East Lothian Council

Haddington Flood Study

Final Report

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1. Introduction

The town of Haddington in East Lothian which is located along both banks of the River Tyne, has been subjected to significant flooding over many centuries. It is reported that some of these flooding incidences were very serious and due to the importance of the town in earlier times, documentary evidence regarding the date, mode and extent of flooding and damage caused still exists. Although the historical evidence of flooding in Haddington goes as far back as 1358, the most recent and largest flood event which affected the entire region including Haddington occurred in 1948. Since then three significant events, but not on the scale of the 1948 event, have occurred in 1956, 1990 and 1992.

Despite relatively frequent flooding incidents, only a small number of investigations to understand the causes of flooding and possible mitigation measures have been carried out. It is understood that two of the earlier studies were carried out by Water Research Centre (WRc) in 1982 and 1991 to look into the extent and frequency of flooding in Haddington. The latest investigation was carried out by Babtie Shaw and Morton (now Jacobs) in 1994 using a one-dimensional mathematical model of the River Tyne through Haddington to predict the peak water levels in the River Tyne for a range of flood events and also investigate possible mitigation options to reduce the risk of flooding in Haddington. All three studies were undertaken for the then Lothian Regional Council (now East Lothian Council).

The representation of certain areas in the mathematical model of the River Tyne was recently improved and the model was used for the assessment of flood risk for a number of development proposals in Haddington.

In view of growing demand for development land in and around Haddington, East Lothian Council considered that a detailed assessment of the flood risk in Haddington should be carried using the most up to-date mathematical modelling techniques to produce a set of plans providing information on the indicative extent of inundation for a range of return period flood events.

The study has involved:

- the hydrological assessment of flood flows in the River Tyne in Haddington using methodology set out in the Flood Estimation Handbook,
- transfer of the existing mathematical model of the River Tyne from the MIKE11 river modelling software platform to the ISIS modelling platform (which is considered as the current industry-standard),
- extension of the model and improvement of representation of key areas using recent topographical survey information,
- model calibration and undertaking model simulations, and
- preparation of a report and plans showing the indicative extent of inundation for a range of flood events.

This report details the work undertaken and the findings of the study together with recommendations for further investigations.

2. History of Flooding in Haddington

As indicated above, due to the historic importance of the town of Haddington, documentary evidence regarding the date, mode and extent of flooding and damage caused still exists. To provide an insight to the history of flooding in Haddington and its effect on the town's fabric, information on some significant flood events was extracted form various sources and is given below.

4 October 1775 - A major flood occurred which is well documented. A flood mark exists as well as several eye-witness accounts. For example the following is an extract from a letter, written on the 5th of October 1775 by a visitor staying in the town..... *The whole town is now in the utmost confusion. On Tuesday a heavy rain came on and continued without intermission till this morning.......The River Tyne swelled prodigiously, so that about two o'clock yesterday morning it overflowed the whole east end of the town, and continued so impetuous for two hours that it rose six or eight feet during that period, and seemed to threaten destruction to the whole town. For three or four hours there was nothing to be seen but everyone trying to save themselves. Numbers of carts came floating west ...... with fowls sitting on them where they had roosted for shelter, some of the people who lived in the lower end of town coming west wading in water up to the armpits, and cries of women and children, formed a picture of the most shocking nature. On the other side of town numbers of people were seen sitting on the tops of their houses and dead cattle, furniture, etc. were floating on the surface of the water. About four o'clock the waters took a turn and began to decrease gradually.*

Millar (1844) adds that the water rose up to the second storey of the houses from the bridge westward to the foot of the High Street (i.e. Church Street and part of Sidegate). Another level is given to *'the third step of the cross'*. Sargent[1] states that the commemorative 1775 flood stone still exists but has been moved slightly from its original position. "A tablet erected in the town commemorates a great flood that took place on 4 October 1775, when the river rose 17 feet in one hour. *'Thanks be to God' concludes the Latin inscription, 'that it was not in the night-time, for no one perished*.' "

For the same event, the Annual Register Vol 18 1775 Chronicle page 163-164 quotes "*At Haddington, in Scotland, a heavy rain came on, which swelled the river Tyne so much, that it overflowed the east end of the town, and threatened the destruction of the whole. It rose eight feet perpendicular. The people were in the utmost consternation, some wading up to the armpits to escape, and others climbing up the roofs of the houses. The cries of women and children were*

[1] Sargent, R.J. (1982) Prediction of Extent and Frequency of Flooding at Haddington on Behalf of Lothian Regional Council. Chapter 2 Analysis of historical floods p 4-15, WRc 27-C.

dreadful; houses, bridges, mills, and furniture of all sorts, were seen floating together, and much cattle were carried off by it."

According to Sargent in **29 September 1846,** the Nungate area was flooded and parts of the lower town to Sidegate Lane and the Custom Stone. The level reached five feet along Gimmersmill's orchard wall (now part of Bermaline mill). The railway bridge at East Linton was swept away but it is likely that this was under construction at the tim*e*.

23 September 1927 The East Lothian Courier on 30 September 1927 reports "*greatest since 1846, nearly equal to 1775 ..... frequently recurring floods this summer ..... on Thursday afternoon the Tyne was falling after a spate which caused low-lying parts to be inundated ..... Earth was saturated ...... rain started again late Thursday p.m. and by 4 p.m. water was rushing down roadway to Nungate. River flowed up Ford row and reached a spot 12 paces from the cross roads. Water over a foot deep in houses in Ford Row ..... Water hid the concrete retaining wall for half the distance between Victoria Bridge and the south-west end of the cauld ..... stretched from wall of Kitty's garden across and up Ford Row*".

Haddington, built as it is, on the banks of the Tyne, has always been prone to flooding and pictures of Haddington under water are familiar to everyone with an interest in local history.

Arguably, the most devastating of the floods that have occurred within living memory happened on the night of the **12th and 13th of August, 1948**. High Street as far west as the Town House was under several feet of water which stretched to the gates of Amisfield Park. Distillery Park, the Nungate, Peffers Place and Brewery Park were similarly devastated with some individuals finding themselves up to their necks in water. 50 families were registered homeless and many were rescued from their dwellings in a boat borrowed from North Berwick. Records held by Haddington Community Council report:

Throughout East Lothian twenty roads and footbridges were swept away and Army Nissen huts were commandeered as emergency housing. One of the many heroes thrown up in the emergency was local joiner Tom Wark, who swam from his house above Rose's Garage in an attempt to rescue the occupants of a bus stranded in the Hardgate. Tom recalls how he was driven back by the force of the current disappearing down Gowls Close, but thankfully, everyone was saved by the boat. Tom, still a well known character in Haddington is reluctant to talk of his part in the proceedings but vividly recalls the devastation caused by the relentless rainfall upstream"[2].

A paper written on this event reports "*In the town of Haddington the waters of the River Tyne rose*

[2] http://www.haddingtoncc.org.uk/hundred5.htm

2in. above the bottom of the plate which commemorates a previous flood of October, 1775, and flooded the High Street of the town to a depth of 57 in."[3]. Extent of the1948 flood event was accurately mapped by then the Haddington Town Council.

The flood of **28 August 1956** occurred when heavy rain followed a period of several days of rain (some flooding had already occurred a few days previously). The extent of this flood was accurately mapped by East Lothian Council.

[3] George Baxter (1949) "Rainfall and Flood in South-East Scotland, 12th August, 1948" Journal, Institution of Water Engineers Vol 3, page 261- 268

3. Hydrological Assessment

3.1 Estimation of Design Flows

As stated in the earlier sections the town of Haddington has suffered from flooding caused by the River Tyne for many years. Since the early 1990s, a number of investigations have been carried out by various consultants following each sizable flood event in order to determine the frequency of this event in the light of the information available for the particular event in question and historical anecdotal information for past flood events.

Flows in the River Tyne are monitored at East Linton using a velocity-area station. The low flow control is a gravel bar some 100m downstream near the A199 road bridge. Flows in the River Tyne have been recorded at East Linton Gauging Station since 1959.

The A199 road bridge was rebuilt in 1982. It is understood that following the bridge re-construction the Forth River Purification Board carried out 16 spot gaugings between 1982 and 1987. Although it was considered that the control of water levels for large flow events at the gauging station moved to the narrower bridge opening, Forth River Purification Board continued to use the rating equation representing pre-reconstruction conditions.

The spot gaugings carried out between 1982 and 1987 were for flows lower than those gauged pre-1982. The new information complemented the existing spot gauging information and provided no real basis for a need to change the rating equation current at the time. The rating equation used since 1959 was adjusted by SEPA at the end of 1993 and since 1994 a new equation has been used for estimation of flows at the East Linton Gauge. It is understood that the original rating was adjusted by SEPA to take into account the effect of the new bridge crossing on the stage measurements and subsequently on the flows for large flow events. Figure 1 below shows the comparison of spot gaugings at East Linton.

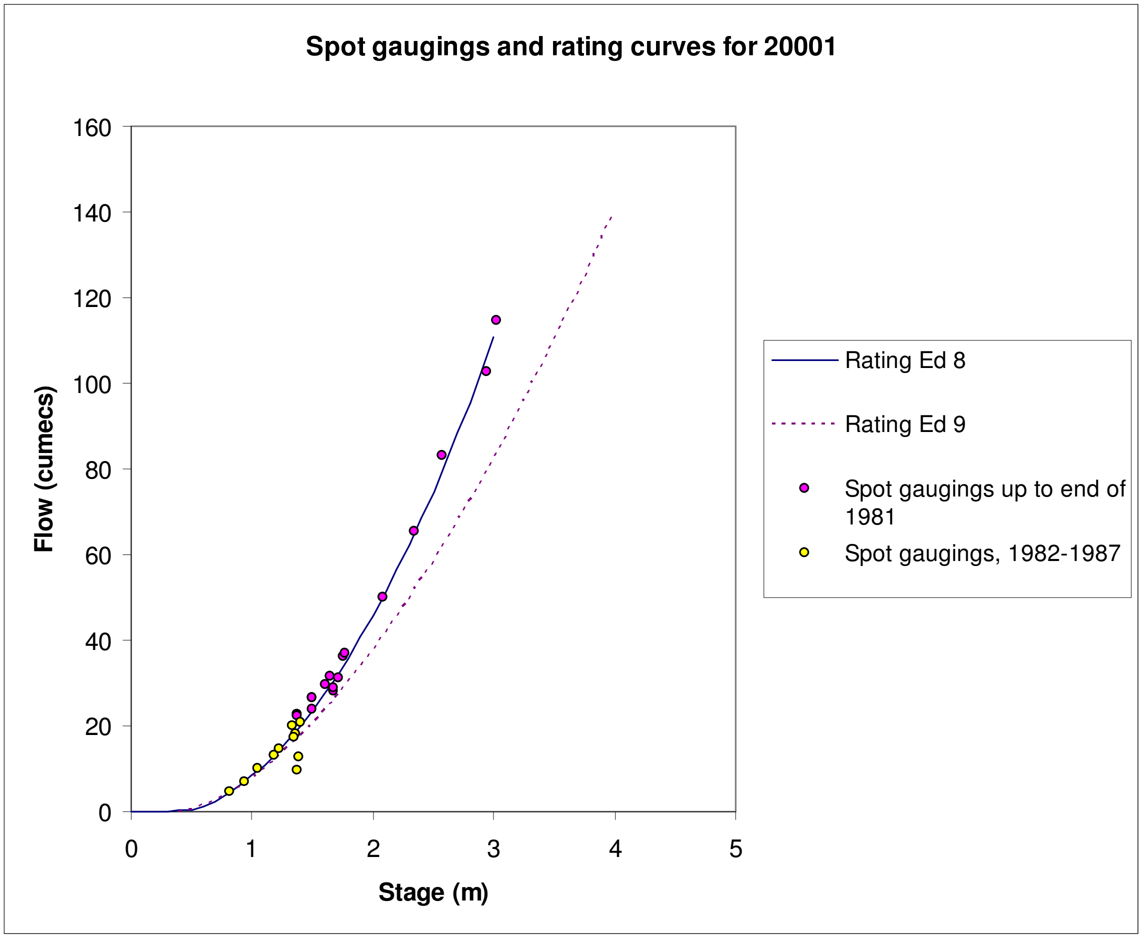


Figure 1 - Comparison of Spot Gaugings (Rating Ed 8 suitable for period pre-1982, Rating Ed 9 the revised relationship applied by SEPA from 1994 onwards)

As there appears to be no explanation for the change in rating equation, using the stage information for the annual maximum flood events recorded at East Linton, it was possible to generate three separate estimates of annual maximum flow in the River Tyne at East Linton, these are:-

1. Using rating equation 8 up to 1994 and rating equation 9 for records 1994 onwards (flows provided by SEPA based on this assumption)
2. Using rating equation 8 up to 1982 and rating equation 9 for records 1983 onwards
3. Using rating equation 8 for estimation of all flows since the records began which appears reasonable to assume as model simulations indicated that the bridge would not have influenced the water levels at the gauge for the events which have occurred since 1982.

Using Flood Estimation Handbook (FEH) pooling group analysis the following flows for flood events of various Annual Exceedance Probabilities (AEP)[4] were estimated based on each of the three annual maximum series.

[4] % Annual Exceedance Probability (AEP) is the probability associated with a particular flood event expressed as a chance of occurring in any one year rather than the previously applied term ‘return period’. Thus an event of return period 50 years has an AEP of 1/T*100 or 2%.

% AEP	1 Design flows (m^3/s)	2 Design flows (m^3/s)	3 Design flows (m^3/s)
50	49	47	54
20	70	67	76
10	85	81	92
4	105	100	113
2	122	116	130
1	141	134	149
0.5	162	153	169
0.2	193	181	200

Table 1 - Pooling group at Haddington: comparison of various flood event flows in the River Tyne at Haddington estimated using combinations of Rating Ed 8 and 9

Using FEH single site analysis the following flows for various flood events were estimated for each of the three annual max series for the East Linton Gauge.

% AEP	1 Design flows (m^3/s)	2 Design flows (m^3/s)	3 Design flows (m^3/s)
50	54.7	52.7	59.8
20	82.9	76.0	91.4
10	103.2	91.3	114.1
4	132.2	111.6	146.4
*2**	*157.0*	*127.8*	*173.9*
*1**	*185.0*	*144.9*	*204.8*
*0.5**	*216.7*	*163.3*	*239.7*
*0.2**	*265.4*	*189.6*	*293.1*

**FEH suggests that these flood estimates are less reliable and should be treated with caution. This is a function of the length of record at the gauge.*

Table 2 - Single site analysis at East Linton: comparison of various flood event flows in the River Tyne at East Linton Gauge estimated using combinations of Rating Ed 8 and 9

In order to resolve the apparent uncertainty in the magnitude of annual maximum flows in the River Tyne at East Linton, a meeting was held in the SEPA Perth offices in September 2007 to discuss the way forward. During this meeting the Council's Engineer stated the existence of a 1948 event flood marker on the wall of the building immediately downstream of the East Linton Bridge. It was decided that a short mathematical model of the River Tyne through East Linton should be constructed to determine the magnitude of the flood flow that generated the flood mark on the wall.

A short mathematical model of the River Tyne between a location approximately 200m upstream of East Linton Gauging Station and a location approximately the same distance downstream of the rock weir was constructed using surveyed channel cross-sections. The flood mark was also surveyed as 21.04mAOD based on the Ordnance Survey Bench Mark (OSBM) at Phantasy Farm.

A letter to Mr Murray Hutchison from Mr Alastair Skinner (who was the Chief Drainage Engineer with the Lothian Regional Council in the 1990s) indicated that during the 1948 flood event there was a considerable mass of debris (Including fallen trees) which had collected on the weir and the East Linton Bridge. The weir which used to serve the mill downstream no longer exists. Mr Skinner indicated that under these circumstances he would view the flood mark on the wall with suspicion as it would have been influenced by the weir and the debris accumulation. He also added that in his personal opinion if an event similar to1948 event happened today, the water level would have been at least 0.5m lower that that marked on the wall. This would yield a water level of approximately 20.50mAOD.

Model predictions using the mathematical model of the River Tyne through East Linton indicated that flows of 580m^3/s and 480m^3/s would produce 21.04mAOD and 20.50mAOD respectively. It shows that August 1948 event was significantly larger than 255m^3/s estimated in the assessment undertaken by Sargent.

In his communication with the East Lothian Council, Mr Alastair Skinner also provided a photograph of the East Linton Bridge during the 6 October 1990 flood event. It is understood that the photograph was taken at the time of the peak flow in the River Tyne at East Linton. The Council's Engineers surveyed the water level under the bridge based on the information provided on the photograph. The water level was 18.47mAOD.

Jacobs carried out a model simulation using the short mathematical model of the River Tyne through East Linton using a flow of 106.5m^3/s. This flow is based on the Rating Equation 9 which is the latest equation and it is still in use. Model predictions indicate that the water level in the River Tyne immediately downstream of the East Linton Bridge would be 18.43mAOD which is only 40mm lower than the estimated peak water level for the 6 October 1990 flood event at East Linton.

Summary of design flow estimates:

Figure 2 graphically summarises the various design flow estimates for the River Tyne in Haddington. (Note that because there remains uncertainty as to which set of Annual Maximum Flows (AMAX series) best represents the flows at East Linton all three series have been considered). Information from the following approaches is shown in the figure:

i) FEH statistical pooling group analysis. (This is generally considered to be the recommended approach to use in such studies).

ii) FEH single site analysis on the East Linton flow record but transposed to being applicable to Haddington. (This is generally considered to provide valuable low return period estimates – the extent of reduced reliability is depicted by the dotted line)

iii) The plotting position of the 1948 event based upon the Gringorten formula. (The 1948 event is considered by Sargent to be the largest flood going back beyond 1755). This suggests a rarity of at least 0.2% AEP. The flow has been determined in this project from the hydraulic model for two independent locations along the river.

iv) Additionally the average FEH single site growth curves for the upstream gauges (Spilmersford, Lennoxlove, Saulton Hall) have been applied to the Haddington index flood. (These upstream catchments all have steeper growth curves than East Linton, though are more distant from Haddington).

It was concluded that:

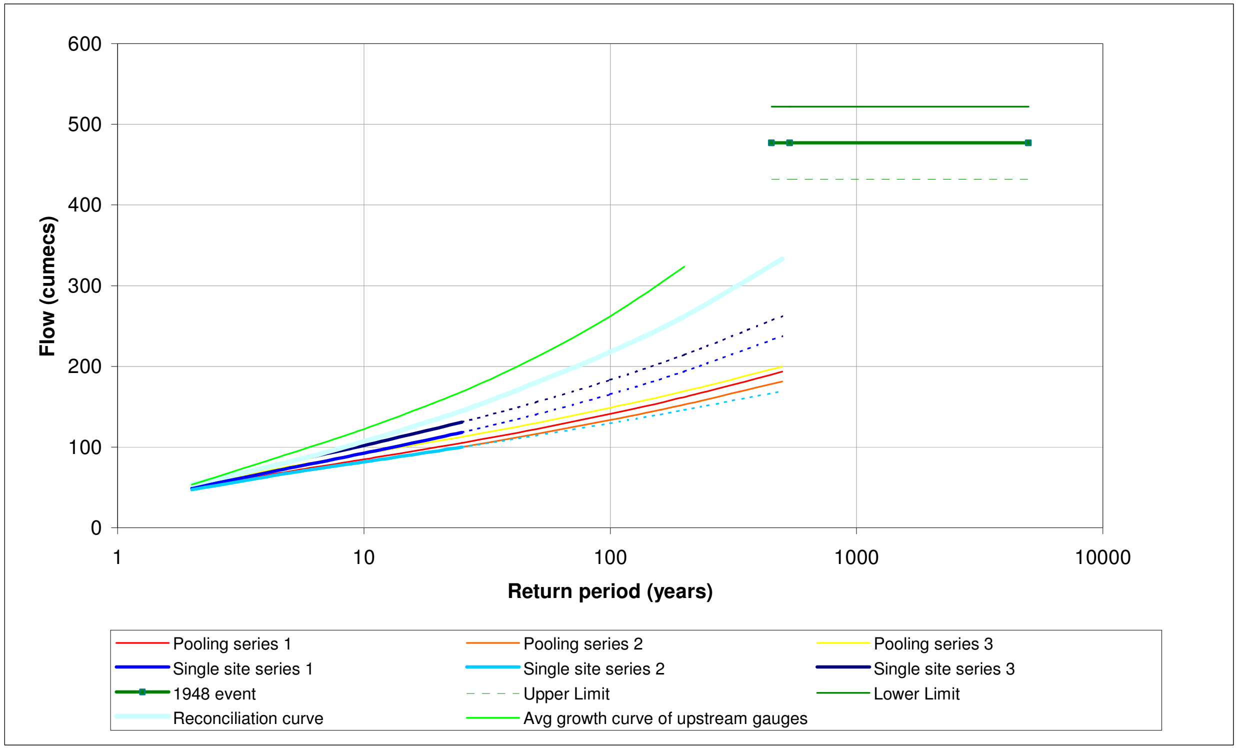
a) The pooling group approach appears to offer rather low estimates given that the single site analyses suggest at low return periods that a steeper growth curve is required, plus the established size of the experienced 1948 event is very difficult to reconcile.
b) The plotting position of the 1948 event is extreme though not with out precedent. The ratio of the flow to QMED is 9. To set this in context: generally for UK catchments the ratio for the 1% AEP event is between 2 and 3.5. This suggests that the 1948 event would have had a rarity of well in excess of 0.1% AEP and probably closer to 0.01% AEP. The rarity of the daily rainfall that caused the 1948 event is estimated (based on catchment wide rainfall depths) to be between 0.33% and 0.25% AEP. However the antecedent conditions were observed to be very wet with anecdotal accounts of the rivers running full and the ground being fully saturated. This together with the storm rainfall does point to an event that was rarer than 0.2%.

Therefore a flood growth curve that attempts to reconcile the above facts is included in Figure 2. The values are tabulated in Table 3.

% AEP	Design flows (m^3/s)
50	54
20	82
10	107
4	145
2	180
1	218
0.5	262
0.2	333

Table 3 - Final design flows in the River Tyne proposed for Haddington

Figure 2 - Summary of flood frequency estimates plus proposed reconciliation design flood frequency curve



Based upon these different strands of evidence, it is considered that a view, supported by SEPA, needs to be reached as to what is an acceptable flood flow frequency relationship. The findings of this detailed hydrological assessment of flows in the River Tyne at Haddington were sent to SEPA in November 2008.

A response was received from SEPA in the form of a letter dated 26 January 2009 indicating that SEPA will accept the proposed design flows as shown in Table 3 for use in this study.

3.2 Derivation of Design Hydrograph Shape

The shape of the flow hydrograph determines the volume of water that passes through the river channel at a given location during a particular event. Both the peak flow rate and the shape of the hydrograph (i.e. volume) are important in terms of determining the risk of flooding along the watercourse.

The most widely used method in determining the shape of the design flood event hydrograph is based on the analysis of the recorded flow hydrographs which represent the general characteristics of the river system at that location. The recorded flow hydrographs for larger flow events at East Linton Gauging Station were analysed for the period of 1993 to 2005 to identify the larger flow events. Figure 3 and Figure 4 show the recorded hydrographs used for the analysis. These are plotted to a common scale for ease of comparison.

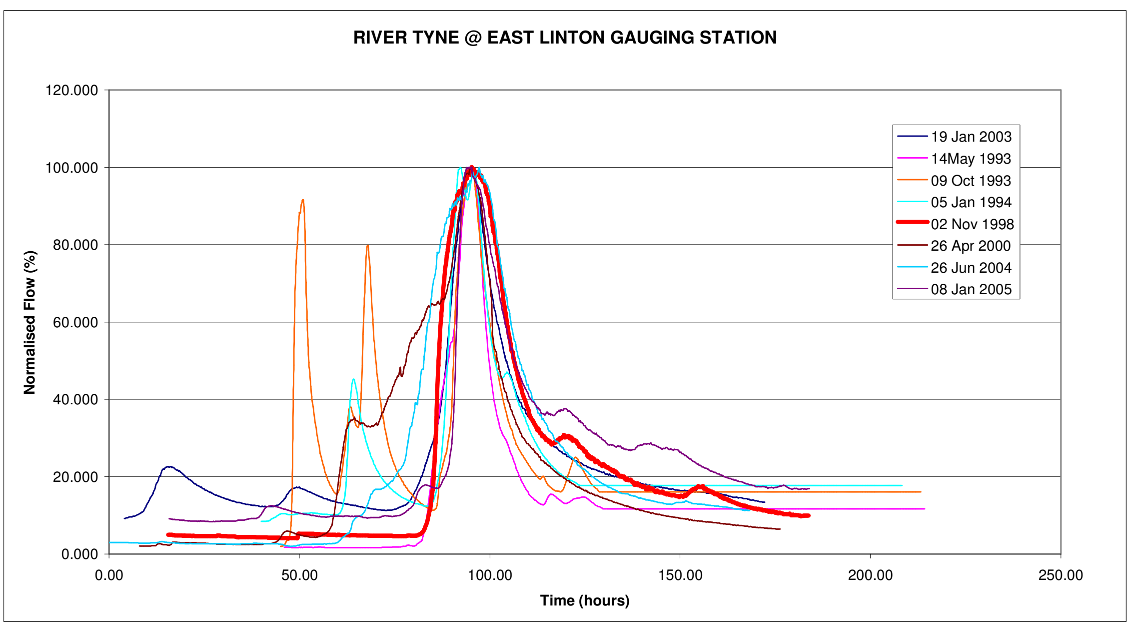


Figure 3 – Estimation of design hydrograph shape at East Linton Gauging Station (1).

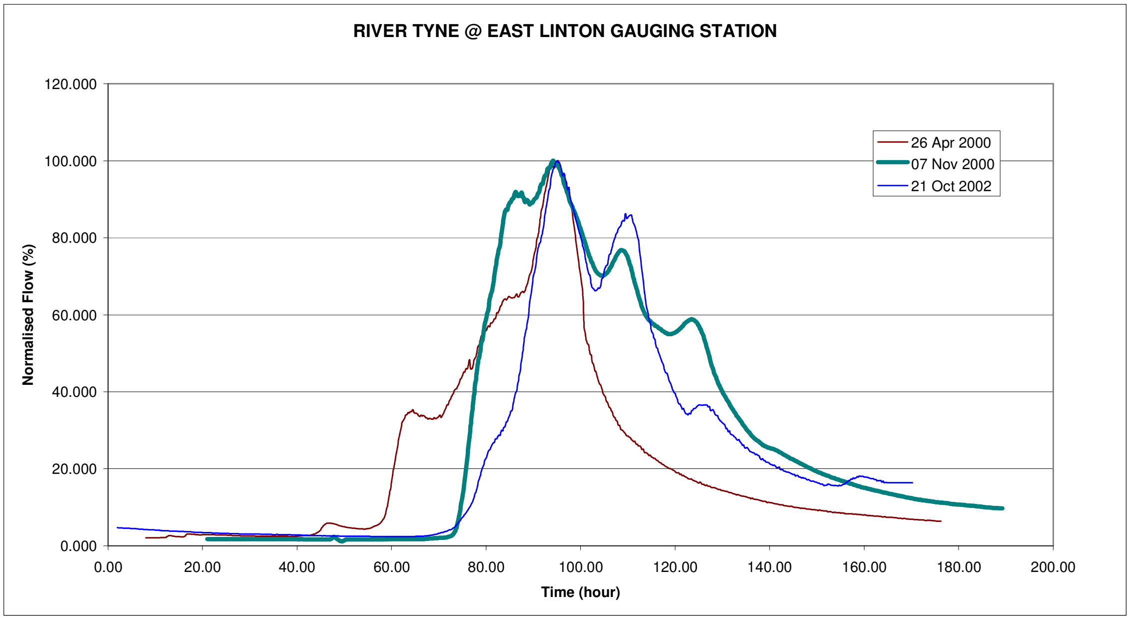


Figure 4 - Estimation of design hydrograph shape at East Linton Gauging Station (2)

As can be seen in Figure 3 the flow hydrographs in the River Tyne generally follow a shape characterised by October 1998 flood event. The shape of the events observed in 2000 and 2002 is different to the shape generally observed. However it is considered that the 1998 flood event shape is more representative of the flood event hydrograph shape likely to occur during various % AEP flood events. It should be noted that any flood alleviation option involving upstream storage should include assessment of the performance of the scheme for different design event hydrograph shapes.

4. Walkover Inspection and Topographical Survey

4.1 Walkover Inspection

A walkover inspection of the reach to be modelled is generally carried out to become familiar with the area, to gain a better understanding of the flood related issues which could be used in the representation of the watercourse and the surrounding area in the mathematical model; also to interpret the model predictions in terms of depth, extent and mechanism of flooding, effect of certain structures and the flooding of certain areas. A walkover survey of the River Tyne was carried out on 3 August 2006 with Mr Murray Hutchison of East Lothian Council. The survey involved walking along the banks of the river where access was available and driving to other locations and either viewing the watercourse from high ground or bridges to gain an understanding of significant characteristics and potential issues. It covered the reach between Samuelston Bridge and Abbey Bridge upstream and downstream of Haddington respectively.

The survey indicated that there are large floodplain areas downstream of Samuelston Bridge and immediately downstream of urban Haddington. It was noted that relatively flat areas rise at a gentle slope away from the watercourse. The channel is generally clear of large debris with the exception of large mid channel island formations with large trees and other vegetation immediately downstream of both Nungate and Victoria Bridges. The river banks were covered with trees and brush vegetation and the floodplain areas were either pasture or farming land with crops of various types. Floodplain areas or ‘haughs’ in Haddington town itself comprise short grass.

The walkover inspection also assisted in selection of relevant channel roughness coefficients which were used in the calibration of the mathematical model.

4.2 Topographical Survey

Detailed survey of the main watercourses, floodplains and the significant hydraulic structures is essential to achieve a good representation of the study area in the mathematical model.

The original channel cross-sectional survey of the River Tyne between a location near Lennoxlove Mains upstream of Haddington and Sandy’s Mill downstream of Abbey Bridge was carried out by the then Lothian Regional Council in 1994. Details of significant hydraulic structures such as bridges and weirs were also surveyed during this original exercise. The survey information was used to represent the river system using the MIKE11 river modelling software platform.

Additional survey information in the vicinity of The Maltings and Amisfield Park was provided by W A Fairhurst & Partners to improve the representation of certain areas in the model and undertake assessment of the risk of flooding to these areas for planning purposes was added into the model in the early 2000s.

For the purposes of this commission, it was pointed out to the East Lothian Council that although channel cross-sections could be easily transferred from a MIKE11 software environment into an ISIS river modelling software environment, due do large differences in representation of hydraulic structures, it would be advisable that either original plans of these structures were obtained from the relevant departments of the Council or a new survey exercise undertaken to collect details of these structures together with channel cross-sections immediately upstream and occasionally downstream of the structures.

East Lothian Council also requested that the existing model should be extended up to a location upstream of Samuelston Bridge to represent possible effects of floodplains between Samuelston and Haddington on the flood flows.

The Council survey team surveyed thirteen new channel cross-sections between a location approximately 900m upstream of Samuelston Bridge and Clerkington Mill which is located near the south-western urban boundary of Haddington. The survey also included all bridge and weir structures between Samuelston Bridge and Abbey Bridge.

Enquiries regarding the availability of LIDAR based survey information through Scottish Government and private survey companies indicated that this information did not exist for Haddington and surrounding areas. Although the Council made available printed copies of IfSAR survey information based contour plans of the areas of interest, a comparison of the survey information on these plans with those available on the relevant Ordnance Survey plans indicated that, there could be difference of up to 1.0m in elevations which is considered to be significant in terms of flood mapping. Hence this information has not been used for mapping purposes in this study.

A limited spot level survey of the areas indicated on the plans prepared by the Council showing the observed extent of the 1948 flood event was carried out by the Council survey team. Although the survey was not comprehensive, it provided a useful source of information for representation of floodplain storage areas in Haddington.

It was understood through communications with various sources that a detailed topographical survey of Bermaline Mill and the grounds in the immediate vicinity was available through Pure Malt. This information was requested by the Council from Pure Malt and it was kindly provided in September 2006. The detailed topographical survey information, even though late in the modelling process, was used to improve the representation of Bermaline Mill area and to include the Mill Lade in the mathematical model.

5. Mathematical Modelling

5.1 Extent of Mathematical Model

A mathematical model of the River Tyne was set up covering the reach between a location approximately 900m upstream of Samuelston Bridge and Sandy's Mill covering a total length of approximately 10.0km.

5.2 Model Construction

Version 3.01 of the ISIS river modelling software package was used for modelling the River Tyne in Haddington. The software package is able to model complex looped and branched networks, and is designed to provide a comprehensive range of methods for simulating flood plain flows. ISIS Flow incorporates both unsteady and steady flow solvers, with options that include simple backwaters, flow routing and full unsteady simulation. The simulation engine provides a direct steady-state solver and adaptive time-stepping methods to optimise run-time and to enhance model stability

A key feature of ISIS Flow is its ability to model a wide range of hydraulic structures including all common types of bridges, sluices, culverts, pumps and weirs. Other units include Reservoirs to represent flood storage areas and Junctions to model flows and water levels in the channel confluences. Wherever possible, standard equations or methods are incorporated into the software so that the calculation of level and discharge relationships is fully handled by the software.

ISIS provides full interactive views of the model data and results using plan views, long sections, form based editing tools and time series plots. Results can also be reported in text and tabular formats.

The model requires the input of river cross sections to represent the main channel, input of floodplain data including bank levels to represent out of bank flows and physical geometry of man-made structures such as bridges, culverts and weirs.

A survey of large number of channel cross-sections had already been carried out as part of the original study in 1994. Thirteen additional channel cross-sections together with bridges were surveyed as part of the survey work for this commission between May and August 2006.

The reach between Samuelston Bridge and Stevenson Bridge was represented as extended channel cross-sections where floodplains were present using the survey information and contours available on relevant Ordnance Survey plans. The storage of floodwater in the floodplains upstream and downstream of Haddington due to the flat but continuously rising nature of the land appeared to be insignificant. It was considered that flow spreading onto the flat floodplain areas during extreme flood events would not be conveyed to the same extent as the main channel flows; however it would form ponded areas of floodwater over the floodplain. In order to represent this limited storage effect, channel roughness value (Manning's n) was set to zero over large floodplain areas.

The reach between Stevenson Bridge and the beginning of Ball Alley was represented as channel cross-sections extending to the high walls or the high points on the ground between the Mill Lade and the River Tyne. The Mill Lade was represented using the channel cross-section information extracted from detailed topographical survey plans used for a previous investigation. Where no information on the Mill Lade channel was available, interpolated sections were incorporated in the model for completeness. Initially it was considered that the relationship between the Mill Lade and the River Tyne during extreme flood events should be maintained by inclusion of spills representing the high ground between the two watercourses.

The reach between Ball Alley and upstream of Victoria Bridge was represented as channel cross-sections extending between walls along both banks. The right hand bank (looking downstream in the direction of flow) along Waterside and the new residential development immediately downstream of Nungate Bridge was represented by the existing masonry wall. The spill unit representing the masonry wall allows overtopping by floodwaters during extreme flood events and the floodwaters spread towards Nungate.

Along the left bank, the grounds of St Martin's Church, Sands and the gap between Peter Potter and Elmhouse were connected to the River Tyne by spill units using the topographical survey information provided by the Council. Low level ground between Ball Alley and Sands forms the inlet for floodwaters to enter the centre of Haddington. The centre of Haddington is represented as a shallow storage reservoir using the topographical survey information.

The floodplain storage area on the right bank extending from Waterside to Nungate and from Whittingehame Drive to Lennox Road was divided into smaller compartments. Each compartment was connected to the other and to the river, where necessary, by banks representing the higher ground in between. The possible flowpath between the reach upstream of Nungate and Victoria Bridges and the reach downstream of St Martin's Cemetery is maintained through the flood storage reservoirs.

The complex hydraulic structure comprising Bermaline Weir and Victoria Bridge is represented by two separate channels. The left side arrangement included a section of Bermaline Weir and the left hand arch of Victoria Bridge. In the right side arrangement, the right hand arch of Victoria Bridge was followed by the remainder of Bermaline Weir. There was conflicting information on the crest levels available for the Bermaline Weir. The levels changes from 41.33mAOD in 1994 to 41.88mAOD in 2006 with respect to the surveys carried out by the Council. The survey carried out for Pure Malt indicated a level of 41.55mAOD. A level of 41.88mAOD has been used for the purposes of this commission with greater reliance placed on the more recent survey.

Due to complex nature of the interactions between a double arch bridge and a skew weir weaving through the arches, the representation of the combined effects of these two structures for all flow conditions proved to be very difficult. As the facilities available in one-dimensional mathematical models are likely to be inadequate to fully describe the interactions, a situation such as this should ideally be analysed using a physical model representing the channel reach between Nungate Bridge and a location downstream of the sharp bend including Bermaline Weir and Victoria Bridge.

The reach between Victoria Bridge and the confluence of the River Tyne with Bermaline Mill Lade was represented as parallel channels with the channels of the River Tyne and Bermaline Mill Lade running parallel and able to communicate with each other during flood events via the banks formed by high ground levels between the two channels. The large storage area including the mill buildings was connected to the Mill Lade and other storage areas to the south of Whittinghame Drive via banks representing the high ground in-between

The remaining reach of the River Tyne from St Martin's Cemetery to the downstream boundary at Sandy's Mill is represented as extended channel cross-sections. The value of channel roughness coefficient in large floodplain areas was set to zero to represent quiescent storage of floodwater.

Photographs of all key structures are presented in Appendix A,

Initial test runs were carried out using the model of the main channel and the weir structures. Following these tests, mill lades were included in the mathematical model and further model runs were carried out without the inclusion of any hydraulic structures. Where practicable, difficulties in model operation and conditions that could give rise to unrealistic model results were identified and resolved. Following the inclusion of all major structures and any bypass facilities further model test runs were carried out as before to identify and resolve any potential anomalies in model operation and model predictions.

Once the initial model results were considered reasonable for conditions representing in-bank flows, the banks representing engineered and natural high ground between the river and the floodplain areas where ponding is likely to occur and storage compartments representing ponding in Haddington were included in the model.

5.3 Model Calibration

Mathematical river models require to be calibrated against historical flood events to increase confidence in model predictions. The degree of model calibration that can be carried out depends on the quantity and quality of recorded water level and flow data for a number of historical events. Ideally, these events should cover a range from moderate in-bank flood events to out-of-bank events. Model calibration is carried out by adjusting some of the model parameters including channel roughness coefficient and weir coefficient that are not precisely known until a reasonable agreement is obtained with recorded water levels and flows.

The accuracy of prediction of water levels for design events is based upon the accuracy with which the main channel and floodplains are represented in the model. In general, mathematical river models are calibrated for both in-bank and out-of-bank flow events. In-bank flow conditions are used to adjust the channel roughness and weir coefficients within the main channel and out-of-bank flow conditions are used to adjust the coefficients representing floodplains, overflow to and from floodplains and also head-loss coefficients at bridges and other hydraulic structures.

A good calibration event is one where there are observed water levels (normally in the form of peak levels) at all critical locations within the model area and where the corresponding flows are known. With the exception of the level gauge approximately 100m upstream of Nungate Bridge and water level data collected in the days following 1956 flood event, there is little other reliable historical water level data available in Haddington. It is essential that in order to increase the level of confidence in the model predictions through Haddington, the water level observations in the River Tyne along the reach between West Mills Weir and the footbridge downstream of Bermaline Mills during and in the days following the high flow event should be carried out for each significant event.

The plan prepared by Lothian Regional Council showing the extent of inundation for the August 1948 and August 1956 flood events and the level information provided on this plan representing the water levels obtained from flood marks following the August 1956 event were used to verify the extent of inundation predicted by the mathematical model as calibrated.

The selection of channel roughness coefficient was based on the observations made during the walkover inspection of the watercourse and also the values used for the MIKE 11 based original mathematical model. The bed roughness coefficient (Manning's 'n' value) generally varied between 0.030 and 0.050. A channel roughness coefficient of 0.1 was adopted to represent the channel with large trees downstream of Nungate and Victoria Bridges. For the floodplain areas it ranged from 0.045 for the short grass floodplain areas to 0.055 for floodplain areas with longer grass and larger bush type vegetation.

The main channel in Haddington has been calibrated against the level hydrographs recorded at the gauge mainly used for flood warning purposes located approximately 100m upstream of Nungate Bridge for:-

- 8 January 2005
- 2 November 1998
- 26 April 2000 high flow and flood events.

Comparison of Q_{MED} values in the River Tyne in Haddington and East Linton indicated that flows in the watercourse in Haddington should be approximately 90% of the flows at East Linton. Comparison of catchment areas also produced a similar ratio. Although this is a general ratio to reduce the flows to get a comparable water level, calibration simulations indicated that the ratio could vary between 0.75 and 1, possibly depending on the changes in the direction of storm and antecedent conditions dominant in at the time of each event. Generally a ratio of 0.9 is adopted for the comparison simulations. Figures 5, 6 and 7 show the water level comparisons obtained.

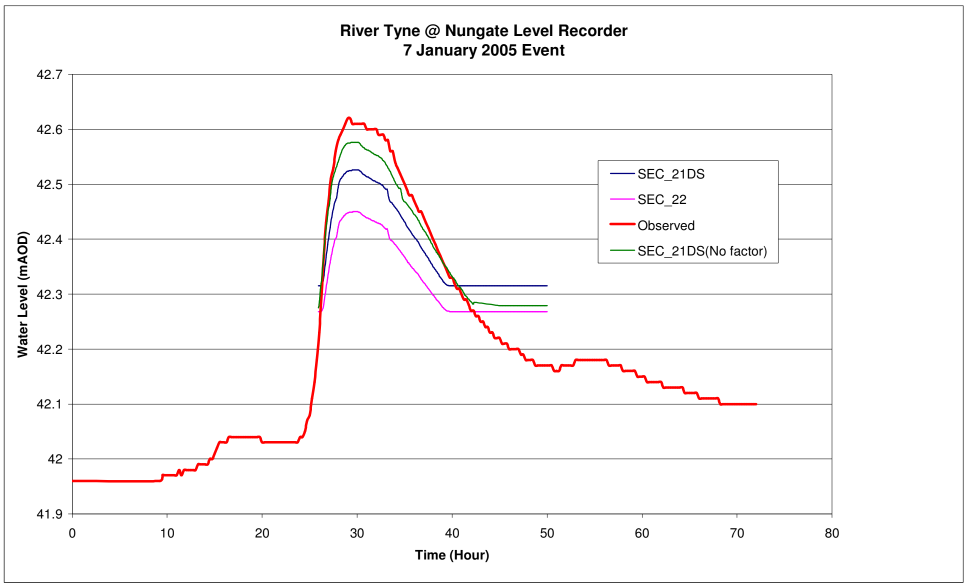


Figure 5 - Comparison of Observed and Predicted Water Levels at Nungate Level Recorder (7 January 2005 event)

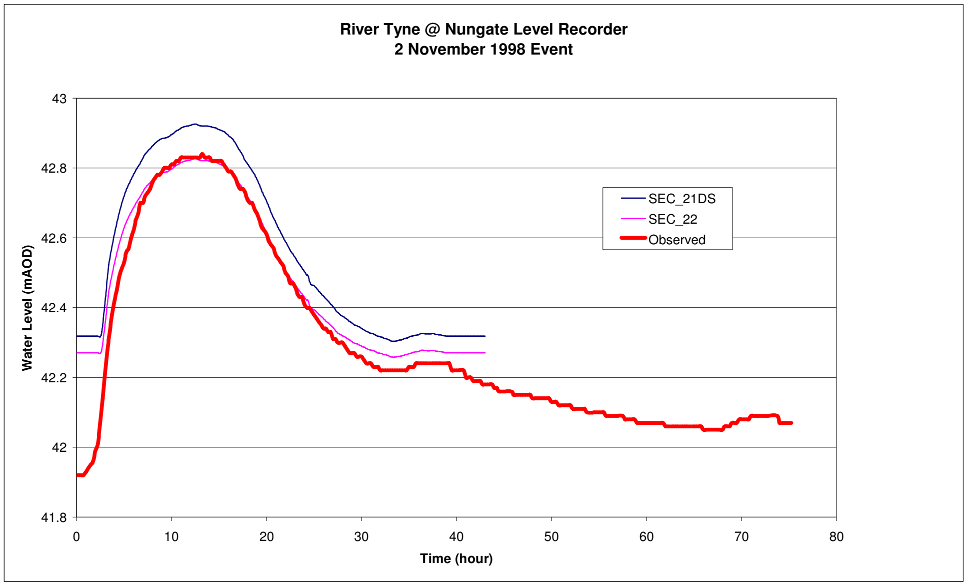


Figure 6 – Comparison of Observed and Predicted Water Levels at Nungate Level Recorder (2 November 1998 flood event)

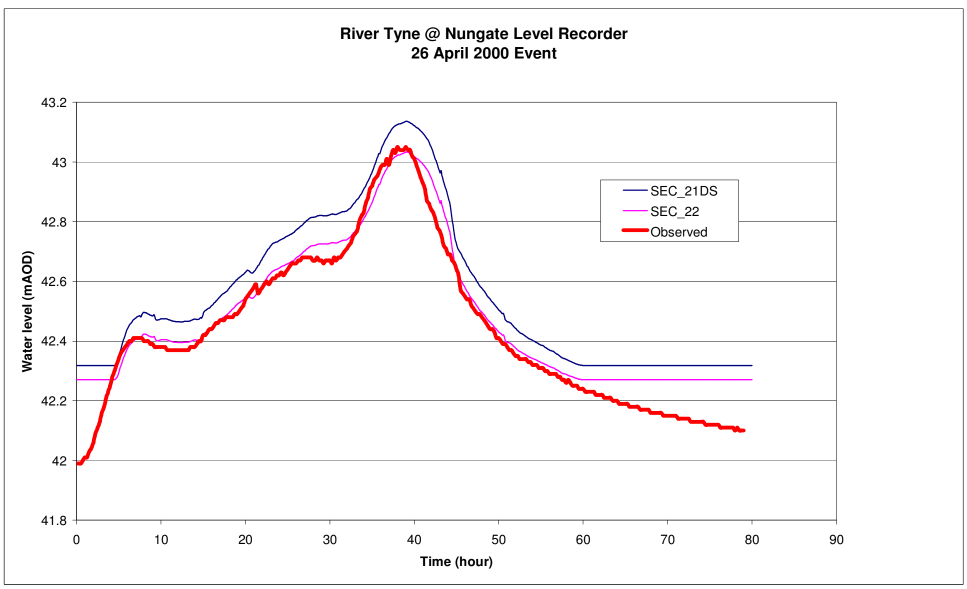


Figure 7 - Comparison of Observed and Predicted Water Levels at Nungate Level Recorder (26 April 2000 flood event)

Model predictions indicate that there is a close correlation between observed and predicted water levels in the River Tyne at Nungate Level Recorder. This close correlation helps to increase the level of confidence in model predictions in the River Tyne at Haddington.

Water levels recorded at Nungate Level Recorder for the following high flow events were used for the validation of the River Tyne mathematical model through Haddington.

- 6 October 1990
- 7 November 2000

Figures 8 and 9 show the water level comparisons for 6 October 1990 and 7 November 2000 respectively.

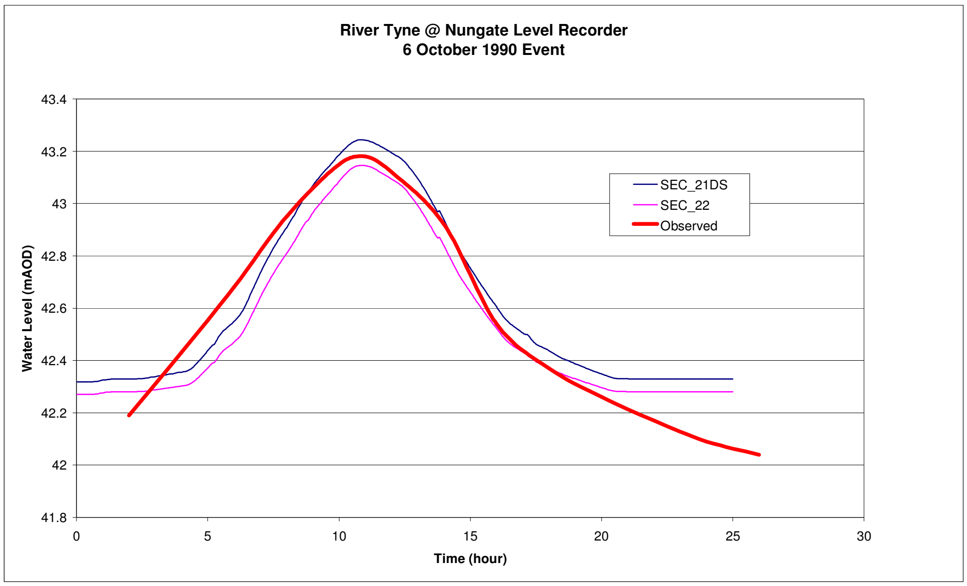


Figure 8 - Comparison of Observed and Predicted Water Levels at Nungate Level Recorder (6 October 1990 flood event)

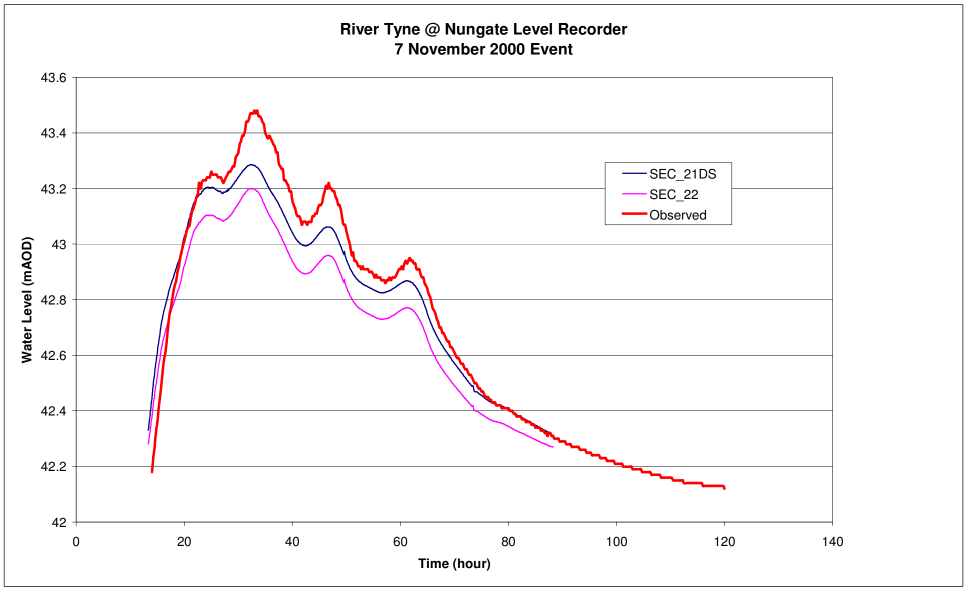


Figure 9 - Comparison of Observed and Predicted Water Levels at Nungate Level Recorder (7 November 2000 flood event)

It should be noted that there are no other water level observations in the River Tyne upstream and downstream of Haddington. Hence a series of sensitivity simulations were undertaken to determine the sensitivity of model predictions to changes in certain key model parameters such as channel roughness. The detail of this investigation is provided in the following section.

As indicated above, it is understood that water level measurements were carried out at various locations in Haddington in the days following the August 1956 flood event by the Council personnel. These levels were measured/surveyed from the flood marks left on the walls or other fixed objects. Depending on the type of material and the duration when the material was in contact with water, some degree of migration of water marks to a higher level is likely to occur. The table below shows the comparison of measured and predicted water level in Haddington for August 1956 flood event.

Location	**Observed Water Level (mAOD)**	**Predicted Water Level (mAOD)**	**Difference (mm)**
Downstream of Nungate Bridge	43.37	43.40	+30
St Martin's Gate(East End)	43.32	43.26	-60
St Martin's Gate(West End)	43.32	43.26	-60
Junction of Hardgate & Sidegate	43.43	43.48	+50
East end of Church Street	43.45	43.48	+30
West end of Ford Road	43.57	43.55	-20
Distillery Park	44.84	44.68-45.03	-190/+160

Table 4 – Comparison of observed and predicted water levels for the 1956 flood event

In general good agreement was obtained between observed and modelled water levels at the Nungate recorder for the various flood events considered. These verification results confirm that, overall, a reasonable calibration of the model has been achieved sufficient for the purposes of this study.

6. Model simulations

The calibrated model of the River Tyne was used to predict the peak water levels in order to asses the risk of flooding and identify the indicative extent of flooding along the modelled reach of the River Tyne between Samuelston Bridge and Abbey Bridge. Model runs corresponding to the 50%, 20%, 5%, 4%, 2%, 1%, and 0.5% AEP flood events were carried out. Runs were also carried out for the 0.5% AEP event with a 20% increase in flow**.** Flood and Coastal Defence Appraisal Guidance FCDPAG3 Economic Appraisal Supplementary Note to Operating Authorities – Climate Change Impacts (October 2006) by DEFRA indicates that the limited number of catchments researched to date supports applicability of a 20% allowance to the 2080[5] for peak river flow. Research is ongoing[6] to assess *regional* variations in flood allowances. Current research thus far does not provide any evidence for the rate of future change but as a pragmatic approach it is suggested that 10% should be applied up to 2025, rising to 20% beyond 2025

Parameter	1990- 2025	2025-2055	2055-2085	2085-2115
Peak rainfall intensity (preferably for small catchments)	*+5%*	**+10%**	*+20%*	*+30%*
Peak river flow (preferably for larger catchments)	+10%	**+20%**		

Table 5 - Indicative Sensitivity Ranges

A summary of the peak water levels and flows at key locations along the watercourse is presented in Table 6.

A full set of model results with peak flows and water levels for all the above % AEP fluvial flood events is presented in Appendix B.

Additional model simulations to assess the sensitivity of water level predictions to changes in channel roughness coefficient (Mannings 'n' value) indicated that a 20% increase in channel roughness coefficient could increase the peak water levels by up to 200mm in the River Tyne through Haddington for a 0.5%AEP fluvial flood event.

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[5] Environment Agency/Defra (2005). Impacts of climate change on flood flows in river catchments. R&D Technical Report W5-032/TR, pp107
[6] FD2020 project Regionalised impacts of climate change on river flows

Location	Predicted Peak Water Level (mAOD)			
	0.5% AEP	**1%AEP**	**2% AEP**	**4% AEP**
Samuelston Bridge	56.90	56.45	56.02	55.58
Westfield Bridge	52.99	52.75	52.53	52.30
West Mills Weir	46.97	46.61	46.29	46.06
Stevenson Bridge	46.68	46.33	46.00	45.55
Waterloo Bridge	45.06	44.76	44.47	44.16
Nungate Bridge	44.37	44.11	43.84	43.55
Victoria Bridge	43.86	43.54	43.30	43.07
Cascade Weir	40.46	40.15	39.88	39.68
Abbey Bridge	39.48	39.22	38.95	38.68

Table 6 - Predicted Peak Water Levels at Selected Locations along the River Tyne

It must be emphasised that the water level values quoted in this report are predictions from a one – dimensional mathematical model of the River Tyne which does not include effects such as variation of water surface across the channel cross-section, local effects, and fluctuations or elevation of water surface due to wind induced turbulence etc.

7. Inundation Mapping

The indicative extents of inundation for various % AEP flood events were drawn manually using the peak water levels predicted by the one dimensional ISIS mathematical model at the river sections and the flood storage cells, spot level information available, IfSAR data where considered of reasonable accuracy and contour information presented in relevant Ordnance Survey plans. Ordnance Survey and IfSAR survey information was generally used along upstream reaches where insufficient ground survey information was available. The spot level survey information provided by the Council, W A Fairhurst & Partners and Pure Malt was used to determine the indicative extent of inundation for areas in Haddington and downstream.

It should be noted that due to the one-dimensional nature of the modelling software and the limited spot level information, the lines showing the extent of flooding for various % AEP flood events are broadly indicative only and should not be used for assessing the risk of flooding to individual properties.

The inundation maps have been plotted for the 4% AEP, 2% AEP, 1% AEP, 0.5% AEP and 0.5% AEP +20% increase in flow flood events and are provided in Appendix C. A plan showing the location of channel cross-sections upstream of Samuelston Bridge and downstream of Abbey Bridge is also included in Appendix C

For a 1% AEP flood event the likely areas that would be flooded in Haddington town are;

Areas likely to be flooded	**Watercourse**	**Flooding Mechanism**
• Playing Fields • Tynehouse • Poldrate Road • Tynehouse School • St Mary's Church • Sidegate	Mill Lade / River Tyne	In the reach between the Aubigny Sports Centre and the Tynepark School, the Mill Lade interacts with the River Tyne along the right hand bank. Although the flow in the Mill Lade is likely to be controlled by the sluice gate upstream, the interaction between the two watercourses during extreme flood events is likely to initiate flooding of certain areas either from one or the other. Grounds of St Mary's Church could be affected by floodwaters entering via the gate at Sidegate depending on the size of the event. The high point on

Areas likely to be flooded	Watercourse	Flooding Mechanism
		Sidegate did not overtop allowing floodwaters to enter Hardgate for the food events investigated.
• The Sands • Ball Alley • Parts of St Mary's Pleasance • Parts of Church Street / High Street • Elm House • Garage • Holy Trinity Church	River Tyne	The floodwaters overtop the natural bank upstream and downstream of Nungate Bridge. Grounds of St Mary's Church and St Mary's Pleasance are likely to be flooded via the gates connecting both areas to The Sands and Ball Alley and also to each other. Flows entering Ball Alley and The Sands would progress towards the town centre via Church Street and Hardgate causing flooding of large areas in town centre. The opening and narrow alleyway behind Peter Potter and the wall of the memorial garden would also allow floodwaters to enter The Sands contributing to the flooding of the town centre.
• Waterside area adjacent to Nungate Bridge. • North of Bridge Street • Superstore adjacent to Victoria Bridge • Parts of Lennox Road area • St Martins Gate area • Nungate area • Whittinghame Drive	River Tyne	The floodwaters overtop the wall along right hand bank of the River Tyne between Tynebank Adult Resource Centre and the Victoria Bridge for a large number of flood events. This would cause frequent flooding of flooding Waterside. Depending on the magnitude of the flood event, in addition to Waterside, area to the north of Bridge Street is also likely to be affected. For larger events, the wall to the north of Bridge Street is also likely to overtop causing flooding of grounds of Superstore, Lennox Road, St Martin's Gate, Nungate, Nungate playing fields, and Whittinghame Drive areas. Depending on the magnitude of the flood event, floodwaters could overtop the western

Areas likely to be flooded	Watercourse	Flooding Mechanism
		sector of Whittinghame Drive and flow into the grounds of Bermaline Mills. The remainder of the floodwaters flow to the north-east over the playing fields opposite cemetery and the Amisfield Park area.
• The open area adjacent to Bermaline Mills	Bermaline Mill / River Tyne	The floodwaters rise above the right hand side channel banks downstream of the Bermaline Mills and flood the open area surrounding the Bermaline Mills. The floodwaters then flow over the low lying reaches near the cemetery towards the Amisfield Park area and the River Tyne.

When interpreting the indicative flood maps the following must be taken into account:

- The flood maps provide an indicative estimate of the extent of flooding, based upon the predicted levels of a one-dimensional mathematical model.
- It should be noted that certain locations may be at risk of flooding from other sources such as pluvial flooding (surface flooding associated with very intense rainfall), sewer flooding, road drainage, field ditches, water mains etc; also from other watercourses not modelled in this study.
- The inundation outlines are based upon water levels predicted at discrete points along the main channel and on flood plains where appropriate. The inundation at all other locations is based on interpolation and therefore the flood outlines need to be considered as broadly indicative.
- It is assumed that any embankments remain intact during flood events, and that they act as an impermeable barrier. This may not always be the case – flood banks can breach and the associated rapid inundation can be more serious than normal flood plain flooding.
- Channel roughness used in the model represents average conditions and would not necessarily reflect the conditions if heavy weed growth, or debris were allowed to build up in the channel.
- The modelling cannot predict the potential occurrence of transitory debris dams nor the associated consequences.
- Advances made in the future in understanding flooding mechanisms, in modelling approaches, and in obtaining more comprehensive data could lead to more refined flood outlines.

8. Conclusions and Recommendations

In order to assess the risk of flooding in Haddington a mathematical model of the River Tyne between Samuelston Bridge at Samuelston and Sandy's Mill downstream of Abbey Bridge has been constructed. A topographic survey was carried out of the main channel in the form of cross sections and of the floodplains in the form of spot levels. The survey also included hydraulic structures such as bridges and weirs which could have a significant effect on flood flows in the channel. The information obtained from the survey was used to set up the mathematical model of the River Tyne. A walking survey was carried out to assess current conditions along the banks of the river.

The model has been calibrated and validated against historical data made available by the SEPA. The close agreement of the calibration and validation modelling results with the observed flood event data, provide confidence in model predictions for the design events. The predicted flood pattern in Haddington town confirmed the existing understanding of the mechanism of flooding.

Detailed consultation was carried out with SEPA in order to reach an understanding of the flood flows likely to occur in the River Tyne in Haddington for a range of flood event probabilities (% AEP).

The current investigation sets a benchmark in terms of flows and indicative extent of inundation in Haddington and areas in the vicinity for a range of % AEP flood events.

In order to consider further the viability of flood mitigation measures for Haddington, and if necessary surrounding areas, we would recommend that the following be undertaken:

- Undertake a physical model study to determine the interaction between Bermaline Weir, Victoria Bridge and channel reaches upstream and downstream for all flow conditions.
- Undertake observations of water levels ands survey of wrack marks during and in the days following the significant flow events.
- Further refine the mathematical model using detailed topographical survey information including LIDAR and the observations made during the significant flow events and refine the assessment of flood risk based on this information.
- Assess in outline possible flood mitigation options.
- Undertake an assessment of the outline costs for technically viable options and undertake a benefit/cost appraisal of these options to assess economical viability.
- Assess the risk of flooding from other sources including surface water flooding. This would involve a preliminary assessment of pluvial flood risk; also liaison with Scottish Water to determine the risk of flooding through sewers and surface water drains.
- Assess the potential impact of possible flood mitigation measures on the sewerage and drainage system and local watercourses.

- Determine ownership of areas of land likely to be affected directly by likely flood mitigation options.
- Collate information on the condition of existing masonry walls and river retaining walls and undertake further structural inspection and condition assessment where necessary to determine the areas where existing walls need repair or replacement. Carry out an initial assessment of stability under design flood conditions.
- Enter into discussions with SEPA and other relevant organisations to determine their views on possible flood mitigation options and in particular the impact on amenity, habitat, groundwater and water quality and likely CAR (Controlled Activities Regulations) issues.
- Consider the public acceptability of proposals through initial consultation, possibly via elected members.
- Obtain information on water, sewerage, electricity, gas, cable networks and any other utilities and make contact with authorities to identify ‘sensitive’ apparatus and obtain preliminary estimates for diversion works.
- Undertake a geotechnical desk study to determine availability of site investigation (SI) data and requirements for subsequent ground investigation.
- Undertake a preliminary environmental scoping study to identify key issues to be addressed.

Appendix A

Photographs

Samuelston Bridge

Westfield Bridge

West Mills Weir

Sluice Gate (West Mills Mill Lade)

Waterloo Bridge

Waterside – looking upstream

Nungate Bridge

Channel d/s of Nungate Bridge

Bermaline Weir(u/s of Victoria Bridge)

Bermaline Weir(d/s of Victoria Bridge)

Victoria Bridge

Abbey Bridge

Appendix B

Results of Model Runs

Node		50% AEP		20% AEP		10% AEP		4% AEP		2% AEP		1% AEP		0.5% AEP		0.5% AEP+20% Q	
	Chainage	**Flow**	**W Level**	**Flow**	**W Level**	**Flow**	**W Level**	**Flow**	**W Level**	**Flow**	**W Level**	**Flow**	**W Level**	**Flow**	**W Level**	**Flow**	**W Level**
	m	m^3/s	**mAOD**	m^3/s	**mAOD**	m^3/s	**mAOD**	m^3/s	**mAOD**	m^3/s	**mAOD**	m^3/s	**mAOD**	m^3/s	**mAOD**	m^3/s	**mAOD**
SEC_K	-6264	54.0	56.95	82.0	57.20	108.0	57.43	145.0	57.76	180.0	58.05	218.0	58.34	264.6	58.93	318.0	59.20
SEC_J	-5792	54.0	55.41	82.0	55.86	108.0	56.23	145.0	56.69	180.0	57.05	218.0	57.42	264.6	57.77	316.6	58.09
SEC_I	-5390	54.0	54.35	82.0	54.91	108.0	55.34	145.0	55.89	180.0	56.34	218.0	56.79	264.6	57.19	316.2	57.54
US_SAM_BRG	-5355	54.0	54.22	82.0	54.69	108.0	55.10	145.0	55.58	180.0	56.02	218.0	56.45	264.6	56.90	316.2	57.32
SEC_IX	-5329	54.0	54.09	82.0	54.59	108.0	55.00	145.0	55.37	180.0	55.72	218.0	55.99	264.6	56.28	316.2	56.59
SEC_G	-4659	54.0	52.48	82.0	52.82	108.0	53.07	145.0	53.47	180.0	53.73	217.9	54.02	264.6	54.32	315.9	54.58
SEC_E	-3944	54.0	51.27	82.0	51.76	108.0	52.02	145.0	52.30	180.0	52.53	217.9	52.75	264.5	52.99	315.8	53.24
SEC_D	-3665	54.0	50.54	82.0	50.91	108.0	51.15	145.0	51.41	179.9	51.60	217.9	51.76	264.5	51.92	315.6	52.07
SEC_C	-3412	54.0	49.72	82.0	50.01	108.0	50.21	145.0	50.44	179.9	50.62	217.9	50.78	264.5	50.96	315.6	51.13
SEC_BY	-3079	54.0	48.92	82.0	49.14	108.0	49.34	145.0	49.60	179.9	49.81	217.8	50.01	264.4	50.23	315.4	50.44
SEC_BX	-2937	54.0	48.25	82.0	48.66	107.9	49.00	145.0	49.30	179.9	49.53	217.8	49.74	264.4	49.97	315.4	50.19
SEC_A	-2805	54.0	47.83	82.0	48.33	107.9	48.64	145.0	48.99	179.9	49.27	217.8	49.51	264.4	49.76	315.3	50.00
SEC_1	-2542	54.0	47.44	82.0	47.90	107.9	48.26	144.9	48.60	179.9	48.87	217.8	49.12	264.4	49.38	315.2	49.63
SEC_2	-2391	54.0	47.24	82.0	47.64	107.9	47.96	144.9	48.23	179.9	48.47	217.8	48.69	264.4	48.94	315.2	49.17
SEC_3	-2241	54.0	46.85	82.0	47.20	107.9	47.41	144.9	47.84	179.8	48.06	217.8	48.25	264.4	48.47	315.2	48.68
SEC_4	-2098	54.0	46.58	82.0	46.93	107.9	47.21	144.9	47.53	179.8	47.78	217.8	48.02	264.4	48.32	315.2	48.57
SEC_5	-1952	54.0	45.93	82.0	46.34	107.9	46.66	144.9	47.06	179.8	47.34	217.7	47.62	264.3	47.89	315.1	48.15
SEC_6	-1832	54.0	45.70	82.0	46.04	107.9	46.32	144.9	46.67	179.8	46.96	217.7	47.29	264.3	47.64	315.1	47.97
SEC_7	-1649	54.0	45.51	82.0	45.72	107.9	45.87	144.9	46.17	179.8	46.43	217.7	46.70	264.3	47.00	315.0	47.32
SEC_8	-1397	54.0	45.44	82.0	45.64	107.9	45.80	144.9	46.01	179.8	46.22	217.7	46.55	264.3	46.91	314.9	47.26
SEC_9	-1333	54.0	45.45	82.0	45.67	107.9	45.85	144.9	46.09	179.8	46.31	217.7	46.63	264.2	46.98	314.9	47.33
SEC_10	-1229	51.9	44.11	79.3	44.69	104.7	45.01	141.0	45.71	175.2	46.12	212.1	46.45	258.2	46.79	308.6	47.14
SEC_11	-1170	51.9	43.72	79.3	44.33	104.8	44.81	141.0	45.55	175.2	46.00	212.1	46.33	258.2	46.68	308.6	47.02
SEC_12	-1078	51.9	43.75	79.3	44.26	104.7	44.61	141.0	45.03	175.2	45.36	212.1	45.67	258.2	46.02	308.6	46.34
SEC_13	-941	51.9	43.57	79.3	44.02	104.7	44.32	141.0	44.68	175.2	44.92	212.1	45.15	258.2	45.40	308.6	45.63
SEC_14	-789	51.9	43.35	79.3	43.76	104.7	43.96	141.0	44.35	175.2	44.56	212.1	44.76	258.2	45.00	308.6	45.25
SEC_15	-634	51.9	43.24	79.0	43.70	98.8	43.99	125.3	44.31	151.2	44.54	182.8	44.73	226.3	44.96	274.8	45.20
SEC_16	-542	51.9	43.13	79.0	43.54	98.6	43.80	118.1	44.16	128.8	44.47	136.0	44.76	148.0	45.06	162.8	45.37
SEC_17	-506	51.9	43.07	78.5	43.44	98.8	43.65	120.0	43.96	131.8	44.24	140.0	44.50	152.2	44.78	167.7	45.05
SEC_18	-430	51.9	43.00	78.5	43.37	94.7	43.62	116.8	43.94	130.7	44.22	141.9	44.47	155.2	44.75	169.3	45.02

Node		50% AEP		20% AEP		10% AEP		4% AEP		2% AEP		1% AEP		0.5% AEP		0.5% AEP+20% Q	
	Chainage	Flow	W Level	Flow	W Level	Flow	W Level	Flow	W Level	Flow	W Level	Flow	W Level	Flow	W Level	Flow	W Level
	m	m^3/s	mAOD	m^3/s	mAOD	m^3/s	mAOD	m^3/s	mAOD	m^3/s	mAOD	m^3/s	mAOD	m^3/s	mAOD	m^3/s	mAOD
SEC_19	-339	51.9	42.92	77.9	43.25	90.1	43.53	106.7	43.87	116.0	44.17	123.0	44.45	131.5	44.74	140.4	45.02
SEC_20	-255	51.9	42.85	76.7	43.16	90.1	43.43	107.1	43.77	118.8	44.08	130.2	44.34	144.5	44.62	160.1	44.89
SEC_21	-115	50.1	42.79	75.0	43.08	97.0	43.32	128.8	43.62	158.7	43.90	191.1	44.14	230.8	44.39	273.5	44.63
SEC_22	-45	54.0	42.69	82.0	42.98	107.8	43.24	144.9	43.60	179.7	43.89	217.6	44.11	264.1	44.36	314.2	44.59
SEC_23	0	54.0	42.70	81.8	42.99	107.0	43.22	141.9	43.55	173.0	43.84	198.5	44.10	226.0	44.37	255.1	44.63
SEC_24	80	54.0	42.59	81.8	42.81	107.0	42.99	142.5	43.24	170.3	43.47	192.3	43.69	215.4	43.93	239.8	44.13
SEC_25	141	54.0	42.56	81.8	42.76	107.0	42.93	143.1	43.14	171.1	43.36	190.5	43.59	211.0	43.84	232.6	44.03
SEC_26	197	54.0	42.56	81.8	42.78	107.2	42.95	144.3	43.18	176.2	43.40	199.3	43.62	214.1	43.90	222.5	44.12
BERMALINE WEIR	222	54.0	42.50	81.8	42.70	107.2	42.86	144.3	43.07	176.2	43.30	199.3	43.54	214.1	43.86	222.5	44.08
SEC_28	283	54.0	41.31	81.8	41.81	107.2	42.18	144.3	42.62	176.2	42.94	199.3	43.18	214.0	43.54	222.5	43.75
SEC_29	561	54.0	40.74	81.8	41.22	107.5	41.56	144.3	41.90	176.3	42.16	199.3	42.42	213.5	43.16	222.7	43.42
SEC_30	715	54.0	40.65	81.8	41.14	107.3	41.50	142.9	41.88	174.1	42.15	197.2	42.41	252.7	42.85	270.7	43.12
SEC_31	794	54.5	40.44	82.3	40.95	108.4	41.33	144.8	41.63	175.2	41.90	196.4	42.16	203.2	42.53	204.7	42.83
SEC_32	979	54.5	40.25	82.3	40.73	109.5	41.07	145.3	41.22	180.1	41.48	218.5	41.73	264.3	41.98	314.7	42.20
SEC_33	1159	54.5	40.04	82.3	40.65	116.4	40.99	145.3	41.22	180.1	41.45	218.5	41.66	264.2	41.89	314.6	42.09
SEC_34	1344	54.5	39.81	82.3	40.36	118.4	40.69	145.3	40.83	180.1	41.03	218.4	41.22	264.2	41.43	314.6	41.56
SEC_35	1561	54.5	39.33	82.3	39.42	112.6	39.88	145.3	40.06	180.1	40.25	218.3	40.43	264.2	40.61	314.5	40.89
SEC_36	1692	54.5	39.34	82.3	39.46	112.5	39.58	145.3	39.69	180.0	39.89	218.3	40.16	264.1	40.47	314.5	40.82
SEC_37	1734	54.5	38.39	82.3	38.84	112.3	39.21	145.3	39.54	180.0	39.82	218.2	40.11	264.1	40.43	314.4	40.79
SEC_38	1754	54.5	38.27	82.3	38.72	112.1	39.10	145.3	39.48	180.0	39.78	218.2	40.08	264.1	40.41	314.4	40.77
SEC_39	1873	54.5	37.94	82.3	38.36	111.3	38.78	145.3	39.17	180.1	39.49	218.2	39.80	264.1	40.14	314.4	40.52
SEC_40	2002	54.5	37.56	82.3	37.98	110.8	38.31	145.3	38.88	180.0	39.23	218.1	39.57	264.1	39.91	314.4	40.32
SEC_40A	2148	54.5	37.41	82.3	37.91	110.6	38.27	145.3	38.82	180.0	39.15	218.1	39.49	264.1	39.84	314.4	40.25
SEC_41	2188	54.5	37.34	82.3	37.82	110.5	38.16	145.3	38.69	180.0	38.98	218.1	39.26	264.1	39.52	314.4	39.77
SEC_42	2293	54.5	36.92	82.3	37.42	110.4	37.83	145.3	38.26	180.0	38.56	218.1	38.84	264.1	39.12	314.4	39.37
SEC_43	2419	54.5	36.61	82.3	37.13	110.4	37.50	145.2	37.96	180.0	38.27	218.1	38.55	264.1	38.81	314.4	39.05
SEC_44	2609	54.5	36.31	82.3	36.79	110.3	37.08	145.2	37.50	180.0	37.84	218.1	38.12	264.1	38.36	314.4	38.58
SEC_45	2800	54.5	35.94	82.3	36.46	110.2	36.93	145.2	37.30	180.0	37.59	218.1	37.84	264.0	38.12	314.3	38.39
SEC_46	3094	54.5	35.58	82.3	36.03	109.9	36.44	145.2	36.87	180.0	37.20	218.0	37.48	264.0	37.78	314.3	38.07
SEC_47	3264	54.5	35.43	82.3	35.85	109.8	36.16	145.2	36.49	179.9	36.76	218.0	36.95	264.0	37.24	314.3	37.49

Node	Chainage	50% AEP		20% AEP		10% AEP		4% AEP		2% AEP		1% AEP		0.5% AEP		0.5% AEP+20% Q	
		Flow	**W Level**	**Flow**	**W Level**	**Flow**	**W Level**	**Flow**	**W Level**	**Flow**	**W Level**	**Flow**	**W Level**	**Flow**	**W Level**	**Flow**	**W Level**
	m	**m^3/s**	**mAOD**	**m^3/s**	**mAOD**	**m^3/s**	**mAOD**	**m^3/s**	**mAOD**	**m^3/s**	**mAOD**	**m^3/s**	**mAOD**	**m^3/s**	**mAOD**	**m^3/s**	**mAOD**
SEC_48	3455	54.5	35.21	82.3	35.57	109.8	35.86	145.2	36.19	179.9	36.48	218.0	36.61	264.0	36.83	314.3	37.06
SEC_49	3727	54.5	34.23	82.3	34.53	109.8	34.79	145.2	35.09	179.9	35.35	218.0	35.73	264.0	35.99	314.3	36.23
SEC_50	3986	54.5	33.57	82.3	33.91	109.8	34.20	145.2	34.53	179.9	34.82	218.0	35.09	264.0	35.36	314.3	35.61
Flood Storage Cells																	
TOWN CENTRE		-	43.12	-	43.12	-	43.19	-	43.58	-	43.87	-	44.06	-	44.24	-	44.37
ST MARY'S CHURCH		-	42.00	-	42.00	-	42.00	-	43.61	-	43.90	-	44.13	-	44.39	-	44.69
ST MARY'S PLEASANCE		-	42.70	-	42.70	-	42.70	-	43.58	-	43.87	-	44.06	-	44.24	-	44.39
WATERSIDE		-	42.50	-	42.77	-	43.23	-	43.57	-	43.86	-	44.09	-	44.33	-	44.55
SUPERSTORE		-	42.00	-	42.69	-	43.21	-	43.27	-	43.43	-	43.63	-	43.87	-	44.06
NUNGATE		-	43.00	-	43.00	-	43.21	-	43.27	-	43.43	-	43.62	-	43.83	-	43.99
LENNOX STREET		-	42.00	-	42.00	-	43.21	-	43.27	-	43.43	-	43.63	-	43.86	-	44.03
ST MARTIN'S GATE		-	42.25	-	42.25	-	43.21	-	43.27	-	43.43	-	43.62	-	43.85	-	44.02
WHITTINGHAME		-	42.00	-	42.00	-	42.00	-	42.00	-	42.90	-	43.19	-	43.47	-	43.65
BERMALINE MILLS		-	40.50	-	40.50	-	41.46	-	41.79	-	42.05	-	42.32	-	42.94	-	43.25
Bermaline Mill Lade																	
BERMALIN_28	0	0.5	40.65	0.5	41.14	0.5	41.49	0.5	41.88	0.5	42.15	0.5	42.42	0.5	43.45	0.5	43.80
BERMALIN_28B	80	0.5	40.65	0.5	41.14	1.7	41.49	0.6	41.88	0.8	42.15	1.9	42.42	0.9	43.32	0.6	43.48
BERMALIN_28C	139	0.5	40.65	0.5	41.14	1.1	41.50	1.3	41.88	0.9	42.15	1.2	42.42	0.9	43.37	1.0	43.58
BERMALIN_29	161	0.5	40.65	0.6	41.14	0.6	41.50	1.8	41.88	1.0	42.15	1.3	42.42	1.1	43.35	1.3	43.56
BERMALIN_30	251	0.6	40.65	0.6	41.14	1.4	41.50	2.9	41.88	1.3	42.15	1.9	42.41	1.5	42.85	2.2	43.12
West Mills Mill Lade																	
MILL_0	0	2.1	45.44	2.7	45.65	3.2	45.83	3.9	46.06	4.6	46.29	5.5	46.61	6.0	46.97	6.2	47.32
MILL_30	30	2.1	45.37	2.7	45.55	3.2	45.69	3.9	45.86	4.6	46.02	5.5	46.24	6.0	46.54	6.2	46.87
MILL_45	45	2.1	45.35	2.7	45.53	3.2	45.67	3.9	45.84	4.6	46.01	5.5	46.22	6.0	46.53	6.2	46.86
MILL_125	125	2.1	43.56	2.7	43.77	3.2	44.27	3.9	44.80	4.6	45.12	5.5	45.49	6.0	45.80	6.2	46.07
MILL_139	139	2.1	43.57	2.7	43.78	3.2	44.28	3.9	44.81	4.6	45.13	5.5	45.50	6.0	45.81	6.2	46.08
MILL_154	154	2.1	43.43	2.7	43.61	3.2	44.07	3.9	44.49	4.6	44.68	5.5	44.85	6.0	45.04	6.2	45.26
MILL_158	158	2.1	43.44	2.7	43.62	3.2	44.07	3.9	44.49	4.6	44.69	5.5	44.85	6.0	45.04	6.2	45.26
MILL_167	167	2.1	43.41	2.7	43.60	3.2	44.06	3.9	44.48	4.6	44.68	5.5	44.85	6.0	45.04	6.2	45.26
MILL_193	193	2.1	43.35	2.7	43.56	3.2	44.05	3.9	44.48	4.6	44.68	5.5	44.85	6.0	45.04	6.2	45.26

Node	Chainage	50% AEP		20% AEP		10% AEP		4% AEP		2% AEP		1% AEP		0.5% AEP		0.5% AEP+20% Q	
		Flow	W Level	Flow	W Level	Flow	W Level	Flow	W Level	Flow	W Level	Flow	W Level	Flow	W Level	Flow	W Level
	m	m^3/s	mAOD	m^3/s	mAOD	m^3/s	mAOD	m^3/s	mAOD	m^3/s	mAOD	m^3/s	mAOD	m^3/s	mAOD	m^3/s	mAOD
MILL_267	267	2.1	43.28	2.7	43.52	3.2	44.04	3.9	44.47	4.6	44.67	5.5	44.84	6.0	45.03	6.2	45.26
MILL_326	326	2.1	43.24	2.7	43.49	3.2	44.03	3.9	44.47	4.6	44.67	5.5	44.84	6.0	45.03	6.2	45.26
MILL_372	372	2.1	43.20	2.7	43.47	3.2	44.02	3.9	44.46	4.6	44.67	5.5	44.84	6.0	45.03	6.2	45.26
MILL_SEC15	522	2.1	43.04	3.0	43.38	9.0	43.72	19.6	44.06	28.6	44.35	34.9	44.61	38.4	44.90	40.1	45.18
MILL_SEC16	617	2.1	42.96	3.0	43.35	9.3	43.67	26.8	43.99	51.0	44.28	81.7	44.55	116.2	44.84	152.3	45.11
MILL_SEC17	642	2.1	42.92	3.5	43.31	9.1	43.65	24.9	43.97	48.0	44.25	77.7	44.50	111.9	44.78	147.4	45.04
MILL_SEC18	712	2.1	42.87	4.9	43.31	13.2	43.60	28.1	43.92	49.0	44.21	75.8	44.47	108.0	44.75	142.4	45.03
MILL_SEC19	749	2.1	42.84	5.2	43.24	17.7	43.52	38.2	43.86	63.8	44.16	94.7	44.42	131.7	44.71	171.4	44.99
MILL_SEC20	799	2.1	42.84	5.9	43.16	17.8	43.44	37.8	43.78	60.9	44.10	87.5	44.37	118.7	44.66	151.8	44.94
MILL_SEC21	889	3.9	42.79	7.0	43.08	10.9	43.32	16.1	43.62	21.0	43.90	26.5	44.14	32.4	44.39	38.4	44.63

Appendix C

Plans showing Indicative Extent of Inundation
and
Location of Channel Cross-Sections