11.4.6 Flood depths

Fluvial water surface elevations have been derived for a range of return period events for each option assessed. Return periods assessed include the 2, 5, 10, 25, 50, 100, 200 and 1000 year floods. This provides a range of floods with a bias towards the shorter return period events that derive the greatest proportion of benefits.

The 1000 year flood was included to determine the damages occurring in excess of the design standard. According to the Scottish Government's Flood Prevention Scheme Guidance document[47], the benefits of the scheme should be appropriate to the design standard (i.e. without freeboard). Thus although the scheme would protect against a higher flood than the design standard with additional freeboard included, the assumption in terms of the economic appraisal is that the 1000 year flood overtops the defences and floods Stonehaven.

11.4.7 Above design events

Whilst overtopping will occur for above design events, this will be reduced from the baseline case. It is currently assumed that above design events (1000 year return period) will flood to the same extent and depth as the current 200 year scenario. Additional modelling would assist in refining the above design events.

11.5 Results

Event damages have been calculated for a range of return period floods and are provided for the baseline case in Appendix E. These are summarised below with full results for the appraisal provided in Appendix F.

11.5.1 Direct flood damages

The total number of properties inundated for the options are provided in Table 11-8 below. In total, 372 properties have been considered in the benefit-cost analysis of Stonehaven to be at risk of flooding for the 0.5% AP (200 year) event. 269 of these properties are residential, and 103 are non-residential.

Table 11-8: Total number of properties flooded within the appraised area

Option	Number of properties flooded by return period (years)							
	5	10	25	50	75	100	200	1000
'Do minimum'	0	5	163	280	307	340	372	427
Option 2: Direct defences	0	0	0	0	0	0	0	427
Option 4: Flood storage	0	0	0	0	5	5	163	372
Option 5: Storage plus direct defences	0	0	0	0	0	0	0	427
Option 6: Resilience	0	0	10	11	14	14	19	29
Flooding may still occur at low return periods for Option 6 as we have assumed that flood protection measures cannot protect properties that are flooded to a depth greater than 1m.								

The event damages for each option are provided in Table 11-9 below. These represent the total potential flood damages for the current scenario without climate change.

[47] Scottish Executive. Flood Prevention Schemes: Guidance for Local Authorities. Chapter 5, Paragraph 4.3.20.

Table 11-9: Total flood damages within the appraised area

Option	Total flood damages (£k) by return period (years)							
	5	10	25	50	75	100	200	1000
'Do minimum'	£0	£76	£4,369	£7,516	£8,503	£9,324	£10,796	£13,357
Option 2: Direct defences	£0	£0	£0	£0	£0	£0	£0	£10,796
Option 4: Flood storage	£0	£0	£0	£0	£76	£76	£4,369	£10,796
Option 5: Storage plus direct defences	£0	£0	£0	£0	£0	£0	£0	£10,796
Option 6: Resilience	£0	£0	£519	£619	£742	£747	£1,364	£1,755

The total average annual damages in Stonehaven due to flooding from the River Carron are given in the table below.

Table 11-10: Total AAD and PVd for options appraised

Option	Total AAD (£k)	PVD (£k)	Capped PVD (£k)
'Do minimum'	451.4	13,458	12,517
Option 2: Direct defences	41.7	1,244	1,244
Option 4: Flood storage	53.6	1,597	1,597
Option 5: Storage plus direct defences	41.7	1,244	1,244
Option 6: Resilience	47.3	1,409	1,099

11.5.2 Resilience benefits

For the resilience scenario, it is standard to assume that the whole life benefits (damages avoided) are equivalent to a proportion of the total benefits assuming a permanent solution. This proportion is defined by the operational reliability as follows:

$$\mathbf{B_{TD} = R \times B_P}$$

Where:

B_{TD} = the benefit of household flood protection

R = the operational reliability

B_P = the benefit of an equivalent permanent solution

The reliability measure has been assessed by an event tree analysis that takes into account the following aspects of operational reliability:

- Flooding being correctly forecast;
- Sufficient time available to warn households;
- Householders receiving warning;
- Householders at home and able to respond to warning;
- Sufficient training provided to implement defences; and
- Barrier erected with time available and performs satisfactorily.

Each of the above factors has been defined a probability of occurrence and an event tree generated to multiply each factor and determine the system success rate or operational reliability. The event tree analysis and assumptions are provided in Appendix G.

Most of the above factors can be designed out and allowed for in a suitable scheme (such as training, performance of the barrier and flood forecasting). However, key risk factors are the ability for householders to receive and be in a position to respond to the warnings. The MCM manual suggests that only 38% of householders receive warnings and are able to respond effectively. In this instance we have assumed 50%.

The operational reliability is therefore assessed to be 25% once all the factors are considered. The damages avoided by the scheme are therefore 25% of the total damages avoided.

11.5.3 Key beneficiaries

Ranking the total damages associated with individual properties identifies key beneficiaries of flood defence measures, for example one property may account for a particularly high proportion of the damages. It also highlights particular anomalies in the dataset and acts as a check on the final results. The highest 10 ranked properties (for the Do Nothing case) are shown in Table 11-11 below. The Farmfoods property ranks #1 and accounts for 4% of the total damages. This modest proportion suggests there is no single property, or group of properties, likely to skew the damages.

This analysis reflects where the majority of the flood damages accrue from: namely large floor area, retail warehouse and industrial premises. This is expected, given the high depth damage curves for such premises combined with their extensive floor area.

Table 11-11: Top 10 key beneficiaries (properties with the highest estimated flood damages)

Property	Property type	Property area (m2)	PVd damage (£k)	Proportion of total damages (%)
Farmfoods supermarket, 1 BARCLAY STREET	(High Street) Shop	403	552.3	4%
Celtic Chords music shop, 8 BARCLAY STREET	(High Street) Shop	226	286.7	2%
Stella's Coffee Shop, 5 BARCLAY STREET	Café/Food Court	210	276.2	2%
John A W Briggs Furniture, 19 BRIDGEFIELD	(High Street) Shop	174	238.4	2%
Kitchens Bathrooms Bedrooms, 15 ALLARDICE STREET	Showroom	221	238.3	2%
Parade shop 50, BARCLAY STREET	(High Street) Shop	401	179.0	1%
Toyland shop 19, ALLARDICE STREET	(High Street) Shop	239	152.4	1%
Deli 17, BARCLAY STREET	Café / Food Court	86	111.3	1%
Church Hall, CAMERON STREET	Community Centres / Halls	323	105.8	1%
Church, CAMERON STREET	Church	323	104.6	1%

Site surveys are recommended for large properties with high flood frequencies and for properties that contribute significantly to the overall PVd. The MCM recommends that site surveys for properties that account for more than 10% of the overall PVd[48] are undertaken as standard depth damage curves for key beneficiaries may not be appropriate. This is deemed not to be necessary or relevant to Stonehaven at this stage of the analysis.

11.5.4 Indirect and intangible flood damages

The total indirect and intangible damages for the options are provided in Table 11-12 below. This indicates that the residential indirect and intangible damages are negligible when compared to the direct flood damages.

[48] The Benefits of Flood and Coastal Risk Management: A Manual of Assessment Techniques. Chapter 5.8.3.

Table 11-12: Present Value of indirect flood damages

Option	Indirect PV damages (£k)	Intangible PV damages (£k)
'Do minimum'	1,146	1,384
Option 2: Direct defences	74	54
Option 4: Flood storage	136	124
Option 5: Storage plus direct defences	74	54
Option 6: Resilience	78	49

11.5.5 Breach damages

Damages can be calculated as both 'breach' damages and 'overtopping' damages. Overtopping damages represent the damage that occurs from the intermittent flooding due to bank level exceedance or defence overtopping. Breach damages represent the damage that can occur due to the deterioration of defences and the associated increase in probability of breaching. Breach damages can be significant where existing defences exist.

Due to the fact that most flood damages in Stonehaven are as a result of bank crest exceedance and that few raised flood defences exist in Stonehaven, breach damages have not been assessed.

11.6 Appraisal

The benefit-cost analysis of the flood alleviation options has been carried out based on the methodology given in the 'Flood Prevention Schemes: Guidance for Local Authorities' report[49] by the Scottish Executive, April 2005. The principles are summarised as follows:

- Derive the damages associated with do-nothing;
- Derive the damages associated with each scheme option;
- Derive the benefits (damages avoided) associated with each option;
- Derive the costs for each option; and
- Derive the benefit-cost ratios for each option.

In all cases, the benefits and costs are transformed into present values.

11.6.1 Appraisal calculation

All appraisal calculations have been undertaken using the standard Defra spreadsheets supplied with the Flood and Coastal Defence Project Appraisal Guidance: Economic Appraisal[50]. These calculate the annual average damages and costs associated with each option over the lifetime of the scheme, and undertake the discounting calculations to convert the data into present values.

Amendments to these have been made to incorporate individual property capping. Additional non-standard tables have been added to take into account the indirect flood damages and intangible impacts.

11.6.2 Assumptions

The following assumptions have been made:

- The life span of the scheme is assumed to be 100 years.
- Discounting of damages and scheme costs have been calculated using the revised Treasury discount rates as recommended by the 2003 revision to the Green Book[51]. This revision set a time varying discount rate of 3.5% for the first 30 years, 3% for years 31-75 and 2.5% for years 76-125. This equates to a Present Value factor of 29.81.

[49] Flood Prevention Schemes: Guidance for Local Authorities. April 2005. Scottish Executive.

[50] Flood and Coastal Defence Project Appraisal Guidance: Economic Appraisal. FCDPAG3: A procedural Guide for Operating Authorities.

[51] The Green Book: Appraisal and Evaluation in Central Government, January 2003. HM Treasury.

11.6.3 Benefit-cost results

Table 11-13 below summarises the costs and benefits for the preferred option considered to protect Stonehaven from fluvial flooding at the minimum design standard of a 0.5% AP (200 year) flood.

Table 11-13: Summary of benefit-cost calculation (£k)

	'Do minimum'	Option 2: Direct defence	Option 4: Flood storage	Option 5: Storage plus direct defences	Option 6: Resilience
Standard of protection	**5 year**	**200 year**	**50 year**	**200 year**	**10 year**
Total PV costs + Optimism bias (£k)	-	3,382	4,646	6,083	3,689
PV damage (£k)	15,195	1,143	1,875	1,143	1,229
PV damage avoided (£k)	-	14,051	13,319	14,051	3,492
Net present value (£k)	-	10,669	8,674	7,730	-197
Benefit-cost ratio	**-**	**4.2**	**2.9**	**2.3**	**0.9**
Cost and benefits given as discounted Present Values. A full breakdown of option benefits and costs is given in Appendix F. The damages avoided for the resilience option are reduced by 75% to take account of the impact of operational reliability.					

It should be noted that the resilience option and storage option do not necessarily provide a 0.5% AP (200 year) standard of protection alone due to the limitations of the options proposed (resilience options are unable to easily provide protection for properties likely to flood to a depth greater than 1m, and there is insufficient storage to protect Stonehaven to the 0.5% AP (200 year) standard without additional direct defences).

The direct defence and flood storage options are cost beneficial although the direct defence option provides the highest benefit-cost ratio and is therefore more economically robust. The Net Present Value is highest for the direct defence option suggesting this has the lowest long term costs compared with the long term benefits and is the most economically sustainable option.

The resilience option would be cost beneficial assuming that all resilience measures could be put in place for every property and every flood. Furthermore, the benefit-cost ratio could be raised if the cost of this option could be offset by homeowner contributions. However, for the purposes of this assessment we have assumed that complete operational success for every flood is unlikely and the actual operational reliability may be as low as 25%.

This is not to say however that the provision of flood warning and household protection measures in the short term is not worthwhile. The implementation of these measures will provide an advanced warning of flooding and could reduce the risk to life in Stonehaven and may reduce frequent flood damage to flood events where homeowners have implemented these protection measures. The use of household protection would also provide mitigation against surface water flooding in Stonehaven.

As an option for the Council to consider for complete protection to all those at risk of flooding would require a robust set of warning, response, reaction and implementation processes to be set up and kept in perpetuity to ensure operational success.

11.7 Summary

Based on the above economic analysis, the preferred approach to provide a robust, sustainable flood protection scheme to protect Stonehaven to a 0.5% AP standard is the 'direct defence' option (which includes the construction of direct defences coupled with removal of the remains of the Green Bridge weir and raising / relocating the Green Bridge).

This provides an estimated benefit-cost ratio of 4.0 suggesting that the scheme could be viable despite uncertainties in design at this stage and any increase in costs over the design stage.

Other factors that might increase the benefits and costs of the scheme might include the damages from coastal flooding or from the River Cowie. This assessment does not include the calculation of damages from surface water flooding.

11.8 Sensitivity testing

11.8.1 Sensitivity test on historically flooded properties

As part of the review process the Council have identified a number of properties included within our flood damage estimates that did not flood in the recent flooding in 2009. A total of 112 properties have been identified that did not flood and may not be at risk at the 90-100yr return period (the estimated flood magnitude for the 2009 flood). We have therefore assessed the impact of removing these properties from the economic appraisal. This has been done via two methods:

- removal of flood damages for the properties identified up to an including the 100 year flood
- removal of flood damages for the properties identified for all return periods

The results of the two sensitivity tests are provided in the tables below.

Table 11-14: Benefit-cost ratios assuming identified properties are not flooded up to the 1% AP flood (£k)

	'Do minimum'	Option 2: Direct defence	Option 4: Flood storage	Option 5: Storage plus direct defences	Option 6: Resilience
Total PV costs + Optimism bias (£k)	-	3,382	4,646	6,083	3,689
PV damage (£k)	13,636	1,148	1,869	1,386	1,172
PV damage avoided (£k)	-	12,488	11,767	12,250	3,116
Net present value (£k)	-	9,106	7,121	6,167	-573
Benefit-cost ratio	**-**	**3.7**	**2.5**	**2.0**	**0.8**
Cost and benefits given as discounted Present Values. The damages avoided for the resilience option are reduced by 75% to take account of the impact of operational reliability.					

Table 11-15: Benefit-cost ratios assuming identified properties are not flooded up to and including the 0.1% AP flood (£k)

	'Do minimum'	Option 2: Direct defence	Option 4: Flood storage	Option 5: Storage plus direct defences	Option 6: Resilience
Total PV costs + Optimism bias (£k)	-	3,382	4,646	6,083	3,689
PV damage (£k)	13,101	943	1,630	1,358	1,159
PV damage avoided (£k)	-	12,158	11,471	11,743	2,986
Net present value (£k)	-	8,776	6,826	5,660	-703
Benefit-cost ratio	**-**	**3.6**	**2.5**	**1.9**	**0.8**
Cost and benefits given as discounted Present Values. The damages avoided for the resilience option are reduced by 75% to take account of the impact of operational reliability.					

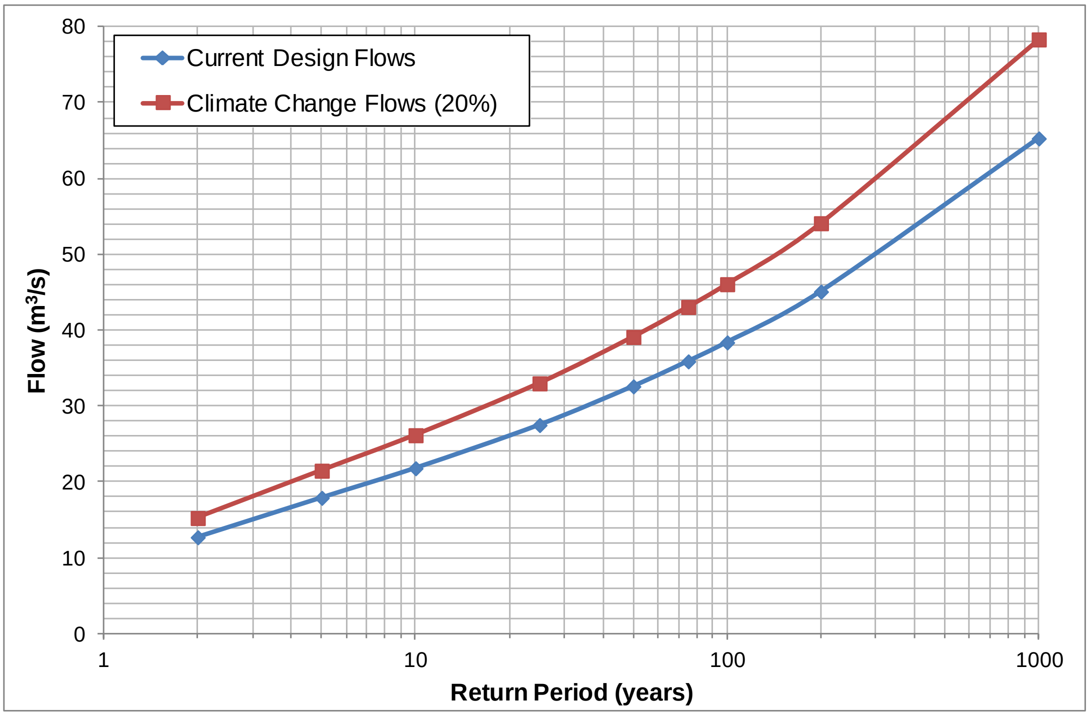
The impact of the removal of these properties reduces the baseline flood damages and with scheme damages avoided. As a result the benefit cost ratios for all options reduce, although the preferred schemes are still cost effective with a benefit cost ratio greater than 1. The options with the highest benefit cost ratio also remains the same.

11.8.2 Sensitivity test for the inclusion of climate change

The scheme has been designed without any allowance for climate change and associated increases in flood flows or increased frequency of flooding. As a result it is necessary to assess the impact of climate change on the economic effectiveness of the scheme as it is likely that over time the scheme standard of protection will reduce.

It this instance we have assumed that future flood flows increase in line with current SEPA guidance of climate and flow sensitivity. The frequency with which flood events of given severities occur (return periods) are approximated for future years by assuming that flood flows increase over the financial period by 20%. I.e. probabilities of events of a given severity are assumed to become greater in future years. The figure below illustrates the impact of this future increase in flow on flood probabilities.

Figure 11-3:



Since the physical performance of flood defences is dependent on flood flows, the graph above can be used to identify future levels of severity and estimated revisions to flood frequencies. For example, a 100 year event now will become a 43 year flood in 2080. The estimated future climate change frequencies of are provided in the table below.

Table 11-16: Summary

Return Period (yr)	5	10	25	50	75	100	200	1000
AP (%)	**20**	**10**	**4**	**2**	**1.33**	**1**	**0.5**	**0.1**
Flow (m^3/s)	17.9	21.8	27.5	32.6	35.9	38.4	45.1	65.3
Climate change flows (m^3/s)	21.48	26.16	33	39.12	43.08	46.08	54.12	78.36
Estimated return periods (yr)	3	5	11	25	33	43	90	400

Based on the above estimated future climate change flood frequencies we can estimate the AAD at both current conditions (without climate change) and at the end of the financial period (incorporating climate change). Discounting is then carried out assuming a linear increase in AAD to account for the increased flood damages as a result of climate change over time.

In addition to the above it is also necessary to consider the impact that this increase in flow will have on the standard of protection of flood defences over time. For instance, a scheme designed to the 200 year standard assuming a 20% increase in flows over the period of interest will end up with a 90 year standard of protection. Therefore the assessment of damages avoided by the scheme must also consider the impact of a gradual reduction in the standard of protection of the scheme, unless this has been designed for or is taken into account through the scheme life.

Based on the above table and the standard return period used for the economic analysis, the following assumptions have been assumed for the options:

- A 200 year scheme becomes a 75 year standard (i.e. it is overtopped at the 100 year flood) with a 20% increase in flows to 2080

- A 100 year scheme becomes a 25 year standard (i.e. it is overtopped at the 50 year flood) with a 20% increase in flows to 2080
- A 50 year scheme becomes a 10 year standard (i.e. it is overtopped at the 25 year flood) with a 20% increase in flows to 2080

These assumptions have been used within the calculations to estimate flood damages for future events over the financial 100 year period. The effect of this is to gradually reduce the damages avoided by a scheme as flows increase over time and the standard of protection falls.

Based on these assumptions the following damages (Table 12-15) are provided for the case with climate change increased flows of 20% to 2080. The results indicate that the damages avoided actually increase for the case with climate change. Despite the reduction in the standard of protection over the scheme life, the flood damages without the scheme will increase and are offset by the flood defence options. This test for climate change also illustrates that the most cost effective solution remains the direct defence solution with a benefit-cost ratio of 4.5. Also of note is the sensitivity of the solutions to climate change, with the resilience and flood storage options only providing a 10 year scheme by 2080. The options with direct defences retain a higher standard of protection over the life of the scheme.

Table 11-17: Summary of benefit-cost calculation including climate change (£k)

	'Do minimum'	Option 2: Direct defence	Option 4: Flood storage	Option 5: Storage plus direct defences	Option 6: Resilience
Standard of protection with climate change	**5 year**	**75 year**	**10 year**	**75 year**	**10 year**
Total PV costs + Optimism bias (£k)	-	3,382	4,646	6,083	3,689
PV damage (£k)	19,670	4,288	4,314	4,288	1,527
PV damage avoided (£k)	-	15,382	15,356	15,382	4,536
Net present value (£k)	-	12,000	10,711	9,299	847
Benefit-cost ratio	**-**	**4.5**	**3.3**	**2.5**	**1.2**
Cost and benefits given as discounted Present Values. A full breakdown of option benefits and costs is given in Appendix F. The damages avoided for the resilience option are reduced by 75% to take account of the impact of operational reliability.					

11.8.3 Sensitivity test for lower standard of protection schemes

It is useful to determine the sensitivity of the scheme to the standard of protection. This is best carried out by looking at both the costs and the benefits of schemes with lower standard of protection. In this instance the benefits have been assessed to determine the sensitivity of the scheme.

The flood damages for the direct defence options have been reassessed assuming a 100, 75, 50 and 25 year return period standard. The analysis has been undertaken in two ways:

- For a given standard of protection what would the upper limits of costs be to retain a benefit cost ratio of 4.0 (the current B-C ratio)?
- For the current cost estimate for the 200 year scheme of £3.38 million what would the resultant benefit cost ratio be for a lower standard scheme? As a high proportion of the costs of direct defences relate to the foundations and less to the defence height, this is a useful assessment of the sensitivity of lower standard schemes.

Table 11-18: Summary of benefit-cost calculation including climate change (£k)

	'Do minimum'	Option 2: Direct defence				
Standard of protection	**5 year**	**200 year**	**100 year**	**75 year**	**50 year**	**25 year**
Assumed PV costs (£k)	-	3,382	2,884	2,503	2,054	1,232
PV damage (£k)	15,195	1,143	3,081	4,683	6,570	10,022
PV damage avoided (£k)	-	14,051	12,113	10,512	8,625	5,172
Benefit-cost ratio	**-**	**4.2**	**4.2**	**4.2**	**4.2**	**4.2**
Cost and benefits given as discounted Present Values.						

The above table provides an upper limit for costs for each of the tested lower standard of protection scenarios for the direct defence option. For example, a 100 year scheme would have an upper limit of £3million assuming the B-C ratio is retained. This illustrates that the scheme costs could be much higher and a lower standard of protection scheme would still be cost beneficial.

Table 11-19: Summary of benefit-cost calculation including climate change (£k)

	'Do minimum'	Option 2: Direct defence				
Standard of protection	**5 year**	**200 year**	**100 year**	**75 year**	**50 year**	**25 year**
Assumed PV costs (£k)	-	3,382	3,382	3,382	3,382	3,382
PV damage (£k)	15,195	1,143	3,081	4,683	6,570	10,022
PV damage avoided (£k)	-	14,051	12,113	10,512	8,625	5,172
Benefit-cost ratio	**-**	**4.2**	**3.6**	**3.1**	**2.6**	**1.5**
Cost and benefits given as discounted Present Values.						

The above table indicates that if a lower standard of protection scheme was chosen the scheme would still be cost beneficial even if the 200 year scheme costs are retained. Whilst this is not realistic, this conservative assumption illustrates that a lower return period scheme is likely to the cost effective and economically robust.

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12 Multi-Criteria Analysis of Options

12.1 Introduction

The preceding chapters have discussed the development of options for flood mitigation from the River Carron in Stonehaven and looked at the feasibility and impacts of each option. This chapter provides a summary of the findings to help in the choice of a preferred option for Stonehaven.

12.2 Analysis

Table 12-1 below provides a summary analysis of the options and incorporates the Agency's consideration of the options at the Meeting of 25 November 2011, using a coloured-coded system on the following basis:

Colour	Result
Green	Positive result / no negative impact
Amber	Intermediate / neutral result
Red	Negative result

Table 12-1: Multi-criteria analysis of options

Criteria	Option 2: Direct defences as stand alone	Option 3a: Direct defences + bridge raising + channel modification	Option 4: Storage	Option 5: Storage + direct defences	Option 6: Resilience
Provides flood mitigation to required standard	Green	Green	Amber	Green	Red
Benefit-cost ratio	Green	Green	Amber	Amber	Red
Impact on fisheries	Green	Green	Red	Red	Green
Impact on in-channel habitat	Amber	Amber	Amber	Amber	Green
Impact on out-of-channel habitat	Amber	Amber	Amber	Amber	Green
Impact on geomorphology	Green	Green	Red	Red	Green
Impact on flood water levels in channel	Red	Amber	Green	Amber	Green
Disruption during implementation	Amber	Amber	Amber	Amber	Green
Disruption during flood event	Green	Green	Red	Green	Red
Impact on amenity value of river	Red	Amber	Amber	Amber	Green
Opportunities for improving footbridge access	Red	Green	Red	Green	Red
Requires effective warnings and manpower during event	Green	Green	Amber	Amber	Red
Impact of failure	Red	Amber	Red	Red	Amber
Risk of operational malfunction	Green	Green	Green	Green	Red
Complexity of design	Amber	Amber	Red	Red	Green
Cultural Heritage	Red	Red	Amber	Red	Amber
Long term maintenance requirements	Green	Green	Red	Red	Amber

12.3 Summary

This analysis shows that Option 3a has the most positive results for the identified criteria of the four viable options, in particular having a good benefit-cost ratio and a limited impact on the regime of the river including geomorphology and habitat, as well as offering opportunities for betterment in terms of bridge access. Option 3a also has only one negative result, being the risk of breaching which should be mitigated by a robust design. Therefore the outcome of this analysis is that overall Option 3a is favoured for Stonehaven.

12.4 Public Meeting

A public meeting was held on 26 January 2012. Members of the public were invited to view display boards (see Appendix I) explaining each of the options being considered and asked to provide feedback and participate in a simple ranking exercise.

All comments collected through questionnaire and other media during the public meeting can be found within Appendix J.

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13 Conclusion

Following extensive flooding in November 2009 JBA Consulting was commissioned to carry out a feasibility assessment with respect to seeking flood alleviation option for the River Carron in Stonehaven. The objectives of this study have been to:

- Improve peak flow estimates within the River Carron.
- Develop the existing model to incorporate a 1D-2D linked domain and hence provide better representation of overland flow and ponding.
- To consider surface water flood risk within Stonehaven.
- To define and consider alleviation options.
- To test the feasibility of the alleviation options through adapting the hydraulic model.
- To develop a cost benefit analysis of options.
- To consider the environmental and structural feasibility of each option.

Analysis of instances of historical flooding recorded within press archives and internet sources highlights that there have been a number of instances of flooding within Stonehaven. While flooding from the Carron Water is discussed within this report, flooding has also occurred from in the past from the Cowie and from the sea. This analysis has been used to inform the process of peak flow estimation within the Carron Water where data previously collected on the watercourse was not collected specifically for peak flow estimation purposes and hence the rating derived by SEPA used to convert recorded levels into flow has low confidence. A cross section is present within the hydraulic model at the location of the SEPA gauge. The model rating defines the relationship between water levels and flow and this data has been extracted and used as the rating to convert the SEPA recorded levels into flow values. This dataset has then been used within the Flood Estimation Handbook peak flow derivation process. The November 2009 event with a flow of approximately 37 m^3/s within the Carron Water at gauge is estimated within this current analysis to be in the region of 89 year return period event. The 0.5% AP (200 year) peak flow is estimated to be 45.1 m^3/s.

13.1 Hydraulic modelling

Given the nature of the topography within Stonehaven a 1D-2D linked hydraulic model was constructed in InfoWorks-RS, with the channel represented through the 1D element and the floodplain within the town represented by the 2D element. The 2D element consists of LiDAR data which was flown for this project. This allows flooding from overland flow pathways and ponding to be better represented. The 1D element the River Carron model extends from Sting Brae to the coast and uses sections of the Burn surveyed for this project. There is also a short reach of the Cheyne Burn between Kirktown of Fetteresso and its confluence with the River Carron. The Glaslaw Burn is also represented within the model between Braehead Cresent and its confluence with the River Carron.

The model has been calibrated using data collected following the 1st November 2009 flood event and this data includes survey of wrack marks and sketches of flood outlines recorded by Aberdeenshire Council and a number of photographs collected by the Council and local residents. This calibration was applied to the River Carron only, as data was not collected on the Glaslaw Burn. In addition to calibration key model parameters were tested for sensitivity, these include Manning's 'n', weir coefficient of the weirs representing the river bank thresholds, downstream boundary and peak flow within the river. This analysis indicated that the model is sensitive to flow while the model is not deemed to be sensitive the other parameters.

The model was first run representing the current channel - floodplain geometry; the 'as existing' scenario. The model was for a range of peak flows including the 2 year, 10 year, 50 year, 200 year and 1000 year events. The downstream boundary of the model is located at the outfall of the River Carron into the North Sea. A full joint probability analysis has not been carried out at this stage, however a simple test of the following model combinations has been tested the 2 year fluvial - 200 year tide, 2 year fluvial - 2 year tide, 200 year fluvial - 2 year tide and 200 year fluvial - 200 year tide. This analysis suggests that the limit of tidal impact on water levels is around the White Bridge during the 2 year fluvial events and between the White Bridge and Bridgefield Bridge during the 200 year fluvial events.

Interrogation of the model results shows that the river banks on the River Carron are first overtopped during a flow of c. 22 m^3/s currently equivalent to the 10% AP (10 year event). The first location to experience out of bank flows is the reach of the river between the Red Bridge and the Green Bridge and this is consistent with records of historical flooding including that of the November 2009 event. As flows increase the river out of bank flow commences along Carron Terrance and Carron Street on the left bank and on the right bank downstream of the White Bridge.

13.2 Consideration of Alleviation Options

Analysis of the 'as existing' scenario indicates that flood alleviation options should be considered between the Red Bridge and Green Bridge, along Carron Terrace and Cameron Street, in the vicinity of the White Bridge and at the south end of Carron gardens. A number of generic options have therefore been considered and include:

- Option 1: Continuation of maintenance and repairs;
- Option 2: Construction of direct defences as a stand-alone solution;
- Option 3: Construction of direct defences combined with modifications to the channel and bridges;
    - raising of Green Bridge and removal of remains of weir at Green Bridge;
    - raising of Green Bridge and White Bridge and removal of remains of weir at Green Bridge;
    - raising of Green Bridge and lowering the river bed at the Green Bridge weir in conjunction with removing the remains of weir at Green Bridge;
- Option 4: Provision of upstream storage;
- Option 5: Construction of direct defences combined with upstream storage; and
- Option 6: Resilience approach.

The geometry of the 'as existing' hydraulic model was thus adjusted to represent the requirements of direct defences (Options 2 and 3) to achieve the required standard of protection. In this case each option has been assessed against a target standard of protection of the 0.5% AP (200 year) event.

Each option was then assessed against the hydraulic impact, engineering feasibility, benefit-cost analysis and environmental constraints and opportunities.

With respect to the benefit-cost analysis all options have been compared using guidelines from the Scottish Government and presently include a 60% optimism bias. Normally a scheme with a benefit-cost of greater than 1.8 is considered robust. Schemes below 1 are not economically sustainable. The economic damages do not include pluvial damages. Option 2, option 4 and option 5 all result in benefit-cost ratios greater than 1, with Option 2 having the largest ratio at 4.0. Considering option 2, a 0.5% AP standard of protection can be provided however it should also be noted that this option would increase water levels for the 200yr compared to as existing at Bridgefield by about 160 mm.

Consideration could be given to raising footpaths beside flood walls.

Furthermore sensitivity analysis undertaken during the construction of the hydraulic model highlighted that the model is sensitive to changes in peak flow. Given the inherent uncertainties in peak flow estimation a secondary level of sensitivity analysis was carried out, whereby the model was tested by passing the 95% tile upper confidence limit 0.5% AP (200 year) flow through the model. This showed that this flow remains within the defences.

Channel or bridge blockage has not been incorporated into the design feasibility.

13.3 Surface Water Flooding

Surface water flooding to Stonehaven has been assessed using JFLOW+, a 2D raster-based modelling software package developed by JBA Consulting. The capacity of the drainage system has been assumed to be equivalent to the 20% AP (5 year) event.

This modelling suggests that surface water flooding poses a significant risk to properties in Stonehaven, with potential depths during the 4% AP (25 year) surface water event reaching approximately 0.6 m on Cameron Street and up to 0.8 m on the High Street. During the 0.5% AP (200 year) surface water event these water depths increase to 0.7 m in the Cameron Street / Barclay Street area and approximately 1.1 m in the low-lying area of the High Street.

This modelling assesses the impact of flooding from this source only and is not combined with a fluvial flooding event. Therefore should flood risk from the Carron be mitigated completely, this level of risk of flooding from surface water sources will still remain.

13.4 Next Step

The next step in the process of developing / achieving an FAS for the River Carron in Stonehaven are:

- Consult with key stakeholders on proposed options
- Public meeting
- Ground Investigation works
- Improve flow estimation at SEPA gauge

- Determine funding availability and programme
- Preparation of final options and revisit benefit-cost analysis
- Submission of proposed final option to the Councilfor approval under FRM 2009
- Discuss the availability of grant with Scottish Government
- Detailed design of proposed option
- CAR license application
- Implement FAS.

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Figures

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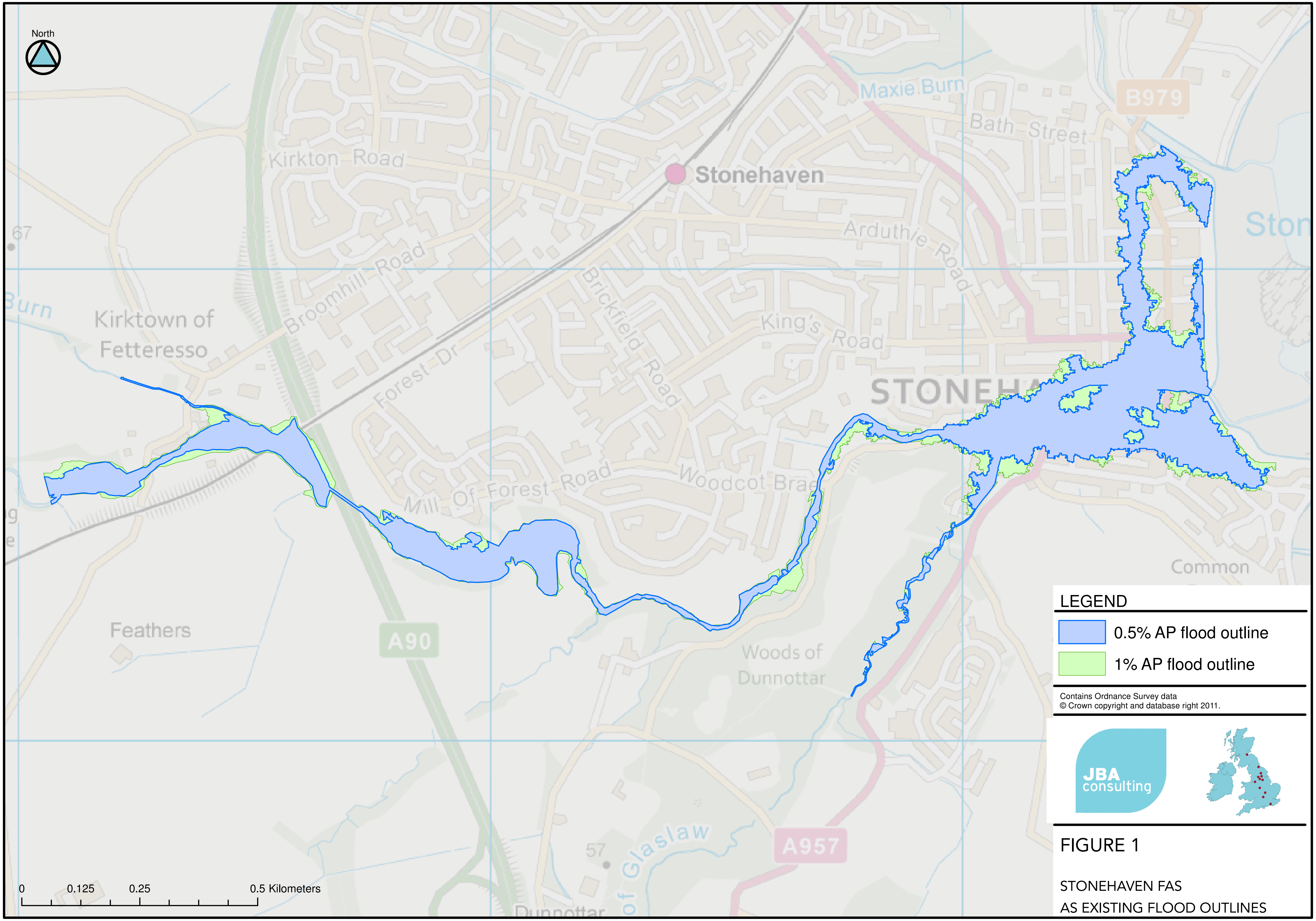
North
Maxie Burn
B979
Bath Street
Kirkton Road
Stonehaven
Ston
Arduthie Road
67
Burn
Broomhill Road
Kirktown of
Fetteresso
Brickfield Road
King's Road
STONEHA
Forest Dr
Mill Of Forest Road
Woodcot Brae
Common
A90
Feathers
Woods of
Dunnottar
57
Glaslaw
A957
Dunnottar
0
0.125
0.25
0.5 Kilometers
LEGEND
0.5% AP flood outline
1% AP flood outline
Contains Ordnance Survey data
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JBA consulting
FIGURE 1
STONEHAVEN FAS
AS EXISTING FLOOD OUTLINES

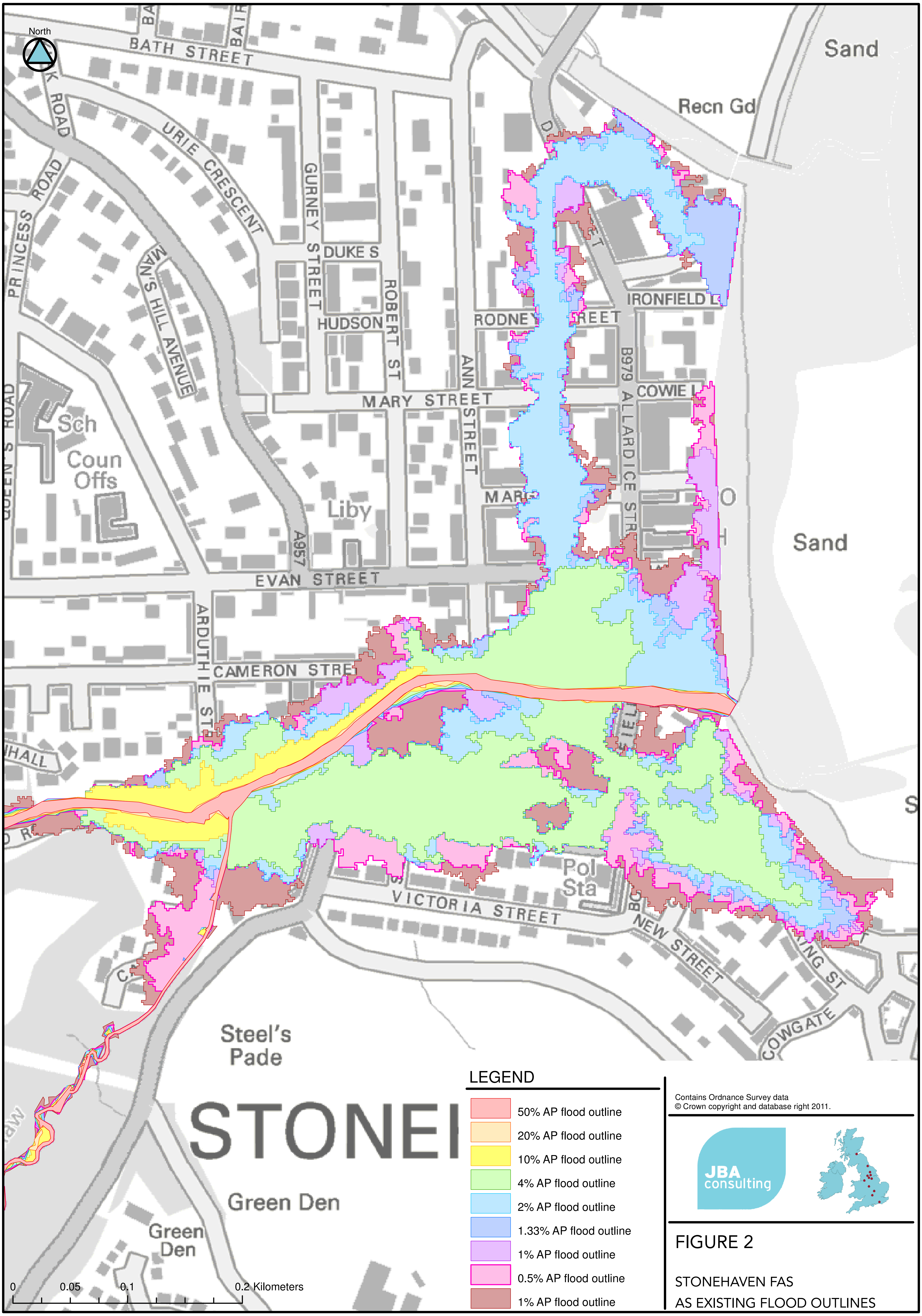


FIGURE 2

STONEHAVEN FAS

AS EXISTING FLOOD OUTLINES

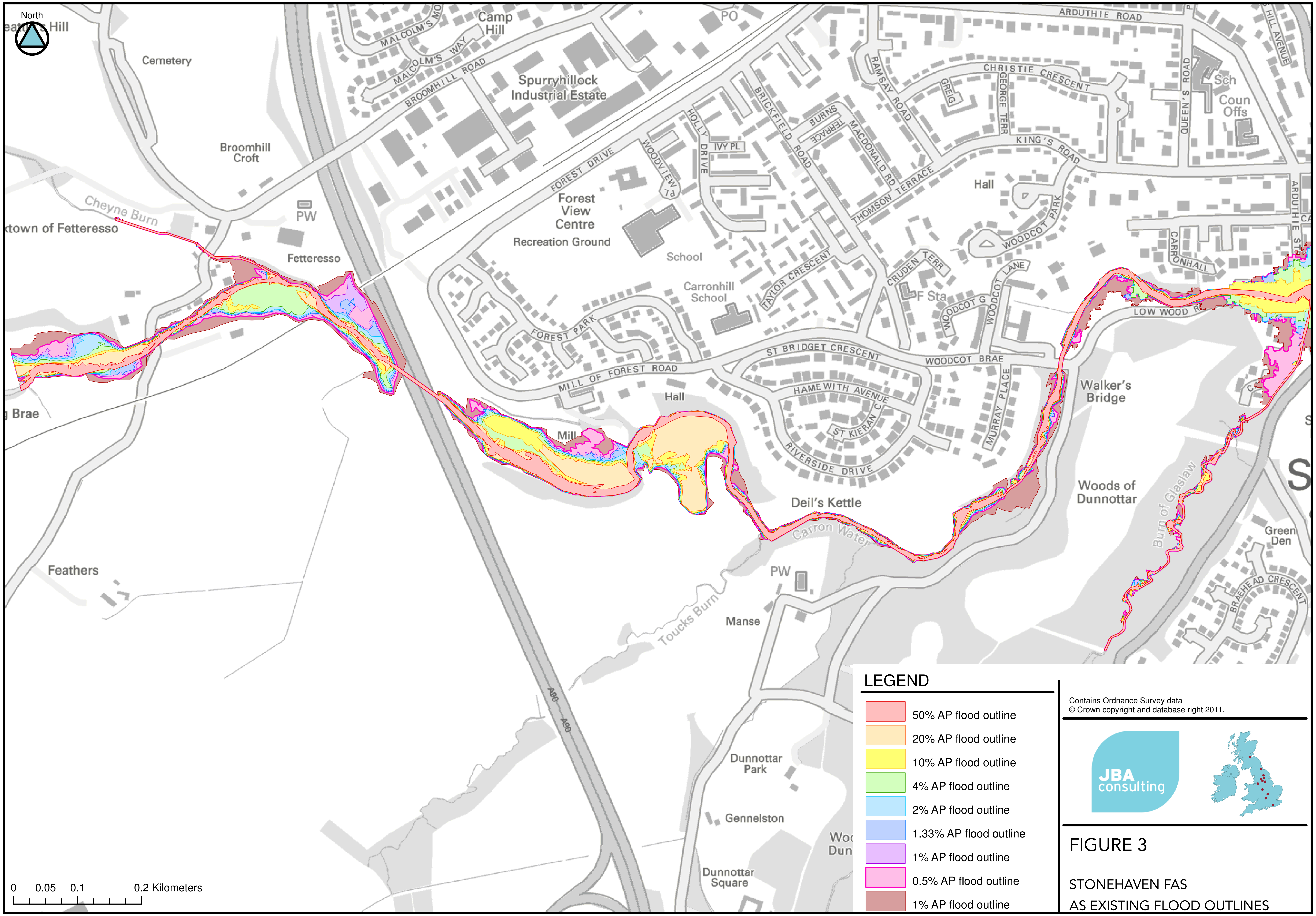
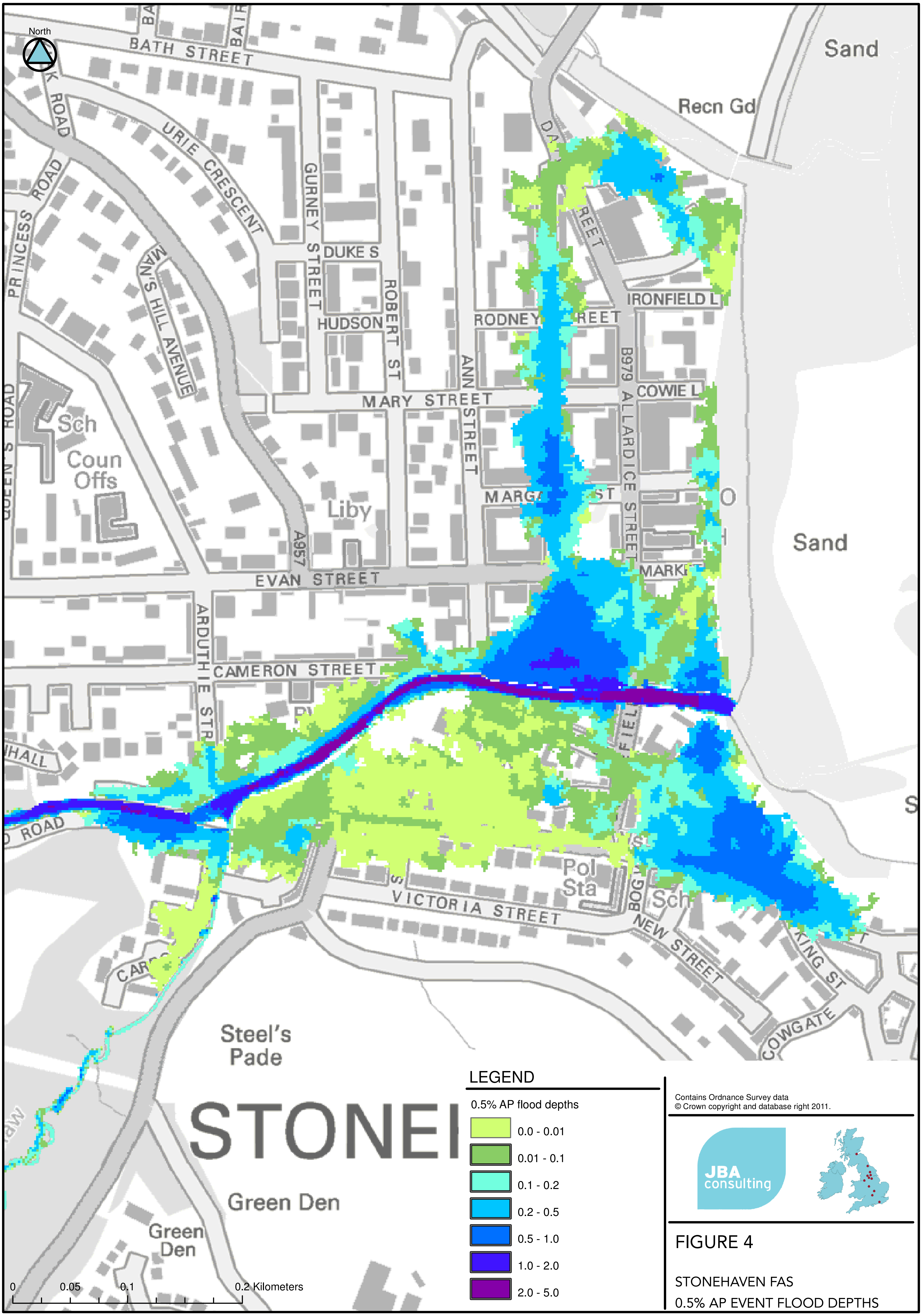


FIGURE 3

STONEHAVEN FAS

AS EXISTING FLOOD OUTLINES



North
BATH STREET
URIE CRESCENT
GURNEY STREET
DUKE S
HUDSON
ROBERT ST
RODNEY
REET
IRONFIELD L
COWIE L
MARY STREET
ANN STREET
ALLARDICE STREET
B979
MARG
ST
MARKE
EVAN STREET
A957
CAMERON STREET
ARDUTHIE STR
PRINCESS ROAD
QUEEN'S ROAD
MAN'S HILL AVENUE
Sch
Coun Offs
Liby
Sand
Recn Gd
HALL
ROAD
Pol Sta
VICTORIA STREET
NEW STREET
KING ST
COWGATE
Sch
Steel's Pade
STONEI
Green Den
Green Den
0 0.05 0.1 0.2 Kilometers
LEGEND
0.5% AP flood depths
0.0 - 0.01
0.01 - 0.1
0.1 - 0.2
0.2 - 0.5
0.5 - 1.0
1.0 - 2.0
2.0 - 5.0
Contains Ordnance Survey data
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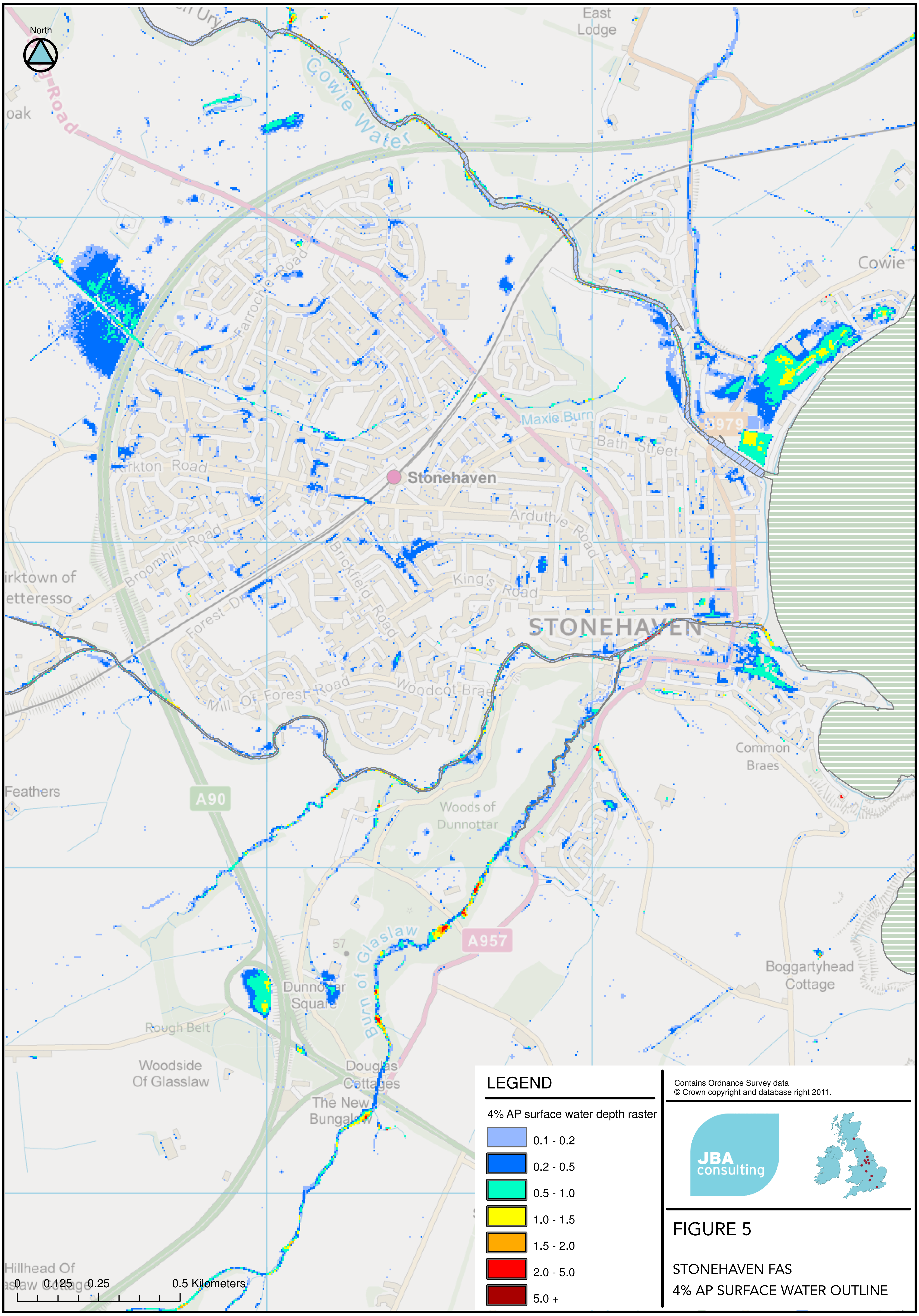
JBA consulting
FIGURE 4
STONEHAVEN FAS
0.5% AP EVENT FLOOD DEPTHS



LEGEND

4% AP surface water depth raster

- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 5.0
- 5.0 +

JBA consulting

FIGURE 5

STONEHAVEN FAS

4% AP SURFACE WATER OUTLINE

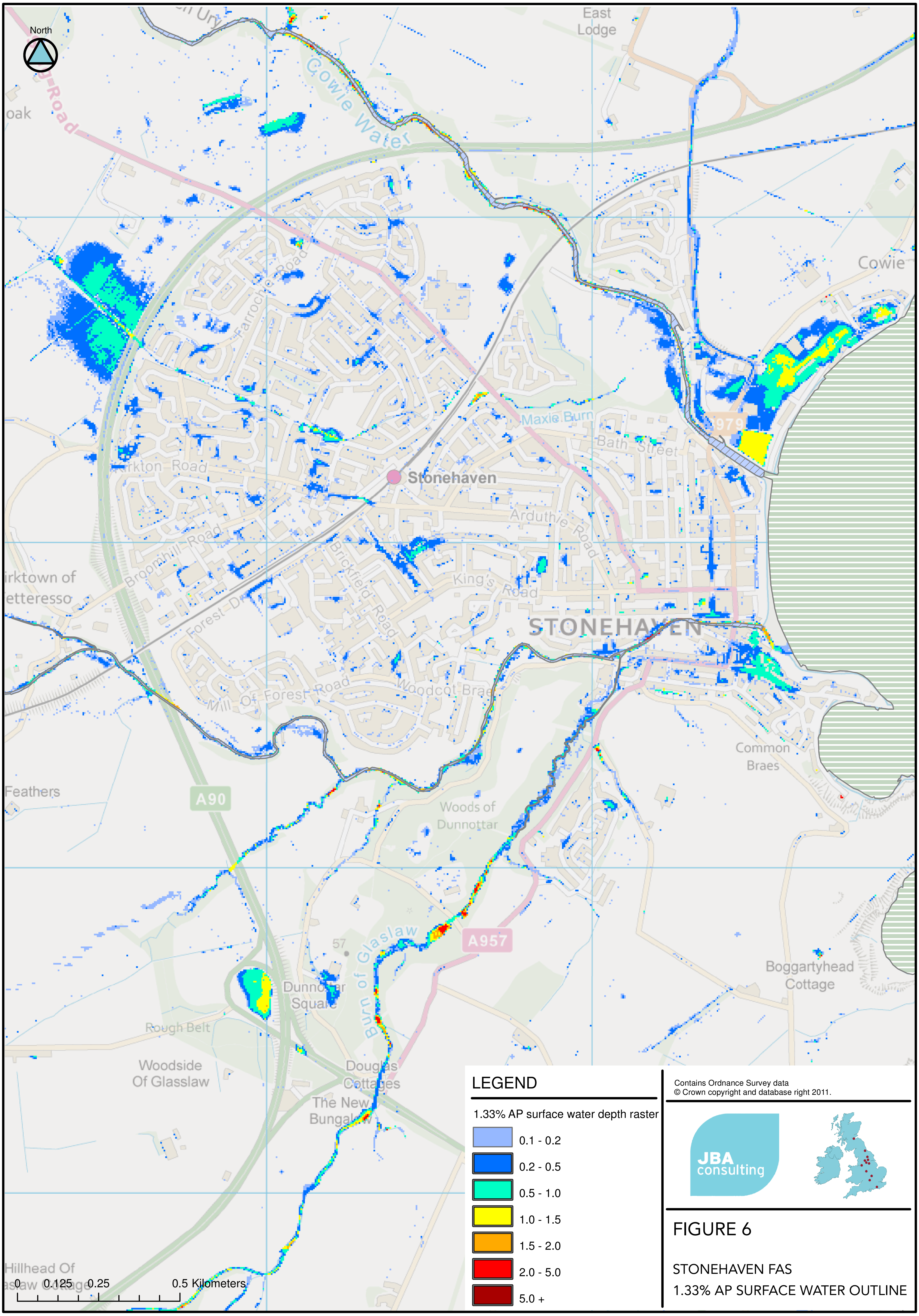


FIGURE 6

STONEHAVEN FAS

1.33% AP SURFACE WATER OUTLINE

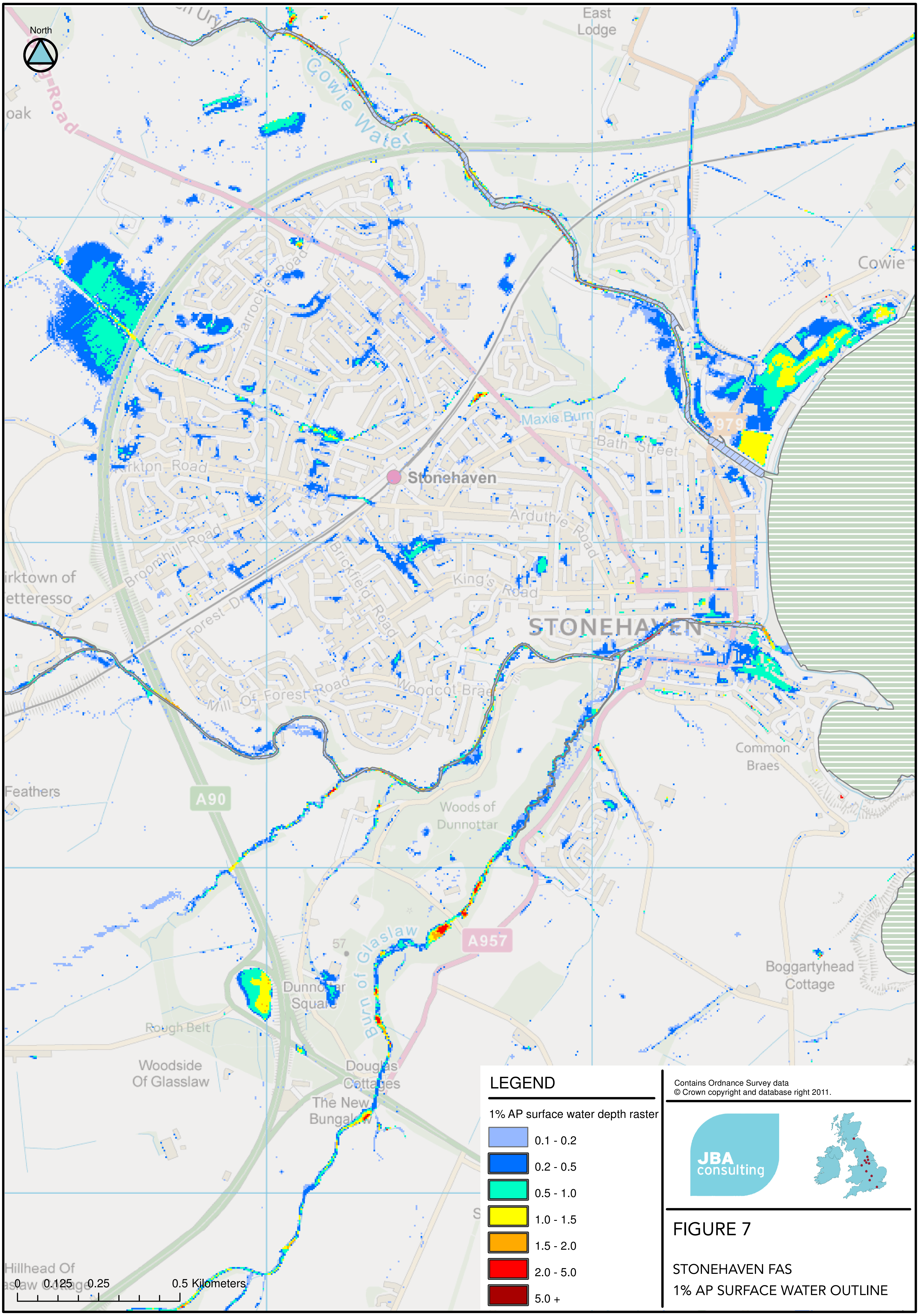


FIGURE 7

STONEHAVEN FAS
1% AP SURFACE WATER OUTLINE

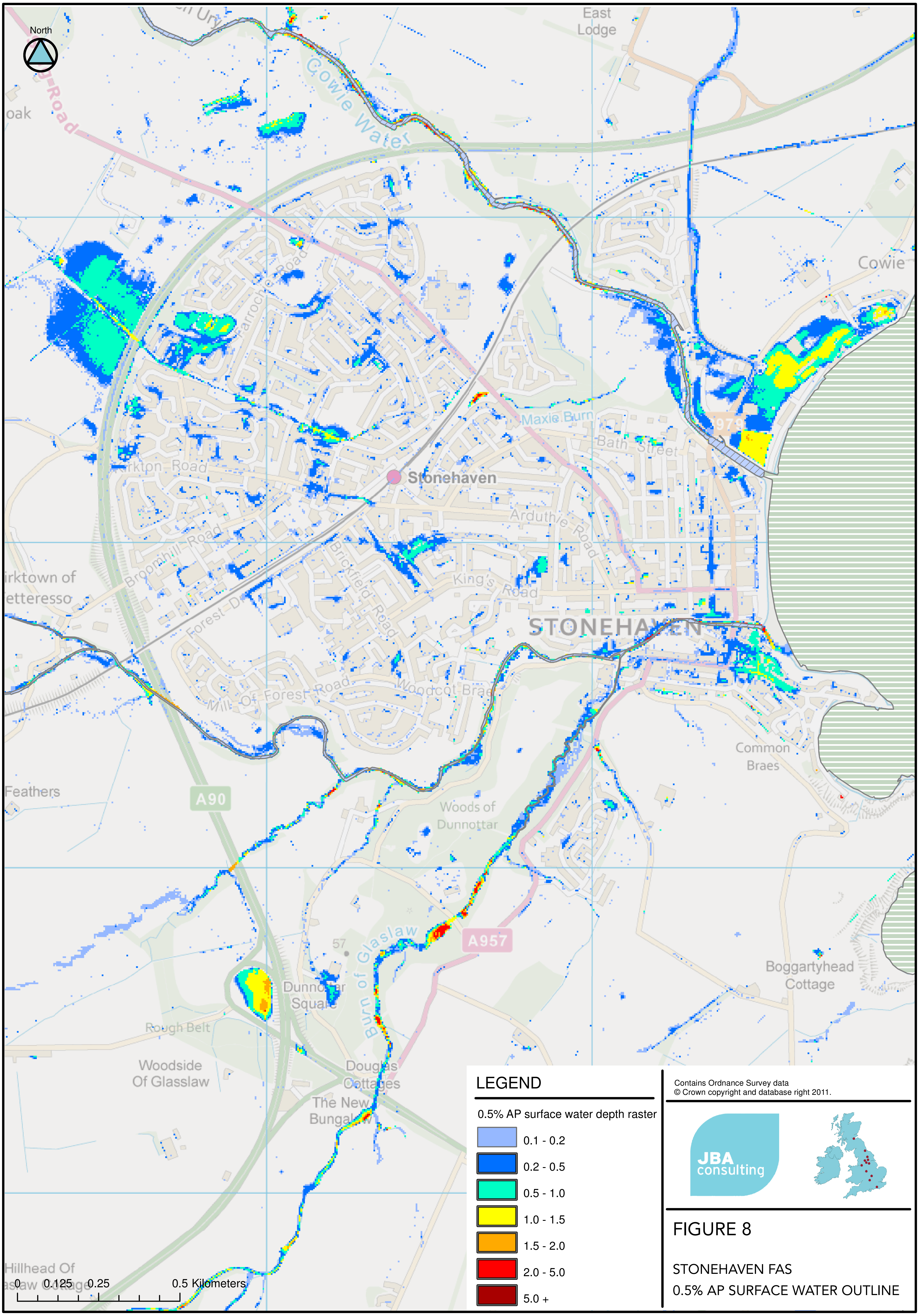
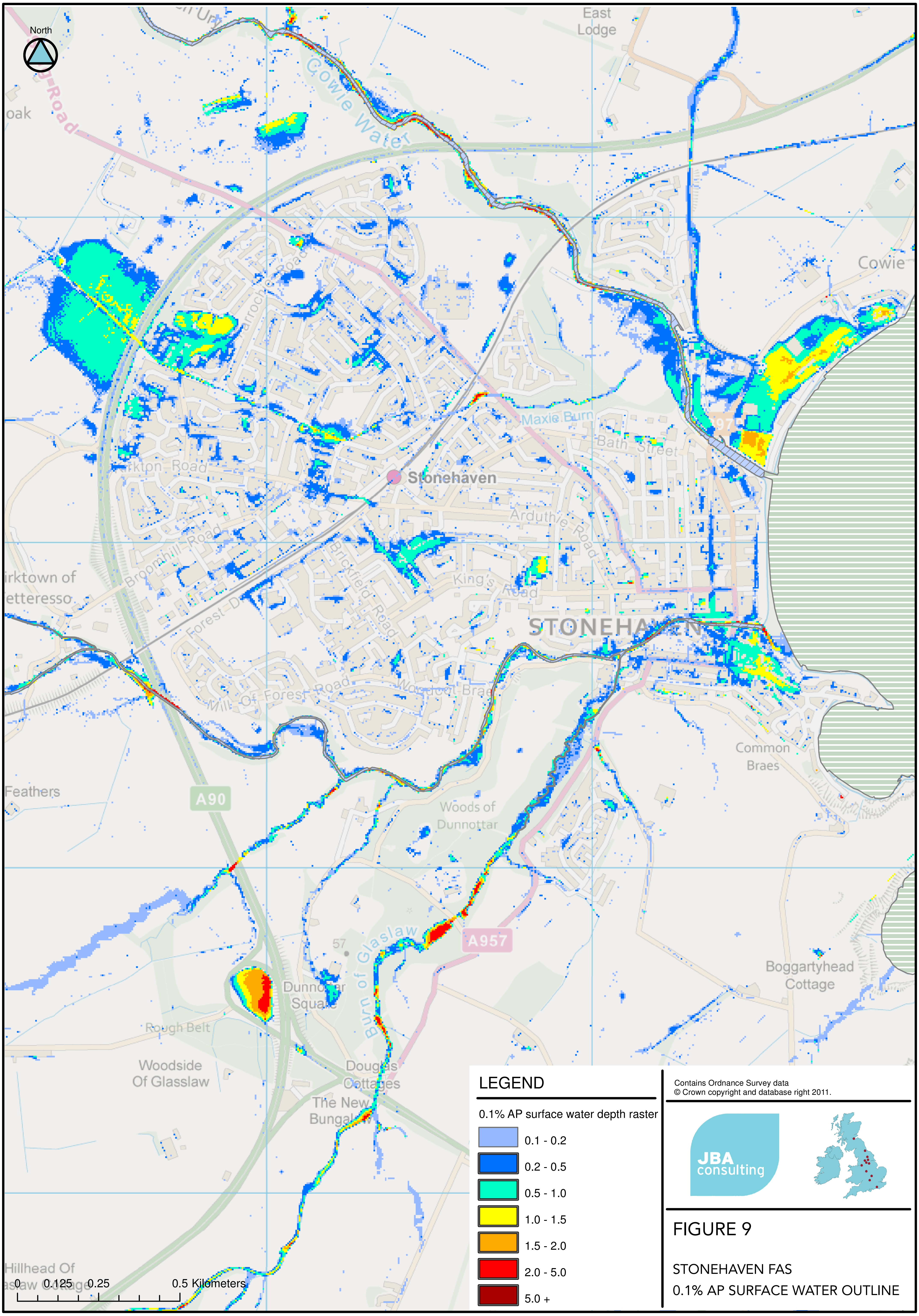


FIGURE 8

STONEHAVEN FAS

0.5% AP SURFACE WATER OUTLINE



LEGEND

0.1% AP surface water depth raster

- 0.1 - 0.2
- 0.2 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 5.0
- 5.0 +

JBA consulting

FIGURE 9

STONEHAVEN FAS

0.1% AP SURFACE WATER OUTLINE

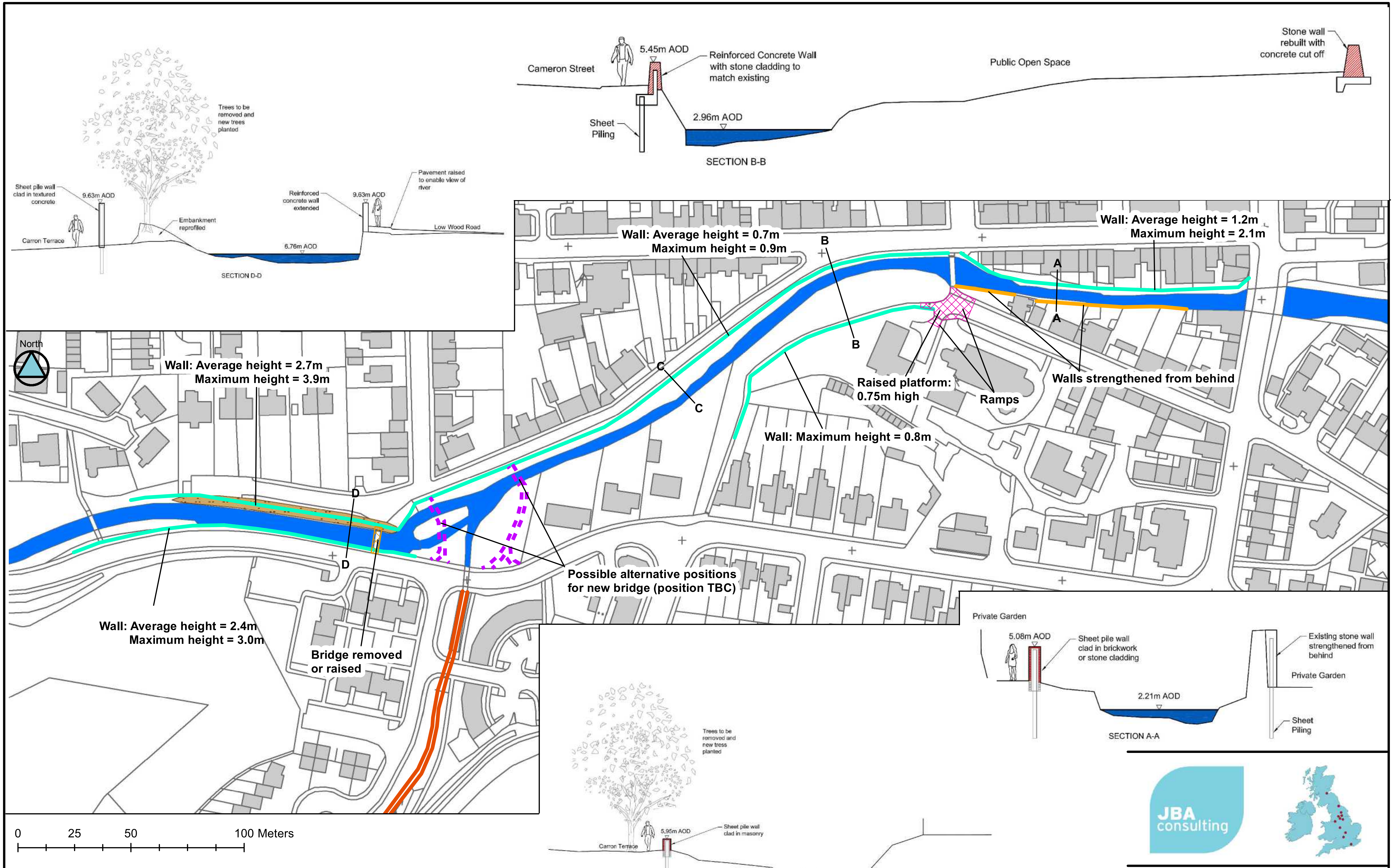


FIGURE 10

STONEHAVEN FAS, OPTION 2

Appendices

A Model results

A.1 As existing scenario model results

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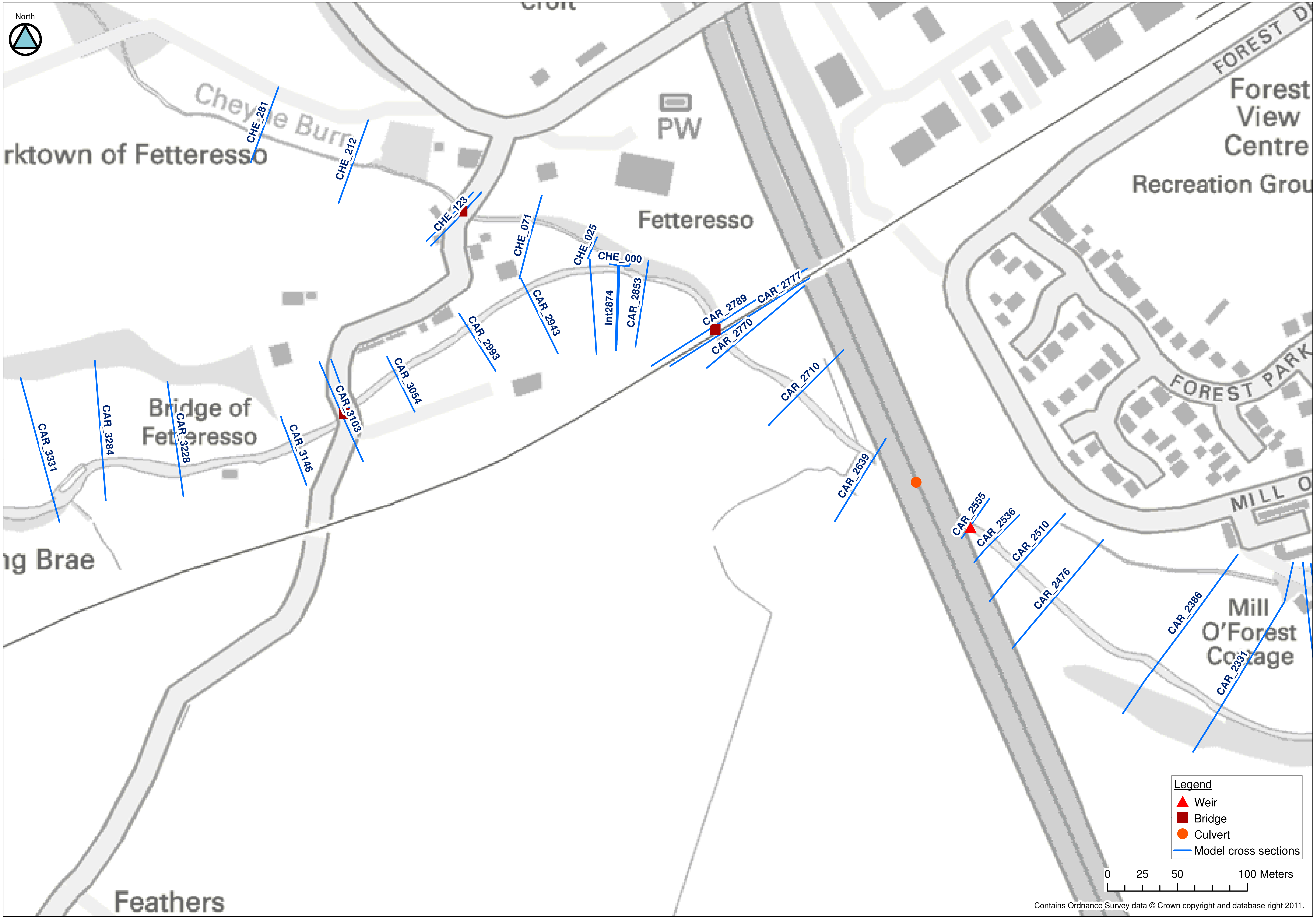
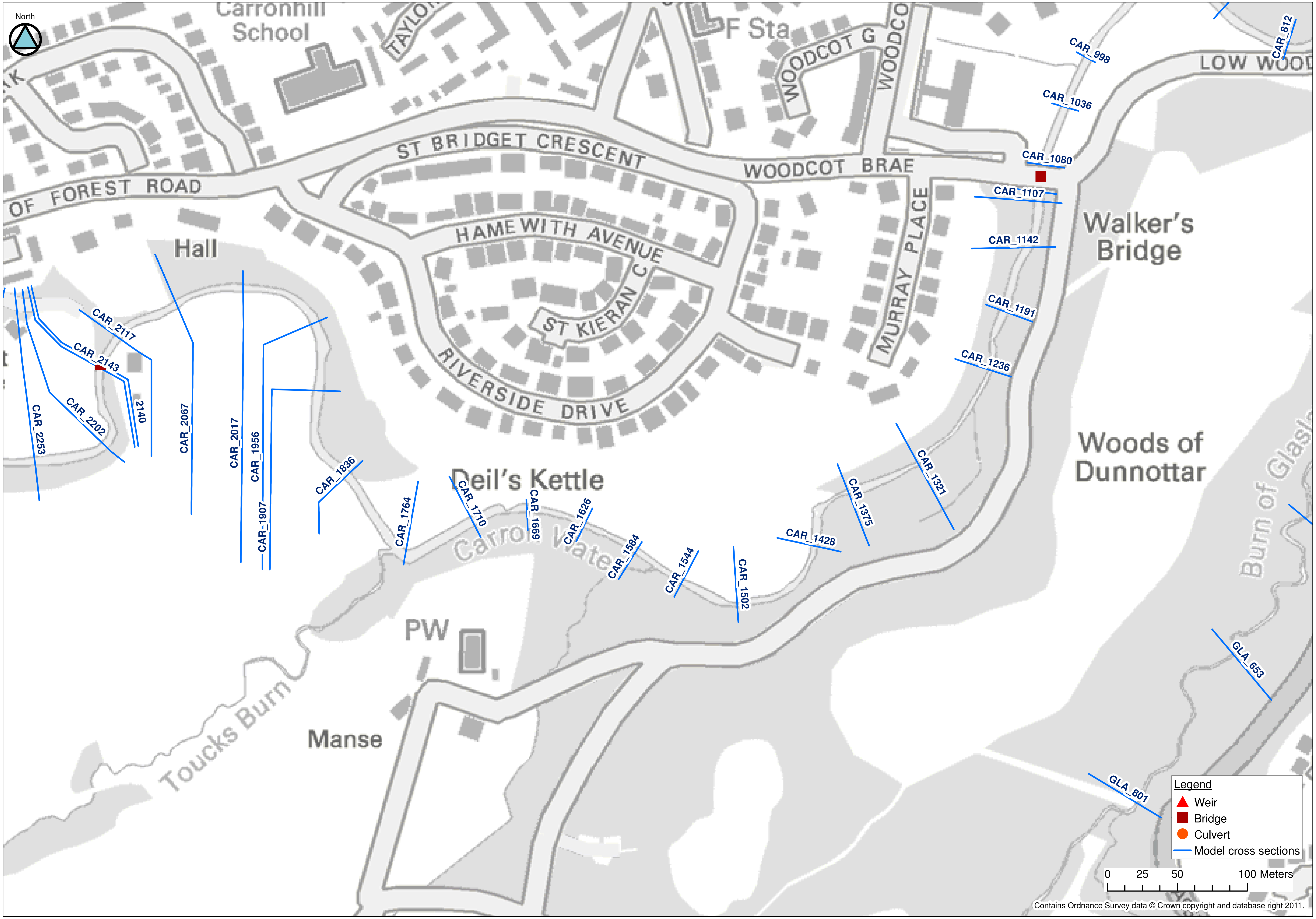
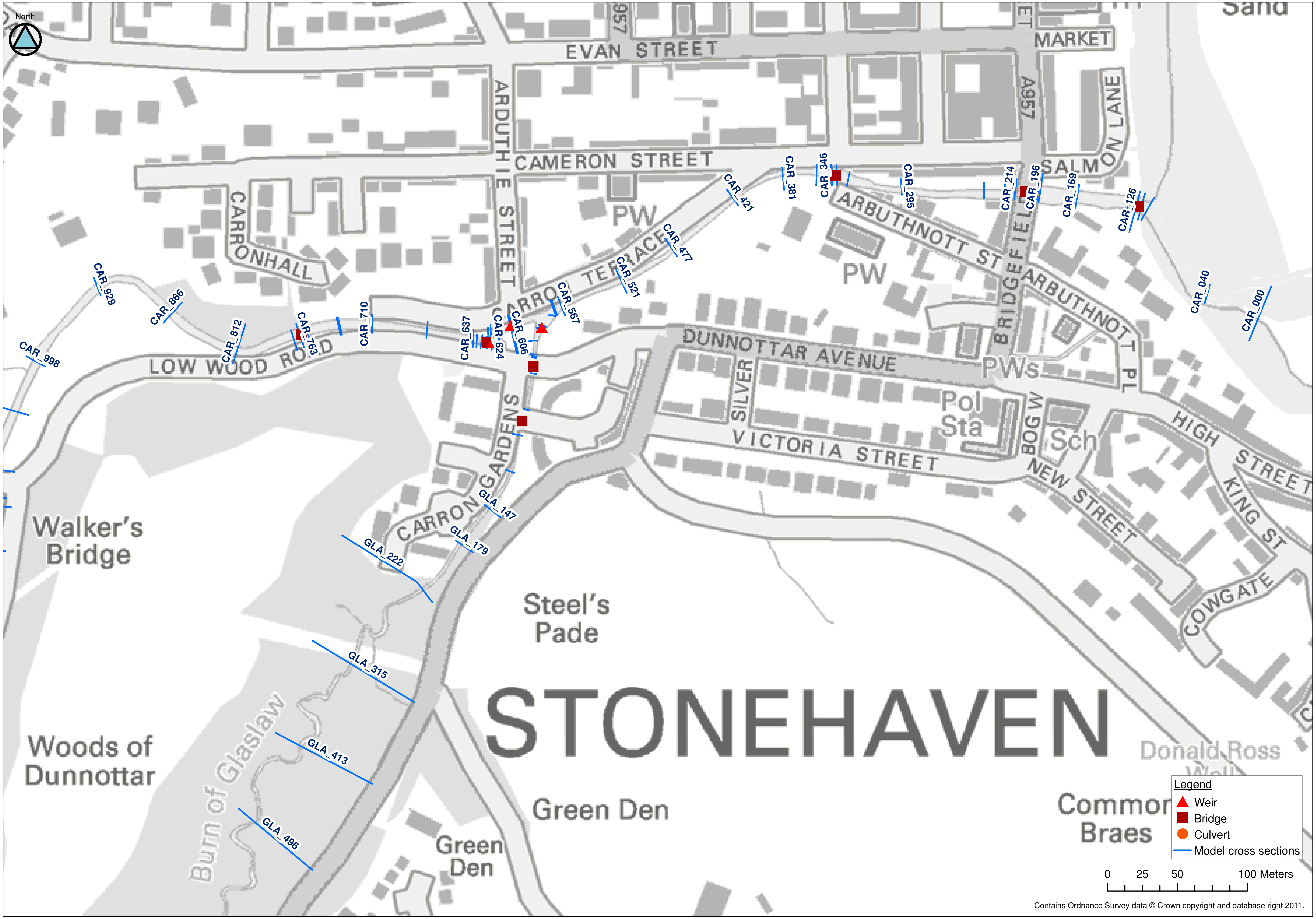


North
Cheyne Burn
Kirktown of Fetteresso
PW
Fetteresso
Forest View Centre
Recreation Grou
FOREST D
FOREST PARK
MILL O
Bridge of Fetteresso
ng Brae
Mill O'Forest Cottage
Feathers
CHE_281
CHE_212
CHE_123
CHE_071
CHE_025
CHE_000
Int2874
CAR_2853
CAR_2943
CAR_2993
CAR_3054
CAR_3103
CAR_3146
CAR_3228
CAR_3284
CAR_3331
CAR_2789
CAR_2777
CAR_2770
CAR_2710
CAR_2639
CAR_2555
CAR_2536
CAR_2510
CAR_2476
CAR_2386
CAR_2331
Legend
Weir
Bridge
Culvert
Model cross sections
0 25 50 100 Meters


North
Carronhill School
F Sta
WOODCOT G
WOODCO
LOW WOOD
ST BRIDGET CRESCENT
WOODCOT BRAE
OF FOREST ROAD
HAME WITH AVENUE
ST KIERAN C
RIVERSIDE DRIVE
MURRAY PLACE
Hall
Walker's Bridge
Woods of Dunnottar
Burn of Glasl
Deil's Kettle
Carron Water
PW
Manse
Toucks Burn
CAR_812
CAR_998
CAR_1036
CAR_1080
CAR_1107
CAR_1142
CAR_1191
CAR_1236
CAR_1321
CAR_1375
CAR_1428
CAR_1502
CAR_1544
CAR_1584
CAR_1626
CAR_1669
CAR_1710
CAR_1764
CAR_1836
CAR-1907
CAR_1956
CAR_2017
CAR_2067
2140
CAR_2117
CAR_2143
CAR_2202
CAR_2253
GLA_653
GLA_801
Legend
Weir
Bridge
Culvert
Model cross sections
0 25 50 100 Meters
Contains Ordnance Survey data © Crown copyright and database right 2011.


North
EVAN STREET
MARKET
A957
SALMON LANE
CAMERON STREET
ARDUTHIE STREET
CARRONHALL
PW
CARRON TERRACE
ARBUTHNOTT ST
BRIDGEFIELD
ARBUTHNOTT PL
LOW WOOD ROAD
DUNNOTTAR AVENUE
SILVER
PWs
Pol Sta
BOG W
Sch
HIGH STREET
VICTORIA STREET
NEW STREET
KING ST
COWGATE
CARRON GARDENS
Walker's Bridge
Steel's Pade
STONEHAVEN
Woods of Dunnottar
Burn of Glaslaw
Green Den
Green Den
Common Braes
Donald Ross
Sand
CAR_998
CAR_929
CAR_866
CAR_812
CAR_763
CAR_710
CAR_637
CAR_624
CAR_606
CAR_567
CAR_521
CAR_477
CAR_421
CAR_381
CAR_346
CAR_295
CAR_214
CAR_196
CAR_169
CAR_126
CAR_040
CAR_000
GLA_147
GLA_179
GLA_222
GLA_315
GLA_413
GLA_496
Legend
Weir
Bridge
Culvert
Model cross sections
0 25 50 100 Meters

River Carron 'As existing' scenario - model results by cross section

Node	Level (mAOD)			Water levels by event (mAOD)									
				2yr	5yr	10yr	25yr	50yr	75yr	100yr	200yr	200+CC	1000yr
	Bed	LB	RB	50% AP	2% AP	10% AP	4% AP	2% AP	1.33% AP	1% AP	0.5% AP	0.5% AP+CC	0.1% AP
CAR_3331	31.95	33.46	40.91	33.15	33.34	33.44	33.54	33.62	33.67	33.70	33.79	33.88	33.96
CAR_3284	31.27	32.82	32.34	32.66	32.85	32.94	33.07	33.16	33.21	33.24	33.33	33.46	33.59
CAR_3228	31.05	31.77	33.51	32.14	32.25	32.34	32.46	32.57	32.64	32.69	32.84	33.09	33.43
CAR_3146	30.26	31.25	31.69	31.22	31.49	31.61	31.82	32.00	32.15	32.26	32.54	32.91	33.34
CAR_3103	29.61	30.61	32.24	30.99	31.24	31.40	31.64	31.84	31.98	32.09	32.38	32.76	33.23
CAR_3096	29.62	30.61	32.57	30.75	30.97	31.10	31.27	31.41	31.49	31.55	31.69	31.87	32.05
CAR_3054	29.20	30.44	30.28	30.47	30.67	30.81	30.96	31.09	31.16	31.21	31.34	31.58	31.98
CAR_2993	28.89	29.71	29.69	29.96	30.20	30.32	30.45	30.55	30.61	30.65	30.80	31.50	31.97
CAR_2943	28.30	29.30	29.92	29.64	29.83	29.93	30.03	30.11	30.15	30.18	30.48	31.50	31.97
CAR_2894	28.04	29.33	29.11	29.34	29.52	29.61	29.73	29.81	29.85	29.90	30.43	31.50	31.97
CAR_2873	27.89	28.95	29.04	29.18	29.39	29.48	29.61	29.70	29.75	29.81	30.41	31.49	31.97
CAR_2874	27.89	28.95	29.04	29.18	29.39	29.48	29.61	29.70	29.75	29.81	30.41	31.49	31.97
CAR_2853	27.72	28.54	28.98	28.97	29.23	29.34	29.50	29.60	29.65	29.74	30.40	31.49	31.96
CAR_2789	27.43	29.12	28.20	28.65	28.85	28.96	29.09	29.23	29.39	29.60	30.39	31.49	31.96
CAR_2777	27.43	29.12	28.20	28.43	28.58	28.69	28.85	29.02	29.15	29.53	30.38	31.49	31.96
CAR_2770	27.20	28.16	28.24	28.15	28.31	28.43	28.64	28.93	29.23	29.53	30.38	31.49	31.96
CAR_2710	26.22	27.29	27.16	27.40	27.66	27.84	28.22	28.78	29.16	29.49	30.37	31.48	31.96
CAR_2639	25.86	28.39	27.05	26.88	27.30	27.54	28.15	28.75	29.15	29.48	30.36	31.48	31.95
CAR_2555	24.72	26.65	27.47	26.08	26.30	26.45	26.64	26.78	26.85	26.90	27.02	27.19	27.37
CAR_2536	24.22	25.88	26.03	25.65	25.84	25.96	26.11	26.22	26.28	26.32	26.42	26.55	26.69
CAR_2510	23.93	25.57	25.39	25.21	25.38	25.48	25.61	25.70	25.75	25.79	25.87	25.98	26.09
CAR_2476	23.67	24.82	24.71	24.90	25.04	25.12	25.21	25.28	25.32	25.35	25.42	25.50	25.60
CAR_2386	22.91	23.97	23.76	24.03	24.16	24.25	24.32	24.39	24.43	24.45	24.51	24.59	24.67
CAR_2331	22.49	23.36	23.07	23.55	23.66	23.75	23.82	23.89	23.93	23.96	24.04	24.12	24.23
CAR_2253	22.01	22.74	22.73	23.03	23.20	23.32	23.38	23.46	23.53	23.57	23.67	23.80	23.95
CAR_2202	21.28	22.86	24.00	22.62	23.03	23.20	23.22	23.28	23.38	23.43	23.54	23.69	23.86
CAR_2143	20.47	22.71	22.70	22.09	22.26	22.35	22.45	22.96	23.15	23.24	23.40	23.57	23.76
CAR_2140	20.47	22.71	22.70	22.09	22.26	22.37	22.49	22.57	22.62	22.66	22.73	22.81	22.91
CAR_2117	20.82	22.78	21.87	21.89	22.02	22.11	22.17	22.23	22.25	22.27	22.32	22.39	22.47
CAR_2067	20.58	22.04	21.45	21.38	21.48	21.55	21.59	21.63	21.66	21.67	21.71	21.76	21.82
CAR_2017	20.03	22.89	21.05	21.03	21.09	21.15	21.17	21.21	21.23	21.24	21.27	21.30	21.36
CAR_1956	19.73	22.19	20.46	20.59	20.67	20.72	20.78	20.82	20.86	20.88	20.93	21.00	21.09
CAR_1907	18.97	20.94	20.25	19.64	19.78	19.85	19.94	20.02	20.06	20.09	20.17	20.29	20.41
CAR_1836	17.32	18.67	19.07	18.18	18.34	18.44	18.56	18.66	18.73	18.77	18.87	19.01	19.18
CAR_1764	16.30	18.34	18.55	17.33	17.50	17.61	17.74	17.86	17.93	17.98	18.10	18.26	18.45
CAR_1710	15.60	17.60	18.40	16.51	16.68	16.81	16.96	17.08	17.16	17.21	17.34	17.52	17.73
CAR_1669	14.91	17.62	17.27	15.83	16.02	16.15	16.31	16.44	16.52	16.58	16.71	16.89	17.12
CAR_1626	14.42	17.05	17.48	15.40	15.58	15.71	15.88	16.01	16.08	16.14	16.27	16.44	16.64
CAR_1584	13.94	16.86	15.73	15.07	15.28	15.41	15.59	15.72	15.80	15.85	15.96	16.10	16.28
CAR_1544	13.74	15.43	18.06	14.73	14.94	15.05	15.20	15.32	15.41	15.47	15.57	15.71	15.90
CAR_1502	13.33	17.62	17.67	14.34	14.55	14.68	14.84	14.93	15.01	15.07	15.16	15.28	15.43
CAR_1428	12.77	14.03	14.65	13.83	13.97	14.08	14.22	14.31	14.36	14.39	14.47	14.59	14.72
CAR_1375	12.37	17.26	13.53	13.11	13.27	13.39	13.52	13.63	13.69	13.73	13.83	13.95	14.11
CAR_1321	11.01	13.10	13.15	12.33	12.54	12.69	12.85	12.97	13.04	13.08	13.20	13.34	13.55
CAR_1236	10.98	12.55	12.59	11.70	11.85	11.95	12.07	12.17	12.24	12.28	12.40	12.62	12.98
CAR_1191	10.39	12.93	11.82	11.21	11.34	11.44	11.57	11.70	11.79	11.86	12.07	12.45	12.96
CAR_1142	10.23	11.30	11.77	10.78	11.01	11.18	11.41	11.60	11.72	11.81	12.06	12.43	12.96
CAR_1107	9.19	11.15	11.56	10.53	10.76	10.93	11.16	11.39	11.52	11.63	11.93	12.36	12.93
CAR_1100	9.31	13.21	13.19	10.46	10.65	10.79	10.97	11.13	11.23	11.30	11.52	11.88	12.40
CAR_1080	9.35	13.24	13.20	10.45	10.62	10.73	10.85	10.96	11.01	11.05	11.19	11.39	11.66
CAR_1036	9.24	11.23	10.50	10.00	10.18	10.31	10.46	10.60	10.68	10.75	10.90	11.12	11.40
CAR_998	8.58	9.80	9.98	9.68	9.89	10.03	10.20	10.34	10.42	10.48	10.63	10.83	11.10
CAR_929	8.31	10.91	9.61	9.28	9.47	9.59	9.75	9.87	9.93	9.98	10.09	10.23	10.44
CAR_866	8.10	8.90	9.88	8.73	8.93	9.08	9.27	9.42	9.51	9.58	9.73	9.92	10.31
CAR_812	7.31	11.74	11.48	8.31	8.59	8.74	8.92	9.03	9.10	9.16	9.31	9.61	10.17
CAR_768	6.95	8.17	9.88	8.19	8.49	8.64	8.80	8.89	8.95	8.99	9.10	9.31	9.89
CAR_763	6.94	9.02	9.36	8.16	8.46	8.62	8.77	8.87	8.92	8.96	9.08	9.30	9.96
CAR_757	6.89	8.73	9.43	8.16	8.46	8.62	8.77	8.86	8.92	8.95	9.04	9.14	9.29
CAR_734	6.83	7.68	8.93	8.09	8.41	8.57	8.72	8.81	8.85	8.89	8.96	9.06	9.18
CAR_733	6.83	7.68	8.93	8.09	8.41	8.57	8.72	8.80	8.85	8.88	8.95	9.05	9.16
CAR_710	6.80	8.66	8.66	8.01	8.35	8.51	8.65	8.72	8.76	8.78	8.84	8.92	9.00
CAR_671	6.60	8.24	8.17	7.89	8.25	8.42	8.57	8.66	8.70	8.74	8.81	8.92	9.06
CAR_637	6.26	8.49	8.01	7.83	8.22	8.41	8.59	8.70	8.77	8.81	8.92	9.08	9.29
CAR_635	6.30	7.80	8.00	7.82	8.21	8.40	8.58	8.69	8.75	8.80	8.91	9.07	9.29
CAR_631	6.32	7.47	8.10	7.81	8.11	8.23	8.35	8.41	8.45	8.47	8.53	8.60	8.68
CAR_627	6.35	8.24	8.11	7.79	8.09	8.21	8.33	8.39	8.43	8.45	8.51	8.58	8.66
CAR_625	5.00	7.86	8.13	6.71	6.87	6.96	7.05	7.10	7.13	7.16	7.22	7.30	7.39
CAR_624	5.00	7.86	8.13	6.70	6.83	6.91	6.99	7.04	7.07	7.10	7.16	7.24	7.33
CAR_617	6.16	6.28	6.58	6.58	6.70	6.78	6.85	6.91	6.93	6.96	7.01	7.08	7.18
CAR_606	5.64	6.28	6.58	6.25	6.38	6.47	6.56	6.62	6.65	6.67	6.73	6.82	6.93
CAR_605	5.64	6.28	6.58	6.21	6.34	6.43	6.52	6.58	6.61	6.64	6.70	6.79	6.90
CAR_573	3.93	5.79	5.64	4.98	5.25	5.41	5.60	5.72	5.79	5.85	5.99	6.18	6.31
CAR_572	3.88	5.78	5.61	4.98	5.25	5.41	5.60	5.72	5.79	5.85	5.99	6.18	6.31
CAR_567	3.63	5.70	5.46	4.94	5.19	5.35	5.53	5.66	5.73	5.79	5.93	6.12	6.25
CAR_521	3.50	5.44	6.33	4.77	5.02	5.17	5.38	5.53	5.61	5.66	5.77	5.88	6.00
CAR_477	3.43	5.26	5.57	4.55	4.81	4.97	5.16	5.30	5.38	5.43	5.54	5.65	5.75
CAR_421	2.97	4.96	3.91	4.15	4.39	4.56	4.75	4.89	4.96	5.00	5.07	5.14	5.22
CAR_381	2.52	5.27	3.64	3.81	4.04	4.26	4.49	4.66	4.75	4.81	4.92	5.05	5.14
CAR_357	2.54	5.16	3.77	3.54	3.78	3.95	4.17	4.36	4.46	4.53	4.67	4.80	4.93
CAR_347	2.72	5.26	4.60	3.62	3.93	4.12	4.36	4.54	4.64	4.70	4.82	4.96	5.09
CAR_346	2.72	5.26	4.60	3.61	3.92	4.12	4.35	4.54	4.63	4.70	4.82	4.95	5.08
CAR_343	2.72	5.26	4.60	3.61	3.92	4.12	4.35	4.52	4.61	4.67	4.78	4.89	5.00
CAR_334	2.38	5.01	5.67	3.56	3.85	4.04	4.25	4.42	4.50	4.56	4.67	4.78	4.89
CAR_295	1.85	3.47	5.66	3.45	3.77	3.95	4.17	4.35	4.43	4.49	4.61	4.73	4.85
CAR_236	1.80	3.45	5.22	3.17	3.39	3.56	3.76	3.96	4.05	4.12	4.25	4.39	4.53
CAR_221	1.71	3.48	6.83	3.08	3.29	3.45	3.65	3.83	3.93	4.00	4.13	4.27	4.42
CAR_214	1.97	6.23	6.24	3.06	3.28	3.44	3.64	3.83	3.93	4.00	4.13	4.27	4.42
CAR_200	1.97	6.23	6.24	3.06	3.28	3.44	3.64	3.82	3.91	3.98	4.10	4.21	4.33
CAR_198	1.97	6.23	6.24	3.06	3.27	3.43	3.63	3.81	3.91	3.97	4.09	4.21	4.32
CAR_196	1.40	5.97	5.86	3.00	3.20	3.35	3.54	3.71	3.80	3.86	3.98	4.09	4.20
CAR_169	1.56	3.27	3.23	2.93	3.09	3.21	3.39	3.57	3.66	3.73	3.85	3.98	4.09
CAR_132	1.22	3.29	3.47	2.86	2.98	3.08	3.25	3.44	3.55	3.62	3.76	3.90	4.03
CAR_126	1.41	3.73	5.76	2.85	2.97	3.06	3.23	3.41	3.52	3.59	3.73	3.87	4.01
CAR_122	1.29	3.73	3.72	2.85	2.97	3.06	3.23	3.41	3.51	3.58	3.68	3.78	3.87
CAR_117	1.02	4.23	4.26	2.84	2.93	3.02	3.18	3.35	3.44	3.50	3.60	3.70	3.78
CAR_040	0.50	3.40	4.22	2.71	2.69	2.66	2.62	2.57	2.56	2.56	2.60	2.66	2.71
CAR_000	0.91	1.15	2.33	2.73	2.73	2.73	2.73	2.73	2.73	2.73	2.73	2.73	2.71

Cheyne Burn 'As existing' scenario - model results by cross section

Node	Level (mAOD)			Water levels by event (mAOD)									
				2yr	5yr	10yr	25yr	50yr	75yr	100yr	200yr	200+CC	1000yr
	Bed	LB	RB	50% AP	2% AP	10% AP	4% AP	2% AP	1.33% AP	1% AP	0.5% AP	.5% AP+C	0.1% AP
CHE_281	33.81	34.60	36.03	34.57	34.57	34.57	34.57	34.57	34.59	34.61	34.67	34.73	34.78
CHE_212	32.78	33.39	34.61	33.39	33.39	33.39	33.39	33.39	33.40	33.42	33.47	33.53	33.58
CHE_129	31.23	33.28	32.66	31.70	31.70	31.70	31.70	31.70	31.71	31.73	31.80	31.86	32.02
CHE_123	31.23	33.28	32.66	31.70	31.70	31.70	31.70	31.70	31.71	31.73	31.80	31.86	32.02
CHE_071	29.87	30.73	30.40	30.48	30.48	30.48	30.48	30.48	30.48	30.50	30.57	31.49	31.97
CHE_025	29.23	30.89	29.73	29.57	29.57	29.61	29.70	29.76	29.80	29.85	30.42	31.49	31.97
CHE_000	27.90	30.89	29.73	29.18	29.39	29.48	29.61	29.70	29.75	29.81	30.41	31.49	31.97

Glaslaw Burn 'As existing' scenario - model results by cross section

Node	Level (mAOD)			Water levels by event (mAOD)									
				2yr	5yr	10yr	25yr	50yr	75yr	100yr	200yr	200+CC	1000yr
	Bed	LB	RB	50% AP	2% AP	10% AP	4% AP	2% AP	1.33% AP	1% AP	0.5% AP	.5% AP+C	0.1% AP
GLA_801	21.13	21.72	22.36	21.73	21.80	21.85	21.89	21.92	21.94	21.95	21.99	22.04	22.08
GLA_653	18.54	18.91	18.96	18.85	18.93	18.96	19.00	19.03	19.04	19.05	19.07	19.09	19.12
GLA_496	15.23	15.55	16.31	15.54	15.59	15.62	15.67	15.72	15.74	15.75	15.79	15.84	15.91
GLA_413	13.42	14.61	14.36	13.75	13.81	13.86	13.90	13.93	13.95	13.96	14.00	14.04	14.09
GLA_315	11.23	11.62	12.54	11.66	11.74	11.78	11.85	11.90	11.93	11.95	12.00	12.06	12.13
GLA_222	9.62	10.55	10.31	10.01	10.10	10.18	10.27	10.34	10.39	10.42	10.49	10.55	10.62
GLA_179	8.65	10.01	9.60	9.19	9.30	9.38	9.47	9.55	9.60	9.63	9.72	9.81	9.90
GLA_147	8.22	9.53	9.70	8.59	8.66	8.72	8.79	8.85	8.89	8.92	9.00	9.09	9.21
GLA_116	7.52	9.11	8.91	7.93	8.00	8.07	8.16	8.23	8.28	8.32	8.42	8.54	8.67
GLA_089	6.89	8.79	8.51	7.44	7.44	7.51	7.67	7.80	7.89	7.97	8.18	8.38	8.55
GLA_070	6.72	9.26	8.20	7.44	7.44	7.49	7.63	7.74	7.81	7.87	8.02	8.20	8.31
GLA_044	6.40	9.18	8.07	6.95	6.99	7.25	7.42	7.53	7.60	7.66	7.80	8.00	8.18
GLA_033	6.43	7.10	8.02	6.95	6.99	7.24	7.40	7.49	7.55	7.59	7.70	7.82	7.92
GLA_032	6.40	7.10	8.02	6.98	7.02	7.18	7.31	7.41	7.46	7.51	7.62	7.74	7.83
GLA_030	4.88	6.18	6.34	5.50	5.63	5.81	5.98	6.11	6.18	6.24	6.35	6.50	6.65
GLA_020	4.88	6.18	6.34	5.41	5.53	5.71	5.88	6.00	6.07	6.12	6.30	6.48	6.65
GLA_011	4.78	6.18	6.34	5.35	5.46	5.64	5.80	5.92	5.98	6.04	6.17	6.34	6.50
GLA_009	4.00	6.18	6.34	4.99	5.26	5.43	5.61	5.74	5.81	5.87	6.01	6.20	6.34
GLA_000	3.90	6.18	6.34	4.98	5.25	5.41	5.60	5.72	5.79	5.85	5.99	6.18	6.31

A.2 Flood alleviation options model results

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River Carron Options scenarios - 0.5% AP event model results by cross section

Node	Level (mAOD)			0.5% AP event water levels by scenario (mAOD)					
	Bed	LB	RB	As existing	Option 2	Option 3a	Option 3b	Option 4	Option 5
CAR_3331	31.95	33.46	40.91	33.79	33.79	33.79	33.79	33.79	33.79
CAR_3284	31.27	32.82	32.34	33.33	33.33	33.33	33.33	33.33	33.33
CAR_3228	31.05	31.77	33.51	32.84	32.84	32.84	32.84	32.84	32.84
CAR_3146	30.26	31.25	31.69	32.54	32.54	32.54	32.54	32.54	32.54
CAR_3103	29.61	30.61	32.24	32.38	32.38	32.38	32.38	32.38	32.38
CAR_3096	29.62	30.61	32.57	31.69	31.69	31.69	31.69	31.69	31.69
CAR_3054	29.20	30.44	30.28	31.34	31.34	31.34	31.34	31.34	31.34
CAR_2993	28.89	29.71	29.69	30.80	30.80	30.80	30.80	30.80	30.80
CAR_2943	28.30	29.30	29.92	30.48	30.48	30.48	30.48	30.48	30.48
CAR_2894	28.04	29.33	29.11	30.43	30.43	30.43	30.43	30.43	30.43
CAR_2873	27.89	28.95	29.04	30.41	30.41	30.41	30.41	30.41	30.41
CAR_2874	27.89	28.95	29.04	30.41	30.41	30.41	30.41	30.41	30.41
CAR_2853	27.72	28.54	28.98	30.40	30.40	30.40	30.40	30.40	30.40
CAR_2789	27.43	29.12	28.20	30.39	30.39	30.39	30.39	30.39	30.39
CAR_2777	27.43	29.12	28.20	30.38	30.38	30.38	30.38	30.38	30.38
CAR_2770	27.20	28.16	28.24	30.38	30.38	30.38	30.38	30.38	30.38
CAR_2710	26.22	27.29	27.16	30.37	30.37	30.37	30.37	30.37	30.37
CAR_2639	25.86	28.39	27.05	30.36	30.36	30.36	30.36	30.36	30.36
CAR_2555	24.72	26.65	27.47	27.02	27.02	27.02	27.02	27.02	27.02
CAR_2536	24.22	25.88	26.03	26.42	26.42	26.42	26.42	26.42	26.42
CAR_2510	23.93	25.57	25.39	25.87	25.87	25.87	25.87	25.87	25.87
CAR_2476	23.67	24.82	24.71	25.42	25.42	25.42	25.42	25.42	25.42
CAR_2386	22.91	23.97	23.76	24.51	24.51	24.51	24.51	24.51	24.51
CAR_2331	22.49	23.36	23.07	24.04	24.04	24.04	24.04	24.04	24.04
CAR_2253	22.01	22.74	22.73	23.67	23.67	23.67	23.67	23.67	23.67
CAR_2202	21.28	22.86	24.00	23.54	23.54	23.54	23.54	23.54	23.54
CAR_2143	20.47	22.71	22.70	23.40	23.40	23.40	23.40	23.40	23.40
CAR_2140	20.47	22.71	22.70	22.73	22.73	22.73	22.73	22.73	22.73
CAR_2117	20.82	22.78	21.87	22.32	22.32	22.32	22.32	22.32	22.32
CAR_2067	20.58	22.04	21.45	21.71	21.71	21.71	21.71	21.71	21.71
CAR_2017	20.03	22.89	21.05	21.27	21.27	21.27	21.27	21.27	21.27
CAR_1956	19.73	22.19	20.46	20.93	20.93	20.93	20.93	20.93	20.93
CAR_1907	18.97	20.94	20.25	20.17	20.17	20.17	20.17	20.17	20.17
CAR_1836	17.32	18.67	19.07	18.87	18.87	18.87	18.87	18.87	18.87
CAR_1764	16.30	18.34	18.55	18.10	18.10	18.10	18.10	18.10	18.10
CAR_1710	15.60	17.60	18.40	17.34	17.34	17.34	17.34	17.34	17.34
CAR_1669	14.91	17.62	17.27	16.71	16.71	16.71	16.71	16.71	16.71
CAR_1626	14.42	17.05	17.48	16.27	16.27	16.27	16.27	16.27	16.27
CAR_1584	13.94	16.86	15.73	15.96	15.96	15.96	15.96	15.96	15.96
CAR_1544	13.74	15.43	18.06	15.57	15.57	15.57	15.57	15.57	15.57
CAR_1502	13.33	17.62	17.67	15.16	15.16	15.16	15.16	15.16	15.16
CAR_1428	12.77	14.03	14.65	14.47	14.47	14.47	14.47	14.47	14.47
CAR_1375	12.37	17.26	13.53	13.83	13.83	13.83	13.83	13.83	13.83
CAR_1321	11.01	13.10	13.15	13.20	13.20	13.20	13.20	13.20	13.20
CAR_1236	10.98	12.55	12.59	12.40	12.40	12.40	12.41	12.40	12.40
CAR_1191	10.39	12.93	11.82	12.07	12.07	12.07	12.15	12.07	12.07
CAR_1142	10.23	11.30	11.77	12.06	12.06	12.06	12.13	12.06	12.06
CAR_1107	9.19	11.15	11.56	11.93	11.93	11.93	12.03	11.93	11.93
CAR_1100	9.31	13.21	13.19	11.52	11.52	11.52	11.67	11.52	11.52
CAR_1080	9.35	13.24	13.20	11.19	11.19	11.19	11.36	11.19	11.19
CAR_1036	9.24	11.23	10.50	10.90	10.90	10.90	11.46	10.91	10.91
CAR_998	8.58	9.80	9.98	10.63	10.63	10.63	11.39	10.64	10.64
CAR_929	8.31	10.91	9.61	10.09	10.09	10.09	11.33	10.22	10.22
CAR_866	8.10	8.90	9.88	9.73	9.73	9.73	11.33	10.06	10.06
CAR_812	7.31	11.74	11.48	9.31	9.30	9.30	11.33	9.99	9.99
CAR_768	6.95	8.17	9.88	9.10	9.09	9.09	11.29	9.88	9.88
CAR_763	6.94	9.02	9.36	9.08	9.07	9.07	11.31	9.90	9.90
CAR_757	6.89	8.73	9.43	9.04	9.03	9.03	10.75	9.51	9.51
CAR_734	6.83	7.68	8.93	8.96	8.95	8.95	10.74	9.49	9.49
CAR_733	6.83	7.68	8.93	8.95	8.94	8.94	10.74	9.49	9.49
CAR_710	6.80	8.66	8.66	8.84	8.83	8.83	10.73	9.44	9.44
CAR_671	6.60	8.24	8.17	8.81	8.77	8.77	10.71	9.36	9.36
CAR_637	6.26	8.49	8.01	8.92	8.87	8.87	10.71	9.33	9.33
CAR_635	6.30	7.80	8.00	8.91	8.86	8.86	10.68	9.27	9.27
CAR_631	6.32	7.47	8.10	8.53	8.44	8.44	9.49	9.26	9.26
CAR_627	6.35	8.24	8.11	8.51	8.44	8.44	9.45	9.26	9.26
CAR_625	5.00	7.86	8.13	7.22	7.17	7.17	7.35	7.30	7.30
CAR_624	5.00	7.86	8.13	7.16	7.08	7.08	7.31	7.25	7.25
CAR_617	6.16	6.28	6.58	7.01	7.00	7.00	7.15	7.11	7.11
CAR_606	5.64	6.28	6.58	6.73	6.76	6.76	6.86	6.86	6.86
CAR_605	5.64	6.28	6.58	6.70	6.72	6.72	6.83	6.83	6.83
CAR_573	3.93	5.79	5.64	5.99	6.03	6.02	6.23	6.23	6.23
CAR_572	3.88	5.78	5.61	5.99	6.03	6.02	6.23	6.23	6.23
CAR_567	3.63	5.70	5.46	5.93	5.97	5.97	6.18	6.19	6.18
CAR_521	3.50	5.44	6.33	5.77	5.77	5.77	5.85	5.85	5.85
CAR_477	3.43	5.26	5.57	5.54	5.54	5.54	5.64	5.65	5.64
CAR_421	2.97	4.96	3.91	5.07	5.07	5.08	5.28	5.29	5.26
CAR_381	2.52	5.27	3.64	4.92	4.93	4.75	5.15	5.15	5.10
CAR_357	2.54	5.16	3.77	4.67	4.68	4.50	4.94	4.95	4.85
CAR_347	2.72	5.26	4.60	4.82	4.83	4.64	5.06	5.06	4.99
CAR_346	2.72	5.26	4.60	4.82	4.83	4.64	5.06	5.06	4.99
CAR_343	2.72	5.26	4.60	4.78	4.79	4.60	4.98	4.98	4.98
CAR_334	2.38	5.01	5.67	4.67	4.67	4.41	4.84	4.84	4.84
CAR_295	1.85	3.47	5.66	4.61	4.61	4.48	4.78	4.78	4.78
CAR_236	1.80	3.45	5.22	4.25	4.25	4.30	4.37	4.37	4.37
CAR_221	1.71	3.48	6.83	4.13	4.13	4.26	4.27	4.28	4.28
CAR_214	1.97	6.23	6.24	4.13	4.14	4.20	4.29	4.29	4.29
CAR_200	1.97	6.23	6.24	4.10	4.10	4.16	4.22	4.22	4.22
CAR_198	1.97	6.23	6.24	4.09	4.09	4.15	4.22	4.22	4.22
CAR_196	1.40	5.97	5.86	3.98	3.98	4.04	4.09	4.09	4.09
CAR_169	1.56	3.27	3.23	3.85	3.86	3.91	3.96	3.97	3.97
CAR_132	1.22	3.29	3.47	3.76	3.77	3.83	3.87	3.88	3.88
CAR_126	1.41	3.73	5.76	3.73	3.74	3.80	3.87	3.87	3.87
CAR_122	1.29	3.73	3.72	3.68	3.69	3.73	3.78	3.78	3.78
CAR_117	1.02	4.23	4.26	3.60	3.61	3.65	3.69	3.70	3.70
CAR_040	0.50	3.40	4.22	2.60	2.61	2.64	2.66	2.66	2.66
CAR_000	0.91	1.15	2.33	2.73	2.73	2.73	2.73	2.73	2.73

B Surface water model set up

B.1 Model requirements

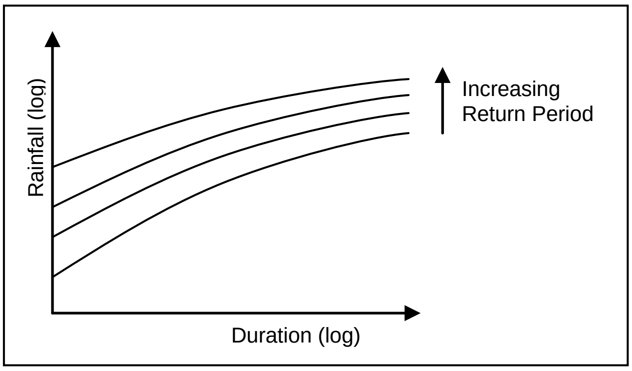
The hydrological input required by JFLOW+ surface water modelling is depth-time hyetograph to represent the storm's rainfall profile, which is applied as a blanket rainfall over the run area. This section outlines the methodology for calculating the rainfall profile applied over Stonehaven in this project.

B.2 Rainfall

B.2.1 Rainfall depth

The Flood Estimation Handbook (FEH) can be used to generate Depth-Duration-Frequency (DDF) curves for any 1 km grid point. A DDF curve relates storm duration to total rainfall depth, with different curves representing different return periods of event. See Figure below for an example.

Figure B-1: Example of DDF curves



Since DDF parameters are defined for each km point this method for calculating rainfall depths allows incorporation of their spatial variability in the surface water study.

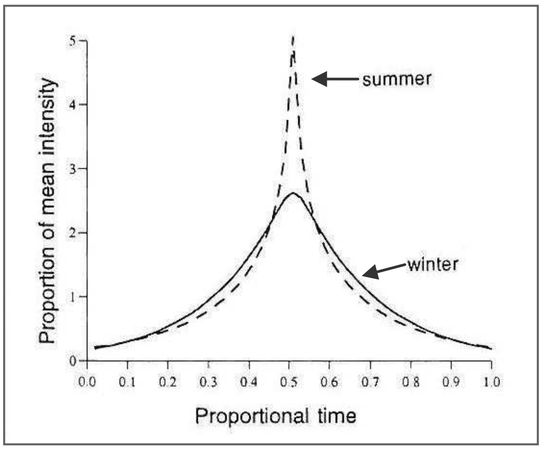
A single run of the JFLOW+ surface water model covers an area of approximately 5 x 5 km. For each run a single rainfall profile is required which is applied as a blanket rainfall over the whole area. Therefore DDF parameters are extracted for the grid point closest to the centre of each JFLOW+ run area to create a rainfall profile. Two tiles were used to cover Stonehaven urban area.

B.2.2 Rainfall profile

To create the inputs required by the JFLOW+ model, the total rainfall depth given by the DDF model needs to be converted into a rainfall profile which varies over time. In order to do this, a standard profile shape was applied, as described in the FEH (volume 2). Two profiles are given: summer and winter. Both profile shapes are symmetric, single-peaked and bell-shaped, and do not vary with duration or location.

The 'summer' profile has a more pronounced peak, representative of the convective storms more common in summer, and is recommended for application to urban catchments where a shorter period of high intensity rainfall is generally more critical. See Figure below. The parameters of the summer storm profile were therefore used to generate a rainfall hyetograph by dividing the total rainfall depth over the storm duration with the relative proportions of the summer profile.

Figure B-2: FEH standard profile shapes



B.2.3 Effect of urban drainage

Drainage systems in urban areas remove some surface water runoff volume from the ground surface. Within an urban area such as Stonehaven, the capacity of the drainage system will vary substantially between locations and therefore to account for drainage, application of a standardised value is appropriate. Research by JBA Consulting during national surface water mapping exercises has suggested that a standardised allowance equating to the average of the 20% AP (5 year) return period event is appropriate for UK cities following testing against historical datasets.

For Stonehaven, a sewer model (in InfoWorks-CS) was provided by Scottish Water, and this was examined to determine whether an improved estimate of the urban drainage capacity could be made. The model suggested that flooding would occur from manholes even down to the lowest return period (1 year) event in a few locations, and with increasing return period there was a slow increase in the number of manholes at which flooding occurred. However there was no particular return period at which substantially more flooding occurred, i.e. no clear indication of a generalised capacity of the sewer system in terms of a return period. As a result, the 5 year return period capacity was used as has been demonstrated to be a reasonable estimate and at this return period a number of manholes in Stonehaven were shown to be flooding.

B.2.4 Rainfall duration

Previous surface water studies conducted by JBA Consulting have suggested that the duration of event used has a significant influence on the areas and depths of surface water flooding predicted by the model. Recent research by JBA Consulting[52] suggests that shorter rainfall event durations are more critical for steeper topography, with longer duration events more critical for flatter topography subject to ponding.

In order to capture this effect it was decided to model two durations of flood events: 1.1 hour and 10.5 hour, which is consistent with JBA's approach to national flood mapping (the decimals give an odd number of values in the hyetograph). The results can be merged to produce a final outline for each return period scenario.

B.2.5 Design rainfall profiles

The final choice of design rainfall for this study is therefore:

- 25, 75, 100, 200 year and 1,000 year return period;
- 1.1 and 10.5 hour duration;
- Subtraction of 5 year event equivalent capacity for urban drainage.

The design hyetographs are given at the end of this Appendix.

[52] N. Hunter et al (2010). Broad Scale Mapping of Surface Water Flooding - Present Status and Future Improvements. Paper to Defra conference, June 2010.

B.3 Digital terrain model

B.3.6 Data available

A combination of data was available for the study area:

- LIDAR data – 1 m cell size with a vertical accuracy of approximately 20 cm;
- NextMap data – 5 m cell size with a vertical accuracy of approximately 1.0 m Root Mean Square Error (RMSE).

B.3.7 Combining DTM datasets

The study area is partially covered by LIDAR, with NextMap available for the entire area. Therefore these two datasets needed to be combined to give a DTM for input to the surface water model. Given the more reliable accuracy of LIDAR, this dataset was used in preference.

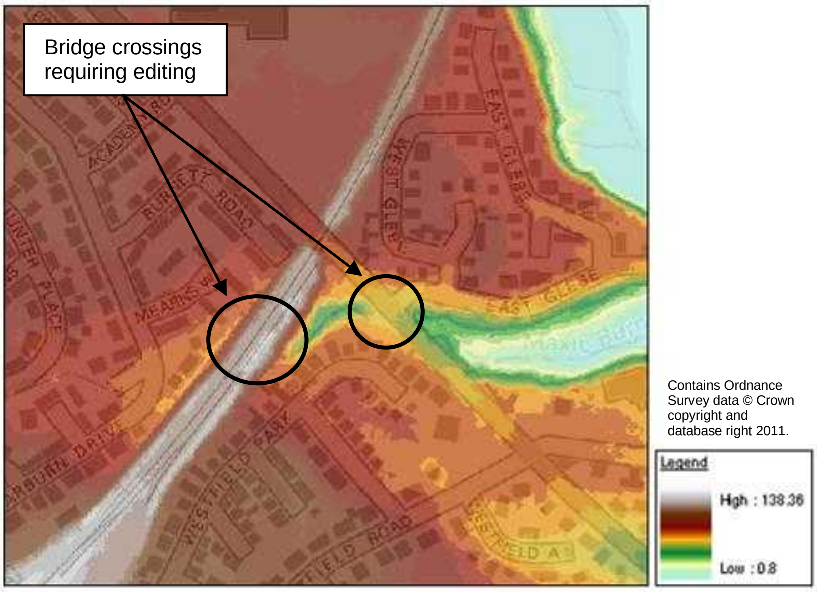
The data was combined by stamping the LIDAR data onto the NextMap DTM. The interface between the two datasets was smoothed to ensure no false changes in level remained as a relic of the merging process. This smoothing was undertaken using a feathering method which interpolates between the LIDAR and NextMap levels within a 100 m wide buffer zone.

B.3.8 Editing the DTM

Both LIDAR and NextMap are based on filtered elevation data from air-based surveys (light detection and ranging and interferometric synthetic aperture radar respectively). Therefore the levels returned capture high points including bridges and embankments. The presence of such features may distort the results due to levels within the DTM which do not represent potential low points and flow routes. Figure below shows an example of this, where flows routed along the low levels of a minor watercourse within a natural valley, without editing of the DTM, come up against barriers to flow where the DTM picks up the level of an old railway embankment and a road crossing. In reality of course the flow there would be bridges or culverts in place to allow flow conveyance and therefore features of this sort need to be edited to allow more realistic flowpaths.

Other features of this kind which require editing include the crossing point of a road and railway line, underpasses beneath embankments, tunnels, river crossings and culverted sections of watercourse.

Figure B-3: LIDAR editing



B.3.9 Adding buildings to the DTM

The filtered LIDAR and NextMap data available for this study has had buildings removed and represent 'Bare Earth' terrain models. However, in surface water mapping the flow routes taken by surface water runoff are strongly influenced by the presence of buildings as these are likely to act as an obstruction to flow. Therefore in order to recreate realistic flow paths within the model, it is appropriate to incorporate building shapes into the DTM.

To achieve this, building outlines were extracted from the freely available Ordnance Survey Streetview mapping for the study area. These outlines were checked in detail and verified against the OS Mastermap data available for the central part of the study area. The buildings were then converted to a format compatible with the DTM (including abstraction of their shape to the 5 m cell size used in the DTM), assigned an arbitrary height of 5 m and stamped onto the DTM. This ensures surface runoff across the DTM will follow flow paths around rather than 'through' the buildings. See Figure below.

Figure B-4: Adding buildings to the DTM

B.3.10 Adding roads to the DTM

Within an urban environment, roads generally provide a clear flow route which is constrained by kerbstones. To recreate this effect in the surface water model, roads were also stamped onto the DTM at a height reduced by 0.1 m. Again, roads were identified using the freely available Ordnance Survey mapping, using the Meridian dataset to identify centrelines and buffering these to an average road width. Again, the road shapes were converted to a format compatible with the DTM (including abstraction of their shape to the 5 m cell size used in the DTM), assigned an arbitrary height of -0.1 m and stamped onto the DTM.

B.4 Model set up

The maximum number of cells that can be used in an JFLOW+ simulation at one time are approximately 1,500,000. The study area was therefore divided into run areas of approximately 5 x 5 km using a 5 m grid. This gives 2 run areas in total to cover the study area.

In order to smooth the interface between run areas, a 500 m buffer was included around each 5 x 5 km square giving a 1 km overlap between run areas. The results within these overlapping areas were then combined to ensure a contiguous results grid.

C Structural assessment

C.1 Purpose

Currently ‘informal’ flood defences have been constructed, including raising the height of embankments and walls. These structures were not constructed as part of a fully studied and designed scheme.

The aims of this structural condition inspection report are:

- To establish the existing condition of the structures either side of the river channel in Stonehaven, their condition and whether they may be retained or raised as part of a formal flood defence scheme.
- Review areas suitable for flood defence structures in and around Stonehaven.

C.2 Survey

A walkover survey was undertaken over three days along a 2 km stretch of the Carron from its mouth at the sea to the A90, and along a 1km stretch along the Burn of Glaslaw from where it meet the Carron to the A90. A visual condition assessment of the structures was completed along both sides of the watercourse for structural stability and their suitability for flood defence.

The structural assessment was a preliminary visual structural inspection undertaken using guidance from the Institution of Structural Engineers and the National Sea and River Defence Surveys Condition Assessment Manual produced by the Environment Agency[53]. This allowed a consistent assessment of each structure regardless of type (wall or embankment) or material (concrete or masonry stone etc) and allocated a score ranging in 5 steps from very good (1), good (2), fair (3), poor (4) to very poor (5).

C.3 Limitations

The intended purpose of this assessment is to inform the optioneering phase. The inspections were visual only and no testing was undertaken on any of the structures. No calculations were carried out to assess the load capacity of structures.

The information provided in this report should not be used for detailed design purposes without further detailed investigations being undertaken.

The aim of the survey was to provide an initial assessment of baseline conditions of the structures running alongside the River Carron and the Burn of Glaslaw and to consider the suitability for consideration as existing direct defence and possible retrofit to provide an improved standard of protection.

Constraints to development and site investigation were considered at the time of inspection.

Statutory services information for the Stonehaven region has been provided by all major utility providers. The record plans are included in the Appendices. The information provided shows the indicative position of the services and is only suitable to identify possible constraints to development and to inform the design feasibility stage.

C.4 General Geotechnical conditions

C.4.1 General

To enable a scheme to be properly designed an adequate site investigation should be undertaken to reduce the risk of delays and cost overruns. It is suggested about 1.5% of the total project cost be allowed for in the budget costs. The watercourse is highly sensitive to pollution; therefore measures should be taken to ensure that there is no pollution of the watercourse during ground investigations.

All services should be located prior to commencing any ground investigation works.

[53] Environment Agency, National Sea and River Defence Surveys – Condition Assessment Manual. A guide to the visual condition assessment of sea and river defences. 1999

C.4.2 Anticipated ground conditions

British Geological Survey maps[54] suggests the following:

Solid. Mainly Carron Sandstone Formation consisting of a fine to coarse-grained locally pebbly lithic sandstone with lenses of conglomerate. In the area where the Burn of Glaslaw meets the A90 the bedrock changes to Dunnottar Castle Conglomerate Formation, a conglomerate with boulders up to 1m across, of mainly 'Highland' provenance, with interbedded sandstone lenses.

Drift. At the bottom of the valley these deposits consist mainly of Alluvium of Clay Silt and Gravel deposits, with river terrace deposits of sand and gravel with lenses of silt, clay or peat. These are have been deposited over Mill of Forest Till consisting of Sandy diamicton, red-brown with clasts predominantly of Devonian rocks, which extend up the valley sides, or in some places over Drumlithe Sand and Gravel which are, red-brown, with clasts predominantly of Devonian sandstone, mudstone and andesite. Locally with lenses of silt and clay

Towards the river mouth the alluvium has been deposited over raised marine beach deposits of Flandrian Age, consisting of gravel and sand, commonly shelly. Gravel typically cobble grade, well sorted, clast supported with well-rounded clasts. Sand mainly medium-grained and shelly.

C.4.3 Anticipated SI requirements

The following are an indication of the types of investigation likely to be required in order to progress the detailed design of flood defences. This is not a definitive list.

C.4.4 In channel

In reaches of the channel, where it is possible that a secondary channel might be created, grab samples will be required to classify the sediments.

C.4.5 Structures

Trial pits or boreholes will be required along the back of retaining structures to determine the foundation depth and bearing strata. Coring at intervals should be used to determine the structural cross section.

C.4.6 Top of bank

In situ and lab testing will be required to establish stratigraphy, permeability, strength and settlement characteristics for possible flood defences.

C.4.7 Services

Where required further investigation work should be carried out to establish the route and condition of services in order that works can be designed to avoid them, or to establish whether they need to be replaced or diverted due to the proposed works.

C.5 Individual structure reports

Summary reports, one for each of the structures, or group of structures along the same stretch that were inspected, are contained in Section C.7. Each sheet provides information on the location of the structure, photographic record and a summary of structural condition. Finally each structure has been given a score based on the 5 categories available in the National Sea and River Defence Surveys Conditions Assessment Manual based on overall condition, as described above.

Some indication of the remedial action required to bring it up to flood protection scheme standard is also provided. The comments do not consider possible retrofit, only the existing condition of the structure.

C.6 Summary

The following findings are a brief summary of the key reaches that were inspected. More detailed conclusions are provided in Section C.7.

[54] Stonehaven, 1:50000, Sheet S67, British Geological Survey

While most of the older structures have not been built to formal standards many of them are capable of being repaired. Having withstood the test of time, these are generally well built, dry stone or random rubble lime mortar walls. They are unlikely to be 'waterproof' but with repointing and remedial works should provide an adequate barrier for low heads of water where required. If these walls are required to resist high heads of water they will need to be rebuilt or strengthened.

Many newer privately owned walls have not been built in accordance with good practice, and would largely require replacement with some other form of bank structure.

The footbridges are generally in reasonable condition. Where the footbridges are providing 'choke' points it should be possible to raise them a small amount, without widespread disruption or excessive cost. The Bridgefield Road Bridge will be more difficult and costly to raise, although it would not be impossible to do so.

C.6.8 River Mouth to Bridgefield Road Bridge (Chainage 0 to 0.197)

Rock armoured banking protects the river banks where the river flows into the top section of the beach. This is in good condition and no works are required along this section.

A timber footbridge crosses the river channel at the top of the beach. This is in good condition, and does not restrict the channel flow.

The walls on the Right Hand Bank (RHB) are traditional random rubble masonry walls, and look well constructed, although they are of some age. These are constructed on river banks whose edges show some signs of erosion. It is likely that some form of river bank protection works will be required combined with repointing and repair of existing walls.

The walls on the Left Hand Bank (LHB) are generally poorly constructed being of single skin blockwork, the river bank on this side also shows signs of erosion. It is likely that some form of river bank protection works or set back of defences will be required combined with rebuilding of existing walls, if this section is to provide part of a scheme.

C.6.9 Bridgefield Road Bridge to White Bridge (Chainage 0.213 to 0.345)

The Bridgefield Road Bridge is a precast concrete road bridge. The deck and its abutments are in good condition. If it is required to raise this bridge it is likely to be a difficult operation. Its closure would cause disruption and it is likely that services would need to be moved. It has a concrete invert which may be lowered if necessary.

The walls on the RHB are traditional random rubble masonry walls, and look well constructed, although they are of some age. These have a concrete cill, to protect against erosion. Further investigation work will be required to establish the form and extent of this protection, and whether it needs to be modified. Repointing and local repair of the walls will be required. This may be combined with strengthening if high heads of water are expected.

The walls on the LHB were generally poor quality and inconsistent, having being erected to extend gardens or possibly as informal flood defences. The bank also showed signs of erosion. It is likely that new walls will be required along this stretch to protect existing properties.

C.6.10 White Bridge to Green Bridge (Chainage 0.345 to 0.634)

The White Bridge is a steel plate girder pedestrian bridge, of some aesthetic merit. If required it would be possible to raise this bridge a reasonable amount by building up the abutments and jacking up the deck.

This section is characterised by semi-natural river bank, combined with sections of stone armouring. On the LHB near the White Bridge there is a section of drystone retaining wall. This section of dry stone retaining wall has areas of loose stonework, and is vegetated. There are no signs of significant movement at the top of the wall. It is likely that maintenance at the top of the wall using drystone walling techniques combined with works at the bottom to improve scour protection should be sufficient. In addition works may also need to be undertaken to ‘waterproof’ the wall, this could take the form of sheet piling behind the walls combined with rebuilding the top section.

Further upstream from the dry stone wall, additional flood defences may be required along the LHB. These may be built on top of the existing embankment. These could take the form of retaining walls on sheet piles to reduce land take. Care will need to be taken to ensure the piles go deep enough to ensure there is no route for water migrating below the wall.

Elsewhere the rock armouring is generally in good condition although there are areas where the bank is eroding, which may need additional protection.

C.6.11 Green Bridge to Walker's Bridge (Chainage 0.634 to 1.081)

The Green Bridge is a steel truss pedestrian bridge. It is in reasonable condition although showing some signs of corrosion. If required it should be possible to raise this bridge, a small amount, by freeing its ends and building up the abutments.

On the LHB, just upstream of Green Bridge, the embankment has been raised to provide additional flood protection. These works, which included hessian matting, were carried out following the Nov 2009 flood. The embankment has been built up around trees, and sand bags have been used to take the defences around the garages. The condition of this embankment will deteriorate, as the trees die and the hessian on the sandbags degrade. It is therefore unlikely that these measures will provide a long term solution. Permanent defences could take the form of a wall on sheet piles, providing a cut-off to prevent seepage. This would reduce land take, although the garages would need to be moved or modified.

Upstream of Green Bridge is the Red Bridge, which is a steel truss pedestrian bridge. It is in fair condition, although showing extensive signs of corrosion. It is understood that debris was trapped on the bridge in the 2009 flood, and items attached to the bridge were dislodged, although no structural damage occurred to the bridge itself.

Elsewhere the banks are characterised by natural river bank on the RHB, combined with a long section of dry stone wall on the LHB. This has a concrete cill at its base to provide scour protection. Further investigation work will be required to establish the depth of this protection, and whether it needs to be extended. Local maintenance and repair of the walls will be required if it is necessary to maintain the current river channel.

C.6.12 Walker's Bridge to A90 (Chainage 1.081 -2.640)

Walker's Bridge is a mass concrete arch culvert. It is in good condition and would appear to be of adequate capacity.

Upstream of this bridge it would be possible to create a flood storage area by raising secondary embankments etc., but this is unlikely to provide sufficient storage capacity to prevent flooding further downstream. The secondary embankments would need to be positioned out with the area subject to future erosion, and as the underlying deposits are likely to be highly permeable, water will need to be stopped from seeping underneath.

The river bank through to the A90 is mainly natural, with the banks eroding on the outside of bends to varying degrees. In some areas small sections of bank have been reinforced with gabions to prevent landslips.

A private accommodation bridge CH 2.141 is in poor condition and is likely to need replacement, although this is unlikely to form part of a flood alleviation scheme.

Flood debris upstream of the culvert at the A90 would indicate this is acting as a throttle. Although the culvert itself is in good condition, the water exits it at a high velocity and would appear to be causing a degree of scour below the gabion baskets either side of the exit.

C.6.13 Burn of Glaslaw (0 to 0.220)

The outfall structure and structures close to the outfall structure are in reasonable condition. Upstream of B10 the LHB is showing signs of severe erosion, and it is possible that the adjacent road, Carron Garden's, will be affected.

Just upstream of this the boundary walls of a house have been built next to the river channel. These are of poor quality, and are being undercut by the Burn. These would need to be replaced if enhanced flood defences are required at this point.