

The reserve comprises a series of pools, marshy grassland and semi-improved neutral grassland. Much of the marshy grassland is dominated by soft rush (*Juncus effuses),* large scale operations have been undertaken to control this species in order to maintain areas of open mud flats to attract water fowl to the reserve.

Marginal vegetation is dominated by reedmace (*Typha latifolia)* with occasional stands of common reed (*Phragmites australis).* The ponds have varying vegetation, with the smaller pools displaying higher macrophyte diversity.

Habitats include open water, bare mud, marginal and inundation vegetation, and dense/ scattered scrub.

The adjacent land use is dominated by improved grassland fields, bordered on the western edge by semi-natural broad leaved woodland. A small watercourse at Long Plantation runs along the reserve boundary on the western edge before discharging into East Hide pool in the north.

A field pond to the north, outside the reserve boundary, was recorded as a feature of significant conservation interest. The pond may support great crested newt, its characteristics and species composition are given in the target notes.

4.2 Morphology

The watercourse at Long Plantation is generally dry but in spate levels has been recorded to flood. The substrate is earth and silt, at the time of the survey there was no water in the channel. Along the eastern reach of the watercourse several perpendicular drainage channels have been excavated through the woodland from the adjacent fields. These channels are likely to have been dug by the local landowner to alleviate problems with standing water and aid drainage of the fields.

The channel profile is typical of many small watercourses with 90º earth banks, and dimensions of approximately 0.5-0.75m wide by 0.5m high. This profile continues along the majority of the surveyed length of the channel.

4.3 Flora And Fauna (General)

The nature reserve supports a variety of important bird species, those recorded during the survey are given below. It also supports protected species such as great crested newt (*Triturus cristatus)* and water vole (*Arvicola terrestris)*.

Birds recorded during survey 14th October 2003, included woodcock, moorhen, jacksnipe and redwing (for a full list refer to the target notes in Appendix A)

4.4 Protected Species

Water vole

No field evidence of water voles was recorded during the survey.

Although water voles are recorded as resident on Filey Dams Nature Reserve it is unlikely that they are present on Long Plantation watercourse. The habitat features required to support a population are absent; the watercourse is generally dry, the conditions are extremely shaded by trees, scrub or hedge vegetation and there is little available forage for the species. Although water voles are not likely to be present on the watercourse itself, care must be taken to avoid any hydrological impact through the scheme on the adjacent reserve. Alterations to the existing levels of 'the Dams' may lead to flooding of water vole burrows or drying of foraging habitat and thereby have an indirect adverse affect on the species.

Great Crested newt

Consultation has revealed the presence of great crested newts on the Filey Dams nature reserve, surrounding vegetation may provide suitable terrestrial habitat for the species. There was evidence of great crested newt mitigation work being undertaken to the north-east of the site at the new housing development, this included newt fencing and the creation of four excavated scrapes.

Due to the close proximity of Long Plantation watercourse and the associated woodland this area may be used as terrestrial habitat for great crested newt, including dispersal routes and sites for forage, refuge and hibernacula.

Further surveys may be required to establish presence/absence in this area of terrestrial habitat followed by a population study undertaken in mid March – mid June in order to determine the number of individuals that may be affected by the works. Alternatively, as newts are already recorded, additional consultation with Filey Dams nature reserve for recent survey records may be able to establish a population estimate.

It is likely that a Defra licence in respect of disturbance of a European protected species will be required for work in this area. As such, it will be necessary to demonstrate that there is no satisfactory alternative to the work, and that the design and operations will not affect the favourable conservation status of the species. In addition, it will be necessary to compile a method statement detailing the works and intended programme and to design a mitigation package that will compensate any loss of terrestrial habitat. Typically, mitigation includes habitat creation or restoration such as the construction of hibernacula or the provision of new breeding ponds. All works should be undertaken in accordance with the 'Great Crested Newt Mitigation Guidelines' (English Nature, 2001).

Badger

No evidence of badger was recorded during the survey and it is unlikely that the species will be affected by the proposals

White clawed crayfish

The watercourse did not display conditions capable of supporting white-clawed crayfish, it is unlikely that the species will be affected by the proposals.

Otter

There have been no records of otter on the watercourse at Long Plantation or within the nature reserve. It is unlikely that the species will use this corridor due to disturbance, lack of fisheries and fluctuating water levels. Although the watercourse provides poor otter habitat, local records for Filey should be checked at the next stage, in order to confirm presence or absence in the area.

Bats

The trees within Long Plantation (and especially the ash trees described in target note 3) have potential to support bat roosts and/or hibernacula. Therefore a full bat survey will be required should there be the need to fell trees along the watercourse as part of the flood alleviation scheme.

Other species of nature conservation value

Brown hare (*Lepus europaeus)* and barn owl (*Tyto alba)* may be present in the area. However, alterations to the watercourse are unlikely to affect these species.

4.5 Invasive Species

There were no invasive species recorded during the survey.

There is no marginal or aquatic vegetation, the flora present in the watercourse is dominated by tall rank grasses including cock's-foot (*Dactylis glomerata)*, false oat grass (*Arrhenatherum elatius),* bramble (*Rubus fruticosus* agg.*)* and nettle *(Urtica dioica).*

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:

- TO BE COMPLETED

Potential Constraints (based on current information):

- Potential extended habitat of great crested newts
- A habitat survey to ascertain the extent of the great crested newt habitat along the Long Plantation Watercourse.
- Work planned would probably need to be licensed to ensure minimised disruption of great crested newt.
- Proposed options may require to be modified based upon discussions with English Nature and proposed habitat survey.

5 Hydrological Modelling

5.1 Catchment Definition

Long Plantation Watercourse is a small, critical ordinary watercourse. The catchment is mainly rural with school fields and a housing estate to the east. It appears that the watercourse has undergone substantial modification over a number of years from the information obtained from the FEH CD-Rom. Therefore, the catchment boundary has been modified to include the changes to watercourse. The changes to the boundary have been made using site observations, OS and survey data.

Long Plantation Watercourse drains a total catchment area of $0.8km^2$ and using the Flood Estimation Handbook (FEH) URBEXT parameter as a guide, is approximately 7% urbanised. The underlying geology of the catchment is Jurassic sandstone, limestone and shales overlain predominantly by a cover of boulder clay.

The Long Plantation Watercourse catchment is depicted in Appendix A.3. Table 5.1 summarises some of the hydrological and hydraulic characteristics of the Long Plantation Watercourse catchment.

Table 5.1 - Catchment Characteristic

	Long Plantation Watercourse
Catchment Area (km^2)	0.79
Length of Watercourse	1.34 km
URBEXT	0.068

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 Long Plantation Watercourse open channel flow system. Design flow estimates have been derived for the, 10, 25, 50, 75, 100 and 200 year return periods for the whole catchment upstream of the allotment gardens. At this location, the watercourse enters a culvert system before discharging into the North Sea. Design inflow hydrographs have been generated for the Long Plantation Beck catchment in accordance with the FEH.

Long Plantation Watercourse 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

As the Long Plantation Watercourse catchment is ungauged, an estimate of the median annual flood (Q_{MED}) is derived initially fom 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 jus t 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 Long Plantation Watercourse 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 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.

Having reviewed the pooling group, summarised in Appendix C.1 all the identified gauging records are for catchments with much large areas.

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 Long Plantation Watercourse 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 Long Plantation Watercourse 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 the Long Plantation Watercourse catchment.

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 the, 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)	Statistical	Rainfall-Runoff	Rational
Q_{MED}	0.11	0.3	-
10	0.22	0.56	0.4
25	0.29	0.76	0.54
50	0.35	0.93	0.70
75	0.39	1.01	0.79
100	0.43	1.10	0.87
200	0.51	1.30	1.08

The rainfall runoff flow estimates are considerably higher than the statistical flow estimates. 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 Long Plantation Watercourse catchment. It is also reasonable to assume that localised topographic factors may result in a localised weather pattern. This would mean the localised frequency, duration and severity of storm events in the 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 lower than the rainfall runoff method, but higher than the statistical 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 catchment.

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 Long Plantation Watercourse 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 Long Plantation Watercourse has been undertaken using ISIS (Version 2.0), a one-dimensional hydrodynamic model. The hydrodynamic facility is particularly prevalent in the context of the Long Plantation Watercourse system due to the storage provided by The Dams. As this occurs, the ability to accurately assess flood 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 Long Plantation Watercourse ISIS model has not been possible but verification of the model for the recent flooding in October/November 2000 has been undertaken.

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

6.2 Flooding Flow Routes

The majority of the flood waters escaping from the watercourses will flow into the housing estate with minimal pooling. 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;
- historical records of flooding within Filey (see Table 2.1); and,
- an assessment of potential flow routes during site visits.

Appendix A.6 shows the flood flow 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 Long Plantation Watercourse 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 The Dams 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 Long Plantation Watercourse system has been adopted as 0.060 and 0.080 for the channel and overbank areas respectively. This relates to the channel being relatively overgrown.

6.3.2 Hydraulic Structures

A total of four (4) bridges and culverts were identified along the Long Plantation Watercourse model reach, in addition to one (1) weir structure. Each structure was assessed individually and modelled appropriately (see Table 6.1). The wooden footbridge at LON01_01355 was not modelled as the bridge does not affect the hydraulics of the channel or the water level.

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

Model Chainage	Name of Structure	ISIS Unit
LON01_01104	Natural Weir	Spill
LON01_00305	New Development Culvert	Orifice
LON01_00185	Pasture Crescent Culvert	Orifice
LON01_00000	Allotment Gardens Culvert	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 then incorporated into the ISIS model at appropriate locations.

6.3.4 The Dams Area

The Dams area is a man made area for conservation reasons. The numerous lakes act as a retention 'basin'. 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 the topographical survey and the approximate capacity is approximately 65,000 m^3. This reservoir was connected to Long Plantation Watercourse in the form of lateral spills.

6.4 Boundary Conditions

6.4.1 Catchment Hydrology

Design flow hydrographs have been derived for Long Plantation Watercourse 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 Long Plantation Watercourse 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)
5	0.461
10	0.564
25	0.757
50	0.925
75	1.018
100	1.095
200	1.303

The peak design inflow represents the catchment area upstream of the allotment gardens culvert.

6.4.2 Downstream Conditions

The downstream limit of the hydraulic model is the allotment gardens culvert. At this point the watercourse enters Church Ravine culvert (approximately 600m in length) which discharges into the sea. 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 Long Plantation Watercourse associated of blocking the culvert. The result of this sensitivity analysis shows that a 50% percentage blockage of the culvert raises the water level upstream to the Dams area between 300 and 400mm. For a 75% percentage blockage these values increase to between 750 to 1000mm.

6.5 Model Verification

No calibration data is available for Long Plantation Watercourse, 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/November 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 5 years) was a shorter duration event than the October 2000 event (estimated return period 15-25 years) and it resulted in lower levels. 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 Long Plantation Watercourse 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 +10% (ie: $n_{channel}$ 0.060 (design) to 0.066; $n_{overbank}$ 0.08 (design) to 0.088 has been considered. This resulted in minimal changes in water level along the modelled river system. The design Manning's 'n' value was determined using information collected during site visits, photographs and engineering knowledge. The effects of reducing the Manning's 'n' by 20% resulted in a maximum decrease in water level of 50mm upstream of the Dams area and a maximum increase 80mm downstream.

6.6.2 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 Long Plantation Watercourse catchment. The result is a 70mm (maximum) increase in peak water level upstream of the Dams area and only an average of 20mm throughout the rest of the watercourse.

6.6.3 Culvert Blockage

During site visits it was noted that debris had collected around the culvert inlets. This was confirmed by responses to the questionnaires distributed to the local residents during the critical watercourse study. There were many reports of debris blocking the culvert inlets.

Potential blockages were analysed by reducing the bore area of the culverts by 50 & 75% to determine the affects on the water levels. The table below shows the increase in water level directly upstream of the culvert.

Table 6.3 – Affects of culvert blockage

Culvert	Water Level increase for 50% blockage	Water Level increase for 75% blockage
Allotment Gardens Culvert (LON01_00000)	400mm	1000mm
Pasture Crescent Culvert (LON01_00185)	200mm	400mm
New Development Culvert (LON01_00305)	120mm	600mm

The level recorded for 75% blockage at the new development & Pasture Crescent culvert would cause overtopping and flooding of the road. Therefore, it is essential to keep the culverts free from blockage.

6.7 Flood Extents

The hydraulic model was run for the existing situation for the 10, 25, 50, 75, 100 and 200 year design flows. It was found that in a 10 year event there was some out of bank flow in the Fewston Close area (LON01_01242 to LON01_01182). Flooding is predicted to occur in this area due to the incapacity of the channel and its inability to convey the flow. The three culvert structures are all undersized and will be surcharged at a 1 in 10 year. The culverts do not cause flooding in the surrounding areas as the channel has the capacity for the increase in water level. However due to the small diameters of these culverts there could be issues with blockages. The flooding extents for various return periods are outlined in Appendix A.7. Changes in the flooding extent due to culvert blockage for the 100year event are shown in Appendix A.7a.

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 – Flood Flow Retention 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.

There are two possible locations for storage with the Long Plantation Watercourse. The Dams area has the potential to store more flow than experienced during the current flow regime. However, a significant proportion of the flooding is upstream of the Dams area. Therefore, to utilise the Dams area channel improvement would have to be made to convey the flow without flooding to the Dams. The flooding upstream of the Dams area is caused by surface water run off from the school field and surrounding land. Therefore, one option is to construct bunds to attenuate the flow from the fields into Long Plantation Watercourse.

For a 1 in 100 year return period event (Q100) the offline storage within the school field and surrounding area has been assessed. In order to model the option of offline storage in Long Plantation Watercourse catchment, the inflow hydrograph peak flow was reduced from $1.1m^3/s$ to $0.45m^3/s$ (for Q100 event). The reduction in peak flow represents the maximum flow capacity of the channel. The minimum volume of offline storage required for the design Q100 flood event is $8,500m^3$ (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 in limiting the maximum flow in the channel to $0.45m^3/s$ this would eliminate the flood upstream of the Dams area.

It is concluded that utilising the school fields to assist in attenuating of the flow into Long Plantation Watercourse in itself could alleviate the flooding problem upstream of the Dams area. However the frequency of flooding and lost of access to the school fields, land purchase and compensation would have to be reviewed in detail.

7.2 Measure 2 - Localised Defences

In this option the following defences are considered:

(i) Constraining Long Plantation Watercourse channels with embankments/floodwalls on the right bank (looking downstream).

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, 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. 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 (including 300mm freeboard) for Q100 (see Appendix A.4 for model node location)

Model Chainage	Description	Required Height of Embanking Right Bank (mm)
LON01_01335	Footbridge by Midhope Way section	380
LON01_01305	Wharncliffe Place section	375
LON01_01242	U/S Fewston Close section	540
LON01_01182	D/S Fewston Close section	375
LON01_01171	U/S Rivelin Way section	595
LON01_01160	Rivelin Way section	485
LON01_01149	D/S Rivelin Way section	355

Table 7.1 shows that the length of embanking required along Long Plantation Watercourse is approximately 200m between LON01_01335 and LON01_01149). The embankment raising would have to be completed in such a way that it does not obstruct the public footpath which runs along the side of the watercourse here. Constructing the flood bund along the right bank would lead to a small increase in the level of flooding to the school fields on the left bank. The measure of flood embanking in itself is not thought to be an optimum solution and thus it was necessary to consider increasing conveyance in the channel itself.

7.3 Measure 3 - Improvements to Structures

The three culvert structures downstream of the Dams area surcharge at flows above 0.1 cumecs. Although the structures are all surcharged the channel is sufficiently large enough to prevent overtopping. However, this is assuming that the channel and culverts are clear of any debris.

From site visits and photographs taken it can be seen that for culverts (LON01_00305) to the new development and (LON01_00000) at the allotment gardens there are no trash screens on the inlets to the culverts. At (LON01_00185) the Pasture Crescent culvert there is a trash screen but it is situation flat against the culvert inlet which could cause debris to collect here.

The results of the sensitivity analysis (see table 6.3) for culvert show that any blockages of these culverts will cause an increase in water level upstream which would result in flooding. Therefore, it is recommended that trash screens should be fitted to each of the culverts and regular maintenance be undertaken of the channel, screens and culverts to reduce the risk of blockage and flooding in the area.

7.4 Measure 4 - Channel Re-profiling

The changes in slope and gradient of the channel upstream of the Dams area are causing a ‘bottle neck’ and as a consequence the flow is backing up. This is resulting in high water levels along this stretch of watercourse.

Subsequently, the channel would need to be re-profiled for approximately 140m between the cross section upstream of Fewston Close to the section upstream of Barden Place (LON01_01242 & LON01_1101). The location of the channel re-profiling is illustrated in Appendix A.10. These works would help improve the conveyance of the channel and reduce the water level for a 1 in 100 year event. However, these works alone would not reduce the water level in the channel to prevent flooding for a 1 in 100 year event. Additional works such as channel widening or localised embankments or flood walls would also be required.

7.5 Measure 5 – Channel Widening

The channel upstream of the Dams area 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 150 m from Fewston Close to Barden Place 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 300mm freeboard. The location of the channel widening is illustrated in Appendix A.11.

As with the channel re-profiling, widening the channel alone will not reduce the water level sufficiently to provide a 1 in 100 year standard of protection. This will have to be complete with either channel re-profiling or localised embankments or flood walls.

8 Description of Flood Mitigation Options

The following options have been considered to alleviate flooding from the Long Plantation Watercourse. 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 num ber of residential properties.

It should be noted that the 'Do Nothing' case is the baseline against which all other schem es are measured and would require SBC 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 watercourse is not reduced through silting and weed growth or through blockages at structures. 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 upstream of the Dams area as no capital work is proposed for the existing culvert which is considered under-capacity.

8.3 Option 3 – Localised Defences and Improvements to Structures

Apart from Measure 2 (Localised Embanking) the measures discussed in Section 7 in themselves are not likely to provide a solution to the flooding issues upstream of the Dams area but not potential issues flooding downstream. A combination of measures is the preferred solution to preventing flooding in for the whole area. This combined option will incorporate the improvements to the structures of new trash screens (Measure 3), and flood embankments (Measure 2). Works to the culverts will solve the issues surrounding the potential for flooding by reducing the probably of debris collecting to block the culverts. The level of the flood bund upstream of the Dams area 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 LON01_01335 with 300mm freeboard	235mm	320mm	380mm	435mm
Height of Flood Embankment LON01_01305 with 300mm freeboard	265mm	330mm	375mm	410mm
Height of Flood Embankment at LON01_1242 with 300mm freeboard	445mm	505mm	540mm	555mm
Height of Flood Embankment LON01_01182 with 300mm freeboard	255mm	315mm	375mm	420mm
Height of Flood Embankment LON01_01171 with 300mm freeboard	490mm	535mm	595mm	650mm
Height of Flood Embankment LON01_01160 with 300mm freeboard	365mm	430mm	485mm	545mm
Height of Flood Embankment LON01_01149 with 300mm freeboard	339mm	395mm	355mm	450mm

(Note: All heights of embankment are to provide a defence level including 300mm of freeboard)

8.4 Option 4 – Storage & Improvements to Structures

This combined option will incorporate the increase in flood flow retention storage (Measure 1) and the improvements to the structures of new trash screens (Measure 3). The flow entering the channel upstream of the Dams area needs to be limited to the channel capacity flow of 0.45 cumecs. To limit the flow to the channel capacity, embankments or bunds would have to be constructed on the left bank to create some retention of the flow. Table 8.2 illustrates the storage volumes required for a variety of return periods; these values include an additional 10% as a factor of safety.

Table 8.2 – Storage Volumes and bund level required for various return periods

Return Period	Storage Volume	Bund Level Left Bank	Bund Level Right Bank
25 year	3,365 m^3	45mAOD	-
50 year	6,069 m^3	45.25mAOD	-
100 year	9,037 m^3	45.5mAOD	-
200 year	9,037 m^3	45.5mAOD	350mm (max height 490mm & min 235mm)

The location of the works and potential of land flooded during the events is illustrated in Appendix A.13. The bund level changes height with return period due the changes in the required storage volume. The bund levels include 500mm of freeboard. As the floodwater recedes there needs to be drainage pipes through the embankment to allow the stored water to drain into the watercourse. This option can not used to protect to a 1 in 200 year standard as the required bund level would be higher than the floor level of the school and houses on Muston Road.

As with option 3 the storage of flow upstream of the Dams area will not resolve the issues of culvert blockage downstream. Therefore, the culverts downstream will require new trash screens.

8.5 Option 5 – Channel Widening & Re-profiling, embankments and Improvements to Structures

This option combines the improvements to structures (Measure 3), channel widening (Measure 5), channel re-profiling (Measure 4) and Measure 2 (Localised Embanking). The localised embanking is only required for the 1 in 200 year standard upstream of the Dams area. The re-profiling and widening of the channel does not sufficiently reduce the maximum water level.

The current profile of the channel backing up of the flow and therefore does not utilise the Dams area storage potential. Therefore, to utilise this storage the conveyance of the channel upstream of the Dams area needs to be improved. This can be achieved by re-profiling the channel from Fewston Close to Barden Place (LON01_01242 to LON01_01101) and some channel widening measures. The amount of channel widening required for the return periods differs and is summarised in Table 8.3. The locations of the works are illustrated in Appendix A.14 and details of the channel re-profiling and widening are detailed in Appendix A.16.

As with the previous options this only solves the flooding issues upstream of the Dams area will not resolve those downstream. Therefore, the culverts downstream will require new trash screens.

Table 8.3 - Width of channel widening and height of flood bund

	Q25	Q50	Q100	Q200
Channel widening (m)	0	1	2	2
Height of Flood Bund including 300mm freeboard (mm)	0	0	0	365

9 Economic Appraisal Methodology

9.1 Objectives

The economic appraisal of various options presented in Section 8 was conducted in accordance with the PAG3, (Defra March 2003). The purpose of conducting this appraisal was to test the economic feasibility of the proposed schemes to alleviate flooding from Long Plantation Watercourse in Filey.

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 Filey from Long Plantation Watercourse. 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. Two property types were assumed to be at risk from flooding; 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 properties affected are likely to experience flooding durations of less than 12 hours, due to the catchment characteristics and that the water should not pond in the area. For these reasons only the scenario of 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, although these are considered to be conservative.

Table 9.1 – Property write-off values

Property Type	Unit write-off (£k)	No. of units	Total (£k)
1975-1985 Detached Bungalow	200	22	4,400
		Total	**4,400**

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) Combined Option A
4) Combined Option B
5) Combined Option C

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.

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	0	
10	3	Fewston Close (3)
25	6	Fewston Close (3), Rivelin Way (3)
50	9	Fewston Close (3), Rivelin Way (3) Barden Place (3)
75	17	Wharncliffe Place (2), Fewston Close (4), Rivelin Way (6) Barden Place (5)
100	22	Wharncliffe Place (2), Fewston Close (5), Rivelin Way (9) Barden Place (6)
200	25	Wharncliffe Place (3), Fewston Close (6), Rivelin Way (10) Barden Place (6)

10.1.2 Residential Property Losses

Table 10.2 summarises the average damage detached bungalow property type, assuming internal flood (various depths) for less than 12 hours 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
1945-1964 Detached Bungalow	£35.4k average per property
Total for 25 properties	£885k

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)
1945-1964 Detached Bungalow	885	4,400	885
Total	**885**	**4,400**	**885**

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 and blockage. The channel has been modelled assuming that they are no constrictions. 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. Emergency measures will have limited impact due to the flashy catchment regime.

10.3 Assessment of Option 3

10.3.1 Q25 Standard of Protection Damages

The results of the hydraulic modelling reveal that the construction of a flood embankment for approximately 200m at an average height of 350mm (max height 490mm & min 235mm) is sufficient to protect all properties upstream of the Dams area from the 1 in 25 year flood event. However, if the culverts downstream of the Dams are kept free from debris there is sufficient channel capacity. To ensure this it is recommended that new trash screens are installed. For events greater than the 1 in 25, floodwaters will overtop the flood bund causing damage to properties upstream of the Dams area. 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 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	9	Fewston Close (3), Rivelin Way (3) Barden Place (3)
75	17	Wharncliffe Place (2), Fewston Close (4), Rivelin Way (6) Barden Place (5)
100	22	Wharncliffe Place (2), Fewston Close (5), Rivelin Way (9) Barden Place (6)
200	25	Wharncliffe Place (3), Fewston Close (6), Rivelin Way (10) Barden Place (6)

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. However, the flood embankment height is increased to an average height of 405mm (max height 535mm & min height 315mm).

For events greater than the 1 in 50 year, flood waters will overtop the flood embankment 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. The flood embankment height required is raised to an average height of 445mm (max height 595mm & min height 355mm).

For events greater than the 1 in 100, flood waters will overtop the flood embankment 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 Q100 standard of protection to all properties is everything included within the Q25 scheme. The flood embankment height required is raised to an average height of 495mm (max height 650mm & min height 410mm).

For events greater than 1 in 200 years, flood waters will overtop the flood embankment and flood bund causing damage to properties. The properties are at risk of flooding for events greater than the Q200 return period. 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	PV damages (£k)	Write-off value (£k)	Adopted Loss (£k)
Q25	532	2,860	532
Q50	417	2,860	417
Q100	238	2,860	238
Q200	88	2,860	88

10.4 Option 4

10.4.1 Q25 Standard of Protection Damages

The results of the hydraulic modelling reveal that construction of a flood bund on the left bank upstream of the Dams area could help to attenuate the flow. As with option 3 the properties downstream of the Dams area could still be at risk from flooding due to culvert blockage, therefore the installation of new trash screens is required. For events greater than the 1 in 25, floodwaters will overtop the bund causing damage to properties. 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 A 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 available storage by 80% to a Q50 standard;
- Increasing the height of the flood bund to a Q50 standard of protection.

For events greater than the 1 in 50, flood waters will overtop the banks and cause 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 A 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 available storage by 170% to a Q100 standard;
- Increasing the height of the flood bund to a Q100 standard of protection.

For events greater than the 1 in 100, flood waters will overtop the banks and cause 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 A 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 available storage by 170% to a Q200 standard;
- Increasing the height of the flood bund to a Q200 standard of protection.
- Construction of an embankment on the right bank to a Q200 standard of protection.

For events greater than 1 in 200 years, flood waters will overtop the banks and cause damage to several properties. The properties are at risk of flooding for events greater than the Q200 return period. 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 A 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 re-profiling channel upstream of the Dams area between Fewston Close and Barden Place can protect all properties from the 1 in 25 year flood event. As with option 3 and 4 this will not protect the properties downstream of the Dams area that are at risk from flooding due to culvert blockage. Therefore, new trash screens at the culverts inlets are required. The channel upstream of the Dams area does not have the capacity for events greater than the 1 in 25 year return period event and the floodwaters will escape the channel and cause damage. 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 A 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:

- Widening the channel by 1 metre as for the length of the re-profiling;
- Forming a wildlife ledge that doubles as a storm water channel.

The channel upstream of the Dams area does not have the capacity for events greater than the 1 in 50, flood waters will escape 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 A 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:

- Widening the channel by 2 metre as for the length of the re-profiling;
- Forming a wildlife ledge that doubles as a storm water channel.

The channel upstream of the Dams area does not have the capacity for events greater than the 1 in 100, flood waters will escape 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 A 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:

- Widening the channel by 2 metres as for the length of the re-profiling;
- Forming a wildlife ledge that doubles as a storm water channel;
- Construction of an embankment on the right bank 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 properties are at risk of flooding for events greater than the Q200 return period. 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 A 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

	Options	Present Value Damages
Do Nothing		£825k
Do Minimum		£713k
Option 3 *Localised defences and improvements to structures*	Q25 SoP	£532k
	Q50 SoP	**£417k**
	Q100 SoP	£238k
	Q200 SoP	**£88k**
Option 4 *Storage and improvements to structures*	Q25 SoP	£532k
	Q50 SoP	**£417k**
	Q100 SoP	£238k
	Q200 SoP	**£88k**
Option 5 *Channel widening, re-profiling, embankments and improvements to structures*	Q25 SoP	£532k
	Q50 SoP	**£417k**
	Q100 SoP	£238k
	Q200 SoP	**£88k**

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' dam ages. However, it is thought that there is a risk to life if no action is taken, e.g. people being swept off their feet by flood water flowing along the roads. The behavioural characteristics of people during a flood are very unpredictable, so the risk to life is difficult to quantify. However, 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. However, the risk to loss of life has been considered when calculating the Defra priority score. Due to the number of bungalows in the area and the age of residents a very high risk to public safety.

10.8 Traffic Disruption

As the flooding from Long Plantation Watercourse only affects a residential housing estate it was decided that the costs of traffic disruption were not applicable.

10.9 Assessment of Risks

The risks associated with each scheme are summarised in Table 10.7. For option 4 the main risk is acquiring permission to flood the land and build the flood bund. Option 5 has more risks associated with it because it has the combined risks of options 3 and 4. All options have an inherent risk associated with the presence of great crested newts in The Dams.

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

Risk	Option 3	Option 4	Option 5
Permission to flood school fields	Yes	No	No
Permission to build flood bund along left bank on school fields	Yes	No	No
Environmental consent associated with construction in an area with great crested newt	Yes	Yes	Yes
Permission to construction a flood bund along the public footpath	No	Yes	Yes
Issues with increasing the flow into the Dams conservation area	No	Yes - marginally	Yes - marginally
Public consultation issues	Yes	Yes	Yes

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. For option 4 a compensation fee has been included for loss of access to the school field during flooding.

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 in accordance with current Defra guidelines and 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)		31.5
Option 3 (Embankment on right bank upstream of the Dams area & culvert trash screens)	Q25 SoP	211.3
	Q50 SoP	228.2
	Q100 SoP	247
	Q200 SoP	268
Option 4 (Flood retention storage on left bank upstream of the Dams area & culvert trash screens)	Q25 SoP	350.3
	Q50 SoP	337.4
	Q100 SoP	409.1
	Q200 SoP	587.2
Option 5 (channel re-profiling & widening and culvert trash screens)	Q25 SoP	153.6
	Q50 SoP	170.0
	Q100 SoP	181.8
	Q200 SoP	370.0

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 PV Damages, and full details are provided in Appendix G.

Table 12.1 It may be seen that the highest benefit cost ratio of 3.2 given by Option 5 with a Q100 standard of protection. This option also has the highest incremental benefit cost ratio. It can be seen that option 4 does not give a favourable benefit cost ratio (less than 2).

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.

[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

			Cost Benefits for Option 3 (Embankment on right bank upstream of the Dams area & culvert trash screens)				**Cost Benefits for Combined Option 4** (Flood retention storage on left bank upstream of the Dams area & culvert trash screens)				**Cost Benefits for Combined Option 5** (channel re-profiling & widening and culvert trash screens)			
	Do Nothing	Do Minimum	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)	-	31.5	211.3	228.21	247.02	267.95	350.38	377.38	409.06	587.22	153.63	169.98	181.93	370.03
PV damage (PVd) (£k)	*825.29*	*712.52*	531.64	416.74	237.70	87.99	531.64	416.74	237.7	87.99	531.64	416.74	237.7	87.99
PV damage avoided (£k)	-	*112.76*	293.65	408.54	587.59	737.3	293.65	408.54	587.59	737.3	293.65	408.54	587.59	737.3
Total PV benefits (PVb) (£k)	-	112.76	293.65	408.54	588.59	739.3	293.65	408.54	588.59	739.3	293.65	408.54	588.59	739.3
Net Present Value (NPV) (£k)	-	81.26	82.35	180.33	341.57	471.35	-56.73	31.16	179.52	152.08	140.01	238.56	406.75	369.26
Average Benefit/Cost Ratio	-	3.58	1.39	1.79	2.38	2.76	0.84	1.08	1.44	1.26	1.91	2.4	3.24	2.00
Incremental Benefit/Cost Ratio	-	-	1.01	6.79	9.58	7.2	0.57	4.26	5.68	0.85	1.48	7.03	15.19	0.80
Defra Priority Score	-	-	-	-	12.4	-	-	-	7.9	-	-	-	15.4	-

13 Conclusions & Recommendations

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

13.1 Flooding causes, extents and mechanisms

(i) Flooding within the properties upstream of the Dams area is reasonably frequent and extensive and justifies the designation of Long Plantation Watercourse 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, in Fewston Close. This rises to 6 properties for the 25 year event and 22 properties for the 100 year event. Flood depths of up to 0.3m are predicted for some properties for the 1 in 100 year event.

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

1	Upstream of the Dams area (22 properties affected)	Limited capacity of the channel causing poor conveyance of flow (Flooding starts at a return period of 10 years)
2	Downstream of the Dams area	There is a potential risk of flooding due to small culverts which surcharge at a 1 in 5yr event but will not cause flooding unless there is a build up debris blocking the culvert entrance

13.2 Preferred flood mitigation option

A number of mitigation measures were assessed, tested and costed. Option 5 is the preferred scheme (channel re-profiling, widening and culvert trash screens) based on the higher cost benefit ratio (3.2 calculated), the fewer perceived risks associated with the scheme and some ecological benefit. This scheme designs flooding out of the system by re-profiling and widening the existing channel for approximately 200m upstream of the Dams area and installation of trash screens on the culvert inlets downstream of the Dams area. The new channel is proposed as a two-stage system accommodating normal and storm flows without detriment.

The preferred option (option 5) is summarised below.

Protecting properties upstream of the Dams area

(i) Re-profile the channel upstream for approximate 200m to counter the backing up of flow along the channel.

(ii) Widen the channel by 2m to counter the incapacity of the channel.

Protecting Properties downstream of the Dams area

(i) Installation of trash screens on the three culvert to reduce the risk of debris blocking the culvert and causing flooding.

Maintenance Measures

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

(ii) The channel vegetation and debris is required to be kept 'under control' to assist in maximising the channel capacity.

13.3 Consideration of risks

The main risk associated with the preferred option is the presence of great crested newts in the area. 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. Land ownership issues also requie consideration.

13.4 Recommendations

(i) Long Plantation Watercourse is 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 100-200mm for the 100 year design event. It is recommended that this robustness should be accommodated for in the design as freeboard and a minimum 300mm should be allowed for.

(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 with a benefit cost ratio of 3.24 and a Defra priority score of 15.4.

(iv) 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 permission to do works on land will also need to be further investigated.

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

(vi) 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.