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Flooding in Nettleham Village
June 2007 Flood

Nettleham Parish Council
November 2007

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Flooding in Nettleham Village

Rev No	Comments	Date
00	Draft for comments by Nettleham Parish Council	Nov. 2007
01	Final issue	Dec. 2007

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Job No 55886 Reference 01 Date Created October 2007

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Executive Summary

Nettleham Parish Council appointed Faber Maunsell, in September 2007 to undertake a hydrological study to establish the cause of the 25th and 26th June 2007 flood which inundated the centre of the Nettleham Village and some of the properties in Danby Hill area upstream of the village within the parish. In addition, Fauber Maunsell were asked to advise on what measures (if any) could be taken to prevent/ alleviate reoccurrence of the same.

Following thorough examination of the catchment and hydrological analysis and discussions with Nettleham local residents, a report has been prepared outlining the causes of flooding and proposing a way forward for alleviation measures in order to prevent similar flooding in the Nettleham Village and Danby Hill area in the future.

The study identified that there was not a single cause of flooding. There was a series of events, and situations as described below, which resulted in the flooding:

- Saturated catchment condition following continuous wet weather over a long period of time prior to June 2007 flood.
- Unusually high water table (i.e. high ground water level) due to continues wet weather.
- Heavy rainfall of 25th and 26th June. Over a period of 25 hours, 53mm (2 inches), of rain fell on the already saturated catchment. This was the equivalent of almost one month of rainfall compared to the annual average rainfall of 605mm for the area.
- There was reverse flow through the highway drainage outfalls and surcharging of the outfalls preventing discharge of surface water into the Nettleham Beck.
- The condition of the Nettleham Beck's channel immediately downstream of the Nettleham Village due to overgrown vegetations.
- At Danby Hill, the limited size of the existing culvert on the tributary of the Nettleham Beck, along the old Lincoln Road and high level of the water downstream at the tributary's confluence with the Nettleham Beck.
- It is also considered that the lack of capacity of various culverts along the Nettleham beck may also have been a contributory factor.

The 25th – 26th June 2007 flood event in the Nettleham Village was estimated to have a very high return period (probably in excess of 1 in 200 years). In hydrological terms this can be considered as a very significant flood event.

In statistical terms an event with a return period of 200 years has the following probability of occurrence:

- There is a 0.5% chance of it occurring or being exceeded in any one year. This means that over a long period of time, on average such an event will happen once every 200 years. However in any given period of 200 years it may not happen at all, **or may happen several times**.
- There is a 14% chance of at least one 200 year return period flood occurring in a period of 30 years
- There is a 33% chance of at least one 200 year return period flood occurring in a period of 80 years (being deemed to be an average person's lifetime).

The following actions are recommended

- Development of a hydraulic model of the Nettleham Beck and its tributary through Danby Hill.

  Definition of hydraulic model:
  Hydraulic modelling involves the representation of the hydraulic behaviour of a river and its floodplain by mathematical means using computers. It provides a powerful tool in river engineering which can be subjected to various rainfall storm events and catchment information to study the behaviour of the river under flood conditions. In addition, physical modifications, (such as enlargement of culverts), can be tested on the model before they are constructed. Possible flood defence schemes can be tested under extreme storm events which may not be seen in a lifetime

- Assessment of the model under various hydrological and hydraulic scenarios including the sequence of events which resulted in the June 2007 flood.

- Assessment of various flood alleviation proposals using the hydraulic model in order to achieve the most appropriate and cost effective recommendation.

- Consideration of the capacity of the various culverts, together with the impact of siltation and debris on the long-term sustainability of solutions.

- Consideration of potential environmental issues and costs in delivering an adequate maintenance standard for the Nettleham Beck.

- A detailed survey of the Nettleham Village surface water drainage and road drainage systems to identify inadequacies in the systems.

- The Parish Council should vigorously maintain their current objections to the proposed large scale residential development off Nettleham Road, (adjacent to the Waitrose Supermarket), as this will further exacerbate the risk of serious flooding in the village, unless appropriate flood defence measures or prevention measures such as Sustainable Urban Drainage Systems (SUDS) are introduced as an integral part of the proposed development.

  Definition of SUDS
  SUDS is an approach to urban drainage design which seeks to control the quantity of surface runoff and mitigate the effects of pollution on the natural environment and divert it for other useful purposes and long term sustainability.

- West Lindsey District Council, City of Lincoln Council, Lincolnshire County Council, the Environment Agency and Nettleham Parish Council to agree a way forward.

Note: Responsibilities for the various elements involved are:-

Surface water:	Anglian Water
Highway drainage:	Lincolnshire County Council and West Lindsey District Council.
Private drains:	Individual property owners
Nettleham Beck:	West Lindsey District Council (with involvement of the Environment Agency) and riparian owners
Bridges and culverts:	Highways authority and possibly others

1 Introduction

1.1 Nettleham Parish Council (the Parish Council) appointed Faber Maunsell Ltd in September 2007 to carry out a flood study for Nettleham Beck (the Beck) at Nettleham Village (the Village) to identify the cause of 25th and 26th June 2007 flood which inundated centre of the Village and some of the properties in Danby Hill within the parish upstream of the Village, Figure (1). The scope of the commission was outlined in the Parish Council's letter dated 21st August 2007 and developed through discussions with representatives of the Parish Council.

1.2 This study identifies the flood inundation areas and properties within the Village and Danby Hill and provide the predicted peak flows through the Village for various flood return periods of flood and discusses the cause of flooding.

1.3 This document has been prepared by Faber Maunsell Limited ("Faber Maunsell") for sole use of the Client detailed above in accordance with generally accepted consultancy principles, the budget for fees and the terms of reference agreed between Faber Maunsell and the Client. Any information provided by third parties and referred to herein has not been checked or verified by Faber Maunsell, unless otherwise expressly stated in this document. No third party may rely upon this document without prior and express written agreement of Faber Maunsell.

2 The Nettleham Beck Catchment

2.1 The total catchment area of the Beck as far downstream as the existing low flow gauging station near Nettleham Sewage Treatment Works is about 18.3km^2, Figure (2) The catchment above the village is predominately rural in character with the majority of surface runoff coming from rural sources and small urban communities.

2.2 The Flood Studies Report (FSR) soil classification map indicates that the catchment of the Beck is covered by Class 1, SOIL, indicating that the catchment has high infiltration capacity and hence very low runoff potential.

2.3 The Beck rises in the Lincolnshire Show Ground area to the west of the Village at an elevation of around 53m AOD. It initially flows in a southeasterly direction through the existing manmade lake in Riseholme Park and its outlet control structure. The lake provides irrigation water to the surrounding agricultural land and is also used for pleasure fishing. The lake is not used for flow balancing. It is in the grounds of Lincoln University, Agricultural Department. Downstream of the lake, the Beck initially flows in an easterly direction and then turns in a south easterly direction, passes under the existing Riseholme Lane and then under the existing old Lincoln Road where it is joined by a small tributary (the Tributary) (see paragraph 2.9).

2.4 Downstream of old Lincoln Road the Beck turns 90 degrees and flows in a northerly direction through a wide and deep channel towards the Village passing under Washdyke Lane. According to the residents this area use to be a meadow area but was changed to the existing condition in late 1960's.

2.5 Downstream of Washdyke Lane, the Beck runs parallel to Kingsway and south of the Police Head Quarters site and enters the Village from a westerly direction through an old short culvert.

2.6 At the edge of the Police Head Quarters, the Beck passes alongside the existing balancing pond, (in the grounds of the Head Quarters), which is used to control the surface runoff from this development area using a concrete 'V' notch weir control structure.

2.7 Downstream of the old culvert the Beck passes through the built up area of the Village under three footbridges and enters an open area in the centre of the Village along the High Street and opposite of the Cemetery. At this location the Beck passes under Church Street through four 600mm diameter skewed cut circular culverts. Downstream of the culvert, the Beck once again flows through the built up area of the Village crossing Vicarage Lane through four identical culverts with a rectangular appearance but with built in circular culverts (dimensions could not be confirmed). According to the residents these culverts were built probably pre 1940's.

2.8 Downstream of Vicarage Lane, the Beck again flows through the built up area of the Village before crossing Brookfield Avenue through a culvert and leaving the village from the north eastern corner.

2.9 Whilst the upstream reaches of the Beck have a slope of around 1:230, with natural profile as the Beck passes through the Village, the gradient reduces to around 1:265 with a wide rectangular channel.

2.10 The Tributary rises on the north skirt of Lincoln in an area indicated on the Explore Map of the area as 'Roman Aqueduct (Course of)', Figure (2). It flows in a north easterly direction passes under the A46, (Lincoln Ring Road), and flows parallel to Lincoln Road in a northerly direction. About 400m along the Lincoln Road, it crosses this road through the existing culvert and then runs parallel to the old Lincoln Road for about 60m before crossing it through another culvert. The Tributary then runs parallel to the old Lincoln Road again before discharging into the Beck about 400m downstream. Along the old Lincoln Road the Tributary flows under an access road to Roswill property through a circular culvert about 1000mm diameter. Further downstream it passes through an old circular brick culvert (Dimension not confirmed).

2.11 The Village has expanded dramatically since 1950s.

3 Watercourse Channel Condition

Nettleham Beck Channel Condition

3.1 A walkover survey of the Beck was carried out by Faber Maunsell engineers in September and October 2007. This was conducted in order to determine the existing condition of the Beck's channel and structures and to compare the channel profile in the Village to that outside of the Village. Some areas could not be assessed due to access restrictions.

Upper Catchment

3.2 The Beck's channel profile consists of irregular cross section with overgrown vegetation along some sections.

Upstream of Village

3.3 The existing Beck downstream of the old Lincoln Road and immediately upstream of the Village consists of a trapezoidal shape channel with a wide and deep profile.

Tributary Channel Condition

3.4 The existing Tributary channel along the old Lincoln Road appeared to be in good condition. However, it was confirmed by the owner of Roswill property that the channel had been dredged and cleared following the June 2007 flood.

Through Village

3.5 The Beck runs parallel to Kingsway, again the channel profile varies from rectangular to trapezoidal shape with a wide and fairly deep channel. The profile of the Beck through the Village is rectangular, wide and shallow with a flat bed. This indicates that the profile of the channel through the Village has been modified in the past. In fact, the Beck is used as an access road by residents of some the properties located to the north of the Beck. The approximate date of modification of the Beck's profile could not be confirmed by residents who have lived in the Village for a long time.

Downstream of Village

3.6 The Beck's channel profile appears to be smaller in cross section. During the September 2007 site visit, considerable vegetation was observed in the Beck downstream of the village along its length.

4 June 2007 Flood

Introduction

4.1 There are usually two types of flooding: “Primary” flooding which is usually regarded as flooding coming directly from a specific source e.g. from overtopping of a watercourse or from groundwater. “Secondary” flooding which is flooding of areas that are not flooded directly by overtopping of the banks of the watercourses

Extent of Flooding

4.2 The Parish Council provided DVD footage of the flood, which occurred in June 2007. Further information was obtained from the BBC web site. No further evidence was found during this study that the Beck has overtopped its banks in the past.

4.3 During 25th and 26th June 2007, according to the Parish Council’s reports, severe flooding occurred in many areas in the Village. Areas affected by overtopping of the Beck included: Part of the High Street, Cross Street, the Green and approaching roads i.e. Vicarage Street, Church Street and part of the Crescent.

4.4 Figures (3) and (4) show the extent of flooding in the Village and in Danby Hill respectively during the June 2007 flood. The plan showing the extent of the flood was produced using DVD footage of the flood provided by the Parish Council and information gathered from the local residents affected by the June flood.

Residents Survey

4.5 As part of the flood study, residents in the Village who had been affected by the June 2007 flood, along with representatives of local businesses, were also approached to provide details of June 2007 flood and other historic flooding events.

4.6 Whilst residents around the Green and the High Street helped to confirm and provide details of the aforementioned event, several also recounted flooding of the roads usually after heavy intense rainfalls as the result of the existing road drainage in this area not being able to cope or being blocked.

4.7 The owner of No. 17, the Green, who has lived in the Village for 42 years, did not recall any flooding from the Beck in the past. She stated that, during the June flood, the floodwater from the Beck to her house was blocked off by home made sand bags. However, she indicated that the flooding of her house was the result of water entering through the floor of the house.

4.8 The owner of No. 16, the Green which is built on a higher ground, reported that the house itself was not flooded directly from the Beck, but the cellar of the house which is located away from the flooded area was flooded to a depth of about two feet.

4.9 Mr and Mrs Clayton, residents of No 1, the Crescent who have lived in the area more than 25 years with extensive local knowledge, provided considerable information about the flood, the catchment of Nettleham Beck and drainage of the area in general. They experienced flooding of the lower part of their property, with water lapping at the doorstep of the house. They have also experienced flooding of the Crescent in front of their property on numerous occasions following heavy rainfall.

4.10 The owner of the Plough Inn Public house in the Green stated that, the floodwater was about two inches deep at the entrance. The owners of some properties on the Green stated that the floodwater had come near to entering the properties.

4.11 The owner of No. 19, High Street reported that the house was flooded from the Beck on the morning of 26th through the front door while later the water entered the ground floor through the interconnecting door frame.

4.12 The owner of No. 7, High Street also reported that the house was flooded from the Beck and through the concrete floor of the house.

4.13 The residents of Brookfield and Ash Tree Avenues were concerned about the capacity of the existing culvert at the end of Riverdale and Brookfield Avenues. During the June flood event, it is reported that the culvert was blocked by debris resulting in flooding of the garden of properties in Brookfield and Ash tree Avenues.

4.14 The owner of Roswill Property in Danby Hill reported that four of the properties were flooded in outbuilding and garden areas. Part of Roswill property was flooded for four days. During this time the septic tanks were flooded creating an environmental hazard and distress to the residents of Danby Hill.

4.15 Flooding was also reported at Beck Cottage upstream near Riseholme Lake.

Primary Flooding

4.16 Two main sources of primary flooding are identified, i.e. overtopping from the Beck and groundwater. The overtopping of the watercourse could be associated with inadequate capacity of the watercourse channel, culverts and bridges, or obstruction and blockage of these during flood.

4.17 It should be noted that, the Highways Agency are the authority responsible for bridges and culverts.

Secondary Flooding

4.18 Sources of flooding were identified from surface runoff and the road drainage systems.

4.19 In hydraulic terminology, this condition is associated with secondary flooding. Secondary flooding is flooding of areas that are not flooded directly by overtopping of the banks of the watercourses. This type of flooding is due to reverse flow through drainage outfalls or surcharging of these outfalls during a flood event preventing discharge of surface water into the watercourse.

4.20 Following meetings with the local residents, some were concerned about the existing capacities of the local drainage systems. It is reported that some drainage works were carried out in the area of the Green approximately 5 to 10 years ago, but this could not be confirmed.

4.21 The Village surface water drainage network which consists of road drainage as well as drainage of properties has been extended in line with the expansion of the Village. Without further investigation, it is not possible to describe the interaction between these two systems.

4.22 It should be noted that, the surface water drainage authority for the Village drainage is Anglian Water and the road drainage authority is Lincolnshire County Council and West Lindsey District Council. The private drains from individual properties are the responsibility of their owners.

4.23 It is believed that the high water in the Beck was preventing the discharge of surface water into the Beck causing secondary flooding exacerbating the flooding situation.

4.24 The locations of drainage outfalls discharging directly into the Beck were not investigated, as this was not part of the brief of the study.

5 Hydrology

5.1 Hydrological analysis was carried out to establish the return period of flood, which occurred on 25th and 26th June 2007.

5.2 Detailed discussion on the derivation of the catchment hydrology and flows is presented in Appendix A. A brief introduction of the hydrological methods is presented below.

5.3 The Flood Estimation Handbook (FEH) was used to estimate design flows at the site. The FEH was published in January 2000 by the Centre for Ecology and Hydrology, Wallingford (formerly the Institute of Hydrology), a component body of the Natural Environment Research Council. The FEH is the successor to the Flood Studies Report (FSR) and Flood Studies Supplementary Reports (FSSR) also published by the Institute of Hydrology. The FSR was the recognised method in the UK for estimation of flood flows from the time of its publication in 1975 until the publication of the FEH.

5.4 In addition to the FEH methodology, the MAFF Report No. 5[1] and Report No. 124[2] were also used to calculate flows for various return periods.

Flood Event of 25th and 26th June 2007

5.5 Recorded hydrological data of Nettleham Beck catchment as well as recorded rainfall event of 24th, 25th and 26th June 2007 were provided by West Lindsay District Council through their contact with the Environment Agency.

5.6 According to the information about 53mm (2 inches), of rain fell in 25 hours on the already saturated catchment of the Beck dramatically affecting the Village. Compared to the annual average depth of the rainfall 605mm for the area, in all, about one month of rain fell in 25 hours. The situation was made worse by the wet condition of the catchment as the result of previous days rainfall.

5.7 Detail investigation was not carried out to compare the June's flood to the notorious flood which hit England in 1947 as this was not part of the Brief. However, the present owner of 19 High Street recalled the remark made by the previous owner that the water entered the house from the back entrance of the house during 1947 flood.

[1] Ministry of Agriculture, Fisheries and Food (MAFF) now DEFRA, Report No. 5, which is suitable for small catchments, was published in 1980 by ADAS, Land Drainage Service Research and Development.

[2] The report was published in 1994 by the Institute of Hydrology and is recommended for use on small catchments <25km^2 with a particular emphasis on flood response times

5.8 The peak flow of 2.21 m^3/sec was estimated for the flood in June through the Village. Figure (5), shows the predicted hydrograph of runoff for the catchment. The calculated peak flows are shown in table 5.1.

Table 5.1- Estimated Peak Flows

Return Period (yrs)	Peak Flow (m^3/s)			
	FEH Statistical Method	Report 124	MAFF 5	June 2007 Estimated Peak Flow
2	0.40	0.37	0.47	2.21
5	0.57	0.54	0.67	
10	0.67	0.69	0.79	
25	0.80	0.94	0.95	
50	0.90	1.19	1.06	
100	1.00	1.49	1.18	
200	1.11	1.87	1.30	

5.9 The above table compares the estimated June 2007 peak flow and calculated peak flows in the Beck through the Village for various flood return periods using different hydrological analysis.

5.10 The peak flows which were calculated using the FEH statistical method are lower than those calculated using MAFF 5 and Report 124 methods. In turn those predicted by the MAFF 5 method are less than those calculated using Report 124. These discrepancies are usually expected in hydrological analysis when using different methods of analysis and results should be used based on local knowledge and experience.

5.11 The above table indicates that the return period of 25th – 26th June 2007 flood event in the Village was estimated to have a very high return period (probably in excess of 1 in 200 years). In hydrological terms this can be considered as a very significant flood event.

6 Conclusion and Recommendations

Conclusion

6.1 The return period of 25th – 26th June 2007 flood event was estimated to have a very high return period (probably in excess of 1 in 200 years). In hydrological terms this can be considered as a very significant flood event.

6.2 A return period is usually attributed to a flood event i.e. 1 in 50 year flood or 1 in 100 year flood. An event with a return period of 200 years has a 0.5% chance of occurring or being exceeded in any one year. This means that over a long period of time, on average such an event will happen once every 200 years. However in any given period of 200 years it may not happen at all, or may happen several times. Statistical analysis shows that there is a 14% chance of at least one 200 year return period flood occurring in a period of 30 years, and a 33% chance in a period of 80 years.

6.3 The flooding that occurred was the result of both primary flooding (from the Beck and groundwater) and secondary flooding (from the outfalls into the Beck and the road drains).

6.4 Public concern has been expressed regarding the capacity of the road drainage in the Green as well as the lower part of the Crescent and all of Cross Street.

6.5 The expansion of the Village and roads and the surface runoff drainage system since 1950's have created an unknown drainage network that requires investigation. Maintenance standards appear to be below desirable levels but some flooding would probably still have occurred even if standards had been higher. Consideration should be given to improve the surface water drainage system in the centre of the Village.

6.6 Continuous wet weather over a long period of time prior to June 2007 flood created an unusually high water table in the catchment which exacerbated the flooding situation in the Village affecting some of the properties. According to the local residents the Beck has never been seen running dry even in worst drought years. This is an indication that the flow in the Beck is dominated by groundwater.

6.7 Responsibility for maintenance and improvement of the Beck lies with West Lindsey District Council and the Environment Agency has a general supervisory role.

6.8 There are no longer watercourses defined as Critical Ordinary Watercourses. These watercourses were en-mained a few years ago. The Nettleham Beck is not defined as a Main River, hence it is an ordinary watercourse.

6.9 Flooding from extreme events can never be totally eliminated. However, standards of protection could be improved in Nettleham and Danby Hill if the various authorities involved were prepared to finance the necessary investigations and subsequent flood defence improvement scheme.

6.10 In the future, as the result of climate change, it is anticipated that the rare flood events will occur more frequently. Erosion of banks will continue and instability will increase, the changed conditions will increase the probability of flooding at this location, which is already at risk of inundation. It is accepted that increased levels of maintenance alone will not solve the problem. Therefore, a strategy is needed to protect the areas, which are at risk of flooding.

Recommendations

6.11 Hydraulic modelling investigations are recommended to assess the hydraulic capacity of the existing Beck's Channel as well as the existing culverts and the impact of the channel condition upstream and downstream on the flow through the Beck in the Village. The investigation should include assessment of secondary flooding and the need for flood defence structures such as low flood defence walls downstream of the Green or an upstream flood storage reservoir.

6.12 Hydraulic modelling investigations are also recommended to assess the hydraulic capacity of the existing Tributary's channel in Danby Hill and the existing culverts. The investigation should include requirements for flood defence structures such as low flood defence walls along the existing gardens of properties in the Danby Hill area

6.13 The residents of Danby Hill and the Village are concerned about the impact of additional surface runoff from the proposed housing development adjacent to the existing Waitrose Supermarket off Nettleham Road on the flow of the Tributary through Danby Hill and the Beck through the Village. The impact of new developments should be considered in accordance with PPS25[3].

6.14 According to PPS25, a new development should not materially increase the probability of flooding elsewhere. Following discussion with Lincoln City Council Planning Department, it was established that thus far, (November 2007), the Council has not issued drainage consent for the proposed development. It is recommended that discussions should be held with the Lincoln City Council and West Lindsey District Council in relation to the above proposed development.

6.15 The local authority's view in connection with flood risk and their proposals for any flood prevention scheme to protect the affected properties should be investigated.

6.16 The vegetation in the Beck downstream of the village may have led to reducing the capacity of the channel in the flooding event and may aggravated the situation upstream. Vegetation removal and dredging can be very damaging both to the wildlife and the structure of a watercourse. It should be carried out very sensitively once an appropriate wildlife survey has been carried out. This should be followed by clear and specific instructions for the operators.

6.17 A detailed survey of the village surface water and road drainage systems should be carried out to identify inadequacies in the systems (Possible contributors – Lincolnshire County Council, Anglian Water, West Lindsey District Council and Nettleham Parish Council).

6.18 Improvement scheme to raise the standard of protection against flooding and to ensure an integrated overall approach should be investigated, costed and implemented if financially viable.

6.19 An early meeting of all interested parties should be held to discuss and agree responsibilities, future requirements and a possible future programme.

6.20 Residents should be thanked for their input to the study and informed of the outcome.

[3] Planning Policy Statement 25 (PPS25); Development and Flood Risk

References

References

I. Institute of Hydrology (1999), ***Flood Estimation Handbook***. Wallingford

II. ADAS, Land Drainage Service Research and Development (1980), ***MAFF Report No. 5***

III. Institute of Hydrology (1994), ***Flood Estimation for Small Catchments, Report No. 124***

IV. Climate Change Scenarios for the United Kingdom (2002), ***The UKCIP02 Scientific Report***

V. Chow (1973), ***Open Channel Hydraulics***

VI. Planning Policy Statement (PPS25), (2006): ***Planning and Flood Risk***

Abbreviations

Abbreviations

FEH	Flood Estimation Handbook
FSR	The Flood Studies Report
FSSR	Flood Studies Supplementary Reports
m AOD	Meter Above Ordnance Datum
m^3/sec	Cubic metres per second (cumecs)
MAFF	Ministry of Agriculture, Fisheries and Food (MAFF) now DEFRA
PPS25	Planning Policy Statement 25, Development and Flood Risk
SOIL	Soil index according to the Flood Studies Report

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Figures

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Photographs

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Appendix A - Hydrology

Methodology
The Flood Estimation Handbook (FEH) was used to estimate design flows in the Beck through the village. FEH methodology details two main approaches in the determination of design flows.

- Q_{MED} statistical method
- Rainfall runoff method

Q_{MED} statistical method
The FEH statistical methodology is based on derivation of Q_{MED} (the median annual maximum flood with return period of 1 in 2 years) and flood frequency curve as a growth curve, which allows the flood peak values for any given return period to be calculated. The analysis is based on recorded river flow data in the UK, which can be obtained from the FEH CD-ROM (Version 1) which provides data to 2002. The growth curves are calculated using pooling group, or single site analysis.

Q_{MED} can be estimated from recorded data for gauged catchments or from catchment escriptors for ungauged catchments using the information provided by FEH CD-ROM, V2. However, a transfer method is then used for the ungauged site using Q_{MED} calculated from nearby gauged catchment as a 'donor' value to adjust Q_{MED} for the ungauged catchment.

$$Q_{MED(rural)}=1.172AREA^{AE}(SAAR/1000)^{1.560}FARL^{2.642}(SPRHOST/100)^{1.211}\ (0.0198)^{RESHOST}$$

Where:
AE = 1 - 0.015 ln(AREA / 0.5)
RESHOST = BFIHOST + 1.30 (SPRHOST/100) - 0.987
AREA - Catchment drainage area (km^2).
SAAR - Standard average annual rainfall (mm).
FARL - Index of flood attenuation due to reservoirs and lakes.
SPRHOST - Standard percentage runoff derived from HOST soils data.
BFIHOST - Baseflow index derived from HOST soils data.

For basic transfer procedure the following equation applys:

$$QMED_{s,adj} = QMED_{s,cds}\ (\ QMED_{g,obs} / QMED_{g,cds}\ )$$

Where:
s – Subject site
g – Gauged site
cds – Catchment descriptors
obs - Observed data respectively

Revitalisation of the FSR/FEH Rainfall Runoff Method (ReFH)
The ReFH method is similar to FSR (Flood Studies Report) and FEH and is based on the unit hydrograph (UH) method. Such an approach allows design hydrographs, rather than just peak flows, to be produced. The main differences between the ReFH, FEH and FSR are how the parameters of the UH are derived from the catchment descriptors (in relation to ReFH and FEH) and catchment characteristics (in relation to FSR) and how design rainfall is derived.
The original FSR/FEH model adopted a standard triangular-shaped UH scaled to each catchment using the time to peak (Tp) parameter. The ReFH model contains the concept of a standard instantaneous unit hydrograph (IUH) shape scaled to individual catchments. The new standard IUH shape is a kinked triangle described by a time scaling parameter, Tp, and two dimensionless numbers, Up and Uk.

$$Tp(0) = 4.270\ DPSBAR^{-0.35}\ PROPWET^{-0.80}\ DPLBAR^{0.54}\ (1+URBEXT)^{-5.77}$$

Where:
Tp(0) : Instantaneous unit hydrograph Time-to-Peak (hr).
DPSBAR : Mean Drainage Path Slope (m/km).
PROPWET : Proportion of Time SMD was below 6mm during 1961-90.
DPLBAR : Mean Drainage Path Length (km).
URBEXT : Extent of Urban and Suburban Land Cover.

The ReFH method is not recommended to be used on permeable catchments (*BFIHOST* >0.65). Hence, this method was discarded.

Institute of Hydrology Report No. 124, Flood Estimation for Small Catchments
Report No. 124 was also used to calculate flows for various return periods. The report was published in 1994 by the Institute of Hydrology and is recommended for use on small catchments <25km^2 with a particular emphasis on flood response times

$$QBAR = 0.00108\ AREA^{0.89}\ SAAR^{1.17}\ SOIL^{2.17}$$

Where:
QBAR – Mean annual flood (m^3/sec)
AREA - Catchment drainage area (km^2).
SAAR - Standard average annual rainfall (mm).
SOIL - Index of runoff from FSR soil types.

MAFF Report No.5
Whilst the FEH pooling group analysis uses recorded gauged data to provide an estimate of flow in a watercourse, it was thought that it might not be suitable to apply the methodology on small catchments as the vast majority of the data contained in the FEH database reflect larger catchments.

In addition to the FEH and Report 124 methodologies, the MAFF Report 5 method for determining surface runoff from small agricultural catchments was also used to assess various return period flows in the Beck.

Ministry of Agriculture, Fisheries and Food (MAFF, now DEFRA) Report No. 5 which is suitable for small catchments, was published in 1980 by ADAS, Land Drainage Service Research and Development.

$$Qc = 2.78*Fa*A*Rb/T*MF$$

Where:
Qc - Peak Flow (l/s).
A - Catchment Area (ha).
Fa - Annual Rainfall Factor.
Rb/T - Bilham Rainfall Intensity (mm/hr).
MF - Soil Factor.

Hydrological Analysis

The total catchment area of the Beck as far downstream as the existing low flow gauging station at Nettleham Sewage Treatment Works is approximately 18.3km^2. The design peak flood flows in the Beck were estimated using the pooling group methods as described in the FEH. A pooling group containing gauged catchments from the FEH database similar to the Beck was created. A growth curve was then calculated from the catchments in the pooling group.

Table A.1: Pooling Group Details

Station	Years	L-CV	L- Skewe	L-urtosis	Discord.	Dist.
33054 (Babingley @ Castle Rising)	27	0.225	0.076	0.167	0.136	0.620
33032 (Heacham @ Heacham)	37	0.327	0.104	0.044	1.196	0.857
33029 (Stringside @ Whitebridge)	38	0.256	-0.095	0.068	1.145	0.905
39042 (Leach @ Lechlade)	31	0.176	-0.029	0.12	0.814	0.935
34012 (Burn @ Burnham)	37	0.279	0.069	0.162	0.335	0.974
43017 (Avon @ Upavon West)	33	0.247	0.09	0.147	0.018	0.982
39033 (Winterbourne @ Bagnor)	41	0.247	0.189	0.157	0.311	1.056
43014 (Avon @ Upavon East)	32	0.204	0.051	0.093	0.374	1.069
42007 (Alre @ Drove Total)	34	0.172	0.193	0.112	2.232	1.203
41015 (Ems @ Westbourne)	36	0.367	0.257	0.224	1.37	1.211
40033 (Dour @ Crabble Mill)	22	0.281	0.371	0.466	3.108	1.285
33007 (Nar @ Marham)	35	0.247	0.102	0.118	0.096	1.285
42008 (Cheriton Stream @ Sewards Bridge)	33	0.261	0.403	0.357	1.593	1.289
44009 (Wey @ Broadwey)	26	0.359	0.251	0.153	1.454	1.299
42006 (Meon @ Mislingford)	44	0.251	0.201	0.252	0.259	1.357
43806 (Wylye @ Brixton Deverill)	12	0.308	-0.099	-0.063	2.008	1.371
39028 (Dun @ Hungerford)	35	0.194	-0.052	0.121	0.894	1.394
43010 (Allen @ Loverley Mill)	22	0.278	0.027	0.092	0.318	1.346
42011 (Hamble @ Frog Mill)	31	0.169	0.008	0.144	0.787	1.404
42012 (Anton @ Fullerton Total)	30	0.160	0.222	0.154	2.279	1.411
29002 (Great Eau @ Claythorpe Great Eau)	40	0.313	0.325	0.278	0.9	1.466
39019 (Lambourn @ Shaw)	41	0.180	0.051	0.151	0.521	1.483
43018 (Allen @ Walford Mill)	29	0.233	0.059	0.25	1.321	1.509
30003 (Bain @ Fulsby)	41	0.307	0.098	0.084	0.529	1.569
Total	**787**					
Weighted means		**0.253**	**0.113**	**0.152**		

The heterogeneity test 'H2' was found to be 3.7 indicating that the pooling group is heterogeneous a review of pooling group would be desirable. However, further review of the pooling did not improve the heterogeneity of the analysis.

According to FEH a catchment is defined as permeable if SPRHOST is less than 20%. The SPRHOST for Nettleham Catchment is 9.34 indicating a permeable catchment.

The catchment has a BFIHOST value of 0.89. Again according to FEH catchments with BFIHOST greater than 0.8 are considered groundwater- dominated.

A permeable adjustment was undertaken following procedures described in FEH Volume 3 and an adjusted growth curve was derived.

Table A.2: Adjusted Growth Curve

Return Period (yrs)	Pooling Group Derived Growth Curve	Adjusted Growth Curve
2	1	1
5	1.391	1.427
10	1.645	1.689
20	1.979	2.017
50	2.243	2.265
100	2.520	2.516
200	2.814	2.774

The estimated Q_{med} for Beck was obtained by transfer method analysis as outlined in the FEH volume 3. For this, the recorded data for the following gauging stations, which are operated by the Environment Agency were used:

- (Babingley @ Castle Rising) (Station No. 33054)
- (Heacham @ Heacham) (Station No. 33032)
- (Stringside @ Whitebridge) (Station No. 33029)
- (Leach @ Lechlade) (Station No. 39042)

The adjusted growth curve was then applied to the estimated Q_{med} to calculate the peak flows in Beck for different return periods. In addition, Report 124 and MAFF 5 were also used to estimate the peak flows for different return periods.

Flood Event of 25th and 26th June 2007

The Flood hydrograph of the June 2007 was predicted by convoluting the recorded rainfall and synthetic unit hydrograph of the catchment using ISIS hydrology software. The predicted hydrograph shows peak flow of 2.21 m^3/sec for the flood in June through the Village.

It was not possible to calibrate and adjust the catchment unit hydrograph parameters using historical events. Hence the estimated peak flow of the June 2007 must be used with this in mind.

Figure (5) shows the estimated hydrograph of runoff for the June 2007 flood.

The estimated peak flows in the Beck at the Environment Agency low flow gauging station using different methods are shown in table A.3.

Table A.3- Estimated Peak Flows

Return Period (yrs)	Peak Flow (m^3/s)			
	FEH Statistical Method	Report 124	MAFF 5	June 2007 Estimated Peak Flow
2	0.399	0.37	0.47	2.21
5	0.57	0.54	0.67	
10	0.67	0.69	0.79	
25	0.80	0.94	0.95	
50	0.90	1.19	1.06	
100	1.00	1.49	1.18	
200	1.11	1.87	1.30	