Stonehaven December 2012 Flood Event Review

Final

April 2013

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Revision History

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15 April 2013		Rachel Kennedy
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Contract

This report describes work commissioned by Willie Murdoch, on behalf of Aberdeenshire Council, by a letter dated 14 March 2013. Aberdeenshire Council's representative for the contract was Rachel Kennedy. Caroline Anderton, Mark McMillan and Nicola Buckley of JBA Consulting carried out this work.

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Purpose

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Acknowledgements

Thank you to Una Thom of SEPA for supplying updated hydrometric data for the local gauges.

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Executive Summary

Stonehaven experienced significant flooding on 23 December 2012. This report collates the information held on the flood and analyses the rainfall and flows recorded through the event and post flood survey data presented within photographs and videos. This will assist with the design of the Flood Protection Scheme (FPS).

The flood rose in the evening and peaked in the early hours of the morning of the 23 December. Severe disruption and damage was recorded. Flood waters emanated from the River Carron, the Glaslaw Burn and from overland flow of surface water from the Bervie Brae. A tree blocked part of the Green Bridge on the River Carron which raised water levels at a key location which contributed to the flooding. Temporary flood defences were deployed to some affect, however significant flooding occurred in the High Street Area with flood waters ponding to depths of over 1m. Flooding in the square is thought to have been reduced by the temporary defences. Although it has not been confirmed, approximately 50 properties are estimated to have suffered internal flooding.

The most recent hydrometric data has been supplied by SEPA and an updated hydrological analysis undertaken. The analysis undertaken within this report suggests that the flows experienced on the River Carron were lower in December 2012 (around 24m^3/s) than in November 2009 (around 37m^3/s); however flows on the Glaslaw Burn are believed to have been greater than experienced in 2009. Uncertainties with respect to hydrological estimates remain on the River Carron and are greater on the Glaslaw Burn as this watercourse is ungauged. It will be essential to incorporate these uncertainties into scheme designs through the careful consideration of freeboard, and to consider improvements in gauging. The flooding has identified that the extent of the flood wall on the Glaslaw Burn will need to be extended.

The extended flood record has improved flood estimates which are now in the region of 13% higher than those estimated in 2011.

The report identifies flows to be used in the design of the FPS once confirmed with SEPA and their sensitivity.

Recommendations include the gathering of more specific flood level data for the December 2012 event, the installation of a level logger on the Glaslaw Burn and channel maintenance.

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Abbreviations

AM.....	Annual Maximum
AMAX.....	Annual Maximum
AP	Annual Probability
DDF.....	Depth Duration Frequency
FEH.....	Flood Estimation Handbook
GL	General Logistic Distribution
mAOD	metres Above Ordnance Datum
NRFA	National River Flow Archive
POT.....	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
SEPA	Scottish Environment Protection Agency
WINFAP-FEH	Windows Frequency Analysis Package - FEH version

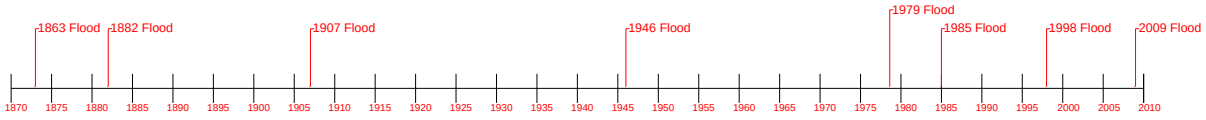
1 Introduction

1.1 Background

This report was commissioned by Aberdeenshire Council as part of the Stonehaven (River Carron and Glaslaw Burn) Flood Protection Scheme. The scheme has been highlighted as a necessity by the flooding that occurred in December 2012. In tense rainfall over an already saturated catchment was the cause of high flows in the River Carron and Glaslaw Burn which overtopped both banks in the early hours of December 2012. Flooding in Stonehaven was contributed to by overland flow of surface water from the Bervie Brae which led to significant flood depths around the High Street and Arbuthnott Place.

Previously, in November 2009, Stonehaven flooded extensively and an estimated 50 people were evacuated with many homes and businesses damaged and interrupted during the flood and subsequent restoration. Following this flood event JBA Consulting were commissioned by Aberdeenshire Council to undertake first a capacity assessment of the River Carron and then a flood alleviation feasibility assessment which was completed in July 2012[1]. These investigations showed the town is potentially vulnerable to flooding from the Rivers Carron and Cowie as well as coastal flooding, surface water and overland flow. JBA's feasibility study focused on assessing options for alleviating the risk associated with the Carron and Glaslaw Burn. In 2009 flood water left the Carron around the Green Bridge flooding Low Wood Road, Carron Terrace, and flowing north east and west to flood Cameron Street, the area around the Market Square, the High Street and Old Town. Review of historical records shows that the Carron has been reported as running high and caused significant flooding in 1998, 1985, 1979, 1946, 1907, 1882 and 1873; (see Section 4).

Figure 1-1: Historical Flooding Timeline



A 1D hydraulic model was constructed in Infoworks-RS to carry out the channel capacity study. This was then used as the base of a 1D-2D hydraulic model used to generate potential options to alleviate flooding in Stonehaven. The hydraulic model was calibrated against the 2009 record data and shows that water first leaves the River Carron upstream of the Green Bridge at flows in the region of 22 m^3/s. The capacity of the Glaslaw Burn was estimated to be in the order of 4 m^3/s. It is noted that all modelling to date has not included any presence of debris blockages within the watercourses which can significantly reduce the estimated channel capacity.

Following the flood event in December 2012 it is important to understand the nature and scale of the flooding in relation to previous floods. The findings of this study will be used to verify and improve the knowledge of the hydrology in the River Carron and the Glaslaw Burn and verify observed hydraulic conditions against modelled conditions. There are limited post flood surveyed points as the flood debris was cleared in the run up to Christmas but some levels can be inferred from photographs and video footage.

1.2 Report approach

The objectives of this report will be achieved by:

- Undertaking a site walkover survey with Aberdeenshire Council to collect post flood evidence.
- Update the hydrological analysis based on the most up to date hydrometric data from SEPA.
- Discuss flood mechanisms for the event. Consider and review how this compares with the November 2009 event.
- Update the historical record for the River Carron and compare with hydrological analysis.

[1] JBA Consulting (2012) Stonehaven River Carron Flood Alleviation Study, Final Report July 2012

- Consider the impact on the previous model, by reviewing the model.
- Calibrate against flood records and levels where possible.
- Consider the requirement for further hydrometric monitoring within the catchment (i.e. rain gauge, level logger on the Glaslaw Burn).

This report will be issued to SEPA (Malcolm MacConnachie and Una Thom) to open discussion and work to agreeing the updated hydrology.

This report will be used to inform stakeholders and the design of the Flood Protection Scheme.

2 Post Flood Data

2.1 Discussion of the December 2012 event

Flooding in December 2013 was recorded through lower Stonehaven close to the River Carron and Glaslaw Burn. Review of the photographs, wrack marks and discussion with council officers and residents has help form an understanding of the flood event.

Flood water is known to have left the River Carron upstream of the Green Bridge on both banks. Water levels at this critical point were exacerbated by the Green Bridge being partially blocked by a tree. The flood water waters were partially contained by temporary flood barriers however video evidence showed that these barriers were unable to fully prevent flows from bypassing them. It was also reported that the flood barriers on Cameron Terrace were moved during the event which allowed flood waters to escape.

Significant flows in the Glaslaw Burn overtopped the channel banks upstream of the Woodview Court to Dunnottar Avenue and from there to the High Street. Water also was reported to have flowed from the Bervie Brae and all along the A957 and onto Dunnottar Avenue and thence the High Street where flood depths of up to 1m were reported. Surface Water was partially prevented from entering the drainage network, where there was capacity, due to the build up of sediments blocking the road gullies.

Inspection of the Glaslaw Burn Catchment shows that there were significant flows in the Burn and also flowing overland. Agriculture drains upstream of the Breahead development were overwhelmed and water flowed overland and down roads and tracks.

Initial assessment suggests that there was a significant flood on the River Carron combined with intense rainfall leading to significant flows in the Glaslaw Burn and significant overland flow from the Bervie Braes. The impact of the flood event can be seen in figures 2-1 to 2-8.

Figure 2-1: Flooding High Street[2]

[2] http://local.stv.tv/stonehaven/galleries/stonehaven-flood-2012/39002/

Figure 2-2: Flooding High Street[3]

Figure 2-3: Flooding High Street[4]

Figure 2-4: Flooding A957 Bridgefield[5]

[3] http://local.stv.tv/stonehaven/galleries/stonehaven-flood-2012/39000/
[4] http://local.stv.tv/stonehaven/galleries/stonehaven-flood-2012/38999/
[5] http://www.bbc.co.uk/news/uk-20830740

Figure 2-5: River Carron Looking at the Downstream Soffit of Bridgefield Bridge[6]

Figure 2-6: River Carron Looking Upstream from Bridgefield Bridge[7]

[6] http://news.stv.tv/galleries/stonehaven-flood-2012/
[7] http://news.stv.tv/galleries/stonehaven-flood-2012/38989/

Figure 2-7: Flooding Arbuthnott Court[8]

Figure 2-8: Water Flowing off fields upstream of SEPA's Fetteresso gauge

[8] http://local.stv.tv/stonehaven/galleries/stonehaven-flood-2012/39049/

3 Hydrological Analysis

The NFRA Monthly Hydrological Summary shows that much of the UK experienced a wet year in 2012 although the north and west of Scotland received lower than average rainfall. Parts of Aberdeenshire experienced over 200% of the average during December (Figure 3-1). River flows within the east of Scotland (including the River Dee) were recorded as exceptional for this period (Figure 3-2).

Figure 3-1: NRFA Monthly Hydrological Summary December 2012 - Rainfall

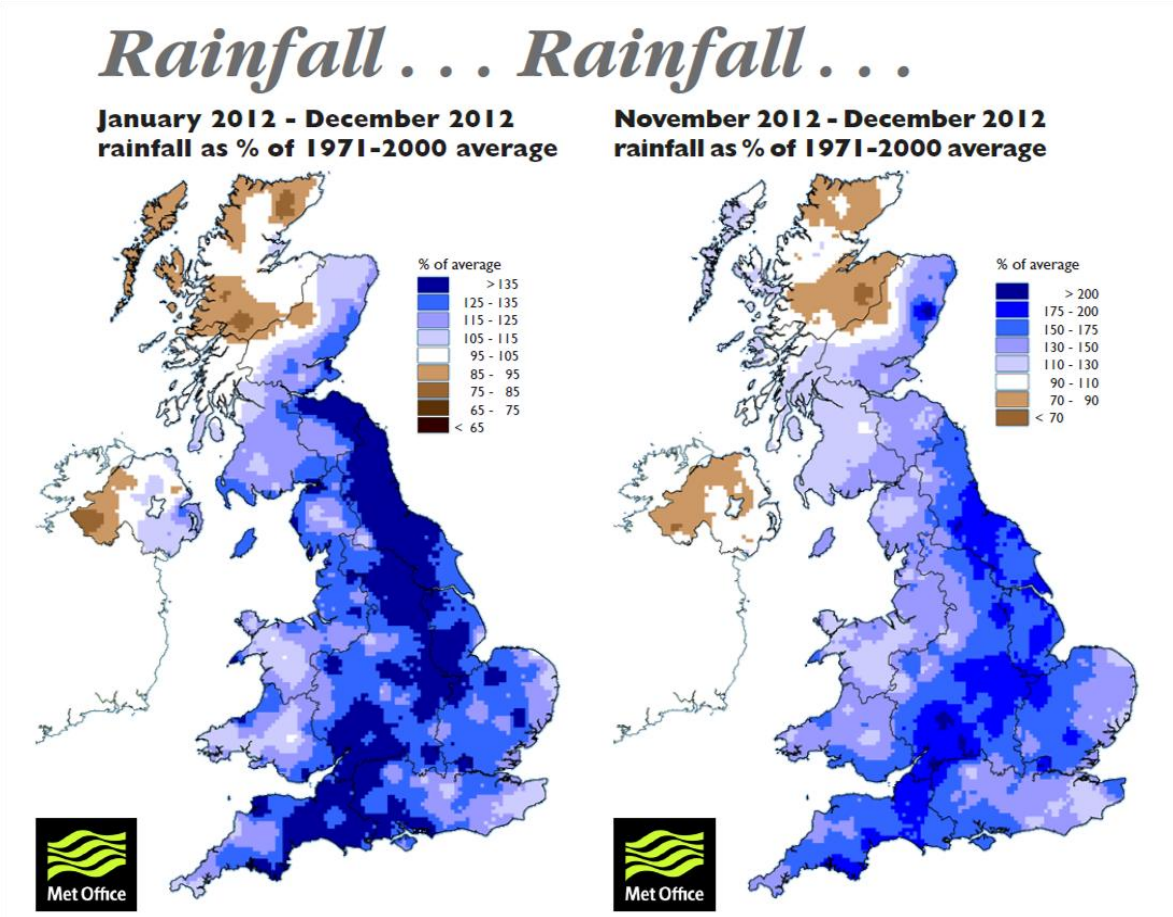
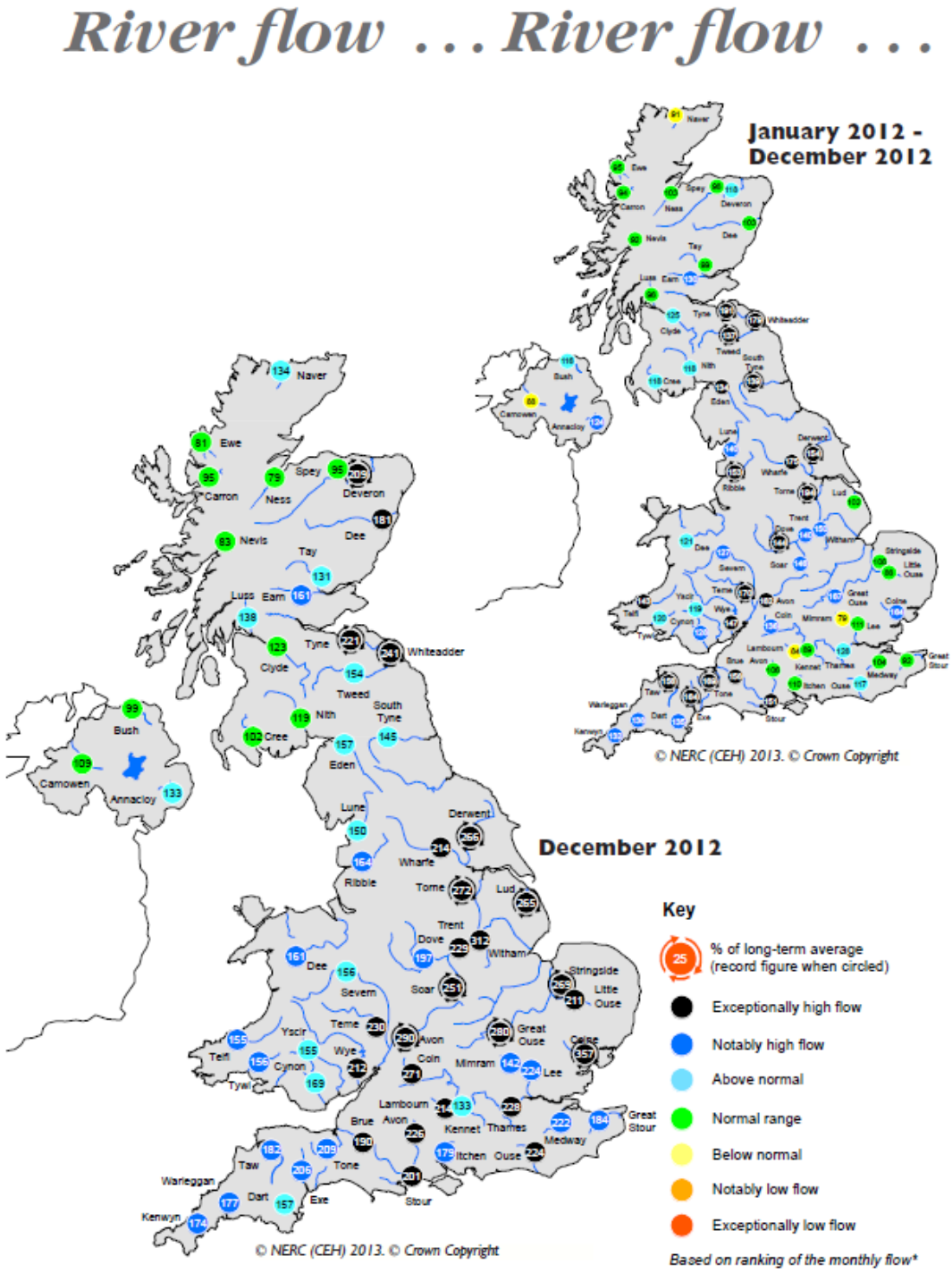


Figure 3-2: NRFA Monthly Hydrological Summary December 2012 - River Flow



3.1 Recorded Data

SEPA maintains a number of hydrometric gauges (see Figure 3-3), collecting rainfall and river data, across the north east of Scotland. Two river level gauges are located within the Carron, one at Bridge of Fetteresso and the second immediately downstream of the Red Bridge. Aberdeenshire Council also maintain a level logger at the Green Bridge which was installed following the flooding experienced in November 2009. There are two SEPA rain gauges located to the north of the Carron catchment at Mongour and Cheyne.

Figure 3-3: SEPA hydrometric Data Locations

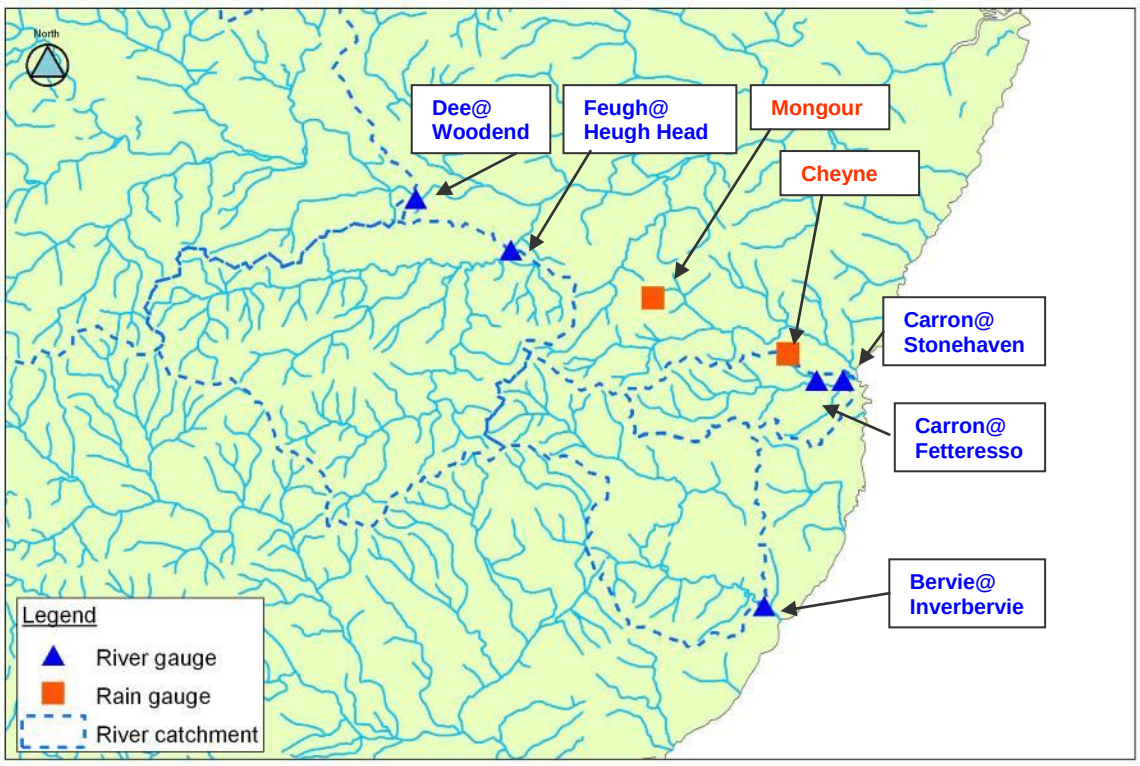


Table 3-1: Hydrometric Data Maintained by SEPA

Gauge name	Gauge ref	Gauge type	Period of record
Carron at Stonehaven	13030	River level / flow	March 2003 - to date
Carron at Fetteresso	-	River level	July 2010 - to date
Bervie at Inverbervie	13001	River level / flow	August 1979 - to date
Feugh at Heugh Head	12008	River level / flow	1985 - to date
Dee at Woodend	12001	River level / flow	1930 - to date
Cheyne	-	Recording rain gauge	April 2005 - to date
Mongour	-	Recording rain gauge	October 1995 - to date

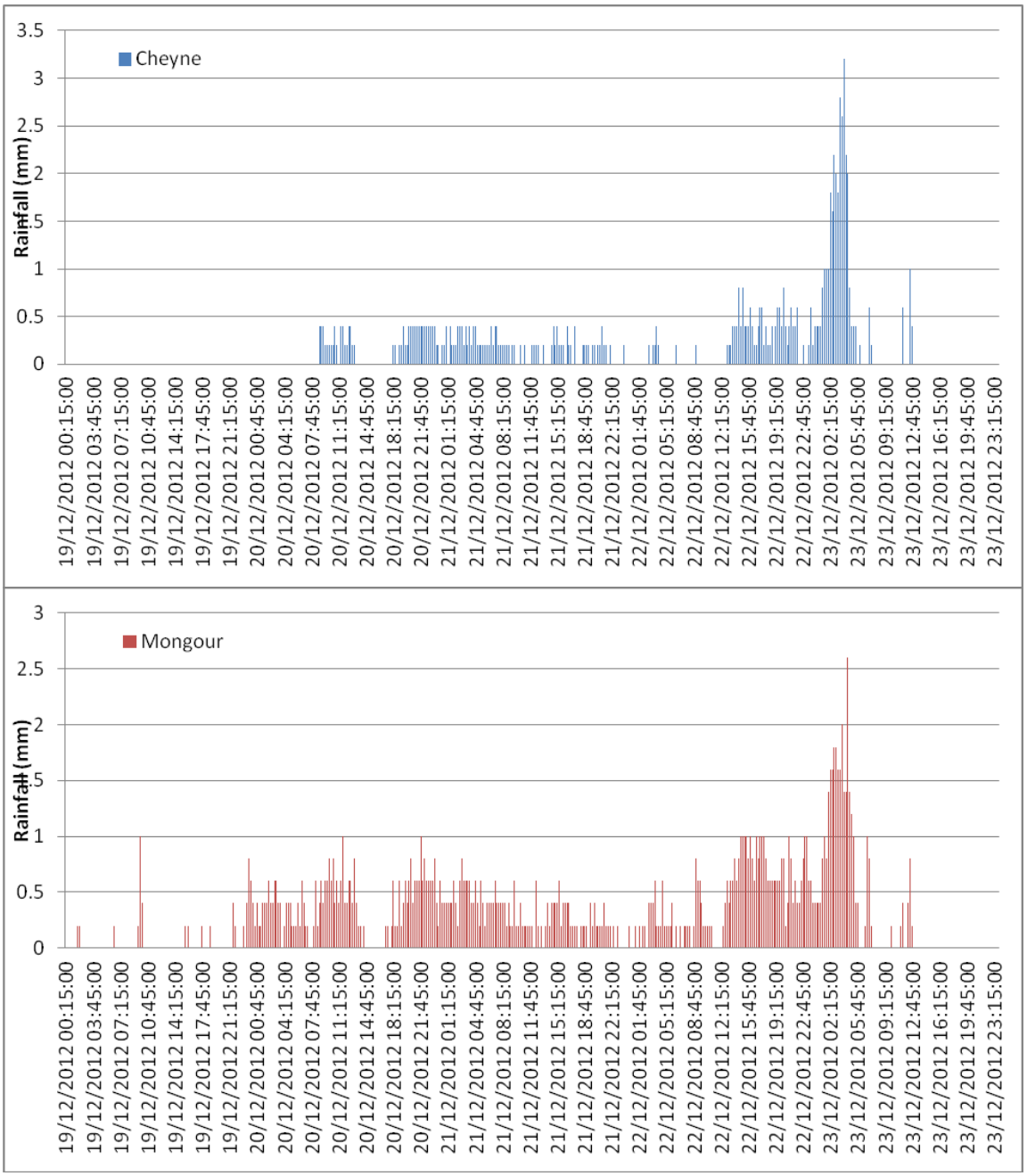
3.1.1 SEPA Rainfall Data

The 15 minute rainfall data recorded at the Mongour and Cheyne rainfall gauges for the period from 19 December 2012 can be seen in Figure 3-4. This data highlights that the Stonehaven area experienced several days of constant rainfall leading up to the flood event on the 23 December 2012. It can also be seen that rainfall depths increased on the 22 December and peaking on the 23 December falling on an already saturated catchment.

A total of 141.2 mm of rainfall was recorded at the Mongour rainfall gauge (located at 315 mAOD) over the period from 19 December 2012 @ 21:45 to 23 December 2012 @ 07:30 (a total of 82 hours), using the Depth Duration Frequency (DDF) model within the FEH CD ROM v3, this total depth of rainfall has an estimated event rarity of 41 years. On 23 December 2013 a total of 65.8 mm was recorded, this total depth of rainfall has an estimated event rarity of 16 years for the 24 hour period.

Rainfall recorded at the Cheyne gauge (located at 146 mAOD) was less significant, with 73 mm of rainfall recorded from 20 December 2012 @ 18:15:00 to 23 December 2012 @ 07:30 (a total of 61 hours), estimated to have a return period of 3 years. On 23 December 2013 a total of 47.2 mm was recorded, this total depth of rainfall has an estimated event rarity of 3.4 years for the 24 hour period.

Figure 3-4: 15 minute rainfall Cheyne and Mongour SEPA rainfall gauges



Daily rainfall totals (where a daily total is taken each day at 09:00 hrs) have also been extracted for the month of December 2012 for both rainfall gauges and can be seen in Figure 3- and Table 3-8.

Figure 3-5: Rainfall Data December 2012

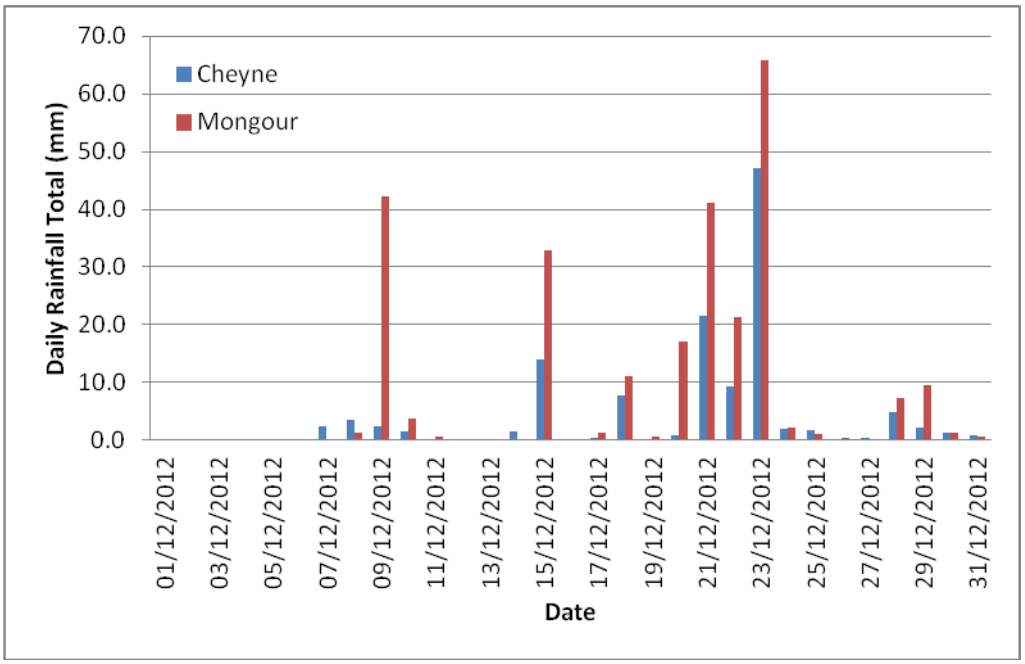


Table 3-2: Daily Rainfall Totals for December 2012(mm)

	Daily Precipitation totals [mm]			Daily Precipitation totals [mm]	
Date	**Cheyne**	**Mongour**	**Date**	**Cheyne**	**Mongour**
01/12/2012	0.0	0	17/12/2012	0.4	1.4
02/12/2012	0.0	0	18/12/2012	7.8	11.0
03/12/2012	0.0	0	19/12/2012	0.0	0.6
04/12/2012	0.0	0	20/12/2012	0.8	17.0
05/12/2012	0.0	0	21/12/2012	21.6	41.2
06/12/2012	0.0	0	22/12/2012	9.4	21.4
07/12/2012	2.4	0	23/12/2012	47.2	65.8
08/12/2012	3.6	1.4	24/12/2012	2.0	2.2
09/12/2012	2.4	42.2	25/12/2012	1.8	1.0
10/12/2012	1.6	3.8	26/12/2012	0.2	0.4
11/12/2012	0.0	0.6	27/12/2012	0.4	0
12/12/2012	0.0	0.2	28/12/2012	4.8	7.4
13/12/2012	0.0	0	29/12/2012	2.2	9.6
14/12/2012	1.6	0	30/12/2012	1.2	1.4
15/12/2012	14.0	32.8	31/12/2012	0.8	0.6

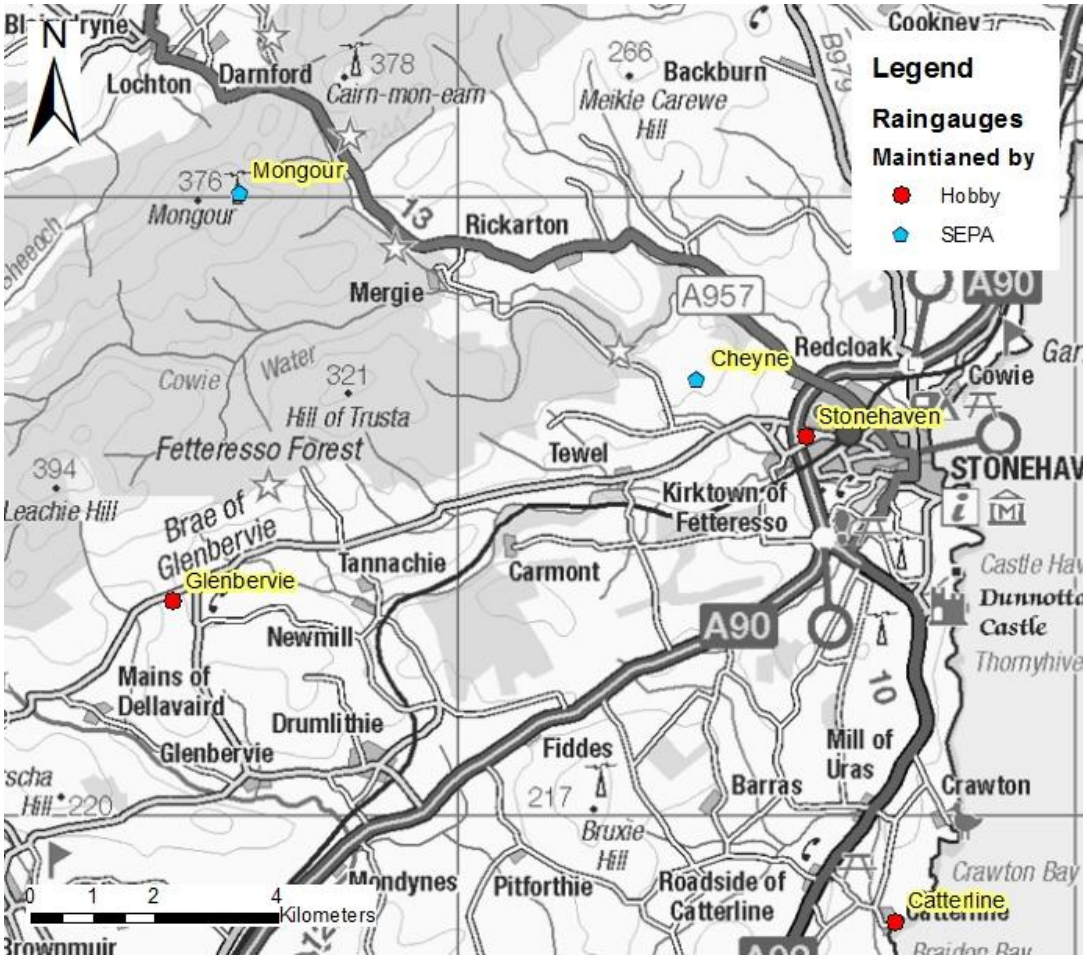
3.1.2 Other Rainfall Data

In additional to SEPA, rainfall data can be collected by Local rainfall collectors, Local Authorities, Private Companies and other Governmental Bodies. An internet search identified the following three gauges.

Table 3-3: Local rainfall collector gauges

Name / Location	Grid Reference	Rainfall Total 23 December 2012 (mm)	Maintained By	Estimated Return Period
Glenbervie	NO 75364 83423	unknown	Hobby[18]	
Catterline	NO 87052 78355	unknown	Hobby[20]	
Stonehaven	NO 85627 86111	47.5	Hobby[22]	2.5 years

Figure 3-6: Rainfall Collected by Local collectors



The daily rainfall totals collected at the Stonehaven gauge are very similar to those collected at SEPA's Cheyne rainfall gauge. On 23 December 2013 a total of 47.5 mm was recorded, this total depth of rainfall has an estimated event rarity of 2.5 years for the 24 hour period. A total of 99mm was recorded between 19 and 23 December, this total depth of rainfall has an estimated event rarity of 11.6 years for the 96 hour period.

18 http://www.glenbervie-weather.org/
20 http://www.pedrox.com/weather/weather.htm
22http://www.wunderground.com/weatherstation/WXDailyHistory.asp?ID=IABERDEE33&graphspan=day&month=12&day=1&year=2012

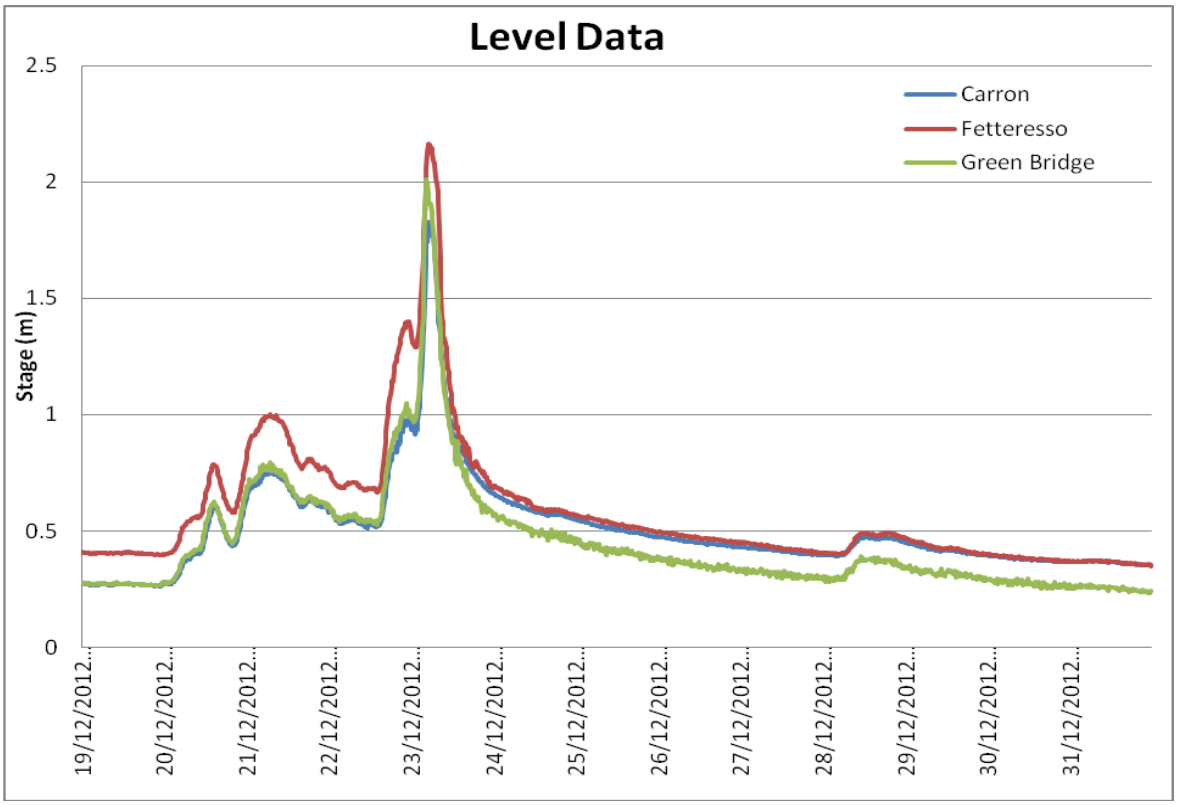
Table 3-4: Local rainfall collector data at Stonehaven compared with Cheyne

Daily Precipitation totals [mm]		
Date	**Cheyne**	**Stonehaven**
14/12/2012	1.6	15.7
15/12/2012	14.0	2.3
16/12/2012	0.2	2.3
17/12/2012	0.4	6.1
18/12/2012	7.8	0
19/12/2012	0.0	4.3
20/12/2012	0.8	18.8
21/12/2012	21.6	17
22/12/2012	9.4	15.7
23/12/2012	47.2	47.5
24/12/2012	2.0	2

3.1.3 Level Data

Figure 3- below shows the stage recorded at the Fetteresso, Carron and Green Bridge gauges. Water levels in the Carron Water started to rise on 20 December reaching their peak between 04:00hrs and 06:00hrs on 23 December. Between 16:00hrs on 22 December 2012 and the peak at the Carron gauge the water levels in the river rose by 1.23m. It can be seen from Figure 3-7 that the three gauges show peak water levels occurring within a short time period.

Figure 3-7: Level Data December 2012



3.2 Updated Statistical Analysis - Derivation of Design flows

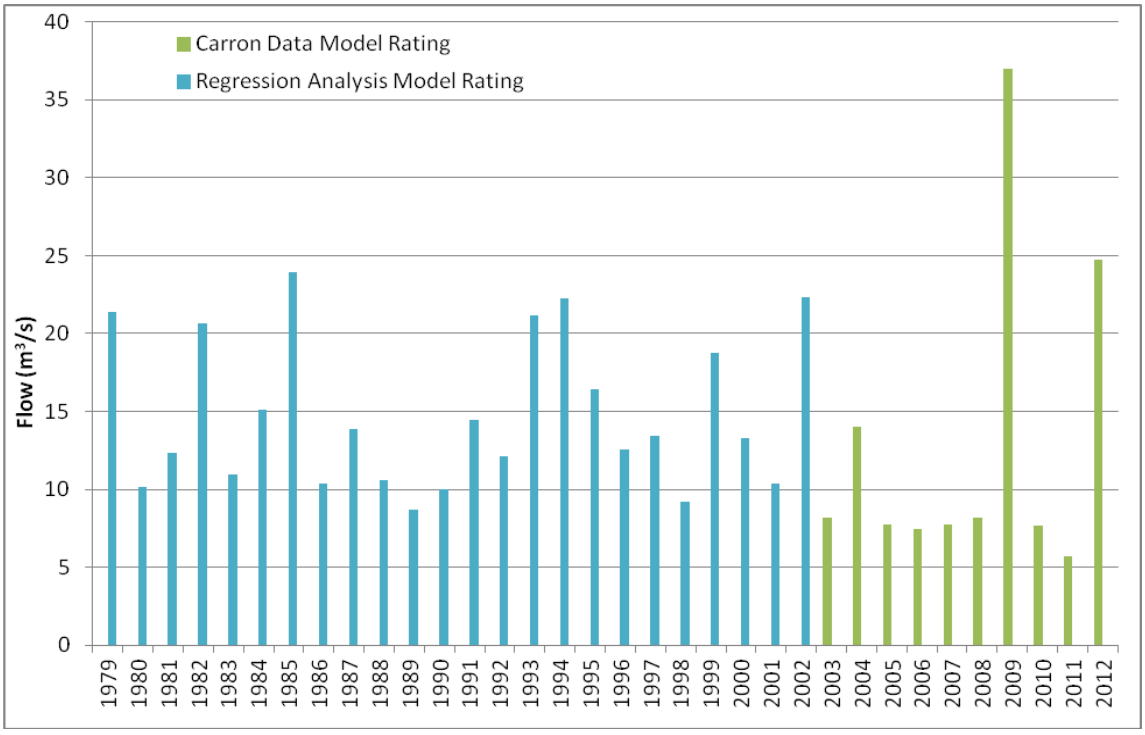
Full details of hydrological analysis are detailed within JBA's Stonehaven River Carron Flood Alleviation Study report dated July 2012. This present analysis undertook to update the Annual Maximum (AMAX) flow series used to derive the design flows and hence update the hydrological analysis.

Updated data for the Carron gauge was obtained from SEPA resulting in 3 years of data being added to the AMAX series used previously and this includes the event in Dec 2012.

In line with previous analysis, four different data series have been derived:

- POT data series using gauged data only for the Carron gauge recorded between 2003 to 2013:
    i. Using the SEPA rating to convert level to flow.
    ii. Using the Model rating to convert level to flow.
- AMAX series extended back to 1979 using regression analysis between the River Carron and the Bervie:
    iii. Using the SEPA rating to convert level to flow.
    iv. Using the Model rating to convert level to flow.

Figure 3-8: AMAX Series - Gauges data and Regression



The four data series and the resulting estimates of the index flood (QMED) are shown within Table 3-5.

Table 3-5: QMED's calculated using Each Data series

Data series derived to estimate QMED	Resulting QMED (m3/s)
(i) Carron gauge data using SEPA rating (from POT data)	17.7
(ii) Carron gauge data using model rating (from POT data)	8.3
(iii) Carron gauge data plus regression analysis on Bervie gauge using SEPA rating	20.8
(iv) Carron gauge data plus regression analysis on Bervie gauge using model rating	14.5

As per JBA's previous analysis the data series used to calculate the design flows is that of the regression analysis and model rating data series (iv within Table 3-5). Growth curves have been derived within WINFAP-FEH v3 using enhanced pooling analysis and fitting the Generalised Logistic (GL) statistical distribution.

However for comparison peak flows derived using each data series are shown in Table 3-6.

Table 3-6: Peak Flow Estimates Derived for Each Data Series

Annual probability	Return period (years)	SEPA Data Only (m3/s)	SEPA with regression (m3/s)	Model Rating Only (m3/s)	Model Rating with regression - (m3/s)
50%	2	17.7	20.8	8.3	**14.5**
20%	5	27.3	30.3	12.4	**20.5**
10%	10	34.4	37.3	15.5	**24.9**
4%	25	44.7	47.8	19.9	**31.3**
2%	50	53.7	57.0	23.8	**36.9**
1.33%	75	59.6	63.0	26.4	**40.4**
1%	100	64.1	67.6	28.3	**43.2**
0.5%	200	76.0	80.0	33.5	**50.4**
0.1%	1000	111.3	117.2	48.8	**71.8**

Table 3-7 below shows the corresponding model stage against the predicted peak flows at the Carron gauge.

Table 3-7: Specific Stage Exceedance

Annual probability	Return period (years)	River Carron peak flow (m3/s)	Stage based on model rating (without log weir)	No of times exceeded in 10 year Carron record
50%	2	14.5	1.37	4
20%	5	20.5	1.68	2
10%	10	24.9	1.83	1
4%	25	31.3		
2%	50	36.9		
1.33%	75	40.4		
1%	100	43.2		
0.5%	200	50.4		
0.1%	1000	71.8		

3.3 Comparison with design flows used previously

The hydrological analysis detailed above results in an average increase in peak flows of 13% compared to those estimated in 2011.

Table 3-8: Design Flows Calculated 2011 and 2013

Annual probability	Return period (years)	River Carron peak flow 2011 (m3/s)	River Carron peak flow 2013 (m3/s)
50%	2	12.7	14.5
20%	5	17.9	20.5
10%	10	21.8	24.9
4%	25	27.5	31.3
2%	50	32.6	36.9
1.33%	75	35.9	40.4
1%	100	38.4	43.2
0.5%	200	45.1	50.4
0.1%	1000	65.3	71.8
Note: Flows calculated using model rating and AMAX data series derived using regression analysis with the Bervie, enhanced pooling.			

3.3.1 QMED uncertainty

There are inherent uncertainties within flood estimation (including data quality and length of record), in order to assess this uncertainty the upper and lower 95% confidence limits have been estimated using the confidence intervals defined within the FEH Volume 3 Table 13.10 for a record length of 15 years or more and AM method of deriving QMED using an upper limit of 0.813 and a lower limit of 1.23. The resulting peak flows are shown in Table 3-9 below.

Table 3-9: QMED 95% Confidence limits

	River Carron peak flow - Best Estimate 2013 (m3/s)	Lower 95% confidence	Upper 95% confidence
QMED	14.5	11.8	17.8
5	20.5	16.7	25.2
10	24.9	20.2	30.6
25	31.3	25.4	38.5
50	36.9	30.0	45.3
75	40.4	32.9	49.8
100	43.2	35.1	53.1
200	50.4	41.0	62.0
1000	71.8	58.4	88.3

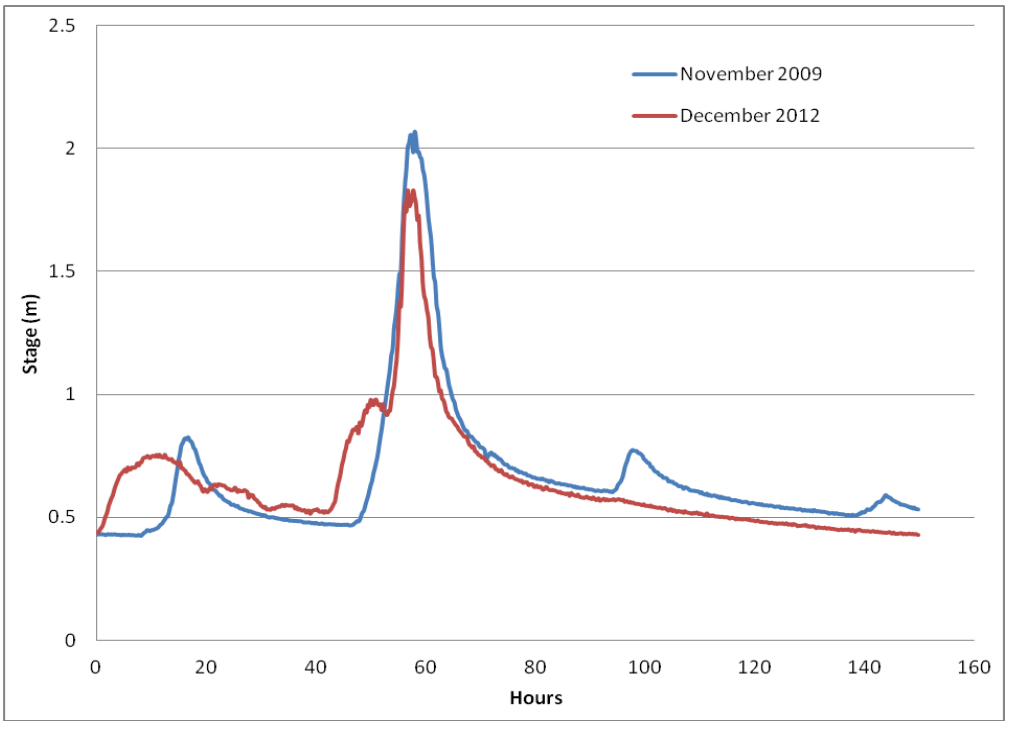
3.4 Discussion of rarity of the Dec 2012 event

The analysis detailed in Section 3.2 suggests that the existing channel capacity (22 m^3/s) equates to a 5 year return period, with the December 2012 event (estimated to be 24 m^3/s using the model rating) equating to a 10 year event. The November 2009 event of 37 m^3/s equates to a 50 year return period (2% AP).

3.5 Context with the Nov 2009 event

When plotting the levels versus time of the November 2009 and December 2012 events centred on the peak, it can be seen in Figure 3- that the rate of rise for both events was very similar. When considering the hydrographs of both events, although the 2009 event had a peak flow which was approximately 34% greater than that of the 2012 event, the difference in total volume was only about 11% (1157786m^3 and1023390m^3).

Figure 3-9: November 2009 and December 2012 recorded stage



When considering the available data for the River Carron only for the November 2009 and December 2012 events it can be seen that the stage recorded at the SEPA Carron gauge was 0.23 m higher in November 2009 (Table 3-10). During both events it is noted that significant debris was caught on the Green Bridge (Figure 3-). Anecdotal evidence suggests that water levels were significantly higher in the Glaslaw Burn in December 2012.

Figure 3-10: Tree Trapped on Green Bridge December 2012

Table 3-10: Comparison of Dec 2012 & Nov 2009 levels on the Carron

Gauge	Gauge zero (mAOD)	December Max Stage (m)	November 2009 Max (m)	Bank Full Stage (m)
Carron @ Fetteresso		2.16	No data	
Carron @ Stonehaven		1.83	2.06	2.07
Carron @ Green Bridge	6.34	2.01	No data	1.66

Table 3-11: Estimated flows at the Carron gauge for recent events using model rating

Max Stage Recorded at Carron Gauge (m)	Date	Estimated Flow using model rating
2.07	November 2009	37
1.83	December 2012	24
1.45	October 2012	14

Flooding in November 2009 was seen as impacting the left bank more than in December 2012. In December 2012 there was deemed to be more flooding on the right bank. It is thought this is due to a combination of:

- Blockage at the Green Bridge.
- Higher flows in the Glaslaw Burn and overflow into the High Street.
- Runoff and overland flow from Bervie Braes.
- Flows largely retained within bank on Carron Terrace on the left bank by demountable defences.

3.6 Glaslaw Burn

During the flood event of December 2012 in Stonehaven, the Glaslaw Burn was noted to have overtopped its banks and inundate areas such as Carron Gardens and Woodview Court. It was apparent that water flowed through Woodview Court and into Dunnottar Avenue.

There are no flow gauges on the Glaslaw Burn or rain gauges within the Glaslaw catchment. The flow in burn during the December 2012 event can only be estimated from observations made during the event and through the evidence of wrack marks left behind after the flood. The hydraulic model has been used to estimate the flow in the Glaslaw Burn during the event by analysing flow level data at critical sections.

A site walkover assessment of the burn following the flood event showed evidence of high flows in the burn as shown is Figures 3-12 and 3-13. Figure 3-11 shows the locations of the sections of the Glaslaw Burn used in the hydraulic model.

Figure 3-11: Glaslaw Burn Model Sections

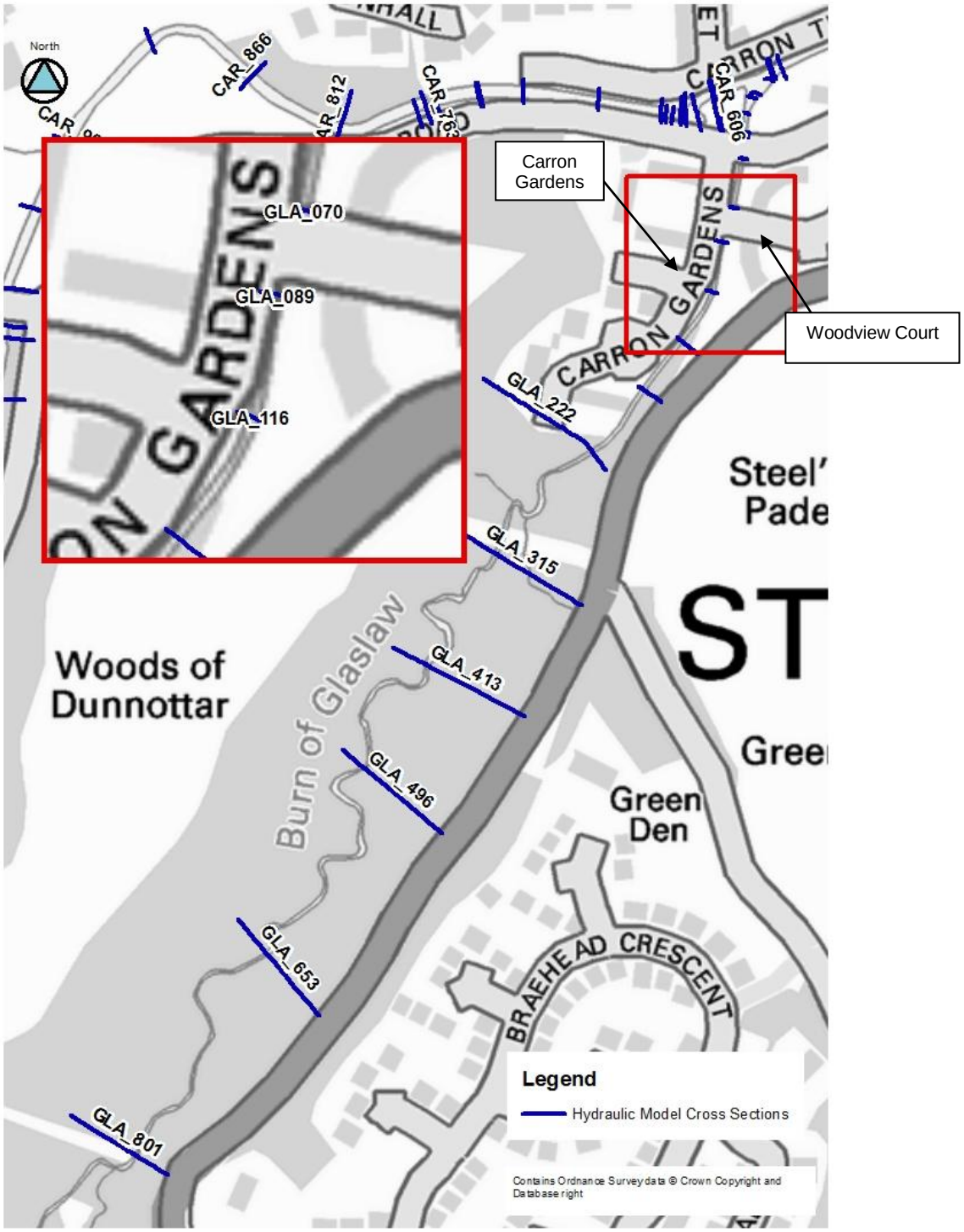


Figure 3-12: Large gravel deposits in active floodplain of the Glaslaw Burn. (section GLA_653)

Figure 3-13 Wrack marks on fencing upstream of Woodview Court. (section GLA_179)

Reports of the flooding from the Glaslaw Burn indicated that water left the channel upstream of Carron Gardens (approximately at section GLA_222) on the left bank and flowed through Carron Gardens. Water also left the channel upstream of the culvert between sections GLA_089 and GLA_070 and flowed into Woodview Court. Additionally water left the burn on both banks downstream of section GLA_070. Table 3-12 indicates the required flow to replicate these observations.

Table 3-12: Flow Estimation in Glaslaw Burn for December 2012 event

Observation	Adjacent Bank Level (mAOD)	Required Flow (m^3/s)	Comment
Overtopping left bank at section GLA_222	11.15	05.94	Estimated from hydraulic model
Overtopping right bank at section GLA_089	08.50	08.24	Does not take into account likely blockage of culvert immediately downstream of section
Overtopping of both banks downstream of section GLA_070	08.20	06.96	Estimated from hydraulic model

Table 3-12 indicates the flow required for the Glaslaw Burn to overtop its banks upstream of the culvert at Woodview Court would require a flow of approximately 8.24 m^3/s. However, given the nature of the catchment and size of the culvert, it has a high risk of blockage during a flood event. There is no evidence that the culvert became blocked or partially restricted during the flood event but it is considered a likely scenario. The hydraulic model does not account for this as an assumed blockage cannot be accurately quantified. If a blockage occurred it is likely that the flow in the burn required to overtop its banks at this section would be between 6 and 7m^3/s. Based on the hydrological analysis conducted after the 2009 flood, these flows would represent a flood event with a return period of between 200 years and 1000 years (0.5% and 0.1% AP respectively).

The severity of the event on the River Carron was estimated to be between 10 years and 20 years (10% AP and 5% AP). The closest rain gauges did not record rainfall that would lead to an extreme event such as this. However, the Glaslaw Burn has a relatively small catchment and it is possible that a localised extreme event could have occurred within the catchment. Considering that the limited recorded data of the flood event does not indicate that a flood event of this severity occurred; the hydrology of the Glaslaw Burn has been reviewed.

3.6.1 Hydrological Analysis of Glaslaw Burn

The previous flows for the Glaslaw Burn were estimated using the FEH Statistical method using the River Carron gauge as a donor. A value for QMED was calculated for the Glaslaw Burn and the adjustment factor derived from the Carron Gauge was used to give a better estimation of QMED. The growth curve for the Carron was then applied to upscale the flows to the design events. This was deemed the most appropriate method as it is best practice to utilise all recorded data available.

Peak flows have also been estimated using the FEH Rainfall Runoff methodology which is also deemed appropriate based on the size and nature of the catchment. The FEH Rainfall Runoff method combines design rainfall with a unit hydrograph for the subject site.

The catchment descriptors used for the analysis are shown in Table 3-12.

Table 3-12: Glaslaw Burn Catchment Descriptors

Parameter	Value
AREA (km2)	5.69
FARL	1
PROPWET	0.37
ALTBAR	104
BFIHOST	0.585
DPLBAR	3.46
SPRHOST (%)	40.81

The results from the previous analysis are compared with those derived using the FEH Rainfall Runoff methodology in Table 3-13.

Table 3-13: Comparison of Peak Flows in the Glaslaw Burn

Annual Probability (%)	Return Period (years)	Statistical Method Flow (m^3/s)	FEH-Rainfall Runoff Flow (m^3/s)
50	2	1.5	2.5
20	5	2.2	3.4
10	10	2.7	4.2
4	25	3.4	4.6
2	50	4.1	6.2
1.33	75	4.6	6.7
1	100	5.0	7.1
0.5	200	5.9	8.2
0.1	1000	9.0	11.7

Both methodologies are considered appropriate and highlight the inherent uncertainties in estimating peak flows for extreme flood events, particularly when there is little available data for the subject watercourse. In light of observed flooding from the Glaslaw Burn during the December 2012 flood event the peaks flows produced by the FEH Rainfall Runoff method will be adopted for this study.

From the analysis of the hydraulic model and observations made during and after the December 2012 flood event it is considered that the flow in Glaslaw Burn exceeded 5.7 m^3/s (this would equate to between a 25 year and 50 year return period (4% and 2% AP).This is based on flow required for the burn to overtop its banks around Carron Gardens and Woodview Court. However, given scale of observed flooding it is likely that the flow could have been higher still. Unfortunately there is insufficient data to predict the exact flow in Glaslaw Burn.

4 Historical Flood Review

Previous modelling suggests that the lowest channel capacity is that of the channel immediately upstream of the Green Bridge, with a capacity of c. 22 m^3/s. The Glaslaw Burn was estimated as having a capacity of c. 4 m^3/s.

A review of historical archives undertaken for the feasibility study and updated for this report shows that flooding has occurred from the River Carron on a number of occasions in the search period from 1829.

When reviewing the historical flood record it is also important to understand that the geometry of the river channel has changed over the years, including the following works within the Green Bridge area alone:

- Filling in of Mill Lade and Mill Pond.
- Scottish water sewer constructed early 1970s and shortening of the weir.
- “Fish Pass” weir constructed in March / April – 2002.
- “Fish Pass” weir remedial works carried out July 2003 – following Oct/Nov 2002 floods.
- Log weir removed 2010.

Table 4-1: Updated Historical Flood Review

Date	Brief description	Source
08/1829	In Stonehaven the houses in Cameron Street, Arbuthnot Street, Ann Street, and part of Barclay Street were inundated to the depth of many feet. Many of the inhabitants only received the first intimation of their perilous situation by the water coming in contact with their warm beds. Two wooden bridges over the Carron were swept down the stream.	Aberdeen Journal, 12th August 1829
11/1873	The Scotsman reported that "The easterly gales and heavy rains of the last two days have flooded many of the rivers... [In] Stonehaven, and other places, houses have been flooded to considerable depth"	The Scotsman, 8th November 1873. Article 5 [no title]. www.proquest.com (accessed 12 July 2011).
12/1882	A report in the Scotsman described a sudden and rapid thaw of snowmelt causing a number of rivers across	The Scotsman, 18th December 1882. Editorial

Date	Brief description	Source
	Scotland to be in spate, the result of which was that "Many houses in Stonehaven have... been flooded to a depth of two or three feet". Historical reports have suggested that the Carron is more likely to cause flooding to property than the Cowie. This report suggests a considerable amount of damage to property resulted.	Article 1 [no title]. www.proquest.com (accessed 12 July 2011).
11/1905	"the rivers Cowie and Carron were in high flood, carrying with them limbs of trees and occasionally poultry".	The Mearns Leader, 16th November 1905
10/1906	The Mearns Leader described "A heavy storm of wind and rain, accompanied by a gale at sea, occurred at Stonehaven... The rain fell incessantly... and as a consequence some of the houses at the top of High Street and Arbuthnott Place were flooded. The rivers Cowie and Carron were in spate". This implies that it was surface water flooding that caused property damage.	The Mearns Leader, 25th October 1906. 'Sea inroads', www.mearnsleader.co.uk (accessed 12 July 2011).
06/1907	Carron in spate? "The abnormally wet weather of the past week or so is the one theme of discussion at present. One can scarcely image that this is the merry month of June. It is a long time since there was such rain at this time of year, and it is to be hoped that it will be a long time before we have the same again. During last week the heavy rain was accompanied by an equally heavy sea, with the result that the promenade sustained some damage. Fortunately, the damage will not be difficult to repair".	Kincardine Observer, Friday 7 June 1907 'County Gossip - Stonehaven'
10/1907	(11th) October 1907 was by all accounts a very wet month, with two severe storms a week apart on the 11th and 18th October. The Scotsman reported a severe wind and rain storm on the 11th which "brought a great deal of sand and stones from the higher parts of the town to Barclay Street and Market Square, and the drains in that part being unable to carry away the rush of water, a great many of the houses were flooded. In the Old Town, in one or two of the low-lying houses, the flooding was serious". Although the rivers were in spate, the flooding to properties was from surface water	The Scotsman, 11th October 1907. Article 55 [no title]. www.proquest.com (accessed 12 July 2011).
10/1907	(18th) The Kincardineshire Observer reported on the 18th that "Rain fell in the Stonehaven district all day yesterday... the weather conditions were of the most wretched description... The heavy rainfall has not occasioned any serious damage in Stonehaven. The Cowie and Carron are in spate, but not to the extent these rivers attained on Thursday of last week"	The Kincardineshire Observer, 18th October 1907. 'Stonehaven'.
04/1934	Barclay Street and part of Cameron Street flooded to depth of several feet.	Mearns Leader and Kincardine Mail, 'And the waters prevailed exceedingly upon the earth' 20 December 1934
06/1938	The Scotsman reported that “the streams Cowie and Carron were running in spate after 12 hours continuous rain. Householders along the banks were greatly alarmed by the rising waters”	The Scotsman, 3rd June 1938. 'Stormy weather in Scottish districts'. www.proquest.com (accessed 12 July 2011).
11/1946	It was reported in the Scotsman that "Over the four days... Aberdeen had 2.98 inches of rain... There was an alarming experience for many householders in Cameron Street, Stonehaven... when the River Carron, in spate, rose to an unusual height. Household goods were carried to upstairs rooms and back doors barricaded with sandbags and wooden boarding. The water gradually subsided, and severe flooding was narrowly averted"	The Scotsman, 22nd November 1946. 'Wild weather'. www.proquest.com (accessed 12 July 2011).
03/1947	In March 1947 again the Carron was at a sufficiently high level to pose a risk to property: “The River Carron is... running exceptionally high and last night tenants of dwelling houses on the river bank took all precautions against flooding”	The Scotsman, 22nd March 1947. 'Flood waters continue to fan out'. www.proquest.com (accessed 12 July 2011).

Date	Brief description	Source
09/1956	A report in the Mearns Leader described how "Stonehaven got its full share of the heavy rain... The result was that both the Cowie and Carron waters came down in spate... On Carronside, several householders in the Cameron Street area, with recollections of former spates, took the precautions of erecting flood barriers at their doors"	The Mearns Leader, 7th September 1956. Article [no title], www.mearnsleader.co.uk (accessed 12 July 2011).
08/1958	The Mearns Leader described how heavy rain at the start of August had lead to a hurried evacuation of the Mill Lade campsite due to flooding from the Cowie and rainwater, and that "Householders near the lower reaches of the Carron, which was also running high, took precautions against the flooding of their properties" . At the end of the month there was a further flood event on the Cowie, and landslides at the Bervie Braes, although no mention of flooding from the Carron was made.	The Mearns Leader, 1st August 1958. Article [no title], www.mearnsleader.co.uk (accessed 12 July 2011).
10/1979	In 1979 severe flooding from the Carron again caused damage to properties in the town centre. The Press and Journal suggested that "In Stonehaven, the combination of a high tide at noon and floodwater pouring down the two rivers either side of the town centre wreaked havoc. Fire services fought a losing battle to pump shops and homes clear and sandbags were brought in to try and stem the floodwaters". Photographs provided by Aberdeenshire Council show flooding to properties on Cameron Street and Barclay Street, and water levels in the river reaching the soffit of both the Green Bridge fretwork and Bridgefield Bridge.	The Press & Journal, 5th October 1979. 'Flood havoc hits N-East'.
12/1985	The Press and Journal described how areas including Stonehaven were affected by "widespread flooding which followed a sudden thaw combined with heavy overnight rain". Photographs in the newspaper showing property flooding on Cameron Street and at the southern end of Barclay Street up to around threshold level, and the fire service working to pump away the water.	The Press & Journal, 7th December 1985. 'Water, water everywhere'.
04/1998	Photographs provided by Aberdeenshire Council show the River Carron at a sufficiently high level to cause flooding to the rear gardens of properties on Cameron Street, but no reports have been found of flooding to property.	Aberdeenshire Council
10/2002	In October 2002 the Press and Journal reported that “the North-east [is] suffer[ing] what is shaping up to be its wettest October ever”. However, although the Carron was at a high enough level to be out of bank, no damage was caused: “Politicians and Stonehaven residents yesterday praised the flood resistance measures introduced by Aberdeenshire Council at the River Carron... though some water toppled over the riverbank on Tuesday night, it was not enough to cause damage to nearby property”	The Press and Journal, 24th October 2001. 'Council riverbank work praised'.
03/2006	Carron in spate and reaching soffit of Green Br	
07/2009	The Mearns Leader reported that "Parts of Stonehaven became submerged under water last Friday afternoon, when drainage systems struggled to cope with the unusually large amount of rainfall". This surface water flooding event was sufficient to cause flooding to properties.	The Mearns Leader, 31st July 2009. 'Flash floods cause town centre chaos', www.mearnsleader.co.uk (accessed 12 July 2011).
10/2009	Just a few days before the November 2009 event the Carron had come close to bursting its banks. The Mearns Leader reported that “Stonehaven... was battered by storms. A massive 37.3 mm of water fell on October 21 alone... The River Carron came perilously close to flooding houses in Cameron Street”. This storm contributed to the very wet antecedent conditions in the catchment which increased runoff in the larger event just a few days later.	The Mearns Leader, 30th October 2009. 'High alert as storms hit Mearns', www.mearnsleader.co.uk (accessed 12 July 2011).
11/2009	The Mearns Leader described the "devastation" as the River Carron burst its banks and flooded businesses and houses, causing around 50 people to be evacuated. This event	The Mearns Leader, 5th November 2009. 'Emergency Services

Date	Brief description	Source
	prompted the Council's current efforts to develop a long-term sustainable strategy for flood alleviation in Stonehaven. Flooding in November 2009 was widespread in Aberdeenshire with a total of 300 people affected by internal flooding at 50 separate sites. Out of bank flooding occurred around the Green Bridge with overland flow both to the north and south of the river. Property flooding occurred on Carron Terrace and Cameron Street, in the Market Square area and on Barclay Street. There was also flooding to properties on Low Wood Road, Dunnottar Avenue and in the High Street, Arbuthnott Place and Bridgefield area.	stretched to the limit', www.mearnsleader.co.uk (accessed 12 July 2011).
01/2010	Carron in spate and reaching soffit of Green Br	
12/2012	Carron and Glaslaw Burn in spate.	

It has been noted that prior to modification of the weir below the Green Bridge the channel had more capacity and flood water did not leave the channel at this point. There are no direct records of flooding upstream of Green Bridge prior to the weir modifications in the 1970s and there was a major reduction in capacity at this time.

5 Hydraulic Model Assessment

5.1 Introduction

Calibration is necessary to develop confidence in the hydraulic model's predictions of flood depths and velocities and test levels of uncertainty and confidence in the parameters used. Calibration is achieved through the use of historic data. Ideally, this information is primarily in the form of peak water levels at specific locations, which correspond to peak recorded river flows. The model was previously calibrated against post flood data collected following the November 2009 event[23]. The model has been further tested against the December 2012 flood event.

5.2 Modelling the Dec 2012 flow

The hydraulic model has been tested by attempting to use it to replicate the impact of the December 2012 flood event. Using the stage data collected at the Carron gauge and the model rating a peak inflow hydrograph has been calculated for the December 2012 event (Figure 3-). The model has been run with this inflow dataset and results compared with post flood data inferred from photos and videos during this report.

Table 5-1: Model assessment levels

Location	Note
Carron Gauge	Stage of 1.83m
Green Bridge	Stage of 2.01m
White Bridge	Water close to soffit
Bridgefield Bridge	Water close to soffit
Carron Gardens	Out of bank flow pathway
High Street	Flood depths c. 1m

There are a number of difficulties in representing the December 2012 event which include:

- Limited calibration survey.
- The presence of temporary barriers in place which were moved during the event.
- The Green Bridge was noted to be partially blocked during the event.

[23] 2011s4980- Stonehaven River Carron Flood Alleviation Study, July 2012, Section 3.3

- There were possible blockages in the culverts at the downstream end of the Glaslaw Burn but these are unverified.
- The flows on the Glaslaw Burn during the event have been assumed based on observations made after the flood event.

The following assumptions were made during the calibration:

- A peak flow of 6.7 m^3/s was used in the Glaslaw Burn to represent the 75 year flood event.
- A peak flow of 24.8m^3/s was used in the River Carron.
- The hydrographs for the River Carron and Glaslaw Burn were set so that the timing of their peaks would coincide.
- The soffit of the Green Bridge was lowered from 70.76 mAOD to 70.40 mAOD to represent the blockage.

5.2.1 Results

River Carron

The predicted flood extent from the hydraulic model is compared to the Post Flood Collation in Figure 5-1.

Figure 5-1: December 2012 Modelled Flood Outline for the River Carron and Glaslaw Burn

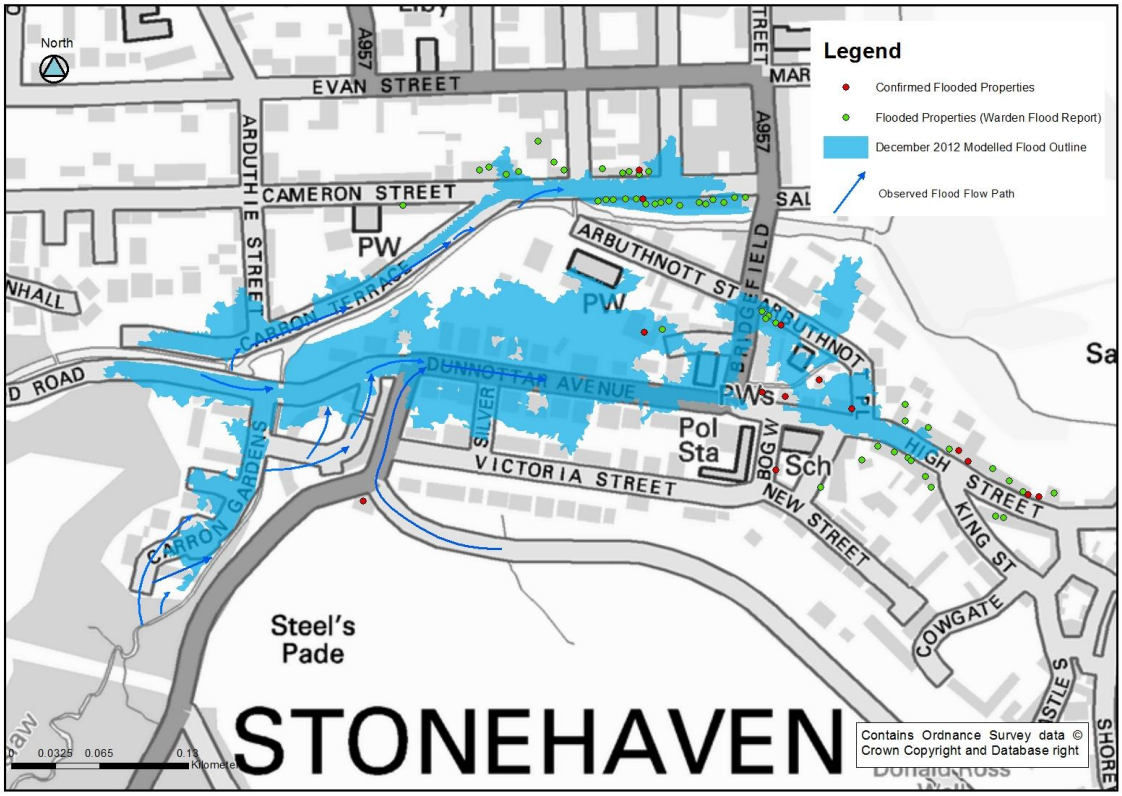


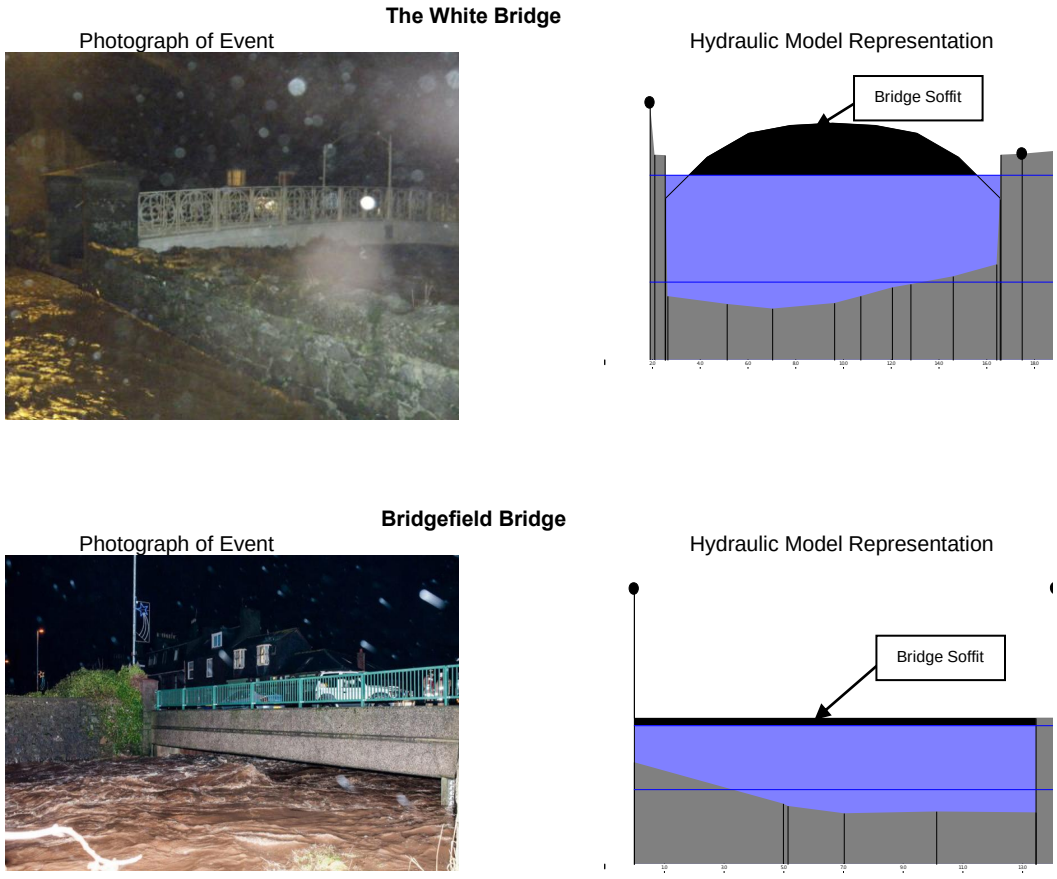
Table 5-1 references noted depths at the River Carron gauge and at the Green Bridge. These are compared to the depths calculated in the hydraulic model in Table 5-2. The levels predicted by the model at the Green Bridge are greater than those recorded. The model includes an estimation of blockage at the Green Bridge to replicate the conditions of the December 2012. The results indicate that the blockage was possibly over estimated as it is extremely difficult to replicate the exact nature of the blockage.

Table 5-2: Comparison of Peak Water Levels in the River Carron

Location	Bed Level (mAOD)	Observed Depth	Observed level (mAOD)	Model River Section	Model Level (mAOD)
River Carron Gauge	6.832	1.83	8.66	CAR_734	8.67
Green Bridge	6.298	2.01	8.31	CAR_635	8.56

During the flood event, levels in the River Carron were close to soffits of both the White Bridge and Bridgefield Bridge. This can give a good indication of levels experienced during the event. Figure 5-2 demonstrates how the hydraulic model levels closely matched observed levels during the event. Photographed levels at the White Bridge appear higher than predicted. This is possibly due to turbulent waters in the reach producing a wave surge effect at the bridge. This would not be replicated by a hydraulic model though would be taken into account when calculating freeboard in the design of flood defences.

Figure 5-2- Comparison of peak water levels at the White Bridge (upstream face) and Bridgefield Bridge (downstream face)



The hydraulic model largely predicts the correct flow paths and can be seen to match the severity of the event very closely. However it appears to underestimate the extent of flooding, particularly on the High Street and Arbuthnott Place. There are various reasons why this might be which include:

- Overland flow from the south of Stonehaven is not included in the model. These overland flows combined with flows emanating from the River Carron on Dunnottar Avenue and heading towards the High Street. Additionally it should be noted that the hydraulic model does not account for any surface water flooding. Surface water was also prevented from entering the drainage network due to the build up of sediments blocking the road gullies.

- The extent of flooding is sensitive to the amount of blockage of the Green Bridge. The blockage experienced during the 2012 event has been approximated but the actual impact the blockage had on flood levels cannot be accurately quantified.
- The impact of flood barriers deployed during the flood is unknown and not accounted for in the model.
- The SEPA gauge from which the flow in the River Carron was estimated is not calibrated for high flows.

An analysis of surface water flooding in Stonehaven carried out in 2011 concluded that the key areas of risk in the centre of Stonehaven include Arbuthnott Place and the High Street.The flood map generated from the hydraulic model is not as great as the observed. It is considered that flooding in these areas was the result of surface water flooding adding to the volume of fluvial flooding from the River Carron and Glaslaw Burn. It is believed that these flows arose predominately from the Bervie Braes and local rainfall.

It is believed that the hydraulic model accurately represents the River Carron by giving a good estimate of peak water levels at the gauge, the Green Bridge, the White Bridge and Bridgefield Bridge. Full results are tabulated in Appendix C.

Glaslaw Burn

The Glaslaw Burn experienced relatively significant flows during the December 2012 event which resulted in some properties being inundated. Unfortunately there is very little data available to gauge what the peak flow in the burn was or the severity of the event in terms of return period. As the proposed flood defence scheme will incorporate defences on the Glaslaw Burn it is essential that the hydraulic model accurately predicts peak flood levels on the burn for the required return periods.

Flood events typically leave behind evidence of peak water levels after the flood waters have receded which are termed wrack marks. These are typically deposits left on obstacles within the floodplain which indicate both level and extent. They can be misleading as turbulent water or blockages can push some wrack marks higher or some may be lower as they have dropped with receding flood waters. Additionally the wrack mark could have been left after the peak of the event. Sufficiently numerous wrack marks over the reach of the watercourse can greatly increase confidence in the suggested peak water level for the flood event.

In this case flows have been estimated from the observations discussed in Section 3.6. The flows were estimated to be between 6 and 7 m^3/s. Validation of the model has been attempted against wrack marks in the Glaslaw Burn upstream in an area with few or no bridges.

Figure 5-3 Wrack Mark Locations

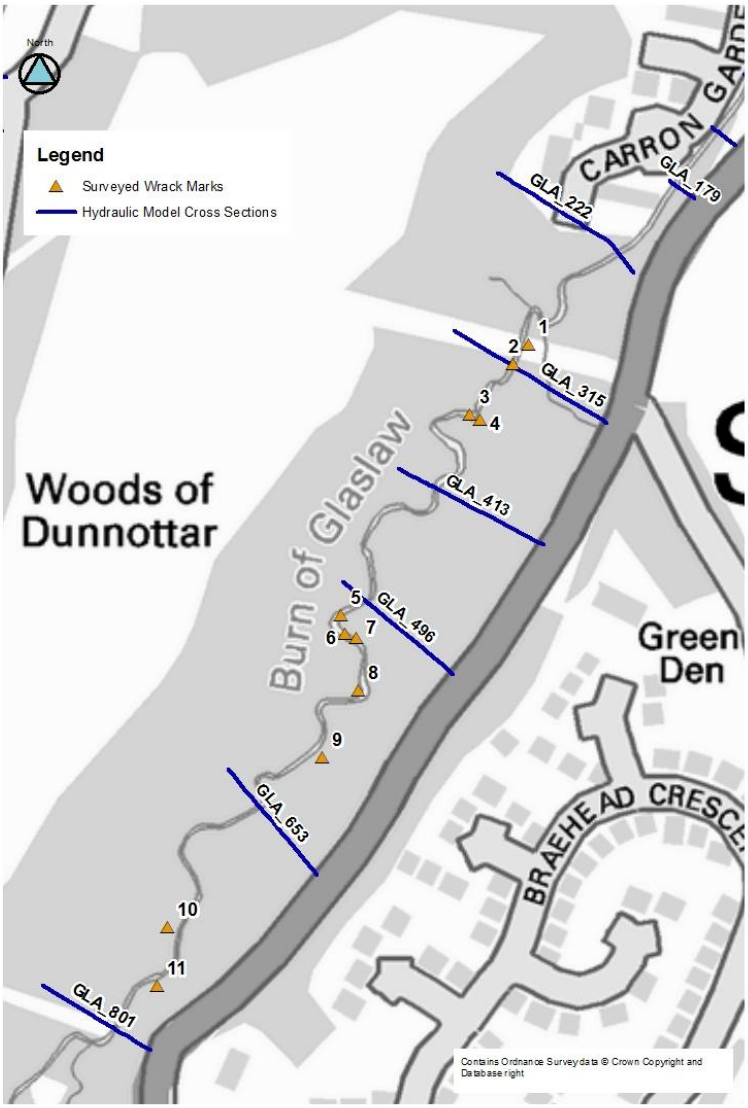
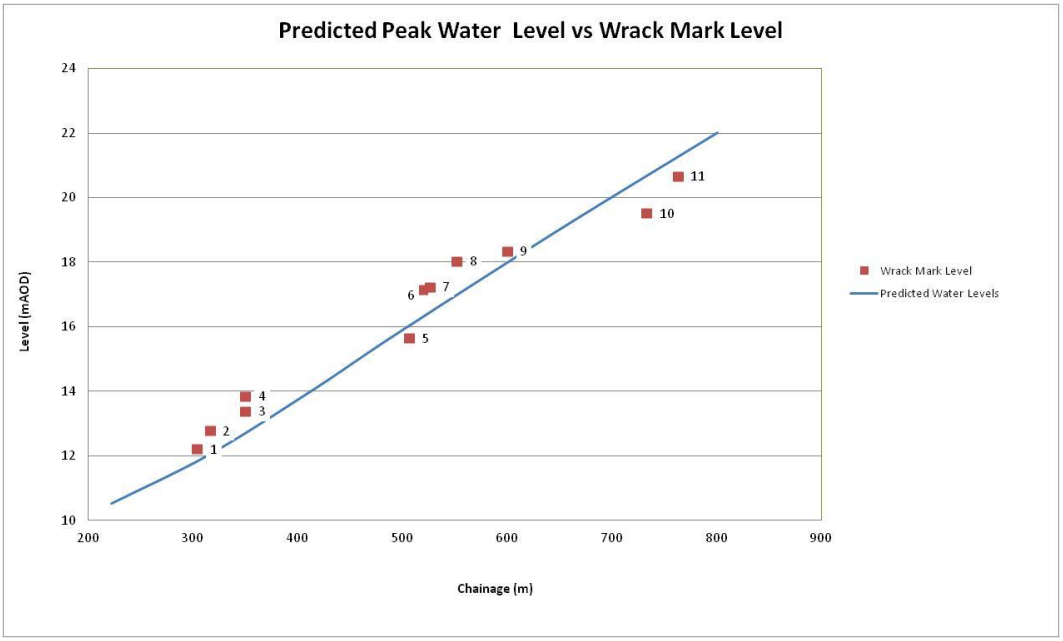


Table 5-3 Wrack Mark Levels

Wrack Mark Number	Chainage	Level (mAOD)	Modelled water Level at Upstream Section (mAOD)	Modelled water Level at Downstream Section (mAOD)	Difference in Elevation (m)
1	304	12.27	12.04	10.54	-0.32
2	316	12.79	12.04	10.54	-0.62
3	350	13.39	14.03	12.04	-0.54
4	350	13.86	14.03	12.04	-0.99
5	506	15.65	19.08	15.83	0.49
6	519	17.15	19.08	15.83	-0.74
7	526	17.24	19.08	15.83	-0.69
8	552	18.04	19.08	15.83	-0.95
9	600	18.35	19.08	15.83	-0.26
10	733	19.52	22.02	19.08	1.25
11	763	20.68	22.02	19.08	0.69

Figure 5-4: Predicted Water Levels vs. Wrack Mark Level



It can be seen from Figure 5-4 that a fairly good correlation has been achieved although the wrack levels are higher that of the predicted peak water levels. It is noted that the surveyed wrack marks were located on larger debris within the Glaslaw Burn as show in Figure 5-5. Some of the marks may be associated with superelevation at bends or as it piles up against obstructions. The levels taken could indicate extreme flows on the Glaslaw Burn or that the wrack marks are higher than the flood water.

There is still a degree of uncertainty pertaining to the December 2012 flood event on the Glaslaw Burn due to the lack of recorded data. However the observations made during the flood event have allowed an estimate of the flow to be arrived at by deriving the required flow to meet these observations, namely the burn overtopping its banks a Carron Gardens and Woodview Court. It is considered that the flow in the burn would have been approximately 6-7m^3/s which would be in the order of a 75 year return period.

Figure 5-5: examples of debris in Glaslaw Burn

6 Recommendations / Next Steps

The 2012 flood was of a smaller magnitude than the 2009 flood on the River Carron. However the blockage at the Green Bridge is likely to have elevated water levels sufficiently such that significant flood waters left the Carron upstream of the Green Bridge.

There are believed to have been significantly higher flows passing down the Glaslaw Burn which overtopped and flowed through Woodview Court and Dunnottar Avenue and overland from the Bervie Braes which then ponded in the High Street area. Flows in the Glaslaw Burn could have exceeded 6.7 m^3/s which equates to the 75 year return period.

The following recommendations should be taken forward:

- Install level loggers on the Glaslaw Burn. It would be a useful measure to install a level logger in an upstream area of the catchment as well as a gauge immediately upstream of the culverts adjacent to Carron Gardens. The latter would eventually be replaced as part of the proposed scheme.

  A level logger requires a stable control (a bridge or weir for example) in stable location that will convey the full flow of the burn and not be bypassed. Much of the Glaslaw Burn is susceptible to erosion. Installation of a flow gauge or logger would therefore require erosion protection works at the desired location.
- To assess records of the actual number of properties that flooded in December 2012.
- Consider improving gravity and pumped drainage from the Arbuthnott Court area to reduce ponding in the High Street.
- Review the operation of the temporary flood barriers and check the levels to ensure the operation will guide water back into the River Carron without causing an increase in risk to property owners. Draft and publish manual for the operation to prevent changes in operation on the night.
- Increase inspection for trees and material that could cause blockage on the River Carron and Glaslaw Burn.
- Consider lowering the weir below the Green Bridge as soon as feasible providing no detriment to others can be achieved.
- Consider improving efficiency of the weir under Green Bridge by removing gravel behind the weir to optimise flow characteristics.

Appendices

Appendix A: Post Flood Collation

North

Legend

- Confirmed flooded properties
- Flooding avoided by temporary defences
- Confirmed non flooded properties
- December 2012 Predicted Flood Outline
- Flood flow path

Ref No.	Source
1	http://news.stv.tv/galleries/stonehaven-flood-2012/
2	http://www.bbc.co.uk/news/uk-20830740
3	http://local.stv.tv/stonehaven/galleries/stonehaven-flood-2012/39049/
4	http://www.bbc.co.uk/news/uk-scotland-20827290
5	http://www.itv.com/news/update/2012-12-23/stonehaven-under-water-as-wet-weather-hits-scotland/
6	http://www.youtube.com/watch?v=PUfAfcsF6OA
7	http://local.stv.tv/stonehaven/galleries/stonehaven-flood-2012/39002/
8	http://local.stv.tv/stonehaven/galleries/stonehaven-flood-2012/38999/
9	http://local.stv.tv/stonehaven/galleries/stonehaven-flood-2012/39000/
10	http://news.stv.tv/galleries/stonehaven-flood-2012/38989/
11	http://www.facebook.com/northsound1/posts/274644659325701
12-14	Supplied by Aberdeenshire County Council
15-16	JBA consulting

Contains ordnance survey data (c) crown copyright and database right 2010.

JBA consulting

FIGURE A

POST FLOOD COLLATION

0 0.05 0.1 0.2 Kilometers

Appendix B: Surveyed Wrack Mark Photographs

Wrack Mark One: Deposit on cable

Wrack Mark Two: Gravel deposits on elevated ground between two channels

Wrack Mark Three: Gravel deposits at start of bifurcation of channel

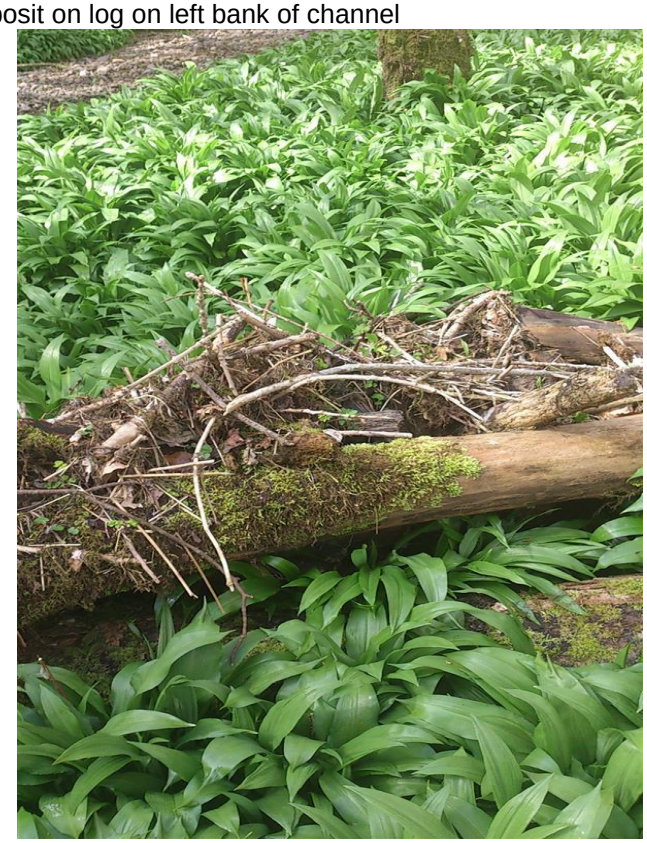
Wrack Mark Four: Deposits at base of tree in flood plain

Wrack Mark Five: Deposits on log across channel

Wrack Mark Six: deposits on large wood debris in channel

Wrack Mark Seven: Deposits on banks that was likely overtopped

Wrack Mark Eight: Deposit on log on left bank of channel



Wrack Mark Nine: Deposits on flood plain on left bank of flood plain

Wrack Mark Ten: Gravel deposits on right bank in flood plain

Wrack Mark Eleven: Deposits on wooded debris on right bank of channel

Appendix C: Hydraulic Model Results

Section ID	Max Stage (mAOD)	Max Velocity (m/s)	Max Flow (m3/s)
River Carron			
CAR_000	2.73	1.39	31.56
CAR_040	2.63	2.75	31.49
CAR_117	3.17	1.61	31.46
CAR_122	3.23	1.36	31.45
CAR_126	3.23	1.36	31.45
CAR_132	3.25	1.38	31.45
CAR_169	3.39	1.52	31.45
CAR_196	3.54	1.13	31.45
CAR_198	3.63	1.62	31.45
CAR_200	3.64	1.61	31.45
CAR_214	3.64	1.61	31.45
CAR_221	3.64	1.91	31.45
CAR_236	3.76	2	31.45
CAR_295	4.16	1.7	31.46
CAR_334	4.24	1.9	31.47
CAR_343	4.33	1.61	31.47
CAR_346	4.34	1.61	31.47
CAR_347	4.34	1.54	31.47
CAR_357	4.16	2.67	31.47
CAR_381	4.47	2.3	31.48
CAR_421	4.74	2.24	31.34
CAR_477	5.15	1.89	31.25
CAR_521	5.36	1.96	30.74
CAR_567	5.52	2.86	30.16
CAR_572	5.59	3.04	30.15
CAR_573	5.59	2.38	22.75
CAR_605	6.46	3.42	21.69
CAR_606	6.5	3.13	21.62
CAR_617	6.79	2.26	20.92
CAR_624	6.92	1.65	20.24
CAR_625	6.98	1.49	18.98
CAR_627	8.15	1.32	18.98
CAR_631	8.17	1.23	18.73
CAR_635	8.58	1	18.73
CAR_637	8.59	0.94	19.08
CAR_671	8.57	1.23	23.03
CAR_710	8.62	1.38	24.57
CAR_733	8.68	1.43	24.58
CAR_734	8.68	1.43	24.58
CAR_757	8.72	1.64	24.58
CAR_763	8.72	1.63	24.58
CAR_768	8.74	1.61	24.58
CAR_812	8.83	2.03	24.58
CAR_866	9.14	2.15	24.57
CAR_929	9.64	2.04	24.56
CAR_998	10.08	1.98	24.54
CAR_1036	10.35	2.27	24.54

Section ID	Max Stage (mAOD)	Max Velocity (m/s)	Max Flow (m3/s)
CAR_1080	10.76	2.4	24.53
CAR_1100	10.83	2.49	24.53
CAR_1107	10.99	2.07	24.53
CAR_1142	11.24	1.38	24.53
CAR_1191	11.47	2.16	24.56
CAR_1236	11.98	2.41	24.58
CAR_1321	12.73	2	24.66
CAR_1375	13.42	2.71	24.66
CAR_1428	14.12	1.94	24.63
CAR_1502	14.73	2.17	24.56
CAR_1544	15.09	2.3	24.49
CAR_1584	15.46	2.11	24.6
CAR_1626	15.76	2.38	24.75
CAR_1669	16.19	2.61	24.73
CAR_1710	16.85	3.14	24.74
CAR_1764	17.65	2.15	24.86
CAR_1836	18.48	2.4	25.13
CAR_1907	19.88	2.81	25
CAR_1956	20.74	1.76	25.1
CAR_2017	21.15	0.64	26.88
CAR_2067	21.56	1.8	26.09
CAR_2117	22.13	1.82	27.6
2140	22.45	3.18	28.64
CAR_2143	22.39	3.6	28.64
CAR_2202	23.21	1.87	27.73
CAR_2253	23.36	1.78	25.96
CAR_2331	23.78	1.4	25.21
CAR_2386	24.28	1.79	24.57
CAR_2476	25.15	1.86	24.87
CAR_2510	25.53	2.69	24.5
CAR_2536	26.01	3.42	24.52
CAR_2555	26.5	3.73	24.52
CAR_2639	27.63	3.66	24.55
CAR_2710	27.93	2.01	24.58
CAR_2770	28.48	2.84	24.6
CAR_2777	28.72	2.17	24.61
CAR_2789	29	1.51	24.61
CAR_2853	29.37	2.39	24.62
CAR_2894	29.65	2.17	24.63
CAR_2943	29.98	2.01	24.62
CAR_2993	30.39	2.33	24.61
CAR_3054	30.89	2.13	24.6
CAR_3096	31.19	2.34	24.58
CAR_3103	31.52	1.52	24.58
CAR_3146	31.7	2.28	24.62
CAR_3228	32.4	1.7	24.69
CAR_3284	33.01	2.19	24.72
CAR_3331	33.49	2.04	24.76

Section ID	Max Stage (mAOD)	Max Velocity (m/s)	Max Flow (m3/s)
Glaslaw Burn			
GLA_000	5.59	1.75	7.39
GLA_009	5.65	1.8	7.39
GLA_011	6.2	1.84	7.39
GLA_020	6.34	1.82	7.37
GLA_030	6.36	1.77	7.33
GLA_032	7.67	1.81	7.33
GLA_033	7.72	1.86	6.77
GLA_044	7.86	2.24	6.77
GLA_070	8.11	1.47	6.77
GLA_089	8.3	2.13	6.77
GLA_116	8.5	2.28	6.77
GLA_147	9.07	2.26	6.69
GLA_179	9.78	2.69	6.62
GLA_222	10.54	2.07	6.72
GLA_315	12.04	1.85	6.72
GLA_413	14.02	2.21	6.72
GLA_496	15.83	2.04	6.72
GLA_653	19.09	1.92	6.72
GLA_801	22.02	1.28	6.72

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