NOVEMBER 2012 FLOODS AT GLASDIR, RUTHIN FROM THE RIVER CLWYD

REPORT ON THE REVIEW

by the Independent Panel for the
Evaluation of Hydrology, Flood Risk and Causes of Flooding

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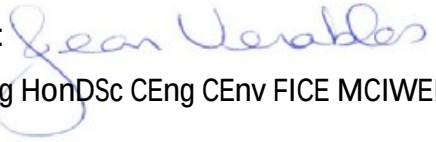
Independent Panel Leader:  Date: 23 August 2013

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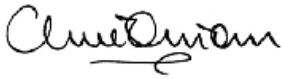
Independent Panel Member:  Date: 23 August 2013

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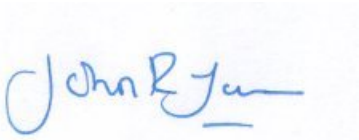
Independent Panel Member:  Date: 23 August 2013

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Executive Summary

On 27th November 2012 heavy rain on a wet catchment caused high flows in the River Clwyd, which flows through Ruthin. Although the Glasdir residential development has a flood defence system comprising flood relief culverts and flood defence bund, 122 houses suffered internal flooding. Serious flooding also occurred in St Asaph and in many rural areas, indicating that it was an extreme event within the general area. However, the houses at Glasdir had recently been constructed, the development was still being built by Taylor Wimpey, and it was understood that the houses were protected to withstand a 1 in 1000 year flood event.

Denbighshire County Council (DCC) and Natural Resources Wales (NRW) (formerly Environment Agency Wales) carried out an initial investigation into the cause and DCC appointed this Independent Panel to assist with the investigation.

The Terms of Reference (see Appendix 1) explain that the Council wanted to understand:

- Why the flooding occurred
- What the likelihood of recurrence may be
- What can/should be done to by all relevant flood risk management authorities to minimise flood risk to properties in future events

And that the investigation should address the following;

a) The weather conditions during and preceding the flood events.

b) The degree to which flood defences and other alleviation/management measures operated as intended, including specifically any factors that may have prevented their full operation.

c) The overall flood risk assessments for the affected areas and the continued adequacy of these in the light of the flood events. This should include assessment of whether changes to river patterns and/or flood management measures have changed flood risks since the last assessment was concluded.

d) Whether, in the light of the flooding experienced on 26th/27th November 2012, relevant flood risk management authorities should implement modifications or additions to their flood defence, alleviation and management measures to minimise risk of future flooding to an acceptable level.

The background to the Glasdir development is that the Welsh Development Agency constructed the Ruthin North Link Road (A525) with a roundabout to the north of Ruthin, to give access to land which had been allocated for development. The Link Road crosses the natural flood plain of the River Clwyd on an embankment, and so the planning application included a bridge and culverts to convey river and flood flows. The project also included a flood bund to protect the land allocated for residential uses, and the Flood Consequences Assessment explains that the flood management system would protect the land beyond a 1 in 1000 year event.

A Developer subsequently acquired the residential land and obtained outline planning consent, which was followed up by reserved matters applications, for the residential

development. At the time of the flood approximately half had been completed, and there is an expectation that the development will be completed in due course.

The independent Panel has visited the site, to understand the local conditions and researched the background to the development and flooding event. The Panel has also met with Officers of DCC and NRW, and met with representatives of the residents to hear about their concerns and to understand what analysis of the event had been undertaken.

NRW was developing the computer flood model for the River Clwyd, and the Panel waited for this to be completed before undertaking its own assessment of the model, and then using the model to test scenarios.

The Panel's analysis began with assessing the records of the maximum flood extent in the Ruthin area, and matching these with the terrain model to determine the river flow in the November event. The extent of flooding in the Glasdir area was then considered in more detail to determine the role that the screens on the culverts under the Link Road had, and particularly the level of blockage.

The flow results were compared with recognised guidance to determine the approximate return period of the flooding, which is judged to be between a 1 in 100 year and 1 in 200 year event, but biased towards 1 in 100 years (i.e. between 1% and 0.5% chance of happening in any one year).

The model also showed that the culverts play a vital role in reducing the risk of flooding at Glasdir. The screens were blocked by between 66% and 95% due mainly to vegetation. If the screens had not been partially blocked, the property flooding would probably not have occurred. The screens were also of poor design, not complying with any recognised standard and were not capable of being safely cleared in an emergency. The screens have since been removed, and the Panel has recommended that the screens are not replaced, since they fulfil no real purpose in terms of health and safety (see CIRIA Culvert Guidance, 2010).

Further analysis was undertaken to determine the level of the flooding for a range of events, including the following, details of which are contained in the Panel's report;

- 1 in 100 year return period (1% chance of flooding in any one year),
- 1 in 100 year with climate change allowance (additional 20% flow)
- Various levels of culvert blockage (0%, 33%,66% and 95%, in line with recognised guidance)
- 1 in 1000 year (0.1% chance of happening in any one year)

The Panel has considered what would be a normal level of protection if the development were to be promoted at the present day, and feels that the appropriate standard would be a level of protection provided by:

1 in 100 year + Climate Change allowance, with 95% culvert blockage and 600mm freeboard.

The analysis shows that this level of defence would also defend against the 1 in 1000 year event, with less freeboard. The culvert blockage allowance has been included because the culverts are wide and shallow, have been shown to block previously with serious consequences, and the floodplain contains trees and other vegetation, which pose a risk of blockage.

A freeboard of 600mm is a standard requirement for residential areas adjacent to sensitive flooding. The River Clywd is a sensitive river because the flow varies depending on the state

of the catchment prior to rainfall, the seasonal growth in the catchment and other criteria such as the tolerances of the flood model.

The levels contained within the report can be related to the floor levels of the houses, based on the topographical survey data obtained by DCC.

A number of potential solutions have been considered to provide the recommended level of protection, including additional culverts below the road, removal of Ruthin weir and forming a high bank adjacent to the river. These all have serious consequences downstream of the Link Road, and cause unacceptable increases in flooding to property downstream.

The recommended solution is to form a bank adjacent and to the east of the existing footway. The additional height will be approx. 1.1m at the north end of the embankment to approx. 200mm at the south end of the existing embankment. The detail design needs to ensure that the bank is robust and is tied into the level on the Link Road.

The Panel recommends that a formal inspection and maintenance regime of all the flood defence structures, culverts and flood plain should be established with clear responsibilities. NRW is installing additional flood warning equipment and will set up a reporting system with the Council and Residents.

It is equally important that, whilst responsibility lies with the Authorities, the residents are alert to the flood risk, and recognise that they need to report immediately potential hazards such as flytipping in the flood plain or fallen trees and branches.

One striking feature of the overall project is that there have been many companies involved in the evolution of the development, with six flood reports by different Consultants. This is common to many projects, and a feature of the commercial world of seeking lowest price at each stage. It is important that the Council seeks to encourage those involved in development to provide continuity on projects in future, to ensure that critical aspects are considered throughout the process and that improvements are made to keep up with developments in design guidance.

Conclusions

a) Key data on the November event – We have estimated that the flow in the November 2012 event was between 35.9 and 40.4 m^3/s, which we judge to be between a 1 in 100 year and 1 in 200 year event but biased towards 1 in 100 year, and the blockage of the culverts was between 66% and 95%.

b) Solutions to restore the level of protection – Various engineering solutions were explored and these are detailed in Section 4 of this Report. It is the Investigating Team's opinion that the solution that offers the earliest and most cost-effective solution to re-instating the flood defences around the development is to raise the bund height.

c) Organisational complexity – The process of preparing the land at Glasdir for development has involved many organisations over many years (see diagram in Appendix 2). During that period the methods of hydraulic modelling have developed and standards and guidance have changed. Communication between the various parties could have been clearer; assumptions previously made could have been challenged. In addition, it is necessary to have an overall view on the interaction between the road built as an embankment and the operation of the flood plain with

respect to the flood risk of the proposed development land. There does not seem to have been continuity of involvement provided during the development of the area, to avoid important criteria being missed.

d) Blockages – The blockage of the culverts played a significant part in causing the flood water to flow over the bund (which was also too low).Thus the proposed height of the bund is based on an assumption of a 95% blockage to the culverts. (See paragraph 3.6.5).

   Although blockage was mentioned in previous reports there is no evidence that work was done to assess its impact. It is only recently that a Welsh Government survey has revealed that 60% of flooding incidents on ordinary watercourses (see paragraph 4.3) were caused by blockages.

e) Response to the event – The belief that this development was protected to an unusually high level of 1 in 1000 meant that it was not on the list of high risk areas to visit in a high rainfall event. The vertical grills are hard to clear during a storm once they had become blocked and certainly not safely. Access to the top of the culvert entrances has been improved since the event in November 2012 but clearing the culvert entrances of debris in a storm will not be easy and could be unsafe in an extreme event.

f) Planning – It is clear from the documentation that the land at Glasdir was expected to be protected to a 1 in 1000 (0.1% annually) standard for flood risk management. The calculated level of this 1 in 1000 standard/level has varied over the years as different models and assumptions have been used consistent with practice at the time.

g) Datum – It is unclear whether 'site datum' referred to on some drawings is the same as AOD. In addition there is reference on one of the drawings to the possibility of a peat layer under the 5 culverts. Therefore possible settlement of the peat in the area could have had an impact on datum levels and bund heights.

h) Grills – Vertical grills are known to be prone to blockage and are difficult to clear during a storm once they have become blocked. The current standard for grills would be difficult if not impossible to achieve given the form of the culverts and their location. The Panel does not see the need for grills and recommends that they are not re-installed. Posts to capture large obstructions such as branches are feasible and recommended.

i) Wind farms and associated tree felling – The tree felling proposed in association with the proposed wind farm construction is not considered to have a significant impact on future flooding at Glasdir.

Recommendations

a) The bund should be raised to the level shown in the Outline Proposal in Appendix 3, which is based on a 1 in 100 year event with climate change and 95% blockage, with a 600mm freeboard.

   Once raised it should be checked regularly and after extreme events (wet and dry) for possible settlement and damage, and repaired if necessary. In setting this height, the demonstrated likelihood of blockage, climate change and uncertainties associated with modelling have been taken into consideration.

Whereas the current bund has an allowance of only 200mm of freeboard, we are recommending 600mm be used as this is in line with custom and practice over several years for residential development. It is anticipated that this flood defence will enable flood insurance to be purchased without significant increases in premium.

b) It is to be hoped that the bund will be permanently raised as soon as possible. However, for the interim, a temporary line of sandbags (or equivalent) should be considered to be used to raise the bund height. Careful monitoring during a storm event is recommended to ensure integrity is maintained.

c) Long term management of the flood plain and catchment area should be organised. The maintenance of the area around the culverts' entrance and exit should particularly be cleared of debris, garden waste and the vegetation kept short. The responsibility for doing the maintenance should be clearly identified.

   There is currently a belief (*Managing Woody Debris in Rivers, Streams and Floodplains* written by the Wildlife Trusts and Water for Wildlife (2005) that catchment management should encourage natural processes and so woody debris in the catchment and watercourse would be encouraged. However, this catchment has been severely impacted by the construction of a road across the flood plain on an embankment rather than a bridge structure. This acts as a dam and the mitigation of providing the 5 culverts to pass the flood water is nullified if they block with debris (as happened in November 2012).

   Thus this catchment should be maintained to avoid debris being carried by flood flows. In addition, the exits from the culverts should be kept clear. A question has been raised about the need for a channel to connect the land immediately to the north of the culverts with the downstream floodplain. Whilst this is unlikely to have a significant impact during a flood, it would allow this land to drain more effectively to the river downstream of the road after the event. This should be the subject of further study.

d) A network of flood wardens should be put in place with tasks that include monitoring the condition of the flood plain and the culverts. There should be a designated DCC officer to respond to wardens. Organising annual river events during dry spells, to inspect and clear potential obstructions, helps to maintain awareness of the flood risk management system, especially during dry spells. This arrangement is becoming commonplace in areas at risk, and is proving to be an important educational opportunity.

e) Linking a flood warning system to an upstream gauge will be useful to the residents, flood wardens, NRW and DCC. It is vital there is a clear means of communication with identified recipients.

f) The grills have been removed from the culvert entrances and exits and should not be put back. Given the shallow height of the culverts and the staggered entrances and exits, designing screens to conform to the CIRIA Guide, with a low risk of blockage, would be a challenge.

g) An alternative that could be explored is a line of posts around the entrances to the culverts that could catch larger debris and vegetation carried in the flow (see Plate 12, Section 4.3 for photo).

h) A 300mm diameter sewer is shown on the drawings running under the culverts and a broken manhole cover was observed just upstream of the culverts on a visit on 7th August 2013. This manhole cover and any others in the area should be inspected, repaired and made safe in this public area.

i) The surface water drainage within the Glasdir site, in our view, had no discernible effect on the consequences of the flooding on 26/27 November 2012. Its ongoing monitoring, inspection and maintenance is vital to ensure it effectively drains rain water within the site.

Contents

EXECUTIVE SUMMARY 3

CONCLUSIONS 5
RECOMMENDATIONS 6

CONTENTS 9

1 INTRODUCTION 11

1.1 BACKGROUND 11
1.2 INDEPENDENT REVIEW PANEL 11
1.3 THE GLASDIR DEVELOPMENT 13
1.4 RUTHIN NORTH LINK ROAD 15
1.5 HISTORY OF FLOODING 17
1.5.1 Flood History to 2000 17
1.5.2 November 2012 17

2 HYDROLOGY 20

2.1 INTRODUCTION 20
2.2 DESIGN HYDROLOGY 20
2.3 RETURN PERIOD ASSESSMENT (NOVEMBER 2012) 20
2.4 SUMMARY 21

3 HYDRAULIC MODELLING 23

3.1 GENERAL 23
3.2 APPROPRIATE STANDARD OF SERVICE 23
3.3 PREVIOUS MODELLING WORK 25
3.4 MODEL REVIEW 27
3.5 EXISTING STANDARD OF SERVICE 29
3.5.1 Strategic Context 29
3.5.2 Hydraulic Model Results 29
3.6 NOVEMBER 2012 32
3.6.1 Context 32
3.6.2 Ruthin Weir Gauge 34
3.6.3 Aerial Photography 36
3.6.4 Sensitivity to Flow 38
3.6.5 Sensitivity to Blockage 39
3.6.6 Assessment of Event Return Period (27 November 2012) 42
3.6.7 Commentary 43
3.7 EFFECTIVENESS OF SECURITY SCREEN REMOVAL 44
3.8 CONCLUSIONS 47
3.9 SUMMARY 47

4 ENGINEERING OPTIONS 49

4.1 INTRODUCTION 49
4.2 MAINTAIN TO A BETTER STANDARD 49
4.3 OPTION 1 – INSTALL TRASH / DEBRIS SCREENS 51
4.4 OPTION 2 - RAISE FLOOD DEFENCES TO THE GLASDIR ESTATE (SCENARIO C & D) 53
4.5 OPTION 3 - FLOOD DEFENCES TO LEFT (WEST) BANK OF THE RIVER CLWYD (SCENARIO E) 58
4.6 OPTION 4 - REDUCED SPILLWAY ELEVATION (SCENARIO F) 61
4.7 OPTION 5 - INTRODUCTION OF ADDITIONAL FLOW ROUTES (SCENARIO G) 64
4.8 OPTION 6 - REMOVAL OF RUTHIN WEIR & RE-GRADING OF THE RIVER CLWYD (SCENARIO H) 67

5 HYDROLOGICAL EVALUATION 70

5.1 DESIGN HYDROLOGY 70
5.1.1 Schematisation and Catchment Descriptors 70

5.1.2 URBEXT 71
5.1.3 Index Flood, QMED 71
5.1.4 QMED Sensitivity 73
5.1.5 Growth Curves 76
5.1.6 Hydraulic Model Boundary Conditions 77
5.1.7 Peak flow analysis from Hydrology routed through Hydraulic Model 78
5.2 CALIBRATION HYDROLOGY 79
5.2.1 General 79
5.2.2 Approach and Uncertainty 80
5.2.3 Review of Inflows 80
5.3 RETURN PERIOD ASSESSMENT (NOVEMBER 2012) 80
6 CONCLUSIONS 82
7 RECOMMENDATIONS 83
APPENDICES 85
APPENDIX 1A: TERMS OF REFERENCE AND COMMISSION FOR INVESTIGATION OF 9 JANUARY 2013 86
APPENDIX 1B: REVISED TERMS OF REFERENCE AND COMMISSION FOR INVESTIGATION, APRIL 2013 SHOWING IN RED THE DIFFERENCES FROM THE JANUARY ISSUE 90
APPENDIX 2: GLASDIR DEVELOPMENT, RUTHIN – RELATIONSHIP BETWEEN MAIN PARTIES 95
APPENDIX 3: OUTLINE OF POSSIBLE PROFILE OF THE HEIGHTENED BUND 96
APPENDIX 4: KEY DOCUMENTS RE GLASDIR FLOODING IN NOVEMBER 2012 97

Explanation of Abbreviations used

AMAX	Annual maximum peak flow (see para 5.1.3 a)
AOD	Above Ordnance Datum
CFMP	Catchment Flood Management Plan
DAM	Development Advice Map
DCC	Denbighshire County Council
EA	Environment Agency
EA (Wales):	Environment Agency Wales, now Natural Resources Wales
FCA	Flood Consequence Assessment
FEH	Flood Estimation Handbook
GIS	Geography Information System
LiDAR	Light Detection and Ranging
NRW	Natural Resources Wales
QMED	Index Flood, Median flood of annual maximum peak flow series (see para 5.1.3)
SEA	Strategic Environment Assessment
SuDS	Sustainable Drainage Systems
WDA	Welsh Development Agency

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1 Introduction

1.1 Background

The summer and autumn of 2012 was characterised by periods of prolonged rainfall in Wales and England with flooding reported by many communities in the south and west of the country. On the 25 November an Amber Warning was issued by the Environment Agency with the Met Office indicating that up to 100mm of rain could fall across mid and north Wales.

On 27 November 2012 there was widespread flooding affecting approximately 500 residential and commercial properties at more than twelve separate locations in Denbighshire including significant numbers of properties in St Asaph and Ruthin. The primary impact at Ruthin was flooding of the Glasdir Estate, which is located to the north of the town, where over 100 properties were affected by flooding (see Plate 1 and Plate 2).

1.2 Independent Review Panel

Following the flooding in November 2012, Denbighshire County Council appointed an Independent Panel to review flooding in Ruthin – See Appendix 1 for the Terms of Reference of the Investigation issued in January and April. The objective of the independent review is to understand the causes of flooding and the likelihood of recurrence and advise Denbighshire County Council on potential schemes to improve protection of the houses. The Independent Review Panel has assessed a range of information obtained from Natural Resources Wales (formally Environment Agency Wales), Denbighshire County Council and residents of the Glasdir Estate including:

- Photographs and video of the November 2012 event
- Topographic surveys and drawings of the Glasdir Estate and Ruthin Link Road
- Hydrological data including rainfall, flow data and Ruthin Weir Ratings information
- An ISIS-TUFLOW model and hydrological analysis of the River Clwyd at Ruthin obtained from Natural Resources Wales (NRW)
- The River Clwyd, Ruthin Flood Risk Assessment (Bullen & Partners, May 1999)
- Ruthin Flooding Project Appraisal Report (Parsons Brinkerhoff 1998)
- Glasdir Estate Flood Consequence Assessment (Weetwood Services 2005)
- Appraisal of Flooding at Ruthin, (Black & Veatch, 2003)
- Analysis of flooding in North Wales, (Environment Agency Wales, November 2012)
- Flooding at Glasdir Estate in Ruthin; (Environment Agency Wales; 14 December 2012)
- Flood Estimation Record (Environment Agency Wales, March 2013)
- Calibration of ISIS-TUFLOW model (JBA Technical Memorandum, June 2013).

Other key documents are listed in Appendix 4.

Plate 1 - Ruthin Glasdir Estate November 2012

Plate 2 - Ruthin Glasdir Estate November 2012

During the period of the study, consultations have been held with the residents of the Glasdir Estate, Denbighshire County Council, EA Wales and subsequently Natural Resources Wales (NRW) in order to gain local knowledge and to identify the key issues and focus the investigation. Consultations have included meetings with residents, presentations of the interim results of the hydraulic modelling, and the production of an interim report. This process has highlighted a number of important issues including the complexity of the hydrological model, uncertainty associated with Ruthin Weir, and the impact of blockage to the culverts beneath the Ruthin Link Road. Accordingly, the Independent Review Panel has:

- Undertaken a detailed review of hydrological estimates for the River Clwyd provided by NRW and JBA (see Annex A).
- Prepared a formal review of the NRW ISIS-TUFLOW hydraulic model of the River Clwyd and Mwrog Street Flood Alleviation Scheme.
- Amended and updated the ISIS-TUFLOW hydraulic model in accordance with the review.
- Undertaken additional hydraulic modelling of the River Clwyd and Mwrog Street Flood Alleviation Scheme using the hydrological estimates supplied by NRW to determine flood extent and depth for a range of return periods and blockage scenarios.
- Undertaken hydraulic modelling in order to establish the approximate flood return period and causes of the flooding which affected the Glasdir Estate in November 2012.
- Proposed possible engineering options and undertaken hydraulic modelling to assess the feasibility of mitigating the risk of flooding to the Glasdir Estate.

The review, including assessment of hydrology and hydraulic modelling, was undertaken between February 2013 and July 2013. During this period the Independent Panel liaised with Glasdir estate residents, Denbighshire County Council Natural Resources Wales and JBA.

JBA were appointed by NRW to undertake a range of work associated with Ruthin including reviewing modifications to the EA model of Ruthin and the development of a technical note associated with model calibration for the November 2012 event. It was agreed with Denbighshire County Council that there would be benefit in using this information in the review. The document was issued by NRW in late June 2013 and this had a significant impact on the Independent Panel's programme of work.

1.3 The Glasdir Development

The Glasdir Estate was constructed by Taylor Wimpey Homes with property being sold "off-plan" in 2009. Flooding to the estate was recognised as a significant planning matter as a Flood Consequence Assessment (FCA), including hydrological analysis and hydraulic modelling, was prepared by Veryard / Opus, Weetwood Services and Capita Symonds in 2005.

The hydraulic modelling undertaken for the purposes of the FCA suggested that the floodplain extent shown on the then Environment Agency's flood risk mapping could be reduced and there would be no residential development within the 100 year flood

outline. Unfortunately it has not been possible to obtain a copy of the model for review by the Independent Panel. The conclusion of the FCA stated that the development of the proposed site could be carried out without conflicting with the requirements of TAN15 subject to the following:

- *'Finished Floor Levels within the 1000 year flood outline predicted by the TUFLOW modelling results would be set at 200mm above the flood levels for the 1 in 1000 year event.'*
- *'The proposed hard landscaped bund along the eastern edge of the proposed development site will be a hard defence and the crest of the landscaped bund will be above that of the estimated top water level for a 1 in 1000 year event (approximately 53.5m to 53.25m AOD from south to north respectively) with a minimum allowance for freeboard of 200mm.'*

It is understood that buyers / residents were assured that the defence provided a high standard of service to the estate in the order of 1 in 1000 years with a freeboard of 0.2m. In addition, the residents have also drawn the Independent Review Panel's attention to the issue of the floor levels of the flooded houses compared to the values used in the planning documents.

A question has been put to us about whether it would be advantageous to the flood risk of the houses still to be built if their floor levels were to be set at the same height as the bund, and whether such a change, and the associated general raising of the ground levels within that part of the estate still to be built would increase flood risk to the existing houses.

There is no requirement in the current TAN15 in relation to the height of house floor levels having to be above predicted flood levels where their flood risk is protected by a bund. Indeed, if house floor levels are to be set to the same level as the bund then that calls into question why a bund is required at all.

However, in the particular case here, whilst we have not analysed the actual difference in water level with the alternative house and infrastructure levels (which would require further detailed modelling), we have undertaken a comparison of two model scenarios to illustrate the point.

That comparison of two model scenarios has compared the water levels outside the Glasdir Estate in the real case of November 2012 and the imaginary case of their being a bund around the estate that excluded all the flood water. This comparison shows that excluding all the water from the Glasdir estate in the November event could have made up to 50mm difference. Therefore a change in level due to different floor and ground levels within the estate can be shown to be much less than 50mm.

Once the recommended new bund is constructed, the risk of overtopping is very significantly reduced so there is, in our view, no need to raise the floor levels of the still-to-be-constructed houses above those already specified.

The two model scenarios used for the above comparison are:

iCD95_Q100+CC: 10m 'glass wall' around Glasdir; Security screens removed; 95% blockage; 100yr+CC design event

iD95_Q100+CC: Security screens removed; 95% blockage; 100yr+CC design event; Bund levels as per survey.

1.4 Ruthin North Link Road

The Glasdir Estate is adjacent to the Ruthin North Link Road. The Ruthin North Link Road was completed in 2006 and runs perpendicularly across the flood plain and impounds water behind the embankment during times of flooding. The River Clwyd is conveyed under the road via a bridge to the east of the floodplain. The design of the Link Road also incorporated five culverts under the highway with the objective of providing conveyance of flood water from the south to the north of the highway. The Environment Agency's (now NRW) Dec 2012 report considered that the presence of security screens and blockage to the culverts could be a contributory factor in flooding to the estate.

A planning application for the 'Northern Link Road' was submitted on behalf of the Welsh Development Agency (WDA) in 2003 and subsequently granted by Denbighshire County Council on 14 July 2004. The assessment of flooding from the River Clwyd was undertaken by Bullen and Partners Consulting Engineers. In February 2004 Bullen wrote to the WDA concluding that "introducing the road across the floodplain would cause the 100-year water levels to rise in this area". The letter recommended various combinations of culverts which would be required beneath the link road in order to convey 6m^3/s and up to four 2.4 x 0.75m box culverts were recommended.

Subsequently, five culverts were built and fitted with vertical grills at both upstream and downstream ends. These were reported as having been partially blocked by vegetation and debris, in the November 2012 event but the actual proportion of blockage during the November 2012 event is not known (see Plate 4 and Plate 5). The grills were removed shortly after the flood event.

Plate 3 - River Clwyd Bridge (Upstream View during November 2012 event)

Plate 4 - Ruthin Link Road Culverts

Plate 5 - Ruthin Link Road Culverts (Post November 2012 Flooding)

1.5 History of Flooding

1.5.1 Flood History to 2000

Ruthin has a long history of flooding within the town and in 2003 Black and Veatch[1] undertook a historical review of flooding through research at the library in Ruthin and identified events in:-

- June 1931,
- October 1966,
- 1990 (no month quoted),
- March 1998,
- October / November 2000.

The most recent of the above events, in November 2000, was stated as being particularly damaging due to the bank of the River Clwyd bursting on three separate occasions in two weeks. The collapse and blockage of the culvert running beneath Mwrog Street exacerbated the situation and it was reported that although the initial event on the 30 October caused much of the damage, the second event one week later resulted in flooding to a greater depth.

Primarily as a result of the November 2000 event a system of flood embankments and walls was constructed alongside the River Clwyd by Environment Agency Wales in 2003 to mitigate the risk within the town (see Plate 6). Subsequently the Mwrog Flood Alleviation Scheme was designed and constructed to reduce problems associated with restricted capacity of the culvert running along Mwrog Street (see Figure 1). The alleviation scheme intercepts the Mwrog stream to the west of Ruthin at Llanfwrog and directs flow around the western perimeter of the town. The flood alleviation channel crosses the Denbigh Road and the Ruthin North Link Road and is conveyed in a northerly direction to the Clwyd downstream of Ruthin Weir.

1.5.2 November 2012

The majority of the first two weeks of November were comparatively dry. Rainfall totals for the month up to 26th November were not considered unusual and in-line with the Long Term Averages for that month. However, rainfall totals for the 7 days leading up to the 26th November were particularly high. In relation to this event the Environment Agency's Hydrology & Water Resources Management Team in their report on flooding in North Wales[2] stated that:-

> *"It is therefore clear that the flooding of the 27th November was the compounded result of two nested rainfall events. The rainfall of 22nd November saturated the catchments and increased river levels, which were then sustained by a series of successive weather fronts leading up to 26th November."*

[1] Appraisal of Flooding at Ruthin, Black & Veatch, June 2003
[2] Analysis of flooding in North Wales, November 2012; Environment Agency; November 2012

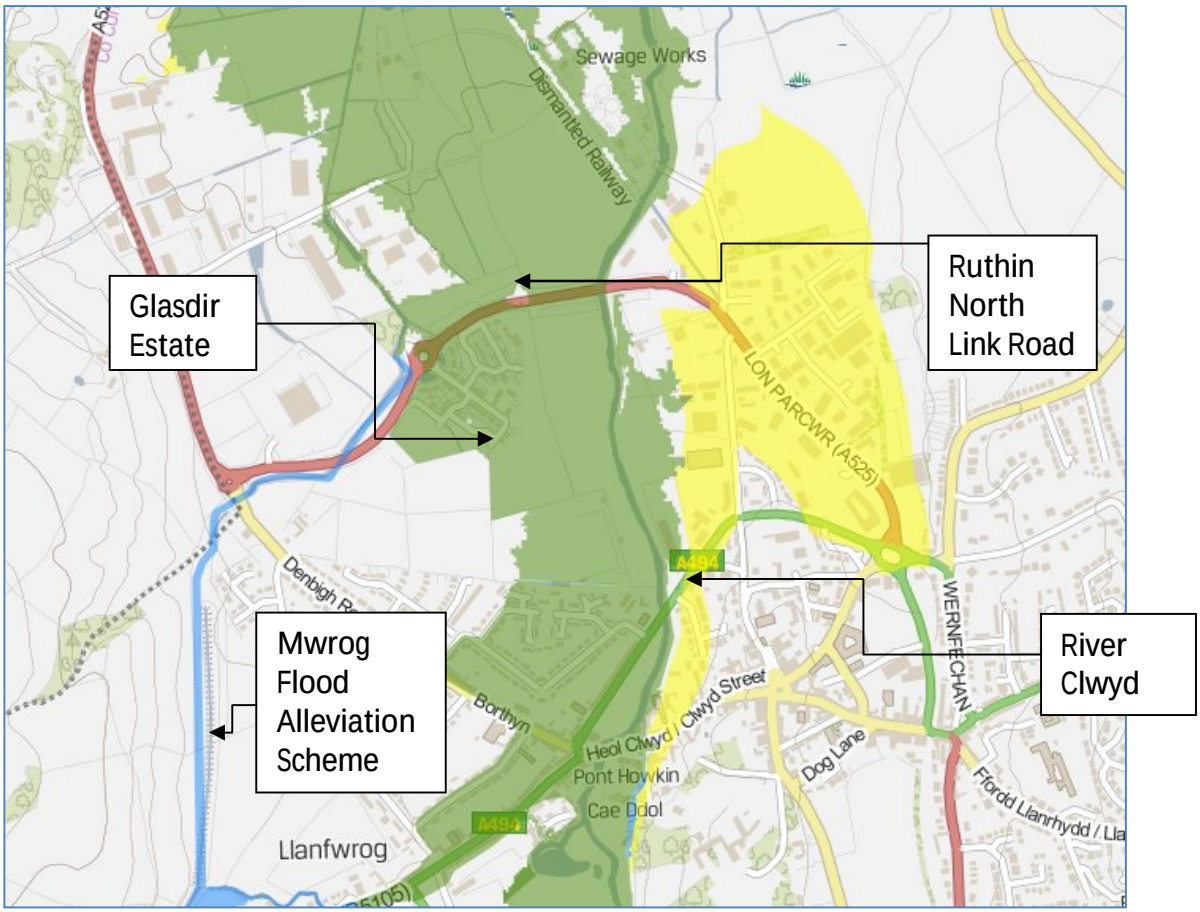


Figure 1- Location Map

The report states explicitly that saturation of the catchment was a significant factor in the hydrological response of rivers on the 27 November 2012. This view is repeated by the Environment Agency Wales in their report on flooding for Glasdir[3] which says that:-

> *"River levels in the River Clwyd and its tributaries were already high before the rainfall event of 26 / 27 November 2012 as a result of prolonged wet weather in the catchment during the previous week. The more intense period of rain on the 26 and 27 November 2012 falling on already saturated land, caused the particularly high river levels that were recorded during the flood."*

[3] Flooding at Glasdir Estate in Ruthin; Environment Agency Wales; 14 December 2012

Plate 6 - Ruthin Flood Embankment adjacent to Park Road: Constructed in 2003

Plate 7 - Mwrog Flood Alleviation Scheme (November 2012)

2 Hydrology

2.1 Introduction

Edenvale Young has undertaken a review of the information provided by Natural Resources Wales and JBA in order to better understand the reliability of the hydrological models used to develop the design and event hydrology.

2.2 Design Hydrology

NRW has provided the Flood estimation calculation record pro-forma for review and it is considered that the hydrological assessment detailed in the pro-forma is generally sound. However, there are a number of issues associated with the use of QMED and the AMAX series at Ruthin Weir which require further review or explanation. Firstly, the catchment immediately upstream has undergone a number of significant changes in the recent past including:-

- Construction of Ruthin Flood Alleviation Scheme (2003)
- Construction of the Mwrog Street Flood Alleviation Scheme (2004)
- Construction of the Ruthin Link Road (2005/06)
- Modifications to the fish pass at Ruthin Weir (2009).

The impact of these changes is not addressed in the FEH Pro Forma although it is recognised that some account of the changes has been made within the calculations. Consequently, it is considered that the AMAX data from 2004 onwards should not be used in the assessment of QMED at Ruthin Weir without accounting first for the effects described above. It is also possible that the site is not considered suitable for use as a donor station.

Secondly, it also appears that the rating underestimates flows around the higher spot gaugings, and as a result may underestimate QMED in the region of 2 m^3/s. In summary, there is some uncertainty associated with the design hydrology and this should be addressed by the NRW or a consultant before any work is undertaken on the detailed design of the flood defences for the Glasdir Estate. It is considered that NRW is best placed to consider these issues and it is recommended that they provide the clarifications and evolve the document as necessary. This would reduce the uncertainty associated with modelled results. However it does not, in our opinion, affect our recommendations for the level of the flood bund and we have taken this into account by using a freeboard of 0.6m.

2.3 Return Period Assessment (November 2012)

A return period assessment of the November 2012 event could be based on either the observed or modelled flow data. However, there is a range of factors which make it difficult to attribute an annual exceedance probability (or return period) to the event for either method with accuracy. These factors are as follows:-

- Reliability of the current calibration hydrology and possibility for a range of permutations which predict the same flooding (including rainfall distribution and calculation of antecedent catchment wetness).

- Construction of Mwrog flow diversion channel and Ruthin Link road may make observed flows during 2012 incompatible with previous recorded flood events.
- Uncertainty as to the degree of culvert blockage which occurred.
- The fact that the flooding was predominantly volume based, rather than related entirely to the peak flow. It was volume based as it was a long duration event on a wet catchment rather than a short duration intense storm.
- Local bypassing of Ruthin gauge and associated problems with rating leading to poor accuracy of high flow data.

The blockage of the culverts under Ruthin North Link Road resulted in the peak of the event being attenuated upstream of Ruthin Weir. Had the culverts not been blocked the peak flow measured at Ruthin Weir is likely to have been higher. Consequently any assessment of return period based on observed peak flow at Ruthin Weir may be unreliable.

2.4 Summary

The methodology followed by NRW to establish the design hydrology is generally good but the use of QMED and the AMAX Series at Ruthin Weir may not be appropriate given the uncertainties associated with the data. In order for the design hydrology to be made suitably robust, suggestions for further work have been made as part of this study (see also 2.2). These suggestions are presented in Table 1 below.

Action	Priority	Significance
Increase confidence in estimated QMED values, including:- • Improved rating for Ruthin Weir GS; • Assess impact of Mwrog channel diversion and Ruthin Link Road on AMAX values; • Review choice of donor station & method of data transfer.	High	The reliability of the estimated QMED values is considered to be critical to the accuracy of this study.
Verify & adjust design hydrograph shapes based on observed flow data where possible. Determine critical duration.	High	Critical to accurate assessment of hydrograph volume, which was a key factor in the 2012 flood event.
Review pooling groups to make growth curves more representative of the study catchments.	Medium	The impact of this may be limited, but is worth undertaking for completeness.
Include urban catchment areas within model inflow representations.	High	The area in question is relatively small, but highly urbanised, so could have a noticeable impact.
Improve representation of lateral inflow at Pont Howkin.	Medium	The contribution of inflow between the top of the River Clwyd and Pont Howkin is relatively small but improvements in representation could be easily applied.

Table 1 – Suggestions for Further Work for Hydrological Assessment

3 Hydraulic Modelling

3.1 General

As noted in the introduction the objective of the hydraulic modelling was to establish the causes of the November 2012 event; assess the standard of service afforded by the Glasdir Flood Bund and investigate possible options to mitigate the risk of future flooding. These issues are discussed in more detail in the following sections but in summary the work has encompassed the following:-

- A review of the ISIS-TUFLOW-ESTRY model supplied by NRW.
- Amendment to the ISIS-TUFLOW-ESTRY model to improve numerical stability and ensure that the model conformed to best practice.
- Hydraulic modelling using scaling of the JBA flow boundaries to establish the return period and causes of the November 2012 event and review flood depths across the Glasdir Estate with a 60 hour storm duration.
- Hydraulic modelling using the FEH flow boundaries provided by NRW conforming to 1 in 50 year, 1 in 100 year, 1 in 200 year, 1 in 1000 years and 1 in 100 year (plus an allowance for climate change) to establish the existing level of protection to the estate. These scenarios were modelled using design a 9.5 hour storm duration commensurate with the NRW analysis.
- Hydraulic modelling to assess the impact of removing the security screens from the culverts to the east of the Glasdir Estate.
- Hydraulic modelling using the FEH flow boundaries noted above to propose possible engineering options to assess the feasibility of mitigating the risk of flooding to the Glasdir Estate to an appropriate standard of service.

Table 2 shows the scenarios which have been investigated by the modelling. Scenario B has been primarily used to investigate the existing standard of service afforded by the existing embankment adjacent to Glasdir (see Section 3.5) and assess the cause of flooding experienced in November 2012 (see section 3.6). Scenarios C through to H are possible engineering options (see Section 4).

Throughout this section the inflow boundary at ISIS node CLWY01-4423D (see Figure 2) has been used to compare and contrast return period estimates. This node is at the upstream end of the model and accounts for a large proportion of the flow within the model but it should be noted that there are other inflows distributed throughout the model (e.g. the urban extent of Ruthin, the Mwrog flood alleviation scheme, etc). Accordingly flow at Ruthin Weir for the equivalent return period is higher than at ISIS node CLWY01-4423D because it takes into account a larger catchment area.

3.2 Appropriate Standard of Service

During consultations with Denbighshire County Council and NRW it was agreed that an appropriate standard of service would be 1 in 100 years plus an allowance for climate change. It was also considered, by the Investigating Panel, that a freeboard allowance of 600mm in conjunction with blockage to the culverts passing below the Ruthin Link Road was appropriate. This standard of service is commensurate with the target

standard of service for flood alleviation schemes and planning requirements contained in TAN15

The basis of flows for this assessment would be the NRW's estimates of flow derived using the methods contained in the FEH.

Scenario	Description
B (baseline)	Baseline model, to represent conditions as at November 2012. Assumes no blockage of the culverts to the east of the Glasdir Estate.
C	As in Scenario B, but with the addition of a raised flood defence embankment / wall around the Glasdir Estate, with northern boundaries at the Ruthin Link Road.
D	As in Scenario B, but modelling 33%, 66% and 95% blockage of the culverts to the east of the Glasdir Estate.
E	As in Scenario B, but with an additional of a raised flood defence embankment / wall along the western bank of the River Clwyd, between Park Road and Ruthin Link Road.
F	As in Scenario B, but with the elevation of the spill area immediately to the north of Ruthin Link Road and to the west of the River Clwyd channel lowered to 52m AOD.
G	As in Scenario B, but with a 20m wide 'cattle creep' under Ruthin Link Road; drainage channels upstream and downstream of the 'cattle creep' to divert out-of-bank flow.
H	Removal of Ruthin Weir. Re-profiling of approximately 900m of channel, from downstream of Park Road to immediately downstream of Ruthin Weir, creating a constant gradient in order to increase channel capacity past Glasdir Estate.
I	Removing security screens from culverts adjacent to Glasdir. This will always be used in combination with other scenarios. This represents the present day conditions as screens were removed following the November 2012 event.

Table 2 - Model Scenarios

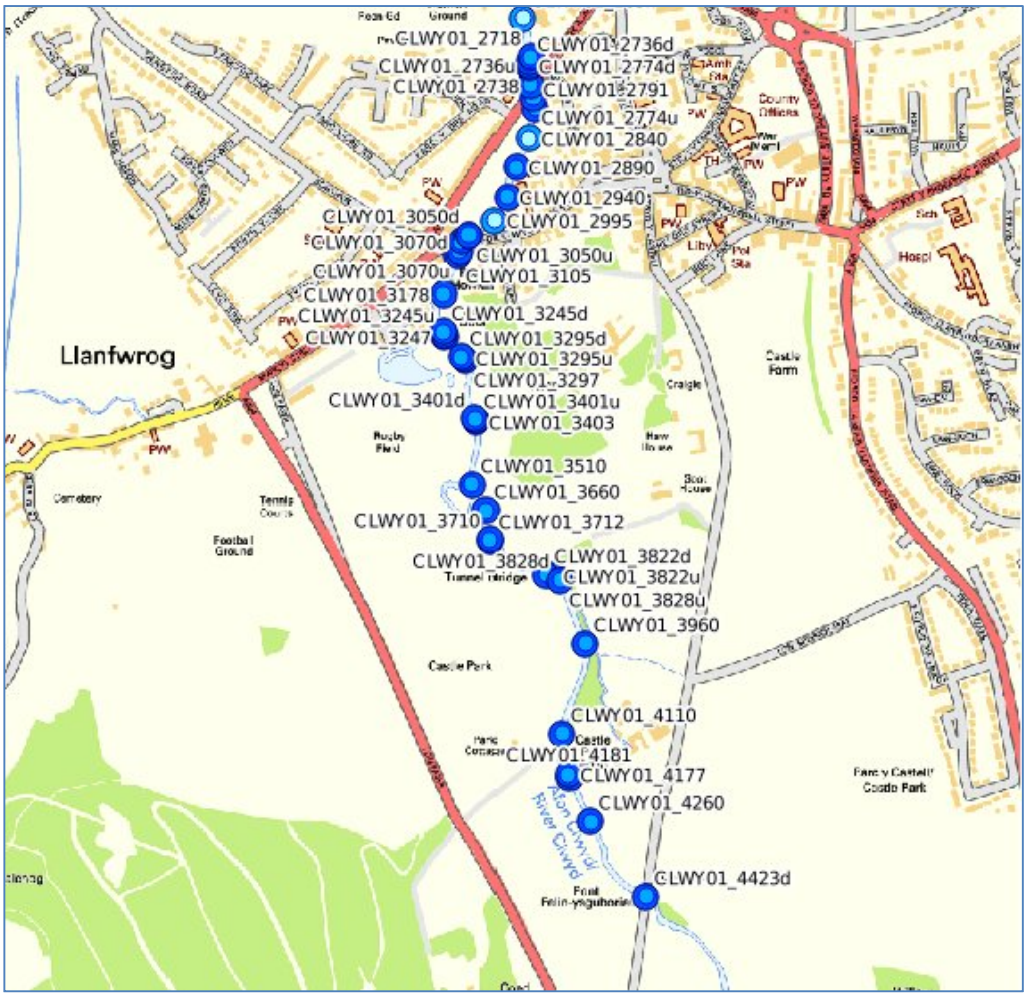


Figure 2 - ISIS Node Locations

3.3 Previous Modelling Work

The Independent review panel is aware that hydraulic modelling was undertaken by Capita Symonds for the Flood Consequence Assessment using an ESTRY-TUFLOW model which was built in 2004 / 2005. Unfortunately it has not been possible to obtain a copy of this model for assessment. It should also be noted that 1D-2D models such as ESTRY-TUFLOW were first introduced to the UK in 2003 / 2004 and that considerable progress has been made in relation to establishing best practice for 1D-2D modelling. In addition BMT WBM (the authors of TUFLOW) has also issued a number of software updates and revisions to improve the functionality of the program.

Figure 3 shows the existing TAN15 Development Advice Map (DAM) published by the Welsh Government. The maps are based on Environment Agency's extreme flood outlines (Zone C) and the British Geological Survey drift data (Zone B). Zone C data was revised in 2013. The mapping indicates that the Glasdir Estate is within the 1 in 1000 year floodplain. Current Environment Agency (EA) flood mapping identifies that the site is located within Flood Zone C1 (shown in Figure 4), indicating that the land here has a low probability of flooding from fluvial sources but does indicate that the Glasdir Estate is within the 1 in 1,000 year floodplain.

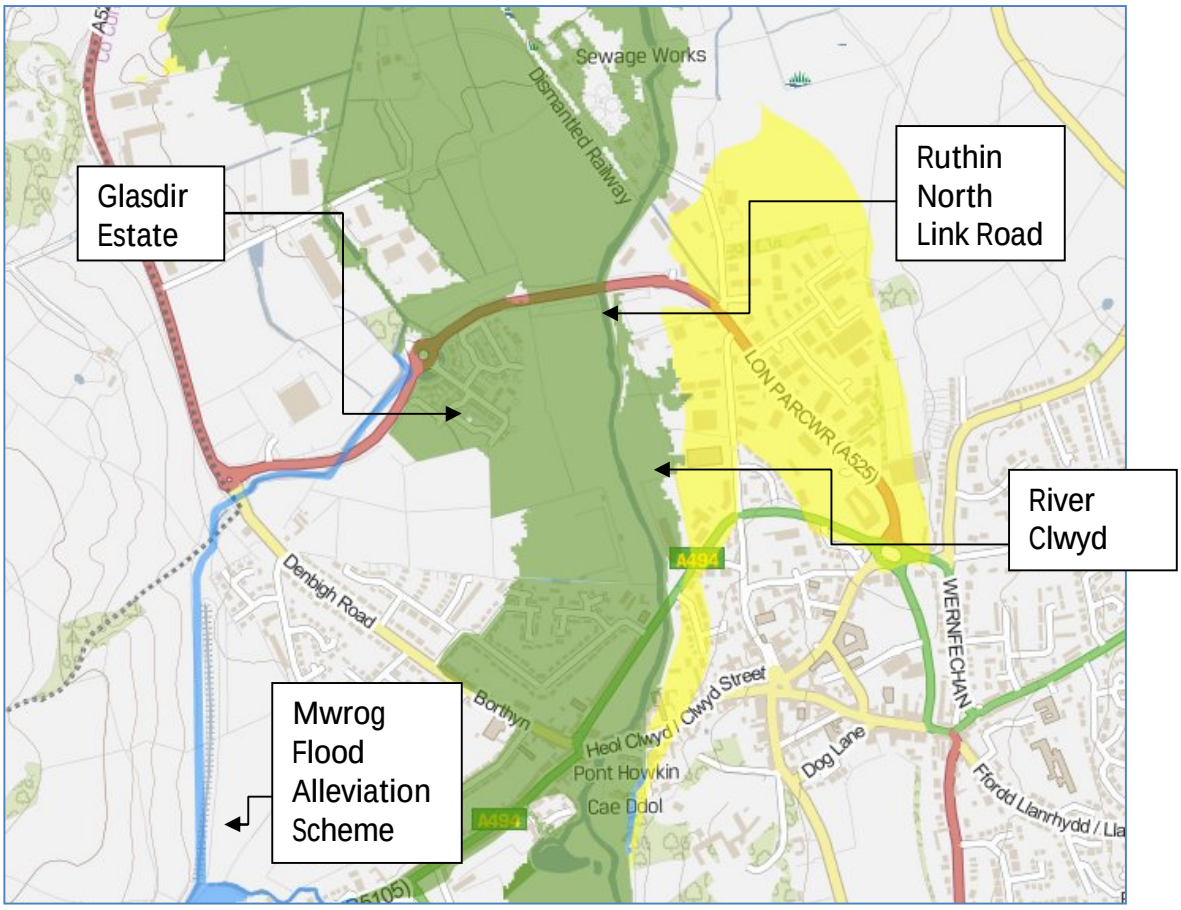
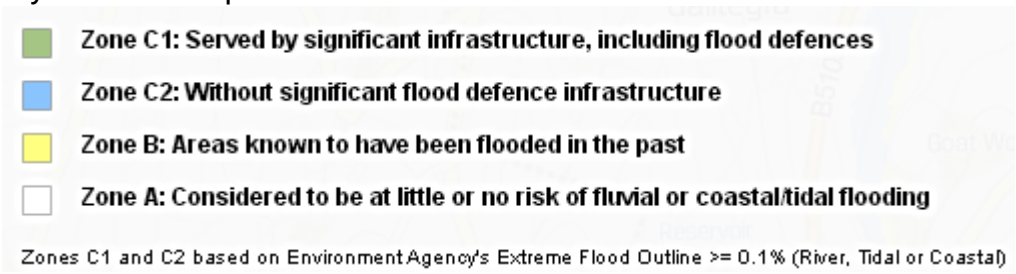


Figure 3 - TAN15 Development Advice Map (http://data.wales.gov.uk/apps/floodmapping)

Key to TAN15 Map



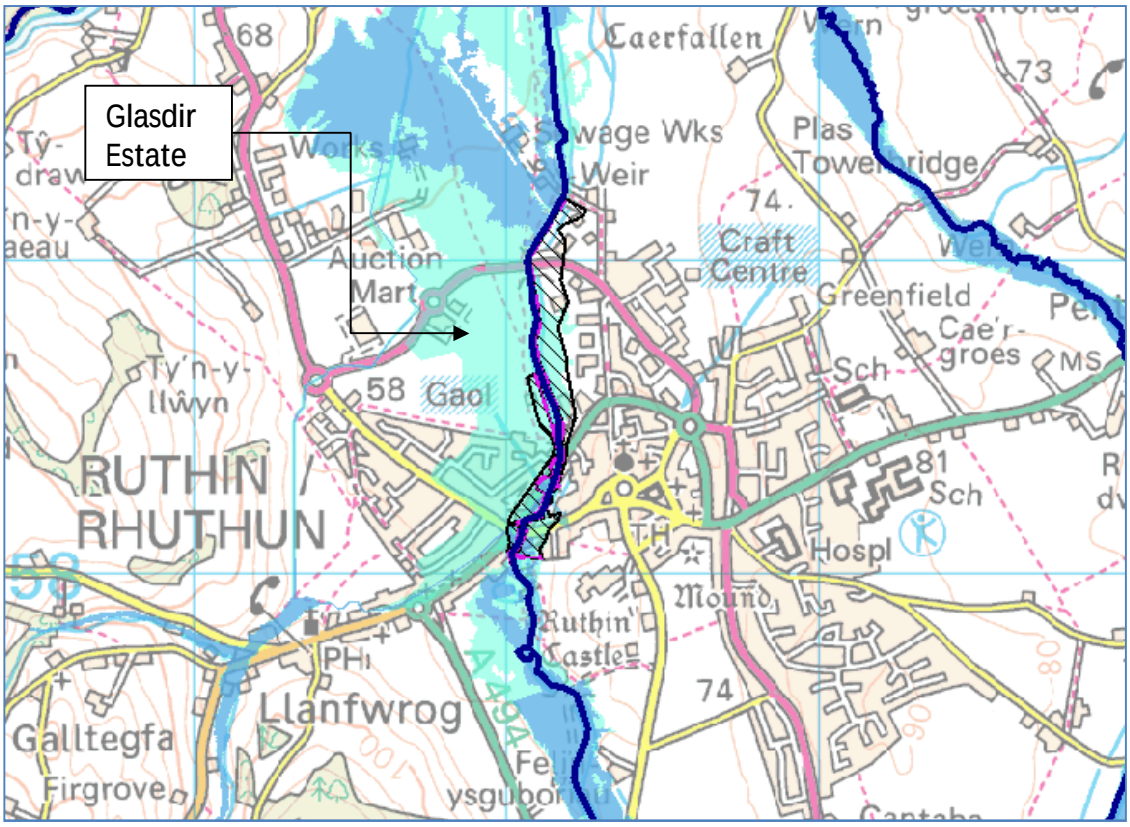


Figure 4 - EA Flood Map at location of site (www.environment-agency.gov.uk)

Key to EA Flood map

- Light blue shows the additional extent of an extreme flood from rivers or the sea. These outlying areas are likely to be affected by a major flood, with up to a 0.1 per cent (1 in 1000) chance of occurring each year.
- Dark blue shows the area that could be affected by flooding, either from rivers or the sea, if there were no flood defences. This area could be flooded from a river by a flood that has a 1 per cent (1 in 100) or greater chance of happening each year.
- Hatched areas benefit from the flood defences shown, in the event of a river flood with a 1 per cent (1 in 100) chance of happening each year. If the defences were not there, these areas would be flooded.

3.4 Model Review

The ISIS-TUFLOW-ESTRY model obtained for the purposes of this study was obtained from NRW in February 2013. It is understood that NRW had undertaken a considerable amount of work following the November 2012 flood event to improve the hydraulic model of Ruthin. The TAN 15 Development Advice Map shown in Figure 3 has not been updated as a result of this work.

The Independent Panel is also aware that JBA has been assisting NRW in developing the model, checking and review. Importantly, it is also recognised that further development continued after the model had been supplied to the Independent Review Panel. Accordingly the version of the model used by the Independent Review Panel may be at variance with the model used by NRW and JBA.

The hydraulic model developed by NRW / JBA incorporated the River Clwyd, Mwrog Flood Relief Channel and floodplains to the river. The model extends approximately 1 km upstream of Ruthin on the River Clwyd and 1.7 km downstream of Ruthin Weir. The 1D ISIS element of the model explicitly incorporated Ruthin Weir, the Mwrog flood diversion channel, bridges and culverts on the river system and the Ruthin Flood alleviation scheme (flood embankments / wall). The culverts below the Ruthin Link Road were represented in ESTRY. The floodplain and embankment for the Ruthin Link Road were represented within the 2D domain using LiDAR data.

No major errors were noted in the configuration of the model but it was considered that improvements to the model could be made to improve the numerical stability of the model and ensure that the model conformed to best practice. Particular attention was paid to sections of channel upstream of Ruthin Weir and the Glasdir Estate. Accordingly a series of amendments were made to the schematisation of the Flood Relief Channel and the River Clywd. These changes are summarised as follows:-

- Amendments were made to the culverts beneath the Ruthin Link Road in order to better represent the performance of the culvers during high flow situations.
- Node chainage within the 1D ISIS model were reviewed and amended, with some adjustment to the equivalent ISIS chainage where deemed necessary. (It should be noted that in some instances there were discrepancies between the surveyor's estimate of open channel length and the length of open channel measured using GIS data. Therefore it was not always possible for the nodes to be positioned on the map at the distances recorded by the surveyor).
- Boundaries between 1D and 2D domains were relocated to ensure that the 1D – 2D boundary was at the top of embankments thus ensuring a better reflection of channel capacity. (Where this resulted in increasing the channel width in the 1D ISIS model the cross-section data was extended using original survey data or LiDAR).
- Removal of interpolates in the Flood Relief Channel to minimise short reaches in 1D schematisation.
- Addition of interpolates to River Clwyd to better represent rapid longitudinal changes in water surface (engineering options).
- Adjustment of cross-section panel markers to ensure correct conveyance calculations in 1D sections.
- Extension of the Glasdir defensive bund. The southern portion of this bund did not appear to have been included in the original model, and was extended based on survey data.
- Repositioning of defence lines to follow apparent alignment.
- Updated schematisation of Ruthin Weir to represent new weir configuration
- Amendment of defence heights in the vicinity of Ruthin Gaol.

- Uniform amendment of bridge to orifice transition distances to the 0.5m for bridges on the River Clwyd.
- Adjustment of cross-section at Park Road Bridge to reduce model instability.
- Removal of three bridge units in the vicinity of Cae Ddol to improve stability.
- Adjustment of spill elevations to match bridge deck heights.

3.5 Existing Standard of Service

3.5.1 Strategic Context

As noted in Section 2 the use of FEH is important as it establishes a common standard for the evaluation of hydrology for flood risk and the assessment of the benefits associated with alleviation schemes. The FEH methodology is also used as the primary source of flow information associated with the development control, flood risk mapping, and for the generation of flood flows within a Flood Consequence Assessment. The FEH estimates of flow and storm duration used for the hydraulic modelling to assess the existing standard of service are based upon the information provided by NRW and shown in Figure 5.

However, it should be noted that the flow estimates were derived in 2012 using the latest version of FEH and not the version used in 2004 / 2005 which would have been used for the generation of the Flood Consequence Assessment. The results contained in this section reflect the current understanding of flood risk to the Glasdir development.

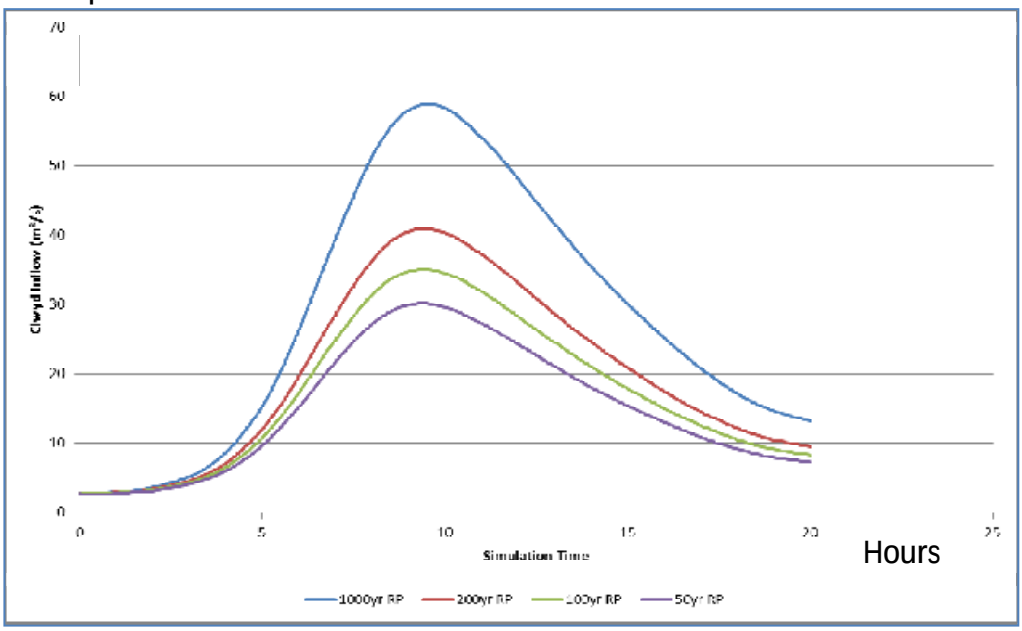


Figure 5 - Design event inflows to River Clwyd (inflow CLWY01-4423D)

3.5.2 Hydraulic Model Results

Figure 6 to Figure 8 show the results of the hydraulic modelling for a 1 in 100 year event, 1 in 100 year event with an allowance for climate change, and the 1 in 1000 year event. The modelling assumes that there is no blockage of the culverts passing under the Ruthin Link Road and is therefore commensurate with the requirements for Development Advice Mapping. Importantly the mapping indicates that the

Glasdir Estate would be inundated during a 1 in 1000 year event. The modelling includes the topography of the estate and the existing flood embankment.

Figure 6 - Design hydrology; Q = 1 in 100 years, 35.2 m3/s Blockage = 0%: (Scenario B)

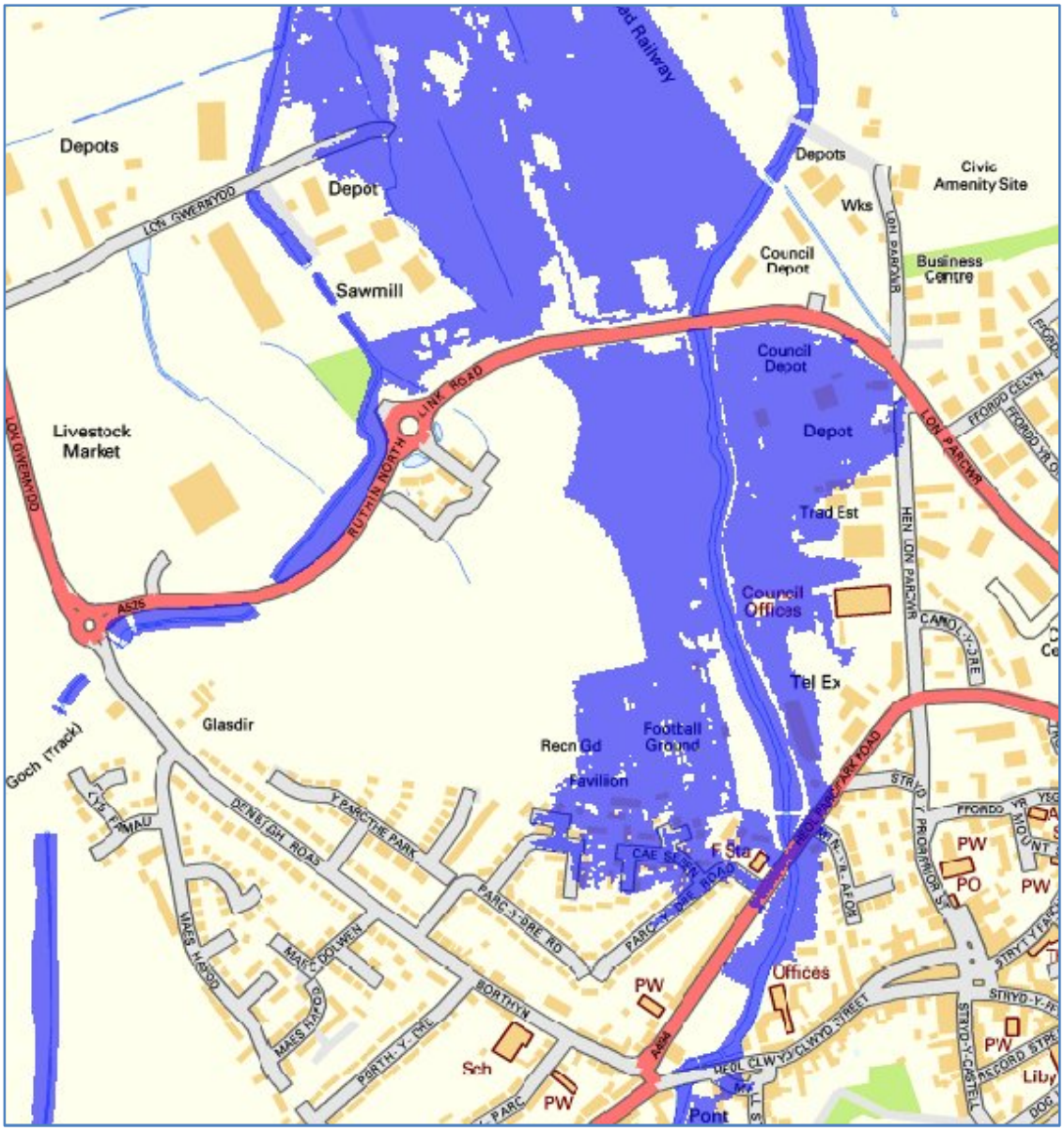


Figure 7 - Design Hydrology; Q = 1 in 100 years plus Climate Change, 42.1m3/s Blockage = 0% (Scenario B)

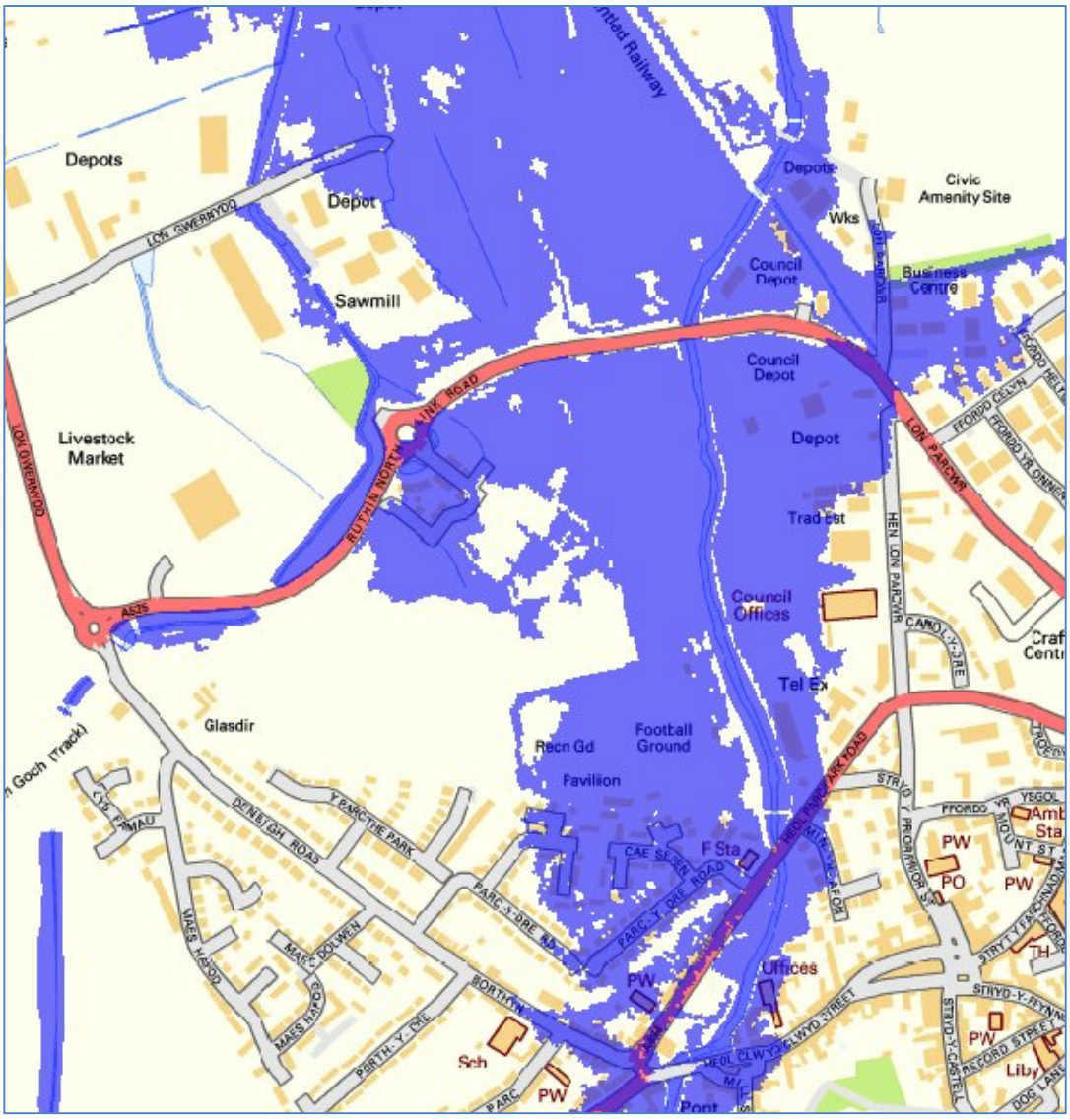


Figure 8 - Design hydrology; Q = 1 in 1000 years, 59.2 m3/s: Blockage = 0% (Scenario B)

3.6 November 2012

3.6.1 Context

Preliminary model runs with the reviewed and amended ISIS-TUFLOW model using the JBA inflow hydrograph indicated that:-

- The extent of flooding to the Glasdir Estate was sensitive to blockage at the culverts below the Ruthin Link Road.
- Applying the JBA inflow and hydrograph to the model produced a greater extent of flooding than recorded in November 2012.
- There was considerable bypassing of flow around Ruthin Weir gauging station which commenced at approximately 17 m^3/s (at Ruthin Weir).

JBA suggest that "event hydrology and blockage are considered to be the two most uncertain elements of the assessment"; such uncertainty has also been highlighted in Section 2 of this report. A series of model runs were therefore undertaken using baseline Scenario B which was representative of conditions as of November 2012. In

order to explore the sensitivities described above, evaluate flooding mechanisms and assess the reliability of Ruthin Gauge for calibration, a range flow hydrographs were scaled from the information provided by JBA. In addition blockage was applied to the culverts below the Ruthin Link Road (commensurate with the guidance in the Trash Screen Design Manual).

The matrix of runs associated with flow and blockage is shown in Table 3 and the hydrographs of the scaled flows is shown in Figure 9. Ninety-five per cent blockage represents the fully blocked scenario. A selection of model results is given in subsequent sections.

Blockage	Inflow = 100% 44.9 m^3/s	Inflow = 90% 40.4 m^3/s	Inflow = 80% 35.9 m^3/s	Inflow = 70% 31.4 m^3/s	Inflow = 50% 22.5 m^3/s
0%	y	y	y	y	y
33%	y	y	y	y	y
66%	y	y	y	y	y
95%	y	y	y	y	y

Table 3 - Summary of November 2012 event hydrology model runs Inflows relate to CLWY-4430

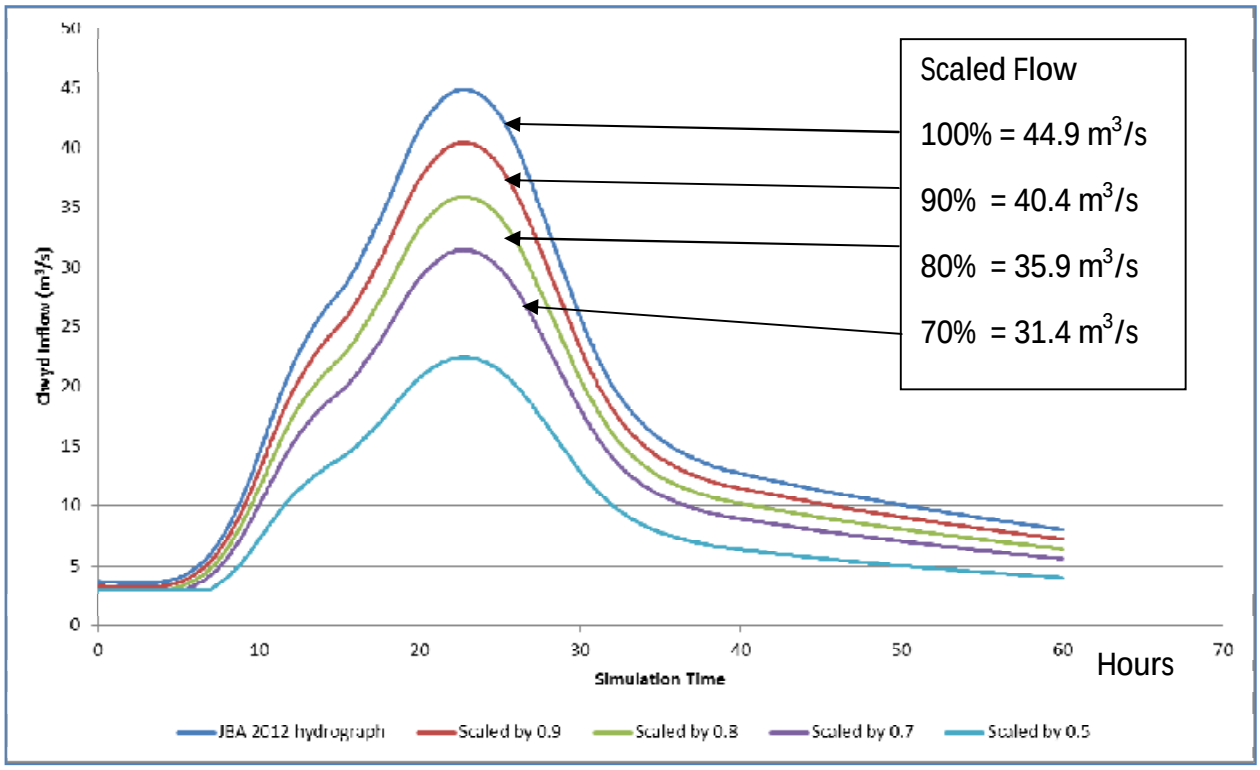


Figure 9 - Scaled Flows Used for Flow Sensitivity

3.6.2 Ruthin Weir Gauge

Ruthin Weir has been used extensively in previous projects to provide hydrological information (such as QMED) and as a tool for the calibration of hydraulic models. Section 2 discussed the inherent uncertainties associated with the use of Ruthin Weir within the hydrological analysis.

Figure 10 and Figure 11 shows a comparison of the observed stage levels at Ruthin Weir by comparison to the modelled results. The observed stage data is given as the red undulating line and the graph also shows a range of modelled output for the scenarios shown in Table 4. Based on this information a number of observations can be made in relation to the use of Ruthin Weir for calibration.

Firstly, irrespective of flow and blockage, it is notable that the response at the Ruthin Weir is largely similar in all modelled scenarios with peak water levels within 50 mm. This is certainly caused by extensive bypassing of the gauge upstream of the weir and the effect of the access bridge upstream of the gauge. As such, inflows at ISIS node CLWY01-4433D of 35.9 m^3/s and 44.9 m^3/s, which represent a divergence of 25%, in flow are only separated by a stage difference of approximately 30mm.

Secondly, all the results fall within the accepted model accuracy of ±150mm and any of the modelled results for the scenarios shown in Table 4 could, in other circumstances, be considered as a "fit". Thirdly, both figures indicate that peak water levels at the gauge are affected by the amount of blockage to the culverts under the Ruthin Link Road. Based on these three observations it is considered that Ruthin Weir Gauge should not be used for calibration purposes and that calibration should be based on the observed flood outline.

Blockage	Inflow = 100% 44.9 m^3/s	Inflow = 90% 40.4 m^3/s	Inflow = 80% 35.9 m^3/s	Inflow = 70% 31.4 m^3/s
66%	y	y	y	y
95%	y	y	y	y

Table 4 - Summary of data given in Figure 10

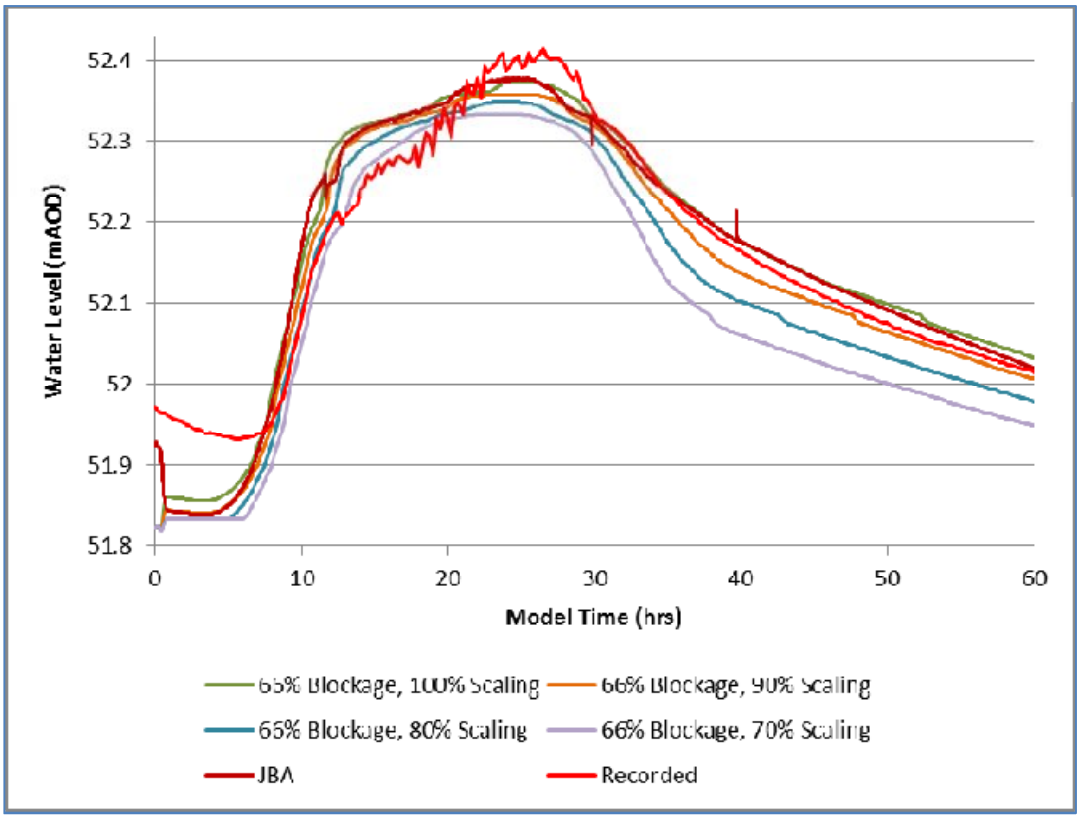


Figure 10 - Response at Ruthin Weir: Sensitivity to Flow with 66% Blockage

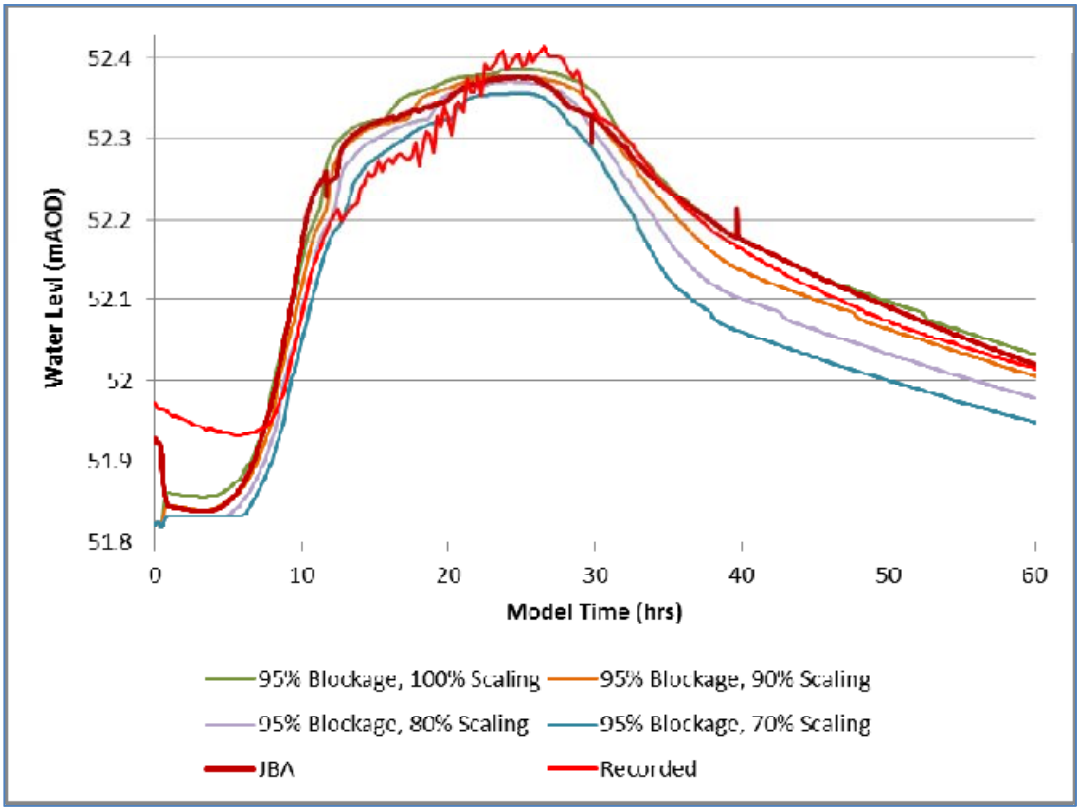


Figure 11 - Response at Ruthin Weir: Sensitivity to Flow with 95% Blockage

3.6.3 Aerial Photography

In order to assess the reliability of the model the output was compared against photographic evidence obtained during and after the peak of flooding. Plate 8 to Plate 11 show a series of stills captured from the aerial photography flown on the 27 November. The aerial photography shows a number of important features associated with the flood mechanism including:-

- Attenuation of flood water behind the causeway formed by the Ruthin Link Road.
- Reduced water levels downstream of the link road.
- Overtopping of the flood embankment bordering the estate.
- Flooding to the majority of the Glasdir Estate.
- No flooding adjacent to the Fire Station and the fields on the left bank directly downstream of Park Road.

Plate 8 - November 2012 flooding to Glasdir

Plate 9 - November 2012 flooding to Glasdir (view from west)

Plate 10 - November 2012 flooding to Glasdir (view from east)

Plate 11 - November 2012 flooding to Glasdir (view of Glasdir)

3.6.4 Sensitivity to Flow

Figure 12 to 14 show the sensitivity of the model to inflows. Figure 12 and Figure 13 show the results of the 70% and 80% scaling of the JBA hydrology which represents an inflow at ISIS node CLWY01-4423D of Q = 31.4 m^3/s and Q = 35.9 m^3/s. The animation of these events shows water overtopping the left bank, flowing across the field and over the flood embankment adjacent to the estate. Critically the field upstream of the site and the properties in Cae Seren and Parc-y-Dre Road are not flooded and the extent of flooding generally agrees with the aerial photography (see Plate 9 in particular).

In contrast Figure 14 shows the field upstream of the site and the properties in Cae Seren and Parc-y-Dre Road as flooded. In addition there, is extensive flooding to the right bank of the River Clwyd. Whilst the aerial photography does indicate some flooding to the right bank the amount is not as extensive as that for the 90% scaling (inflow at ISIS node CLWY01-4423D = 40.4 m^3/s). The modelling for this combination of flow and blockage indicates that flooding is partly the result of overtopping to the Ruthin Flood defences. Overtopping of the defences creates a flow path across Park Road Bridge, inundating the football pitches south of Glasdir and the trading estate east of the River Clywd. This was neither observed during the November 2012 flood event, nor does it appear in the calibrated JBA model outlines.

An inflow of Q = 40.4 m^3/s would be slightly less than a 1 in 100 year event plus a 20% allowance for climate change (Q = 42.24 m^3/s based on the NRW hydrology) and it is assumed that flood defences in Ruthin which were installed in 2003 could potentially be overtopped at flood flows greater than the design standard for the defences.

Accordingly it is considered that the flood flows experienced in November 2012 were between 35.9 m^3/s and 40.4 m^3/s.

3.6.5 Sensitivity to Blockage

Figure 15 to Figure 17 show the sensitivity of flooding to the Glasdir Estate as a result of blockage to the culverts which flow under the Ruthin Link Road. At blockage levels of 0% and 33%, the Glasdir Estate is not shown to flood. This indicates that blockage to the screens *was* a factor in the flooding that occurred in November 2012, and the screens were blocked by greater than 33%.

Between 66% and 95% blockage, significant flooding does occur and flood extents within Glasdir are largely similar to those observed during the event and as shown in Plate 8 to Plate 11. It is likely that blockage at the screens was in the order of 66% to 95%.

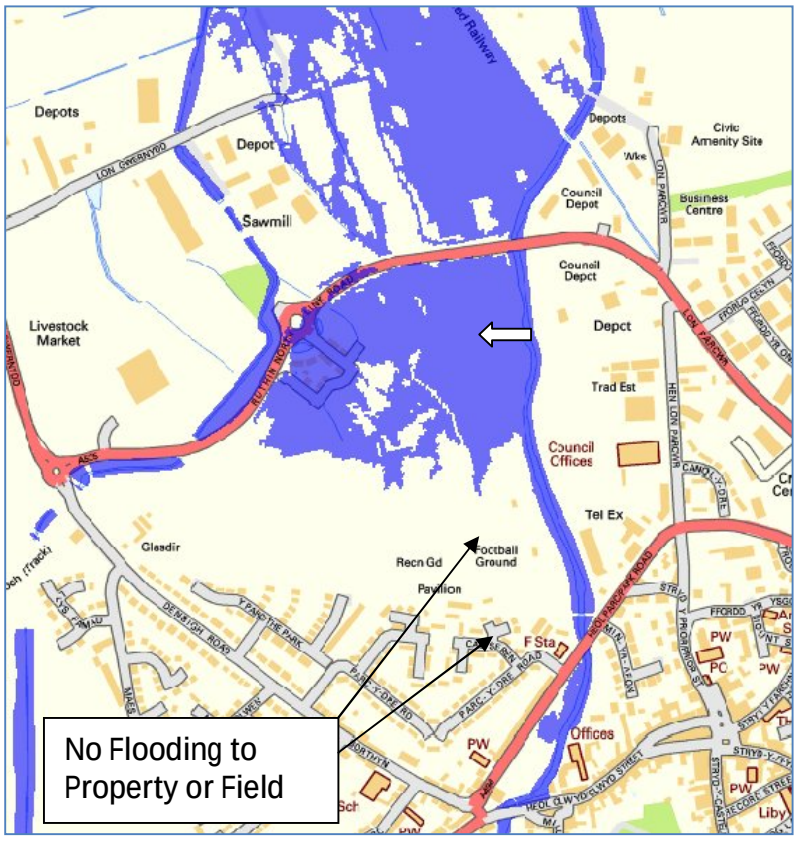


Figure 12 - Sensitivity to flow: November 2012 hydrology; blockage 95%; 70% scaling to JBA 31.4 m3/s

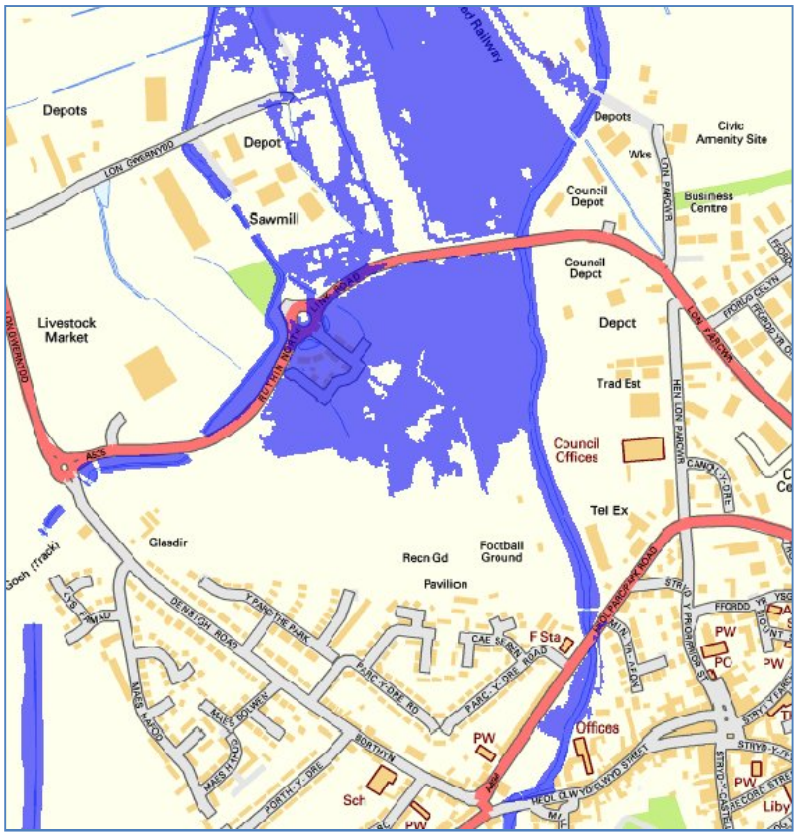


Figure 13 - Sensitivity to flow: November 2012 hydrology; blockage 95%; 80% scaling to JBA 35.9 m3/s

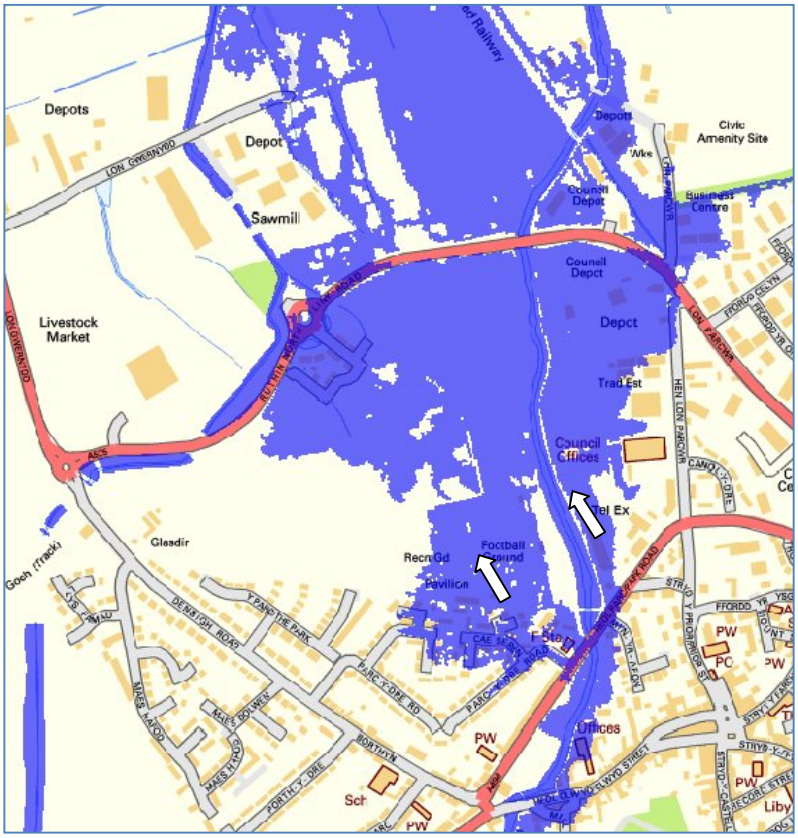


Figure 14 - Sensitivity to Flow: November 2012 hydrology; blockage 95%; 100% scaling to JBA 44.9 m3/s

Figure 15 - Sensitivity to blockage: November 2012 hydrology; Q = 35.9 m3/s = 80% scaling 33% blockage

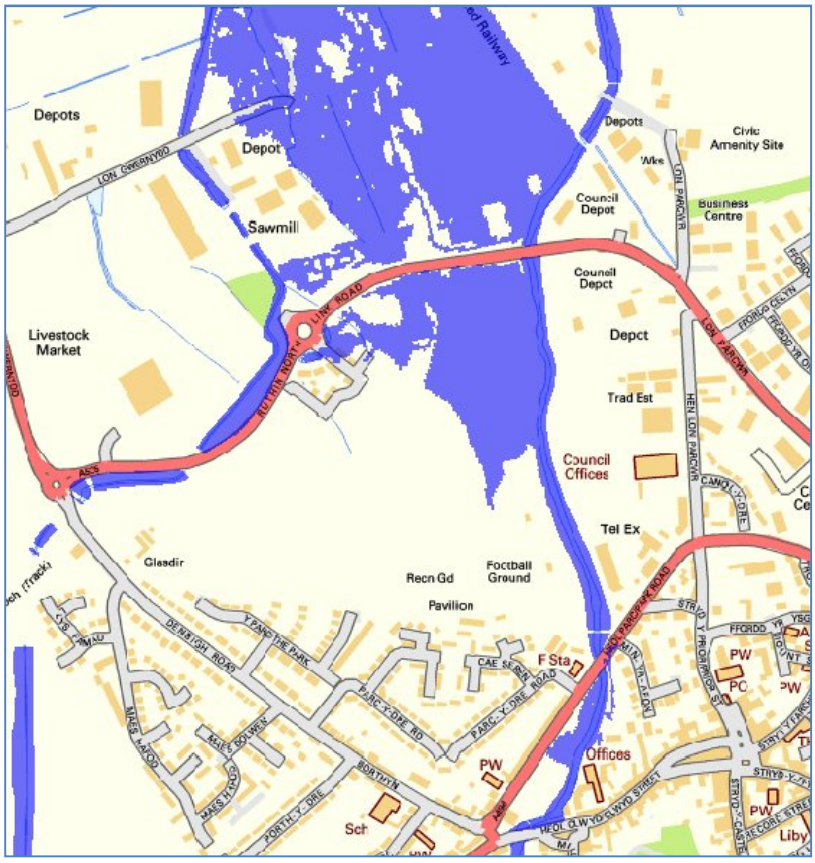


Figure 16 - Sensitivity to blockage: November 2012 hydrology; Q = 35.9 m3/s = 80% scaling 66% blockage

Figure 17 - Sensitivity to blockage: November 2012 hydrology; Q = 35.9 m3/s = 80% scaling 95% blockage

3.6.6 Assessment of Event Return Period (27 November 2012)

Unfortunately there is no definitive information associated with blockage or indeed the flood flow experienced on the 27 November 2012. Accordingly it is only possible to give a range of possible combinations (flow and blockage) which resulted in flooding to the Glasdir Estate. Based on the hydraulic modelling and through comparison with the aerial photography it has been concluded that on the 27 November:-

1. Inflow at ISIS node CLWY01-4423D was between 35.9 m^3/s and 40.4 m^3/s.
2. Blockage at the screen was between 66% and 95%.

In order to better understand the scope and magnitude of the event on the 27 November 2012, Figure 18 shows a comparison of:

- A 1 in 100 year event using the NRW FEH hydrology in combination with a 95% blockage under the Ruthin Link Road.
- An Inflow at ISIS node CLWY01-4423D of 35.9 m^3/s in combination with 95% blockage of the culverts under the Ruthin Link Road (Figure 17).

There is good agreement between the November 2012 event, the 1 in 100 year modelling and the observed flooding as shown by the aerial photography. Accordingly, it is considered that the return period of the November 2012 is equivalent to approximately 1 in 100 years. However, it should be noted that this result is subject to

some uncertainty and other combinations of higher flow / higher return period and reduced blockage could produce a similar flood outline.

3.6.7 Commentary

It is apparent that different combinations of blockages and inflows can result in similar modelled extents and this highlights the uncertainty of these factors in contributing to the Glasdir flooding.

Using the original 100% scaled inflows, the model outputs from this study show flooding to impact a significantly larger area than was observed during November 2012; at the equivalent blockage level, the mapped extents are also greater than those shown by JBA's calibrated model. However, it should be recognised that an inflow of 44.9 m^3/s at ISIS node CLWY01-4423D would exceed a 1 in 100 year event with a 20% allowance for climate change. Overtopping of the flood defences in Ruthin would probably be expected assuming that the standard of service for the defences is 1 in 100 year event with a 20% allowance for climate change.

This difference may also be a result of different schematisation of bridges, structures and defences; of particular influence may be the revised bank top survey referred to in the JBA report, although the nature of this survey is not specified. By scaling the model inflows, this additional area of flood extent is not produced. In particular, a 80% scaled inflow applied with 95% culvert blockage produces mapped extents which are notably similar to those observed during November 2012 event. The similarity between the 80% scaled inflow and the NRW design hydrology for the 1 in 100 year event suggests, therefore, that the November 2012 event may have been close to this return period.

At the 95% blockage level, Ruthin Link Road is flooded and reduced extents are seen downstream of the road than was observed during the November 2012 event. This may be a result of water becoming impounded by the blockage and thus higher levels within the estate cause the Link Road to overtop; consequently, upstream storage results in a decreased flooding to the fields immediately downstream of the Link Road. On this basis, it can be reasoned that the likely blockage level during the November 2012 event was between 66% and 95%.

Figure 18 - Comparison of event hydrology scaled to 80% & NRW design hydrology Q100, both with 95% blockage

3.7 Effectiveness of security screen removal

Following the November 2012 flood event, the security screens across the five culverts under Ruthin Link Road were removed. The effectiveness of this measure was assessed by adjusting the 1D ESTRY section of the model, which is used to represent the presence of these culverts. NRW determined that the screens reduced the area of the culvert inlet by 19%, and subsequent blockage calculations have been adjusted accordingly.

The impact of security screen removal, represented by Scenario iB, was compared against the baseline Scenario B. Difference plots, which contrast changes in flood level between two events, show that removal of the screens generally tends to decrease both flood extent and flood depth upstream of the Ruthin Link Road. Shallow

decreases to flood depth are identified in the field north of the Link Road, close to the culvert outlets. Difference plots for the 1 in 100 year and 1 in 1000 year return periods are shown in Figure 19 and 20.

Figure 21 shows the impact of removing the screens in conjunction with a 66% blockage during the 1 in 100 year design event, removal of the screens prevents flooding to Glasdir as well as reducing levels in the adjacent field. This suggests that a small difference in total blockage at around this level is an important factor in determining whether the defensive bund is overtopped.

Blockage (%)	Blockage within ESTRY Including Screens	Blockage within ESTRY Excluding Screens
0	0	0
33	46	33
66	73	66
95	95.5	95

Table 5 - variation to blockage proportions in 1D ESTRY element of model

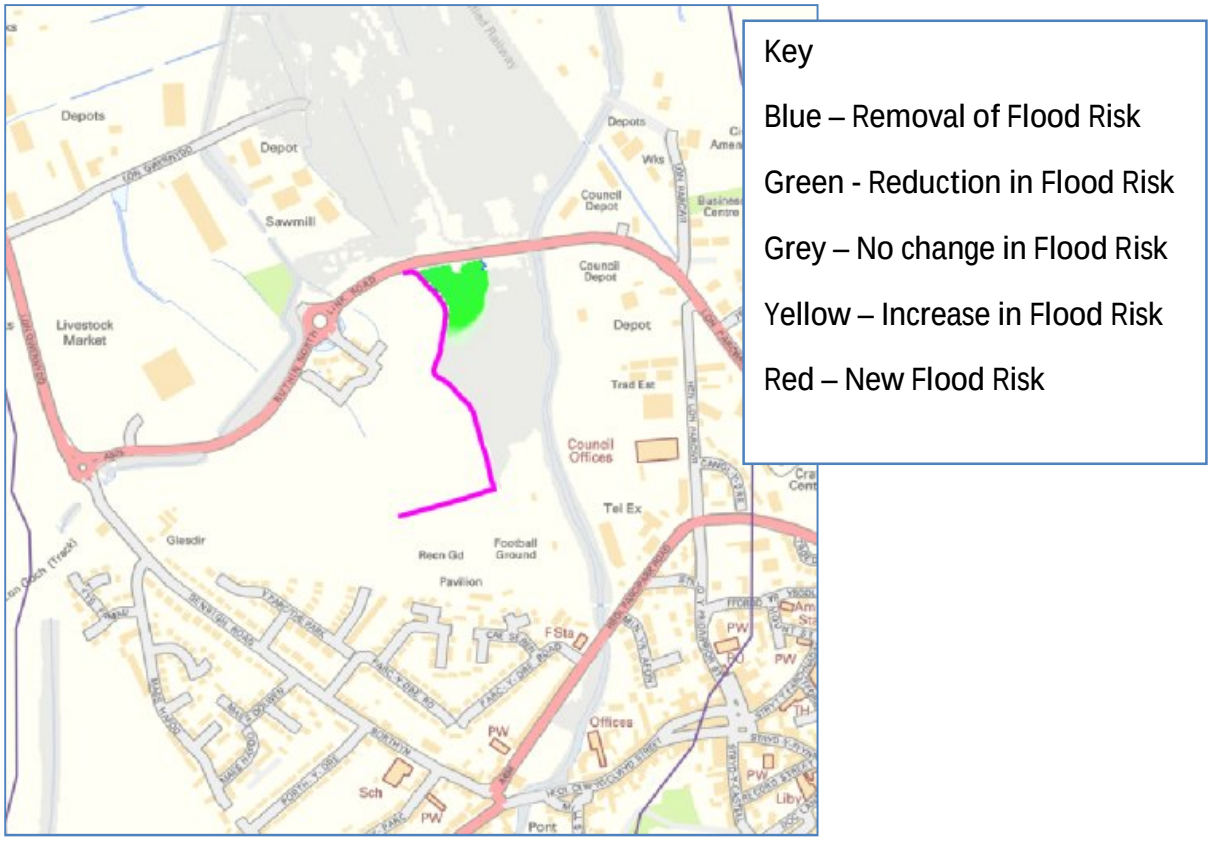


Figure 19 - Difference plot showing impact of screen removal during the Q100 design event, zero blockage

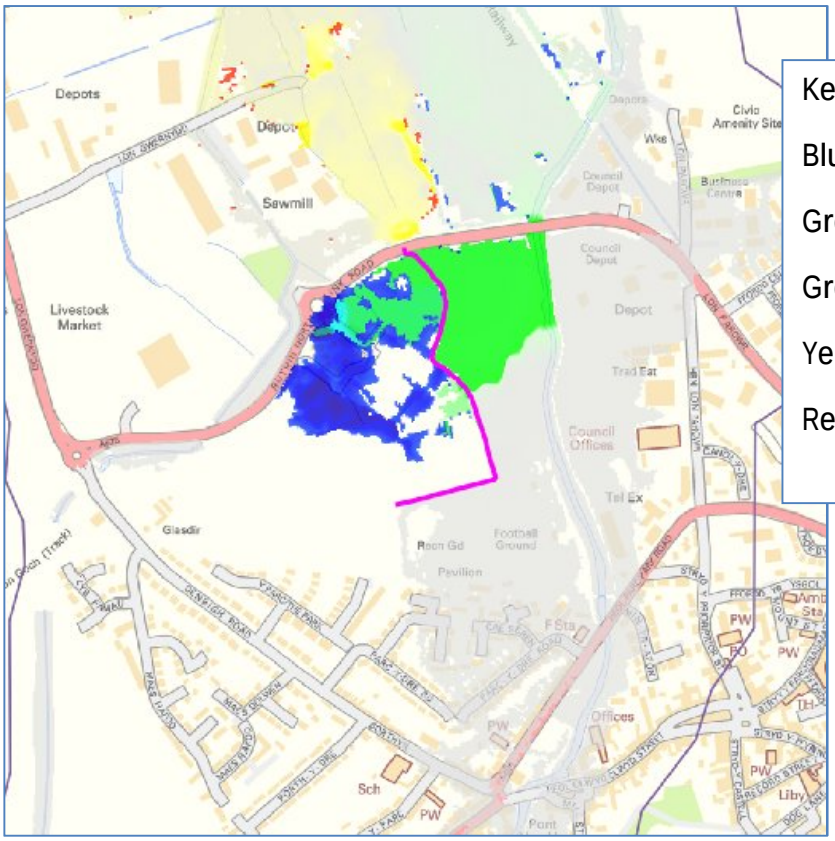


Figure 20 - Difference plot showing impact of screen removal during the Q1000 design event, zero blockage

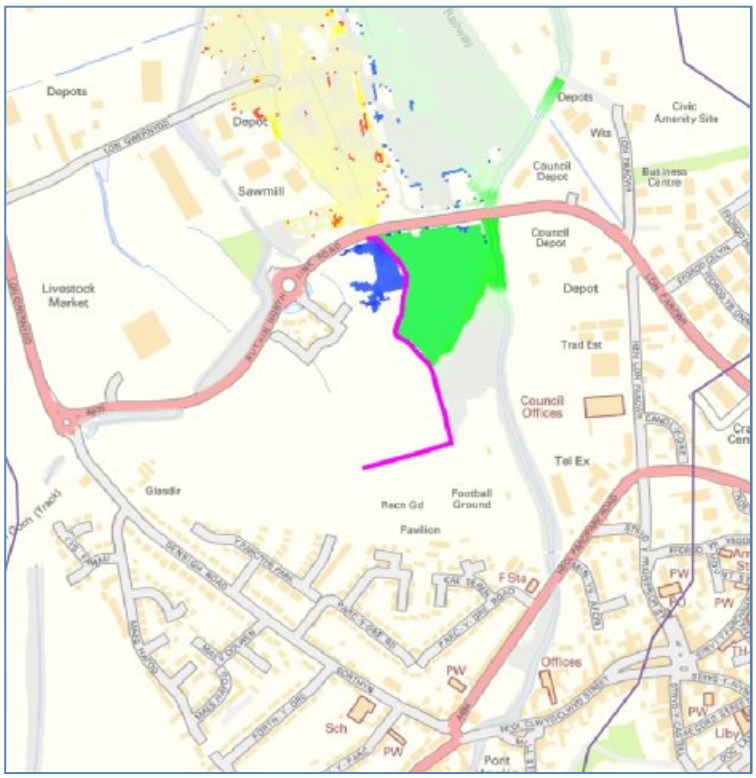


Figure 21 - Difference plot showing impact of screen removal during 1 in 100 year event, 66% blockage

3.8 Conclusions

The removal of the screens tends to result in a decrease to flood depths within Glasdir estate and in the adjacent field upstream of the Ruthin Link Road. Screen removal reduces the risk of flooding to the estate for a 1 in 100 year event in combination with 66% blockage to the culverts under the Ruthin Link Road. Levels in the fields to the north of Ruthin Link Road tend to show a small increase in flood depth, which is likely to be a result of the increased culvert capacity channelling water into these fields.

The results therefore indicate that removal of the screens is generally beneficial to Glasdir, although may only prevent flooding in limited cases.

3.9 Summary

On the 27 November 2012 the Glasdir Estate in Ruthin was subject to significant flooding from the River Clwyd which resulted in significant damage to property within the estate and loss of personal possessions. In order to gain a better understanding of the causes of the flooding the Independent Review Panel has undertaken a review of the hydrology (rainfall and river flows) and carried out hydraulic modelling of the River Clywd, the Mwrog Flood Alleviation scheme and infrastructure (e.g. roads, bridges, weirs, flood defences etc.) in the vicinity of Ruthin and the Glasdir Estate. In addition, hydraulic modelling has also been undertaken to consider engineering options to mitigate flood risk to the Glasdir Estate.

Analysis of rain gauges and rainfall radar undertaken by NRW indicated that rainfall across the Clwyd and Elwy Rainfall totals for the month up to 26 November were not unusual, if looked at without any further information and were in-line with the Long Term Averages for that month. However, rainfall totals for the 7 days leading up to the 26 November were particularly high, with totals on the 26 November significantly so.

As a result, rainfall fell on heavily saturated ground and the response of the rivers within the catchment was affected by higher than normal rates of run-off. Accordingly, flows in the rivers systems were elevated above flow rates for the rainfall return period experienced on the 27 November. Evaluation of information provided by NRW in conjunction with hydraulic modelling indicates that peak flows in the River Clwyd upstream of Ruthin were probably between 35.9 m3/s and 40.4 m3/s on the 27 November.

The Flood Estimation Handbook (FEH) is used to estimate river flows within the UK for a wide range of fluvial problems including the design of flood alleviation schemes and flood risk mapping. Importantly it is also used to provide estimates of flow for use in hydraulic models to prepare Flood Consequence Assessments (FCA) which are an important element of the planning process. The FEH is a nationally accepted standard.

NRW provided hydrological analysis for review by the Independent Panel. The technique used by the NRW was based on the FEH and the application of these techniques was considered to be sound. This method relies on the collation of hydrologically similar catchments and uses statistical methods to produce estimates of extreme flow including the 1 in 100 return period flows.

The use of a statistics means that there is inherent uncertainty in the estimates produced by FEH. Indeed it is recognised that at high return periods such as the 1 in 1000 year return period the accuracy of flow estimates can be plus or minus 20%. The accuracy of the statistical method is dependent on the quality of data available to the hydrologist and can be significantly improved by including gauging stations within the actual catchment under consideration. Accordingly the review included consideration of the information at Ruthin Weir Gauge which is very close to the Glasdir Estate.

However, it was concluded that flow data recovered from Ruthin Weir should be used with caution because:-

- At high flows the gauge is bypassed by flood water coming out of the channel. The gauge does not therefore register all flows within the river and across the floodplain.
- There was uncertainty in the evaluation of QMED which is a key parameter used within the FEH Statistical Method to assess extreme flows. Evaluation of the information provided by NRW indicated that QMED could fall within a range.
- The response of the level gauge at Ruthin Weir is dependent on the degree of blockage at the culverts below the Ruthin Link Road
- There has been considerable change upstream of the weir in the past ten years including the construction of the Mwrog Flood Alleviation Scheme, the installation of the Ruthin Flood Defences, the construction of the Ruthin Link Road which truncated the floodplain and modifications to the weir.

It is considered that the NRW made appropriate assumptions based on the information available to the authority but it is recommended that NRW confirm whether their calculations include consideration of the changes upstream and undertake a review of the level vs. flow (stage discharge) relationship at Ruthin Weir to confirm / improve the accuracy of the flow estimates.

The hydraulic model was run with a range of return periods using the NRW hydrology and the results of the modelling are commensurate with aerial photography and anecdotal information on flooding. Animation of the model indicates that flood waters leave the channel upstream of the Ruthin Link Road and flow across the field where they collect behind the Ruthin Link Road. The Link Road forms an impoundment across the flood plain and flood water collecting on the upstream side of the highway is discharged through the culverts to the downstream side of the Link Road.

The hydraulic modelling included an assessment of the impact of blockage to the security screens and the culverts. As a result a number of conclusions could be reached about the November 2012 event. This includes:-

- Based on the NRW hydrology, the results of the hydraulic modelling and taking into account uncertainty, it is estimated that the flow return period associated with the November 2012 event was between 1 in 100 year and 1 in 200 year. However, it is considered that it is likely that the actual return period was biased towards 1 in 100 year event.

- Blockage on the Ruthin Link Road Culverts was a significant factor in relation to flooding to the estate. The hydraulic model indicated that blockage to the culvert was between 66% and 95% of the cross section area of the culverts.
- The security screens had a negative impact on flooding to the Glasdir Estate.
- Based on the NRW hydrology the Glasdir Estate would have been inundated in a 1 in 1000 year event without blockage to the Ruthin Link Road culverts.

4 Engineering Options

4.1 Introduction

A series of engineering options were modelled to assess their effectiveness in mitigating the risk of flooding to the Glasdir Estate. These options are summarised in Table 6 and are discussed in further detail in the following sections. It should be noted that the engineering options considered in this report have not been explored in the detail required in a Flooding Project Appraisal which would require more extensive modelling, an economic analysis (benefit cost analysis) to identify the optimal economic solution and additional studies associated with Environmental Impact.

Engineering options were modelled individually using a 9.5 hour storm, for a 1 in 100 years return period with an allowance for climate change. The inflow is based on the design hydrology derived by NRW. The target standard of service associated with the engineering options is commensurate with the appropriate standard of service which is a return period of 1 in 100 years plus an allowance for climate change and a freeboard of 0.6m. It should also be noted that, during this part of the investigation, all scenarios were modelled with the exclusion of the culvert security screens but with the culverts blocked to 95%.

4.2 Maintain to a Better Standard

The option is based upon the implementation of an effective maintenance regime to ensure that blockage by vegetation or deposition will reduce problems associated with the reduction in the hydraulic capacity of bridge structures, culverts and highway drainage systems. This is particularly important for the culverts below the Ruthin Link Road at Glasdir but should encompass the management of the flood defences in Ruthin, Ruthin Weir, the Flood Alleviation Scheme and bridges on the River Clwyd.

In addition, a site inspection of the River Clwyd indicated that the watercourse is, in some places, overgrown and includes debris within the river and this has an adverse impact on the water levels during extreme event. Maintenance would include regular inspection, tree works, jetting and clearance of gravel and also assumes enforcement of Notices served under the Land Drainage Act upstream of each of the above structures. The justification for the activities is to maintain the flow capacity within the channel, thus reducing the number of times the river water spills onto the flood plain. Additionally reduction in vegetation and debris which can be carried along on a flood flow will reduce the chances of blockages.

In the context of blockage by trees, maintaining to a better standard would entail implementing good arboricultural practice which includes surveys for root-plate

stability of the larger specimens, selective thinning and coppicing of the developing scrub to increase vigour, thinning for better specimens, removal of non-native species and improvement of the stand for amenity, bank stability and biodiversity purposes. Removal of major fallen dead-wood, obstacles and other debris are desirable. The objective of these works would be to reduce the amount of woody debris liberated in flood conditions which could accumulate on the bridges or sewers.

This will entail a partnership approach which should include the major stakeholders; Flood wardens, Glasdir and Ruthin residents, Denbighshire County Council and NRW.

Option	Scenario	Description
0	B (baseline)	Baseline model, to represent conditions as at November 2012. Assumes no blockage of the culverts to the east of the Glasdir Estate.
1		Install Trash Screen and maintain to a better standard.
2	C / D	As in Scenario B, but with the addition of a raised flood defence embankment / wall around the Glasdir Estate, with northern boundaries at the Ruthin Link Road.
3	E	As in Scenario B, but with an addition of a raised flood defence embankment / wall along the western bank of the River Clwyd, between Park Road and Ruthin Link Road.
4	F	As in Scenario B, but with the elevation of the spill area immediately to the north of Ruthin Link Road and to the west of the River Clwyd channel lowered to 52m AOD.
5	G	As in Scenario B, but with a 20m wide 'cattle creep' under Ruthin Link Road; drainage channels upstream and downstream of the 'cattle creep' to divert out-of-bank flow.
6	H	Removal of Ruthin Weir. Re-profiling of approximately 900m of channel, from downstream of Park Road to immediately downstream of Ruthin Weir, creating a constant gradient in order to increase channel capacity past Glasdir Estate.

Table 6 - Summary of the modelled engineering options around the Glasdir Estate

4.3 Option 1 – Install Trash / Debris Screens

Edenvale Young has undertaken a large number of Flooding Pre-feasibility (250) and Flooding Project Appraisal Studies for Local Authorities in Wales including Powys County Council (40) and Caerphilly Borough Council (20), Cardiff City Council (2) and the Vale of Glamorgan (1). Of the 33 first stage Project Appraisal for Powys County Council, 23 or (73%) of the sites had blockage as the primary or secondary flooding mechanism in conjunction with high rates of flow. A large number of the sites included trash screens, culverts, and medium sized bridges which are vulnerable to blockage.

In Caerphilly Borough 9 of the 16 (56%) Project Appraisal Study sites were flooded as a result of high flows and blockage and combining the Caerphilly and Powys, data with projects in Cardiff, the Vale of Glamorgan and Ribchester gives a total of 52 sites of which for 34 or 65%, flooding was caused by blockage. On a nationwide basis the Welsh Government has calculated that approximately 60% of all flooding problems on ordinary watercourses in Wales relates to the blockage of culverts.

Experience within Powys County Council and elsewhere indicates that if a culvert entrance is well designed and if access for maintenance purposes is good then the residual risk of flooding as a result of blockage by vegetation and other debris can be reduced. Such measures include trash screens, gravel traps, high level alarms and upstream vegetation posts.

However, it should also be noted that the risk of flooding at a site which is formally maintained is dependent upon an authority's ability to react and respond to an event. The 2000 event stretched Powys County Council's resources significantly and countywide they distributed over 80,000 sandbags. Emergency resources are finite and that with a high return period event countywide Local Authorities such as Denbighshire may not be able to respond or react to all reports of culvert blockage particularly if this is at night.

Plate 12 - Vegetation Posts on the River Ennig at Talgarth, Powys

Plate 13 - Typical Raking Screen, Cwmfelinfach, Caerphilly

The advantages and disadvantages are given below:-

Advantages	Disadvantages
Construction of a trash screen / vegetation posts in conjunction with maintenance and the introduction of a comprehensive response plan would reduce the risk of flooding to the Glasdir Estate.	Blockage at a trash screen will continue to occur and monitoring of trash / debris will be required on a continual basis. The risk of flooding at a site which is formally maintained is dependent upon the authority's ability to react and respond to an event and to clear the screen safely. The construction of a trash screen cannot be considered in isolation and must be implemented in conjunction with other engineering options (such as raising the flood embankment) in order to mitigate the risk of flooding to the Glasdir Estate. The site is not suited to the installation of raking screens complying with the requirements of CIRIA guide for the design of Trash Screens due to the restricted height of the culvert.

4.4 Option 2 - Raise Flood Defences to the Glasdir Estate (Scenario C & D)

Option 2 is based on raising the existing flood embankment. The extent of the modelled embankment is shown in Figure 23 but it should be recognised that raising the level of the embankment along the full length of the embankment is not required. The main area where raising is required is adjacent to the Ruthin Link Road (see Figure 24). The modelling of this option assumes that the culverts below the Ruthin Link Road are blocked.

Figures 24 to Figure 26 show the results of the ISIS-TUFLOW modelling for a 1 in 100 year return period event plus an allowance for climate change. Although flooding to the Glasdir Estate is mitigated there is a marked increase in flooding to the field adjacent to the estate. There will also be a minor adverse impact in flood risk in the wider Ruthin area for all return periods, particularly downstream.

A point inspection of modelled peak water levels for a range of return periods and blockages has been undertaken at the locations shown in Figure 22 and the results are given in Table 7. The Table indicates that the current bund level (given in the last column) locations C and D is higher than the peak water level but the bund between A and B is vulnerable to overtopping. These levels can be compared against the information contained in the Weetwood FCA (Section 8.2, p11.), it states that:

> *"The proposed hard landscaped bund along the eastern edge of the proposed development site will be a hard defence and the crest of the landscaped bund will be above that of the estimated top water level for a 1000-year event (approximately 53.5m to 53.25m AOD from south to north respectively) with a minimum allowance for freeboard of 200mm. The proposal for the landscaped bund has been agreed in principle by EAW."*

Grid Reference	Point ID (see Figure 22)	Level (mAOD)				
		Q100; 0% blockage	Q100+CC; 95% blockage	Q1000; 0% blockage	Q100+CC; 95% blockage; plus 600mm freeboard	Current level of bund at adjacent point
311903, 358940	A	52.62	53.86	53.57	54.46	53.4
311925, 358796	B	53.22	53.86	53.62	54.46	53.8
312020, 358616	C	53.7	53.92	54.12	54.52	54.4
311874, 358570	D	-	-	54.46	-	54.88

Table 7 – Point Inspection of modelled water levels

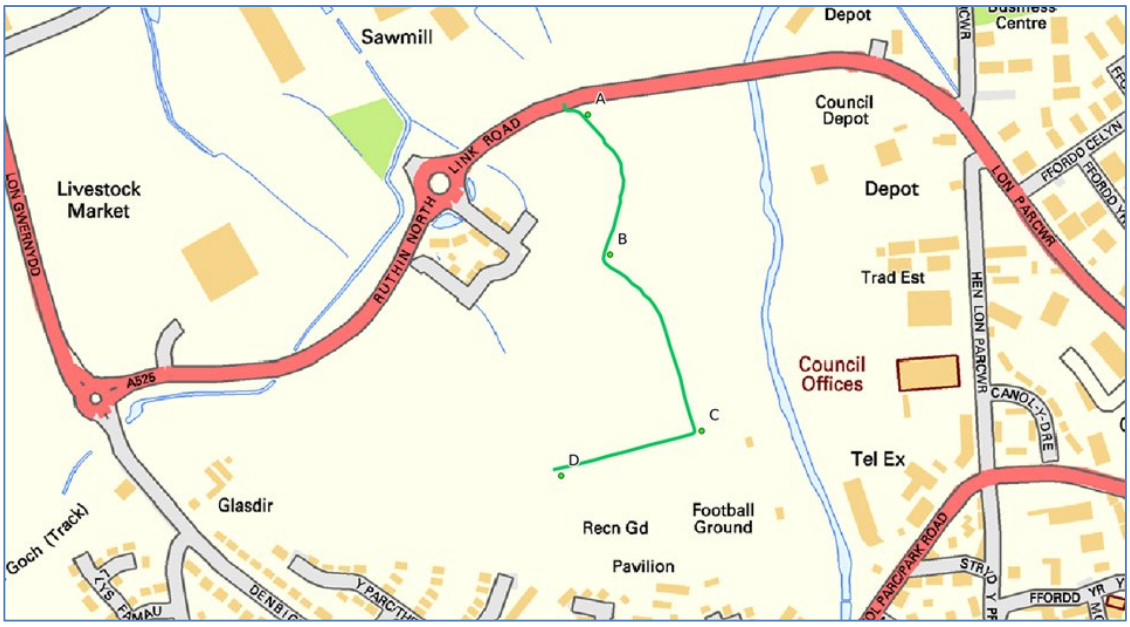


Figure 22 Location of level sample points provided in Table 7

The advantages of adopting this approach are summarised below.

Advantages	Disadvantages
Construction of flood defences at this location delivers an acceptable standard of service to the Glasdir Estate. Raising flood defences can be undertaken on land which is currently owned by the developer. The cost of raising the flood defence is low by comparison to other options. The environmental impact of the scheme is low. Disruption to the general public and residents associated with the construction of the scheme is low. It is unlikely that NRW or the Planning Authority would object to the scheme. There is a high probability that the option can be delivered.	There may be some negative third party impacts downstream of the Ruthin Link Road which would require additional works to be undertaken to protect domestic / industrial / agricultural (see Figure 26).

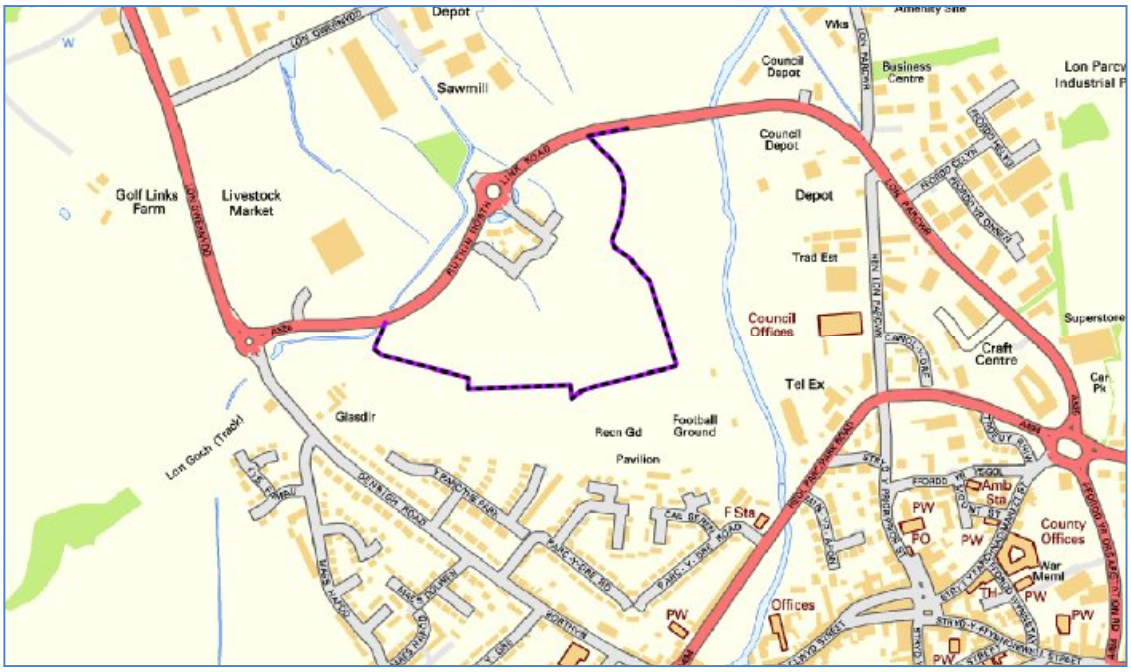
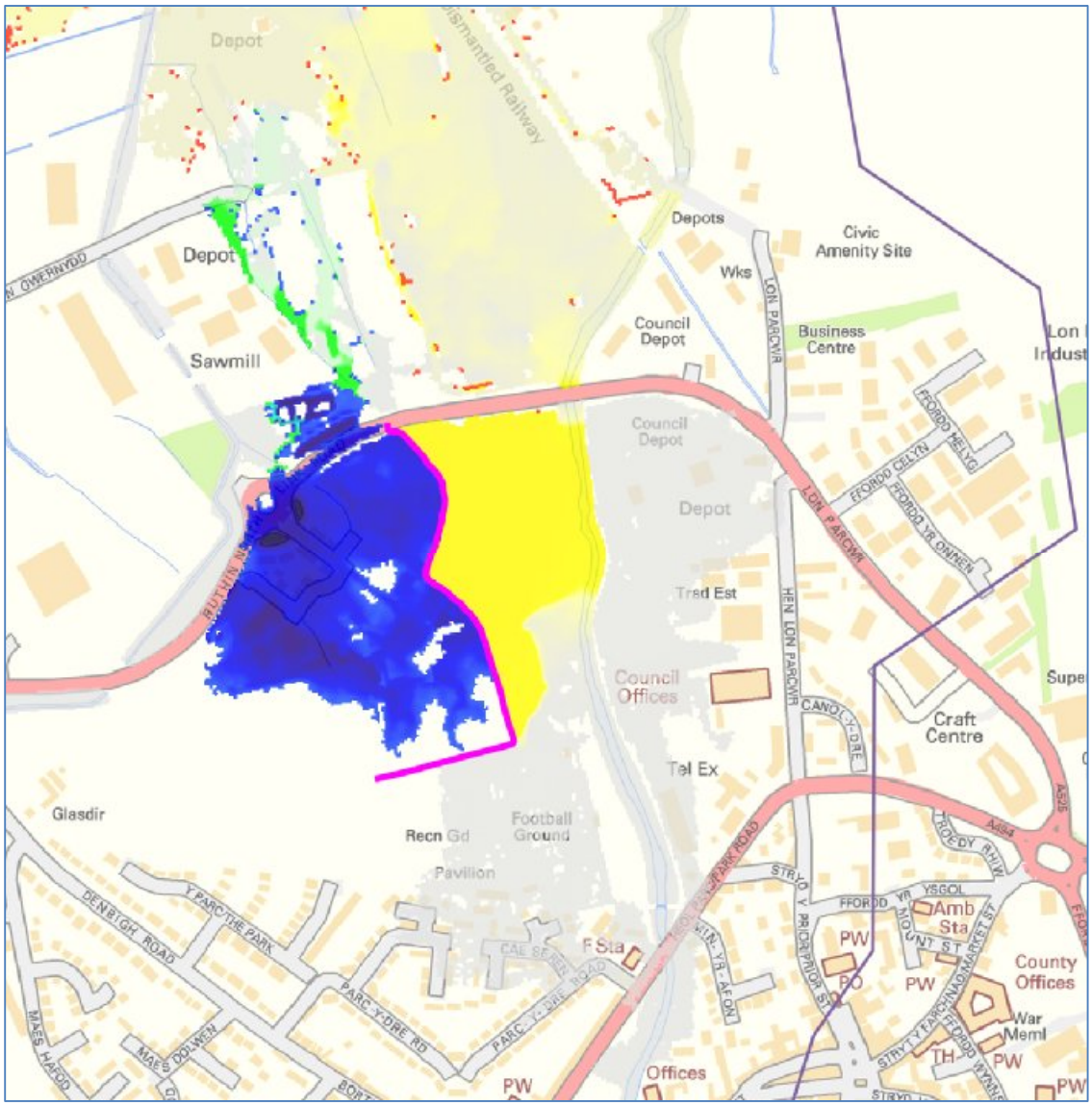


Figure 23 - Location of modelled Flood Defence around the Glasdir Estate. The line of the bund is for analytical purposes and does not indicate a suggested scheme.

Figure 24 - Comparison of modelled peak water level for the 1 in 100 yr return period with Climate Change and 95% blockage, and existing embankment level. Existing embankment levels shown in red; modelled levels shown in black.

Figure 25 – Option 2 - ISIS TUFLOW Model Results for 1 in 100 year return period with Climate Change and 95% blockage



Key
Blue – Removal of Flood Risk
Green - Reduction in Flood Risk
Grey – No change in Flood Risk
Yellow – Increase in Flood Risk
Red – New Flood Risk

Figure 26 – Change in Flood Risk (Existing and Proposed for 1 in 100 year return period with ClimateChange and 95% blockage)

4.5 Option 3 - Flood Defences to Left (West) Bank of the River Clwyd (Scenario E)

Option 3 envisages the construction of a flood embankment / wall adjacent to the left bank of the River Clwyd. The development of this option is in response to resident's requests to investigate this option. The extent of the modelled embankment / wall is shown in Figure 27.

Figure 28 and Figure 29 shows the results of the ISIS-TUFLOW modelling for a 1 in 100 year return period event plus an allowance for climate change. Flood risk to the Glasdir Estate is reduced. There is a variable impact in the wider Ruthin area including areas of benefit and dis-benefit downstream of the site, including some limited areas of additional areas of flooding. The advantages of adopting this approach are summarised below.

Advantages	Disadvantages
Construction of flood defences at this location delivers a high standard of service to the Glasdir Estate. Disruption to the general public and residents associated with the construction of the scheme is low.	There will be negative third party impacts downstream of the Ruthin Link Road which may require additional works to be undertaken to protect domestic / industrial / agricultural. Third party impacts will require further investigation to establish the scale of change in flood risk.
The environmental impact of this option is comparatively low.	Raising flood defences is on land which is under the control / ownership of third parties and this will require negotiation to allow construction to proceed. It is likely that NRW would object to the scheme as the construction of the flood defence would reduce flood storage on the flood plain of the River Clwyd.

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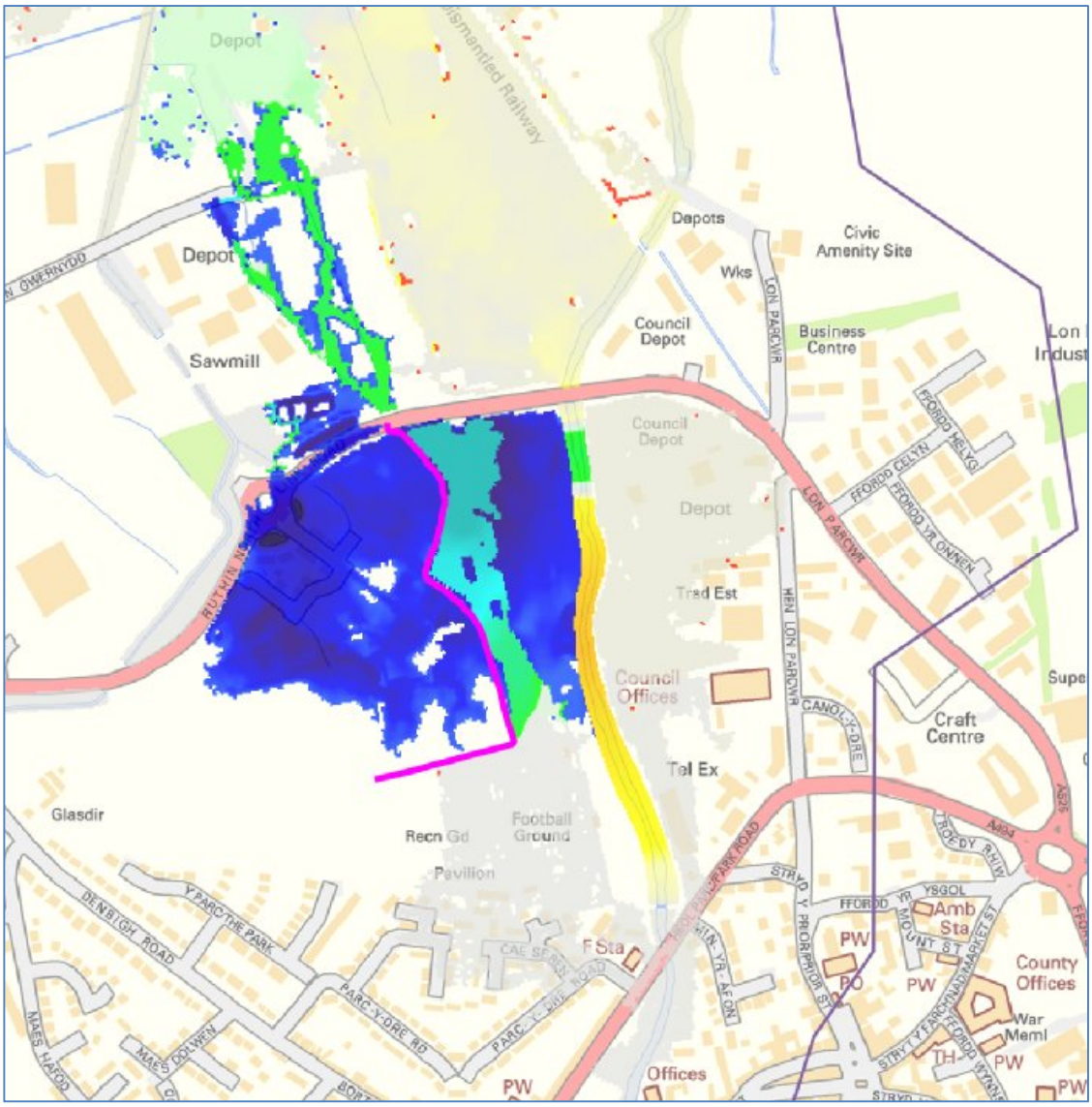
Figure 27 - Option 3 - Flood Defences to Left Bank of the River Clwyd (Scenario E)

Figure 28 - Option 3 - ISIS TUFLOW Model Results for 1 in 100 year return period with Climate Change and 95% blockage



Key
Blue – Removal of Flood Risk
Green - Reduction in Flood Risk
Grey – No change in Flood Risk
Yellow – Increase in Flood Risk
Red – New Flood Risk

Figure 29 - Change in Flood Risk (Existing and Proposed for 1 in 100 year return period with Climate Change and 95% blockage)

4.6 Option 4 - Reduced Spillway Elevation (Scenario F)

Option 4 is based on the reduction of ground levels upstream of Ruthin Weir. The location of the proposed work is shown in Figure 30 and is at the location where flood water first spills from the channel. The objective of exploring this option is to assess whether it is possible to reduce flooding to the Glasdir Estate by increasing discharge to the floodplain downstream of the Ruthin Link Road.

Figure 31 and Figure 32 show the results of the ISIS-TUFLOW modelling for a 1 in 100 year return period event plus an allowance for climate change. In the 1 in 100 year event with an allowance for climate change the flood risk to the Glasdir Estate is mitigated but the extent of flooding elsewhere is largely the same. Flooding still occurs to adjacent field but levels are generally reduced. There are significant dis-benefits downstream of the Link Road, including additional areas of flooding at lower return periods. The advantages of adopting this approach are summarised below.

Advantages	Disadvantages
The scheme delivers a higher standard of service to the Glasdir Estate. Disruption to the general public and residents associated with the construction of the scheme is low. The environmental impact of this option is comparatively low.	Reducing spill levels will be on land which is under the control / ownership of third parties and this will require negotiation to allow construction to proceed. There will be negative third party impacts downstream of the Ruthin Link Road which may require additional works to be undertaken to protect domestic / industrial / agricultural. Third party impacts will require further investigation to establish the scale of change in flood risk.

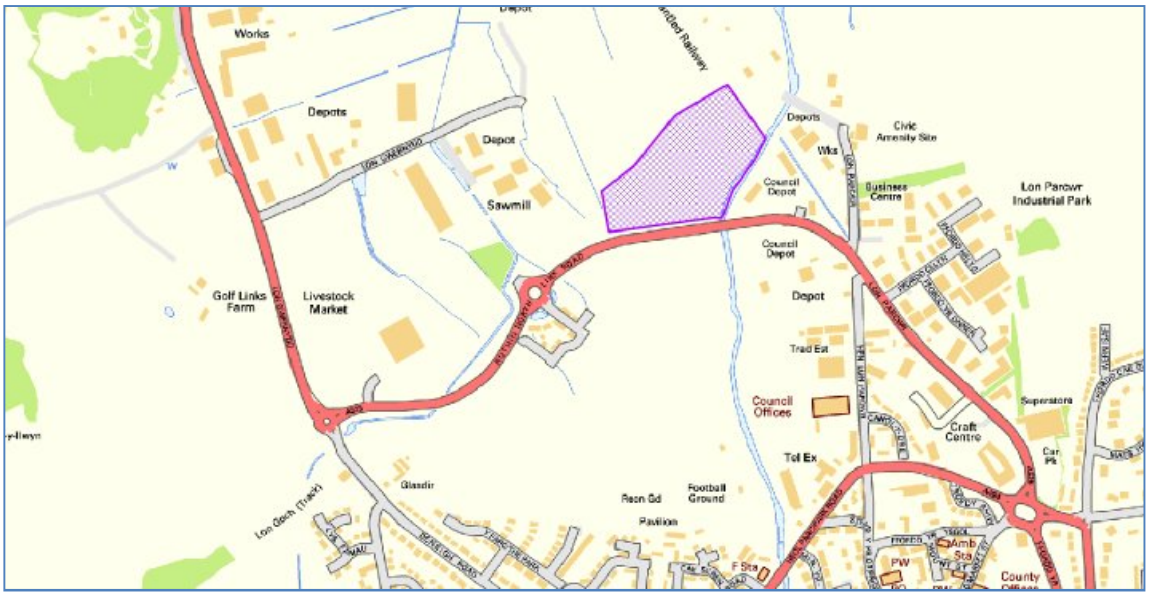
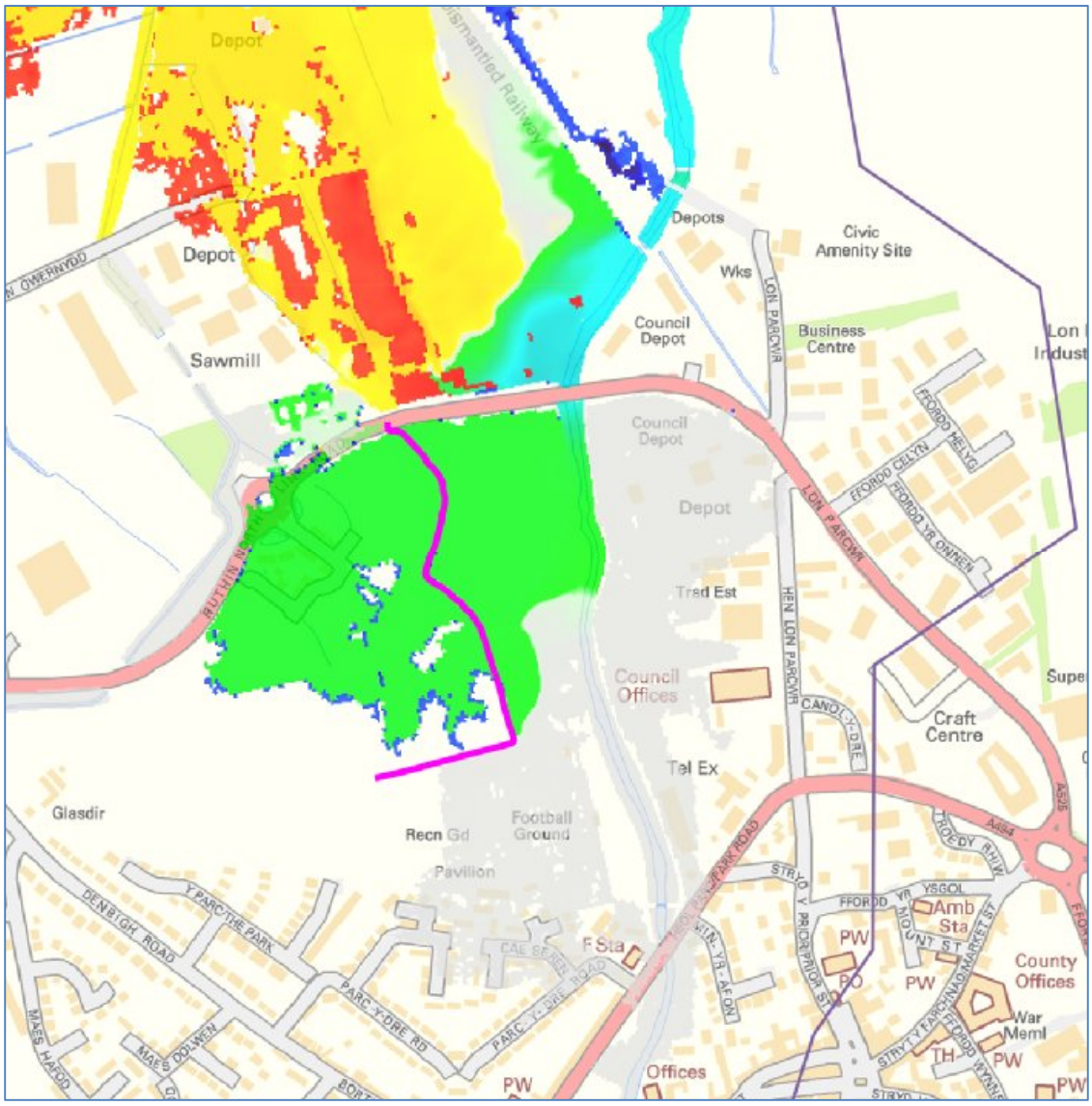


Figure 30 - Option 4 - Reduced Spillway Elevation (Scenario F)

Figure 31 - Option 4 - ISIS TUFLOW Model Results for 1 in 100 year return period with Climate Change and 95% blockage



Key
Blue – Removal of Flood Risk
Green - Reduction in Flood Risk
Grey – No change in Flood Risk
Yellow – Increase in Flood Risk
Red – New Flood Risk

Figure 32 - Change in Flood Risk (Existing and Proposed for 1 in 100 year return period with ClimateChange and 95% blockage)

4.7 Option 5 - Introduction of Additional Flow Routes (Scenario G)

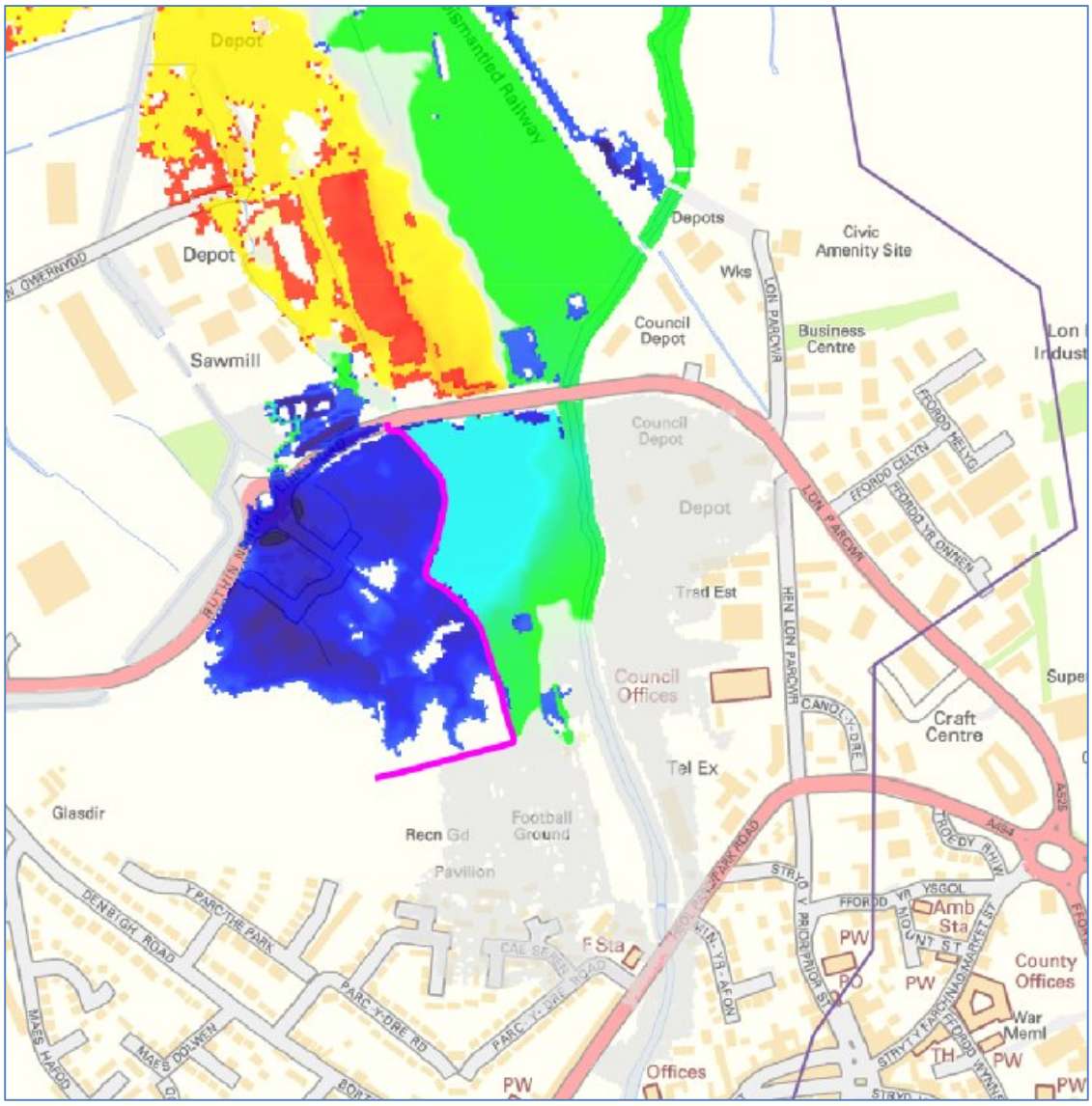
Option 5 is designed to investigate the feasibility of including additional flow routes under the Ruthin Link Road through the construction of additional hydraulic capacity. This would probably be in the form of additional culverts (a cattle creep) and the installation of a conveyance channel on the floodplain to the north and south of the Ruthin Link Road (see Figure 33).

Figure 34 and Figure 35 show the results of the ISIS-TUFLOW modelling for a 1 in 100 year return period event plus an allowance for climate change. Flooding to the Glasdir Estate and adjacent field is reduced by comparison to the baseline scenario. There is variable impact to the wider Ruthin area, although benefits / dis-benefits are typically small. Greatest negative impact to field immediately north of cattle creep towards which flow has been diverted. The advantages of adopting this approach are summarised below.

Advantages	Disadvantages
The scheme does deliver a higher standard of service to the Glasdir Estate. The environmental impact of this option is comparatively low.	Work will be required on land which is under the control / ownership of third parties and this will require negotiation to allow construction to proceed. The costs associated with implementing this option will be high. The likelihood of delivering this option will be low. Blockage to the structure by debris will be a risk. Disruption to the general public and residents associated with the construction of the scheme is high as a result of the work required to the Ruthin Link Road. There will be negative third party impacts downstream of the Ruthin Link Road which may require additional works to be undertaken to protect domestic / industrial / agricultural. Third party impacts will require further investigation to establish the scale of change in flood risk.

Figure 33 - Option 5 - Introduction of an Additional Flow Routes under the Ruthin Link Road (Scenario G)

Figure 34 - Option 5- ISIS TUFLOW Model Results for 1 in 100 year return period with Climate Change and 95% blockage



Key
Blue – Removal of Flood Risk
Green - Reduction in Flood Risk
Grey – No change in Flood Risk
Yellow – Increase in Flood Risk
Red – New Flood Risk

Figure 35 - Change in Flood Risk (Existing and Proposed for 1 in 100 year return period with Climate Change and 95% blockage)

4.8 Option 6 - Removal of Ruthin Weir & Re-grading of the River Clwyd (Scenario H)

Option 6 is designed to evaluate the impact of removing Ruthin Weir on flooding to the Glasdir Estate and would require re-grading of the river channel upstream of the weir in order to accommodate the design (see Figure 36). Figure 37 and Figure 38 show the results of the ISIS-TUFLOW modelling for a 1 in 100 year return period event plus an allowance for climate change.

The modelling indicates that flooding to the Glasdir Estate occurs only during 1 in 1000 year. There are dis-benefits towards downstream extent of the model, with additional flooding caused around the junction with the Flood Relief Channel and River Clwyd, particularly along the Clwyd's eastern bank. There is a significant reduction in flood extent to fields north of the Link Road. The advantages of adopting this approach are summarised below.

Advantages	Disadvantages
The scheme delivers a high standard of service to the Glasdir Estate.	The costs associated with implementing this option will be high.
The environmental impact of this option is potentially high during construction but reducing or improving in the long term.	The environmental impact of this option is potentially high during construction but reducing or improving in the long term.
	The foundations of bridge structures upstream of Ruthin Weir may be compromised.
	The likelihood of delivering this option will be low.
	There could be negative third party impacts downstream of the Ruthin Link Road which may require additional works to be undertaken to protect domestic / industrial / agricultural. Third party impacts will require further investigation to establish the scale of change in flood risk.

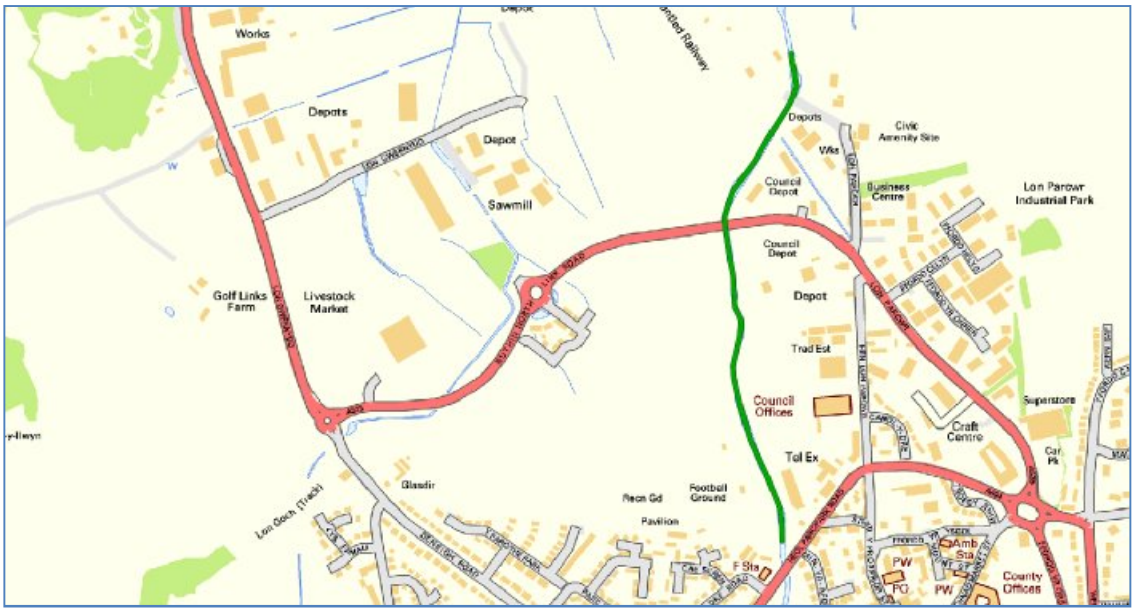
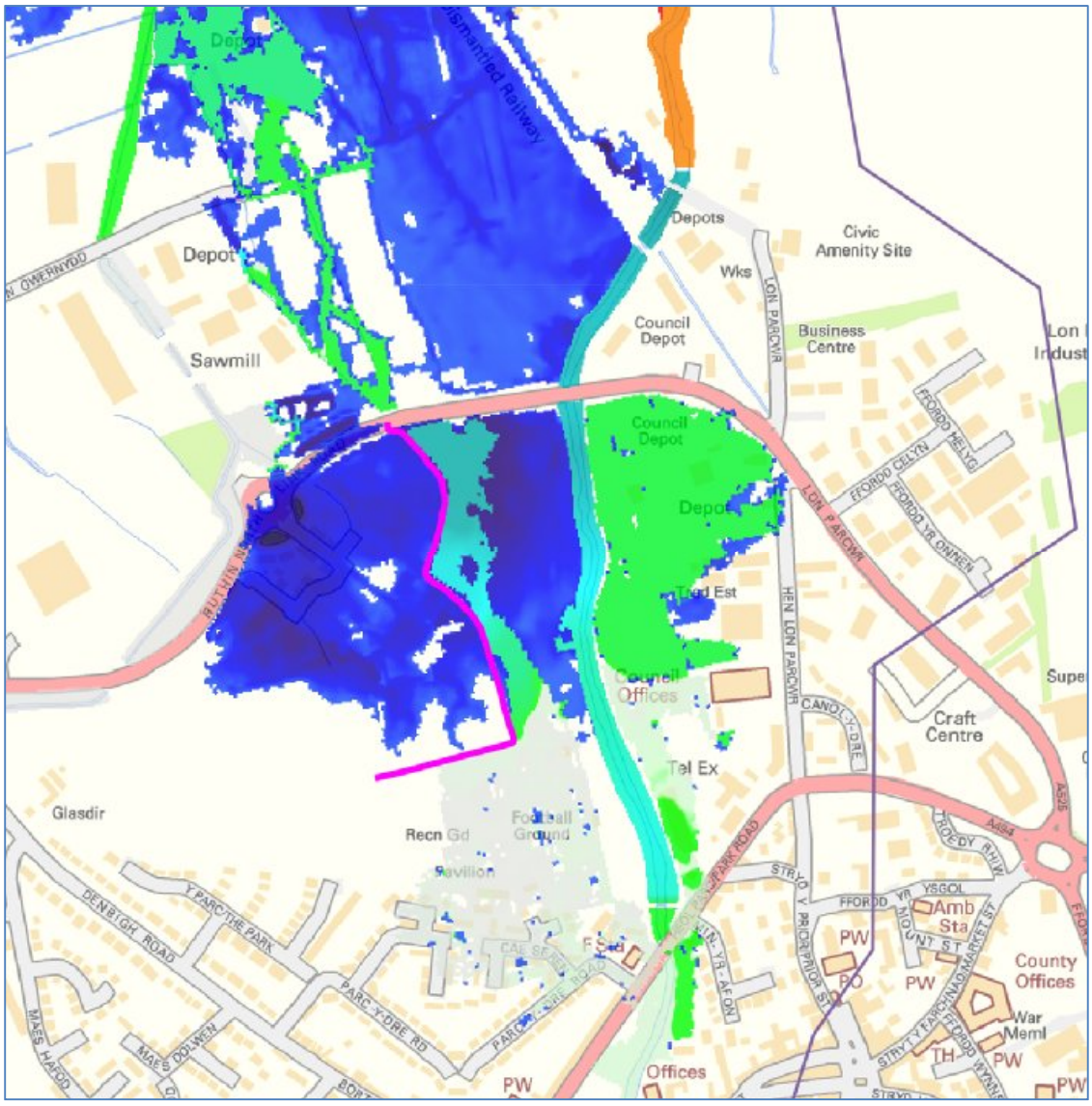


Figure 36 - 4.8 Option 6 - Removal of Ruthin Weir & Re-grading of the River Clwyd (Scenario H)

Figure 37 - Option 6 - ISIS TUFLOW Model Results for 1 in 100 year return period with Climate Change and 95% blockage



Key
Blue – Removal of Flood Risk
Green - Reduction in Flood Risk
Grey – No change in Flood Risk
Yellow – Increase in Flood Risk
Red – New Flood Risk

Figure 38 - Change in Flood Risk (Existing and Proposed for 1 in 100 year return period with Climate Change and 95% blockage)

5 Hydrological Evaluation

5.1 Design Hydrology

Information on the design hydrology has been provided as follows:

- Flood estimation calculation record pro-forma; and
- ISIS hydraulic model *.ied boundary conditions file.

The approach taken to the hydrological assessment detailed in the pro-forma is generally sound; however there are a number of issues for concern, which are discussed in turn below. To aid understanding of the comments made in this review Figure 39 below provides a basic schematic of the modelled catchment.

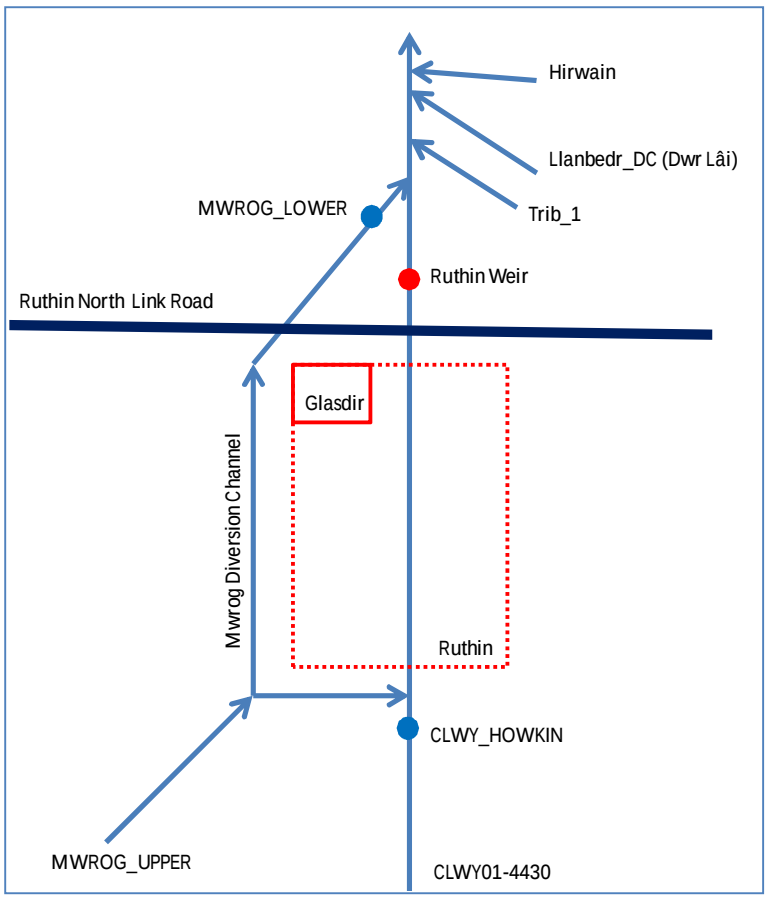


Figure 39 - Schematic of Hydrological Assessment

5.1.1 Schematisation and Catchment Descriptors

The schematisation of the hydrological catchment has been reviewed, with particular focus paid to the Mwrog catchments due to the influence of the flood relief channel. The schematisation is appears to be mostly appropriate, however, the lateral inflows alongside the urban area of the River Clwyd through Ruthin and along the natural Mrwog watercourse downstream of the flood relief channel entry point are not explicitly accounted for in the schematisation.

The impact of this can be tested from FEH CD-ROM outputs which show the total catchment area to Ruthin gauge to be 96.37 km^2, of which 8.88 km^2 is mostly diverted down the Mrwog Diversion Channel, giving an effective catchment area of 87.49km^2. The proforma shows that the total area accounted for in the model is 86.73 km^2, a shortfall of 0.76 km^2.

Whilst this represents a small proportion of the catchment area, it should also be noted that this includes much of the western part of Ruthin, including the most intensely urbanised area. The exclusion of this catchment area will result in an underestimation of volume of hydrograph and may result in an underestimation of peak flow.

5.1.2 URBEXT

The 'Initial Estimate of QMED' is based on a statistical analysis of peak flows using the WINFAP hydrological analysis software. The pro-forma states that the source of URBEXT is the 1990 value; however the statistical analysis of peak flows (as applied by WINFAP) should use the 2000 value. Furthermore, it appears that no Urban Adjustment Factor has been applied to account for the increase in urbanisation to the current day, which should be undertaken for all catchments[4].

Consequently, the 'Initial Estimate of QMED' appears to be underestimated in most catchments, resulting in cumulative errors in determining peak flows at higher return periods. It should be noted that the catchment is predominantly rural and the impacts of errors in URBEXT are expected to be limited, though this may be significant in the small tributary draining the eastern part of Ruthin Town.

5.1.3 Index Flood, QMED

The reliability of the design hydrology determined using the statistical method relies in large part on the accuracy of the Index Flood (QMED, Median flood of annual maximum peak flow series). The pro-forma states that estimates of QMED at each flow determination point have been improved through donor station data transfer using an appropriate gauging station.

The station used as a donor for this project is Ruthin Weir (66005) and the data transfer has been applied to all flow estimates on the main River Clwyd and one minor tributary. This means that the observed QMED has a significant impact upon the hydrological findings (reducing the initial estimate of QMED by nearly half). Accordingly there are two key areas of uncertainty which require thorough review: accuracy of flow measurement at Ruthin Weir; and amount of water bypassing the weir through the flood relief channel.

[4] Environment Agency Flood Estimation Guidelines – Operational Instruction 197_08 (June 2012), p45.

These are considered in turn below.

a) Flow measurement accuracy

The QMED value at Ruthin Weir is calculated using annual maximum peak flow values (AMAX) derived from measured river levels and a rating curve. Inspection of the rating for the period 1971 to 2009 on Hiflows UK website shows that it is well supported by spot gaugings for flows up to 12 m^3/s (see Figure 40). However, it appears that the rating underestimates flows around the higher spot gaugings, and as a result may underestimate QMED in the region of 2 m^3/s.

Ruthin Weir underwent significant repair work in 2009; following this, regular spot gaugings have been undertaken and a new rating relationship was developed in spring 2013. Given the above, it is recommended that the rating for 1971-2009 is improved to provide a better match with the highest spot gauging, and the revised rating used to recalculate the AMAX series.

b) Impact of modifications within the catchment

The AMAX record at Ruthin extends from 1972-73 to present day, with a period of missing data from water years 1984/85 through to 1987/88. A number of significant changes have occurred within the immediate catchment including:-

- Construction of the Mwrog Flood Alleviation Scheme (2004)
- Modifications to the fish pass at Ruthin Weir (2009
- Construction of Ruthin Flood Alleviation Scheme (2003)
- Construction of the Ruthin Link Road (2004)

It is unclear what impact these changes have had on subsequent AMAX values at Ruthin Weir. The construction of the diversion channel is not mentioned in the site notes given on the Hiflows UK website and it appears unlikely that the impact of this has been accounted for in the determination of QMED at the site.

In relation to the Mwrog Flood Alleviation Scheme an initial estimate of impact can be made from flow contributions from the Mwrog catchment. Based on the existing assessment, QMED for the Mwrog upstream of the diversion channel is 2.24 m^3/s. The diversion scheme is shown within the model to allow up to 1 m^3/s to flow to River Clwyd upstream of Ruthin Weir, with the remainder being diverted through the diversion channel and returned to the River Clwyd downstream of Ruthin Weir.

This indicates that QMED could be underestimated by a minimum of 1 m^3/s and potentially more depending on how much water was discharged to the River Clwyd upstream of Ruthin in the AMAX events.

Consequently, it is considered that the AMAX data from 2004 onwards should not be used in the assessment of QMED at Ruthin Weir without accounting first for the effects described above. It is also possible that the site is not considered suitable for use as donor station at all. It is recommended that further work should be undertaken to determine the impact of the diversion channel on the AMAX series and resulting QMED at Ruthin gauge. It is also important to note that any subsequent analysis should ensure that the same assumptions around channel configuration are adopted when comparing modelled and observed QMED flows.

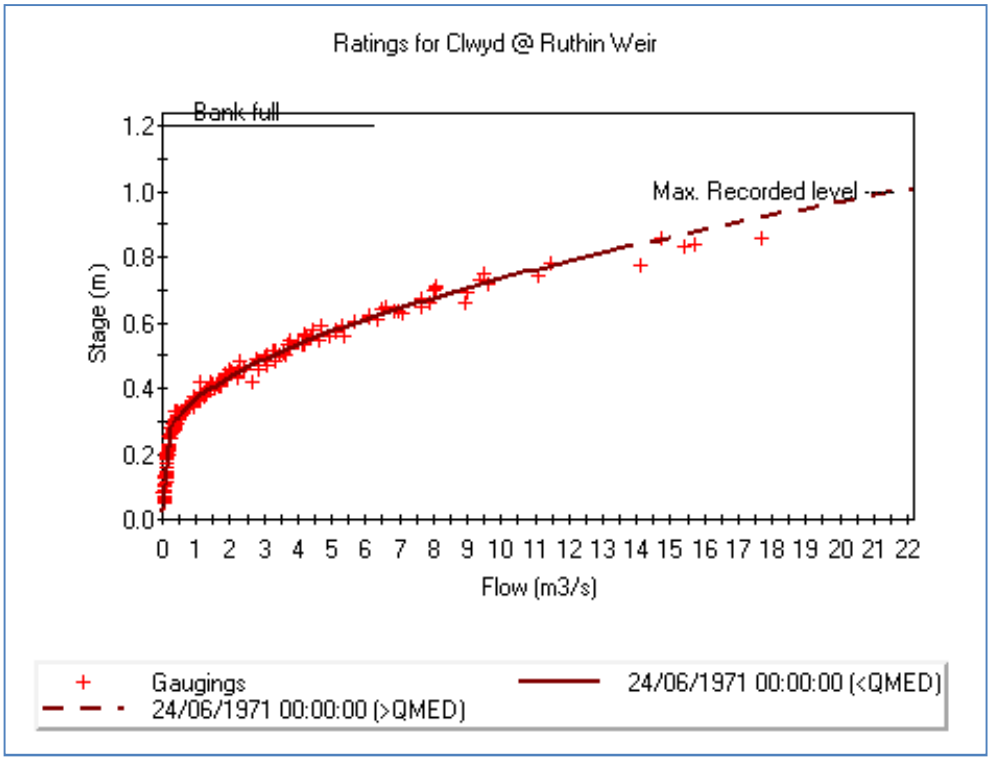


Figure 40 - Rating Curve Extract from HiFlows UK for Ruthin Weir

5.1.4 QMED Sensitivity

There is a significant difference between the empirically derived QMED value at Ruthin Weir and that determined using AMAX values, the former being approximately 75% larger than the latter. A review of nearby gauging stations indicates that this is generally replicated in neighbouring catchments as shown in Table 7 below.

A preliminary review of the gauging stations suggests that this may be related to flow losses to the permeable bedrock underlying parts of their respective catchments. However, it is advised that comment should be made on this issue within the pro-forma, based on the local knowledge held by the Environment Agency as this will mean greater uncertainty especially at higher flow return periods.

Station	QMED AM	QMED CD	QMED AM ÷ QMED CD
66005 (Clwyd @ Ruthin Weir)	14.2	24.7	58%
66001 (Clwyd @ Pont-y-cambwll)	47.8	59.0	81%
67009 (Alyn @ Rhydymwyn)	8.6	15.3	56%
67008 (Alyn @ Pont-y-capel)	21.9	35.7	61%
67003 (Brenig @ Llyn Brenig Outflow)	15.3	19.5	78%
67006 (Alwen @ Druid)	72.4	70.3	103%
67015 (Dee @ Manley Hall)	223.0	338.7	66%
66004 (Wheeler @ Bodfari)	3.7	6.6	56%
67005 (Ceiriog @ Brynkinalt Weir)	29.9	49.9	60%
66002 (Elwy @ Pant yr Onen)	65.6	71.8	91%
66006 (Elwy @ Pont-y-gwyddel)	71.3	69.4	103%

Table 7 - Variation of QMED from AMAX Series (AM) and Catchment Descriptors (CD) at Local Gauging Stations

The pro-forma contains the following note relating to the data-transfer improvement of QMED:

> *"As per the CES Flood Risk Mapping Report for Ruthin (2010), weighting factors used for data transfer between Ruthin Weir gauging station and the subject sites yielded unrealistic estimates of QMED. An area weighting method has therefore been adopted for this study, based on the ratio of catchment area at GS 66005, to the published QMED value from gaugings."*

The CES Flood Risk Mapping Report for Ruthin (2010) has not been provided as part of this review, so it is unclear what the basis is for considering the QMED estimates as unrealistic. However, a preliminary review of data-transfer from nearby suitable gauges using the standard distance weighting method[5] does not appear to indicate results which are immediately concerning. Further explanation should therefore be provided for the above comment made in the pro-forma.

It should be noted that QMED donor data-transfer has been applied only to the River Clwyd and Llanbedr DC catchments and not the other tributaries. Explanation should be provided to justify this, or suitable data-transfer applied.

[5] Environment Agency/ DEFRA (2008), Improving the FEH statistical procedures for flood frequency estimation. Science Report SC050050.

The above analysis shows that the derived QMEDs are influenced by the use of Ruthin Weir as a donor catchment, and that there is significant uncertainty surrounding reliability of observed QMED at Ruthin Weir. As peak flows at higher return periods are scaled from QMED values using a growth factor, the uncertainty in QMED is carried through to peak flows at higher return periods.

For information the confidence intervals for the current estimations of QMED are given in Table 8 below. The confidence interval is dependent upon the method of assessment as outlined below:

- CD – where catchment descriptors have been used to determine QMED, then the standard techniques presented in FEH[6] have been used, but with the revised factorial standard error as presented for the revised QMED procedures[2].
- AMAX – where gauged AMAX data have been used to determine QMED, standard techniques presented in FEH based on the length of the gauged record would normally be used. However, significant uncertainty remains around the accuracy of the AMAX series at Ruthin Weir, so the standard techniques should not be applied without first undertaking investigations. As these issues have not been investigated as part of this review, it is considered more appropriate to revert to the catchment descriptor method of quantifying uncertainty in this case.
- DT – where donor station data transfer has been applied, uncertainty in QMED would normally be reduced (compared to catchment descriptor methods). However, given the uncertainty in the recorded AMAX series at Ruthin Weir, the catchment descriptor method to quantifying uncertainty has been retained here.

The confidence limits should be used when targeting sensitivity analysis or further investigations as part of this study. It should be noted that these limits will require recalculation where QMED values are reassessed.

[6] Robson, A.J. and Reed, D.W. (1999) Statistical procedures for flood frequency estimation. Volume 3 of the Flood Estimation Handbook. Centre for Ecology & Hydrology.

Catchment	Method	QMED	68% Confidence		95% Confidence	
			Lower	Upper	Lower	Upper
MWROG_UPPER	CD	2.24	1.57	3.21	1.09	4.59
MWROG_LOWER	CD	0.36	0.25	0.52	0.18	0.74
Trib_1	CD	0.17	0.12	0.24	0.08	0.35
Hirwain	CD	0.71	0.50	1.02	0.35	1.45
Ruthin Weir GS	AMAX	14.1	9.85	20.18	6.89	28.87
CLWY01-4430	DT	12.6	8.81	18.03	6.15	25.80
CLWY_HOWKIN	DT	12.9	9.01	18.46	6.30	26.42
Llanbedr_DC	DT	3	2.10	4.29	1.47	6.14
Clwy_Total	DT	20.2	14.12	28.91	9.86	41.36

Table 8 - Confidence limits for QMED (m3/s)

5.1.5 Growth Curves

Growth curves have been derived to calculate peak flows at return periods greater than QMED using the FEH statistical pooling group method. The FEH statistical pooling groups have not been assessed in detail, however it is recommended that they are reviewed and revisited for two reasons, as detailed below.

1. The justification for removing stations from the initial pooling group derived by the WINFAP software is based on statistical discordancy alone, rather than explanations relating to the reliability of the hydrological data. This may not be appropriate[7] and should therefore be reviewed and updated as necessary.

2. The pooling group for the permeable catchment of Dwr Lâi appears to have a steeper growth curve than the pooling group on the River Clwyd. The Environment Agency's Flood Estimation Guidelines state that when Version 3 of WINFAP is used for statistical analysis (using new pooling group construction techniques) permeability should be allowed for in the composition of the pooling group by manual editing of the stations used[8]. This does not appear to have been undertaken for Dwr Lâi; therefore the growth curve may not be representative of the catchment.

[7] Robson, A.J. and Reed, D.W. (1999) Statistical procedures for flood frequency estimation. Volume 3 of the Flood Estimation Handbook. Centre for Ecology & Hydrology.

[8] Environment Agency Flood Estimation Guidelines – Operational Instruction 197_08 (June 2012), p100.

It should be noted that overall uncertainty in peak flows assessed using the statistical method arises from a combination of the uncertainty of QMED (discussed in the previous section) and the uncertainty of the growth curve. The Environment Agency's Flood Estimation Guidelines[9] provides the following advice:

> *"There are no widely available straightforward techniques for assessing confidence intervals for flood estimates (1 5.6). The FEH provides confidence intervals for some components of flood estimates, but does not suggest any techniques for combining them together and accounting for the other sources of uncertainty."*

The reference within the quote is to the Flood Estimation Handbook Volume 1. No attempt has been made to assess the confidence intervals of the peak flow values for return periods above QMED as part of this review.

5.1.6 Hydraulic Model Boundary Conditions

To represent the time-varying flow within the hydraulic model the boundary conditions file has used ReFH units to represent the design hydrograph shapes. The ReFH hydrographs have been scaled to fit the peak flow values at each estimation point and each return period, as calculated using the FEH statistical method (discussed above). This hybrid method is generally accepted as good practice; however there are a number of issues which should be considered in this case.

The storm duration specified within the ReFH units is 9.5 hours; however, the storm duration for the entire catchment (to outfall) is stated in the calculation record pro-forma as 7.5 hours. Shorter durations are noted for other sub catchments in the proforma. No explanation is given for the choice of the storm duration in the model boundary conditions therefore the reason for the discrepancy is unknown.

Whilst a standard storm duration (derived from catchment descriptors) may be used in simple catchments, the equation may be inadequate to determine critical storm durations in more complex catchments; particularly those where there is significant storage. Note that a coherent approach must be adopted to determination of critical storm duration and any subsequent reconciliation with observed AMAX values. For example, resulting hydrographs from the critical storm duration with the link road in place should not be scaled to statistical peaks based on a QMED derived from an AMAX series prior to construction of the link road.

Improvements could be made to the representation of the inflows to the top of the model on the River Clwyd. Here, the peak flow at the upstream estimation point (Clwy01-4330) has been subtracted from the peak flow at the next downstream estimation point (Clwy_Howkin); the intervening hydrograph has then been scaled to that value. This has the potential to introduce errors in the volume of water represented within the hydraulic model where these flow estimation points are separated by substantial intervening catchments areas, however, it should be noted that these two locations are relatively close together and the impact of any attenuation moving downstream is likely to be limited.

[9] Environment Agency Flood Estimation Guidelines – Operational Instruction 197_08 (June 2012), p74.

A more appropriate method would be to subtract the full upstream hydrograph from the full downstream hydrograph. The resulting hydrograph could then be specified as the intervening flow. Alternatively, the intervening catchment area could be represented through manual derivation of catchment descriptors[10]. This is likely to result in a better representation of both the timing and the volume of flow for the intervening catchment.

5.1.7 Peak flow analysis from Hydrology routed through Hydraulic Model

Table 9 and Figure 41 - Flow Frequency and Growth Curves from Hydraulic Model below provides a summary of the peak flows and associated growth curves from the baseline design hydraulic model scenarios.

Location	Return Period	2 Years	10 Years	20 Years	50 Years	100 Years	200 Years	1000 Years
Ruthin Weir	Peak Flow (m^3/s)	13.50	17.91	18.80	19.49	19.73	19.84	21.92
	Growth Factor	1.00	1.33	1.39	1.44	1.46	1.47	1.62
River Clwyd (at Link Road)	Peak Flow (m^3/s)	13.50	22.67	26.88	33.98	39.02	42.39	62.73
Flood relief channel (upstream)	Peak Flow (m^3/s)	3.25	4.95	5.82	7.12	8.25	9.65	13.67
River Clwyd + Relief Channel	Peak Flow (m^3/s)	16.74	27.61	32.69	41.09	47.27	52.04	76.40
	Growth Factor	1.00	1.65	1.95	2.45	2.82	3.11	4.56

Table 9 - Flow Frequency and Growth Curves from Hydraulic Model

[10] Bayliss, A.C. (1999) Catchment descriptors. Volume 5 of the Flood Estimation Handbook. Centre for Ecology & Hydrology

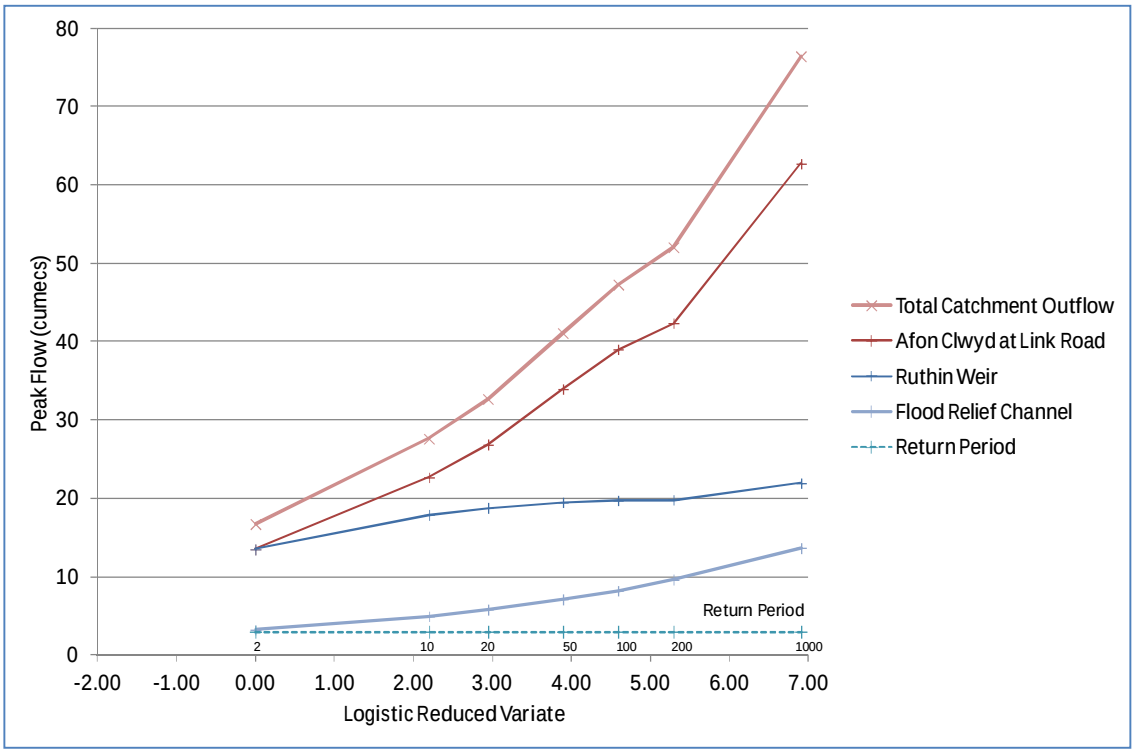


Figure 41 - Flow Frequency and Growth Curves from Hydraulic Model

It should be noted that the total flow in the Clwyd catchment should include the water which is diverted down the Mwrog Diversion Channel; hence these have been summed in the table. It can be seen that the growth curve for Ruthin Weir is relatively flat; the main cause for this is believed to be the extent of bypassing which occurs in the floodplain adjacent to the weir. This table shows that catchment wide, there is a growth factor of 2.82 for the 1 in 100 year storm. This is consistent with the growth factors presented in the hydrological appendix and is within an expected range.

5.2 Calibration Hydrology

5.2.1 General

Information on the calibration hydrology for the 2012 event has been provided as follows:

- Technical Note by JBA Consulting, Subject: 'November 2012 Ruthin Model Calibration – DRAFT' (June 2013).
- ISIS hydraulic model *.ied boundary conditions file (JBA_e2012-11.ied).

It should be noted that the inflow hydrographs for the calibration event appear to have been determined using the ReFH method with an observed rainfall profile. However, neither the rainfall profiles nor any of the other parameters have been supplied; therefore it has not been possible to review these aspects. Instead the inflows in the boundary condition file are represented by flow-time boundaries, with pre-calculated flow values specified for each time step.

5.2.2 Approach and Uncertainty

To construct the calibration event using readily available data, the following steps have been undertaken:

- Estimate rainfall profiles using local rain gauges (one within the catchment and one in a neighbouring catchment) adjusted so that they are representative of rainfall within each catchment;
- Estimate catchment wetness at the start of the event (Cini) based on preceding rainfall and potential evapotranspiration;
- Estimate culvert blockages which took place during the event.

There is often considerable uncertainty in deriving catchment wide rainfall profiles from rain gauges which record rainfall at a single point only. Furthermore, the ReFH model volume (and peak flow) is particularly sensitive to adopted Cini values, and there is little certainty about the degree of blockage of the culverts during the 2012 event. It would therefore be possible to use different permutations of values or assumptions for each of the above to produce model results which approximate the flooding experienced in Ruthin in November 2012.

The JBA Technical Note recognises the inherent uncertainties present in the existing calibration, stating that "The event hydrology and blockage are considered to be the most uncertain elements of the assessment." The results of the calibration exercise should therefore not be considered definitive. Caution should be used when considering their use in altering the design models and/or the assessment of flood risk and mitigation measures.

5.2.3 Review of Inflows

It should be noted that the most upstream inflow on River Clwyd (labelled Clwy01_4430) has a peak flow of 44.9 m^3/s whereas peak flow at Ruthin Weir was measured at 24.6 m^3/s and modelled at 21.6 m^3/s. No comment has been made within the Technical Note to explain or discuss this significant difference, which may be due to bypassing of the gauge and/or attenuation upstream of Ruthin North Link Road. Given the significant difference in flows this issue should be explicitly addressed.

5.3 Return Period Assessment (November 2012)

A return period assessment of the November 2012 event could be based on either the observed or modelled flow data. However, there are a range of factors which make it difficult to attribute an annual exceedance probability (or return period) to the event for either method with confidence. These factors are as follows:

- Reliability of the current calibration hydrology and possibility for a range of permutations which predict the same flooding (including rainfall distribution and calculation of antecedent catchment wetness).
- Construction of Mrwog flow diversion channel and Ruthin Link road may make observed flows during 2012 incompatible with previous recorded flood events.
- Uncertainty as to the degree of culvert blockage which occurred.

- The fact that the flooding was predominantly volume based, rather than related entirely to the peak flow.
- Local bypassing of Ruthin gauge and associated problems with rating leading to poor accuracy of high flow data.

The blockage of the culverts under Ruthin North Link Road resulted in the peak of the event being attenuated upstream of Ruthin Weir. Had the culverts not been blocked the peak flow measured at Ruthin Weir is likely to have been higher. Consequently any assessment of return period based on observed peak flow at Ruthin Weir may be unreliable.

An alternative method could be to compare the volume of the 2012 event to previous flood events. However, the rating relationship at Ruthin Weir gauging station is considered to be uncertain at high flows and local bypassing is known to occur. It is therefore difficult to reliably determine the volume of previous events, particularly those with peak flows significantly above QMED, making this method unsuitable.

It is worth noting that based on available information the November 2012 event appears to be the highest on record in over 30 years of data at Ruthin Weir, in spite of the possible attenuation caused by blocked upstream culverts and from bypassing through the diversion channel.

6 Conclusions

a) Key data on the November event – We have estimated that the flow in the November 2012 event was between 35.9 and 40.4 m^3/s, which we judge to be between a 1 in 100 year and 1 in 200 year event but biased towards 1 in 100 year, and the blockage of the culverts was between 66% and 95%.

b) Solutions to restore the level of protection – Various engineering solutions were explored and these are detailed in Section 4 of this Report. It is the Investigating Team's opinion that the solution that offers the earliest and most cost-effective solution to re-instating the flood defences around the development is to raise the bund height.

c) Organisational complexity – The process of preparing the land at Glasdir for development has involved many organisations over many years (see diagram in Appendix 2). During that period the methods of hydraulic modelling have developed and standards and guidance have changed. Communication between the various parties could have been clearer; assumptions previously made could have been challenged. In addition, it is necessary to have an overall view on the interaction between the road built as an embankment and the operation of the flood plain with respect to the flood risk of the proposed development land. There does not seem to have been continuity of involvement provided during the development of the area, to avoid important criteria being missed.

d) Blockages – The blockage of the culverts played a significant part in causing the flood water to flow over the bund (which was also too low).Thus the proposed height of the bund is based on an assumption of a 95% blockage to the culverts. (See paragraph 3.6.5).

   Although blockage was mentioned in previous reports there is no evidence that work was done to assess its impact. It is only recently that a Welsh Government survey has revealed that 60% of flooding incidents on ordinary watercourses (see paragraph 4.3) were caused by blockages.

e) Response to the event – The belief that this development was protected to an unusually high level of 1 in 1000 meant that it was not on the list of high risk areas to visit in a high rainfall event. The vertical grills are hard to clear during a storm once they had become blocked and certainly not safely. Access to the top of the culvert entrances has been improved since the event in November 2012 but clearing the culvert entrances of debris in a storm will not be easy and could be unsafe in an extreme event.

f) Planning – It is clear from the documentation that the land at Glasdir was expected to be protected to a 1 in 1000 (0.1% annually) standard for flood risk management. The calculated level of this 1 in 1000 standard/level has varied over the years as different models and assumptions have been used consistent with practice at the time.

g) Datum – It is unclear whether 'site datum' referred to on some drawings is the same as AOD. In addition there is reference on one of the drawings to the possibility of a

peat layer under the 5 culverts. Therefore possible settlement of the peat in the area could have had an impact on datum levels and bund heights.

h) Grills – Vertical grills are known to be prone to blockage and are difficult to clear during a storm once they have become blocked. The current standard for grills would be difficult if not impossible to achieve given the form of the culverts and their location. The Panel does not see the need for grills and recommends that they are not re-installed. Posts to capture large obstructions such as branches are feasible and recommended.

i) Wind farms and associated tree felling – The tree felling proposed in association with the proposed wind farm construction is not considered to have a significant impact on future flooding at Glasdir.

7 Recommendations

a) The bund should be raised to the level shown in the Outline Proposal in Appendix 3, which is based on a 1 in 100 year event with climate change and 95% blockage, with a 600mm freeboard.

   Once raised it should be checked regularly and after extreme events (wet and dry) for possible settlement and damage, and repaired if necessary. In setting this height, the demonstrated likelihood of blockage, climate change and uncertainties associated with modelling have been taken into consideration.

   Whereas the current bund has an allowance of only 200mm of freeboard, we are recommending 600mm be used as this is in line with custom and practice over several years for residential development. It is anticipated that this flood defence will enable flood insurance to be purchased without significant increases in premium.

b) It is to be hoped that the bund will be permanently raised as soon as possible. However, for the interim, a temporary line of sandbags (or equivalent) should be considered to be used to raise the bund height. Careful monitoring during a storm event is recommended to ensure integrity is maintained.

c) Long term management of the flood plain and catchment area should be organised. The maintenance of the area around the culverts' entrance and exit should particularly be cleared of debris, garden waste and the vegetation kept short. The responsibility for doing the maintenance should be clearly identified.

   There is currently a belief (*Managing Woody Debris in Rivers, Streams and Floodplains* written by the Wildlife Trusts and Water for Wildlife (2005) that catchment management should encourage natural processes and so woody debris in the catchment and watercourse would be encouraged. However, this catchment has been severely impacted by the construction of a road across the flood plain on an embankment rather than a bridge structure. This acts as a dam and the mitigation of providing the 5 culverts to pass the flood water is nullified if they block with debris (as happened in November 2012).

Thus this catchment should be maintained to avoid debris being carried by flood flows. In addition, the exits from the culverts should be kept clear.

A question has been raised about the need for a channel to connect the land immediately to the north of the culverts with the downstream floodplain. Whilst this is unlikely to have a significant impact during a flood, it would allow this land to drain more effectively to the river downstream of the road after the event. This should be the subject of further study.

d) A network of flood wardens should be put in place with tasks that include monitoring the condition of the flood plain and the culverts. There should be a designated DCC officer to respond to wardens. Organising annual river events during dry spells, to inspect and clear potential obstructions, helps to maintain awareness of the flood risk management system, especially during dry spells. This arrangement is becoming commonplace in areas at risk, and is proving to be an important educational opportunity.

e) Linking a flood warning system to an upstream gauge will be useful to the residents, flood wardens, NRW and DCC. It is vital there is a clear means of communication with identified recipients.

f) The grills have been removed from the culvert entrances and exits and should not be put back. Given the shallow height of the culverts and the staggered entrances and exits, designing screens to conform to the CIRIA Guide, with a low risk of blockage, would be a challenge.

g) An alternative that could be explored is a line of posts around the entrances to the culverts that could catch larger debris and vegetation carried in the flow (see Plate 12, Section 4.3 for photo).

h) A 300mm diameter sewer is shown on the drawings running under the culverts and a broken manhole cover was observed just upstream of the culverts on a visit on 7th August 2013. This manhole cover and any others in the area should be inspected, repaired and made safe in this public area.

i) The surface water drainage within the Glasdir site, in our view, had no discernible effect on the consequences of the flooding on 26/27 November 2012. Its ongoing monitoring, inspection and maintenance is vital to ensure it effectively drains rain water within the site.

Appendices

Appendix 1A: Terms of Reference and Commission for Investigation of 9 January 2013, annotated with Paragraph Numbers showing where the issues have been covered in the report

Appendix 1B: Revised Terms of Reference and Commission for Investigation of April 2013 showing the main changes between the two versions

Appendix 2: Glasdir Development, Ruthin: Relationship between the Main Parties

Appendix 3: Outline of possible profile of the heightened bund

Appendix 4: Key Documents re Glasdir Flooding in November 2012

Appendix 1A: Terms of Reference and Commission for Investigation of 9 January 2013

Denbighshire County Council

Flooding events – 26th/27th November 2012

Flood & Water Management Act 2010

Under the terms of the Flood & Water Management Act 2010, Denbighshire County Council, acting lead local flood authority intends to undertake an investigation into the flooding events of 26th/27th November 2012. These include flooding at Rhuddlan, St Asaph, Brookhouse and Glasdir, Ruthin.

Paragraph from Terms of Reference	**Paragraph numbers where issue is covered for Ruthin**
In commissioning the investigation, the Council wishes to understand:	
• Why the flooding occurred. • What the likelihood of recurrence may be. • What can/should be done to by all relevant flood risk management authorities to minimise flood risk to properties in future events.	1.5 and 3.6 3.6.6 4.4
Terms of Reference	
The overall investigation will address the following points:-	
a) The weather conditions during and preceding the flood events.	1.5 and 3.6
b) The degree to which flood defences and other alleviation/management measures operated as intended, including specifically any factors that may have prevented their full operation.	3.6.1
c) The overall flood risk assessments for the affected areas and the continued adequacy of these in the light of the flood events. This should include assessment of whether changes to river patterns and/or flood management measures have changed flood risks since the last assessment was concluded.	2
d) Whether, in the light of the flooding experienced on 26 th/27th November 2012, relevant flood risk management authorities should implement modifications or additions to their flood defence, alleviation and management measures to minimise risk of future flooding to an acceptable level.	4, plus Conclusions & Recommendations
More detailed questions for the investigation are suggested in Appendix 1.	
Relevant Flood Risk Management Authorities	
For the purposes of this investigation, Denbighshire County Council has identified the relevant flood risk management authorities as:-	
• Denbighshire County Council, as flood management authority responsible for surface flooding and minor water courses, and also as Highways Authority for county roads. • Environment Agency Wales, as flood management authority responsible for main rivers.	

- Welsh Government, as Highways Authority for the A494 & A55 trunk roads

In addition, whilst not a flood risk management authority, Taylor Wimpey North West will require to input to the investigation as currently responsible for the unadopted surface water drainage system at the Glasdir Estate, Ruthin.

Additional Independent Investigation – Glasdir, Ruthin

Whilst the impact of flooding across the County on 26 th/27th November 2012 was significant, specific complexities and issues pertain to the flooding event at the Glasdir housing development in Ruthin.

To this end, and in recognition of the potential for conflict of interest, Denbighshire County Council is additionally commissioning an independent investigation of the flooding at Glasdir. As well as addressing the more general points outlined above in relation to Glasdir, the Council wishes the investigator to review specifically:-

i. The planning process relating to the development of the Glasdir site, Ruthin, including the flood risk and consequence analyses undertaken, the adequacy of these, the degree to which they were incorporated into permissions given, and adhered to during construction.

ii. The maintenance and management regimes in place for all relevant flood risk management authorities, the adequacy of those arrangements and the degree to which such arrangements were adhered. This should include flood alert and warning systems as well as physical measures in place to mitigate and manage flood risks.

iii. The conclusions reached by the Environment Agency in its analysis of the possible causes of flooding at Glasdir, Ruthin, and specifically whether any other contributory factors and/or mitigating measures should be taken into account.

The independent investigation report is expected to fully explore the points raised, and any relevant associated issues, and to present findings and conclusions that arise. The report is also expected to make recommendations of any further action advised for relevant flood risk management authorities to minimise to an acceptable level, the risk of significant future flooding events at Glasdir specifically.

All surveys and studies already undertaken by or on behalf of both Denbighshire County Council or the Environment Agency in relation to Glasdir will be made available to the Independent Investigator. Should s/he consider them necessary to answer the points outlined above, the Independent Investigator will also have the power, in consultation with Denbighshire County Council, to commission additional technical studies, surveys or other such analyses.

Independent Review of Findings

While the Council will carry out the investigation of the causes of flooding at locations other than at Glasdir, the Independent Investigator will undertake a review of the findings and conclusions from those investigations, to provide assurance of their adequacy.

Timescale

The investigations are expected to take 3 months to complete. A final report

on all parts of the investigation is therefore expected by mid April 2013. Governance The investigations will be co-ordinated by an officer working group chaired by the Corporate Director for Economic & Community Ambition. Membership will reflect the relevant flood risk management authorities - Highways & Planning services for Denbighshire County Council, Environment Agency Wales and Welsh Government. The role of the working group will be to investigate the overall flood events and also to support, through the provision of relevant information and evidence, the independent investigation into the specific events affecting Glasdir. A Stakeholder Reference Group will also be established to ensure relevant interested parties are informed about progress with the investigations and offered the opportunity to contribute and comment. The Stakeholder Reference Group will comprise the following groups: • Local Members • Cabinet Lead Member for Environment & Public Realm • Leader of the Council • Resident representatives from the affected communities • Representatives from Ruthin, St Asaph & Rhuddlan Town Councils Reporting The final report from the Investigations will be presented to full Council at its meeting on 7 May 2013. Exclusions The investigations will cover the causes of the flooding events on 26th/27th November 2012, the exercise by the relevant flood risk management authorities of their responsibilities and whether those authorities need to take any specific action to minimise the risk of future significant flooding. The investigations will not evaluate the emergency response to or recovery from the flooding events. These are separately covered in reviews being conducted by North Wales Resilience Forum. The findings from the Resilience Forum reviews will help to improve the Council and its partners' emergency response to and recovery from any future incidents, and will be reported to Members once completed.	
Appendix 1 *(To Terms of reference)***:** **Detailed Questions – Flooding Event, 26th/27th November 2012**	
Rainfall, Weather and Conditions 1. What were the weather, ground and river conditions that led to the flooding event? 2. Were they exceptional? 3. How likely are they and flooding of this magnitude to recur? 4. Are there any warning signs/triggers for future risk management? Flood Alert & Risk Management 5. Are flood alert procedures and mechanisms sufficient? Did they operate as expected on 26/27 November?	1.5.2 and 3.6 1.5.2 and Conclusions

6. Does the flooding event of 26/27 November raise any particular issues to be addressed by any relevant flood risk management authority?	
<u>Flood Protection & Mitigation Measures</u>	
7. Who has responsibility for the various flood protection and mitigation measures involved in the flood event?	3
8. Are current flood protection and mitigation measures adequate? What scale of flood can they be expected to protect against?	
9. What level of flood protection is considered to be 'acceptable'? What, if anything, is needed to deliver that level of protection?	
10. What was the cause of flooding at each of the affected locations?	
11. Is there any evidence that blockages (in culverts or more generally on the river) caused the flood waters to overtop defences?	3.6.5
12. Is blockage/debris inevitable during a flood? Are flood defences designed to operate with an anticipated level of blockage?	
13. What (more) can be done to minimise the risk of unmanageable levels of debris/blockage?	
<u>Glasdir issues</u>	
14. Were planning permissions for the Glasdir development granted in line with recognised practice and in accordance with relevant planning policy, guidance and regulation?	6 and 7
15. Were flood mitigation recommendations appropriately incorporated into the permissions granted?	
16. Were the flood mitigation measures required by the planning permissions adhered to during construction?	
17. Was the expert advice sought on flood risk adequate?	
18. Did the sequential nature of applications for the Glasdir site affect the quality of advice given or flood mitigation measures recommended?	
19. The bund was specified for a 1 in 1000 event, were the culverts designed with sufficient capacity to manage 1 in 1000 volume of flood waters? Including with a reasonable level of blockage?	
20. Should flood mitigation recommendations have specified works downstream of the culverts to direct the subsequent flow of diverted flood waters?	
21. Did the design of the link road exacerbate flooding at Glasdir once the bund had been overtopped?	
22. Did the surface water drainage system exacerbate flooding at Glasdir once the bund had been overtopped?	
23. Could downstream blockages have contributed to the flooding at Glasdir?	
24. Are there any specific measures that need to be taken to reduce the risk of flooding at Glasdir to an acceptable level?	
25. Is protection against a 1 in 1000 flood event at Glasdir achievable?	
<u>St Asaph/ Rhuddlan issues</u>	
26. Did the tide contribute to flooding at St Asaph or Rhuddlan?	
27. Did construction works at Foryd Harbour contribute to flooding at St Asaph or Rhuddlan?	
28. Could anything more have been done to prevent overtopping of the defences at St Asaph?	
29. Are defences/flood mitigation measures at both locations adequate to provide a reasonable level of protection from flooding?	

Appendix 1B: Revised Terms of Reference and Commission for Investigation, April 2013 showing in red the differences from the January issue

Terms of Reference and Commission for Investigation

Denbighshire County Council

Flooding events – 26th/27th November 2012

Flood & Water Management Act 2010

Under the terms of the Flood & Water Management Act 2010, Denbighshire County Council, acting lead local flood authority intends to undertake an investigation into the flooding events of 26th/27th November 2012. These include flooding at Rhuddlan, St Asaph, Brookhouse and Glasdir, Ruthin.

In commissioning the investigation, the Council wishes to understand:

- Why the flooding occurred
- What the likelihood of recurrence may be
- What can/should be done by all relevant flood risk management authorities to minimise flood risk to properties in future events

The purpose of this report is not to allocate blame or fault but to investigate the cause(s) of the flood in order to determine what actions should be taken.

Terms of Reference

The overall investigation will address the following points:-

a) The weather conditions during and preceding the flood events.

b) The degree to which flood defences and other alleviation/management measures operated as intended, including specifically any factors that may have prevented their full operation.

c) The overall flood risk assessments for the affected areas and the continued adequacy of these in the light of the flood events. This should include assessment of whether changes to river patterns and/or flood management measures have changed flood risks since earlier assessments.

d) Whether, in the light of the flooding experienced on 26th/27th November 2012, relevant flood risk management authorities should implement modifications or additions to their flood defence, alleviation and management measures to minimise risk of future flooding to an acceptable level.

More detailed questions for the investigation are suggested in Appendix 1

Relevant Flood Risk Management Authorities

For the purposes of this investigation, Denbighshire County Council has identified the relevant flood risk management authorities as:-

- Denbighshire County Council, as flood management authority responsible for surface flooding and minor water courses, and also as Highways Authority for county roads
- Environment Agency Wales, as flood management authority responsible for main rivers

- Welsh Government, as Highways Authority for the A494 & A55 trunk roads

In addition, whilst not a flood risk management authority, Taylor Wimpey North West will require to input to the investigation as currently responsible for the unadopted surface water drainage system at the Glasdir estate, Ruthin.

Additional Independent Investigation – Glasdir, Ruthin

Whilst the impact of flooding across the County on 26th/27th November 2012 was significant, specific complexities and issues pertain to the flooding event at the Glasdir housing development in Ruthin.

To this end, Denbighshire County Council is additionally commissioning an independent investigation of the flooding at Glasdir. As well as addressing the more general points outlined above in relation to Glasdir, the Council wishes the investigator to review specifically:-

i. The planning process relating to the development of the Glasdir site, Ruthin, including the flood risk and consequence analyses undertaken, the adequacy of these, the degree to which they were incorporated into permissions given, and adhered to during construction.

ii. The maintenance and management regimes in place for all relevant flood risk management authorities, the adequacy of those arrangements and the degree to which such arrangements were adhered. This should include flood alert and warning systems as well as physical measures in place to mitigate and manage flood risks.

iii. The conclusions reached by the Environment Agency in its analysis of the possible causes of flooding at Glasdir, Ruthin, and specifically whether any other contributory factors and/or mitigating measures should be taken into account.

The independent investigation report is expected to fully explore the points raised, and any relevant associated issues, and to present findings and conclusions that arise. The report is also expected to make recommendations of any further action advised for relevant flood risk management authorities to minimise to an acceptable level, the risk of significant future flooding events at Glasdir specifically.

All surveys and studies relevant to these Terms of Reference already undertaken by or on behalf of both Denbighshire County Council or the Environment Agency in relation to Glasdir will be made available to the Independent Investigator. Should s/he consider them necessary to answer the points outlined above, the Independent Investigator will also have the power, in consultation with Denbighshire County Council, to commission additional technical studies, surveys or other such analyses.

Independent Review of Findings

While the Council will carry out the investigation of the causes of flooding at locations other than at Glasdir, the Independent Investigator will undertake a review of the findings and conclusions from those investigations, to provide assurance of their adequacy.

Timescale

The investigations are expected to take 3 months to complete. A final report on all parts of the investigation is therefore expected by late April 2013.

Governance

The investigations will be co-ordinated by an officer working group chaired by the Corporate Director for Economic & Community Ambition. Membership will reflect the relevant flood risk management authorities - Highways & Planning services for Denbighshire County Council, Environment Agency Wales and Welsh Government.

The role of the working group will be to investigate the overall flood events and also to support, through the provision of relevant information and evidence, the independent investigation into the specific events affecting Glasdir.

A Stakeholder Reference Group will also be established to ensure relevant interested parties are informed about progress with the investigations and offered the opportunity to contribute and comment. The Stakeholder Reference Group will comprise the following groups:

- Local Members
- Cabinet Lead Member for Environment & Public Realm
- Leader of the Council
- Resident and business representatives from the affected communities
- Representatives from Ruthin, & Rhuddlan Town Councils and St Asaph City Council
- For Glasdir only, Tai Clywd Housing Association & Taylor Wimpey North West Ltd

Reporting

The final report from the Investigations will be presented to full Council at its meeting on 7 May 2013.

Exclusions

The investigations will cover the causes of the flooding events on 26th/27th November 2012, the exercise by the relevant flood risk management authorities of their responsibilities and whether those authorities need to take any specific action to minimise the risk of future significant flooding.

The investigations will not evaluate the emergency response to or recovery from the flooding events. These are separately covered in reviews being conducted by North Wales Resilience Forum. The findings from the Resilience Forum reviews will help to improve the Council and its partners' emergency response to and recovery from any future incidents, and will be reported to Members once completed.

Appendix 1

Detailed Questions – Flooding Event, 26th/27th November 2012

Rainfall, Weather and Conditions

1. What were the weather, ground and river conditions that led to the flooding event?
2. Were they exceptional?
3. How likely are they and flooding of this magnitude to recur?
4. Are there any warning signs/triggers for future risk management?

Flood Alert & Risk Management

5. Are flood alert procedures and mechanisms sufficient? Did they operate as expected on 26/27 November?
6. Does the flooding event of 26/27 November raise any particular issues to be addressed by any relevant flood risk management authority?

Flood Protection & Mitigation Measures

7. Who has responsibility for the various flood protection and mitigation measures involved in the flood event?
8. Are current flood protection and mitigation measures adequate? What scale of flood can they be expected to protect against?
9. What level of flood protection is considered to be 'acceptable'? What, if anything, is needed to deliver that level of protection?
10. What was the cause of flooding at each of the affected locations?
11. Is there any evidence that blockages (in culverts or more generally on the river) caused the flood waters to overtop defences?
12. Is blockage/debris inevitable during a flood? Are flood defences designed to operate with an anticipated level of blockage?
13. What (more) can be done to minimise the risk of unmanageable levels of debris/blockage?

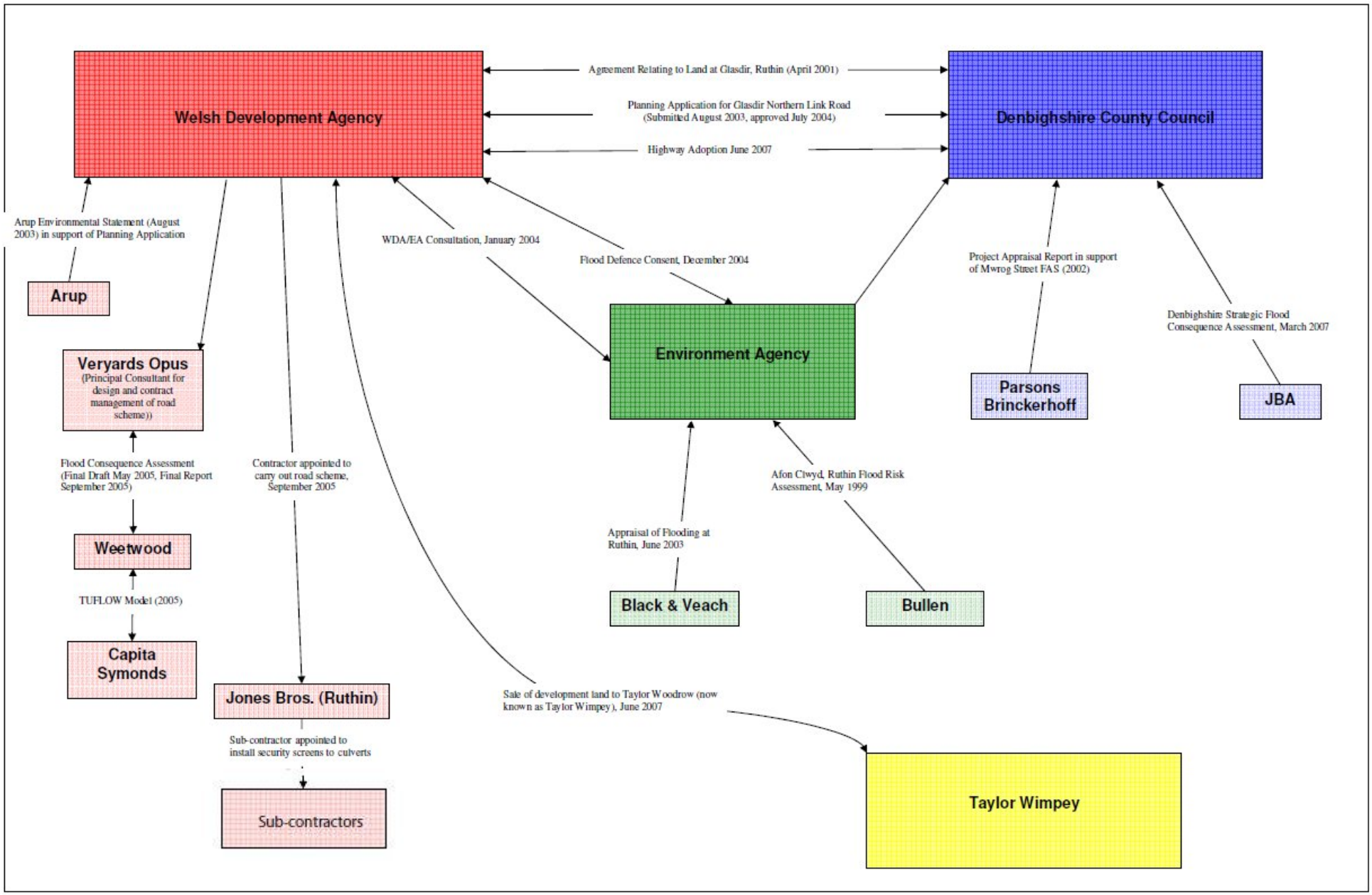
Glasdir issues

14. Were planning permissions for the Glasdir development granted in line with recognised practice and in accordance with relevant planning policy, guidance and regulation?
15. Were flood mitigation recommendations appropriately incorporated into the permissions granted?
16. Were the flood mitigation measures required by the planning permissions adhered to during construction?
17. Was the expert advice sought on flood risk adequate?
18. Did the sequential nature of applications for the Glasdir site affect the quality of advice given or flood mitigation measures recommended?
19. Do the culverts have sufficient capacity to manage a 1:1000 event with or without a reasonable level of blockage?
20. Should flood mitigation recommendations have specified works downstream of the culverts to direct the subsequent flow of diverted flood waters?
21. Did the design of the link road exacerbate flooding at Glasdir once the bund had been overtopped?
22. Did the surface water drainage system exacerbate flooding at Glasdir once the bund had been overtopped?
23. Could downstream blockages have contributed to the flooding at Glasdir? Specific reference has been made to the bridge/weir just north of Glasdir.
24. Are there any specific measures that need to be taken to reduce the risk of flooding at Glasdir to an acceptable level?
25. Is protection against a 1 in 1000 flood event at Glasdir achievable?

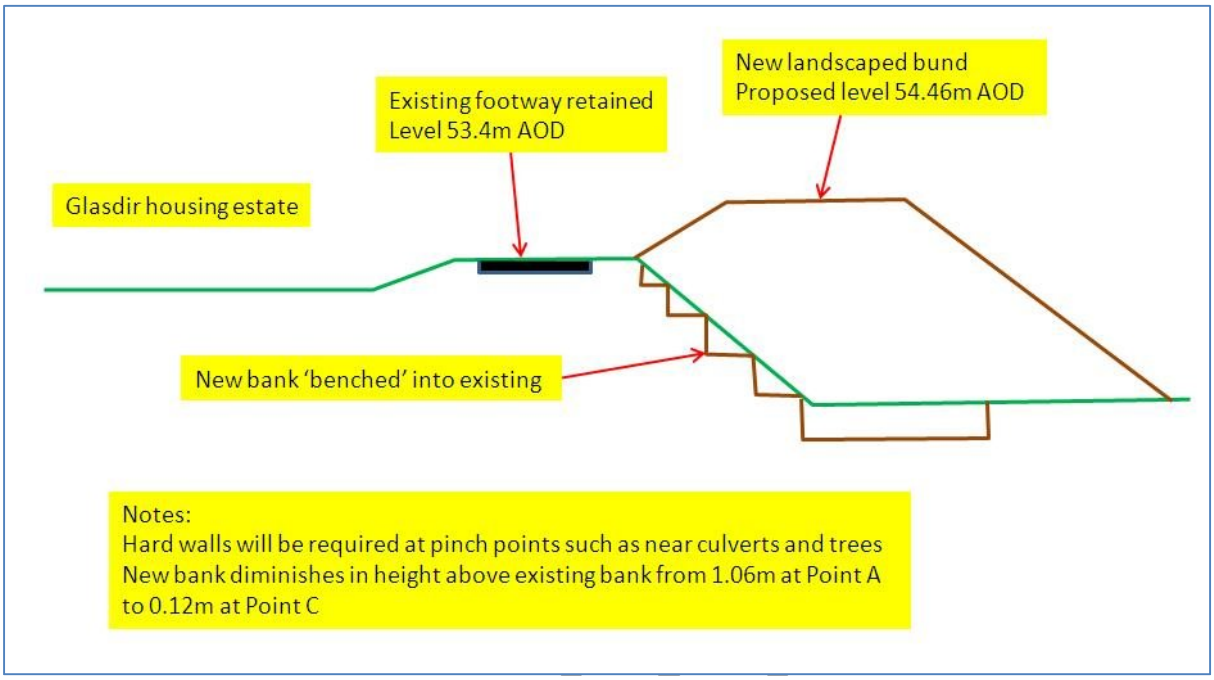
St Asaph/Rhuddlan issues

26. Did the tide contribute to flooding at St Asaph or Rhuddlan?
27. Did construction works at Foryd Harbour contribute to flooding at St Asaph or Rhuddlan?
28. Could anything more have been done to prevent overtopping of the defences at St Asaph?
29. Are defences/flood mitigation measures at both locations adequate to provide a reasonable level of protection from flooding?
30. Should additional measures be put in place at St Asaph or Rhuddlan?

Appendix 2: Glasdir Development, Ruthin – Relationship between main parties



Appendix 3: Outline of possible profile of the heightened bund



Appendix 4: Key Documents re Glasdir Flooding in November 2012

- 1999 Bullen Report (Afon Clwyd, Ruthin Flood Risk Assessment for EAW), May 1999
- Mwrog Street, Ruthin Flood Alleviation Scheme Project Appraisal and Cost benefit Study, Parsons Brinckerhoff for DCC, 2001
- Mwrog Street, Ruthin Flood Alleviation Scheme Project Appraisal and Cost benefit Study, Parsons Brinckerhoff for DCC, 2003
- Appraisal of Flooding at Ruthin Report, Black and Veatch for EAW, June 2003
- Arup Environmental Statement (Glasdir Northern Link Road) – Extract with references to drainage and flooding 13/8/2003
- Flooding Consequences Assessment, Glasdir, Ruthin, Veryards Opus/Weetwood Report for West Development Agency, May 2005
- Amended Flooding Consequences Assessment, Glasdir, Ruthin, Veryards Opus/Weetwood Report for Welsh Development Agency, September 2005 (Annotated by DCC in December 2012 to identify changes from May 2005 report)
- Letter from EAW to WDA concerning River Clwyd Flood Extents at Ruthin, 30/5/2006
- Letter from EAW to DCC concerning flood at Glasdir 26/9/2006
- Denbighshire Strategic Flood Consequence Assessment : March 2007, Final Report
- Planning and Consenting History Relating to the Glasdir Site (EAW document) 25/10/12
- EA Wales Report on the flooding at Glasdir, December 2012
- Interim Planning and Highways Report on Flooding Incident at Glasdir, Ruthin 2012
- Planning and Consenting History relating to Glasdir site, Ruthin 25/1/2013
- Report into the Planning History of Glasdir Residential Estate, Ruthin, March 2013

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