Almondbank Flood Mitigation Scheme

Hydraulic Modelling and Option Assessment Report

August 2012

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Executive Summary

Almondbank is a town situated 5 miles northwest of Perth in Scotland and has two watercourses running through it: the River Almond and the East Pow Burn. Almondbank has been affected by a number of flood events, with the largest events recorded in January 1993 and September 1999. In September 2007 Mouchel was commissioned by Perth & Kinross Council to provide an assessment of the flood risk in Almondbank and to develop a flood mitigation scheme to protect the town from flooding.

A review of the previous reports by other consultants was undertaken as part of this study. In particular the hydrology for both the East Pow Burn and the River Almond was reviewed and assessed in detail in consultation with SEPA.

The major source of flooding has been assessed to be fluvial based on evidence from Perth & Kinross Council, residents and information from previous studies. There is some flood risk from surface water and a negligible flood risk from groundwater.

This report aims to address the risk from the fluvial flood risk only. Proposed solutions to mitigate surface water flood risk have been addressed in Mouchel's report "*Almondbank Surface Water Flooding Solutions*" completed in 2012. The known fluvial flooding mechanisms in the town have been a useful source of information used by Mouchel during the hydraulic model development and model verification. The hydraulic model replicates well flow paths and water levels recorded at the SEPA gauge located in the River Almond.

The combined one and two dimensional hydraulic modelling undertaken for this study has shown that the onset of flooding occurs in Almondbank during the 1 in 10 year flood event in the East Pow Burn and the 1 in 25 year flood event from the River Almond. The hydraulic model was built, verified and results were compared with anecdotal flooding evidence to ensure the model was accurately replicating the flooding mechanisms.

Supported by the hydraulic model, three flood mitigation solutions have been proposed by Mouchel to Perth & Kinross Council to protect the town from flooding up to the 1 in 200 year return period event. Solution 1 included flood defences along the two watercourses with two storage areas; Solution 2 incorporated flood defences with one storage area, a small diversion channel, and flood defences along the two watercourses; and Solution 3 incorporated flood defences and a single storage area.

Solution 3 was selected as the 'preferred solution'. In agreement with Perth & Kinross Council, the 200 year standard of protection was selected to provide a high level of flood protection in the town. This report recommends that Solution 3 is taken forward to detailed design and be incorporated into the Flood Order Submission.

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List of Abbreviations

AMAX	-	Annual Maximum Flow
CES	-	Conveyance Estimation System
DEFRA	-	Department for the Environment, Food and Rural Affairs
DTM	-	Digital Terrain Model (Ground Level Information)
EA	-	Environment Agency
FEH	-	Flood Estimation Handbook
FEHRR	-	Flood Estimation Handbook Rainfall Runoff Method
ISIS	-	One-Dimensional Hydraulic Modelling Software
MAFF	-	Ministry of Agriculture Fisheries and Food
mAOD	-	Metres Above Ordnance Datum
OS	-	Ordnance Survey
PKC	-	Perth & Kinross Council
POIs	-	Points of Interest, locations of inflows into the study area
Q_{med}	-	The Median Annual Flow
SAAR	-	Standard Annual Average Rainfall
SEPA	-	Scottish Environmental Protection Agency
SPP	-	Scottish Planning Policy
TuFLOW	-	Two-Dimensional Unsteady Hydraulic Modelling Software
$URBEXT_{2000}$	-	An FEH catchment descriptor, indicating the level of urban development

1 Introduction

1.1 Background Information

As part of Mouchel's study to develop a flood mitigation scheme for the town of Almondbank, it was necessary to accurately simulate the high flow events along the watercourses which flow through the town and the floodplain. The two watercourses included in this study were the River Almond and the East Pow Burn. The hydrological catchments included in the study were the River Almond Catchment, East Pow Burn Catchment, Gelly Burn Catchment and the Methven Loch Catchment (Methven Loch is not a watercourse but simply an additional FEH catchment area). The Perth Town Lade is a manmade concrete channel which passes through Almondbank. The lade has no natural upstream catchment area but acts as a drainage channel allowing water to flow away from the River Almond in high flow events. Figure 1 shows the location of these watercourses and points of inflow into the hydraulic model.

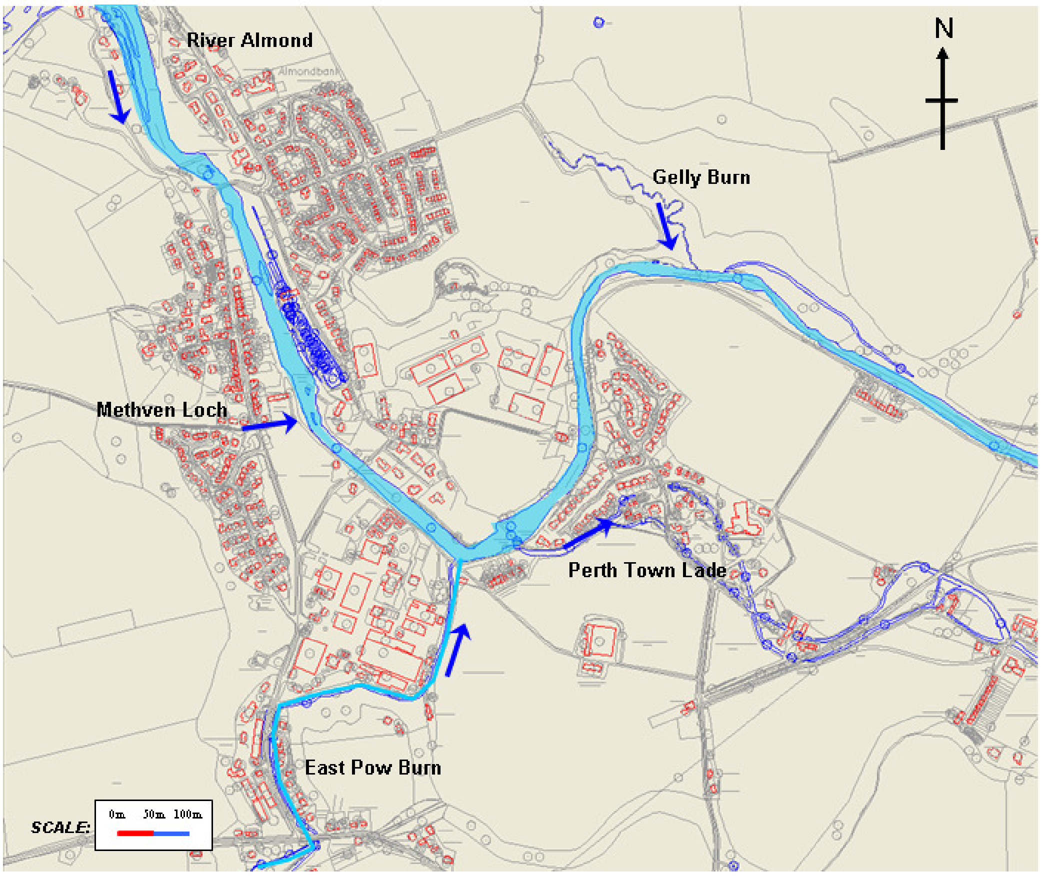


Figure 1 - Location of watercourses and Methven Loch catchment inflow

The previous hydraulic model built by Babtie Group was not available, therefore it was recommended by Mouchel to Perth & Kinross Council that a combined one and two dimensional hydraulic model of the watercourses and study area was required. In order to simulate high flow events in the watercourses which flow through Almondbank, this study needed to incorporate the following activities:

- A study of the catchment hydrology of the watercourses which flow through Almondbank and an accurate assessment of the flows for high flow events.

- A new one dimensional hydraulic river model, incorporating the two main watercourses (the East Pow Burn and the River Almond) was required to accurately assess the water levels in these watercourses.

- A new two dimensional hydraulic model linking with the one dimensional hydraulic model to simulate flow paths, depths and velocities of flood water, once overtopping of the river banks occurs.

- A verification of the combined one and two dimensional model using anecdotal information and recorded water levels of historic flood events to increase the confidence that the "base case" model accurately simulated high flow events in the watercourses and flooding within the town, before the model could be used for testing flood mitigation solutions.

A review of previous studies has been undertaken by Mouchel at the beginning of this study. The documents provided to Mouchel by Perth & Kinross Council for this review included:

- *"Report on Investigation of Flooding from River Almond"* produced by Babtie Group on behalf of Tayside Regional Council Water Services Department in February 1994.

- *"Benefits and Costs of Flood Defences Almondbank"* produced by Ove Arup and Partners on behalf of Perth & Kinross Council in March 1996.

- *"Almond Valley Village Final Report on Flood Risk Assessment"* produced by Babtie Group on behalf of Murdock Chartered Architects in February 1998.

- *"Pow Burn / Mill Lade Flooding"* produced by Babtie Group on behalf of Perth & Kinross Council in December 1998.

- *"Reappraisal of Flood Defences at Almondbank"* produced by Babtie Group on behalf of Perth & Kinross Council in March 2000.

- *"Almondbank Site Flood Appraisal"* produced by McLay Collier and Partners on behalf of the Ministry of Agriculture Fisheries and Food (MAFF) in April 2000.

- *"Almondbank Flood Prevention Scheme, Engineer's Report"* produced by Royal Haskoning on behalf of Perth & Kinross Council in March 2004.

- *"Almondbank Flood Management Options Report"* produced by Mouchel on behalf of Perth & Kinross Council in March 2006.

- *"Almond Valley Flood Risk Assessment"* produced by URS Corporation Limited on behalf of Perth & Kinross Council in March 2008.

- *"Almondbank Flood Mitigation Scheme Public Consultation Report"* undertaken by Mouchel on behalf of Perth & Kinross Council in March 2008.

- *"Geotechnical Factual Report"* completed by Geotechnics on behalf of Perth & Kinross Council in November 2010.

- *"Feasibility Assessment Low's Work Weir Repairs"* produced by Halcrow on behalf of Perth & Kinross Council in February 2011.

- *"Proposed Development Site at Almond Valley Village, Perth Flood Risk Assessment"* produced by Kaya Consulting in May 2011.

The key outputs from the review of these previous studies include:

- Some key locations prone to flooding in Almondbank have been identified in these reports.

- Hydrological calculations of the catchments have been undertaken in previous studies.

- The highest flow measured along the River Almond occurred in January 1993 and was estimated by SEPA *at the time* to be a 1 in 70 year return period event.

- The influence of the water levels in the River Tay on those in the River Almond for the study area is likely to be negligible.

- Some information is available in previous studies about water levels in the study watercourses.

- Some areas of erosion along the banks of the East Pow Burn and the River Almond were identified and should be considered in the flood mitigation design.

- The proposed changes to the Low's Work Weir were noted (and then incorporated into Mouchel's 'final outline design' solution).

1.2 Site Visits

Numerous site visits were undertaken by members of Mouchel's Project Team during December 2007, January 2008, April 2008, February 2009, February 2010 and February 2011 to:

- Consult and gather from the residents of the town historic anecdotal flood information.

- Consult with the residents regarding the proposed flood mitigation scheme.

- Understand better the flood mechanisms within Almondbank and identify locations prone to flooding within the town.

- Visually inspect infrastructure, particularly bridges, weirs and the College Mill Trout Farm.

- Assess better the practicalities, through on-site discussions with a contractor, of building a proposed flood mitigation solution within the town.

Appendix C presents a selection of photographs taken during the site visits and additional photographs are also in the following Sections in this report.

Further to the recent flood event of January 2011, an investigation has been undertaken by Mouchel on behalf of Perth & Kinross Council as reaches of the River Almond banks have been subject to accelerated erosion as a result of this event. "Emergency Works" including boulders lining the banks of the River Almond have been put in place to protect the banks from further erosion. These works have slightly altered the channel geometry in some sections of the River Almond.

2 Sources of Flooding

2.1 Fluvial Flood Risk

An initial assessment of flood risk, based on SEPA's indicative undefended flood outline, shows that parts of Almondbank are located within the SEPA 1 in 200 year return period flood outline presented in Figure 2.

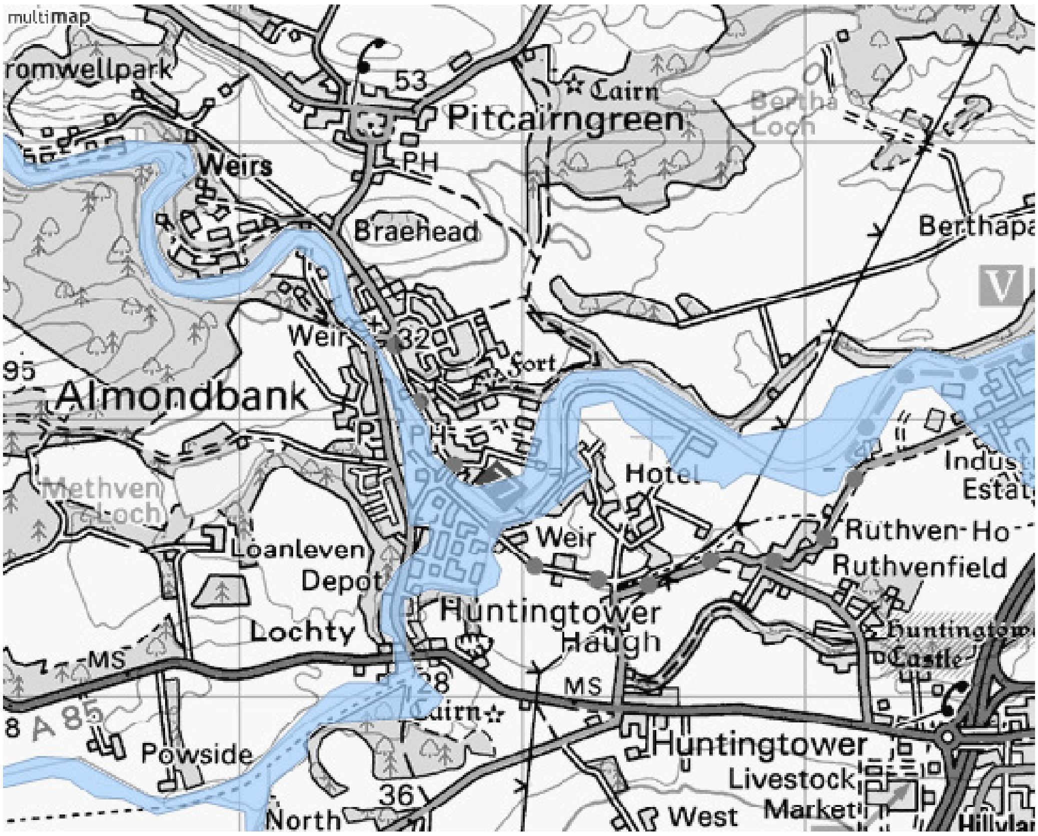


Figure 2 - SEPA's indicative 1 in 200 year undefended flood outline

The light blue area on Figure 2 represents the area that could be affected by fluvial flooding in a 1 in 200 year return period event if there were no flood defences (the only existing formal flood defences located in Almondbank is a flood wall approximately 100 metres in length close to Waterside Cottages), bridges or other structures. Based on the accuracy of the digital terrain model used to generate these maps, the water levels are stated by SEPA to have an accuracy of (+ / -) 0.7 – 1.0 metres[1].

The River Almond and the East Pow Burn have the largest upstream catchment areas of the four catchments included in this study. The River Almond and the East Pow Burn therefore have the largest flows conveyed by any of the watercourses flowing into the town. These two watercourses are also likely to be the largest contributors to any fluvial flooding within the town. Two smaller catchments were also considered in this study in

[1] The SEPA website provides more information about the SEPA flood maps and their accuracy http://www.sepa.org.uk/flooding/flood_risk_maps/view_the_map.aspx

agreement with Perth & Kinross Council, the Gelly Burn Catchment and Methven Loch. The contributing flows conveyed by these two catchments are small in comparison to the flows of the River Almond and East Pow Burn but have been included in this study to account for the whole catchment area upstream of the town. The hydrological assessment of the four catchments is presented in Sections 3 of this report. Figure 1 presents the locations of the River Almond, East Pow Burn, Gelly Burn and Methven Loch catchment inflow into the River Almond.

2.2 Previous Fluvial Flood Events

A review of previous flood events has been undertaken to support the promotion of this Almondbank Flood Mitigation Scheme. Table 1 outlines the key flood events that occurred in Almondbank together with a brief description of each event. The information was collected from Perth & Kinross Council, resident consultation and previous reports from various consultants.

Event	Description
January 1909	Approximately one square mile of land flooded in Almondbank. Extensive and widespread flooding occurred and was exacerbated by thawing snow fall.[2]
January 1993	This flood was extensive throughout Almondbank affecting in particular the College Mill Trout Farm, Vector Aerospace, Deer Park and Low's Work Cottages. The Black Bridge was washed away during this event. It seems that fast thawing of heavy snow and heavy rainfall contributed to this flood event.[3]
September 1999	This flood was on a similar scale to the January 1993 event and affected also in particular the College Mill Trout Farm, Vector Aerospace, Deer Park and Low's Work Cottages. The gauge data for this event shows that the peak flow was in the similar to the January 1993 event, but the event had a shorter duration.[4]
December 1999	Flooding from the East Pow Burn occurred at a similar magnitude to the September 1999 event. No gauge records were available on the East Pow Burn.[5]
January 2011	High flows along the River Almond, as a result of snow thaw, caused localised erosion along both banks of the River Almond. Flooding occurred on the East Pow Burn and affected Lochty Park and Vector Aerospace.[6]

Table 1 - Summary of recent flood events in Almondbank

Appendix A provides a collection of photographs as further evidence of the flooding history in the town, and the need for a flood mitigation solution to this on-going issue. The

[2] "Report on Investigation of Flooding from River Almond" produced by Babtie Group on behalf of Tayside Regional Council Water Services Department in February 1994.

[3] "Report on Investigation of Flooding from River Almond" produced by Babtie Group on behalf of Tayside Regional Council Water Services Department in February 1994.

[4] "Reappraisal of Flood Defences at Almondbank" produced by Babtie Group on behalf of Perth & Kinross Council in March 2000.

[5] "Reappraisal of Flood Defences at Almondbank" produced by Babtie Group on behalf of Perth & Kinross Council in March 2000.

[6] Photographs in January 2011, provided by Perth & Kinross Council in Appendix A of this report.

events listed in Table 1 and the supporting photographs of Appendix A are not exhaustive as other less severe flood events have also occurred in Almondbank.

2.3 Fluvial Flooding Mechanisms

Details of the flooding mechanisms have been collected from Perth & Kinross Council, local residents (including the public consultation of January 2008) and the previous studies listed in Section 1.1. The information has been summarised below and Appendix B provides a layout of Almondbank and of the key locations mentioned.

- Residents living along Main Street have reported flooding of their rear gardens from the River Almond.

- As water levels rise further in the River Almond, the playing field adjacent to the Bowling Green starts to flood. It was reported that when the playing field starts to flood the lower ponds of the College Mill Trout Farm begin to flood simultaneously.

- As water levels continue to rise in the River Almond, flood water has been reported by residents to flow from the playing field area and onto the Vector Aerospace site.

- Flood water has also been reported to come from the East Pow Burn and to flood the field at Huntingtowerfield Haugh (right bank of the East Pow Burn).

- Flood water at the confluence of the East Pow Burn and River Almond has been reported to affect the Low's Work Cottages and the property named Brockhill.

- Overland flooding has been reported to flow down Main Street from the East Pow Burn, starting near Lochty Park Road Bridge and flowing into the Vector Aerospace site and towards the playing field area.

Based on the anecdotal evidence and the complexity of the flooding mechanisms in Almondbank, in agreement with Perth & Kinross Council it was necessary to build a combined one and two dimensional (1D and 2D) hydraulic model to determine the flood mechanisms as accurately as possible and enable water levels to be accurately assessed when water overtops river banks and flows overland. The flooding mechanisms derived with the combined hydraulic model are presented in Section 4.

The actual flooding mechanisms summarised above have been used as a comparison with the flooding mechanisms produced by the hydraulic model to ensure accuracy of the model. Details are provided in Section 4.

2.4 Surface Water Flood Risk

Surface water flooding has been considered in detail in Mouchel's Report "*Almondbank Surface Water Flooding Solutions*" completed in 2012 on behalf of Perth & Kinross Council. Surface water flooding of up to a depth of 0.60 metre has been estimated for the 1 in 200 year pluvial event in Almondbank. The locations with the highest surface water flood depths are Vector Aerospace, Lower Main Street and the Bridgeton Road Bridge. Drainage solutions for the 1 in 30 year pluvial event have been proposed for these three locations. Where flood defences are proposed, effective drainage has been recommended to ensure surface water can still be effectively drained with flood defences in place in the future.

2.5 Groundwater Flood Risk

Flood risk from groundwater in Almondbank is considered to be small when compared to the fluvial flood risk posed to the town by the River Almond and East Pow Burn. Previous studies have stated that there has been no major aquifer with recorded groundwater levels in Almondbank. According to the "*Geotechnical Factual Report*" by Geotechnics, commissioned by Mouchel in 2010 on behalf of Perth & Kinross Council, groundwater levels were monitored via temporary boreholes between September 2010 and November 2010 and found to be between 1.75 metres and 3.08 metres below ground level at four locations in Almondbank.

2.6 Summary of Flood Risk

Based on the information collected and analysed the flood risk in Almondbank can be summarised as follows:

- Fluvial sources are the main source of flood risk and are the focus of this report.
- Surface water is also a source of flood risk and needs to be managed. Consideration needs to be given to surface water flooding in the town in conjunction with flood mitigation solutions.
- Groundwater has been considered as part of the geotechnical assessment and implementation of floodwalls or / and embankments, but groundwater flood risk is considered to be small compared to the fluvial flood risk.

3 Hydrological and Hydraulic Modelling

3.1 Data Collection

Before undertaking the hydrological and hydraulic modelling, it was necessary to obtain the most up to date available data to produce the most accurate hydraulic model possible and then derive the best representation of the flooding mechanisms within the town. The data collection included:

- A river cross section survey of the watercourses and hydraulic structures.
- A topographical survey of the floodplain and property flood threshold levels.
- Obtaining from SEPA any available hydrometric data.

3.1.1 Topographical Survey of the Watercourses

An existing topographical survey of the East Pow Burn, River Almond and surrounding areas had already been undertaken in April 2003 by DG Surveys on behalf of Royal Haskoning and Perth & Kinross Council.[7]

As this survey was five years old at the beginning of this study and could be inaccurate due to siltation or any movement in the river channels with time, a new topographical survey of watercourse cross sections and hydraulic structures was commissioned and completed by Mouchel in July 2008.

The cross sections were surveyed at regular intervals along the River Almond (27 cross sections) and the East Pow Burn (15 cross sections). All hydraulic structures (6 bridges, 3 weirs and 1 pipe bridge) within the study reaches were also included in this watercourse survey. The locations of the river cross sections and hydraulic structures surveyed are in Figure 3 and Figure 4 respectively.

[7] “Almondbank Flood Prevention Scheme, Engineer’s Report,” produced by Royal Haskoning on behalf of Perth & Kinross Council in March 2004.

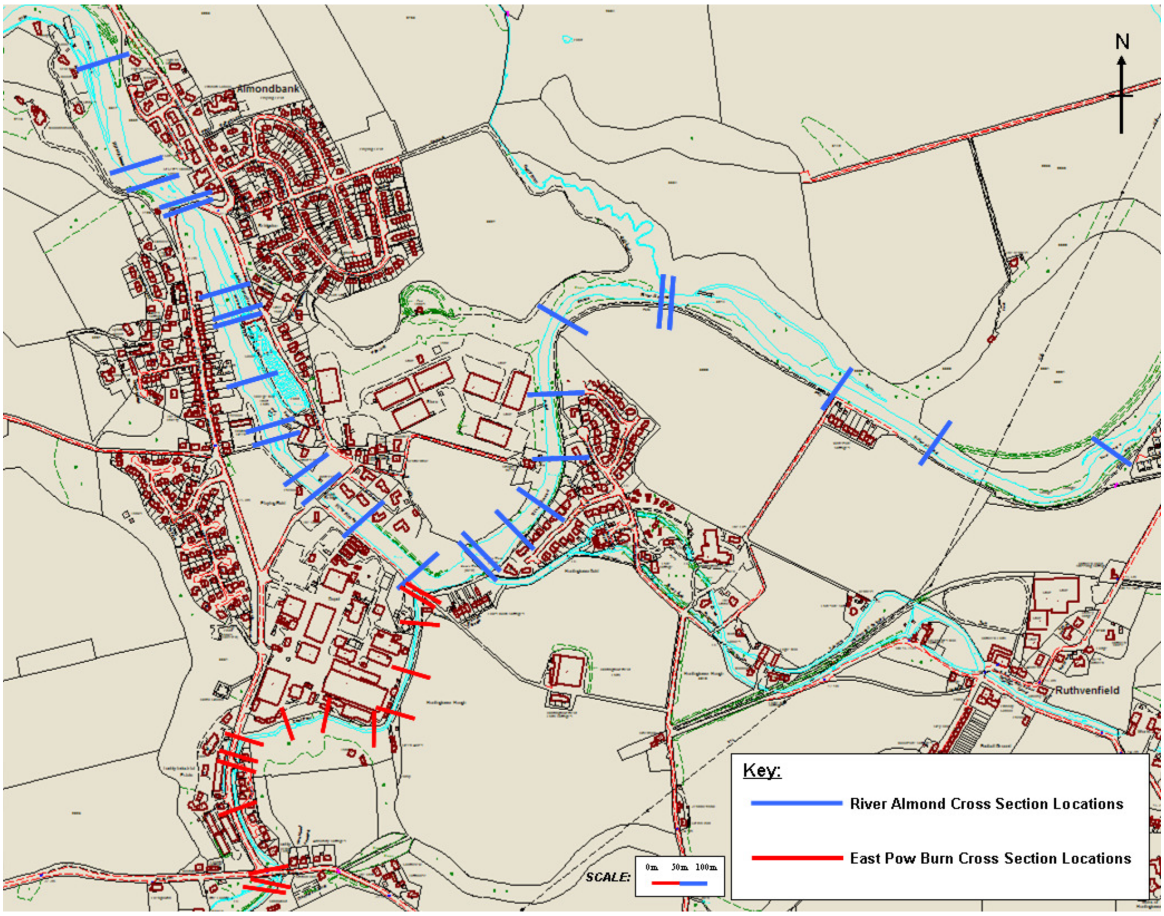


Figure 3 - Location of the river cross sections surveyed

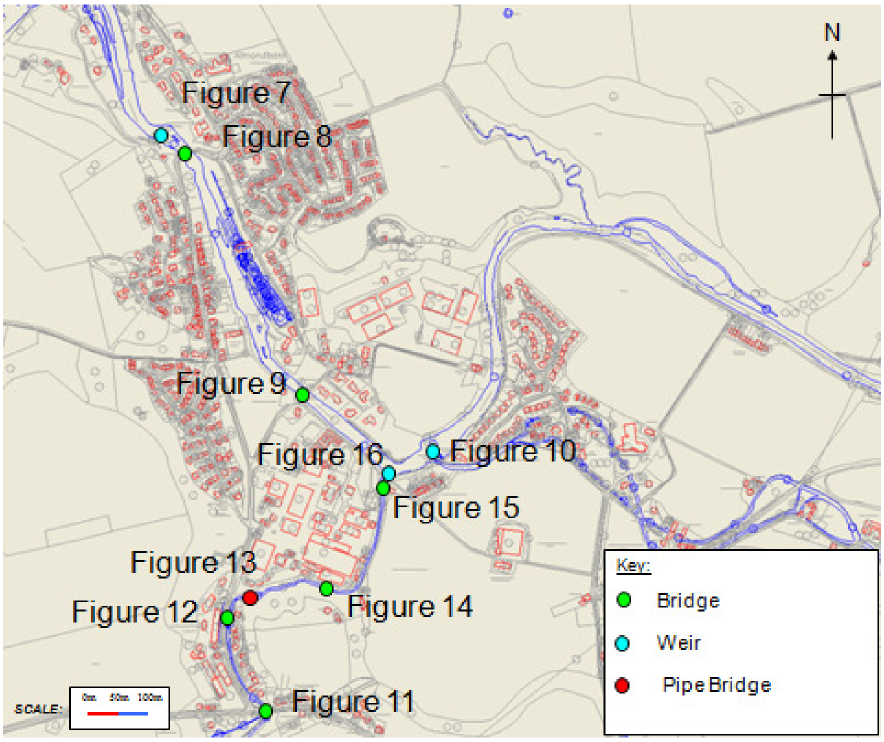


Figure 4 - Location of the hydraulic structures surveyed

Note : refer to the Figures mentioned in Figure 4 for more details

3.1.2 Topographical Survey of the Floodplain

An existing topographical survey of the East Pow Burn, River Almond and surrounding areas was undertaken in April 2003 by DG Surveys on behalf of Royal Haskoning and Perth & Kinross Council. The topographical survey was extended by Mouchel in July 2008 following the January 2008 public exhibition to enable a ground level assessment of the whole of the study area and to simulate flow paths and water levels across the floodplain.

Where the two surveys overlapped, the July 2008 topographical survey was used in preference as it was the most recent survey and therefore more confidence could be placed in it.

The extent of the two dimensional component of the hydraulic model (shown in Figure 5) was based on the combined topographical data of the April 2003 and January 2008 surveys.

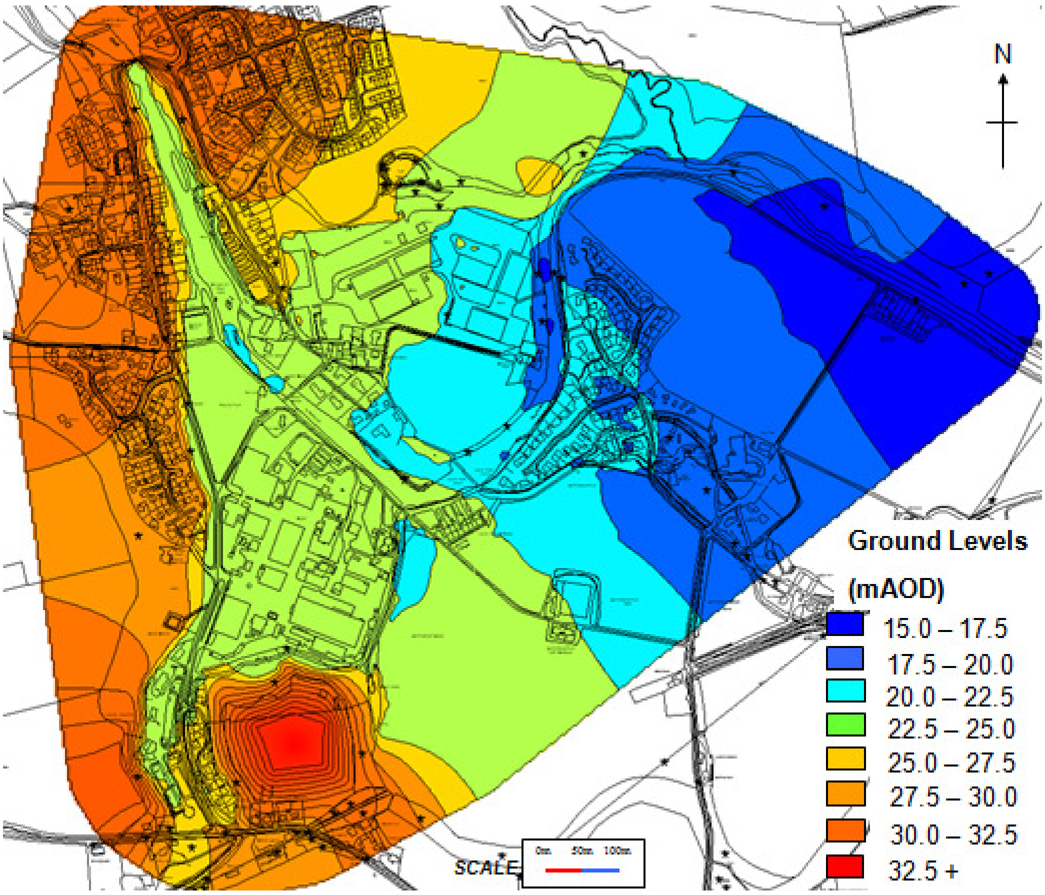


Figure 5 - Ground model of Almondbank used in the two dimensional component of the hydraulic model

3.1.3 Hydrometric Data

Data collected from SEPA included the following information from the river gauge (NFRA station number 15013 on the UK Hi-Flows website) located on the left bank of the River Almond immediately upstream of the River Almond Footbridge.

- Peak flows (Annual Maximum Flows – AMAX) measured at the river gauging station between 1973 and 2008. This information was used in the hydrological assessment described in Section 3.3.

- Flow and level data for the January 1993 and September 1999 flood events were used to verify the hydraulic model as detailed in Section 3.6.

- A rating curve for the River Almond gauge was provided by SEPA and also used to verify the hydraulic model as detailed in Section 3.6.

3.2 Hydraulic Model Development

The one dimensional component of the combined hydraulic model of the River Almond developed by Mouchel begins at Braehead Cottage and extends 2940 metres downstream along the River Almond to approximately 500 metres downstream of Waterside Cottages. The one dimensional component of the combined hydraulic model of the East Pow Burn begins 50 metres upstream of the A85 road bridge and extends downstream to its confluence with the River Almond. The extents of the one dimensional component of the model are shown in Figure 3.

The Gelly Burn is a small watercourse located approximately 200 metres upstream of Waterside Cottages. The Methven Loch is not a watercourse but a small catchment and surface water runs off from it into the River Almond close to the playing field. The locations of their inflow points have been identified using FEH CD ROM 2. Flows from the Gelly Burn and Methven Loch are significantly smaller than the flows within the River Almond and the East Pow Burn due to their much smaller catchment areas. The catchment areas and peak flows using the FEH rainfall runoff are presented in Table 6 and Table 9 respectively. No topographical surveys were carried out on the Gelly Burn and Methven Loch and their hydrological contributions have been modelled as inflows in the one dimensional component of the River Almond hydraulic model.

The one dimensional components of the hydraulic model extend 350 metres and 400 metres further upstream and downstream along the River Almond and 50 metres further upstream along the East Pow Burn than the two dimensional component (shown in Figure 5) of the hydraulic model because the main purpose of the two dimensional component of the model was to model flow paths and flood depths through Almondbank and therefore did not need to include reaches along the River Almond and East Pow Burn which extend outside of the town.

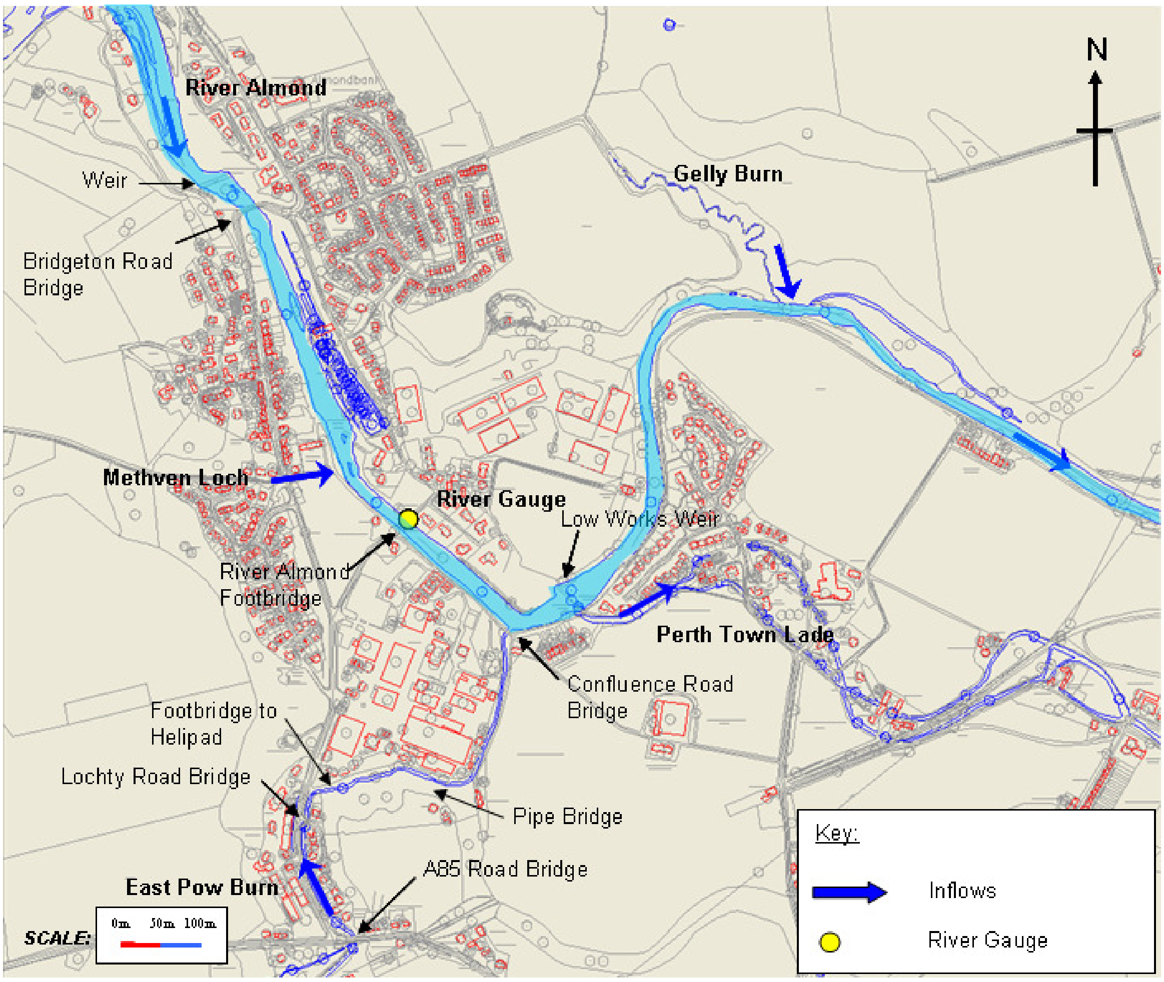


Figure 6 - Location of hydraulic structures and direct inflows to the model

The combined hydraulic model was developed using the two software packages ISIS and TuFLOW. ISIS provides the one dimensional element of the model and can be linked with TuFLOW which provides the two dimensional component simulating overland flows.

The one dimensional component of the model (ISIS) included the cross sections of the river channels, hydraulic structures and the hydrological model. The two dimensional component (TuFLOW) incorporated the ground levels of the floodplain and features such as the height of road centre lines, walls, embankments and bridge parapets, enabling the flooding mechanisms occurring in Almondbank to be simulated.

Once the hydraulic model accurately represented known flooding mechanisms and historical water levels, it was then used to test flood mitigation solutions and derive flood defence heights and volumes of storage for the flood mitigation scheme.

3.2.1 Hydraulic Structures across the River Almond

There are two bridges and two weirs on the River Almond within the extents of the combined hydraulic model. They are described from upstream to downstream and shown in the following figures.

The upstream weir feeding flow into the College Mill Trout Farm (Figure 7 and Table 2) has been modelled as a broad crested weir in the ISIS model. Due to the age of the weir, the elevation of the weir crest is irregular and has been set in the model to an elevation of 25.65mAOD (i.e. the average elevation across the weir crest).

Figure 7 - Weir structure adjacent to the inlet of the College Mill Trout Farm

The first bridge, located at the most upstream extent of the study area (Figure 8 and Table 2), on the River Almond, is the Bridgeton Road Bridge connecting Main Street on the right bank of the River Almond to College Mill Road on the left bank. The arch opening of the bridge is approximately 9m high from the river bed to the crown of the opening.

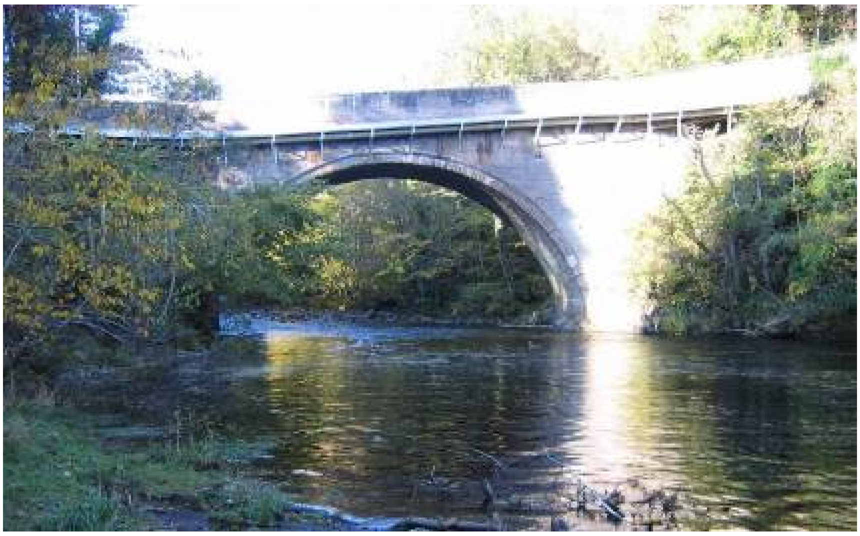


Figure 8 - Bridgeton Road Bridge across the River Almond (Main Street)

The second bridge in the hydraulic model on the River Almond is a steel footbridge erected temporarily to replace the masonry bridge (known as the Black Bridge) washed away during the January 1993 flood (Figure 9 and Table 2). The footbridge is a 31m long, single spanned bridge and supported on either sides of the River Almond. The underside of the footbridge has an average height of 3.2 m from the river bed.

Figure 9 - River Almond Footbridge at the location of the former Black Bridge

The Low's Work Weir is located downstream of the confluence of the East Pow Burn and the River Almond and acts as a hydraulic control structure to feed water into the Perth Town Lade. The weir structure is a 0.5m wide broad crested weir made up of rectangular quarried stones with an energy dissipation spillway downstream of the weir, made up of more rounded stones. The intake into the Perth Town Lade was not included in the hydraulic model, in agreement with Perth & Kinross Council, because at high flows this intake would normally be closed; this assumption is a conservative approach.

During the December 2007 site visit, it was noticed that a section of the weir structure was in a state of disrepair and that the weir was breached on the left side. The section of the weir still intact was overgrown with algae and plants, and was dry as the water flowed through the breached section during low flow conditions and would only flow over the intact section of the weir at higher flows (Figure 10 and Table 2).

It is proposed by Perth & Kinross Council to restore the Low's Work Weir (the proposed works are anticipated to take place in April 2012) to enable it to operate correctly. The weir is intended to be reinstated to its original condition and at a level of 20.25mAOD across the entire river channel. The restored weir has been incorporated in the 'final outline design' model.

Figure 10 – The Low's Work Weir in state of disrepair during the December 2007 site visit

3.2.2 Hydraulic Structures across the East Pow Burn

There are five bridges on the East Pow Burn within the extents of the hydraulic model. They are described from upstream to downstream and shown in the following figures.

The most upstream structure on the East Pow Burn is the A85 Road Bridge (Figure 11 and Table 2) which is a masonry arched bridge. This bridge is the upstream extent of the hydraulic model along the East Pow Burn.

Figure 11 - The A85 Road Bridge, over the East Pow Burn

The second structure is the Lochty Park Road Bridge at the entrance into Lochty Park consisting of three box culverts: one large culvert for normal flow conditions and two smaller culverts at a higher level for flood relief during high flow conditions (Figure 12 and Table 2). The three culverts appeared visually to be in good condition during the site visits. The river bank adjacent to the road bridge is protected by gabions.

Figure 12 – Lochty Park Road bridge on the East Pow Burn

The third structure on the East Pow Burn is a footbridge spanning across the Burn and which provides access from the Vector Aerospace site to a Helipad (Figure 13 and Table 2). This structure appeared visually to be in sound condition during the site visits.

Figure 13 – Bridge over the East Pow Burn providing access between Vector Aerospace and the Helipad

The fourth structure is a pipe bridge spanning across the East Pow Burn slightly further downstream from the Helipad footbridge (Figure 14 and Table 2). This structure appeared visually to be in sound condition during the site visits.

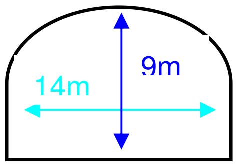
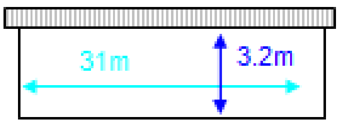
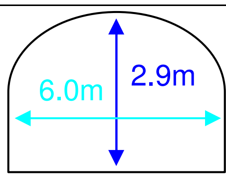
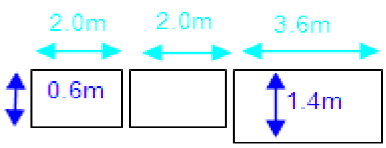
Figure 14 – Pipe bridge over the East Pow Burn

The fifth structure is the Confluence Road Bridge, a road bridge supported by steel beams, located at the confluence with the River Almond (Figure 15 and Table 2). The bridge appeared visually to be in a poor condition during the site visits with established vegetation growing from the side of the bridge. The steel beam supporting the bridge had rusted, the concrete deck was spalling and the edge protection was in a very poor state.

Figure 15 –Confluence Road Bridge located at the confluence of the East Pow Burn with the River Almond

3.2.3 Summary of the Hydraulic Structures incorporated the Hydraulic Model

All of the bridge and weir structures described above have a significant hydraulic impact on the water levels of these watercourses and therefore have been incorporated in the hydraulic model. A representation of these structures is outlined in Table 2.

Structure	Watercourse	Dimensions
College Mill Trout Farm Weir (Figure 7)	River Almond	
Bridgeton Road Bridge (Figure 8)	River Almond	
River Almond Footbridge (Figure 9)	River Almond	
Low's Work Weir (Figure 10)	River Almond	
A85 Road Bridge (Figure 11)	East Pow Burn	
Lochty Park Road Bridge (Figure 12)	East Pow Burn	

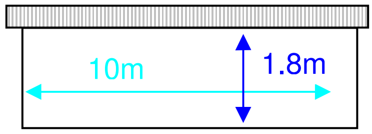
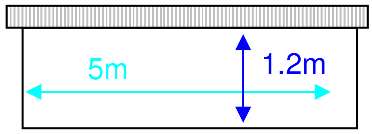
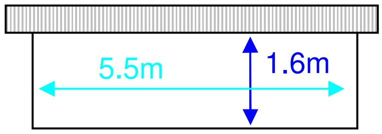
Structure	Watercourse	Dimensions
Bridge providing access to Helipad (Figure 13)	East Pow Burn	
Pipe Bridge (Figure 14)	East Pow Burn	
Confluence Road Bridge (Figure 15)	East Pow Burn	

Table 2 – Hydraulic structures across the River Almond and the East Pow Burn within the model extents

3.2.4 Manning's Roughness Values

To model the watercourses a parameter known as the Manning's roughness has been determined and applied to the river channels and the floodplains. Together with the slope and cross sectional area, this parameter affects water velocity and water levels in a river channel and defines the roughness of a river channel and floodplain. Its value depends on the surface material and is subject to seasonal variations (i.e. as vegetation grows in the summer and is reduced in the winter months). Manning's roughness values are often subjective but they fall within an acceptable upper and lower range for a given section of watercourse based on its physical characteristics.

The Manning's roughness values in the River Almond and the East Pow Burn were initially estimated using the CES (Conveyance Estimation System)[8]. This approach takes into account the river profile and provides estimated roughness values for the river bed and river sides. Based on this assessment a combined Manning's roughness value is assigned to the whole river cross section. The Manning's values are reasonably uniform along the respective study reaches of both the River Almond and the East Pow Burn.

During the December 2007 site visit, the flow in the River Almond was observed to be fast flowing and turbulent, hence most of the smallest bed particles are transported downstream. The reach of the River Almond in Almondbank is rocky, consisting of boulders ranging from approximately 0.3m to 1.5m in diameter, which characterises watercourses with turbulent flows and steep gradients (Figure 16).

[8] The CES is a method of estimating roughness values in the river channel, developed by HR Wallingford. The Conveyance Estimation System has been produced in response to the Environment Agency's vision for reducing uncertainties in the estimation of river flood levels, discharge capacities, velocities and extent of inundation and is widely used.

Figure 16 – Boulders of various sizes in the River Almond

Manning's values along the study reaches of the River Almond channel fell within a range of 0.031 and 0.049 with an average roughness of 0.039. A value of 0.040 was initially selected for the length of the River Almond channel downstream of the Bowling Green. A higher value of 0.055 was initially used for the length of the River Almond channel upstream of the Bowling Green as this river reach has more vegetation and irregularities in the river channel. A value of 0.08 was used for the River Almond islands, located adjacent to the College Mill Trout Farm, playing field and next to the Gelly Burn outfall. These localised islands constitute a build up of gravel, shingle and silt and act as obstructions to flow. The same value of 0.08 was also used for the banks of the River Almond in the hydraulic model.

The hydraulic model's flow / stage relationship at the location of the River Almond Footbridge has been compared with the SEPA's rating curve in Section 3.6. This comparison indicated that the initial estimate of Manning's roughness values estimated in the River Almond using the CES were too high and therefore have been reduced accordingly to provide a closer match with the SEPA's rating curve.

After reducing the Manning's roughness values, the hydraulic model's time / stage relationship was also compared with two large events recorded at the gauge (January 1993 and September 1999) which both occurred during autumn and winter months (when Manning's roughness values are slightly lower). The comparison showed that the hydraulic model produced a good match with the recorded data at the SEPA gauge for both events. Sensitivity runs were also undertaken as described in Section 3.7.

The Manning's values for the East Pow Burn were also estimated using the CES method. The estimated values for the main channel fell within a range of 0.026 and 0.042 with an average roughness of 0.034. Without gauge data or other reliable anecdotal flooding information available for the East Pow Burn to verify this model reach, the Manning's value of 0.042 was selected as a conservative approach. A value of 0.057 was selected for the banks of the East Pow Burn. Sensitivity runs were also undertaken as described in Section 3.7.

It is anticipated that seasonal variations would have only a small affect on roughness in the River Almond channel as there is little vegetation along most of the channel. As a conservative approach, the Manning's value applied to the banks of the River Almond (0.08 - Table 3) makes some allowance for some increase of vegetation as the value is within a range considered suitable for light brush and trees in summer (0.070 – 0.160).

For the East Pow Burn, the Manning's values applied in the model are also conservative as some allowance was made to account for seasonal variations.

It should be noted for both the River Almond and East Pow Burn that regular maintenance of vegetation in the river channels and along the banks (particularly in the spring / summer months) is anticipated to be undertaken by Perth & Kinross Council, hence keeping Manning's values reasonably uniform throughout the year. Table 3 summarises the values used in the final model of the 'do minimum' scenario (described in Section 3.4.2) and in the model of the 'final outline design' (described in Section 3.4.3) after the model verification (described in Section 3.6). At high flows, the Manning's values used in the hydraulic model tend to contribute further to the conservative approach used in the hydraulic model development and which is illustrated in Figure 21.

Watercourse	Manning's values used in the Hydraulic Model
River Almond main channel (bowling green to downstream extent)	0.035
River Almond main channel (bowling green to upstream extent)	0.045
River Almond Islands / bank tops (in the river cross section)	0.080
East Pow Burn main channel	0.042
East Pow Burn bank top (in the river cross section)	0.057

Table 3 – Final Manning's values used in the model for 'do minimum' and 'final outline design' scenario

The 'do nothing' model (Section 3.4.2) assumed that the main channel and bank vegetation has not been maintained, which results in an increase of Manning's values by 20% as presented in Table 4.

Watercourse	Manning's values used in the Hydraulic Model
River Almond main channel (bowling green to downstream extent)	0.042
River Almond main channel (bowling green to upstream extent)	0.054
River Almond Islands / bank tops (in the river cross section)	0.096
East Pow Burn main channel	0.050
East Pow Burn bank top (in the river cross section)	0.068

Table 4 – Final Manning's values used in the hydraulic model for the 'do nothing' scenario

For the floodplain (simulated with the two dimensional component of the model), standard Manning's values used are listed in Table 5 and were the same in the 'do minimum', 'do nothing' and the 'final outline design' models.

Category	Manning's values used in the Hydraulic Model
Grazed fields/ short grass	0.05
Kept fields (playing fields etc)	0.04
Covers Urban primarily, accounts for gardens, fences etc.	0.08
Scrubland	0.055
Trees/Wooded	0.1
Ploughed Field Area	0.045
Building locations	10.00

Table 5 – Manning's values used for the floodplain in the two dimensional component of the model

3.3 Hydrological Assessment

As part of the hydraulic modelling of the River Almond and the East Pow Burn, a hydrological assessment was conducted to determine the inflows into the hydraulic model. Within the study area four watercourses relevant to this study were identified from an Ordnance Survey (OS) map and the FEH (Flood Estimation Handbook) CD-ROM 2: The River Almond, the East Pow Burn, Methven Loch and the Gelly Burn. Figure 6 in the previous Section 3.2 shows the locations of these watercourses and of their inflows into the main watercourse.

3.3.1 FEH Catchment Descriptors and Points of Interest (POI)

Once the catchments had been identified, the FEH catchment descriptors were obtained using the FEH CD-ROM 2 for the Points of Interest (POI). The POIs are the upstream boundaries or direct inflows into the hydraulic model. The catchments boundaries from the FEH CD-ROM 2 were checked against the OS map to ensure accuracy. No alterations to the catchment boundaries were undertaken following this check.

The River Almond has a catchment area of 172km^2 just upstream of the stone arch road bridge along Main Street in Almondbank. The catchment is mainly rural, and starts from the mountains of Ben Chonzie, west of Almondbank. Based on the FEH CD-ROM 2 the standard average annual rainfall (SAAR) of this catchment is 1397mm (Table 5). This value is significantly higher than the other catchments of the study area due to the surrounding hills located in the upstream parts of the River Almond catchment. The other catchments are generally located in lower lying areas. The description of the River Almond catchment in the Hi-Flows UK website (upstream of the SEPA gauge 15013) is:

"the geology of the catchment is 66% metamorphic, 44% sandstone. Mountainous, often snowy in winter. Long, narrow, steeply sloping catchment. The land use is heather moor, rough grazing in upper parts with some cattle in the lower, and some forest cover (8%). Very flashy. Hydrometric Register BFI=0.54."

The East Pow Burn catchment, located to the southwest of Almondbank has an area of 48.4km^2. It is more urbanised than the River Almond catchment (urban/suburban extent $URBEXT_{2000}$ of 0.0131 compared to the $URBEXT_{2000}$ of 0.0002 for the River Almond catchment).

The other two tributaries of the River Almond at Almondbank are Methven Loch (catchment area of 0.6km²) and Gelly Burn (catchment area of 1.8km²). These two catchments are significantly smaller than the catchments of the River Almond and the East Pow Burn. The full sets of FEH catchment descriptors for each of the four catchments are in Appendix D.

A number of the key FEH catchment descriptors for each of the four catchments are in Table 6. The location and extents of the four catchments are presented in Figure 17.

Catchment	Location	Area (km^2)	SAAR (mm)	$URBEXT_{2000}$	% of total area
River Almond	306350, 726600	172.21	1397	0.0002	77.2%
East Pow Burn	306800, 725400	48.4	860	0.0131	21.7%
Methven Loch	306600, 725850	0.62	807	0.0101	0.3%
Gelly Burn	307300, 726200	1.85	839	0.004	0.8%

Table 6 – Key FEH catchment descriptors for the four POI

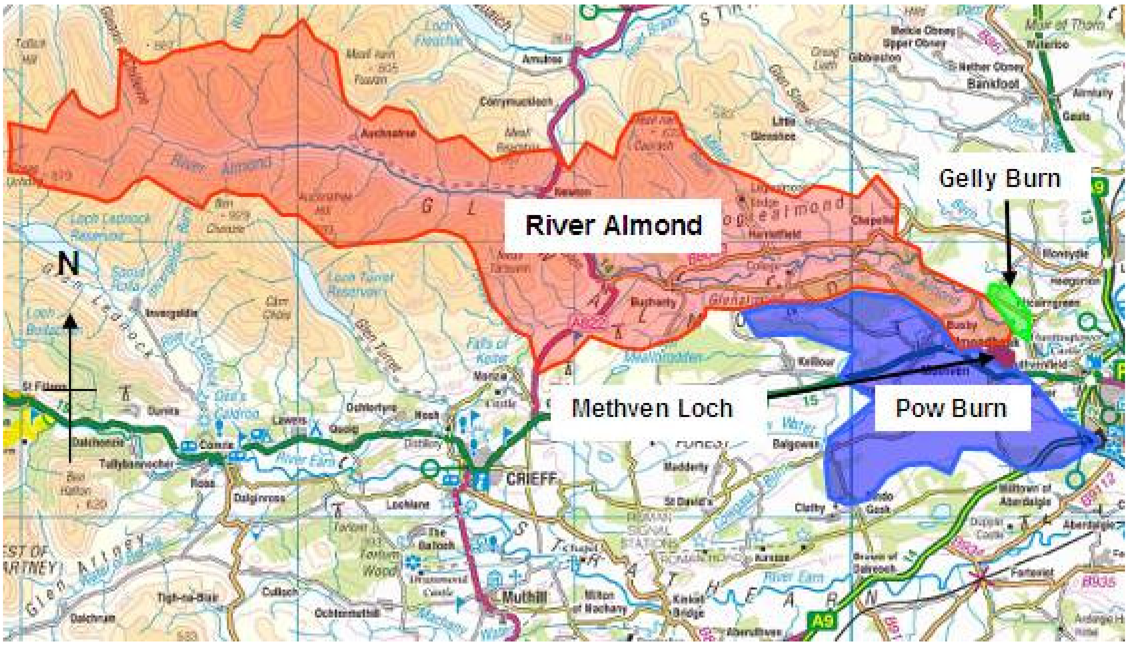


Figure 17 – Catchment boundaries of the four watercourses in Almondbank

3.3.2 Hydrometric Data available for this Study

Gauge data for the water levels in the River Almond in Almondbank is available from the SEPA gauging station (NRFA station reference: 15013) from February 1973 to present day. The description on the Hi-Flows-UK website states that this station is a velocity / area station with natural control. Between January 1955 and January 1973 the water level was monitored by reading daily from the gauge boards. The monitoring chart at the station began in 1973 and ended in 1990. From 1990 onwards a digital gauging station was installed to automatically measure and record water levels.

After the January 1993 flood a new steel bridge was built downstream of the gauging station to replace the old bridge washed away during that event. During the September

1999 event, the bank further upstream of the station was eroded and the water bypassed the gauging station and the bridge via parkland on the left bank.

Key information about the gauging station is presented in Table 7. There are no other gauging stations on any other of the watercourses within the study area. The highest flows for each water year are available from the Hi-Flows-UK website or on request from SEPA. The highest recorded flows are listed in Table 8.

Gauge	Location	NRFA reference	Rating Curve	Datum
Water Level Gauge	306350, 726600	15013	Yes	20.374 mAOD

Table 7 – Key information of the River Almond level gauge

The SEPA rating curve for this gauge was used to verify the hydraulic model as described in Section 3.6.2.

Ranking	Water Year	Annual maximum of flow (cumecs)
1	1993	233.2
2	1999	225.4
3	2006	208.0
4	2008	175.9
5	1988	165.9
6	2005	153.2
7	2004	148.4
8	2002	140.5
9	1974	139.7
10	1990	136.9

Table 8 – Highest flows recorded at the River Almond gauge

3.3.3 Estimations of the Return Period of the January 1993 Flood Event

Hydrological investigations of the River Almond have previously been conducted by other consultants. A range of return periods have been estimated for the January 1993 event, which is so far the highest gauged flow measured in the River Almond since 1973.

- Babtie Group estimated in 1994 that event to be a 1 in 45 year return period event[9].
- Royal Haskoning estimated in 2004 that event to be 1 in 100 year return period event, which was then revised to a 1 in 50 year event[10].

[9] Report on Investigation of Flooding from River Almond by Babtie Group - February 1994 on behalf of Perth & Kinross Council.

- SEPA initially assessed the event at the time to be a 1 in 100 year event and which was revised to a 1 in 70 year event in March 2000 (but the method used by SEPA to calculate these return periods is not known). This estimate was then later revised to a 1 in 40 year event using a single site FEH statistical analysis (only the gauge and catchment descriptors where used). The default pooling group analysis (using the gauge at the site and a range of other catchments) was also used by SEPA in their most recent estimate of a 1 in 43 year event.

- Mouchel estimated in 2009 the event to be a 1 in 50 year event based on a FEH statistical pooling group analysis.

In summary, as more gauged data becomes available with time the return period of the January 1993 event can be estimated more accurately.

3.3.4 Hydrological Analysis

As agreed with SEPA, two methods have been used by Mouchel for the hydrological analysis: the FEH rainfall runoff method and the FEH statistical method. Both of these methods are suitable for large to medium sized catchments and are widely used in Scotland. Another standard method of hydrological analysis is the revitalised flood hydrograph (ReFH) method which takes more into account of infiltration of surface water in a catchment, however this method is not approved by SEPA and was therefore not used in this study.

3.3.4.1 FEH Rainfall Runoff Method

The FEH rainfall runoff peak flows and hydrographs were generated using ISIS software and the FEH catchment descriptors from the FEH CD-ROM 2. The FEH rainfall runoff flows at each respective inflow to the hydraulic model for the return periods of interest are presented in Table 9.

Return period (years)	River Almond (m^3/s)	East Pow Burn (m^3/s)	Methven Loch (m^3/s)	Gelly Burn (m^3/s)
2 (Qmed)	79	15.0	0.30	0.91
10	134	25.5	0.50	1.56
25	165	31.7	0.60	1.95
50	190	36.9	0.70	2.30
75	204	39.7	0.80	2.40
100	215	42.0	0.84	2.58
200	245	47.9	0.97	2.95

Table 9 – Peak flows derived using FEH rainfall runoff method for the four catchments

The two smallest catchments (Metheven Loch and Gelly Burn catchments) contribute a very small percentage of the combined flows of the four catchments (approximately 1% – 2%). Therefore it was considered that the FEH rainfall runoff method provided sufficiently

[10] Almondbank Flood Prevention Scheme produced by Royal Haskoning in March 2004 on behalf of Perth & Kinross Council.

accurate estimate of the flows for these two catchments as a change in the flows of these small catchments would induce negligible changes to the combined flow. It was not necessary to apply the FEH statistical method for these two catchments.

The two largest catchments (River Almond and East Pow Burn catchments) contribute the vast majority of flows in Almondbank and their flows have also been assessed with the FEH statistical method. A comparison was carried out to determine the most suitable flow estimates for this flood mitigation scheme as small changes in flow values from these large catchments could have induced significant changes to the combined flow.

3.3.4.2 FEH Statistical Method

For the FEH statistical method, Q_{med}, (the median annual flood) was calculated from the AMAX series (annual maximum gauged flow) available at the River Almond gauge for the River Almond catchment. This was the most accurate technique for estimating Q_{med}, as the gauge has more than 14 years of data (at least 14 years of gauged data is required in the FEH statistical method to determine Q_{med} using a gauging station). Gauge data is available from 1973 to 2011 (38 years of data at the time of writing), therefore using the AMAX series to derive Q_{med} was suitable. It should be noted that the design flows in Table 14 were agreed with SEPA in 2009 when data was only available from 1973 to 2008 (35 years of data). The flows have not been revised to include the most recent 3 years of data.

The growth curves, which are used to factor up the Q_{med} value into a range of return period flows, are generated from a group of catchments which have hydrological similarities. The flows derived by both SEPA and Mouchel for the various return periods of interest are outlined in Table 10.

Return period (years)	SEPA Flow (m^3/s)	Mouchel Flow (m^3/s)	% Difference
2 (Qmed)	112	121.3	-7.3
10	174	182.3	-4.6
25	210	210.7	0.0
50	240	230.8	4.0
75	260	243.0	7.0
100	273	250.0	9.2
200	311	268.4	15.9

Table 10 – River Almond flows derived with the FEH statistical method by Mouchel and SEPA

As Mouchel did not have access to the detailed calculations undertaken by SEPA it was not possible to be conclusive regarding possible reasons of discrepancies between the two sets of results. However, the differences in the flows calculated by SEPA and Mouchel could be due to:

- The Qmed value calculated by SEPA differs from Mouchel's due to a different methodology. The Qmed can be calculated from the FEH catchment descriptors or from an estimate of the channel capacity in the absence of any other information. Alternatively if a gauge is present at the site (which is the case in the

River Almond) Qmed can be calculated directly from the recorded flows if more than 14 years of data is available (statistically this is considered in the FEH methodology to be a minimum data record in order to determine Qmed). This final approach was used by Mouchel to estimate the value of Qmed.

- The growth curves were different due to a slightly different pooling group used to determine the growth factors. A pooling group is a collection of similar catchments with flow records which is used to determine growth curves. However a range of catchments could be used for this analysis, and therefore a range of growth curves could be obtained.

Mouchel also calculated the FEH statistical flows for the East Pow Burn. The results are presented in Table 11. As no gauge is present on the East Pow Burn, a donor gauge from an appropriate catchment was used to determine the value of Qmed, and a pooling group analysis was carried out to determine growth curves. No comparative flow values were received from SEPA for the East Pow Burn at this stage.

Return period (years)	Mouchel Flow (m3/s)
2 (Qmed)	12.3
10	21.0
25	26.2
50	30.7
75	33.6
100	35.8
200	41.5

Table 11 - East Pow Burn flows derived using the FEH statistical method by Mouchel

3.3.4.3 Critical Storm Durations

Critical storm durations have been modelled in both the River Almond and the East Pow Burn. The critical storm duration is the duration of a storm in a particular catchment which will result in the highest peak flow in the response hydrograph producing maximum water levels and as a standard practice, it is a conservative approach. In reality, for any given storm the duration is unlikely to coincide exactly with the critical storm durations of each catchment and water levels would not be as high as the water levels which have been modelled. The critical storm duration for the River Almond Catchment and East Pow Burn catchment is 17.25 hours and 15.25 hours respectively.

For the Gelly Burn and Methven Loch catchments, the same storm duration as the River Almond catchment (17.25 hours) has been used to ensure their contributing peak flows coincide with the peak flows in the River Almond as a conservative approach.

3.3.4.4 Summary of the Hydrological Analysis

The flows for the 1 in 200 year flood return period event estimated with the FEH rainfall runoff and FEH statistical methods are summarised in Table 12. The high return period flows have been compared (particularly the 1 in 200 year event) as these flows were more critical to this study for the flood mitigation solutions described in Section 4.

Watercourse	Catchment area (km^2)	FEH Rainfall Runoff (m^3/s)	FEH Statistical (m^3/s)
River Almond	172.2	245	311 (SEPA), 268.4 (Mouchel)
East Pow Burn	48.4	47.9	41.5 (Mouchel)
Methven Loch	0.6	0.97	-
Gelly Burn	1.8	2.95	-

Table 12 – Flows of the 200 year design event for the four catchments in Almondbank

As expected, the River Almond is the watercourse generating the highest flow and the East Pow Burn has the second largest flow.

For the River Almond, the FEH statistical method produced a higher flow (268.4m^3/s Mouchel and 311 m^3/s SEPA) than the flows estimated with the FEH rainfall runoff. The flows calculated by Mouchel for the River Almond for the 1 in 200 year event is approximately 15% lower than the flow estimated by SEPA. As a conservative approach is preferred when assessing potential flood mitigation solutions, it was agreed with SEPA, that Mouchel would adopt and take forward SEPA's statistical flow estimates as shown in Table 10 for the River Almond.

For the East Pow Burn, the peak flows estimated using the FEH rainfall runoff method were higher than the those estimated by Mouchel using the FEH statistical method. SEPA had not undertaken a hydrological assessment of this catchment which could be used as a comparison. However after consultation with SEPA, and based on the comparison with flows estimated from other studies, the FEH rainfall runoff flows were considered to be overly conservative. Table 13 lists other peak flow estimates for the 1 in 200 year event for the East Pow Burn.

Institution and year	Estimated 1 in 200 year peak flow (cumecs) for the East Pow Burn.
Babtie Group in 1994	34
MAFF in 2000	34
URS in 2008	54.2, however 34 was adopted
Mouchel in 2009	41.5

Table 13 – Estimated 200 year peak flows from previous studies

All previous studies had adopted flows of 34 cumecs for their 1 in 200 year flows which are approximately 30% less than Mouchel's FEH rainfall runoff flow of 47.8 cumecs (Table 12) and approximately 20% less than Mouchel's FEH statistical flow of 41.5 cumecs (Table 13). It was therefore agreed in consultation with SEPA that the FEH statistical flows (using a donor catchment) estimated by Mouchel (Table 10) were considered appropriate as ''final design flows' for the East Pow Burn. The FEH statistical method flow was considered to be a more accurate estimate than the FEH rainfall runoff method but also a conservative estimate in comparison to previous studies.

As previously mentioned, the catchment areas of Methven Loch and Gelly Burn are relatively small and even large changes in flows would result in negligible difference to the combined flow in the River Almond. The flows calculated from the FEH rainfall runoff method were therefore considered to be a sufficiently accurate for these two catchments and were taken forward as 'final design flows'.

During the course of this study SEPA recommended a 'conservative yet pragmatic approach to the hydrology'. The full correspondence between SEPA and Mouchel regarding the hydrology for the watercourses and Mouchel's own hydrological calculations has been included in Appendix E. Table 14 is a summary of the catchment areas and the 'final design flows' for the River Almond and the East Pow Burn together with the two smaller catchments of Gelly Burn and Methven Loch. Also, the FEH winter storm profile has been used in all model scenarios for all return periods.

Catchment	Area (km^2)	Peak Flows (m^3/s)							
		1 in 10 years	1 in 25 years	1 in 50 years	1 in 75 years	1 in 100 years	1 in 200 years	1 in 200 years +cc	1 in 1000 years
River Almond	172.2	174	210	240	260	273	311	373	430
Gelly Burn	1.8	1.56	1.95	2.30	2.40	2.58	2.95	3.54	4.34
Methven Loch	0.6	0.50	0.60	0.70	0.80	0.84	0.97	1.20	1.36
East Pow Burn	48.4	21.0	26.2	30.7	33.6	35.8	41.5	49.8	58

Table 14 – Summary of the 'final design flows' used in the hydraulic modelling [11]

3.4 Hydraulic Model of the Scenarios

This Section describes the hydraulic models used for the 'do minimum', 'do nothing' and the 'final outline design' scenario. The 'do minimum' and 'do nothing' scenarios have been used to determine flood damages in the town to assess benefit cost ratios of the proposed flood mitigation scheme.

3.4.1 Hydraulic Model of the 'Do Minimum' Scenario

A 'do minimum' scenario was used to assess flood damages if the river channels and hydraulic structures remain in good condition over time and do not fall into disrepair. Damages were assessed based on a range of return period (10, 25, 50, 75, 100, 200 years) and the flows in Table 14. The following assumptions were made for this scenario:

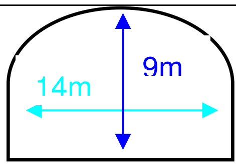
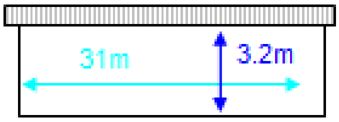
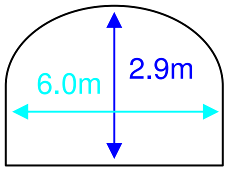
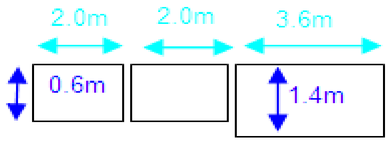
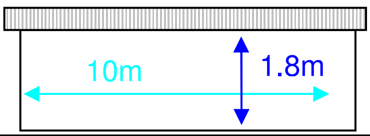
- The river banks are maintained at their current condition. The Manning's values used are presented in Table 3.

[11] 1000 year return period events have been estimated using the method recommended in the Environment Agency 'Updating of the Environment Agency FEH Guidelines' (2006) and is based on the following formula : Q Recommended = Q FEHRR x (Q100 FEH STAT / Q 100 FEH RR), where:

- Q1000 FEH RR is Q1000 peak flow estimated with the FEH Rainfall Runoff method
- Q100 FEH Stat is Q100 peak flow estimated with the FEH Statistical method
- Q100 FEH RR is Q100 peak flow estimated with the FEH Rainfall Runoff method.

- All the hydraulic structures of the study area kept at their current condition.
- No blockages occur at any of the bridges or culverts as it is anticipated that debris build up would be cleared promptly.
- The values of the critical storm durations used were: 17.25 hours the River Almond, 15.25 hours for the East Pow Burn, and 17.25 hours for both the Methven Loch and Gelly Burn catchments (peaks coinciding with the peak of the River Almond).
- The peak flows in Table 14 have been used.

A summary of the way the structures have been modelled in the 'do minimum' scenario is presented in Table 15. The flood extents of all 'do minimum' design events are in Appendix G and the modelled water levels are in Appendix I.

Structure	Watercourse	Dimensions	Alterations
College Mill Trout Farm Weir (Figure 7)	River Almond		No blockage or alteration
Bridgeton Road Bridge (Figure 8)	River Almond		No blockage or alteration
River Almond Footbridge (Figure 9)	River Almond		The footbridge has been left at its current height.
Low's Work Weir (Figure 10)	River Almond		At the time of writing, the weir is dilapidated. It has not been altered for the 'do minimum' scenario
A85 Road Bridge (Figure 11)	East Pow Burn		No blockage or alteration
Lochty Park Road Bridge (Figure 12)	East Pow Burn		No blockage has been inputted
Bridge providing access to Helipad (Figure 13)	East Pow Burn		No blockage has been inputted

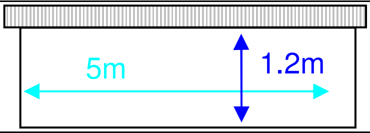
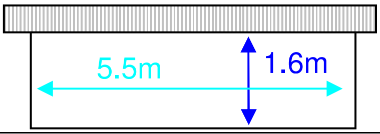
Pipe Bridge (Figure 14)	East Pow Burn		No blockage or alteration
Confluence Road Bridge (Figure 15)	East Pow Burn		No blockage or alteration

Table 15 – Alterations to the hydraulic structures for the 'do minimum' scenario

3.4.2 Hydraulic Model of the 'Do Nothing' Scenario

A 'do nothing' scenario was used to assess flood damages in the town if the river channels and hydraulic structures do not remain in good condition over time and therefore fall into disrepair. Damages were assessed using a range of return period (10, 25, 50, 75, 100, 200 years) and the flows in Table 14. The following assumptions were made for this scenario:

- The river channel and banks are not maintained and become overgrown in time. Roughness values have been increased by 20% from the 'do minimum' scenario to reflect this. The Manning's values used are presented in Table 4.

- Over time the hydraulic structures are not maintained and fall into disrepair, hence reduction of their openings for flow conveyance occurs. A structure blockage percentage was assigned to the structures in the hydraulic model to reduce the opening area of bridges and culverts. Blockages up to of 70% could occur at some bridges and culverts due to the build up of debris (Table 16). The blockages have been assumed to all take place simultaneously.

- The River Almond footbridge was erected as a temporary footbridge to replace the old masonry bridge (the former Black Bridge) washed away during the January 1993 flood event. Due to the previous history of a collapsed structure at this location and the steel bridge being a 'temporary' structure, the same scenario was assumed and was simulated by removing the bridge structure and replacing it with a river channel of reduced cross sectional area shown in Figure 16. Also, some erosion has been observed at this 'temporary' structure.

- On the East Pow Burn, the two primary structures that would have a major impact on the flow conveyance are the road bridge to Lochty Park and the road bridge at the confluence with the River Almond. As the openings of the bridge structures are not large, the risk of blockage is high. Therefore a 70% blockage of opening area was assigned to these two structures.

- The stone arch road bridge connecting Main Street and College Mill Road and the A85 stone arch road bridge on the East Pow Burn were both visually inspected during site visits and were assessed as being at low risk of failing, therefore the risk of blockage at the bridges due to a collapse is low. As a result, no blockage or collapse scenarios were modelled for these two structures.

- The current earth embankment located downstream of Deer park has broken down and no longer provides any flood protection to properties in the area.
- The values of the critical storm durations used were: 17.25 hours the River Almond, 15.25 hours for the East Pow Burn, and 17.25 hours for both the Methven Loch and Gelly Burn catchments (peaks coinciding with the peak of the River Almond).
- The peak flows in Table 14 have been used.

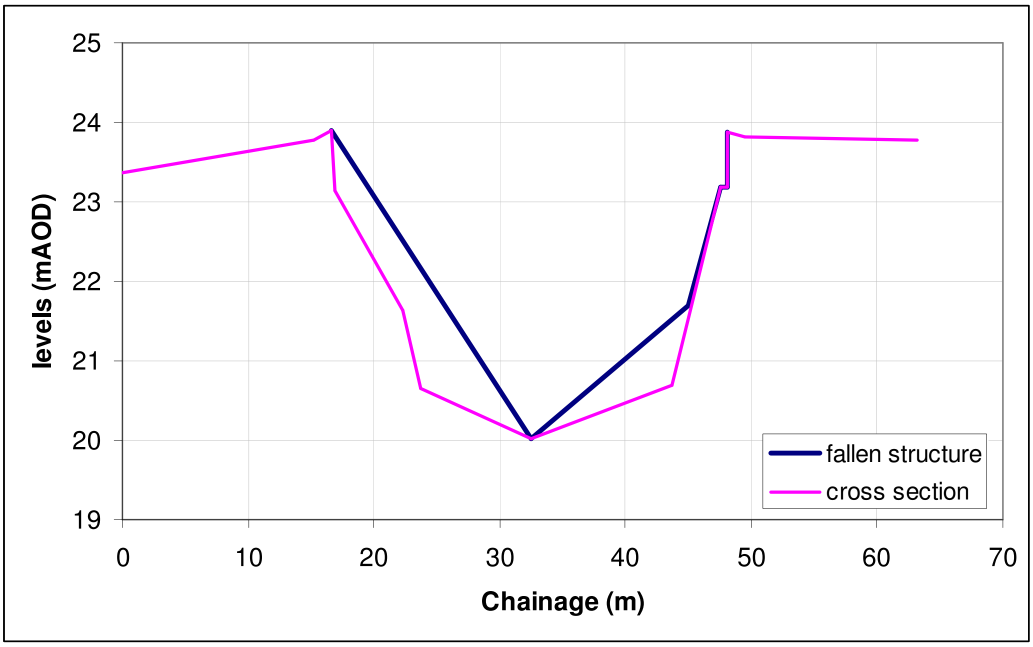
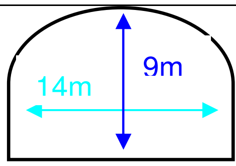


Figure 16 – River cross section before and after the fallen Black Bridge in the 'do nothing' scenario

A summary of the way the structures have been modelled in the 'do nothing' scenario is presented in Table 16. The flood extents of all 'do nothing' design events are in Appendix H and the modelled water levels are in Appendix I.

Structure	Watercourse	Dimensions	Alterations
College Mill Trout Farm Weir (Figure 7)	River Almond		No blockage has been inputted due to the large size of the opening.
Bridgeton Road Bridge (Figure 8)	River Almond		No change
River Almond Footbridge (Figure 9)	River Almond	Structure has been modelled as having collapsed and obstructing the river channel.	Fallen structure, (Figure 16)

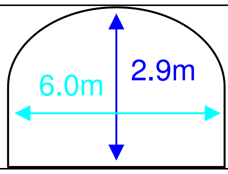
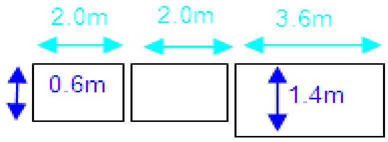
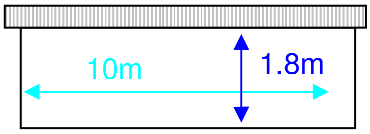
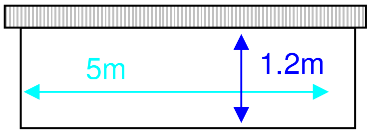
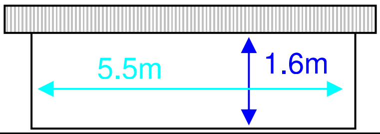
Low's Work Weir (Figure 10)	River Almond		At the time of writing, the weir is dilapidated. It has not been altered for the 'do nothing' scenario
A85 Road Bridge (Figure 11)	East Pow Burn		No blockage has been inputted due to the large opening.
Lochty Park Road Bridge (Figure 12)	East Pow Burn		No blockage has been inputted
Bridge providing access to Helipad (Figure 13)	East Pow Burn		No blockage has been inputted
Pipe Bridge (Figure 14)	East Pow Burn		70% blockage
Confluence Road Bridge (Figure 15)	East Pow Burn		70% blockage

Table 16 – Alterations to the hydraulic structures for the 'do nothing'' scenario

The flood damages based on flood depths of both the 'do nothing' and 'do minimum' scenarios can be estimated. If the costs calculated over time to build and maintain the scheme are less than the total flood damages, then the scheme is economically viable.

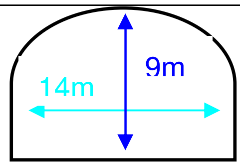
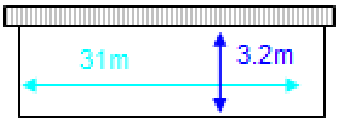
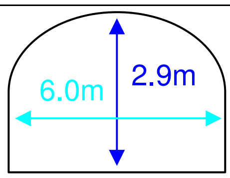
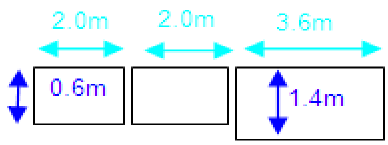
3.4.3 Hydraulic Model of the 'Final Outline Design'

'Final outline design' solutions have been assessed and are described in Section 4. It was agreed with Perth & Kinross Council that any 'final outline design' solution needed to incorporate the following requirements:

- The scheme was to be designed for the 1 in 200 year standard of protection using the flows in Table 14.
- The river banks are maintained at their current condition. The Manning's values used are presented in Table 3.
- None of the existing hydraulic structures are dilapidated.
- No blockages occur at any of the bridges or culverts as it is anticipated that debris build up would be cleared promptly.
- The existing River Almond Footbridge over the River Almond was to be raised by approximately 1 metre.

- The Low's Work Weir was modelled as being reinstated based on a recent report by Halcrow on the Low's Work Weir reinstatement as mentioned in Section 1.
- The culvert of the Lochty Park Road Bridge was to be removed and replaced with a new road bridge with a soffit raised by 0.75 metre.
- The Confluence Road Bridge at the East Pow Burn's confluence with the River Almond has been removed and replaced with a new bridge with a raised soffit level.
- The values of the critical storm durations used were: 17.25 hours the River Almond, 15.25 hours for the East Pow Burn, and 17.25 hours for both the Methven Loch and Gelly Burn catchments (coinciding with River Almond peak).
- Finally, the Perth Town Lade channel which has its intake at Low's Work Weir was not to be included in the hydraulic model because the sluice gate on the Perth Town Lade is usually closed during high flow events. This was considered to be conservative as the flows across the floodplain would not be intercepted.

A summary of the way the structures have been modelled in the 'final outline design' scenario is presented in Table 17. The flood extents of all events are in Appendix J as well as the modelled water levels.

Structure	Watercourse	Dimensions	Alterations
College Mill Trout Farm Weir (Figure 7)	River Almond		No blockage or alteration
Bridgeton Road Bridge (Figure 8)	River Almond		No blockage or alteration
River Almond Footbridge (Figure 9)	River Almond		The footbridge is raised by approximately 1m
Low's Work Weir (Figure 10)	River Almond		The weir has been assumed to be reinstated as part of any proposed solutions.
A85 Road Bridge (Figure 11)	East Pow Burn		No blockage or alteration
Lochty Park Road Bridge (Figure 12)	East Pow Burn		No blockage has been inputted

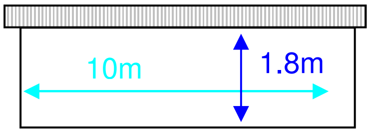
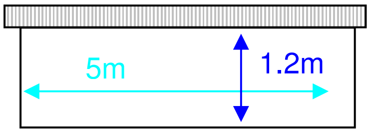
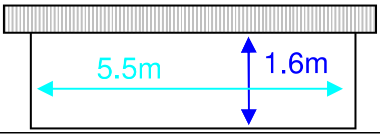
Bridge providing access to Helipad (Figure 13)	East Pow Burn		No blockage has been inputted
Pipe Bridge (Figure 14)	East Pow Burn		No blockage or alteration
Confluence Road Bridge (Figure 15)	East Pow Burn		The road bridge is to be raised.

Table 17 – Alterations to the hydraulic structures for the 'final outline design' scenario

3.5 Downstream Boundary of the Hydraulic Model

In the absence of any level data at the downstream end of the hydraulic model, the downstream boundary has been based upon a normal depth curve derived from the gradient and cross sections at the downstream extent of the model.

A sensitivity analysis was undertaken on the level of the downstream boundary (Section 3.7) to assess potential effects on the upstream water levels. Results show local variations at the downstream boundary but no propagation in the study area upstream.

The highest water levels recorded at the River Tay were checked from previous studies to assess whether their potential influence on water levels along the River Almond in the study area. Based on the 1 in 500 year level in the River Tay estimated to be 9.06 mAOD, the influence of the River Tay on levels upstream was considered negligible.[12]

3.6 Verification of the Hydraulic Model

A range of techniques can be employed to verify a hydraulic model depending on the data available. In this study Mouchel have used a number of techniques to ensure that the model represented accurately the flooding in the town. The 'do minimum' hydraulic model was used for the verification. These techniques include:

- Verifying the model with the two largest gauged historical events (January 1993 and September 1999).
- Verifying the hydraulic model with the SEPA rating curve available at the gauge.
- Comparing for the January 1993 event the known flood mechanisms and flood outlines based on anecdotal evidence with the flood mechanisms and flood outline produced with the hydraulic model.

[12] Report on Investigation of Flooding from River Almond Perth Flood Study by Babtie in Feb. 1994 for Perth & Kinross Council.

- Verifying the modelled flood outline by a comparison with the SEPA flood outline.
- Verifying the model by comparing Mouchel's water levels with water levels from previous studies.

3.6.1 Verification Events

The January 1993 and September 1999 events were used as verification events as both events resulted in out of bank flooding of the town. The water levels recorded at the SEPA's gauge on the River Almond were compared with model results. For both events, the modelled water levels compared favourably with the historical levels recorded at the gauge as illustrated in Figure 18 and Figure 19.

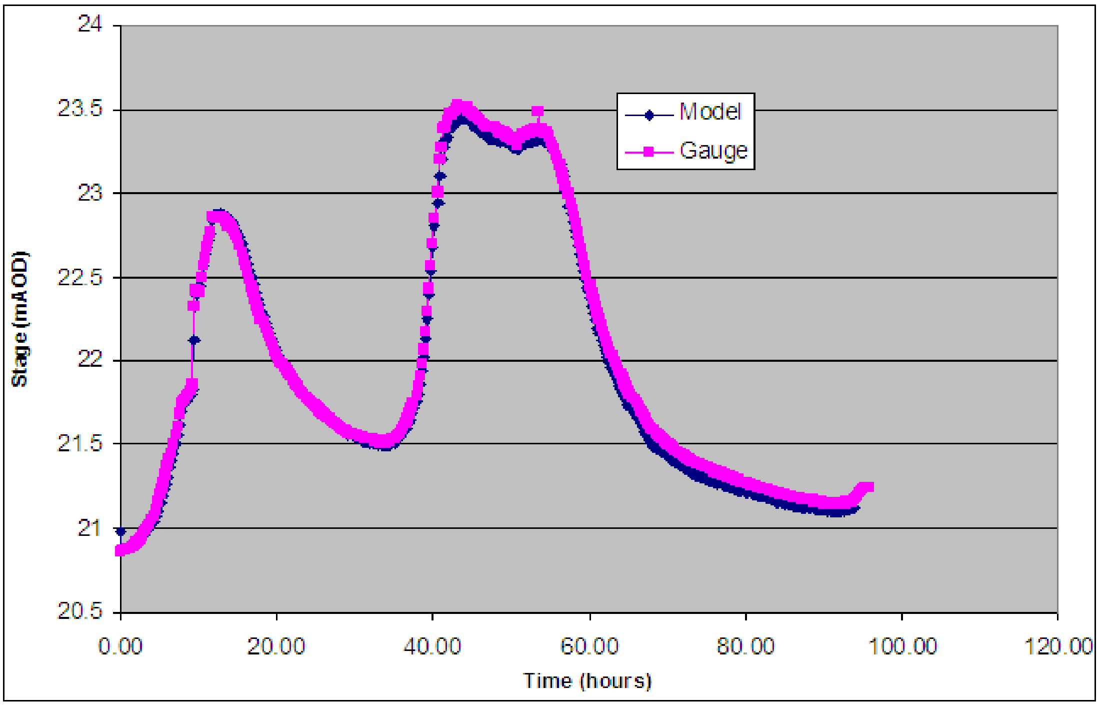


Figure 18 - Comparison of modelled and historical water levels at Almond Gauge for January 1993 event

The maximum and minimum differences in water levels for the January 1993 event were 0.06 and -0.20 metres respectively.

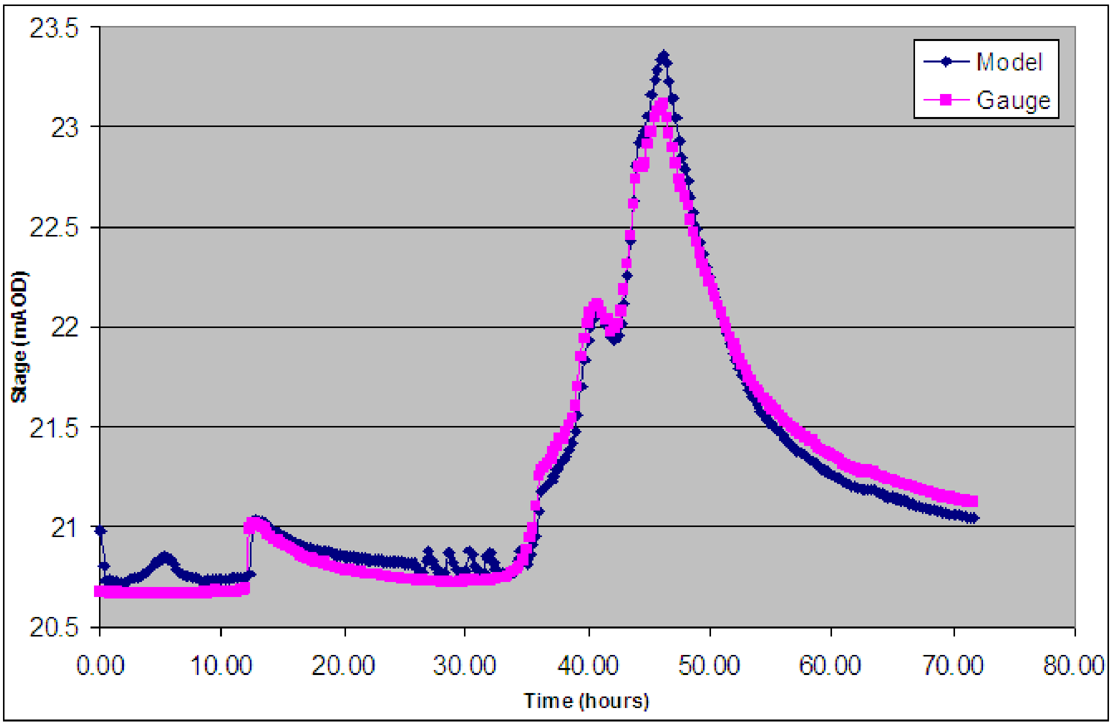


Figure 19 – Comparison of modelled and historical water levels at Almond Gauge for September 1999 event

The maximum and minimum differences in water levels for the September 1999 event were 0.27 and -0.23 metres respectively.

The modelled water levels were slightly lower than those recorded during the January 1993 event and slightly higher for the September 1999 event but were no greater or less than 0.27 metre from the recorded levels for either of the two flood events (i.e.: a percentage difference in water level of approximately 7.8%). Therefore, the hydraulic model simulated the recorded levels at the gauge within an acceptable margin of error.

However, during the January 1993 flood event, the footbridge on the River Almond collapsed and obstructed the flows, resulting in a localised increase in water levels. Figure 20 is a photograph provided by Perth & Kinross Council of the bridge during the January 1993 event. This obstruction to the flows is likely to contribute to the slight under prediction (approximately 200mm) by the hydraulic model of the peak water level for that event.

The flood outlines generated for these two verification events are in Appendix F.

Figure 20 – Photograph of the collapsed footbridge on the River Almond during January 1993 event[13]

3.6.2 Rating Curve of the SEPA Gauging Station

As mentioned in Section 3.3.2, the only river gauging station within the study reach is located upstream of the River Almond Footbridge on the River Almond, Part of the verification of the model, a comparison was undertaken of the modelled results and the SEPA's rating curve (derived by SEPA from historical gauging at the Almond gauge, including the January 1993 and September 1999 events).

The gauge begins to be by-passed at high flows as flood water leaves the River Almond and flows overland to the playing fields on the opposite bank resulting very likely in the rating curve slightly underestimating the water levels at high flows. The comparison between the SEPA's curve and the one generated with the hydraulic model at the same location is provided in Figure 21.

[13] Photograph provided by SEPA.

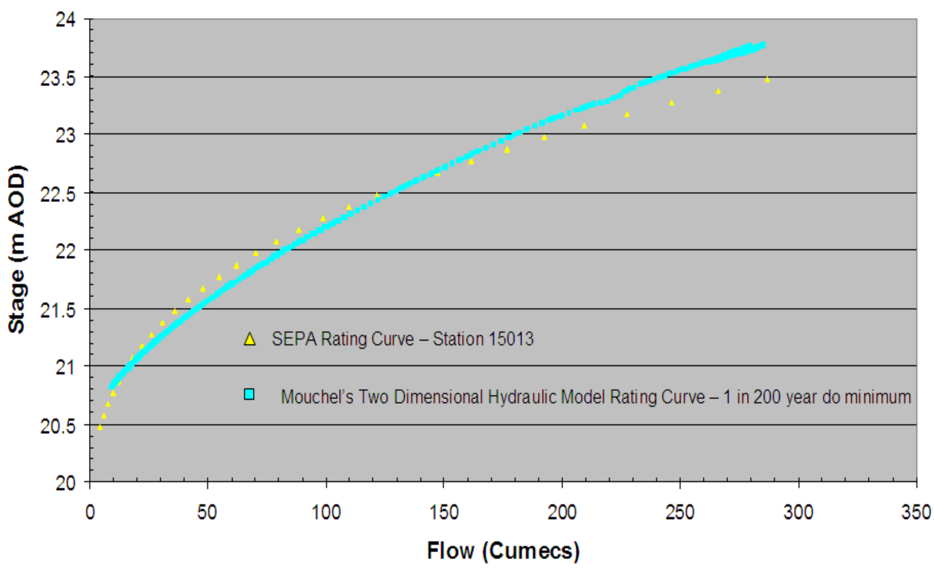


Figure 21 – Comparison of the two-dimensional hydraulic model results and with the SEPA rating curve.[14]

To achieve a close match, the roughness values in the one dimensional component of the model have been adjusted (Table 3). The final Manning's values used were within a range which is realistic based on the physical characteristics of the river channels.

As the adjusted roughness values provided a good match with the SEPA's rating curve at the gauge, the same values were then applied upstream as far as the Bowling Green and also in the downstream reach of the model as the physical characteristics of the river channels were considered to be similar.

The highest water level from Mouchel's hydraulic model for the 1 in 200 year event differs from the SEPA rating curve by approximately -300mm (7.9 %). For high flow values, water levels calculated by the model tended to be conservative when compared to the SEPA rating curve.

3.6.3 Historical Flood Mechanisms used in Model Verification

The known flooding mechanisms have been described in Section 2. To verify further the model, checks have been carried out between the model results and the flooding mechanisms reported by Perth & Kinross Council and local residents for the January 1993 event. The locations reported to have been flooded are described below and shown on Figure 22.

1) There have been reports by residents of the River Almond flood water reaching the lower extents of back gardens of some of the properties along Main Street.

2) As river levels start to rise, flooding begins in the playing field adjacent to the Bowling Green.

[14] The equation of the SEPA rating curve is Q = 4.812*(H + 0.8690) ^2.966 where Q is the flow (m3/s), H is the water depth above bed level (m), and the datum is 20.374 mAOD.

3) The College Mill Trout Farm is reported to have been flooded (but flooding extents are not clear).

4) As river levels continue to rise, flood water was reported to flow from the playing field area and onto the Vector Aerospace site.

5) Flooding has been reported from the East Pow Burn: as water levels rise, the field at Huntingtowerfield Haugh (on the right bank of the Burn) has been flooded.

6) Flooding at the confluence of the East Pow Burn and River Almond has been observed in the past and flood water affected some of the Low's Work Cottages and also the property named Brockhill.

7) Flooding has been observed at Lochty Park and at the Lochty Park Road Bridge.

Figure 22 presents the maximum flood outline simulated with the hydraulic model for the January 1993 event using the roughness values in Table 3 and Table 5 and historical recorded levels at the SEPA gauge. The flooding mechanisms produced with the hydraulic model matched the anecdotal information above, hence providing a good verification of the hydraulic model and confidence in the results of the hydraulic model.

Although the hydraulic model shows flooding at the expected locations, other locations are also prone to flooding, but because of the lack of further anecdotal records, flooding in other locations simulated with the hydraulic model could not be confirmed.

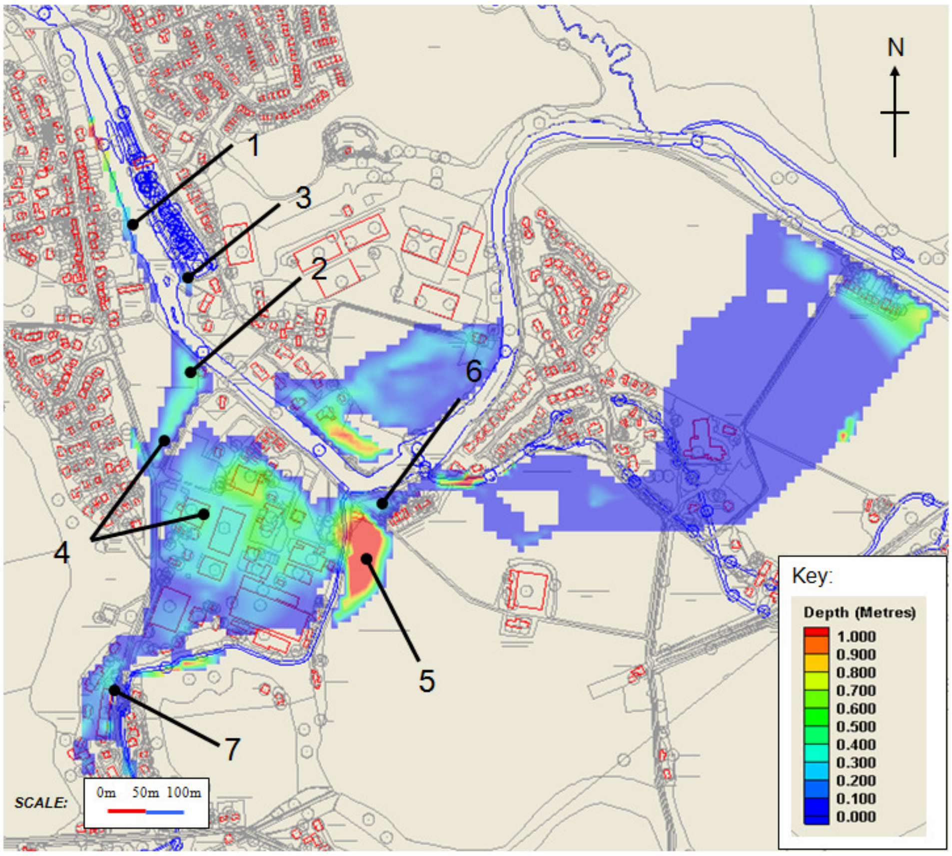


Figure 22 – Modelled flooding mechanisms in Almondbank for the January 1993 flood event

3.6.4 Flood Extents from SEPA

As an additional way of model verification, the flood outline generated with the model for the 1 in 200 year event has been compared to the SEPA flood extents for the same design event as illustrated in Figure 23. SEPA's and Mouchel's flood extents can be compared as they have both been modelled as an undefended scenario (SEPA have taken into account a flood defence wall approximately 100 metres in length behind Waterside Cottages, but the rest of the town has been modelled as undefended).

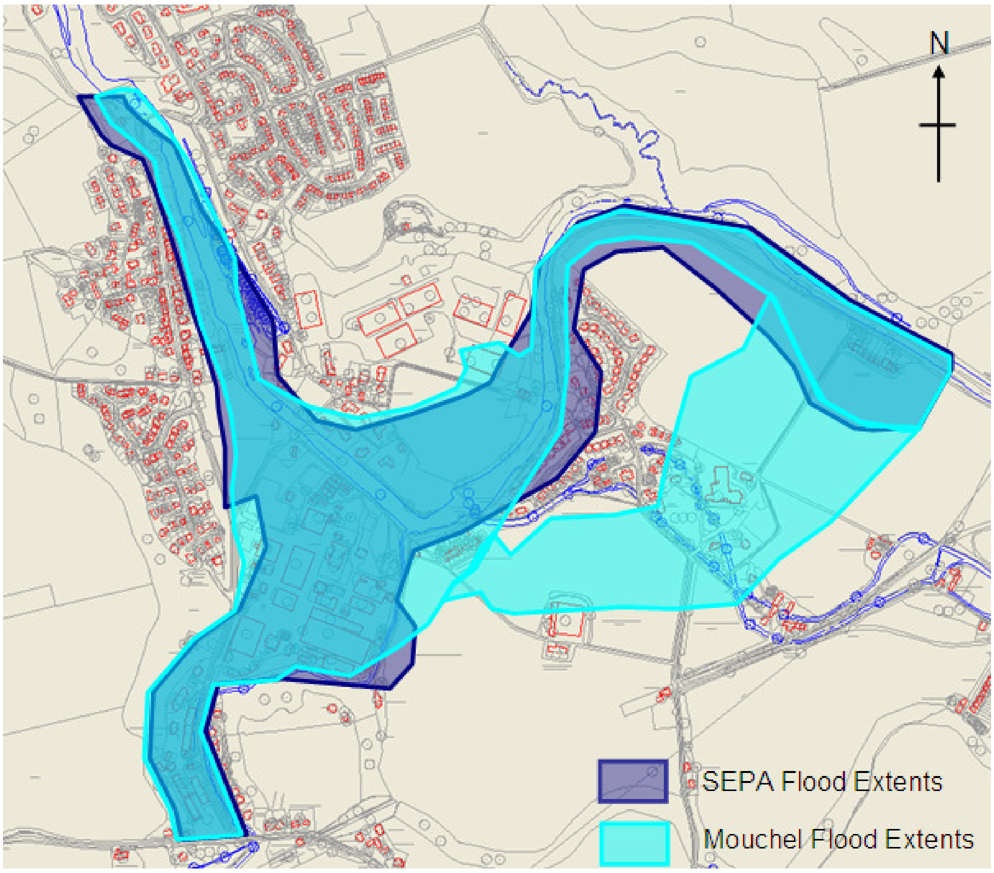


Figure 23 – Comparison of the SEPA and Mouchel undefended 1 in 200 year flood outlines

The two flood outlines were similar, however, the flood outline produced by Mouchel was a more accurate representation of event than the strategic SEPA's outline due to the enhanced accuracy of the ground levels and hydrological and hydraulic models used by Mouchel in this study. Differences included the following:

- The Mouchel's flood outline extended further towards the south-east of the town than the outline produced by SEPA.
- The SEPA's flood outline has a greater extent of the College Mill Trout Farm.
- The SEPA's flood outline has a greater extent at the Almond Grove Estate.

3.6.5 Other Consultant's Studies used in the Verification of the Hydraulic Model

3.6.5.1 Babtie Group

The results from the hydraulic model were compared with the water levels of the flood risk assessment report completed by Babtie Group in February 1998 which was based on a calibrated hydraulic model (using the January 1993 event). As limited information was known about the details of Babtie's hydraulic model, a simple check was undertaken. The Babtie Group's report states that *"The mathematical model "Floodtide" developed in-house by Babtie Group was used to model the River Almond and the resultant floodplain inundation. Further calibration work was undertaken to calibrate against observed water levels for the January 1993 flood event using the refined model arrangement. The model calibration was also improved upstream of Almond Weir as additional peak water level information was made available to us for the January 1993 flood event at the College Mill Trout Farm and the Mill Lade intake which were both inundated."*

Table 18 outlines the results of the comparison along the River Almond and Figure 24 shows the location of the four river cross sections where water levels have been compared.

	1 in 100 (years)		1 in 200 (years)	
	Babtie	Mouchel	Babtie	Mouchel
Flow (m^3/s)	280	273	335	311
Water level (mAOD) at cross section 1	24.89	25.37	25.21	25.57
Water level (mAOD) at cross section 2	23.18	23.32	23.40	23.40
Water level (mAOD) at cross section 3	19.20	19.33	19.55	19.55
Water level (mAOD) at cross section 4	14.80	15.05	15.03	15.29

Table 18 – Mouchel and Babtie Group's modelled water levels (mAOD) at four locations of the River Almond

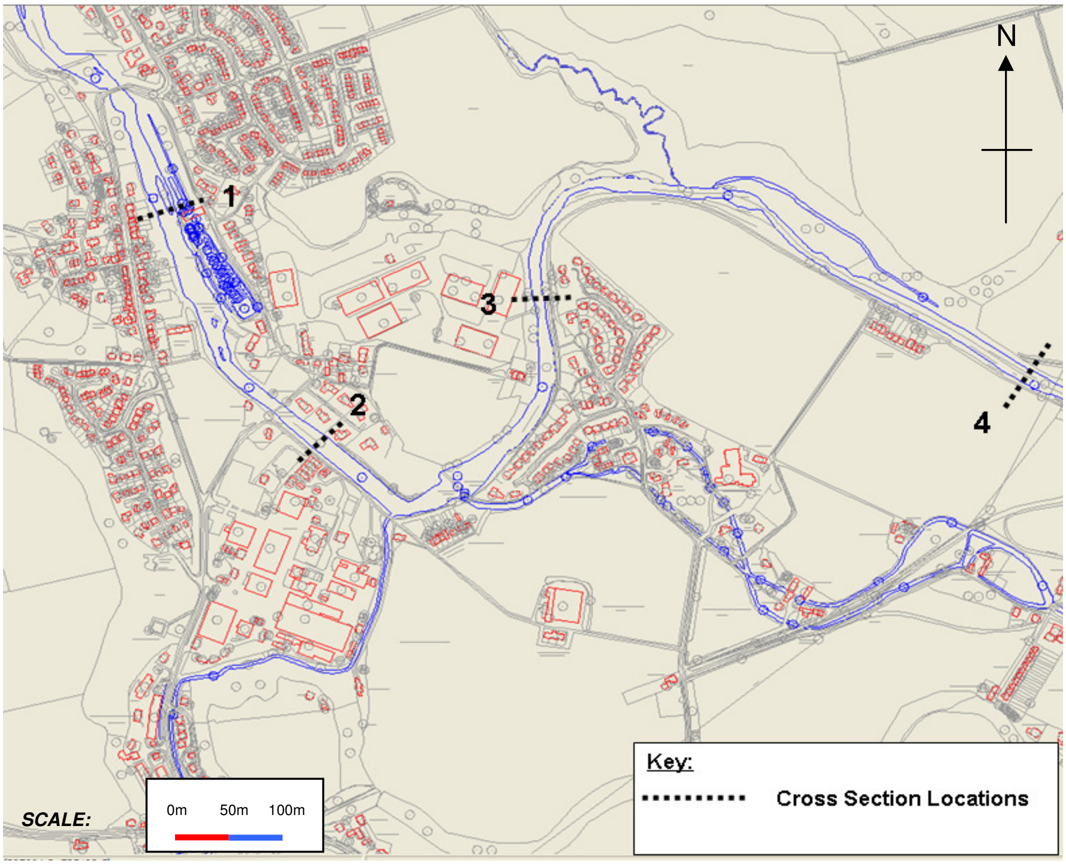


Figure 24 – Location of cross sections for the comparison between Mouchel and Babtie Group's water levels

The water levels modelled by Mouchel are similar to the water levels provided by Babtie Group in 1998.

For the 1 in 200 year event, the peak flow estimate by Mouchel (311 m^3/s) in the River Almond was lower than Babtie Group's estimate (335 m^3/s) which suggests that Mouchel's hydraulic model provides conservative water levels as a lower flow produces, at some cross sections, higher water levels. Mouchel's water levels are also conservative for the 1 in 100 year event.

3.6.5.2 Kaya Consultants

More recently, Kaya Consultants undertook a Flood Risk Assessment (FRA) for the Almond Valley area in May 2011 focusing on the land upstream of Waterside Cottages. Kaya Consultants developed a hydraulic model on behalf of a private developer who wanted to develop on this land. Kaya Consultants used ISIS and ISIS 2D to estimate water levels and produce flood extents.

As Mouchel had already undertaken river cross sections survey and assessed the hydrology in consultation with SEPA, the information was provided to Kaya Consultants for their hydraulic model development.

A comparison of the flood levels and extents (for the 1 in 200 year event) derived by Kaya Consultants and Mouchel was undertaken as shown in Figure 25 and Figure 26.

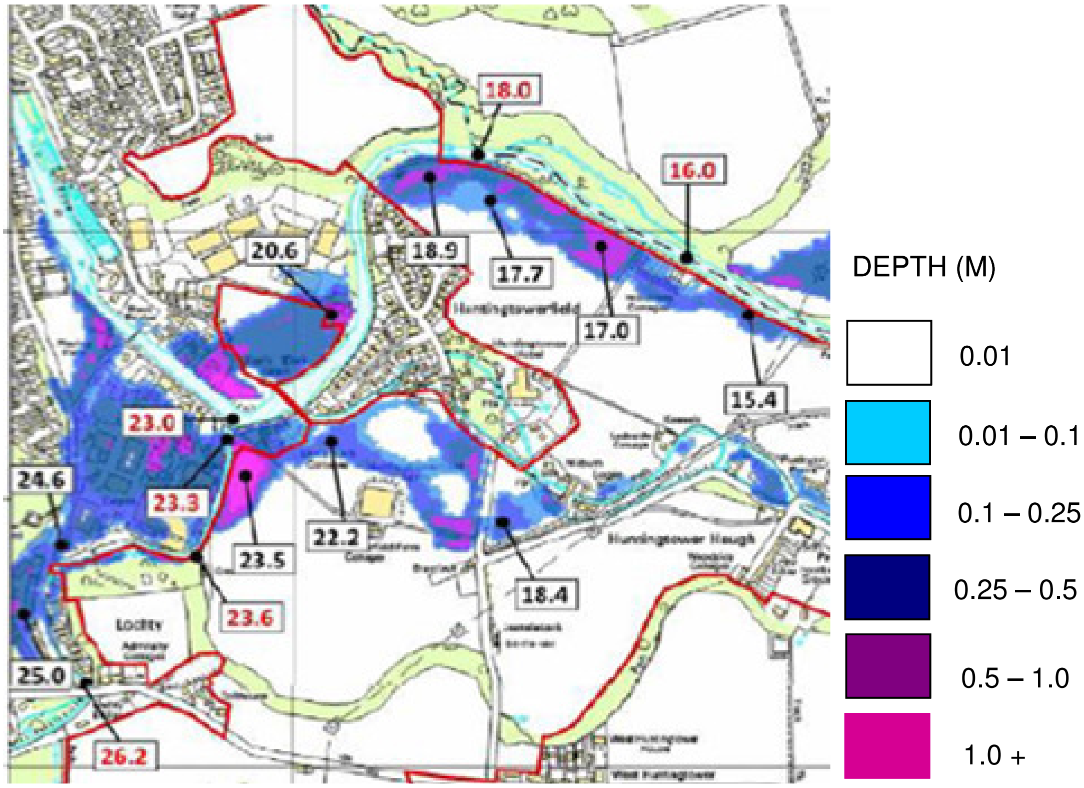


Figure 25 – Extract from the FRA produced by Kaya Consultants for the Almond Valley Area showing modelled flood levels (mAOD), depths and extents for the 200 year event

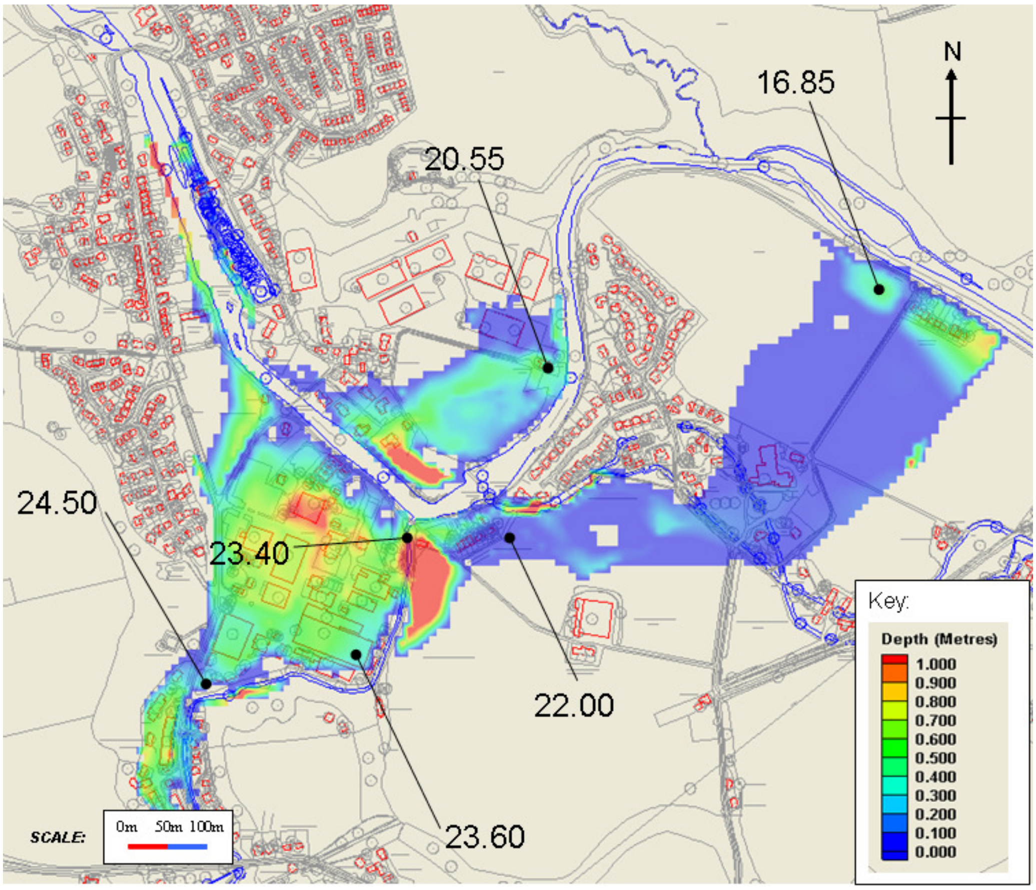


Figure 26 – Flood levels (mAOD), depths and extents modelled by Mouchel for the 200 year event

The 1 in 200 year flood extents in Figure 25 and Figure 26 compare favourably particularly in the Vector Aerospace site, playing field, Deer Park and Low's Work Weir. The main differences identified included:

- The extent of flooding around Waterside Cottages was more extensive in Kaya's map likely because of the slightly higher roughness values used by Kaya in this reach of the model. Mouchel used 0.035 in the main channel and 0.08 along the banks while Kaya used 0.04 in the main channel and 0.1 along the banks. In addition, Kaya's ground model indicated a lower bank for approximately 100 metres upstream of Waterside Cottages than Mouchel's model, resulting in flood water spilling earlier than Mouchel's model, and hence spreading more extensively in this area.

- Flood path from the East Pow Burn to Waterside Cottages did not exist in Kaya's map but was clearly shown in Mouchel's flood outline. This was due to Mill Lade not being incorporated in Mouchel's hydraulic model in agreement with Perth & Kinross Council as a more conservative approach. Kaya included Mill Lade in their model which intercepted this flow path from the East Pow Burn. In reality, this flow path would be intercepted by the Mill Lade except when the Mill Lade is flowing at full capacity.

Mouchel's and Kaya's modelled flood levels compared favourably. Water levels in the floodplain did not differ more than +/- 150mm as shown in Figure 25 and Figure 26.

3.6.6 Conclusions of the Model Verification

Using the best available data the model verification highlighted that the model provided a good representation of water levels and flood extents within the town on Almondbank.

- The model derived the water levels for the two largest recorded historical events (January 1993 and September 1999) with a maximum error of 7.8 %. The model slightly underestimated the January 1993 event and overestimated the September 1999 event.
- For the peak flow of the 1 in 200 year event, the model overestimated by 7.9% the water levels in comparison to the SEPA's rating curve.
- The model represented well the flooding mechanisms within Almondbank showing flooding at all the expected locations.
- The model's and SEPA's flood extents for the 1 in 200 year 'do minimum' event compared favourably.
- The model's water levels in the river channel and floodplain were similar to water levels produced in previous studies by other consultants.

Based on the model verification carried out, it was concluded that the model was fit for the purpose of this flood mitigation scheme and therefore has been used to develop the flood alleviation solutions described in Section 4.

3.7 Sensitivity Analysis

A sensitivity analysis was undertaken using the verified model to assess potential changes in water levels occurring from changes in a few parameters of the model. The parameters altered in the model for the sensitivity runs and the results are presented in Table 19 outlining 'typical changes' in water level when a parameter was altered (i.e. values could be slightly different at any other cross section).

		Typical Change in Water Level (mm) for the 1 in 200 year event					
		East Pow Burn			River Almond		
Parameter	Change	Level Change	% Change	Cross Section	Level Change	% Change	Cross Section
Roughness	+20%	+90	4.0%	02_0233	+400	11.1%	01_1509
	- 20%	-100	-4.5%	02_0233	-320	-8.8%	01_1509
Flow	+20%	+40	1.2%	02_0064	+500	13.8%	01_1509
	- 20%	-200	-5.6%	02_0064	-370	-10.2%	01_1509
Downstream boundary	+0.5 m	0	0%	02_0004	+500	13.7%	01_0000
	- 0.5 m	0	0%	02_0004	-500	-13.7%	01_0000

Table 19 – Results of sensitivity analysis on roughness, flows and downstream boundary (200 year event)

The overall sensitivity of the model to changes both in roughness and peak flows was approximately the same and higher in the River Almond than the East Pow Burn.

Alterations to the levels of the downstream boundary have only a localised effect along 400 metres of the most downstream extent of the model and changes in water level further upstream of this point were negligible.

3.8 Morphological Changes in the River Channels

During the model development and the preparation of this report some morphological changes[15] have occurred in the main channel of the River Almond and East Pow Burn, including:

- Increased erosion of the right river bank along the playing field.
- Erosion and deposition of material upstream and downstream of the Low's Work Weir (along the right bank).
- Erosion of the left bank downstream of the Low's Work Weir, large boulders were used to line the channel to reduce further erosion of the bank in this area.
- Erosion of the East Pow Burn channel at Lochty Park.

All of these changes have had some impacts on the channel geometry along the River Almond and East Pow Burn in these locations and should be taken into account when the scheme is developed further during detailed design stage as these changes could induce small changes on the modelled water levels.

[15] Detailed information on the geomorphology of the River Almond can be found in Mouchel's Geomorphology Report produced in 2011 on behalf of Perth & Kinross Council.

4 Hydraulic Modelling Results and Flood Mitigation Solutions

4.1 Advantages of a Combined 1D and 2D Hydraulic Model

The one dimensional (1D) component of the combined hydraulic model enables modelling of water levels along the study reach and takes into account head losses from structures, river cross sectional area, channel roughness and flows. But, this component has limitations when modelling flows across the floodplain. As out of bank flows have occurred in Almondbank it was deemed necessary to incorporate a two dimensional (2D) component into the hydraulic modelling. This has the following advantages:

- It enables the flooding mechanisms to be simulated more accurately.
- It enables water levels, flows and velocities to be modelled more accurately in the floodplain.
- It enables more accurate flood outlines to be generated.
- It allows possible flood mitigation solutions for Almondbank to be tested more accurately than with a one dimensional hydraulic model.

4.2 Hydraulic Model Simulations

The combined 1D and 2D hydraulic model developed by Mouchel was used to replicate the following out of banks events: the January 1993 and September 1999 events. The flows recorded at the SEPA gauge on the River Almond during these events were run in the 'do minimum' model for model verification (Section 3.6.1). The flood outlines generated for these two events are in Appendix F.

The design events (1 in 10, 25, 50, 75, 100 and 200 year return period events, and the 1 in 200 year event including climate change allowance also run as a sensitivity event) were run with the 'do minimum' scenario described in Section 3.4.1. For each design event, the in-bank water levels are provided in Appendix I, and the flood outlines including maximum flood depths are in Appendix G.

The design events (1 in 10, 25, 50, 75, 100, 200, and 200 including climate change allowance events) were run with the 'do nothing' scenario described in Section 3.4.2. For each event, the in-bank water levels are provided in Appendix I, and the flood outlines including maximum flood depth are in Appendix H.

The 1 in 200 year return period design event was run with the 'final outline design' scenario described in Section 3.4.3.

4.3 Hydraulic Model Results

After the combined hydraulic model had been verified as described in Section 3.6, the model was run for the various scenarios.

- The results from the one dimensional component of the combined model showed that the model was more sensitive to changes in flow and roughness in the River Almond than the East Pow Burn as described in Section 3.7.

- Increases in water levels from the 'do minimum 1 in 10 year event' to the 'do minimum 1 in 200 year event' were on average 0.88 metre in the River Almond and 0.54 metre in the East Pow Burn.

- Increases in water levels from the 'do nothing 1 in 10 year event' to the 'do nothing 1 in 200 year event' were on average 0.87 metre in the River Almond and 0.57 metre in the East Pow Burn.

- Typical increase in water levels for the 'do minimum' scenario and the 'do nothing' scenario compared to the 1 in 10 year event are outlined in Table 20 and Table 21 respectively.

Return Period (years)	River Almond - Typical Water Level Increase (m)	East Pow Burn - Typical Water Level Increase (m)
10	0.00	0.00
25	0.28	0.19
50	0.49	0.31
75	0.61	0.40
100	0.69	0.44
200	0.88	0.55

Table 20 – Typical increases in water levels with the 'do minimum' scenario compared to the 10 year event

Return Period (years)	River Almond - Typical Water Level Increase (m)	River Almond - Typical Water Level Increase (m)
10	0.00	0.00
25	0.33	0.16
50	0.57	0.25
75	0.71	0.29
100	0.80	0.31
200	1.07	0.37

Table 21 – Typical increases in water levels with the 'do nothing' scenario compared to the 10 year event

The analysis of the results of the combined hydraulic model showed that:

- Increases in water levels from the 'do minimum 1 in 10 year event' to the 'do minimum 1 in 200 year event' were on average 0.50 metre.

- Increases in water levels from the 'do nothing 1 in 10 year event' to the 'do nothing 1 in 200 year event' were on average 0.34 metre.

The maximum modelled water levels, depths and velocities in the floodplain for the 'do minimum' 1 in 100 and 1 in 200 year events are summarised in Table 22 and their location are illustrated in Figure 27.

Return Period (years)	Maximum water levels (m AOD)	Maximum water depth (m)	Maximum velocities (m/s)
100	25.91	1.95	3.11
200	26.10	2.04	3.50

Table 22 – Maximum modelled 'do minimum' water levels, depths and velocities in the floodplain

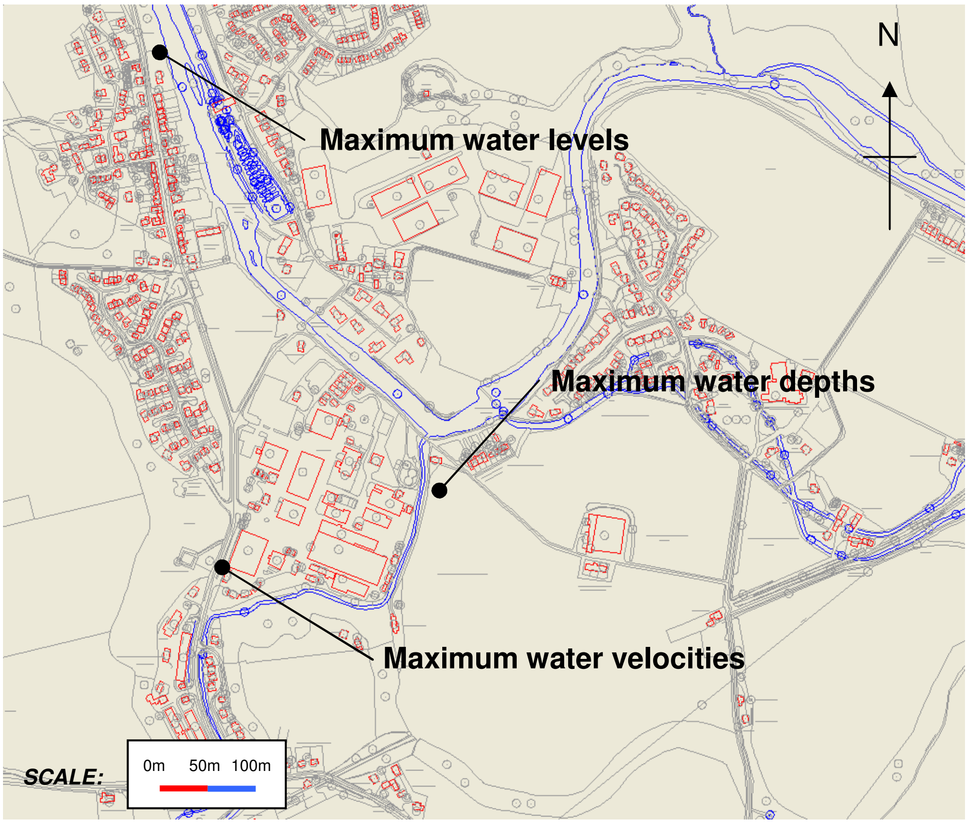


Figure 27 – Location where water levels, depths and velocities are maximum for the 'do minimum scenario

- The location of the maximum water levels is the point of the highest ground elevation within the town.
- The location of the maximum water depths is at the confluence of the East Pow Burn and the River Almond.
- The location of the maximum velocities is at the point where the East Pow Burn initially overtops its banks into the Vector Aerospace site.

4.4 Royal Haskoning's Flood Mitigation Scheme of 2003

The original flood mitigation scheme for Almondbank was developed by Royal Haskoning in 2003 on behalf of Perth & Kinross Council; the scheme was not implemented but was developed to outline design stage. The 'Royal Haskoning proposed scheme' was based on water levels provided from earlier hydraulic modelling by Babtie Group in 1993. The Babtie's model was no longer available for use in this present study, therefore, in agreement with Perth & Kinross Council, Mouchel developed a new hydraulic model for this flood mitigation scheme.

The 'Royal Haskoning proposed scheme' is shown in Figure 28 and included a flood storage area in the playing field and behind the residential property "Brockhill." The remaining elements of the proposed scheme included flood walls, sheet pile walls and embankments.

The 'Royal Haskoning proposed scheme' was tested with Mouchel's verified combined hydraulic model to determine whether this scheme would fully protect the town from flooding during the 1 in 200 year event, which was agreed with Perth & Kinross Council to be the standard of protection required of the Mouchel's flood mitigation scheme.

The 'Royal Haskoning proposed scheme' was originally designed in 2003 to protect the town from flooding for the 1 in 200 year flood return period, which was taken to be equivalent to the 1 in 100 year plus climate change allowance. Based on Mouchel's hydrological assessment (Section 3.3), the 1 in 200 year flows are approximately the same as the 1 in 100 year plus a 20% allowance for climate change.

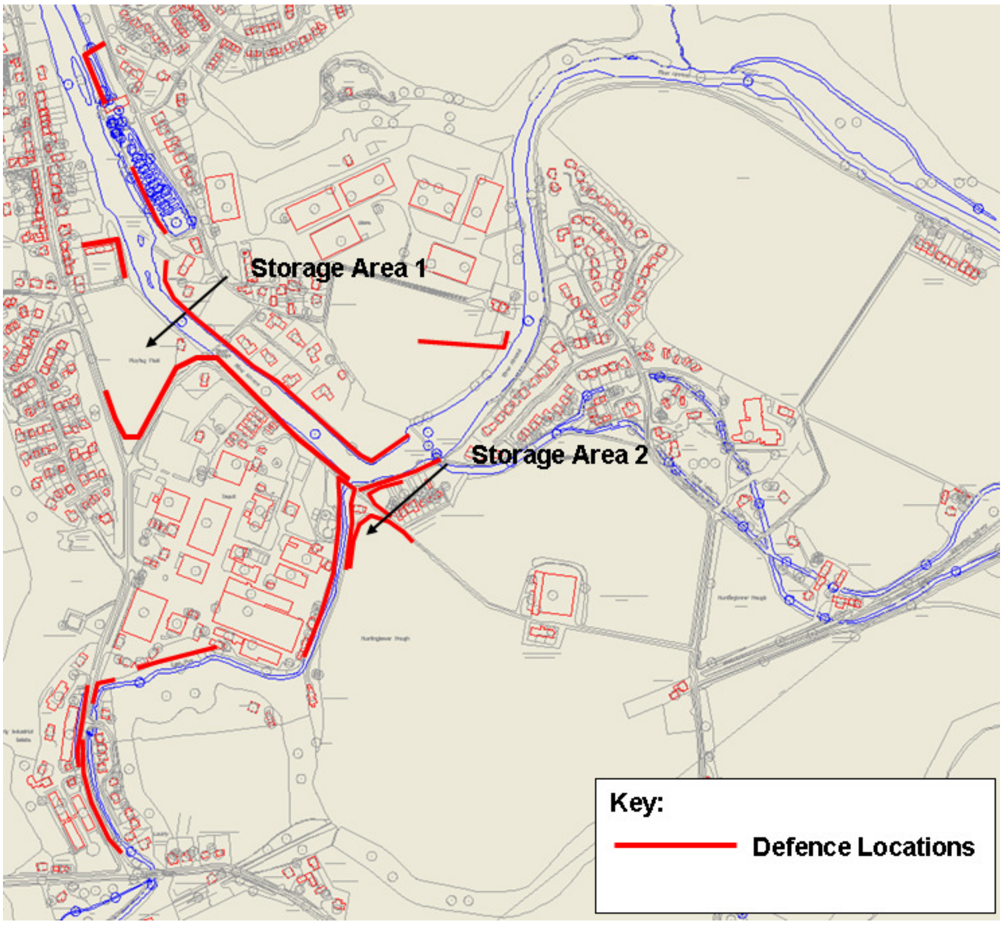


Figure 28 – Flood defence scheme proposed by Royal Haskoning in 2003

Based on Mouchel's hydraulic assessment, the 'Royal Haskoning proposed scheme' did not fully protect the town from flooding for the 1 in 200 year return period event, and embankments and flood defence walls needed to be raised and lengthened in some locations to prevent flood water from overtopping and by-passing flood defences. However:

- Babtie's hydraulic model with which the levels of the defence were derived for the 'Royal Haskoning proposed scheme' did not benefit from a two dimensional hydraulic component to better assess overland flow.
- The Babtie's hydraulic model used different flows than those calculated by Mouchel.
- The proposed scheme was considered to be the most appropriate and based on the best available information at the time.

The locations where breaches[16] would first occur with the 'Royal Haskoning proposed scheme' during a 1 in 200 year event are shown in Figure 29 and Figure 30.

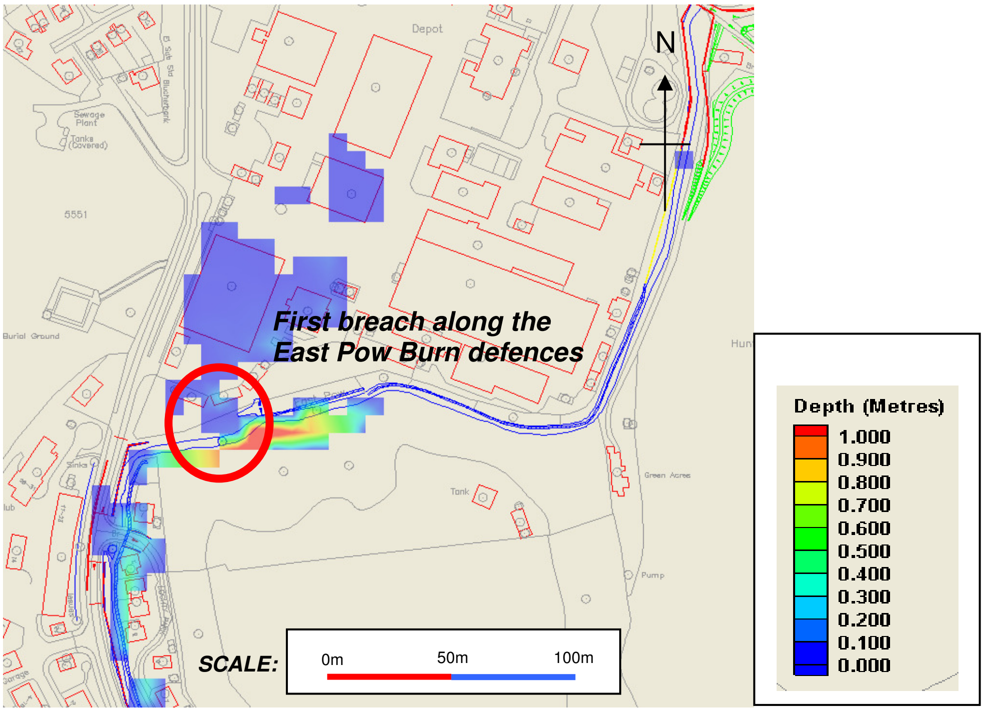


Figure 29 - First location of a breach in the East Pow Burn with 'Royal Haskoning proposed scheme' 2003

In the East Pow Burn, the first breach of the 'Royal Haskoning proposed scheme' would occur approximately 100 metres downstream of the Lochty Park Road Bridge when the flow in the East Pow Burn reaches 26 m^3/s, which has been estimated by Mouchel to be approximately the 1 in 25 year return period event.

[16] In this report, a breach in flood defence includes flood water either overtopping a river bank, flowing around a flood defence or inducing the full collapse of a defence.

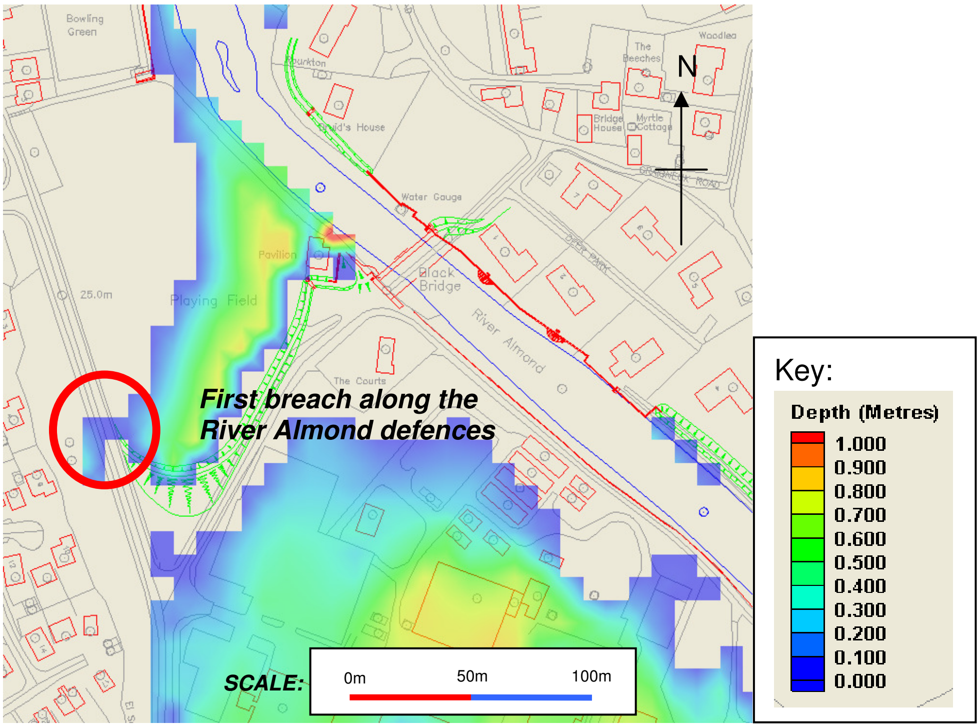


Figure 30 – First location of a breach in the River Almond with 'Royal Haskoning proposed scheme' 2003

In the River Almond, the first breach of the 'Royal Haskoning proposed scheme' would occur at the playing field, which was proposed to be used as a flood storage area in the scheme. The breach would occur when the flow in the River Almond reaches 250 m^3/s, which has been estimated by Mouchel to be approximately a 1 in 60 year flood event.

As the 'Royal Haskoning proposed scheme' did not fully protect the town from flooding from the East Pow Burn nor the River Almond for the 1 in 200 year event, Mouchel have developed improvements to this proposed scheme in agreement with Perth & Kinross Council.

4.5 Mouchel's Flood Mitigation Solutions

In initial discussions with Perth & Kinross Council, it was agreed that any proposed solution would be designed for the 1 in 200 year event plus climate change, however this was on the basis that a scheme at this standard of protection was both feasible and economically viable.

Flood defence heights required to defend the town for the 1 in 200 year event with an allowance for climate change were in excess of 2.5 metres in some locations, therefore the standard of protection for the scheme was reduced to a 1 in 200 year event with no specific climate change allowance, hence reducing flood defence heights throughout the town. The standard of protection of the 'final outline design' solution is discussed further in Section 4.5.3.

4.5.1 Summary of Mouchel's Flood Mitigation Solutions

Solution 1

This solution includes 2 flood storage areas and flood defences along the East Pow Burn and the River Almond. The key features of Solution 1 are outlined in Table 23 and illustrated in Figure 31. Figure 32 presents the maximum flood extents with Solution 1 for the 1 in 200 year flood event.

Solution 1	Summary
Number of flood storage areas	2
Storage volume of area 1 for the 1 in 200 year event	Approximately 5,100 cubic metres
Full volume capacity of area 1	Approximately 11,000 cubic metres
Storage volume of area 2 for the 1 in 200 year event	Approximately 13,100 cubic metres
Full volume capacity of area 2	Approximately 38,000 cubic metres
Total length of defences along the 2 watercourses	3.82km

Table 23 – Summary table of flood mitigation measures included in Solution 1

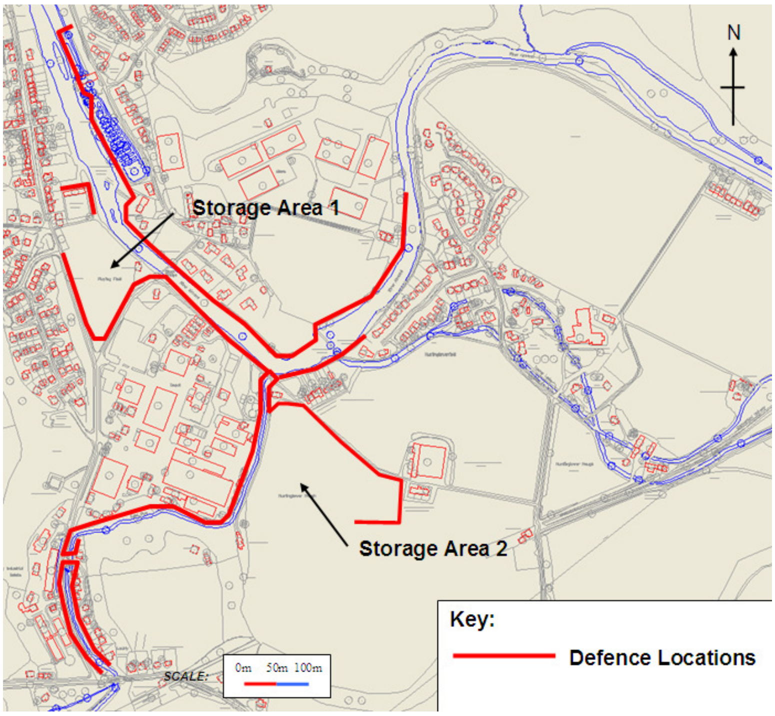


Figure 31 - Solution 1: flood defence walls and embankments and two flood storage areas

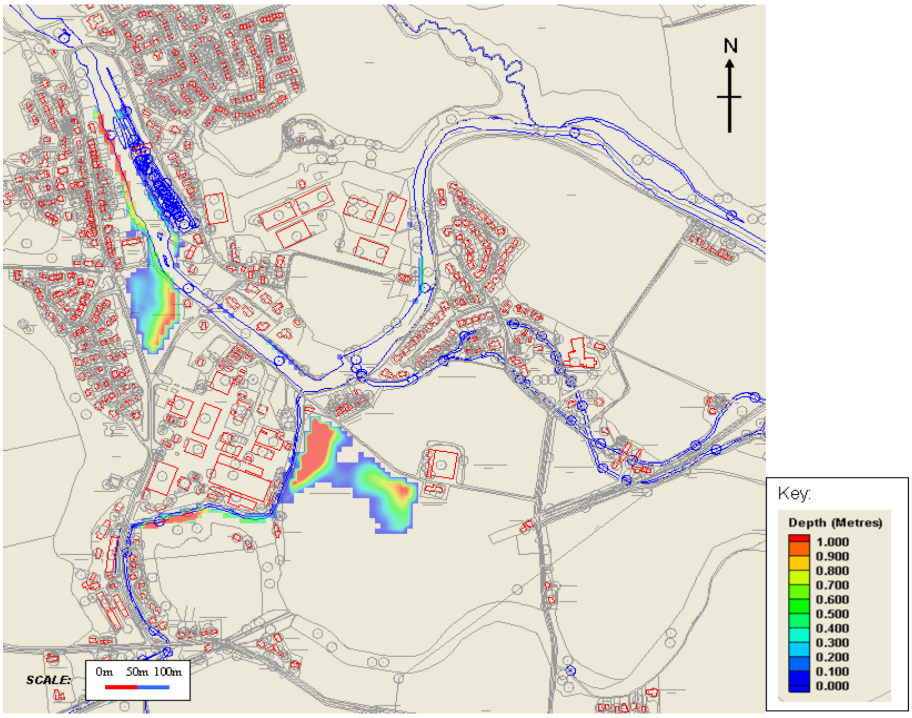


Figure 32 - Maximum flood extents of Solution 1 for the 1 in 200 year flood event

Solution 2

This solution includes 1 flood storage area, a diversion channel and flood defences along the East Pow Burn and the River Almond. The key features of Solution 2 are outlined in Table 24 and illustrated in Figure 33. Figure 34 presents the maximum flood extents with Solution 2 for the 1 in 200 year flood event.

Solution 2	Summary
Number of storage areas	1
Storage volume of area 1 for the 1 in 200 year event	Approximately 5,100 cubic metres
Full volume capacity of area 1	Approximately 11,000 cubic metres
Diversion channel	1 – length: 280 metres
Total length of defences along the 2 watercourses	3.2 km

Table 24 – Summary table of flood mitigation measures included in Solution 2

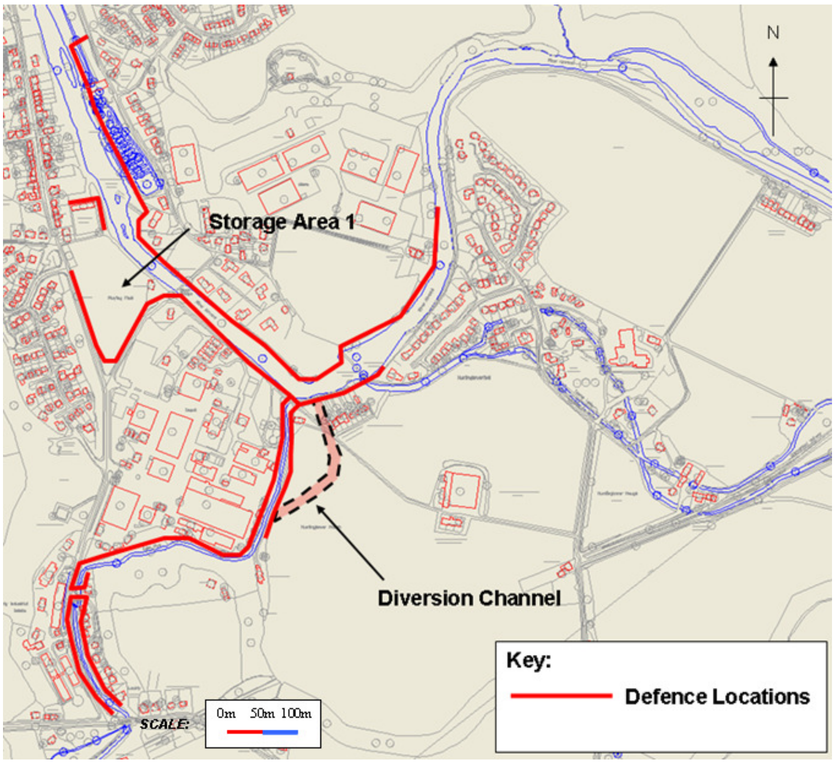


Figure 33 - Solution 2: flood defence walls and embankments, 1 flood storage area and a diversion channel

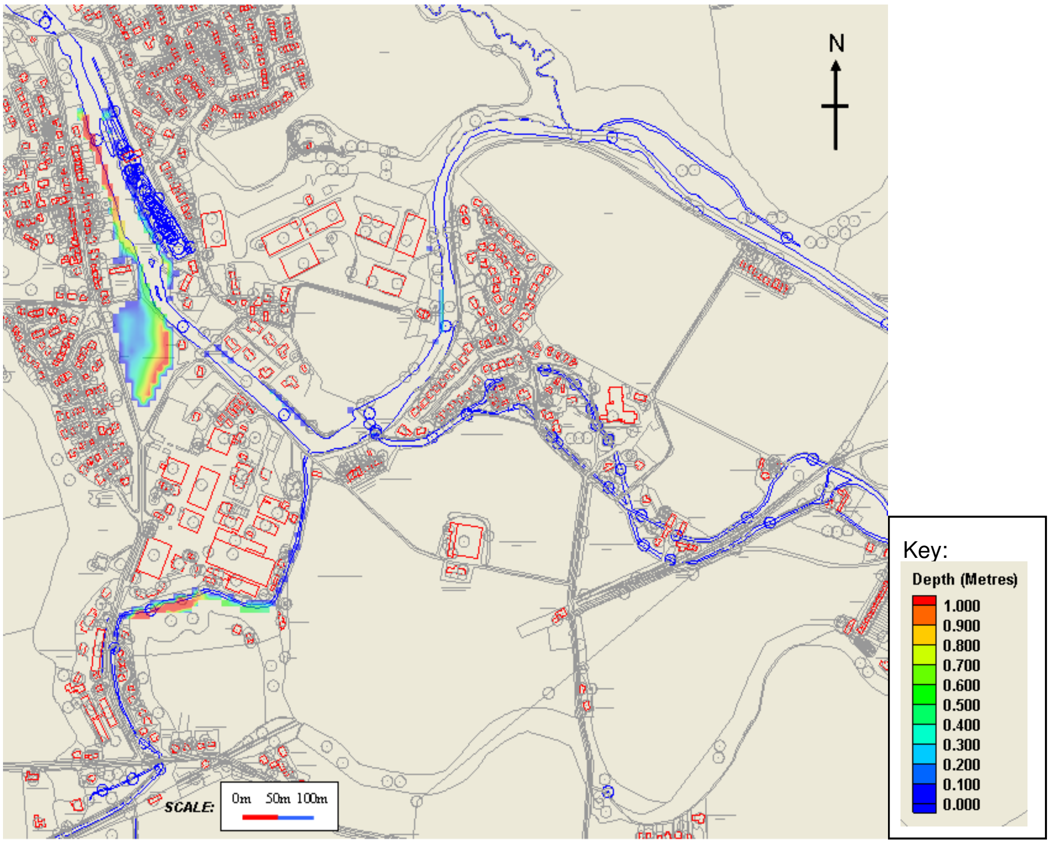


Figure 34 – Maximum flood extents for Solution 2 for the 1 in 200 year flood event

Solution 3

This solution includes 1 flood storage area and flood defences along the East Pow Burn and the River Almond. The key features of Solution 3 are outlined in Table 25 and illustrated in Figure 35. Figure 36 presents the maximum flood extents with Solution 3 for the 1 in 200 year flood event.

Solution 3	Summary
Number of flood storage areas	1
Storage volume of area 1 for the 1 in 200 year event	Approximately 5,100 cubic metres
Full volume capacity of area 1	Approximately 11,000 cubic metres
Total length of defences along the two watercourses	3.2 km

Table 25 – Summary table of flood mitigation measures included in Solution 3

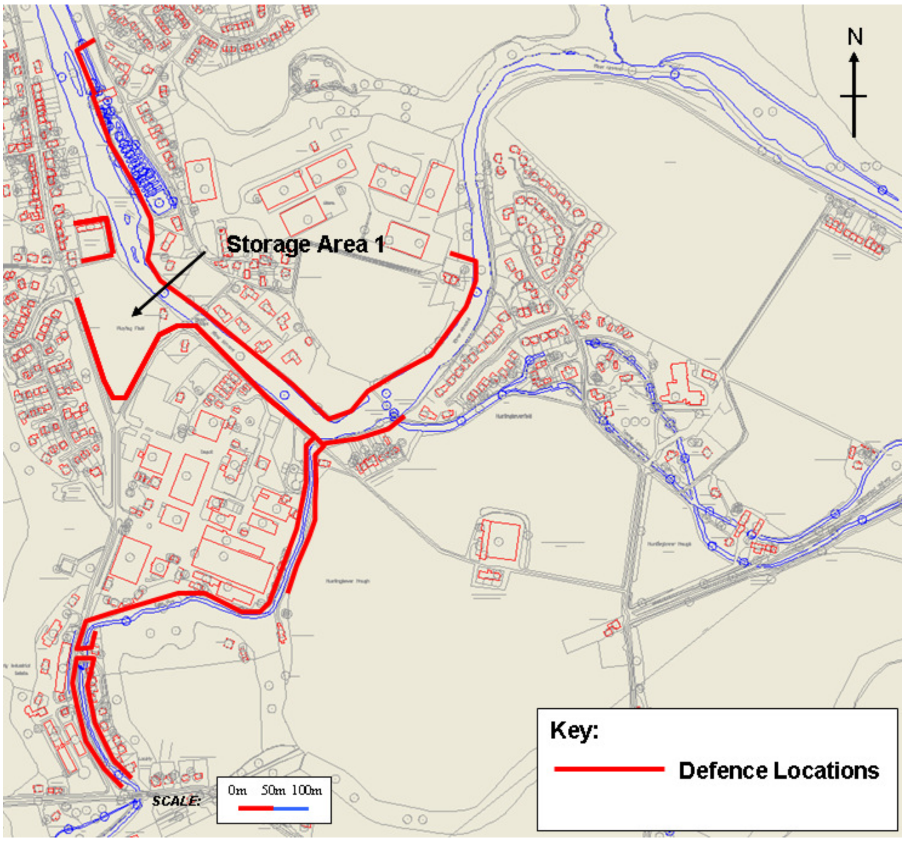


Figure 35 – Solution 3: flood defence walls and embankments and 1 flood storage area

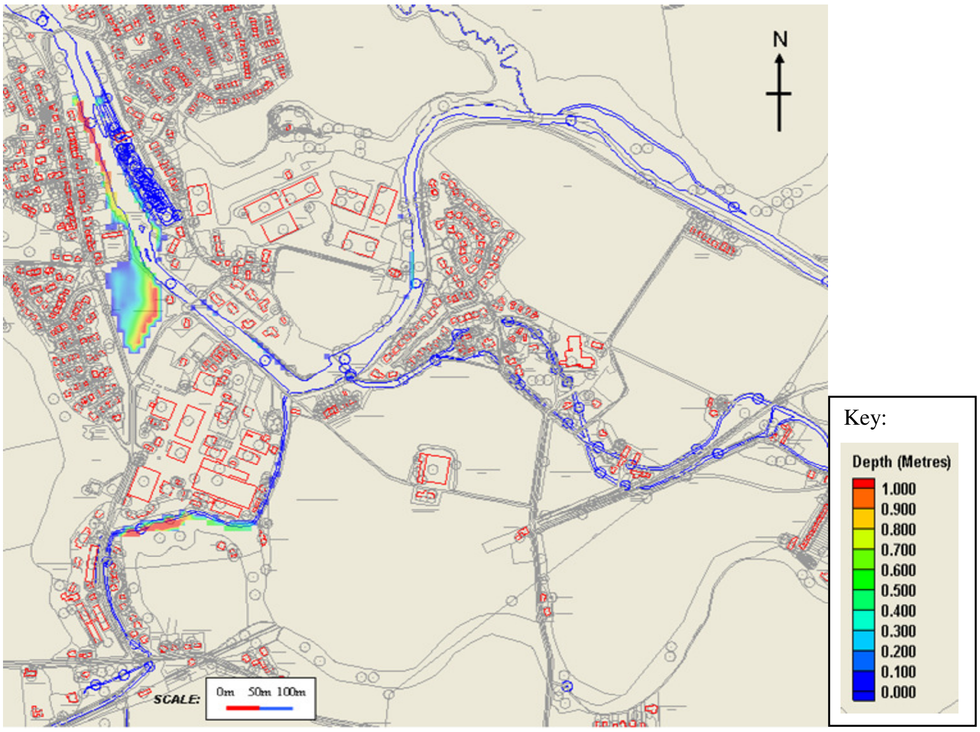


Figure 36 – Maximum flood extents for Solution 3 for the 1 in 200 year event

For each of these three solutions, the College Mill Trout Farm will have its own flood protection system in place due to its uniqueness. Whilst it needs protecting from flooding, the flood defence scheme must still enable the College Mill Trout Farm to function as normal, hence water abstracted from the river must be allowed to flow through the farm to supply fresh water to the farm ponds.

4.5.2 Analysis of the Solutions

Solution 1: 2 flood storage areas and wall and embankment flood defences along the East Pow Burn and the River Almond

This solution has not been selected as the 'preferred solution' mainly due to the solution incorporating a very large flood storage area indicated as Storage Area 2 in Figure 31. A disadvantage of this option is that storage area 2 would take up a large area of land. Also as the storage area can hold a volume of water when at full capacity which exceeds 10,000 cubic metres. This would need regular inspections, incurring significant maintenance costs for a storage area of this size (refer to Table 23 for values of the storage volumes for storage areas 1 and 2). Storage area 2 in particular would also induce a flood risk hazard to the residents of Almondbank due to its close proximity to property and infrastructure if a breach / overtopping of the embankment did occur. Injury to residents (or in the worst case loss of life) is a possibility if failure of an embankment in Storage area 2 did occur.

Note: An additional storage area was also modelled on the field between Deer Park and Craigneuk East and Wes, as part of Solution 1, however it was much more cost effective (additional lengths of walls and embankments would have been needed) not to include this flood storage area. Including this storage area proved not to add any overall value to the scheme.

Solution 2: 1 flood storage area, 1 diversion channel and wall and embankment flood defences along the East Pow Burn and the River Almond

For this solution, instead of a storage area located in the Huntingtower field (as in Solution 1) a diversion culvert has been incorporated to divert flood water from the East Pow Burn to the River Almond further downstream during the 1 in 200 year flood event. In addition, the playing field has been used as a storage area for flood water from the River Almond (refer to Table 24 for values of the storage volumes of storage area 1). This solution would result in reducing some of the flood defence heights along the East Pow Burn compared to Solution 1 due to the reduction of flows in the lower section of the East Pow Burn. Based on the hydraulic modelling, the reduction of defence heights along the East Pow Burn would be no greater than 100mm and the incorporation of a diversion channel at this location would be difficult and costly to implement. This solution has not been selected as the 'preferred solution'.

Solution 3: 1 flood storage area and wall and embankment flood defences along the East Pow Burn and the River Almond

This solution has been selected as the 'preferred solution' as it will enable the town to be fully protected for up to a 1 in 200 year return period flood event. An embankment has been incorporated along the lower section of the East Pow Burn in preference to a flood storage area in Huntingtower field or a diversion culvert. The preferred solution similarly to Solutions 1 and 2 incorporates a flood storage area in the playing field area; (refer to Table 25 for values of the storage volumes of storage area 1). The solution also incorporates flood defences along the River Almond from the upstream end of the College Mill Trout Farm Hatchery to downstream of Low's Work Cottages and the properties at Craigneuk. Also, flood defences have been incorporated along most of the East Pow Burn. Defence heights range from approximately 2.5 metres at the downstream end of the East Pow Burn to less than 0.5 metre along some of the River Almond reaches.

4.5.3 Design Standard of Protection and Climate Change

The preferred solution (Solution 3) had been taken forward to outline design by Mouchel in agreement with Perth & Kinross Council. During the development of the 'final outline design', the standard of protection was re-considered and revised from 1 in 200 year plus climate change allowance (i.e. 20% addition on peak flows) to simply a 1 in 200 year to reduce flood defence heights in certain locations (in particular at the downstream end of the East Pow Burn) and the impacts flood defences in excess of 2.5 metres may have on the town.

A 200 year standard of protection with an allowance for climate change (i.e. 20% addition on peak flows) was initially considered as the best standard of protection for any proposed flood mitigation scheme in Almondbank by Mouchel and Perth & Kinross Council. However, from presenting initial measures of solutions 1, 2 and 3 to Perth & Kinross Council, it was then agreed due to the potential adverse visual impacts that could be caused by the height of the defences in the immediate vicinity of the residential and commercial properties that the 1 in 200 year standard of protection[17] was to be used for the 'preferred solution'. Also, this is consistent with Defra's Supplementary Note to Operating Authorities on Climate Change[18] and the current Scottish Planning Policy (February 2010) as this scheme has a design life of 100 years. The agreed standard of protection of 200 year reduced the heights of the flood defences but still provided a good level of flood protection for the town.

Providing different levels of protection along the River Almond and the East Pow Burn had been considered as a possibility for the flood mitigation scheme because the probability of a 1 in 200 year event to occur on both watercourses concomitantly is very small. The annual probability of 1 in 40,000 years was estimated by multiplying the annual probabilities of 200 year flood event in the River Almond and in the East Pow Burn (assuming that the rainfall events in the River Almond and East Pow Burn catchments are fully independent of each other). However in agreement with Perth & Kinross Council, in order to provide an equal standard of protection throughout the town this approach was not taken any further.

The modelled flood outlines, water levels and cross sections of the preferred solution (Solution 3) are in Appendix J.

4.5.4 Flood Defences Breach Scenarios and Risk to Life

Possible breach scenarios were assessed by modelling for the preferred solution 3. The breach analysis was undertaken in order to assess the risk to life in the event of a flood defence failing during the design flood event. Five key breach locations were identified and modelled individually (i.e. not simultaneously) at locations considered to be important infrastructure and also where flooding has previously been witnessed in the town. Maximum water velocities and depths have been determined at each of the breach locations.

The assumptions for the breach analysis modelling were as follows:

- Each breach was modelled with total collapse of the flood defence at each location.
- Each breach was 10 metres in length and started at the time of the peak flows in each respective watercourses.

[17] The 200 year return period flood event is approximately equal to a 1 in 100 year return period event plus a climate change allowance of 15% on peak flows for both the East Pow Burn and River Almond

[18] Defra's Supplementary Note to Operating Authorities on Climate Change (FCDPAG3 Supplementary Note to Operating Authorities on Climate Change Impacts - October 2006 states that as a precautionary approach climate change should be accounted for over the next 100 years by increasing fluvial flows by 20%. However, the guidance states also that lower values of climate change can be considered (between 10% - 20% for the 1 in 100 year event).

- It was assumed that the flood defences had fully collapsed to existing ground level immediately behind the defence.

- The breach was not repaired at all during the remaining part of the flood event.

The locations of the breaches modelled are shown in Figure 37.

- *Breach 1: College Mill Trout Farm – This is a key infrastructure and the effect of a defence failure needs to be tested at this location.*

- *Breach 2: Storage Area 1 – This location is a proposed storage area (in the 'preferred solution') and failure at this location could cause a significant threat to human life and infrastructure in the immediate vicinity. This is also the location where flood water has been observed during previous flood events from the River Almond.*

- *Breach 3: Craigneuk East and West – The adjacent field has flooded in the past. The effect of a breach at this location downstream of the confluence of the two watercourses was modelled to assess the local flood risk during a defence failure.*

- *Breach 4: Brockhill upstream of the confluence – At this location, water depths are the highest of the low reaches of the East Pow Burn. Defence failure at this location would release large volumes of flood water at high velocity. This would cause a significant threat to human life and infrastructure in the immediate vicinity.*

- *Breach 5: Lochty Park – At this location, water has overtopped the banks of the East Pow Burn in the past and flooded the Vector Aerospace site and Industrial Estate.*

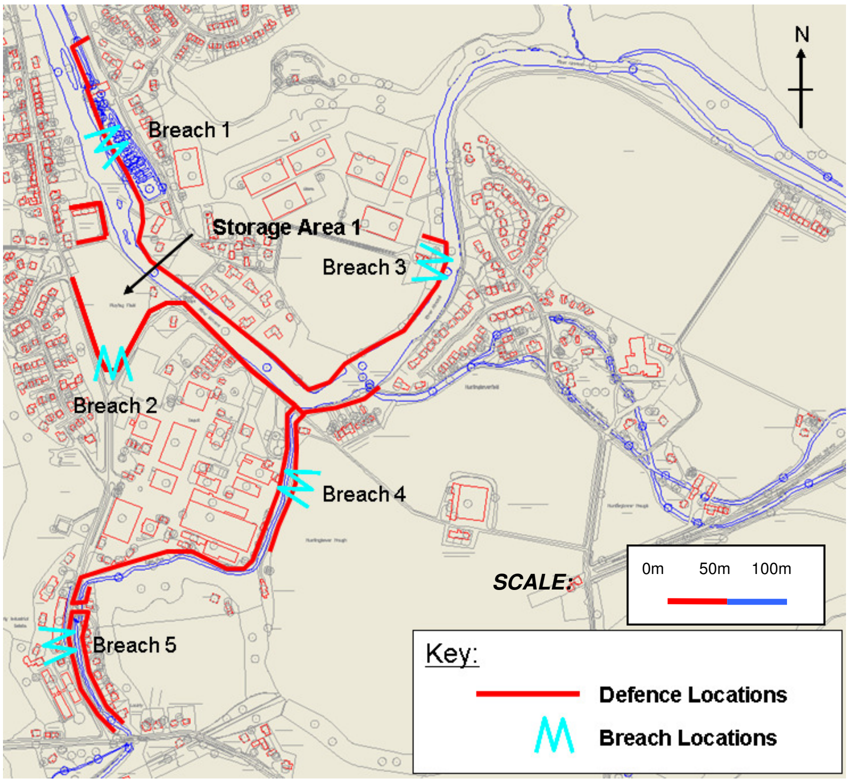


Figure 37 – Locations of breaches individually modelled along the defences of Mouchel's preferred solution

Table 26 presents a summary of the modelled maximum velocities and depths of flood water at each of the five breaches. The breaches have been modelled at the time of peak water level in the River Almond for breach locations 1, 2 and 3 and at the time of peak water level in the East Pow Burn for breach locations 4 and 5. Velocities and depths have been derived immediately after the breach of the defence, therefore this was a worst case scenario approach as water levels behind the defences (and therefore the maximum volume of water) and water velocities were at their highest.

The results in Table 26 indicate that velocities and depths at breach locations 4 and 5 could cause a potential risk to human life as illustrated in Figure 38[19].

In general, it is considered that when the velocity V (m/s) x depth, D (m) equals to 1 the wading limit of an average adult is reached, and when V x D is greater than 1 (the area of red in Figure 38) the depth and velocity of flowing water is known to cause a potential risk to human life.

[19] Flood Hazard Research Centre, Middlesex University 2008.

Breach Location	Maximum Water depth (m)	Maximum velocities (m/s)	V x D
1	0.10	0.20	0.02
2	0.60	1.20	0.72
3	0.40	0.30	0.12
4	1.21	3.55	4.30
5	0.60	1.34	0.80

Table 26 - Maximum water depths and velocities for each breach location derived with the hydraulic model

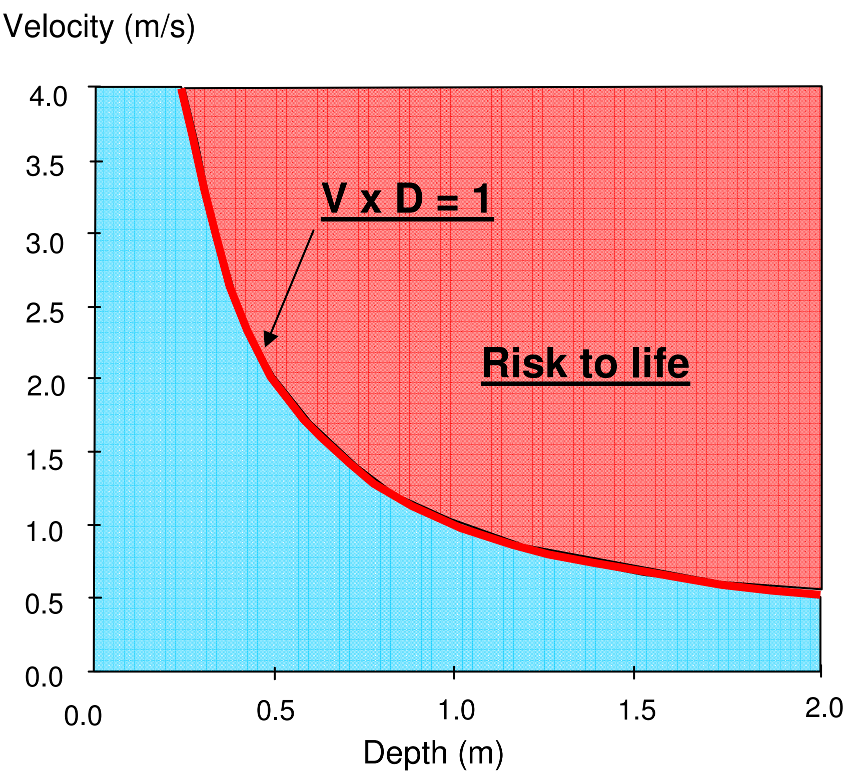


Figure 38 – Risk to life based on velocity and depth of flood water[19]

These results should assist during the detailed design of the scheme. Location of breach location 4 has the highest value of V x D and is located in the immediate vicinity of a residential area.

The area *immediately* to the right bank of the East Pow Burn is undeveloped (with the exception of Brockhill Cottage) and the velocity of any flood water breaching the defences would be reduced considerably prior to reaching any residential locations. The risk of breaches along any length of the proposed defences is likely to be reduced if the following actions are undertaken (list non exhaustive):

- The walls and embankments are constructed using established industry procedures, standards and codes.
- Regular inspections and maintenance of the flood walls and embankments are undertaken by qualified experienced staff.

- The flood storage area is retained during the whole life of the scheme to its design capacity.
- The walls and embankments are replaced at the end of their design life of 50 years. The other capital works are also expected to be replaced at the end of their design life of 50 years and to last for another 50 years (i.e. in total a design life of 100 years).

4.5.5 Flows exceeding the 1 in 200 year return period

As part of the hydraulic modelling, Solution 3 was tested also with two extreme events exceeding the 1 in 200 year design event to assess the likely flood paths of flood water when defences are overtopped during these events. The two extreme events were:

- The 1 in 200 year return period event plus 20% of the peak flows, and
- the 1 in 1000 year return period event.

The maximum flood extents for each event, with Solution 3 in place, are presented in Figure 39 and Figure 40.

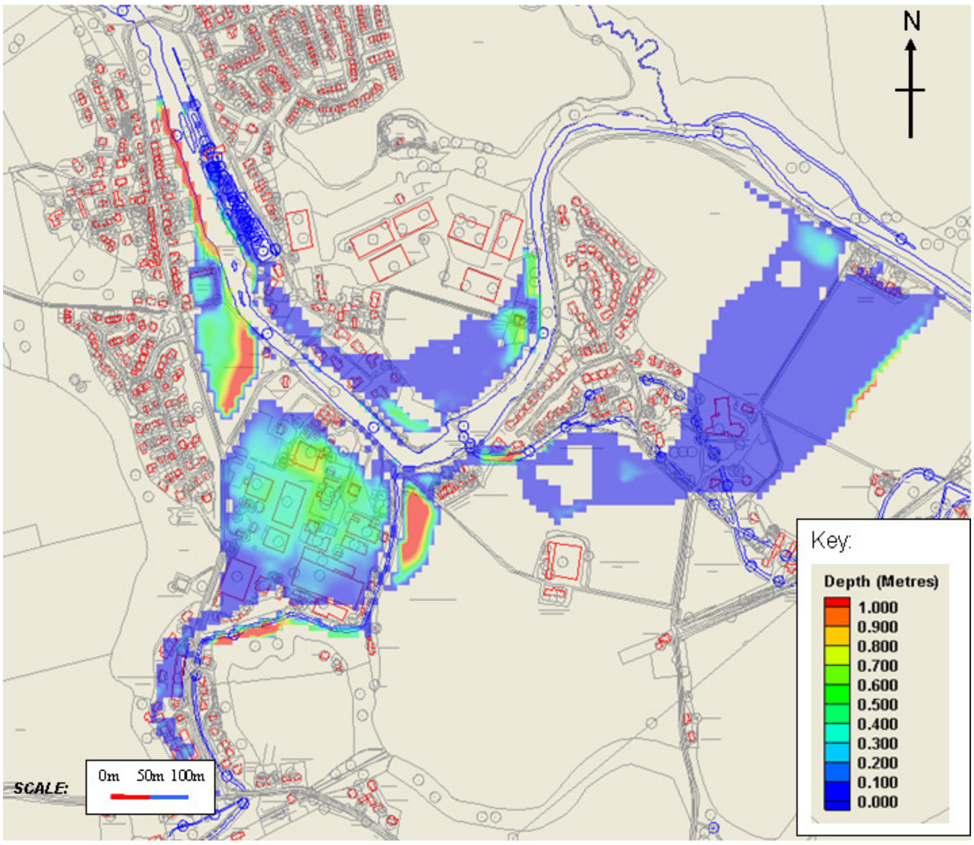


Figure 39 – Maximum flood extents for the 1 in 200 year plus 20% peak flows with Solution 3 in place

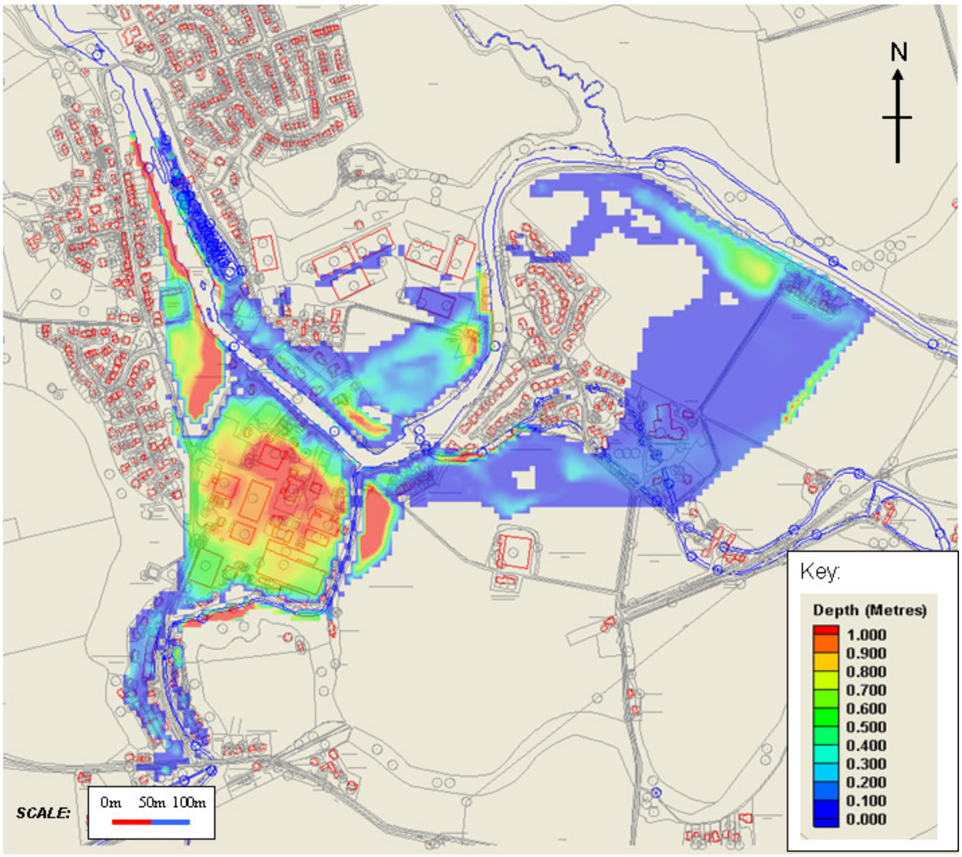


Figure 40 – Maximum flood extents for the 1 in 1000 year flood event with Solution 3 in place

For these extreme events, although flood embankments were overtopped, flooding to the surrounding areas was greatly reduced with Solution 3 in place. With Solution 3 in place, flood depths did not exceed 0.60 – 0.70 m for the 1 in 200 year event plus 20% of peak flows, nor exceeded 0.90 m – 1.00 m for the 1 in 1000 year event.

4.5.6 Potential Increase of Flood Risk Downstream Induced by Solution 3

As a result of implementing Solution 3, the potential increase in flood risk both upstream and downstream was assessed as 'good practice'. Possible areas of concern included upstream of the A85 Road Bridge along the East Pow Burn and downstream of Waterside Cottages along the River Almond. Table 27 provides a comparison of the change in water levels between the 1 in 200 year 'do minimum' scenario and the proposed Solution 3 at these two locations.

Watercourse	Location	Model Label	1 in 200 year water level (mAOD)		Difference in Levels (m)
			Before Solution 3	After Solution 3	
East Pow Burn	Upstream of A85 Road Bridge	02_0776	27.14	27.17	0.03
River Almond	Upstream of the College Mill Trout Farm Hatchery	01_2944	27.51	27.59	0.08
	Downstream of waterside cottages	01_0394	15.29	15.30	0.01

Table 27 – Maximum change in water levels pre and post implementation of Solution 3 for the 200 year event

The results showed negligible change in water levels at these three locations, therefore the increase in flood risk potentially induced by the implementation of the scheme (solution 3) was considered negligible.

If lower return period water levels differences for pre and post implementation of Solution 3 were compared to the differences in water level shown in Table 27, it would be expected that the differences in water level would be smaller.

5 Conclusions and Recommendations

5.1 Conclusions

- Several large flooding events have occurred in the town of Almondbank over the recent years and confirmed the urgent need for a flood mitigation scheme. The most severe flooding events occurred in 1909, January 1993, and September 1999. Other less severe flood events have occurred and caused distress to residents and disruption to infrastructure in Almondbank.

- The hydraulic model built by Mouchel replicated well the flooding within the town of Almondbank for the January 1993 and September 1999 historic events. The hydraulic model has been verified using data from the SEPA gauging station located upstream of the River Almond Footbridge, and water levels from previous studies to increase the confidence in the modelling results. In addition, flood outlines have been compared favourably with SEPA indicative flood maps, anecdotal evidence gathered from Perth & Kinross Council and through consultation with residents in the town.

- The flows used by Mouchel for the River Almond and then used in the combined 1D and 2D hydraulic model were derived and approved by SEPA.

- The flows derived by Mouchel for the East Pow Burn and then used in the combined hydraulic model have been agreed with SEPA.

- The flood outlines for Almondbank have been generated for a range of design return periods (1 in 10, 25, 50, 75. 100 and 200). The 1 in 200 year plus climate change was also generated as a sensitivity run for the ‘do minimum’ and ‘do nothing’ scenarios. The flood outline for the 1 in 200 year event showed extensive flooding throughout Almondbank, particularly in the College Mill Trout Farm, the playing field area, the Vector Aerospace site, Deer Park, Low’s Work Cottages and Lochty Park Industrial Estate, which was consistent with anecdotal evidence gathered from Perth & Kinross Council and through consultation with residents in the town.

- The flood defence scheme proposed by Royal Haskoning in 2003 was tested with the verified combined one and two dimensional hydraulic model built by Mouchel for this scheme and was assessed as not being sufficient to protect fully the town from flooding for the 1 in 200 year event.

- The preferred Solution 3 for a flood mitigation scheme, proposed by Mouchel, protects all current residential and commercial properties within the town of Almondbank from flooding for up to the 1 in 200 year flood event. Solution 3 includes one flood storage area in the playing field area together with flood walls and embankments along large stretches of the River Almond and East Pow Burn.

5.2 Recommendations

- It is recommended that the preferred Solution 3 (which provides a 1 in 200 year standard of protection as agreed by Perth & Kinross Council) is taken forward to detailed design and Flood Order Submission.

- It is recommended to use the combined hydraulic model developed by Mouchel in this study during the detailed design phase of the scheme. However, new topographic survey data would be required to account for changes induced by recent erosion in the River Almond and East Pow Burn, in particular around the location of Low's Work Weir.

- At the location of the proposed flood defences, effective drainage is recommended to ensure that surface water can still be effectively drained when the proposed flood defences are put in place in the foreseeable future.

- It is recommended that an emergency plan is developed and implemented in the unlikely event of a breach (by overtopping) of the proposed flood defences.

- It is recommended that the breach analysis is further refined during detailed design stage to better model the failure of any proposed flood mitigation measures.

- It is recommended that the existing SEPA flood warning system takes account of Solution 3 after it has been built.

- Consultation has been undertaken with SEPA (Appendix E) during the hydrological and hydraulic model development and the outline design stage of this study, and it is recommended that on-going consultations continues during future phases of the scheme.

We have used our reasonable endeavours to provide information that is correct and accurate and have discussed above the reasonable conclusions that can be reached on the basis of the information available.

APPENDIX A

Photographs of past flooding in Almondbank

Photograph 1: Flooding of the playing field in January 1993

Photograph 2: Collapse of the footbridge over the River Almond in January 1993

Photograph 3: East Pow Burn bursting its banks in January 1993

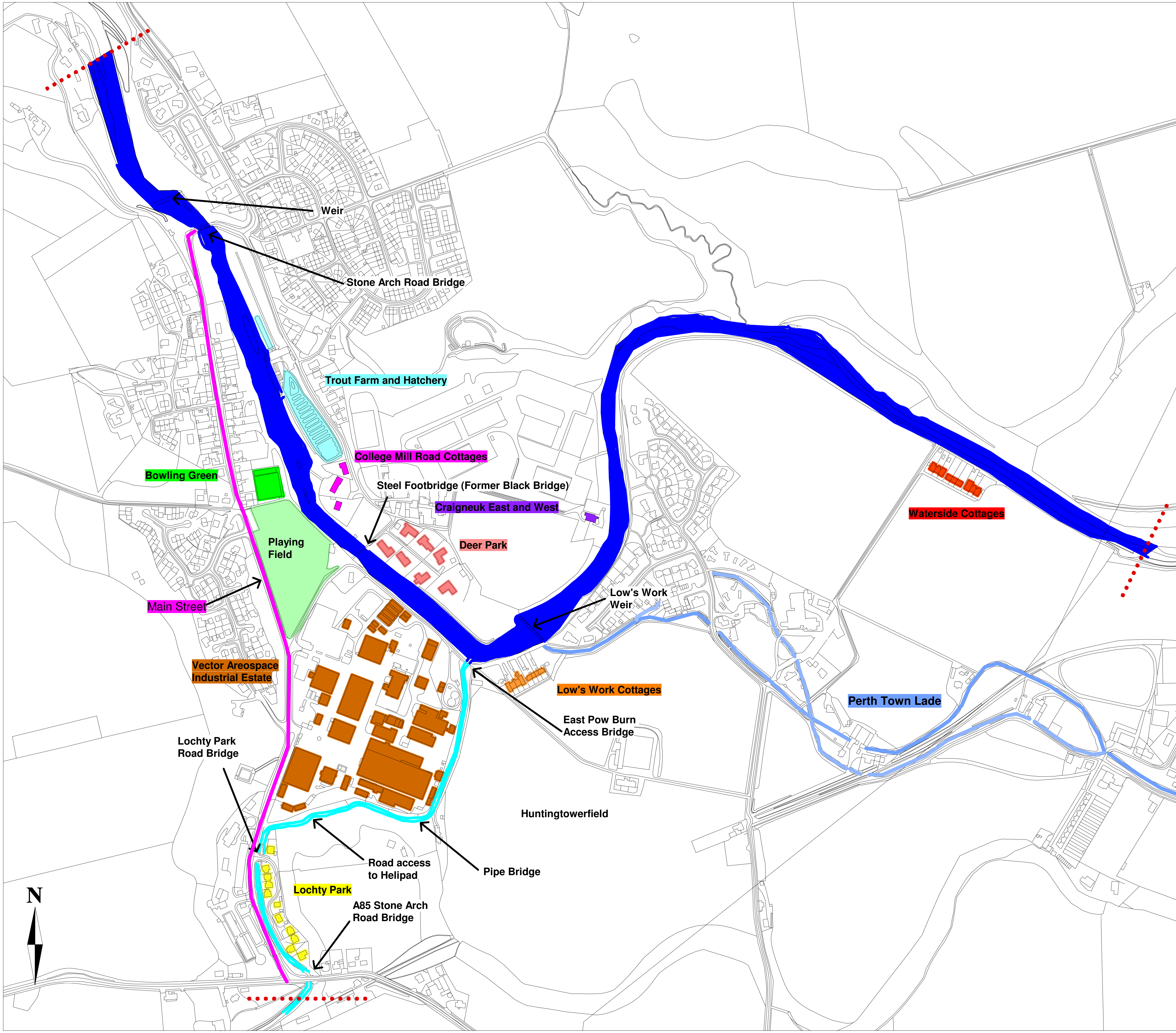
Photograph 4: Vector Aerospace flooded in January 1993

Photograph 5: Vector Aerospace flooded in January 2011

Photograph 6: Lochty Park Bridge flooded in January 2011

APPENDIX B

A layout of Almondbank



NOTES

It should be noted that certain locations not shown may be at risk of flooding from other sources (piped drain systems, watermains etc.) and from other watercourses not shown in this study.

LEGEND

- Location of River Almond
- Location of East Pow Burn
- Location of Town Mill Lade
- Limits of the Hydraulic Model

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
5	25/07/12	Final
4	24/04/12	Final
3	18/04/11	Draft
2	09/09/10	Draft
1	12/07/10	Draft

PERTH & KINROSS COUNCIL
The Environment Service

mouchel

Almondbank Flood Mitigation Scheme
Modelling Component

Site Layout

Date of Issue: 25th July 2012

Scale: Not to Scale

APPENDIX C

Photographs of Almondbank

Photographs of Almondbank:

1) *Almondbank Trout Farm*

2) *Looking upstream along the River Almond, towards the Trout Farm, from the playing fields.*

3) The playing fields

4) The Steel Footbridge, at the location of the former "Black Bridge," located just downstream of the playing fields

5) *Looking downstream along the River Almond, from the Low's Work Weir located just downstream of the Steel Footbridge*

6) *The Low's Work Weir located just downstream of the Steel Footbridge*

7) The culvert bridge, located along the Pow Burn at Lochty Park

8) Huntington Haugh, located adjacent to the Pow Burn

9) The confluence of the Pow Burn with the River Almond

10) Low's Works Cottages

APPENDIX D

FEH Catchment Descriptors and Mouchel's calculated flow values

FEH Catchment Descriptors (FEH CD ROM Version 2.0):

	Easting	Northing	AREA (Km^2)	FARL	PROPWET	ALTBAR	ASPBAR. (degrees)	BFIHOST	DPSBAR (m / km)	DPLBAR (Km)	LDP	SAAR. (mm)	SPRHOST	C	D1	D2	D3	E	F	$URBEXT_{1990}$	$URBEXT_{2000}$
River Almond	306350	726600	172.21	0.99	0.61	410	0.17	0.465	197.6	28.05	50.28	1397	42.68	-0.016	0.492	0.432	0.341	0.244	2.331	0.0002	0.0008
Pow Burn	306800	725400	48.4	0.99	0.46	85	0.22	0.564	41.4	7.13	17.33	860	37.86	-0.015	0.451	0.374	0.294	0.246	2.206	0.0041	0.0133
Methven Loch	306600	725850	0.62	0.77	0.46	48	0.53	0.625	51.5	0.84	1.62	807	37.82	-0.015	0.461	0.363	2.889	0.246	2.197	0.0101	0.0263
Gelly Burn	307300	726200	1.85	0.97	0.46	71	0.37	0.562	79.3	2.33	4.37	839	43.09	-0.015	0.458	0.354	0.293	0.247	2.191	0.004	0.0440

Return Period (years)	Q_{med} Value	Growth Curve Factor	Flows (m^3/ s)
2	121.3	1	121.30
5	121.3	1.309	158.78
10	121.3	1.503	182.31
25	121.3	1.737	210.70
50	121.3	1.903	230.83
75	121.3	2.000	242.60
100	121.3	2.061	250.00
200	121.3	2.213	268.44
200 + CC	-	-	322.12

Table 1: Statistical flows calculated by Mouchel for the River Almond

Return Period (years)	Q_{med} Value	Growth Curve Factor	Flows (m^3/ s)
2	12.29	1.00	12.29
5	12.29	1.41	17.33
10	12.29	1.71	20.97
25	12.29	2.13	26.21
50	12.29	2.496	30.68
75	12.29	2.731	33.57
100	12.29	2.909	35.76
200	12.29	3.377	41.51
200 + CC	-	-	49.81

Table 2: Statistical flows calculated by Mouchel for the East Pow Burn

APPENDIX E

SEPA Correspondence

Letter dated the 27th of November 2009 to SEPA with accompanying appendices

Malcolm MacConnachie
Senior Hydrologist
Scottish Environment Protection Agency
7 Whitefriars Crescent
Perth
PH2 0PA

Contact Paul Swift
Tel 0151 242 7777
Mob 07976 341425
Fax 0151 242 7700
E-mail Paul. Swift@mouchel.com

27th November 2009

Our ref:10020063/SEPA/001

Dear Malcolm,

Flows for the River Almond and East Pow Burn

Mouchel Group has been commissioned by Perth & Kinross Council to undertake a Flood Mitigation Scheme for the town of Almondbank. We began the study in September 2007 and are currently in a position where we are finalising the outline design drawings for a planning submission. Since the schemes commencement, Mouchel and SEPA have liaised on matters relating to the scheme. The liaison between SEPA and Mouchel has been as follows:

1) December 2007: Mouchel met with SEPA to discuss the scheme, SEPA committed to review and comment on all aspects of the proposed scheme, covered in the following documents;
   - Mouchel's Environmental Impact Assessment (2006)
   - Jacobs Babtie Reports (1994,1998 &2000)
   - Royal Haskoning Engineers Report (2004)
   - Royal Haskoning Outline Design (2004)

2) February 2008: SEPA provided Mouchel with a review of the scheme hydrology only (it is understood that SEPA were unable to comment fully at this time due to an internal restructure and subsequent unavailability of resource). The review provided was with reference to the hydraulic flow figures in the various reports and suggested that these were suitable flow values to be used in a hydraulic model for this scheme. (Please refer to Appendix A for a copy of this correspondence and Appendix B, Table 1 for a summary of the flow data.)

3) March 2008: Further to SEPA comments received in February 2008, Mouchel provided SEPA, for completeness, with the results of their own hydrological calculations, however SEPA did not comment on these river flow values. Mouchel continued their hydraulic models based on these proposed values. (Please refer to Appendix B, Table 2 for a summary of Mouchel's flow data.)

4) August 2009: Mouchel approached SEPA to further discuss the 1D & 2D hydraulic model and draft outline design that had been developed using Mouchel's March 2008 calculated river flow values. SEPA proceeded to review and re-calculate river flow values, providing Mouchel with an additional set of flow data. These flow values are different to Mouchel's data provided in March 2008. Note, the data provided by SEPA at this time was not in response to Mouchel letter issued in March 2008. (Please refer to Appendix C for a copy of SEPA's correspondence and Appendix B, Table 3 for a summary of SEPA's flow data.)

When compared to Mouchel's March 2008 flow values, for the 1 in 200 year event, SEPA's August 2009 values have increased flow by approximately 15%.

To establish the impact of the revised flows provided by SEPA in August 2009, Mouchel have inputted the flows calculated from SEPA's data using the AMAX series methodology. In addition, we have further calibrated a model based upon the rating curve at the Black Bridge (To calibrate the flows against the rating curve given at the Black Bridge, Mouchel reduced the roughness values in the hydraulic model). The new flow values combined with a reduction in roughness values in the hydraulic model has meant that the 1 in 200yr flood event water level would be reduced by an average of 300-400mm.

In additional correspondence during August 2009, SEPA requested that Mouchel revisit the analysis of the East Pow Burn flows using the statistical method. Table 4, Appendix B is a comparison of Mouchel's flows using the two different methodologies; rainfall runoff and statistical. The methodology which has been used for calculating these flows is listed in Appendix B. Mouchel propose to continue to use the flow values derived from the rainfall runoff method, which are more conservative than the statistical method. Reference was made to the effect of using the lower flows on the cost benefit, the cost benefit will remain sustainable using these more conservative flow values.

Whilst Mouchel appreciate SEPA's recent comments on the design flows, Mouchel's current outline design solution is based upon our hydraulic calculations provided to SEPA in March 2008. To apply SEPA's latest flow data to the model at this stage will require substantial re-working to the 1D and 2D models, the Outline Design drawings (an extract of one of the drawings is contained in Appendix D to allow SEPA to see the level of detail the scheme has progressed to,), the Economic Appraisal and forthcoming Planning Submission. Any delays, as a result of this will therefore jeopardise the Council's plans to submit the planning application in the early part of 2010.

Mouchel therefore ask SEPA to notify Mouchel if you would find the approach we have used on which to base the outline design and propose to continue using are not to your satisfaction. Your timely response would be appreciated as we are unable to pursue further key elements of the project until we can confirm the appropriate flow values.

If you require any further information or additional discussion on the matter, please do not hesitate to contact myself using the details above.

Yours sincerely

Paul Swift
Project Manager
For and on behalf of Mouchel.
cc Peter Dickson, Perth & Kinross Council
enc Appendices A,B,C&D

Appendix A – Correspondence with SEPA, February 2008

From: Caswell, Sean [Sean.Caswell@SEPA.org.uk]
Sent: 29 February 2008 12:28
To: Paul Lambert
Subject: FW: Almondbank Flood Prevention Scheme - initial response (EA/2007/1510)

Hi Paul, here is copy email from our Alistair Cargill, provided as an interim response. I hope that you find this helpful.

Regards, Sean

Sean,

As discussed here is an initial response on the Almondbank Flood Prevention Scheme, with specific reference to the design hydrology aspects.

In order to provide a view on this important issue (which really needs to be discussed and agreed prior to any critique on the actual scheme design), I have reviewed all past reports for Almondbank as supplied by P&KC to us, including the most recent Mouchel Parkman report (i.e. their Environmental Statement, dated May 2006).

I provide a brief summary table below of all the reports I have examined and what they say regarding design flows. Within this I summarise by providing what our current best estimate design flow estimates are, based on SEPA gauged data at Almondbank used within standard flood frequency analysis methods.

Almondbank FPS – review of design hydrology from past reports

Year	Consultant	Comments
1994	Babtie	Design flows were based on the former standard UK method for flood frequency analysis, i.e. the Flood Studies Report (FSR), 1975. 100-year flow given as 280 cumecs. 50-year flow given as 243 cumecs. 200-year flow estimate was not provided but a 500-year estimate of 380 cumecs was given. The 1993 flood of 233 cumecs is thus ascribed a return period estimate of 1 in 45-years by Babtie. The report makes reference to the historical flood of 18th January 1909 on the River Almond. Design flows were also provided for the Pow Burn and the Mill Lade.
1998 (Feb)	Babtie	Same conclusions as the 1994 Babtie report (as above)
1998 (Dec)	Babtie	This report focussed on the Pow Burn and Mill Lade hydrology only.
2000	Babtie	Report states that SEPA revised it's estimate of the return period for the 1993 flood from 1 in 100-years to 1 in 70-years. This is anomalous – SEPA never considered the 1993 flood to ever have been as rare as 1 in 100-year event. At the time of the flood, SEPA assessed it as being a 1 in 70-year event. This statement by Babtie in this 2000 report conflicts with what they said in their 1994 report regarding SEPA's rarity estimate. The report then references the 1999 flood (which was almost the same magnitude as the 1993 flood), but makes no statement on how the inclusion of this important additional data affects the return period of the 1993 flood (or the rarity estimates of the 1999 flood itself, for that matter).
2004	Royal Haskoning – P&KC Engineers Report.	This report also states that SEPA's estimate of the 1993 flood was 1 in 100-year (originally) but had now been revised to 1 in 50-year. It also states that SEPA consider both 1993 and 1999 floods on the Almond to be 1 in 50-year flood events.
2006	Mouchel Parkman	Report states that SEPA estimate of 1993 flood is 1 in 70-years.
2008 (Feb)	SEPA	SEPA's estimate of the 1993 flood (at the time of the flood event, in 1993) was 1 in 70-years SEPA's current estimates for the 1993 and the 1999 floods (based on FEH methods) are as below: **FEH Single-Site analysis:**

		1993 flood (233 cumecs) = 1 in 43-year event 1999 flood (225 cumecs) = 1 in 36-year event 100-year flow estimate = 272 cumecs (note this is less than Babtie est. in 1994) 200-year flow estimate = 310 cumecs **FEH 'default' Pooling-Group analysis:** 1993 flood (233 cumecs) = 1 in 40-year event 1999 flood (225 cumecs) = 1 in 30-year event 100-year flow estimate = 277 cumecs (note this is less than Babtie est. in 1994) 200-year flow estimate = 318 cumecs **NOTE:** none of the above FEH methods (which utilise the 'up-to-date' SEPA record at Almondbank gauging station) incorporate any analysis or consideration of past, historical flood events on the River Almond, e.g. Jan 1909 event. As such, the sampling variability of the analysis is high and such estimates may suffer from an underestimation in risk due to the non-inclusion of pre-instrumental flood events. SEPA have not undertaken a rigerous review of the Pooling-Group approach and merely used a 'default' group – there is thus scope for this method to be improved. SEPA thus recommend a precautionary approach to flood frequency analysis and any design flows adopted for the design of the Almondbank Flood Prevention Scheme. The original analysis by Babtie in 1994 (based on the FSR methods) may provide the most conservative estimates available at this time in the absence of a more detailed study which looked at all known historical floods on the River Almond. SEPA consider the FSR approach to still be a valid technique if used alongside other standard methods including the more contemporary FEH. Whilst the FEH provides the analyst with greater freedom to apply hydrological judgement and experience, issues of subjectivity and station data heterogeneity prevail within this approach – it is not a panacea. As such SEPA are happy to adopt a conservative estimate based on the more prescriptive FSR approach, provided it has been compared against other viable approaches (as laid out above).

Whilst I have not yet been able to devote time to considering the design hydrology for the Pow and Mill Lade, I hope I can do this soon if required.

For now, I hope the above is useful in order to make an initial response to the Flood Prevention Authority and their consultants on the design hydrology for the River Almond at Almondbank.

Alistair

Dr Alistair Cargill
Flood Risk Hydrology Section
Scottish Environment Protection Agency
7 Whitefriars Crescent
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Appendix B – Comparison of Flow data for the River Almond and the Pow Burn

Table 1: River Almond Flow values from SEPA review, February 2008.

Return Period (Years)	Flow Values (m^3/s)
2	No data available
5	No data available
10	No data available
25	No data available
50	No data available
100	277
200	310

Table 2: River Almond Flow values calculated by Mouchel, March 2008.

Return Period (Years)	Flow Values (m^3/s)
2	120.93
5	158.30
10	181.76
25	210.06
50	230.13
100	249.24
200	267.62

Table 3: River Almond re-calculated Flow values from SEPA, September 2009.

Return Period (Years)	Flow Values (m^3/s)
2	112
5	148
10	174
25	210
50	240
100	273
200	311

Table 4: Statistical and Rainfall Runoff Method Comparison for the East Pow Burn, undertaken by Mouchel September 2009.

Return Period (Years)	Rainfall Runoff Method (m^3/s)	Statistical Method (m^3/s)
5	21.25	17.33
10	25.52	20.97
25	31.68	26.21
50	36.87	30.68
75	39.67	33.57
100	41.95	35.76
200	47.99	41.51

Appendix C - Correspondence with SEPA, August 2009

Cunard Building Water Street Liverpool L3 1ES

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Andrew Williamson

From: MacConnachie, Malcolm [Malcolm.MacConnachie@sepa.org.uk]
Sent: 13 August 2009 17:16
To: Andrew Williamson
Cc: Hamilton, Richard
Subject: RE: Almond Bank Hydrology
Attachments: Almondbank an max series (2009).xls

Hi Andy,

Please find the annual maximum peak flows and estimated design flows for the River Almond at Almondbank.

I would recommend that these flows be used as the upstream boundary to your model but I would also suggest running your model in both steady and unsteady states for comparison.

The information contained in this email is supplied to you by SEPA under the Environmental Regulations 1992 in response to your request for information under these Regulations. This information is the information relating to your request held by SEPA as at date hereof under Section 25(1) of the Environment Act 1995.

I am not in the office tomorrow (Friday) so you if you have any queries can you please contact my colleague Richard Hamilton or wait till I am back on Monday.

Regards,

Malcolm

A.Malcolm MacConnachie
Senior Hydrologist
Scottish Environment Protection Agency
7 Whitefriars Crescent
Perth

tel: 01738 627989
fax: 01738 630997
email: malcolm.macconnachie@sepa.org.uk

From: Andrew Williamson [mailto:Andrew.Williamson@mouchel.com]
Sent: 12 August 2009 11:54
To: MacConnachie, Malcolm
Subject: Almond Bank Hydrology

Dear Malcom,
Further to our conversation yesterday, please find attached an annotated drawing showing the location of the river gauge and the flooding mechanism. Basically my question was what was the best approach to be using in terms of the hydrology - this is really a key issue for us in taking the scheme forward.

Obviously the gauge data has been used to determine the flows coming into the catchment, but when these flows have been placed into the top of the model, the flows are less at the bridge than at the top of the catchment, as water is lost from the system before it reaches the bridge. To rectify this, flows have been increased so that they are what they have been measured to be at the bridge. This however has meant that flows coming into the catchment are considerably higher than those measured at the bridge.
The values we have measured at the bridge and the values we have placed in the top of the catchment in order to achieve this figure are also attached. It does seem however that these figures to seem very high for inflows coming into the catchment and maybe something to do with the roughness values used along the river banks.
We just really need to bottom out what is the best approach to take for this, i.e. increasing flows coming into the catchment to achieve the measured flow at the bridge, or just using the measured flows at the bridge as the inflow into the catchment.
I will phone you later to discuss.
Many Thanks,
Andy

Andrew Williamson

Assistant Engineer

Mouchel Group plc

Cunard Building

Liverpool

L3 1ES

(Tel) 0151 – 242 7777

(Fax) 0151 – 242 7704

Andrew Williamson

From: MacConnachie, Malcolm [Malcolm.MacConnachie@sepa.org.uk]
Sent: 17 August 2009 17:12
To: Andrew Williamson
Subject: RE: Almond Bank Flows

Hi Andy,

I refer to your email below (17 August 2009) and our telephone conversation.

River Almond
The return period figures that I emailed to you previously for the River Almond were based on a single site analysis using the Amondbank annual maximum flow data that I sent you. SEPA would be satisfied if you adopted the 311 cumecs the 1:200 yr design flow for the River Almond.

Pow
I note that you used the Rainfall -runoff method to estimate a 1:200 yr flow of 48 cumecs for the Pow. I have also repeated this execise and got a similar answer. However I would question if the rainfall-runoff method is the best method to apply to this catchment. There is considerable upstream storage and I would recommend using the FEH statistical method for this catchment for comparison. Previously Babtie had derived an estimate of about 34 cumecs for this watercourse - this may have been derived using the FSR method. I also note that using the reFH gives an estimate of around 33 cumecs. I understand the desire to take a precautionary approach by using the higher design flow but would be concerned if the scheme failed the cost benefit analysis based on this decision. I would suggest that the impact could be quickly checked by runing both flows in the hydraulic model.

The information contained in this email is supplied to you by SEPA under the Environmental Regulations 1992 in response to your request for information under these Regulations. This information is the information relating to your request held by SEPA as at date hereof under Section 25(1) of the Environment Act 1995.

Regards,

Malcolm MacConnachie

A.Malcolm MacConnachie
Senior Hydrologist
Scottish Environment Protection Agency
7 Whitefriars Crescent
Perth

tel: 01738 627989
fax: 01738 630997
email: malcolm.macconnachie@sepa.org.uk

From: Andrew Williamson [mailto:Andrew.Williamson@mouchel.com]
Sent: 17 August 2009 12:27
To: MacConnachie, Malcolm
Cc: Ling Tong; Olivier Drieu
Subject: Almond Bank Flows

Hi Malcolm,
Thank you for the information regarding the Almond Bank flows. Would you be able to infom us as to how these figures have been worked out from the Q-Med? Either from the pooling group analysis or growth curves? It was suggested that these figures you sent us were actually calculated using the rainfall runoff method as apposed to the Q-Med.
I have attached the flows we have used for the POW Burn which have also been used in our model, do you have any comments regarding these flows? This is really so that we do not have to go back and change any of these flows in the model at a later date. These figures were calculated using the rainfall runoff method, as they were more conservative than the statistical method.
I will call later to discuss.
Many Thanks,
Andy

Andrew Williamson

Assistant Engineer

Mouchel Group plc

Cunard Building

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(Tel) 0151 – 242 7777

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Summary Sheet for the FEH statistical analysis for Pow Burn (Almond Bank)

1. Introduction

A hydrodynamic model was required due to the possible over bank flow routes and the potential for key structures to attenuate flood flows. During larger events the ability to accurately assess over bank flow routes becomes critical, and this cannot be achieved within the confines of a simple steady–state (peak flow) regime. Therefore, flow hydrographs are required as input to the hydrodynamic model.

Hydrological analysis has been undertaken to derive design flow estimates for the flood prevention scheme and in particular for Pow Burn, tributary of the River Almond in the town of Almond Bank.

For Pow Burn catchment, design event hydrographs were generated for events with return periods of 5, 10, 25, 50, 75, 100 and 200 years. Events with return periods of 75, 100 and 200 years are of particular interest for further stages of the flood mitigation scheme.

The standard approach taken for this hydrological analysis is to use the hybrid method i.e. a combination of FEH statistical and rainfall runoff techniques. For the analysis, the FEH CDROM 2 (2007) has been used.

This Summary Sheet provides a summary of the FEH statistical method developed for Pow Burn at the point of interest located 50 m upstream of Lochty bridge (306849, 725401). This location is referred to the 'bridge site' in the analysis.

2. Site Information

Site Name:	Pow Burn at Lochty bridge (tributary of river Almond)
Grid reference of the point to assess	306849, 725401

Table 1 – Point of Interest Information Summary

3. FEH Statistical Method

The bridge site is ungauged.

a. Qmed Estimation

Qmed (the index flood) was estimated by using various methods :

- FEH catchment descriptors using both the original and revised Qmed equation.
- Bankfull channel width method: three cross-sections immediately upstream of the bridge site were used to get the average of the channel width at the location and to estimate Qmed.
- A suitable analogue site was selected using WINFAP 2 : Station No 15008 Dean Water@Cookston (SEPA station (334000, 747900, NO34004790)
- Data transfer with revised method developed by CEH for the ungauged catchment.

b. FEH Catchment Descriptors

Catchment descriptors were derived from the FEH CD-ROM 2 for both bridge and analogue sites. Both catchments are fluvial and essentially rural catchments.

The current cut-off year for the scheme is 2009, therefore URBEXT2000 has been updated to year 2009. Please note that it is currently been discussed with the client (Perth and Kinross

Council) a possible design life of 50 years for this scheme (URBEXT2000 value may be then updated to year 2059 at a later stage).

For the analysis, the URBEXT2000 values were estimated with an updated UEF equation[1].

The key catchment descriptors the bridge site and the analogue catchment are shown in Table 2.

FEH catchment descriptor	Pow Burn at Lochty bridge	Analogue site: Station No 15008 Dean Water@Cookston	Units
AREA	48.4	176.6	km^2
ALTBAR	85	140	m
BFIHOST	0.564	0.622	
DPLBAR	7.13	14.42	km
DPSBAR	41.4	59.2	m / km
FARL	0.994	0.973	
LDP	17.33	26.3	km
PROPWET	0.46	0.38	
RMED – 1H	8.3	8.2	mm
RMED – 1D	34.9	37.1	mm
RMED – 2D	45.1	48.3	mm
SAAR	860	840	mm
SPRHOST	37.86	37.21	
URBEXT2000	0.0133	0.0146	
URBEXT2000 (2009)	0.0136	0.0149	

Table 2 – FEH catchment descriptors

c. Analogue site

A suitable analogue site was selected from the WINFAP pooling group: Station No 15008 Dean Water@Cookston (SEPA station (334000, 747900, NO34004790) which is on the Hi-Flows-UK database. The Hi-Flows-UK database has an AMAX series of more than 13 years of data and states that this site is suitable for Qmed calculations and pooling group analysis.

The current AMAX series available on Hi-Flows-UK was from 1956 to 2002. SEPA was contacted and the AMAX series was updated till 2009. The maximum annual peak on record to date occurred in 1957 (45.47 m^3/s). Qmed from AMAX series at this analogue site = 26.45 (m^3/s).

Out of the four criteria recommended recently by FEH methodology for the selection of analogue site (FARL, BFIHOST, SAAR and AREA), all four criteria were satisfied.

Catchment descriptor	Bridge site	Analogue site	Criteria required	Criteria satisfied?
FARL	0.99	0.97	Difference of 0.05	Yes
BFIHOST	0.56	0.62	Difference of 0.18	Yes
SAAR	860	840	Factor of 1.25	Yes
AREA	85	140	Factor of 4 to 5	Yes

Table 3 – Catchment descriptor selection criteria for analogue site

[1] *UEF = 0.7851 + 0.2124 tan-1[(Year – 1967.5) / 20.32)] The equation used is taken from CEH document named 'The use of LCM2000 to provide improved definition of the FEH catchments descriptor URBEXT in Northern Ireland; Stage 2- Calculation and dissemination of URBEXT2000 values' CEH, March 2006*

d. Pooling Group

WINFAP automatically selects hydrologically similar catchments from the Hi-Flows-UK sites that are defined as being suitable for pooling. The growth curves of these gauged locations are then combined to create a composite growth curve for the study site, allowing predictions of peak flow for return periods of interest to be generated.

Details of the pooling group are provided in Appendix and Table 4 shows the growth factor for each return period.

Return Period	Growth Factor
2	1.00
5	1.41
10	1.71
25	2.13
50	2.496
75	2.731
100	2.909
200	3.377

Table 4 – Growth factor from the pooling group analysis

4. Results

a. Qmed Results

Table 4 outlines the different methods used for obtaining Qmed and the values.

Site	Qmed from catchment descriptors (original equation) (m3/s)	Qmed from catchment descriptors (revised equation)2 (m3/s)	Qmed (bankfull) (m3/s)	Qmed at Bridge site from data transfer (m3/s)	Final value of Qmed (m3/s)
Pow Burn at Lochty bridge	7.95	9.53	14.63	12.29	12.29

Table 5 – Q-med results and comparison

Please note that: for an ungauged upstream catchment, the FEH warns that the estimation of Qmed from catchment descriptors is inappropriate for flood frequency estimation in the design of major flood defence schemes. Therefore, the final value of Qmed is the one derived with analogue site.

The product of QMED and the growth curve was then used to obtain a peak design flow for each return period.

---

2 *Qmed is estimated with the most recent FEH equation (New (2007) CEH Wallingford QMED equation - from project funded by the Environment Agency 'Improving the FEH statistical procedures for flood frequency estimation' - June 2008):*

$$QMED = 8.3062 AREA^{0.8510} 0.1536^{\left(\frac{1000}{SAAR}\right)} FARL^{3.4451} 0.0460^{BFIHOST^2}.$$

b. Statistical Method Peak Flow Estimates

Table 5 shows the statistical estimates based on pooling analysis of peak flows generated for each return period.

Site	Flood peak (m3/s) for the following percentage chance of an event occurring in any one year (with return periods in years in brackets)						
	20% (5)	10% (10)	4% (25)	2% (50)	1.33% (75)	1% (100)	0.5% (200)
Pow Burn at Lochty bridge	17.33	20.97	26.21	30.68	33.57	35.76	41.51

Table 6: Peak flows estimated using the FEH statistical method (based on final value of Qmed)

FIGURES

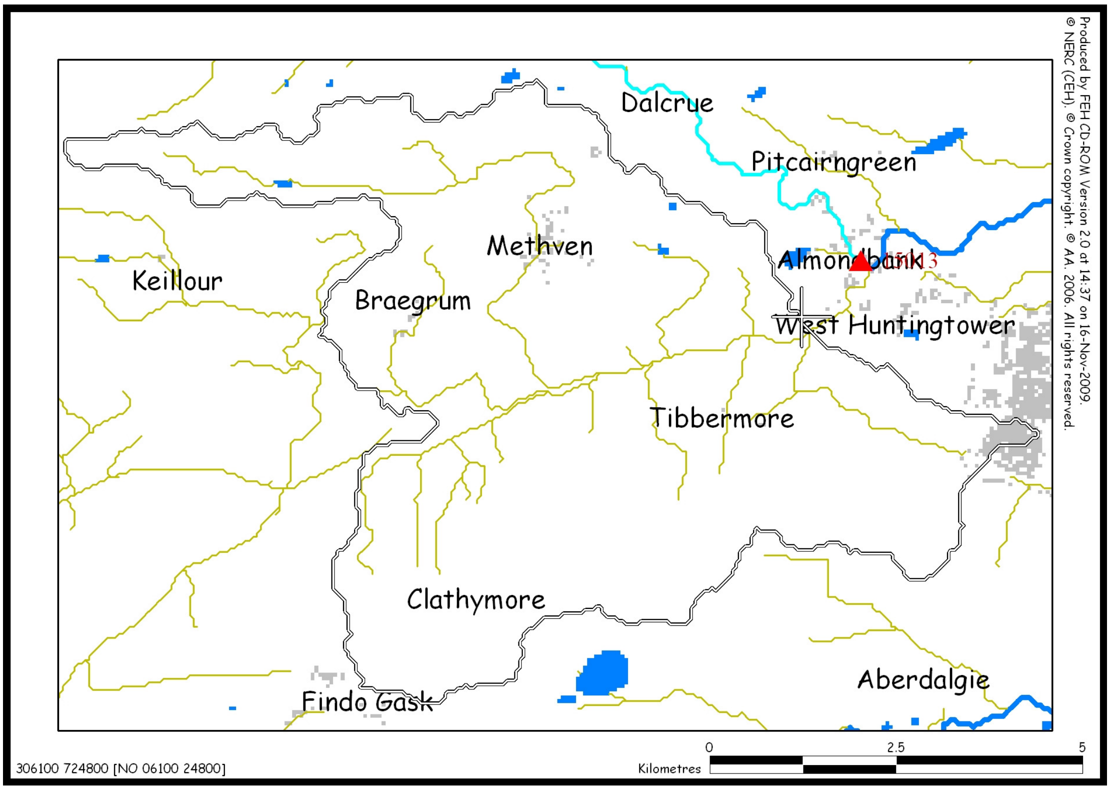


Figure 1: Pow Burn Catchment Area

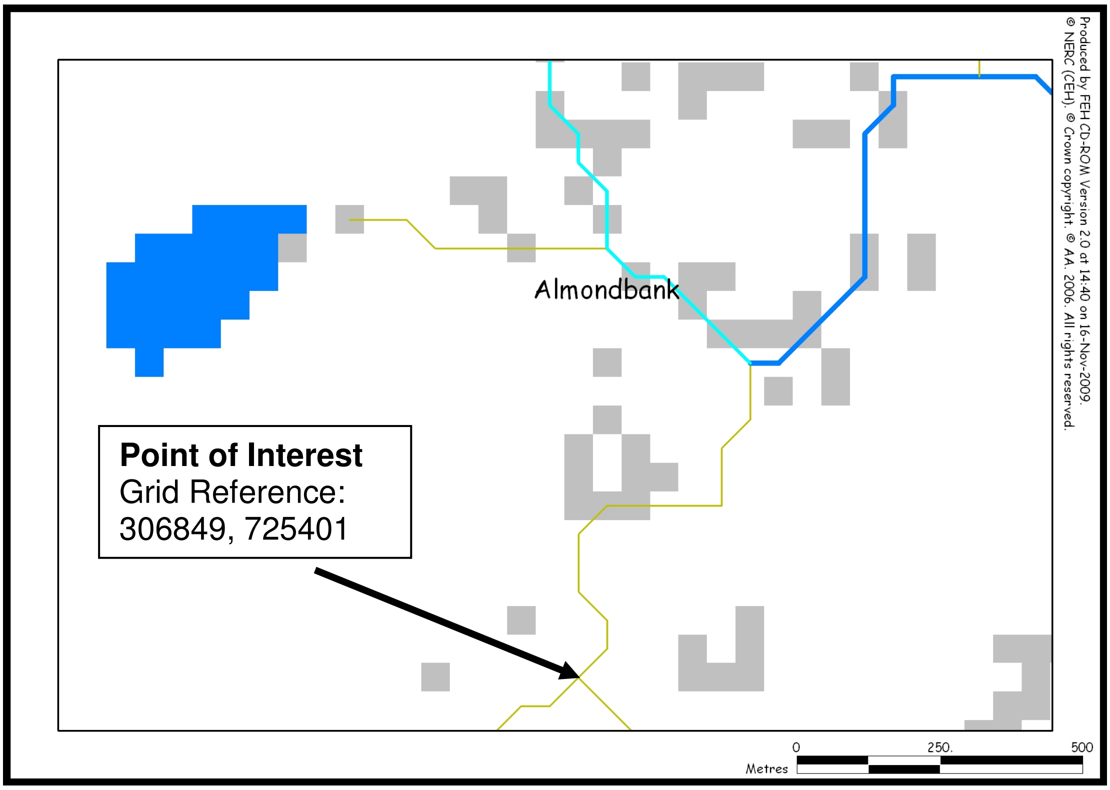


Figure 2: Pow Burn Lochty Bridge Location

	Station	Years	L-CV	L-Skewne	L-Kurtosis	Discordancy	Distance
1	19004 (North Esk @ Dalmore Weir)	42	0.208	0.234	0.254	0.829	0.371
2	20007 (Gifford Water @ Lennoxlove)	30	0.436	0.310	0.149	2.822	0.421
3	53017 (Boyd @ Bitton)	30	0.260	0.125	0.116	0.241	0.478
4	19008 (South Esk @ Prestonholm)	26	0.367	0.304	0.318	1.382	0.487
5	20005 (Birns Water @ Saltoun Hall)	41	0.289	0.220	0.199	0.136	0.503
6	13001 (Bervie @ Inverbervie)	24	0.187	0.196	-0.005	1.638	0.511
7	51001 (Doniford Stream @ Swill Bridge)	36	0.284	0.351	0.362	1.794	0.512
8	67009 (Alyn @ Rhydymwyn)	47	0.244	0.286	0.327	1.400	0.537
9	52004 (Isle @ Ashford Mill)	39	0.124	0.008	0.032	1.036	0.542
10	66005 (Clwyd @ Ruthin Weir)	27	0.143	-0.047	0.222	1.596	0.554
11	19011 (North Esk @ Dalkeith Palace)	41	0.319	0.294	0.216	0.353	0.560
12	41022 (Lod @ Halfway Bridge)	30	0.274	0.207	0.118	0.204	0.562
13	55022 (Trothy @ Mitchel Troy)	25	0.167	-0.190	0.133	2.761	0.576
14	206004 (Bessbrook @ Carnbane)	17	0.082	0.023	0.076	1.605	0.581
15	55013 (Arrow @ Titley Mill)	35	0.208	0.174	0.167	0.152	0.589
16	53013 (Marden @ Stanley)	34	0.276	0.184	0.151	0.107	0.592
17	52010 (Brue @ Lovington)	39	0.288	0.388	0.265	1.069	0.605
18	30004 (Lymn @ Partney Mill)	41	0.246	0.045	0.070	0.772	0.607
19	49004 (Gannel @ Gwills)	34	0.250	0.116	0.018	0.991	0.631
20	54034 (Dowles Brook @ Oak Cottage, Dowles)	32	0.238	0.188	0.071	0.413	0.669
21	25019 (Leven @ Easby)	24	0.319	0.305	0.255	0.490	0.675
22	21016 (Eye Water @ Eyemouth Mill)	36	0.279	0.135	0.257	0.717	0.678
23	76010 (Petteril @ Harraby Green)	33	0.188	0.253	0.117	1.021	0.688
24	42014 (Blackwater @ Ower)	27	0.183	0.229	0.120	0.850	0.695
25	11004 (Urie @ Pitcaple)	15	0.300	0.220	0.143	0.280	0.737
26	21027 (Blackadder Water @ Mouth Bridge)	29	0.327	0.243	0.153	0.518	0.741
27	39025 (Enborne @ Brimpton)	36	0.198	0.104	-0.027	1.388	0.746
28	9004 (Bogie @ Redcraig)	23	0.329	0.323	0.196	0.480	0.753
29	68020 (Gowy @ Bridge Trafford)	24	0.155	-0.186	0.178	2.918	0.755
30	49002 (Hayle @ st Erth)	46	0.249	0.253	0.176	0.178	0.786
31	15008 (Dean Water @ Cookston)	50	0.129	0.044	0.158	0.858	0.787
32							
33	Total	1013					
34	Weighted means		0.253	0.193	0.180		

Figure 3 - Details of the Pooling Group Analysis (from WINFAP 2)

Growth Curve Fittings

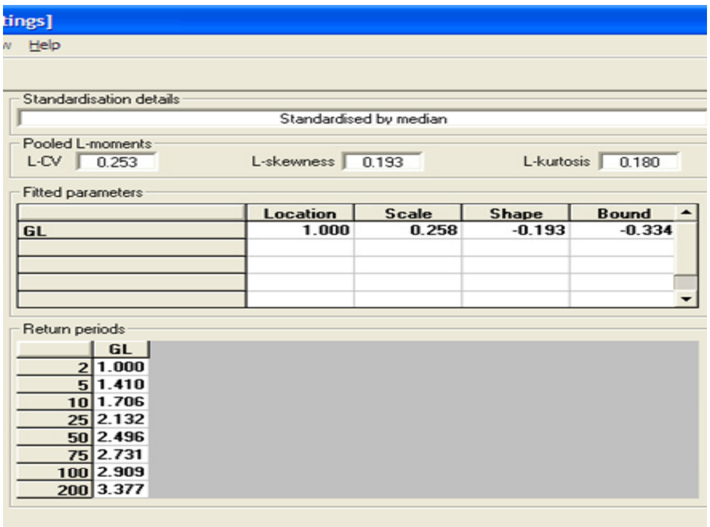
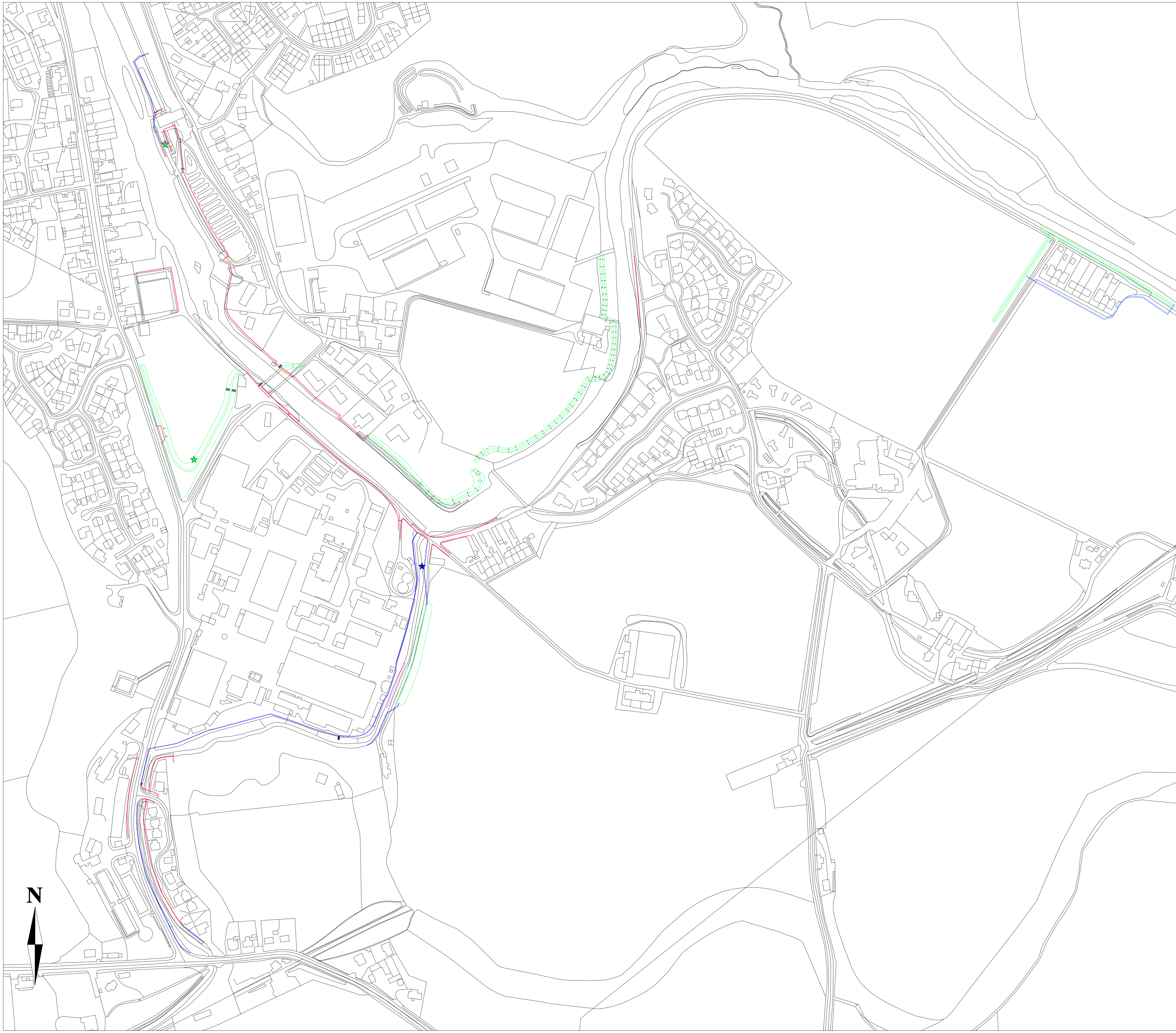


Figure 4 – Growth Curve Fittings

Appendix D – Mouchel overall plan of the proposed flood defences for Almondbank

Cunard Building Water Street Liverpool L3 1ES

T 0151 242 7777 **F** 0151 242 7700 info@mouchel.com www.mouchel.com



NOTES

It should be noted that certain locations not shown may be at risk of flooding from other sources (piped drain systems, watermains etc.) and from other watercourses not shown in this study.

LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

- PROPOSED WALL DEFENCE LOCATIONS
- PROPOSED SHEET PILE WALL DEFENCE LOCATIONS
- PROPOSED EMBANKMENT DEFENCE LOCATIONS

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
1	10/09/10	Draft

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Almondbank Flood Alleviation Scheme Modelling Component

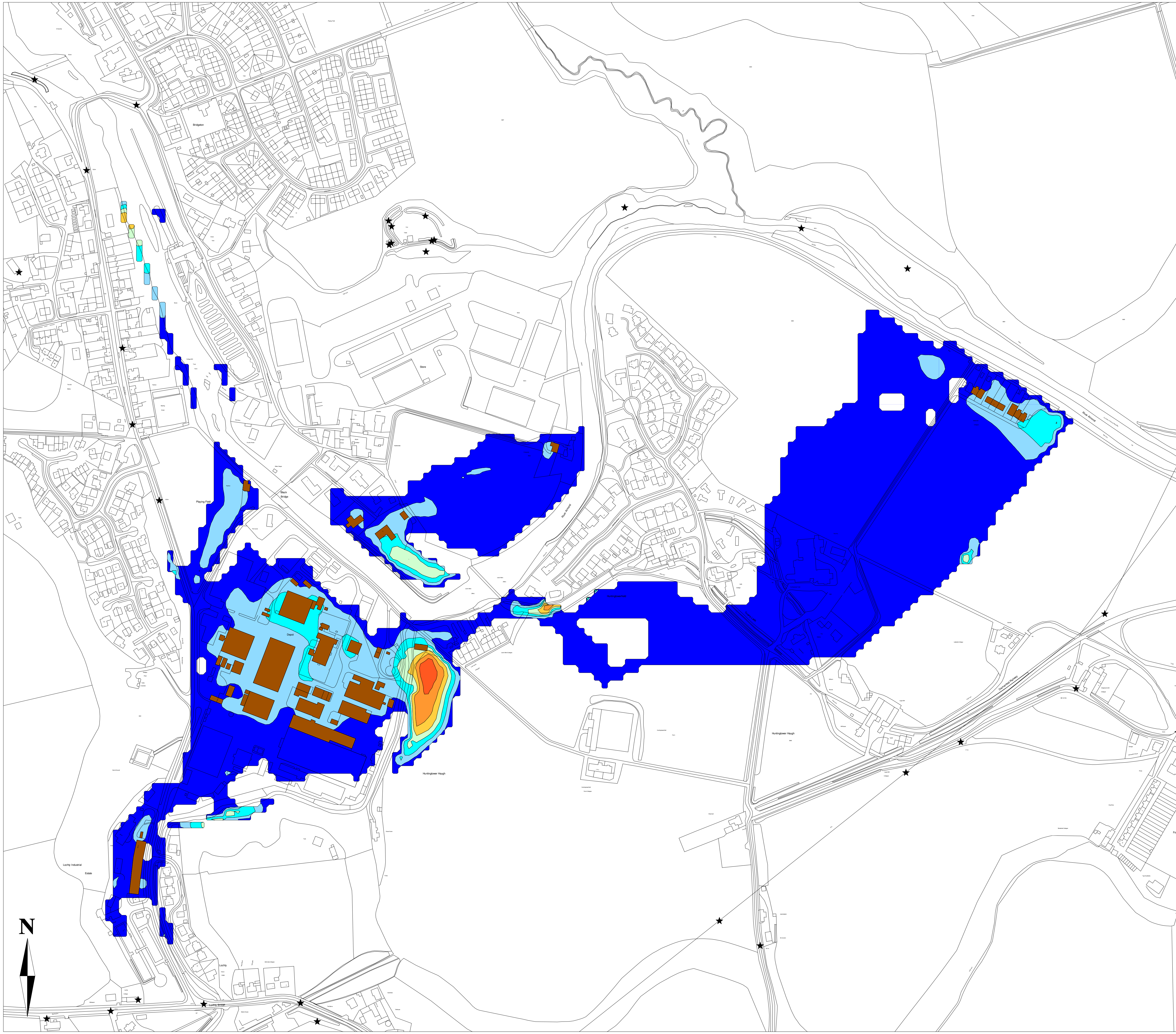
Preferred Option Flood Defence Locations

Date of Issue: 9th September 2010

Scale: Not to Scale

APPENDIX F

Verification Event Flood Outlines, January 1993 and September 1999



NOTES

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LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

Buildings with flooding above threshold level (Estimated not ancedotal)

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

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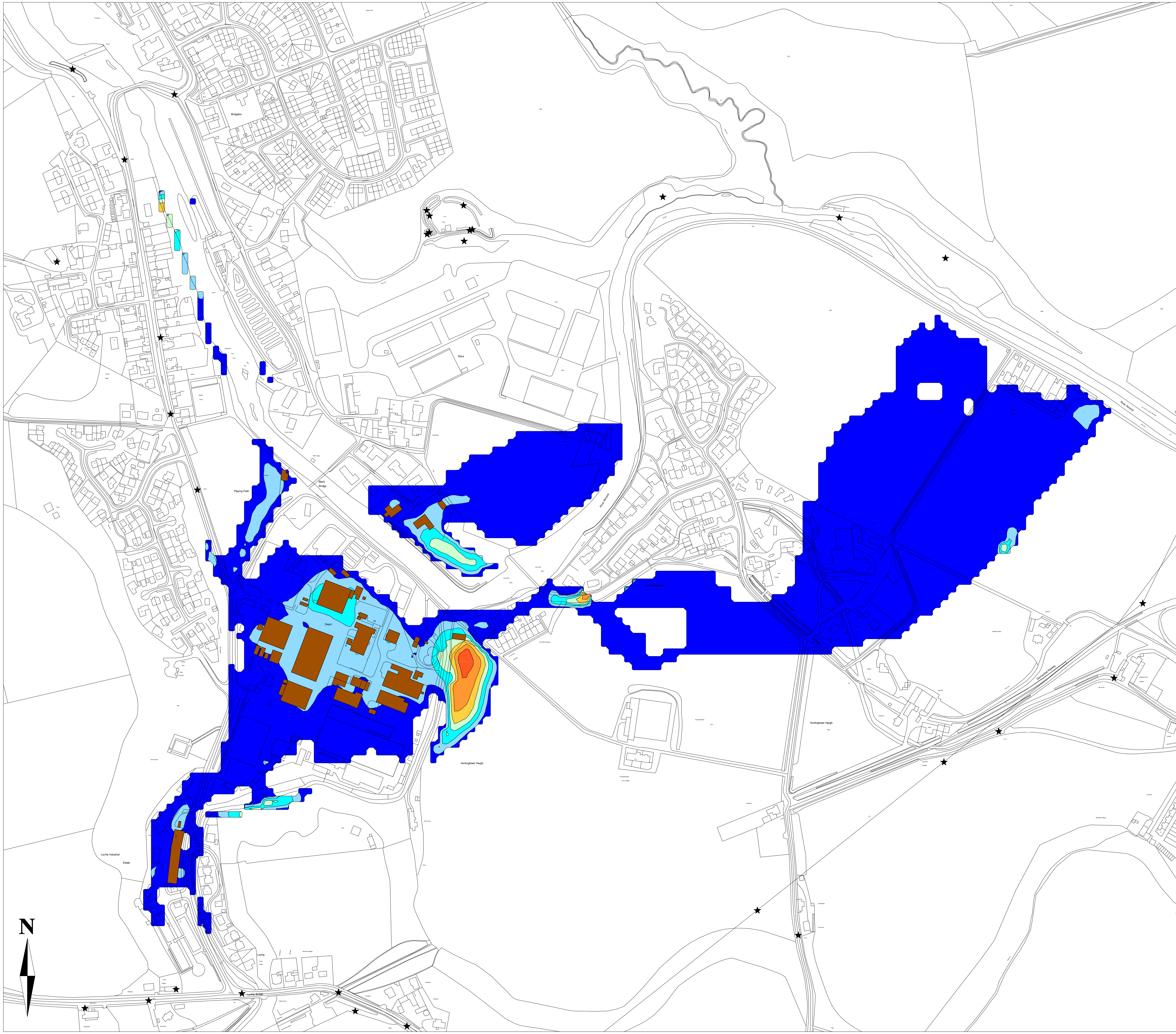
Almondbank Flood Mitigation Scheme

Simulation of Flooding in January 1993 (Maximum Flood Extents)

Date of Issue: 27.02.12

Scale: Not to scale



NOTES

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LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

Buildings with flooding above threshold level (Estimated not ancedotal)

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

Almondbank Flood Mitigation Scheme

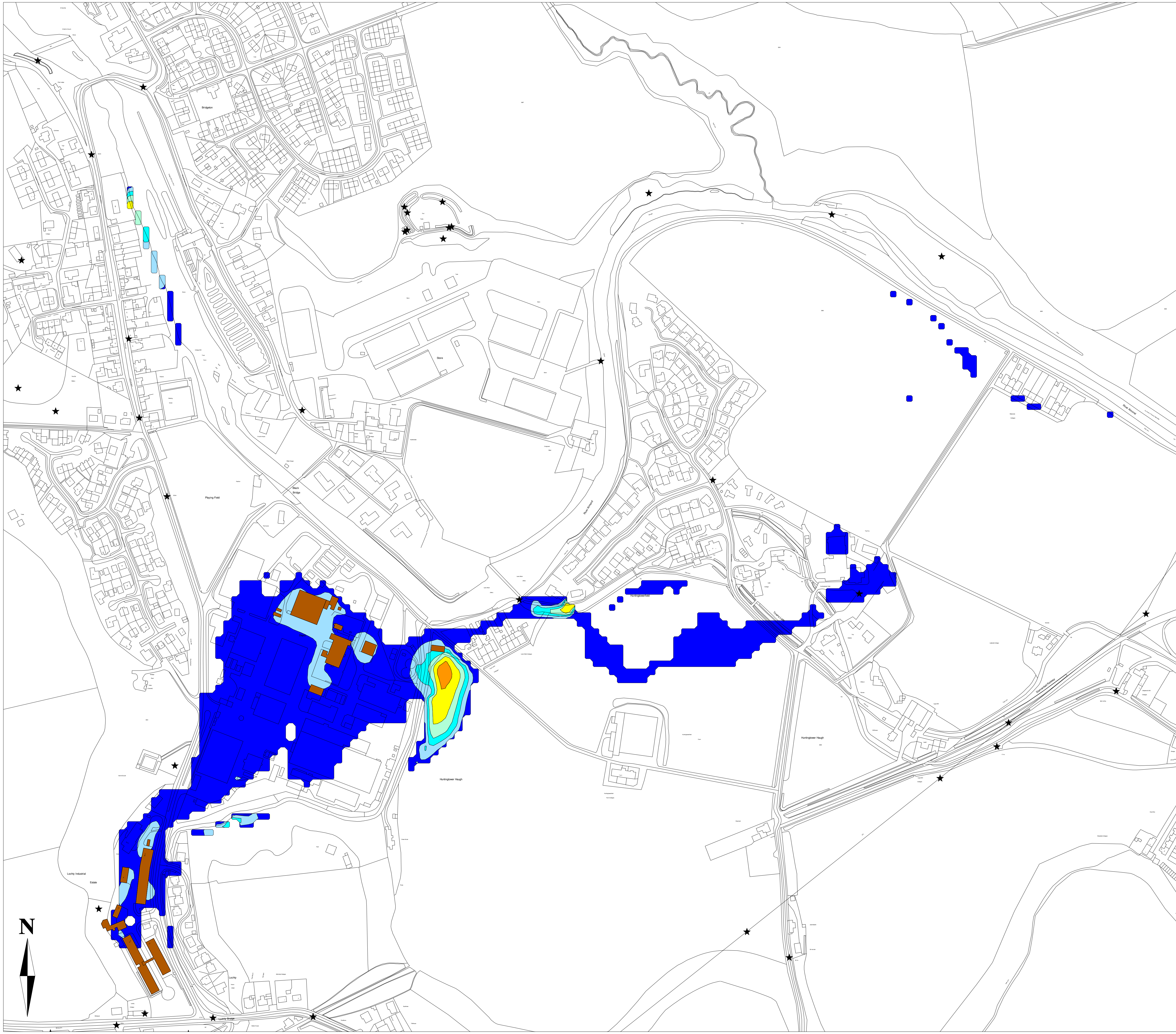
Simulation of Flooding in September 1999 (Maximum Flood Extents)

Date of Issue: 27.02.12

Scale: Not to scale

APPENDIX G

Do Minimum Flood Outlines (1 in 10, 25, 50, 75, 100, 200 and 200 + CC)



NOTES

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LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

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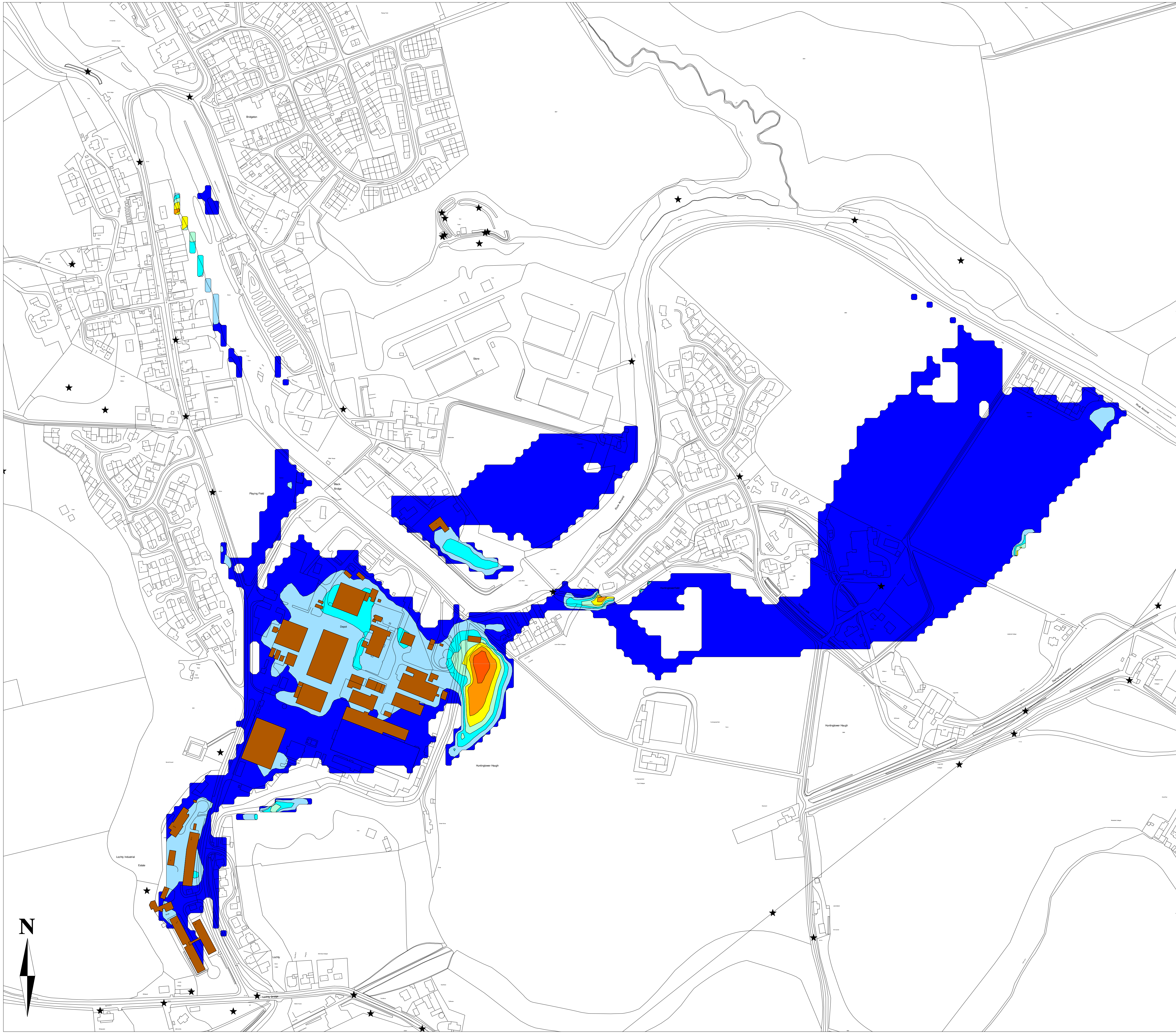
Almondbank Flood Mitigation Scheme

1 in 10 year do minimum

Date of Issue: 27.02.12

Scale: Not to scale



NOTES

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LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

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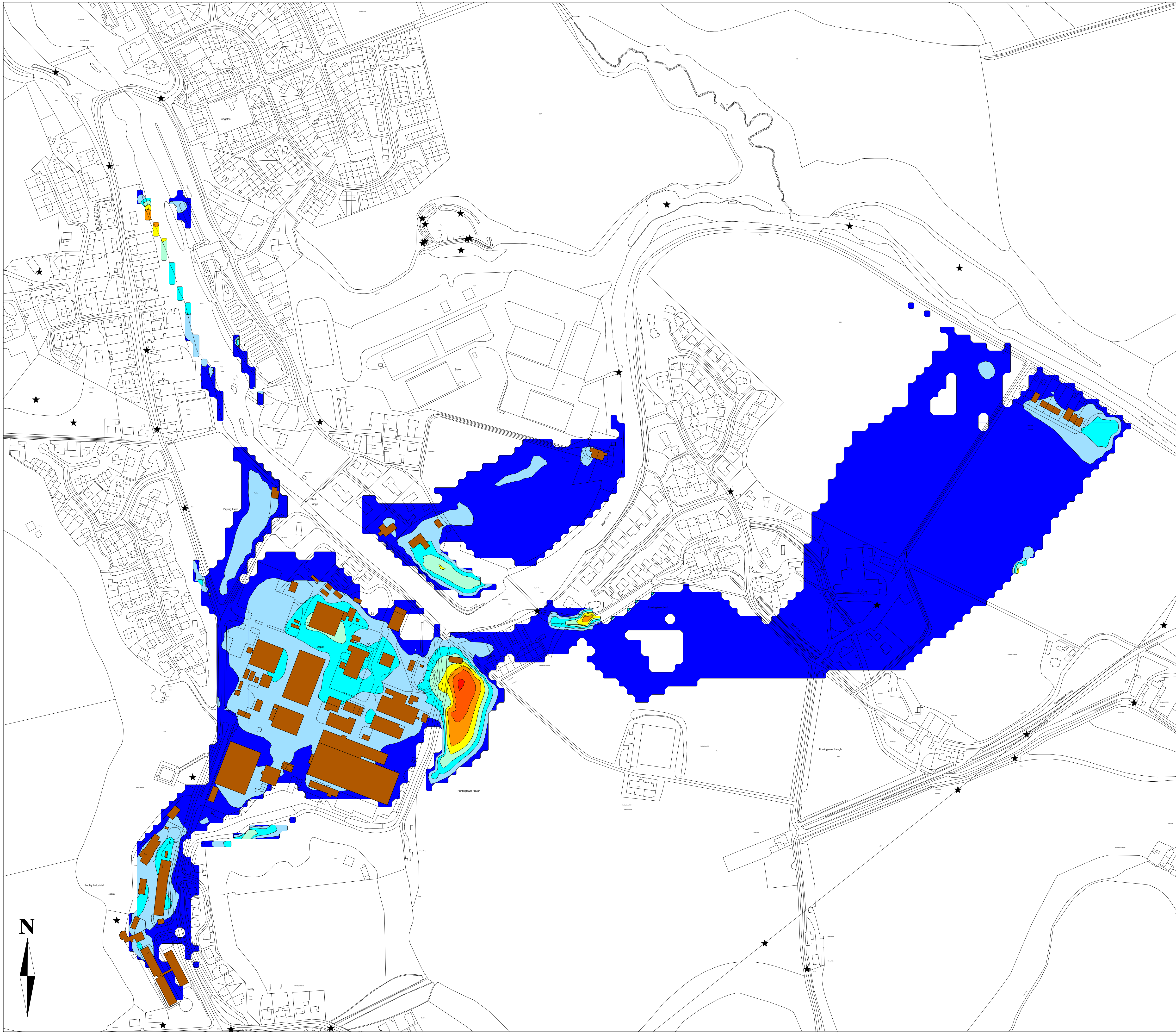
Almondbank Flood Mitigation Scheme

1 in 25 year do minimum

Date of Issue: 27.02.12

Scale: Not to scale



NOTES

It should be noted that certain locations not shown may be at risk of flooding from other sources (piped drain systems, watermains etc.) and from other watercourses not shown in this study.

LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

0.00 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.00

Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

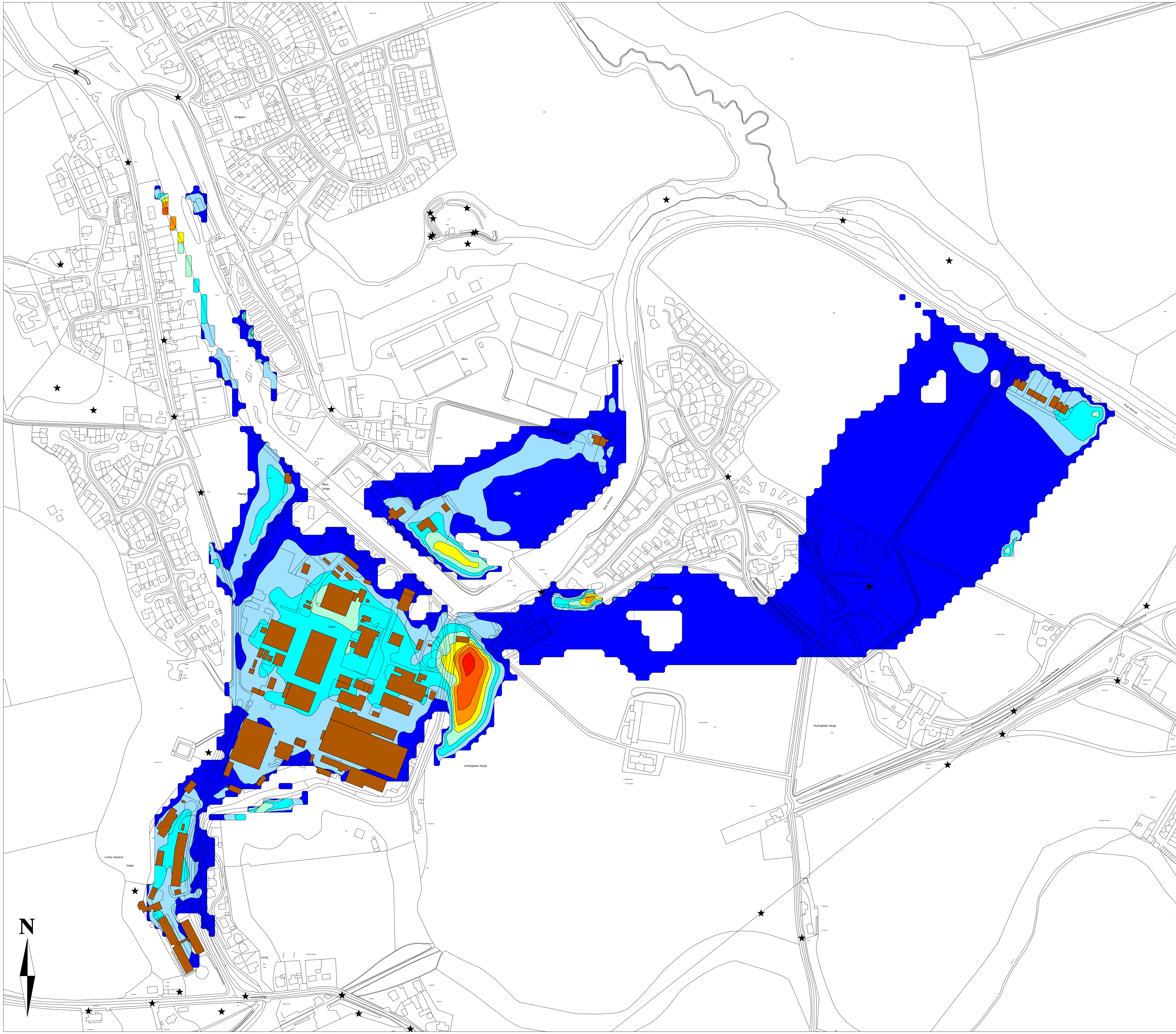
REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

Almondbank Flood Mitigation Scheme

1 in 50 year do minimum

Date of Issue: 27.02.12

Scale: Not to scale



NOTES

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LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00
- Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

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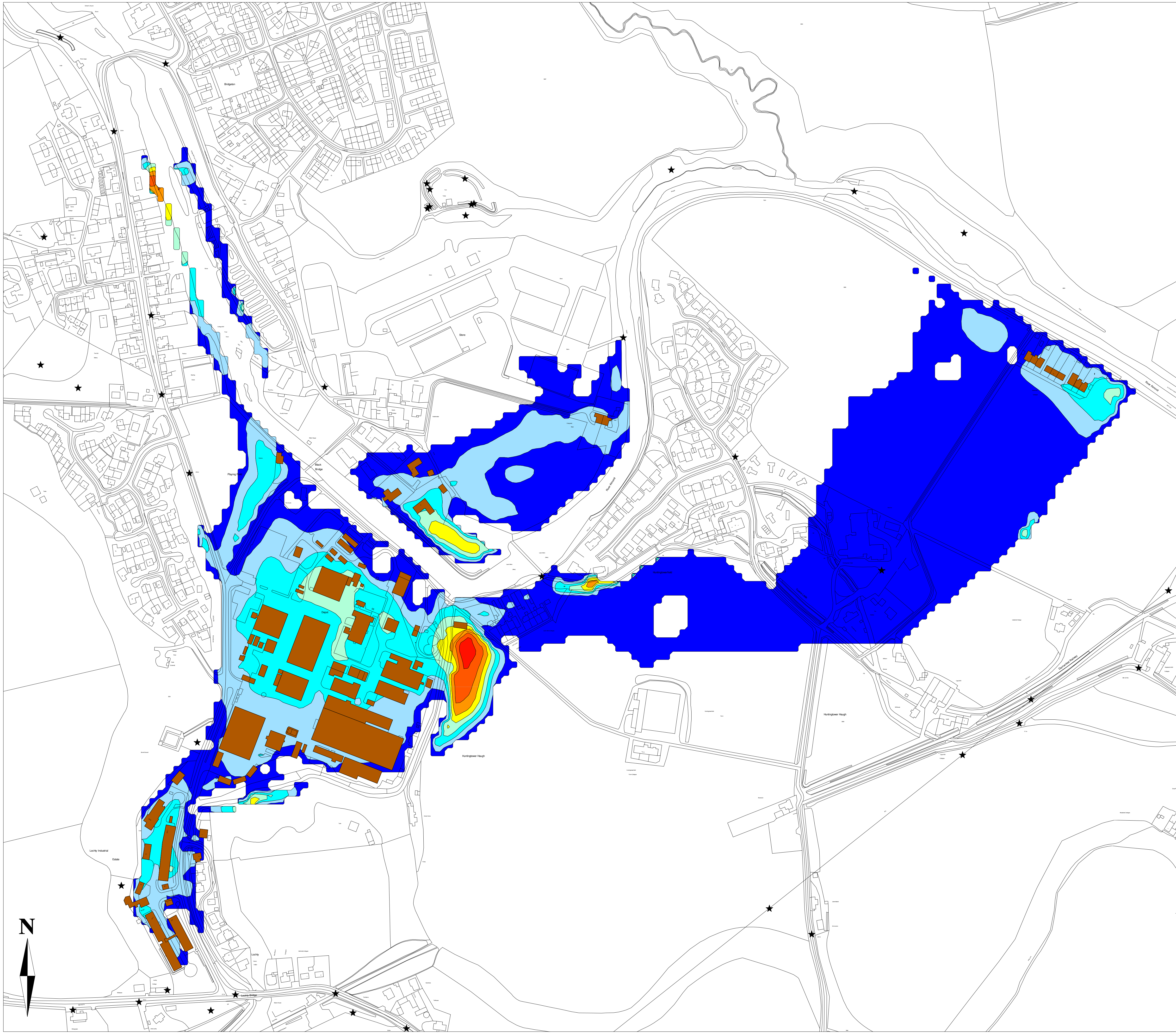
Almondbank Flood Mitigation Scheme

1 in 75 year do minimum

Date of Issue: 27.02.12

Scale: Not to scale



NOTES

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LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

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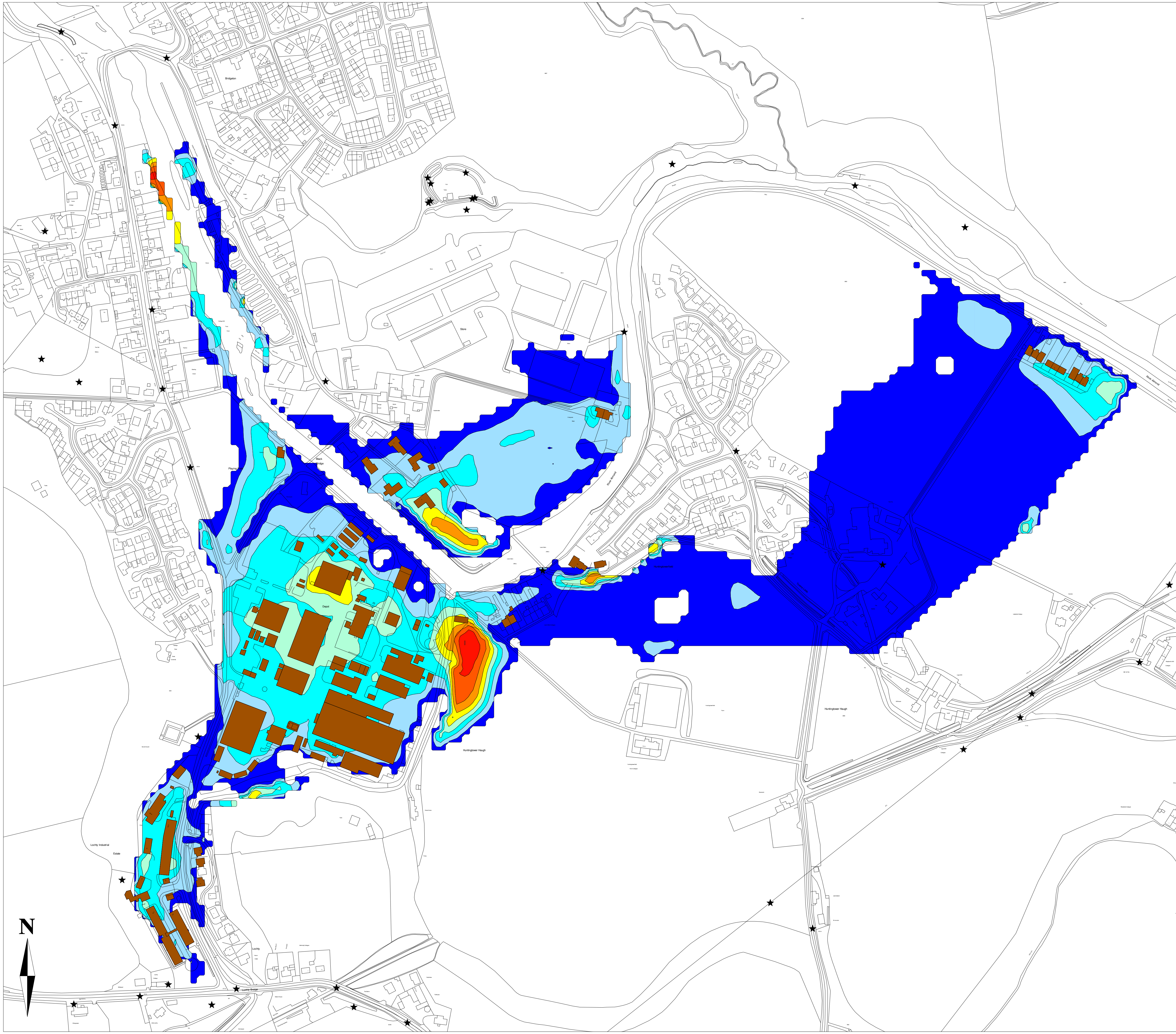
Almondbank Flood Mitigation Scheme

1 in 100 year do minimum

Date of Issue: 27.02.12

Scale: Not to scale



NOTES

It should be noted that certain locations not shown may be at risk of flooding from other sources (piped drain systems, watermains etc.) and from other watercourses not shown in this study.

LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

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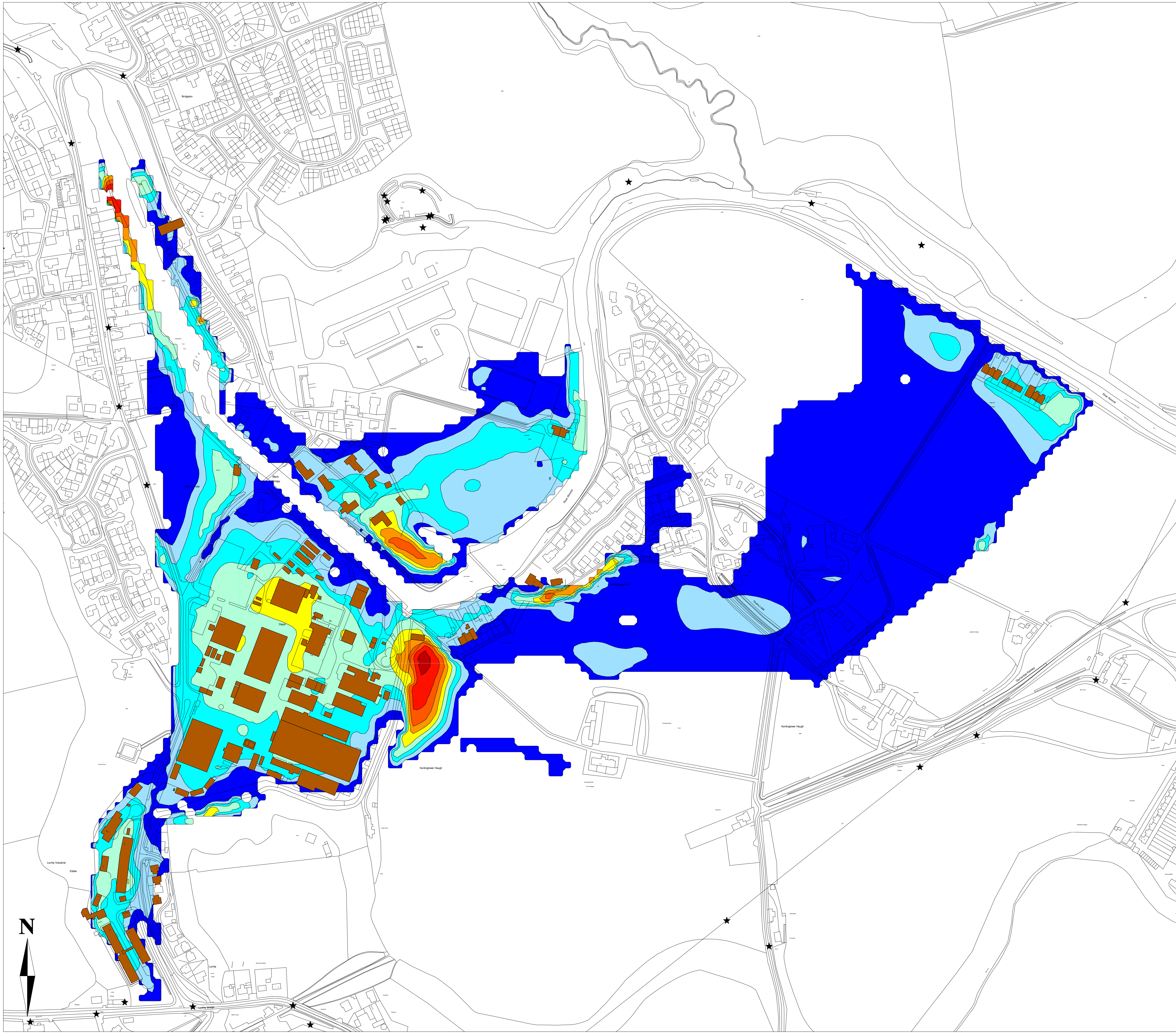
Almondbank Flood Mitigation Scheme

1 in 200 year do minimum

Date of Issue: 27.02.12

Scale: Not to scale



NOTES

It should be noted that certain locations not shown may be at risk of flooding from other sources (piped drain systems, watermains etc.) and from other watercourses not shown in this study.

LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00
- 2.00 - 2.25
- Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

Almondbank Flood Mitigation Scheme

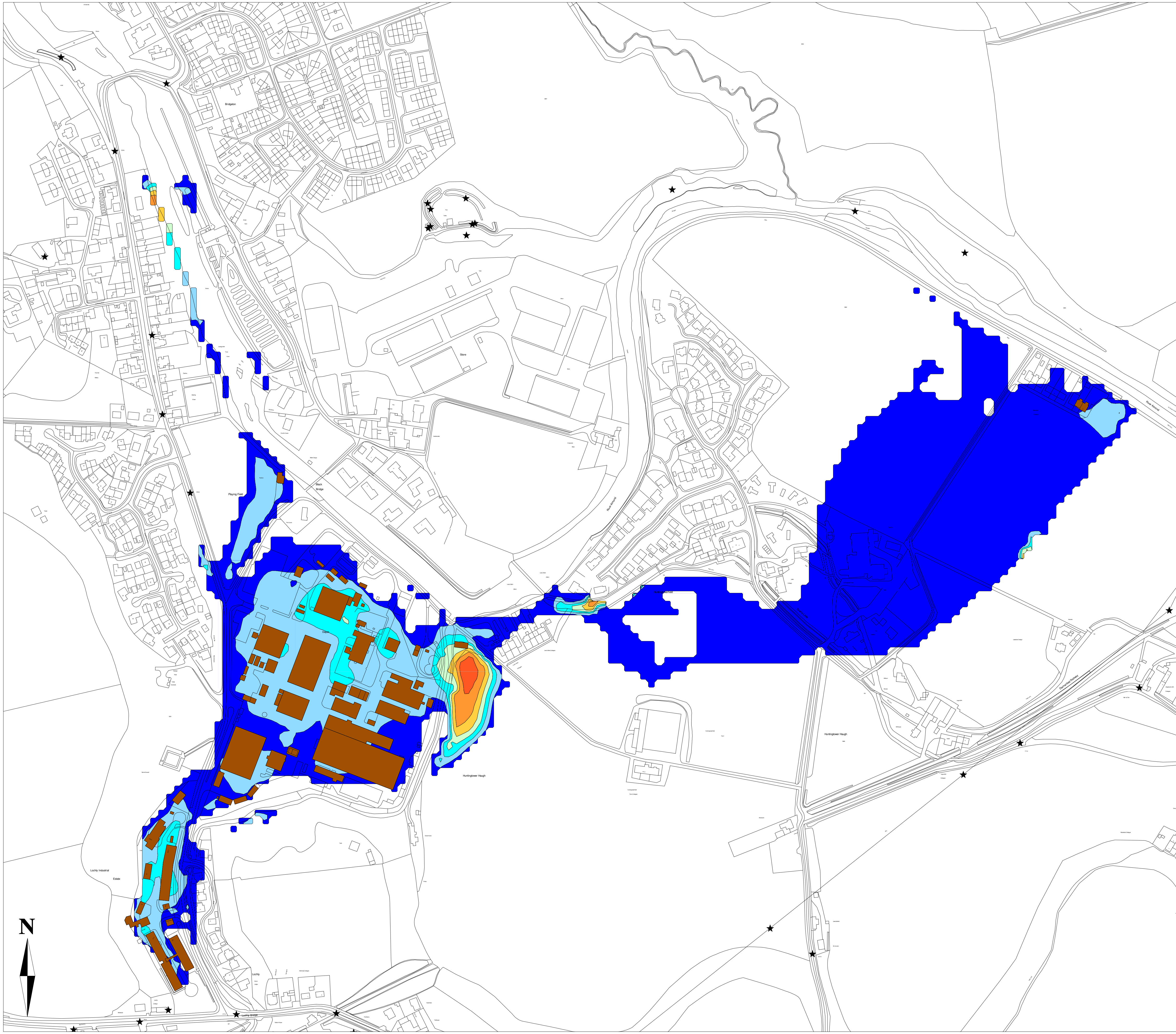
1 in 200 + CC year do minimum

Date of Issue: 27.02.12

Scale: Not to scale

APPENDIX H

Do Nothing Flood Outlines (1 in 10, 25, 50, 75, 100, 200 and 200 + CC)



NOTES

It should be noted that certain locations not shown may be at risk of flooding from other sources (piped drain systems, watermains etc.) and from other watercourses not shown in this study.

LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00

Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

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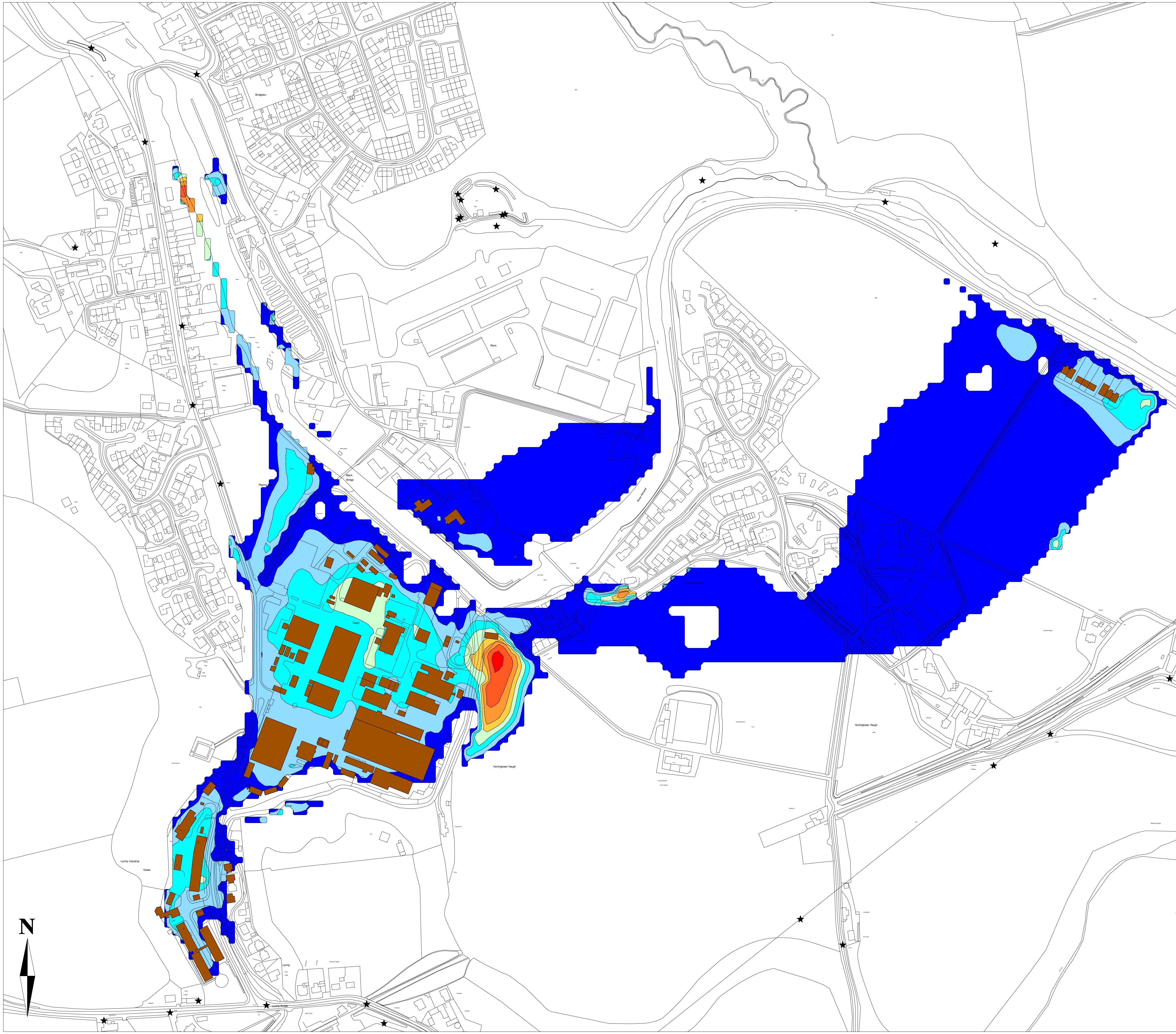
Almondbank Flood Mitigation Scheme

1 in 10 year do nothing

Date of Issue: 27.02.12

Scale: Not to scale



NOTES

It should be noted that certain locations not shown may be at risk of flooding from other sources (piped drain systems, watermains etc.) and from other watercourses not shown in this study.

LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

0.00 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.00
2.00 - 2.25

Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

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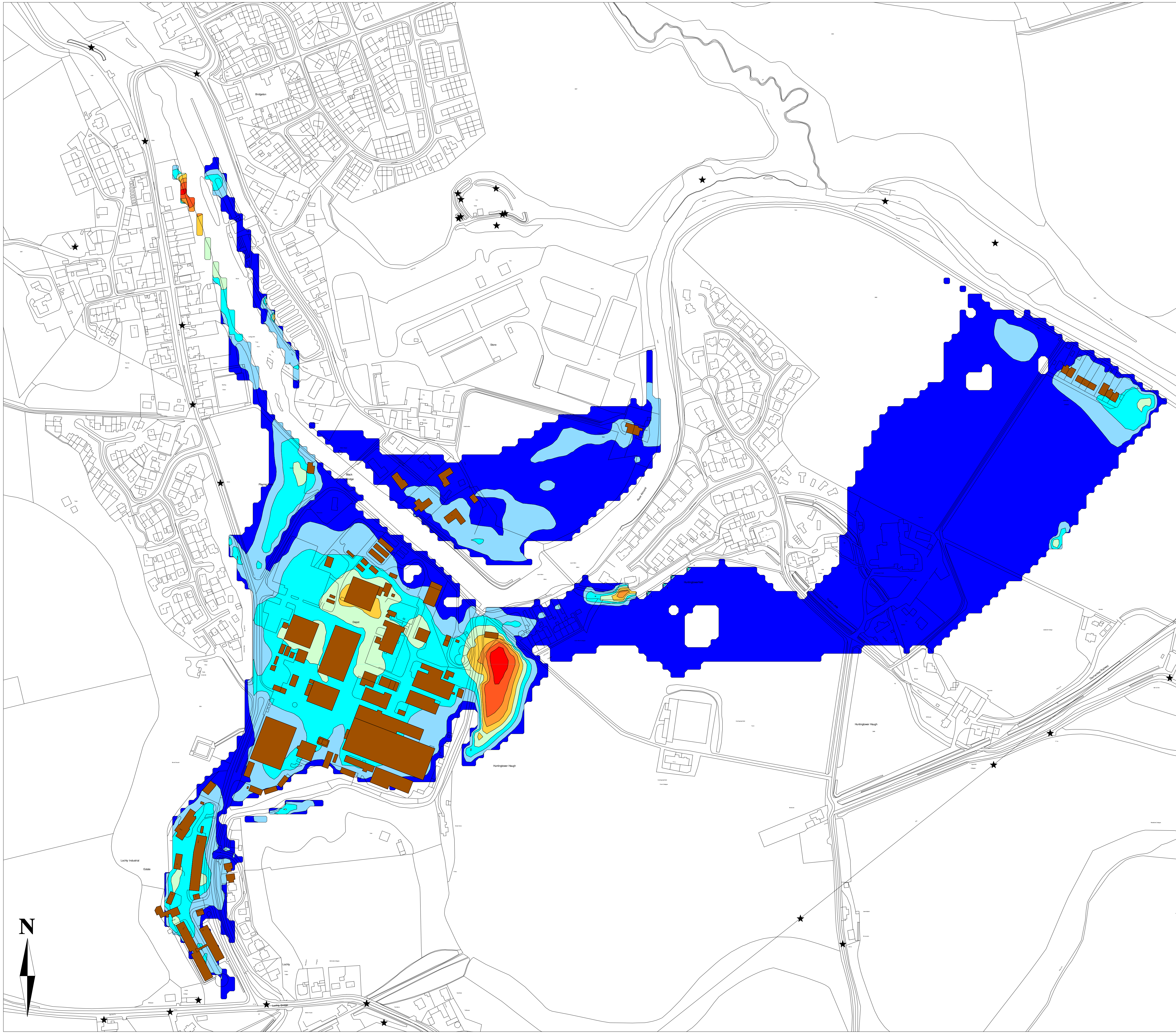
Almondbank Flood Mitigation Scheme

1 in 25 year do nothing

Date of Issue: 27.02.12

Scale: Not to scale



NOTES

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LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

0.00 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.00

Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

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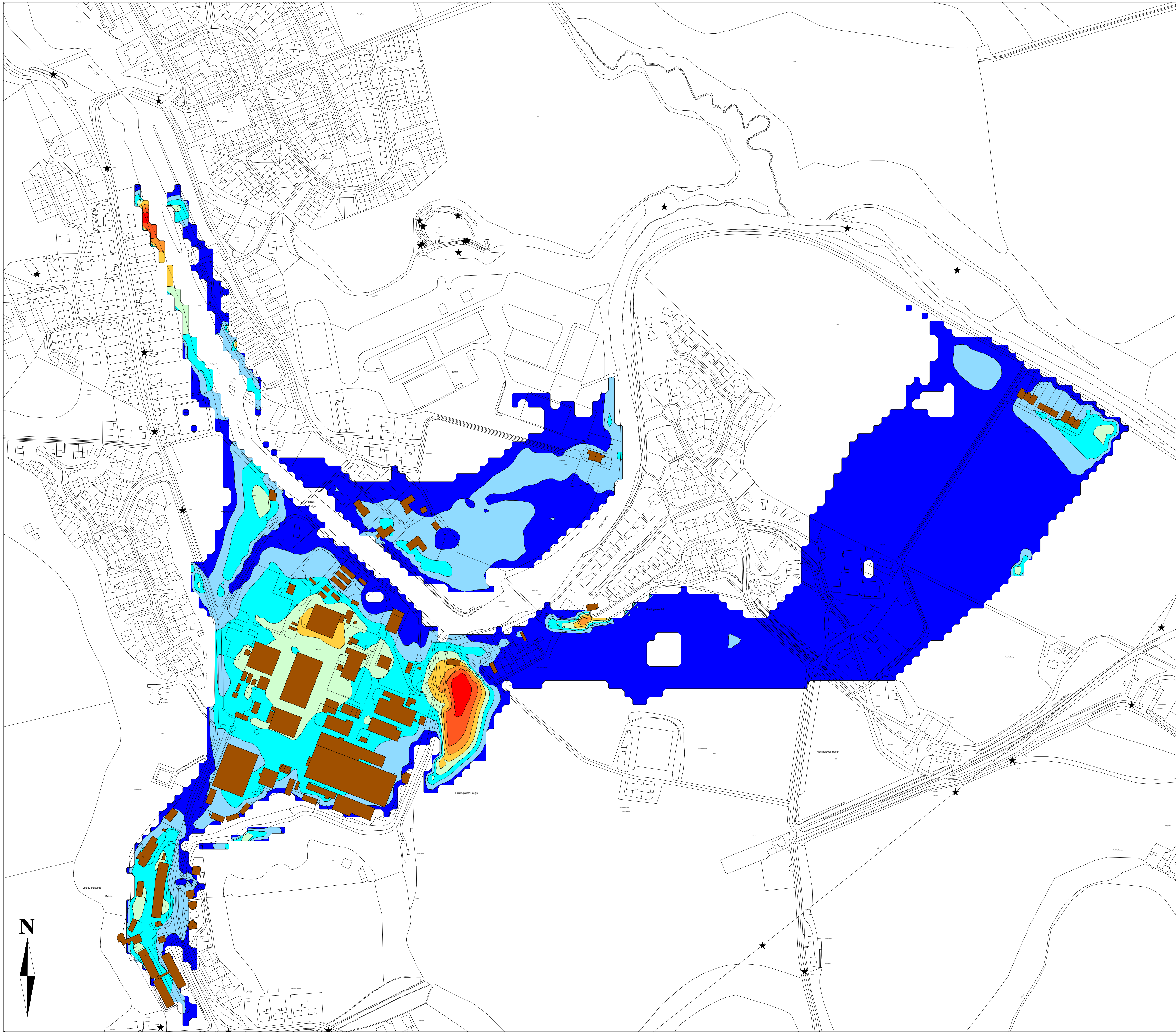
Almondbank Flood Mitigation Scheme

1 in 50 year do nothing

Date of Issue: 27.02.12

Scale: Not to scale



NOTES

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LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00
- 2.00 - 2.25

Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

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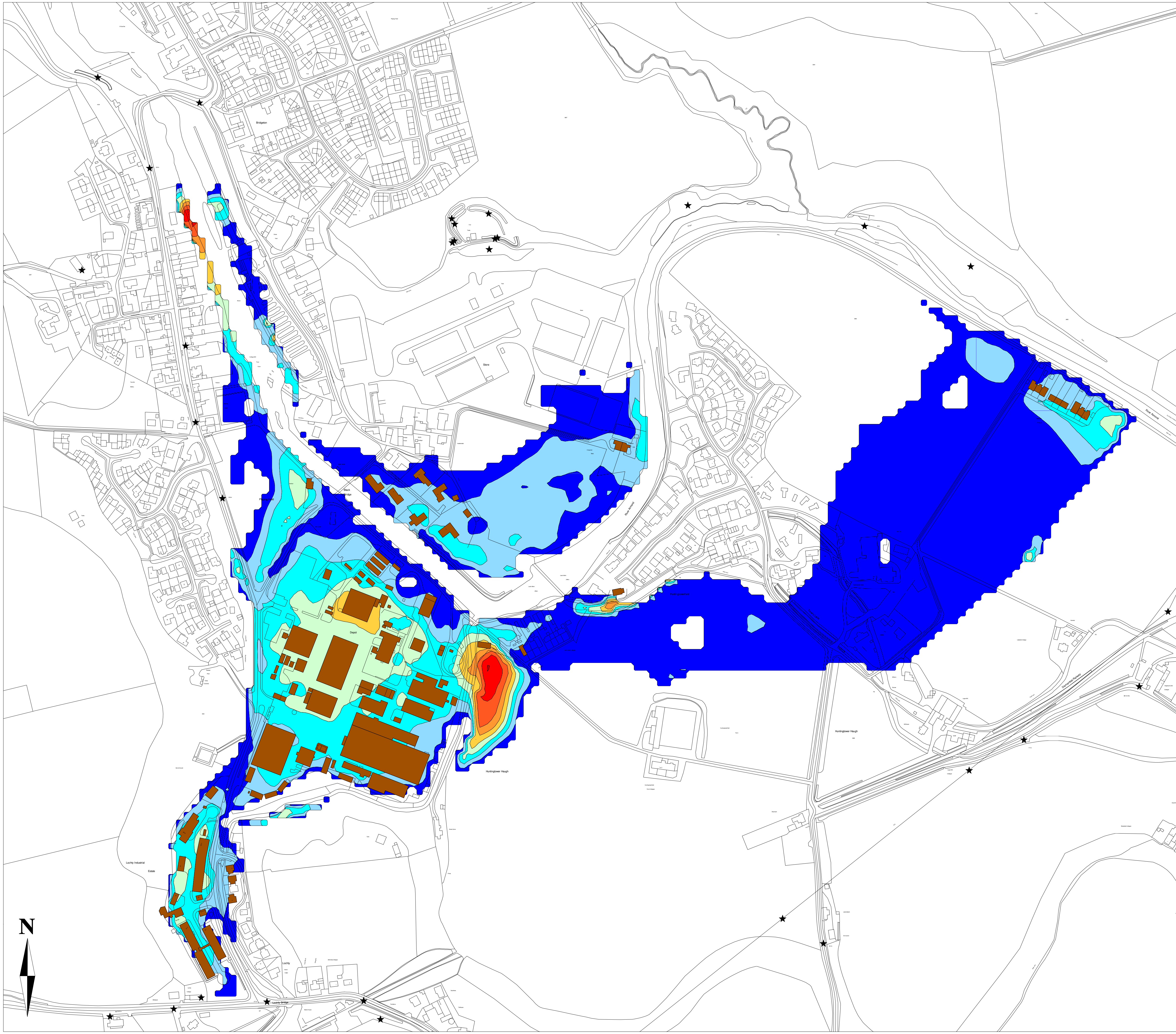
Almondbank Flood Mitigation Scheme

1 in 75 year do nothing

Date of Issue: 27.02.12

Scale: Not to scale



NOTES

It should be noted that certain locations not shown may be at risk of flooding from other sources (piped drain systems, watermains etc.) and from other watercourses not shown in this study.

LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

0.00 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.00
2.00 - 2.25

Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

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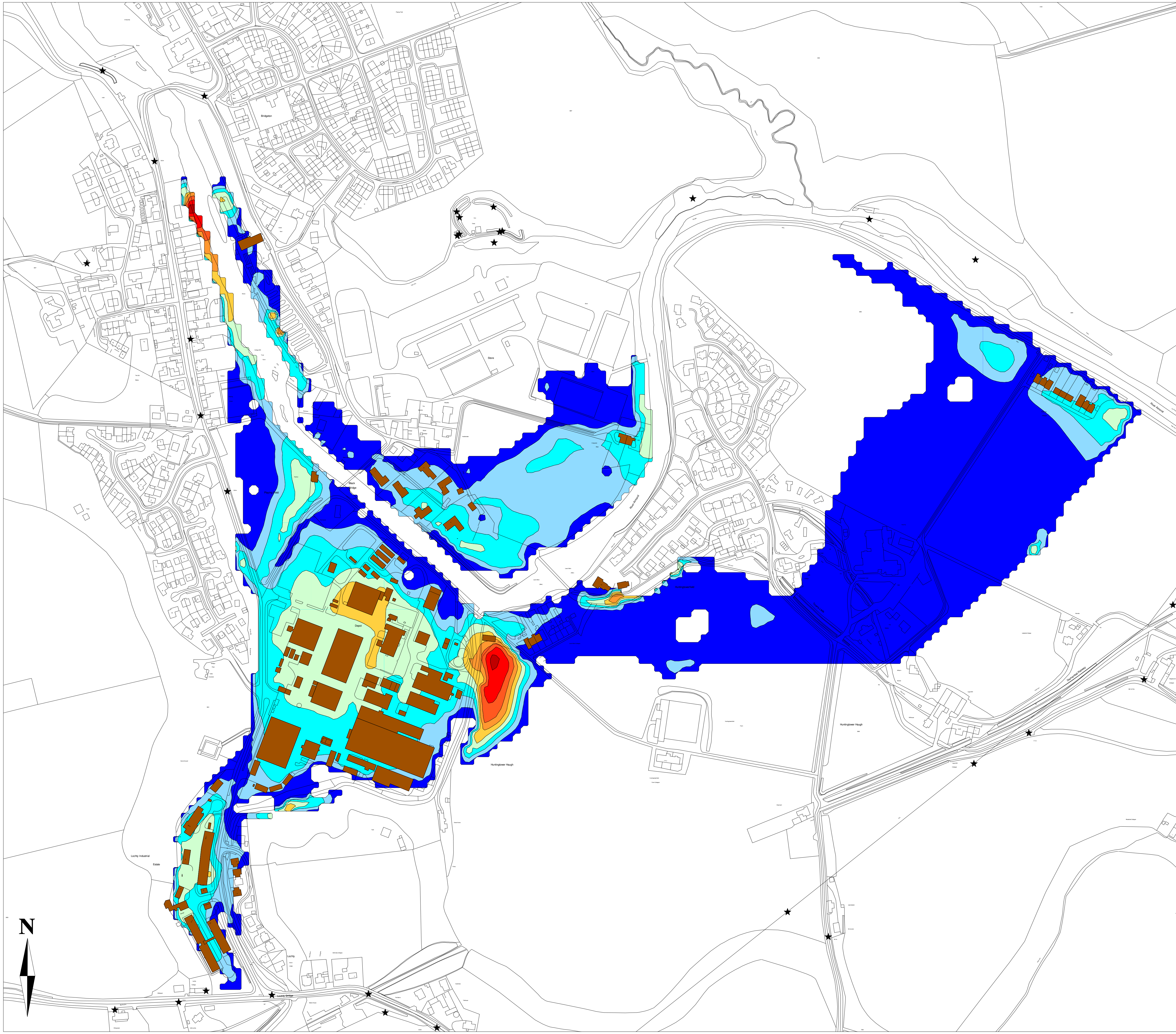
Almondbank Flood Mitigation Scheme

1 in 100 year do nothing

Date of Issue: 27.02.12

Scale: Not to scale



NOTES

It should be noted that certain locations not shown may be at risk of flooding from other sources (piped drain systems, watermains etc.) and from other watercourses not shown in this study.

LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00
- 2.00 - 2.25

Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

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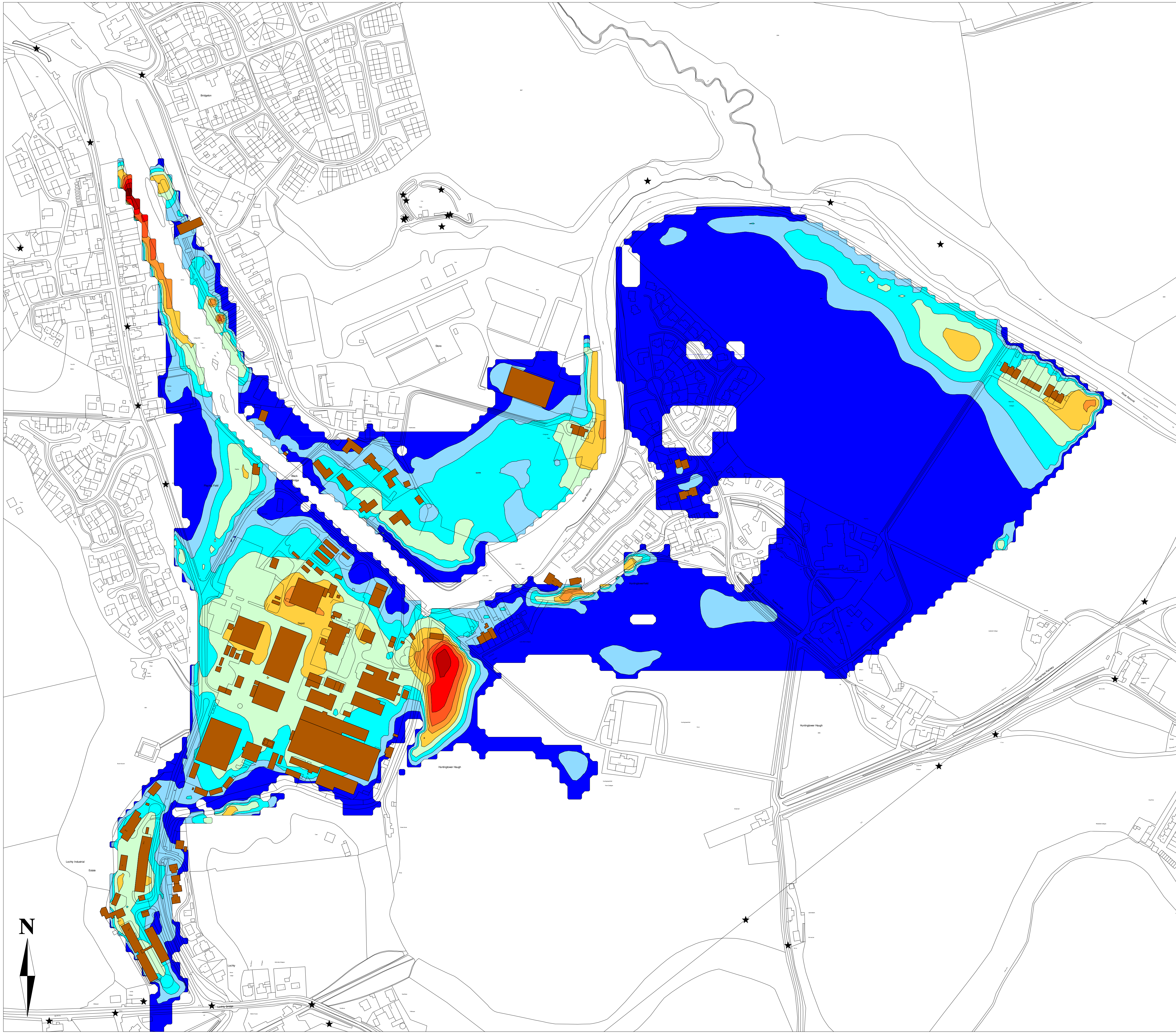
Almondbank Flood Mitigation Scheme

1 in 200 year do nothing

Date of Issue: 27.02.12

Scale: Not to scale



NOTES

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LEGEND

ALL FLOOD DEPTHS SHOWN IN THE LEGEND ARE IN METRES

- 0.00 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.25
- 1.25 - 1.50
- 1.50 - 1.75
- 1.75 - 2.00
- 2.00 - 2.25

Buildings with flooding above threshold level

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
3	27/02/12	Final
2	18/04/11	Draft
1	09/09/10	Draft

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Almondbank Flood Mitigation Scheme

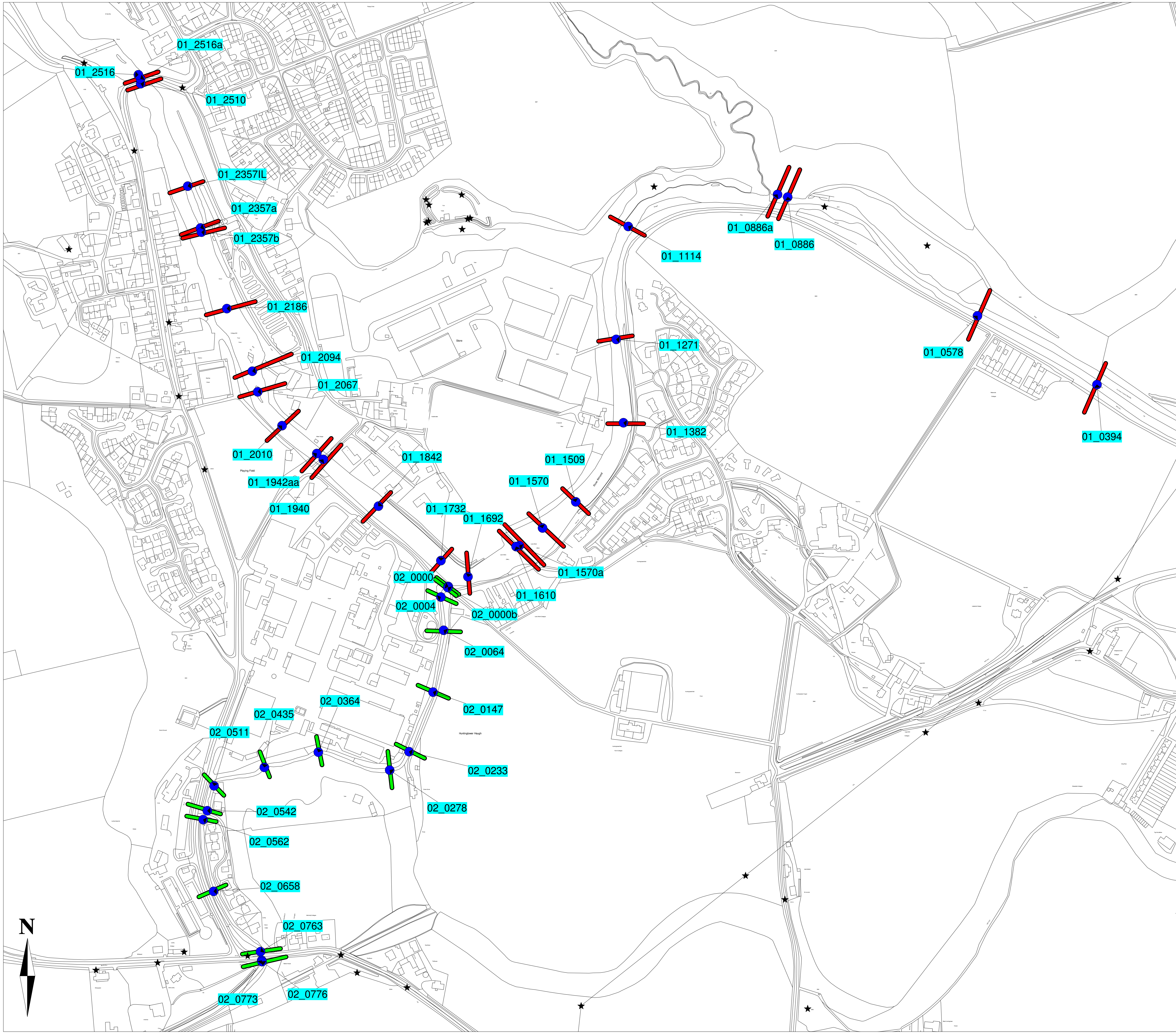
1 in 200 + CC year do nothing

Date of Issue: 27.02.12

Scale: Not to scale

APPENDIX I

Cross Section Locations with Do Minimum and Do Nothing Flood Levels (m AOD)



NOTES

It should be noted that certain locations not shown may be at risk of flooding from other sources (piped drain systems, watermains etc.) and from other watercourses not shown in this study.

LEGEND

01_0394 — **Cross section location and number for the River Almond**

02_0000 — **Cross section location and number for the East Pow Burn**

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
2	27/02/12	Final
1	18/04/11	Draft

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Almondbank Flood Mitigation Scheme

Locations of Model Cross Sections

Date of Issue: 27.02.12

Scale: Not to scale

Model Node Label	Return Period – Do Minimum						
	1 in 10	1 in 25	1 in 50	1 in 75	1 in 100	1 in 200	1 in 200 + CC
01_2516	26.335	26.671	26.943	27.119	27.235	27.575	28.151
01_2516a	26.284	26.615	26.882	27.056	27.170	27.509	28.086
01_2510	26.067	26.296	26.459	26.554	26.615	26.792	27.050
01_2357a	24.837	25.03	25.190	25.291	25.371	25.570	25.770
01_2357b	24.778	24.97	25.130	25.232	25.314	25.516	25.780
01_2186	24.197	24.37	24.527	24.624	24.682	24.849	25.123
01_2094	23.481	23.805	24.012	24.054	24.164	24.292	24.513
01_2010	23.237	23.522	23.736	23.855	23.914	24.044	24.146
01_1942	22.931	23.228	23.444	23.556	23.616	23.774	24.135
01_1940	22.931	23.222	23.349	23.399	23.422	23.481	23.632
01_1842	22.771	23.074	23.217	23.282	23.317	23.398	23.479
01_1732	22.425	22.722	22.908	23.010	23.067	23.138	23.280
01_1692	22.570	22.884	23.078	23.184	23.244	23.373	23.513
01_1610	22.611	22.936	23.133	23.239	23.298	23.431	23.603
01_1570	20.014	20.315	20.590	20.729	20.818	21.069	21.437
01_1570a	20.325	20.561	20.771	20.893	20.973	21.206	21.553
01_1509	19.448	19.734	19.970	20.155	20.270	20.593	21.053
01_1382	18.957	19.265	19.504	19.648	19.735	19.970	20.329
01_1271	18.583	18.878	19.106	19.246	19.328	19.547	19.856
01_1114	17.678	17.939	18.150	18.284	18.367	18.584	18.888
01_0886	16.476	16.769	17.004	17.141	17.255	17.454	17.762
01_0886a	16.476	16.769	17.004	17.141	17.255	17.454	17.762
01_0578	15.298	15.629	15.890	16.045	16.137	16.410	16.717
01_0394	14.425	14.661	14.841	14.967	15.049	15.291	15.694
02_0776	26.259	26.492	26.680	26.800	26.889	27.135	27.446
02_0773	26.116	26.329	26.504	26.619	26.707	26.959	27.274
02_0763	25.980	26.141	26.271	26.359	26.427	26.626	26.813

Model Node Label	***Return Period – Do Minimum***						
	1 in 10	***1 in 25***	***1 in 50***	***1 in 75***	***1 in 100***	***1 in 200***	***1 in 200 + CC***
02_0658	25.477	25.543	25.557	25.560	25.572	25.578	25.613
02_0562	25.281	25.400	25.478	25.536	25.573	25.626	25.719
02_0542	24.804	24.903	25.030	25.136	25.183	25.269	25.396
02_0511	24.730	24.789	24.895	24.981	25.010	25.051	25.101
02_0435	24.567	24.759	24.872	24.968	24.999	25.042	25.092
02_0364	24.505	24.659	24.770	24.868	24.901	24.948	25.007
02_0278	24.086	24.169	24.245	24.299	24.323	24.353	24.394
02_0233	23.430	23.641	23.715	23.767	23.796	23.866	23.948
02_0147	23.066	23.300	23.416	23.491	23.533	23.628	23.734
02_0064	23.073	23.317	23.435	23.512	23.553	23.647	23.752
02_0004	22.852	23.186	23.308	23.391	23.443	23.553	23.675
02_0000b	22.657	23.000	23.208	23.324	23.393	23.515	23.646
02_0000	22.650	22.952	23.154	23.269	23.335	23.464	23.604

Table showing the levels in metres above ordnance datum (mAOD) for a range of do minimum flood return periods

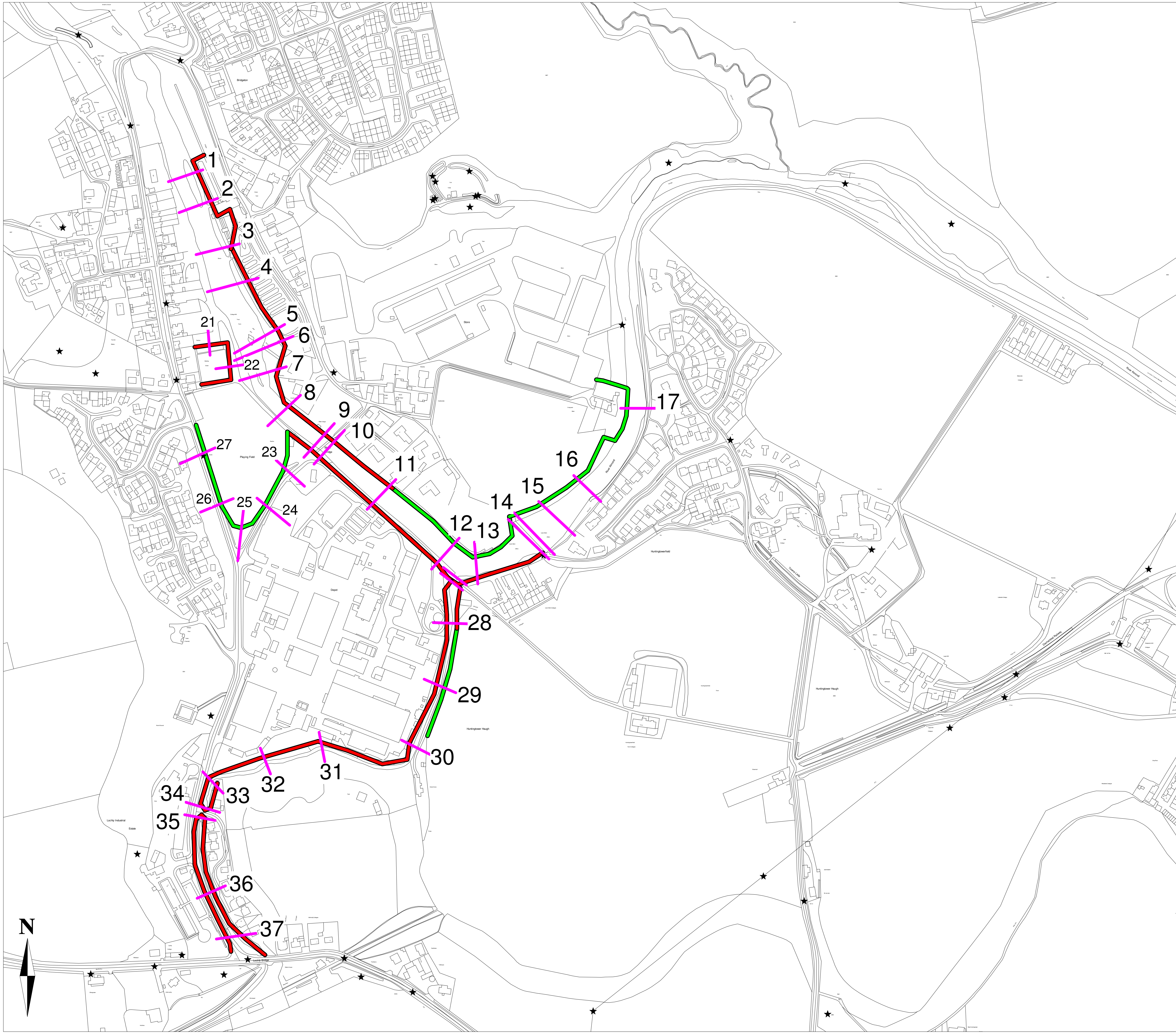
Model Node Label	Return Period – Do Nothing						
	1 in 10	1 in 25	1 in 50	1 in 75	1 in 100	1 in 200	1 in 200 + CC
01_2516	26.588	26.933	27.217	27.384	27.495	27.827	28.378
01_2516a	26.535	26.873	27.152	27.316	27.425	27.754	28.303
01_2510	26.350	26.600	26.791	26.888	26.954	27.141	27.420
01_2357a	24.978	25.198	25.400	25.507	25.571	25.728	25.944
01_2357b	25.008	25.231	25.391	25.491	25.552	25.730	25.986
01_2186	24.384	24.603	24.757	24.853	24.915	25.096	25.362
01_2094	23.917	24.126	24.241	24.305	24.347	24.460	24.646
01_2010	23.711	23.927	24.028	24.070	24.097	24.158	24.230
01_1942	23.232	23.433	23.555	23.623	23.668	23.792	23.973
01_1940	23.199	23.399	23.523	23.592	23.637	23.763	23.946
01_1842	22.905	23.153	23.283	23.340	23.375	23.451	23.538
01_1732	22.490	22.769	22.930	23.003	23.051	23.175	23.303
01_1692	22.592	22.873	23.037	23.116	23.167	23.301	23.452
01_1610	22.600	22.884	23.046	23.125	23.176	23.311	23.479
01_1570	20.266	20.581	20.812	20.953	21.048	21.314	21.648
01_1570a	20.502	20.769	20.975	21.102	21.189	21.440	21.754
01_1509	19.726	20.062	20.335	20.513	20.626	20.942	21.351
01_1382	19.239	19.576	19.815	19.963	20.056	20.342	20.737
01_1271	18.830	19.160	19.398	19.541	19.632	19.901	20.243
01_1114	17.931	18.232	18.458	18.591	18.675	18.914	19.101
01_0886	16.767	17.103	17.341	17.484	17.574	17.802	18.103
01_0886a	16.767	17.103	17.341	17.484	17.574	17.802	18.103
01_0578	15.560	15.906	16.178	16.357	16.470	16.779	17.234
01_0394	14.696	14.969	15.182	15.319	15.405	15.633	15.969
02_0776	26.357	26.594	26.789	26.915	27.011	27.287	27.574
02_0773	26.227	26.447	26.632	26.756	26.853	27.136	27.465
02_0763	26.120	26.300	26.452	26.553	26.631	26.841	27.093

Model Node Label	***Return Period – Do Nothing***						
	1 in 10	***1 in 25***	***1 in 50***	***1 in 75***	***1 in 100***	***1 in 200***	***1 in 200 + CC***
02_0658	25.530	25.586	25.598	25.617	25.631	25.666	25.715
02_0562	25.504	25.577	25.601	25.634	25.659	25.722	25.802
02_0542	24.642	24.868	24.931	25.031	25.118	25.298	25.427
02_0511	24.514	24.726	24.754	24.846	24.933	25.058	25.114
02_0435	24.346	24.551	24.704	24.810	24.904	25.038	25.093
02_0364	24.262	24.472	24.608	24.712	24.807	24.942	24.997
02_0278	23.914	24.086	24.191	24.261	24.309	24.403	24.445
02_0233	23.546	23.713	23.813	23.867	23.901	23.977	24.026
02_0147	23.332	23.488	23.581	23.619	23.642	23.699	23.762
02_0064	23.330	23.489	23.585	23.626	23.649	23.708	23.770
02_0004	23.224	23.357	23.458	23.506	23.535	23.612	23.695
02_0000b	22.719	23.086	23.241	23.304	23.347	23.485	23.607
02_0000	22.659	22.965	23.135	23.214	23.265	23.406	23.549

Table showing the levels in metres above ordnance datum (mAOD) for a range of do nothing flood return periods

APPENDIX J

Option 3 Cross Section Locations, Flood Outline and Levels



NOTES

LEGEND

10	Cross Section Location
	Proposed Wall
	Proposed Embankment

Maps show flood extents of the existing case scenario. Elevations above Ordnance Datum (Newlyn)

REV	DATE	REMARKS
2	27/02/12	Final
1	18/04/11	Draft

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Almondbank Flood Mitigation Scheme

Option 3A Layout and Cross Section Locations

Date of Issue: 27.02.12

Scale: Not to scale

Drawing Cross Section Label	*Model Node Label*	*Left Bank Level (mAOD)*	*Right Bank Level (mAOD)*	*Option 3 - 1 in 200 year Water Level (mAOD)*	*Defended Level Option 3 - 1 in 200 year*
1	01_2357IL	25.24	24.25	26.13	26.43 (L)
2	01_2357a	25.24	24.33	25.59	25.89 (L)
3	Level Interpolated	25.20	25.67	25.34	25.64 (L)
4	01_2186	24.60	24.14	24.93	25.23 (L)
5	Level Interpolated	25.21	24.27	24.61	25.21 (L)
6	01_2094	23.67	23.86	24.56	24.86 (L)
7	01_2067	24.38	24.08	24.51	24.81 (L)
8	01_2010	23.87	23.45	24.14	24.41 (L)
9	01_1970	23.89	23.88	24.01	24.31 (L & R)
10	01_1940	23.91	23.87	23.91	24.21 (L & R)
11	01_1842	22.89	23.64	23.73	24.03 (L & R)
12	01_1732	23.23	23.34	23.20	23.80 (L) / 23.72 (R)
13	01_1692	23.40	22.99	23.51	24.11 (L) / 23.81 (R)
14	01_1610	23.26	23.37	23.64	24.24 (L) / 23.94 (R)
15	01_1570	21.15	22.05	21.45	22.05 (L) / 23.94 (R)
16	01_1509	20.74	21.49	20.45	21.05 (L)
17	01_1382	19.39	20.69	19.94	20.24 (L)
21	2D Grid Level	-	-	24.61	24.91
22	2D Grid Level	-	-	24.56	24.86
23	2D Grid Level	-	-	24.35	24.95
24	2D Grid Level	-	-	24.35	24.95
25	2D Grid Level	-	-	24.35	24.95
26	2D Grid Level	-	-	24.35	24.95
27	2D Grid Level	-	-	24.35	24.95
28	02_0064	22.42	22.08	23.85	24.15 (L & R)
29	02_0147	22.67	23.86	23.88	24.18 (L) / 24.48 (R)
30	02_0233	24.16	24.10	24.25	24.25 (L & R)
31	02_0364	25.01	25.01	25.65	25.95 (L & R)
32	02_0435	24.91	23.66	25.79	26.09 (L & R)
33	02_0511	25.16	24.94	25.72	26.02 (L & R)
34	02_0542	24.89	25.26	25.77	26.07 (L & R)
35	02_0562	25.01	25.20	25.82	26.12 (L & R)
36	02_0658	25.40	25.55	26.25	26.55 (L & R)
37	Level Interpolated	26.50	26.00	26.56	26.86 (L & R)

APPENDIX K

Mouchel's hydraulic model development timeline

ALMONDBANK FLOOD MITIGATION SCHEME - HYDROLOGY TIMELINE
Late 2007 to 2008

Date	*Action*	*Progress*	*Additional Information*
Dec-07	Mouchel meet with SEPA to discuss the RH recommended flood mitigation scheme	SEPA commit to review the presented Royal Haskoning scheme	
Jan-08	Mouchel, in partnership with Perth & Kinross Council conduct the Public Consultation exercise, presenting the Royal Haskoning recommended flood mitigation scheme	Feedback from the consultation determines that a new hydraulic model should be built	Additional topographic survey will be required & Further consultation with SEPA required
Feb-08	SEPA complete their review of the **scheme hydrology** only	SEPA provide a summary of flows previously used by other consultants	The flows used by the different consultants, quoted in SEPA's correspondence, is included in Appendix D of this report.
Mar-08	Additional topographical survey completed	Additional data included with and checked against the existing topographical data	
	Mouchel independently complete their hydrology calculations and submit to SEPA for review	No comment has been received from SEPA at this stage, therefore Mouchel continue with the model build using their calculated input data	Rainfall runoff flows have been used for the East Pow Burn and Mouchel's statistical flows have been used for the River Almond at this point in the process. For the East Pow Burn the 1 in 200 year rainfall runoff value is 47.9 cumecs and for the River Almond the 1 in 200 year statistical flow value is 268 cumecs.
Apr-08	Mouchel build an ISIS one dimensional hydraulic model of the River Almond and the East Pow Burn	The one dimensional element of the model includes the river in channel cross sections and also the hydrological inputs.	
Sep-08	Mouchel build a Tuflow two dimensional model of the River Almond and the East Pow Burn. The Tuflow model is linked to the one dimensional element of the ISIS model	The two dimensional element of the model (Tuflow) incorporates the ground levels and geographic features.	The flooding mechanisms which occur at the site of interest can be replicated using this information.
Nov-08	Mouchel test the Royal Haskoning recommended flood mitigation scheme in their Tuflow model, using Mouchel's calculated hydrology for the 1 in 200 year event	A number of breach locations are identified for the proposed RH scheme	The main breaches are identified along the East Pow Burn and one at the proposed storage area on the right bank of the River Almond
Dec-08	Mouchel present their review of the RH scheme to Perth & Kinross Council, including breach locations and flood extents	Mouchel presented their recommended improvements to the RH scheme in order for it to withstand the tested 1 in 200 year event	Further work required to consider alternative options other than the improved RH scheme

ALMONDBANK FLOOD MITIGATION SCHEME - HYDROLOGY TIMELINE

2009

Date	***Action***	***Progress***	***Additional Information***
Early 2009	Mouchel carry out investigations and proposals into alternative solutions to the RH improved scheme	Potential flood mitigation solutions were assessed, with 3 of these solutions considered viable schemes and tested within the Tuflow model	1) Flood defence walls & embankments with 2 storage areas 2) Flood defence walls & embankments with 1 storage area & 1 diversion channel 3) Flood defence walls & embankments with 1 storage area
Mid 2009	Conclusion of optioneering exercise and recommendation that Solution 3 is taken forward to outline design	Solution 3 is incorporated into the one and two dimensional hydraulic model	Solution 3 consists of one flood storage area on the playing fields on the right bank of the RA and a series of flood walls and embankments along the banks of both the RA and EPB
Aug-09	Mouchel make contact with SEPA to discuss and review the one and two dimensional hydraulic model, specifically the input data (ie hydrology)	SEPA complete their review and also provide their own hydrology calculations, giving a set of input flow values that differed from those calculated by Mouchel in Mar 08 (approx 15% increase in flows).	The values below show both rainfall runoff flows and statistical flows for both watercourses. First entries are Rainfall runoff and second entries are statistical flows for each return period. River Almond - (245, 311 - (200), 294, 373 - (200 +cc)) East Pow Burn (47.9, 41.5 - (200), 57.5, 49.8 - (200 +cc))
Sep-09	In light of SEPAs rating curve, roughness values along the River Almond were modified in order to enable the model rating curve and the measured rating curve to tie in.	Changes in roughness values to align the rating curve with SEPA's combined with SEPA's flow values, reduce TWL's for the whole scheme in the region of 300-400mm	
Nov-09	Mouchel contact SEPA, further to review of the information received during August to determine SEPA's approval in principal for continued use of Mouchel's input data	SEPA commit to timely response	
Dec-09	SEPA respond to Mouchel with recommendation to progress the outline scheme using their flows provided in August	Mouchel, in partnership with PKC, propose to adopt SEPA's recommended flows of Aug 09, incorporating the changes in roughness required to align with SEPA's rating curve	

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2010

Date	*Action*	*Progress*	*Additional Information*
Jan-10	Mouchel make changes to the hydraulic model input data and assess impact of these changes to TWL's across the scheme	As the resulting TWL is reduced by approximately 300-400mm, PKC propose that it may be appropriate to consider an allowance for climate change	Input flows are to be increased by 20% to give a design event of 1 in 200 years plus an allowance for climate change
Feb-10	Mouchel make changes to the hydraulic model input data and assess impact of the inclusion of climate changes to TWL's across the scheme	Mouchel work through impacts of changes in TWL along both watercourses and highlight a number of locations where further outline design work is required	The vehicle and pedestrian bridge crossings and also the extents of the proposed scheme, specifically the inclusion of Waterside cottages to the downstream extent of the RA
Apr-10	Mouchel work through those areas identified for additional outline design work	Contiued liaison with PKC to discuss specific locations and how current hydrology impacting on outline design proposals	
Nov-10	Mouchel submit draft outline design scheme and 'Hydraulic Modelling and Option Assessment Report' to PKC for review	PKC and Mouchel identify that some of the proposed defence structure heights are in excess what may be deemed acceptable ('too high') by those residents on whom they impact	An exercise to summarise and mitigate against 'too high' defences is required
Jan-11	Mouchel review the identified 'too high' defence structures and investigate possibile mitigation measures at specific locations	Dependant upon specific location, some 'too high' defences were assessed as acceptable, others could be mitigated by reprofiling of existing GL's. It was not possible to mitigate all 'too high' defences	Mouchel identified those defences in excess of 1.5m above existing Ground Level as 'too high'. TWL determined by model input and determines defence height plus an allowance for freeboard
	Mouchel re-visit the scheme hydrology to identify any further measures to mitigate the remaining 'too high' defence heights	Mouchel identify and assess the impact of a number of changes to the scheme hydrology. These changes are inputted and assessed in the hydraulic model. It is recommended that these changes are implemented.	Key changes to input data included: Removal of the allowance for climate change and the use of the less conservative flow figures for the EPB. These changes will need to be approved in principal by SEPA
Feb-11	Mouchel contact SEPA, further to the proposed changes in scheme hydrology, to determine SEPA's approval in principal to progress with these changes. Climate change factors are removed from the model and the model is re-run.	SEPA are satisfied with the changes proposed and the reasons why and confirm that they are happy for the porposed scheme outline design to be based on these figures	The hydraulic model now incorporates these changes and the outline design, for inclusion n the Flood Order Submission incorporates any changes required as a result of the change in TWL and hence required defence heights.