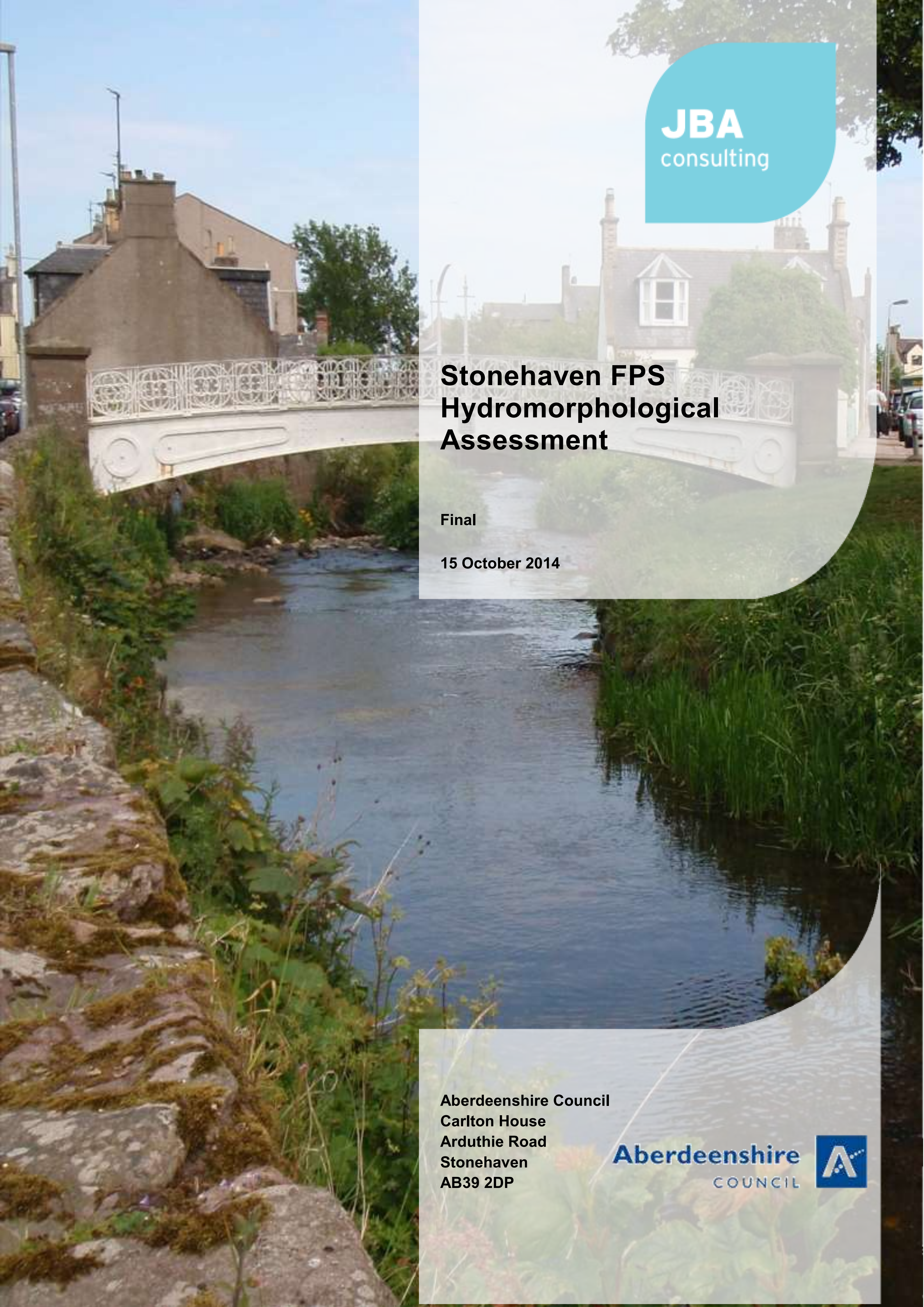

Stonehaven FPS Hydromorphological Assessment

Final

15 October 2014

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Revision History

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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, Steven Thompson, Sandesh Amatya, Mark McMillan and Alice Gent of JBA Consulting carried out this work.

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Purpose

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Executive Summary

Aberdeenshire Council are proposing to develop a Flood Protection Scheme (FPS) for a section of the watercourses which run through Stonehaven - the Carron Water and the Glaslaw Burn. This is likely to have an impact on the hydromorphology of the watercourses and so this report examines the extent to which the water depths and velocities will be affected.

A model of the 800m study reach of the Carron Water and Glaslaw Burn was created in InfoWorks RS 2D with inputs of hydrographs for the two watercourses and a Digital Terrain Model (DTM) derived from a topographical survey, channel bed survey and LiDAR data.

The model produced depth and velocity grids that were mapped in ArcGIS to allow a comparison of pre- and post-scheme conditions. Critical shear stress was then calculated to understand the flows and conditions which would be required to mobilise sediment. Post-scheme conditions suggest that only in lower flow conditions will gravel and other sediment accumulate in the channel and in higher flow conditions it will be mobilised downstream to the mouth of the River Carron (as experienced during and after previous flood events).

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Abbreviations

2D	Two Dimensional (modelling)
CS	Cross Section
DTM	Digital Terrain Model
FPS	Flood Protection Scheme
GPS	Global Positioning System
LiDAR..............................	Light Detection And Ranging
QMED	Median Annual Flood (with return period 2 years)
SEPA	Scottish Environment Protection Agency

1 Introduction

1.1 Purpose of this assessment

JBA Consulting have been commissioned by Aberdeenshire Council to assess the potential impact of the proposed Flood Protection Scheme (FPS) in Stonehaven on hydromorphology.

The Carron Water is one of the primary watercourses which passes through Stonehaven. Its source lies in the hills around the Brae of Glenbervie and flows for approximately 15 km before discharging into the sea at Stonehaven. Much of the 43 km^2 catchment is composed of Devonian Old Red Sandstone sedimentary deposits overlain by a variety of glacial tills, sands and gravels. The main channel drains generally to the east with short, steep tributaries joining principally from the north (in particular Cheyne Burn). Two tributaries join the main river from the south in the vicinity of Stonehaven, namely Toucks Burn and the Burn of Glaslaw. Isostatic rebound following the last glaciation has resulted in channel incision reworking the glacial and fluvio-glacial deposits and creating limited areas of lowland floodplain. This encourages high energy conditions during elevated flows within the channel. The upper catchment is covered in plantation forest and pastoral farmland and the lower reaches of the main river are extensively engineered throughout its course through Stonehaven.

The proposed flood defences are approximately 800 m in length and lie along approximately 600 m of the Carron Water upstream of the outfall into the North Sea and 200 m of the Glaslaw Burn upstream of the confluence with the Carron Water. This report details the findings of the hydromorphological assessment conducted for the section of the watercourses where the FPS is proposed and considers the local river dynamics in relation to wider influences on sediment transport and channel change.

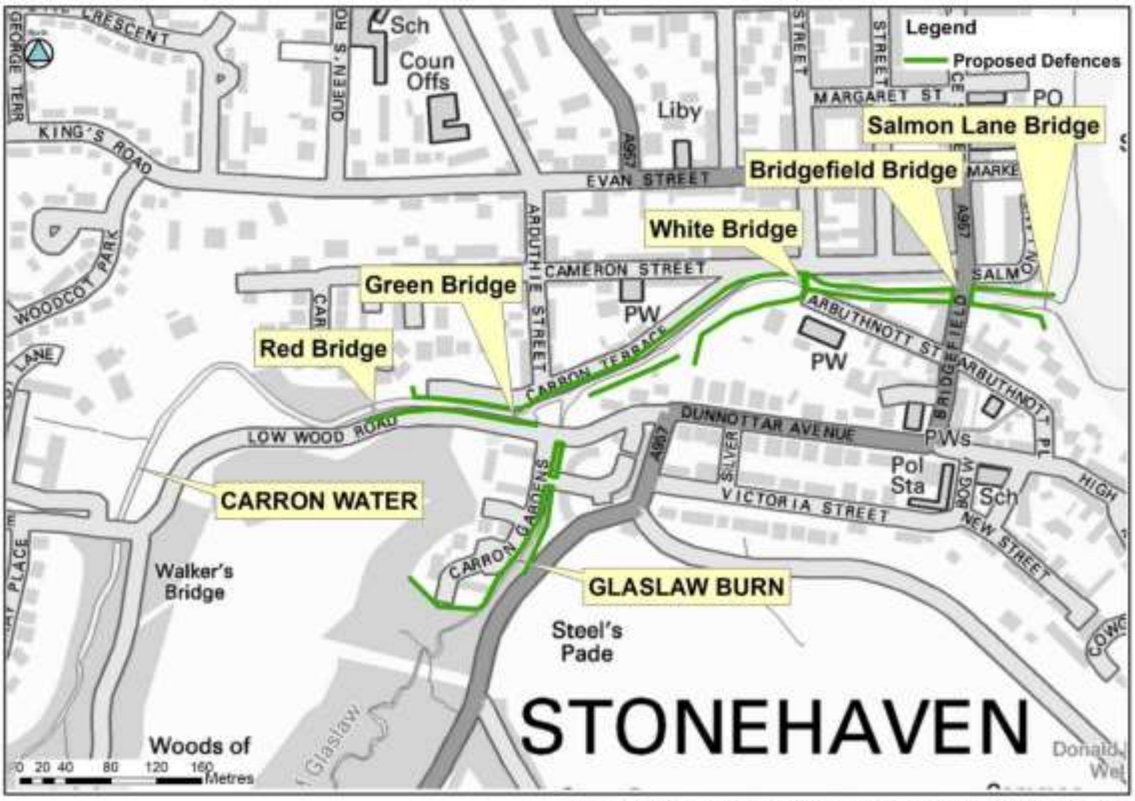


Figure 1-1: Scheme location

Changes occurring to a river are a function of both local controls on flow pattern and energy concentration and other wider catchment controls on flow magnitude, frequency and sediment transport. A study of the dynamic fluvial geomorphology of a catchment provides an integrated perspective, as well as a rigorous understanding of the physical processes by which the river channel is formed and alters.

This assessment will allow the nature and approximate rate of change of any erosion and deposition to be qualified to help understand the river behaviour as a result of the proposed scheme.

1.2 Hydromorphological assessments to date

A number of assessments have been previously undertaken by JBA, as part of this and preceding assessments, including a Geomorphological Audit in 2010[1]. In 2011 JBA Consulting undertook a Flood Alleviation Scheme Action Plan[2] for the River Carron at Stonehaven in order to promote the most technically sound, economically viable and environmentally sustainable option based on relevant legislation. This hydromorphological assessment is in keeping with the recommendations made in the action plan.

1.3 Scheme proposal

The preferred scheme proposal is a combination of flood walls, a flood embankment, bridge raising, culvert replacement, island lowering on various sections of the Carron Water and Glaslaw Burn.

1.4 Ground investigation data

JBA Consulting's March 2014 report "Stonehaven River Carron & Burn of Glaslaw Flood Protection Scheme, Ground Investigation Interpretive Report, March 2014", details the results of the ground investigation works within the limits of the scheme. A summary of information extracted from this report is shown in Table 1-1. Here it can be seen that for the lower reaches of the Carron Water, i.e. downstream of the White Bridge, for depths of up to 8.5m bedrock has not been found. There are some areas of clay present, with the remainder of below river bed material consisting of sands, gravels and some peat.

Table 1-1: Summary of Ground Investigation Information

Cross Section	Location	Bedrock Found?	Depth of Bedrock Found (m)	General Comment
73	Immediately upstream of Bridgefield Bridge	N	-	Investigation depth c.5m.
66	Between of CS 73 and 62	N	-	Immediate below sand and gravel, peat, then sand and then clay (c. 2m below bed) below this. Investigation depth c.8.5m.
62	Immediately downstream of White Bridge	N	-	Channel bed on sand and peat present to depth of c.2.5m, with clay and sand below. Investigation depth c.8.5m.
48	Carron Terrace	Y	c. 6.5m	Channel bed on sand, minor pockets of clay present.
36	Adjacent to Green Bridge	Y	c. 3m	Channel bed on sand with layer of clay c.1m below bed.
31	Immediately downstream of Red Bridge	Y	c. 4m	Channel bed on sand. Layer of sand and gravel (c.1.5m thick) above the bed rock.
21	Glaslaw Burn	Y	c. 5m	Channel bed on sands and gravels. Below which there is a layer of sand and clay (c.2m below bed) and then bedrock.

[1] JBA Consulting (2010) Geomorphological Audit of the River Carron, Final, October 2010

[2] JBA Consulting (2012) Stonehaven FAS Action Plan, Final, December 2012

2 Sediment sampling

The main Carron Water may be classified as a moderately active, sinuous, single thread channel displaying a cobble and gravel bed and the morphologic features associated with the temporary storage of this material (riffles, point bars, lateral bars etc.). The tributary channels appear steep but are generally stable, flowing through confined wooded valleys. The river has been extensively altered through Stonehaven over time, resulting in a single thread channel that in places is wider than natural sections upstream. The banks are well protected by a variety of revetment types and a number of ad-hoc structures presently encroach across the bed of the river. Grade control structures in the form of boulder weirs influence the character and hydraulics of the river and tributary in the vicinity of Green Bridge. The combined effects of the channel alterations has disrupted the sediment balance in the river through the town and concerns have been expressed that the sediment deposits seen at several locations along the river may be leading to localised flooding during extreme flow events. The river bed is active and some of this deposited sediment is likely to be mobilised during floods.

In order to assess the channel conditions, sediment samples were taken from 8 locations in the Carron Water and Glaslaw Burn. Samples were taken in the form of a photograph which represented the general sediment conditions, these photographs are then digitised in ArcGIS and hence sediment dimensions can be assessed rapidly. This was a non-intrusive method of sampling the environment and allowed a detailed analysis to be undertaken off site.

The sediment sample site locations are shown graphically in Figure 2-1 and the photographs of the site sediment displayed in Table 2-1.

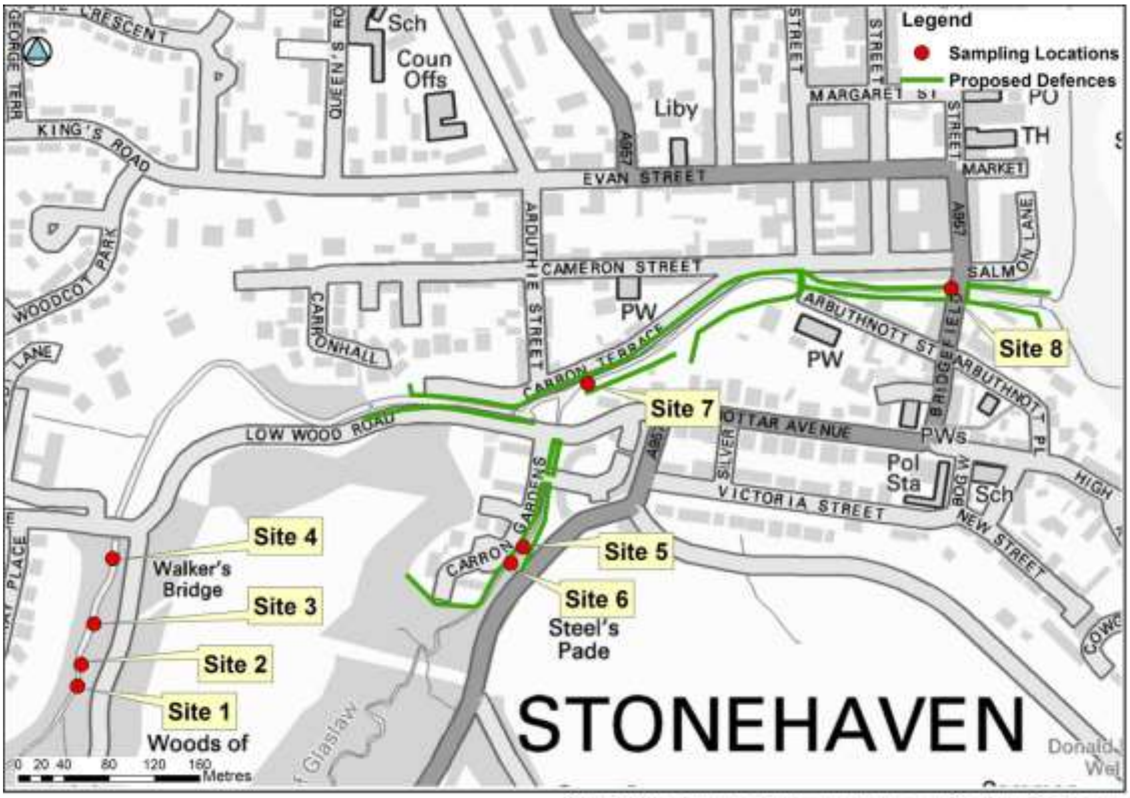


Figure 2-1: Sampling site locations

At each of these sample locations, the photographs were used to record the intermediate axis (b axis) of the gravel for 100 clasts, the distribution of which have been plotted in Figure 2-2. This then enabled the values for D16, D50 and D84 to be determined (i.e. by calculating the cumulative distribution) and a plot produced of D50 for each of the sediment sample locations (Figure 2-3). The largest gravels were measured at the two uppermost sites on the Carron Water (Site 1 and 2) and also at the confluence of the Carron Water and Glaslaw Burn (Site 7). The range of commonly transporting material is generally between 30 mm up to 90 mm.

Table 2-1: Photographs of sediment samples

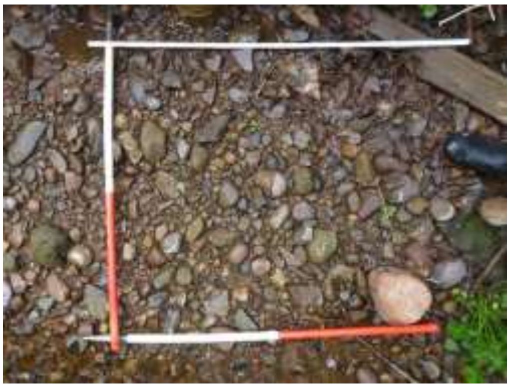
Site 1	Site 2
	
Site 3	**Site 4**
	
Site 5	**Site 6**
	
Site 7	**Site 8**
	

Table 2-2: Tabulated results of the key sediment size distribution at each site

	Site 1 (mm)	Site 2 (mm)	Site 3 (mm)	Site 4 (mm)	Site 5 (mm)	Site 6 (mm)	Site 7 (mm)	Site 8 (mm)
D16	42	43	36	18	26	45	32	32
D50	85	83	62	33	37	60	69	47
D84	167	156	106	65	49	91	106	76

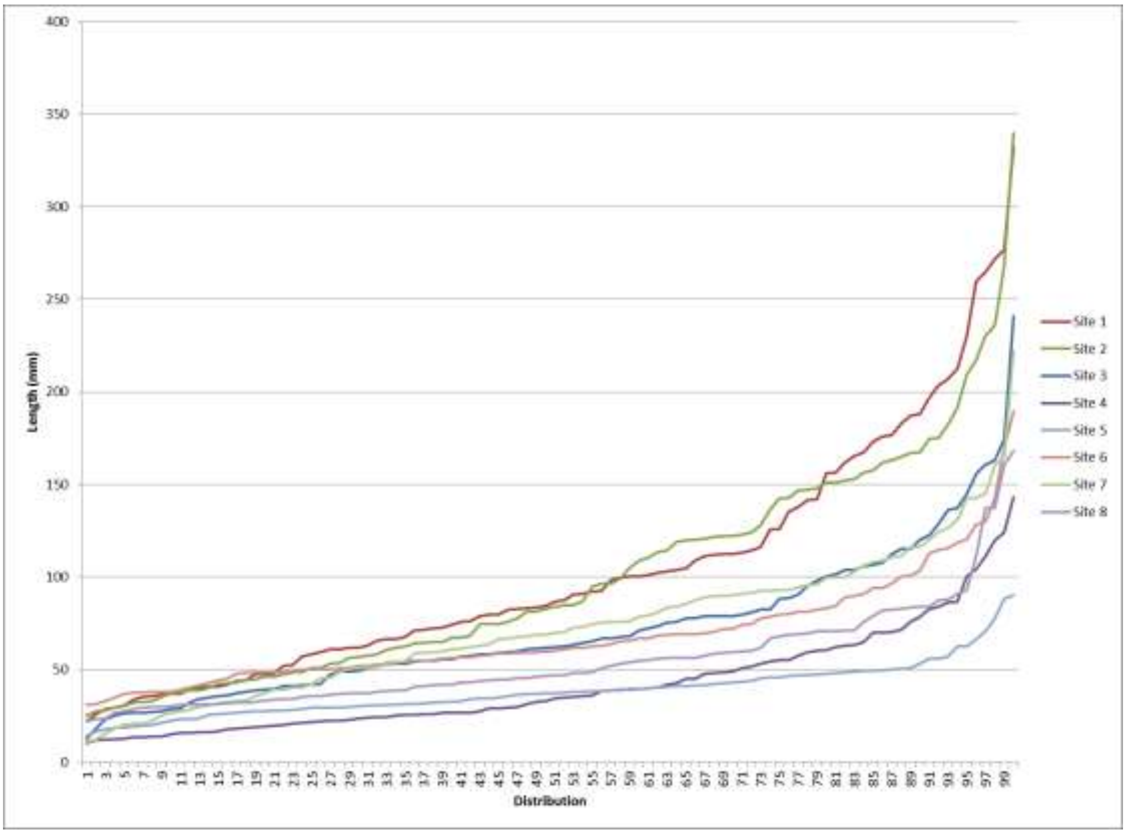


Figure 2-2: Plot of all the distributions for each site

Figure 2-3: Plot of the D50 (mm) for each sample site

3 2D Hydraulic modelling

3.1 Inflow hydrographs

The scheme design flows are used for this assessment (as shown in Table 3-1).

Table 3-1: Design flows

Return period (year)	Design inflow Carron Water (m^3/s)	Design inflow Glaslaw Burn (m^3/s)	Approximate flow in model downstream of Glaslaw Confluence (m^3/s)
2	14.5	2.5	17.0
5	20.5	3.4	23.8
10	24.9	4.2	29.0
25	31.3	4.6	35.8
50	36.9	6.2	42.8
75	40.4	6.7	46.5
100	43.2	7.1	49.3
200	50.4	8.2	56.2
200 + climate change	67.0	10.9	70.5

In addition low flows were also estimated for the watercourse as part of this assessment using the Low Flows 2000 software, resulting in a Q95 of 0.112 m^3/s and mean flow of 0.583 m^3/s for the Carron Water.

3.2 2D Hydraulic modelling

InfoWorks RS is a software program which enables modelling of open channels, floodplains, embankments and hydraulic structures. It is suited to combine time varying flows with a variable ground model mesh which allows for efficient simulation times without impacting the accuracy of the results.

For the Stonehaven model, the inputs consisted of a ground model derived from a Digital Terrain Model (DTM) (the spatial elevation of the terrain displayed as a raster dataset) and input hydrographs (which display the rate of flow in the River Carron and Glaslaw Burn over time).

The DTM was produced through the combination of a topographical survey and a channel bed survey carried out by JBA Consulting in 2010. The channel survey was carried out using a combination of total station and GPS survey in areas where the water depth was less than 1 m. The survey also included some additional spot height along the bank tops to enable it to be tied into existing LiDAR data which was obtained for the floodplain area in Stonehaven. A DTM point grid with 1m resolution was generated.

The InfoWorks RS 2D model was run for a range of flows including Q95, 2 year (QMED), 200 year and 200 year plus an allowance for climate change. Outputs from the model include extents, depth grids and velocity grids.

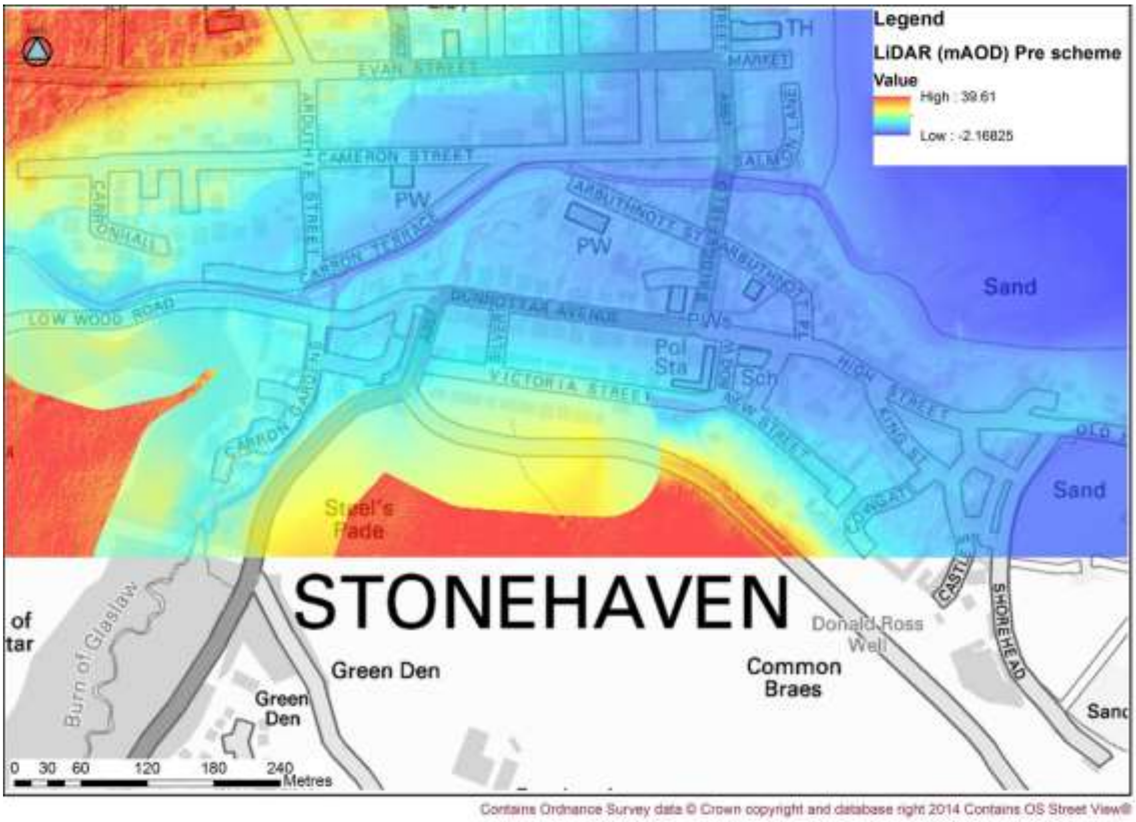


Figure 3-1: LiDAR data pre-scheme

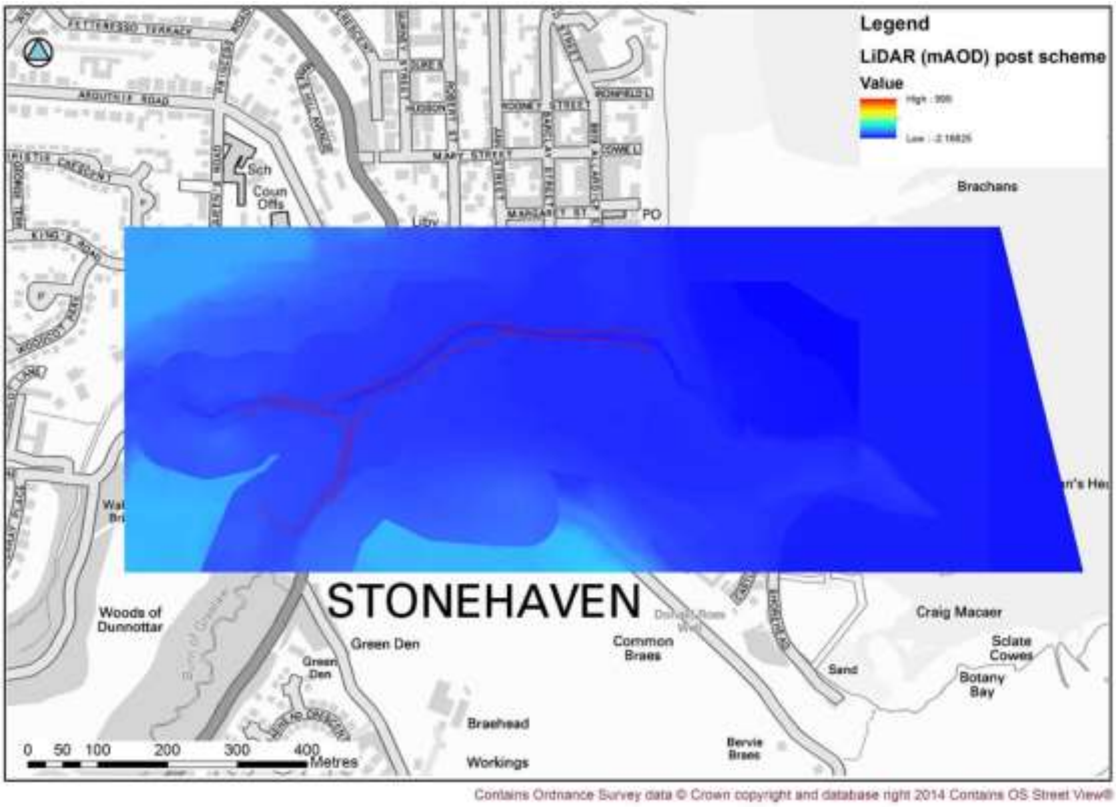


Figure 3-2: LiDAR data post-scheme

4 Results

4.1 Depth & Velocity

The depth and velocity grids from the InfoWorks RS model have been used to produce a number of maps to represent the effect of the FPS on the water depths and velocities.

The first set of maps depict the water depths for existing conditions and post-scheme conditions (Figure 4-1 and Figure 4-2). The existing conditions show that a large proportion of the floodplain on the right bank of the Carron Water is flooded at the 0.5% Annual Probability (AP) (200 year) event to depths between 0 and 2 m. Post scheme, the water depths increase in the channel and hence causing energy levels in the channel to increase, but no flooding is occurring out of bank. Figure 4-5 depicts the post-scheme depths subtracted from the existing conditions in order to clearly see the changes which would occur and it can be seen that the greatest increase in water depth would be about 2 m and occur on the right bank, upstream of Bridgefield Bridge.

Similarly, the maps depicting velocities (Figure 4-3 and Figure 4-4) show that there is a decrease in the velocities out of bank post scheme as there are no flows, but velocities are increased within the channel - particularly in the section under the bridge at Bridgefield.

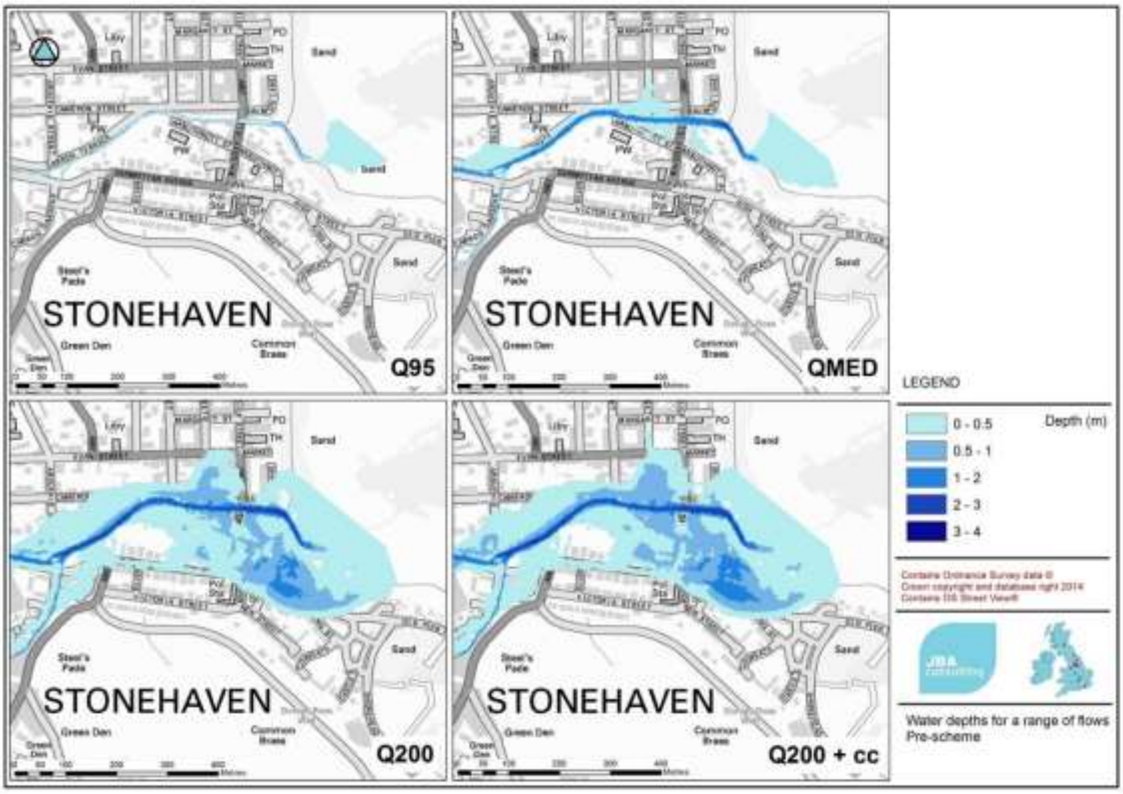


Figure 4-1: Existing depths

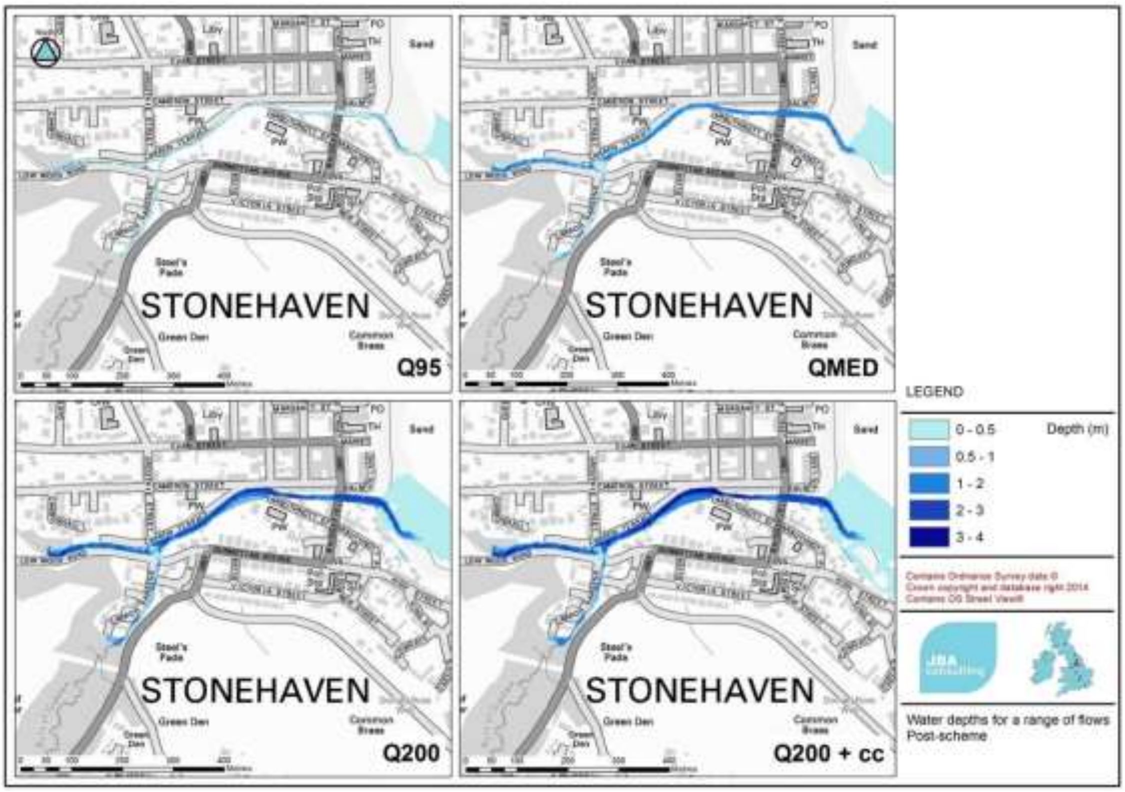


Figure 4-2: Post-scheme depths

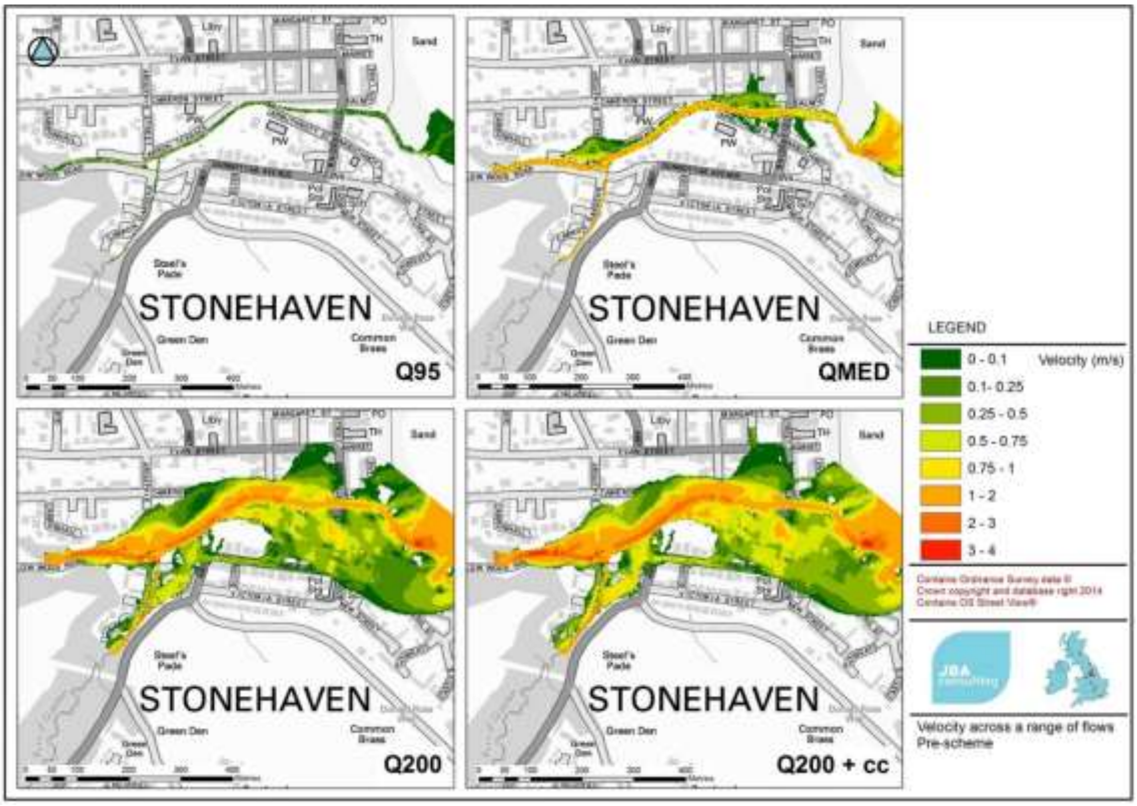


Figure 4-3: Existing velocities

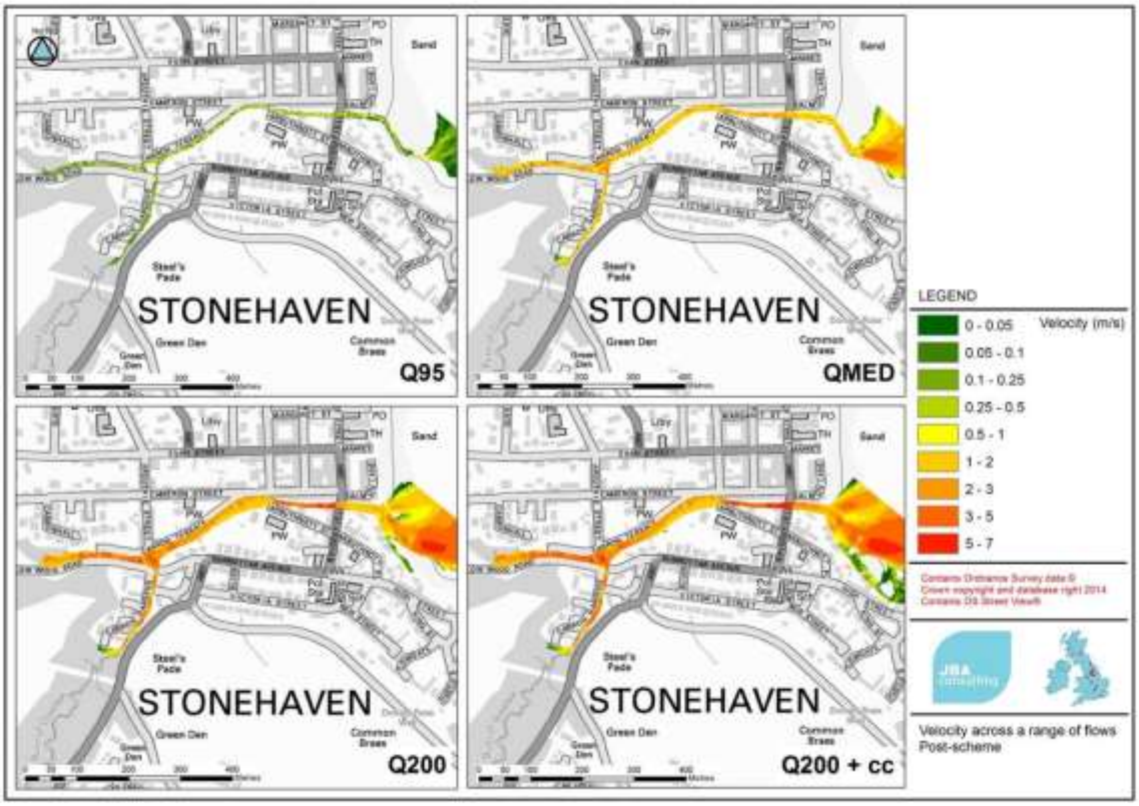


Figure 4-4: Post-scheme velocities

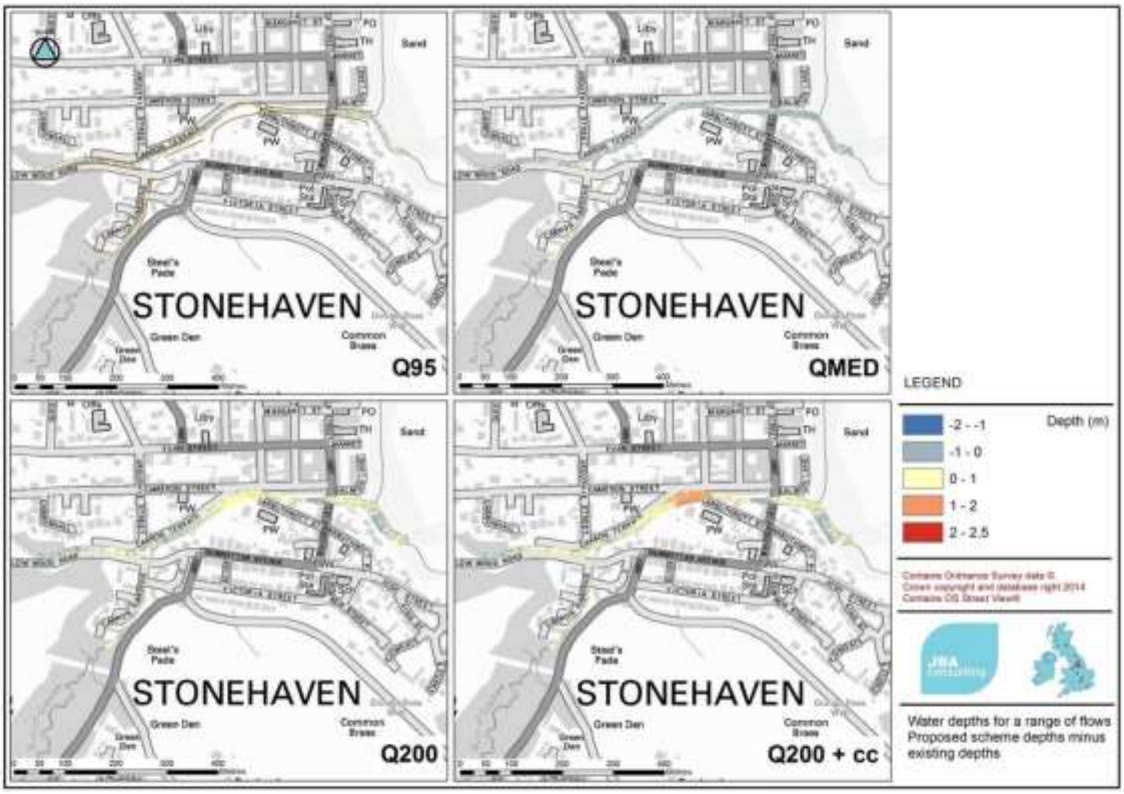


Figure 4-5: Post-scheme depths minus existing depths

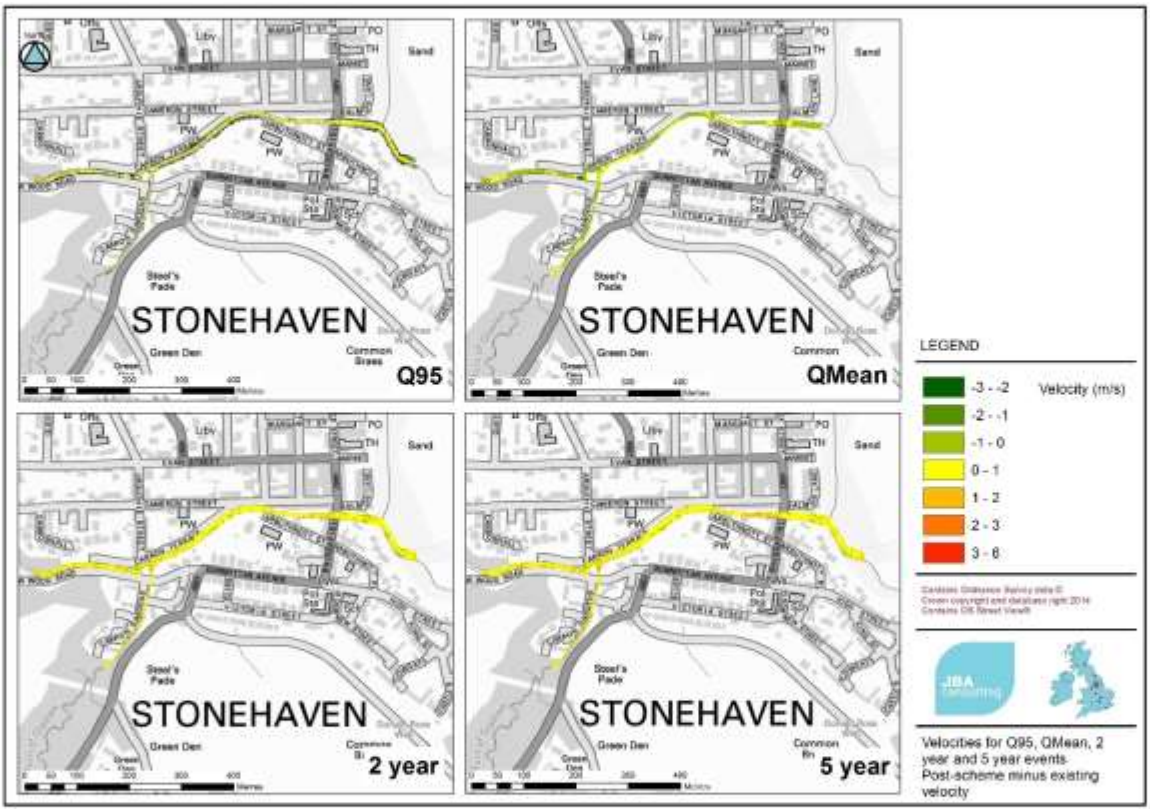


Figure 4-6: Post-scheme velocities minus existing velocities for Q95, QMean, 2 year and 5 year

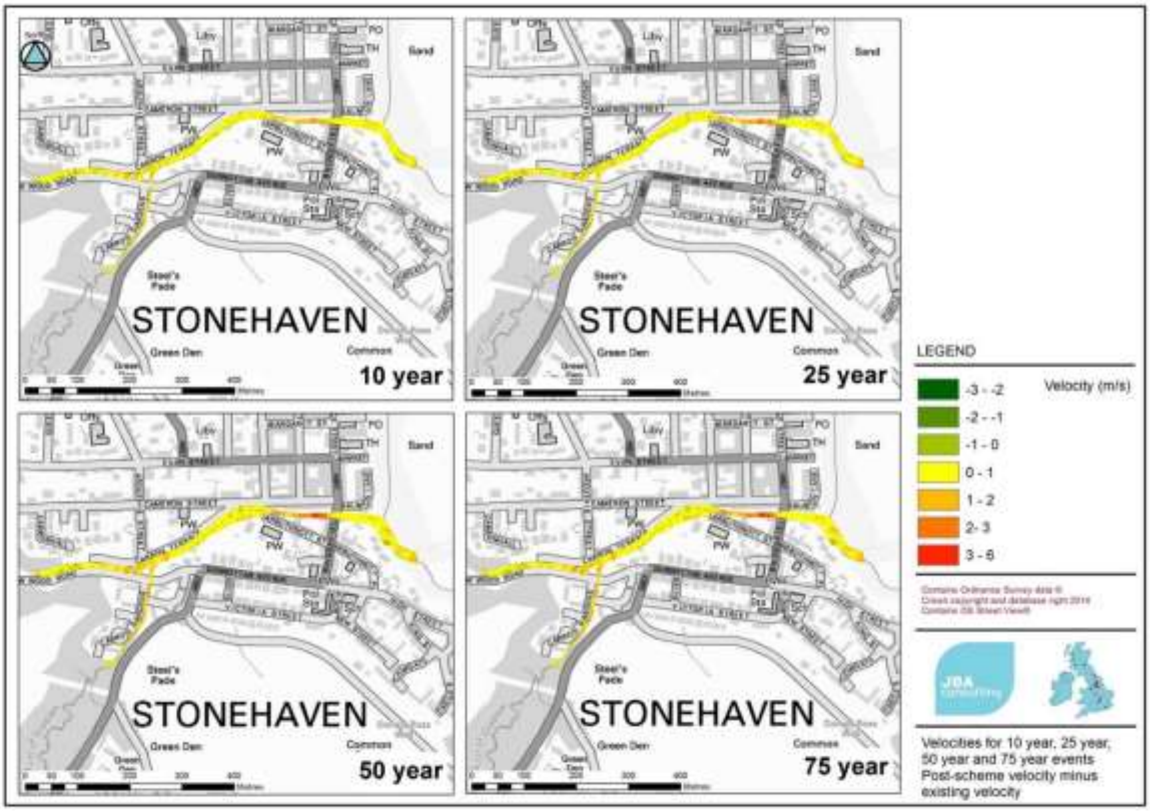


Figure 4-7: Post-scheme velocities minus existing velocities for 10 year, 25 year, 50 year and 75 year

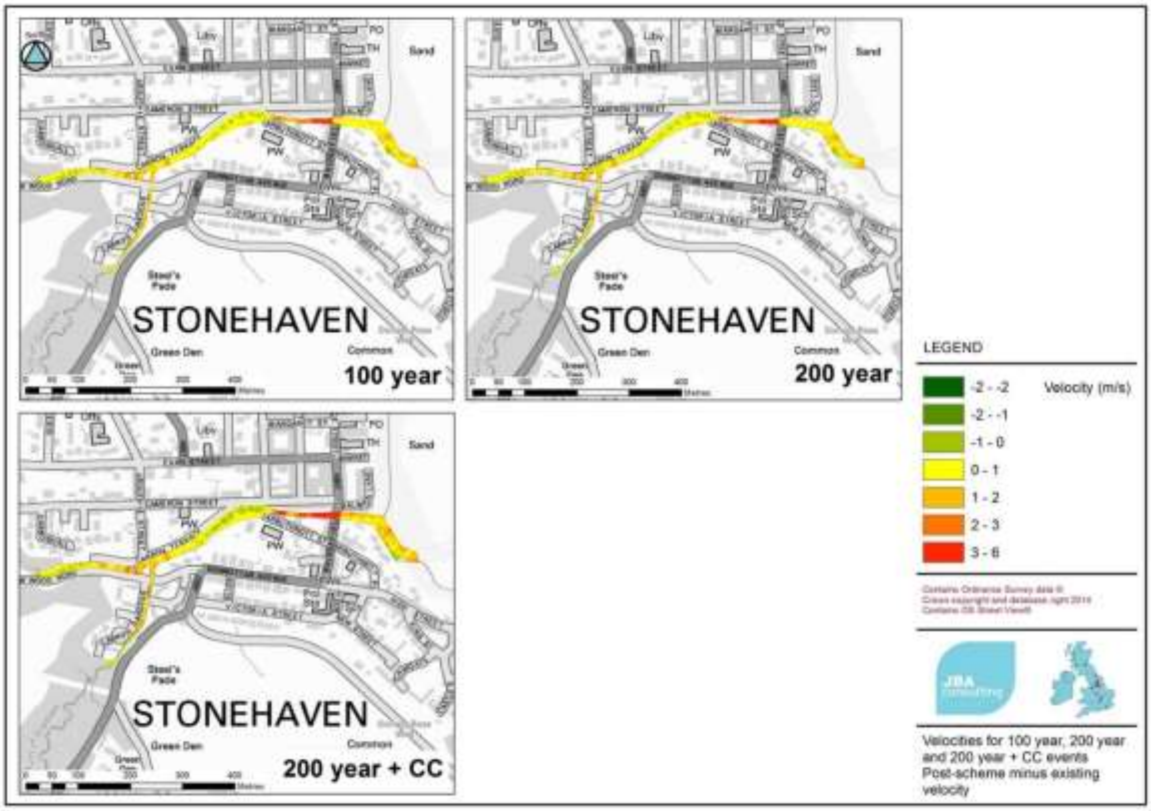


Figure 4-8: Post-scheme velocities minus existing velocities for 100 year, 200 year and 200 + CC

Table 4-1: Comparison of post scheme velocities

Event	Maximum Velocity Post Scheme (m/s)	Maximum difference (m/s)	General difference (m/s)
Q95	0.9	0.7	0.3
QMED	4.1	3.4	1.4
5 year	4.5	3.4	1.7
10 year	4.8	3.7	1.8
25 year	5.0	3.8	1.9
50 year	5.3	4.4	2.3
75 year	5.3	4.4	2.6
100 year	5.9	4.5	3.0
200 year	5.9	4.5	3.2
200 year +cc	6.7	5.6	3.5

Figure 4-6, Figure 4-7 and Figure 4-8 show the post scheme velocities minus the existing condition velocities for the modelled range of flows. The existing condition channel capacity is estimated to be in the region of 16 m^3/s at the Green Bridge and 19 m^3/s at the White Bridge. In terms of the modelling this is equivalent to the 2 year to 5 year modelled flow events. These figures show significant changes in the velocities estimated during the 5 year event and greater, thus this correlates with the current channel capacity and hence point at which any new flood defences will influence the in-channel hydraulics. The greatest impact in terms of velocity can be seen between the White Bridge and Bridgefield Bridge and upstream of the Green Bridge on the Carron and on the reach of the Glaslaw Burn immediately upstream of the confluence with the Carron Water. As the inflows rise, and hence water levels rise, the increase in velocity is estimated to be as much as 4.5 m/s during the 200 year event (Table 4-1), which is a very significant rise in velocity. The maximum modelled velocities range from 4.1 m/s to 5.9 m/s during the post scheme model scenario. With reference to the Hjulstrom curve (Figure 4-9), consolidated sediments will experience erosion, under such velocity conditions sediments such as clay and silt in nature (as little as 0.001mm) in size will be transported and erosion of sediments over 0.01mm in size will be eroded.

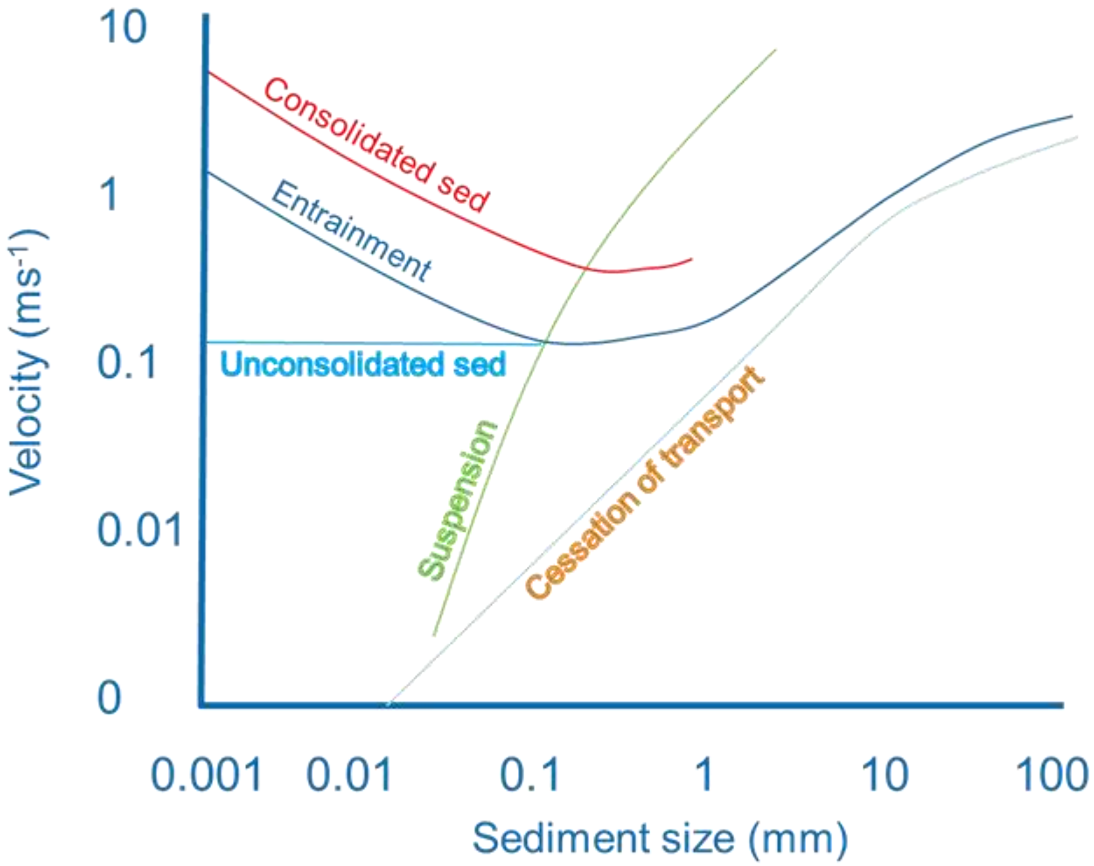


Figure 4-9: Hjulstrom Curve

The section between the Glaslaw Burn confluence and the White Bridge is likely to continue as a deposition zone, with modelled limited changes in velocity and in some locations decreases in velocity. For example through the deposition of sediment and bar formation on the right bank of the bend upstream of the White Bridge. This is likely to be caused by the increased capacity of the channel through maintenance (gravel bar and vegetation removal) upstream of the White Bridge.

From experience of existing conditions, it is known that there is a reasonable flux of sediment, with natural scouring of the river bed gravels occurring during flood events and significant delivery from upstream sources, but then replenished within the following months, for example this was observed following for the November 2009 event, that limits the ability to quantify fully the impacts on the sediment regime. Unfortunately sediment budget data is not available for the catchment or study reach. Figure 4-10 shows event analysis using the Carron Water SEPA gauge data (this gauge is located immediately downstream of the Red Bridge and is hence upstream of the Glaslaw Burn confluence) and this shows all of the peak events which exceed a set threshold of 3 m^3/s for the 10 year period between May 2003 and May 2013. In addition Table 4-2 shows the actual number of exceedances of a range of set thresholds from 3 m^3/s to 16 m^3/s. This shows that flows above the 2-5yr threshold at which the scheme will start to influence hydraulics and increase the erosive capability of the flows are infrequent but could potentially be significant in terms of risk of increased scour as a result of the scheme. The more frequent lower flood flows will continue to deliver sediment to the impacted reach that is likely to replace some of that scoured during extreme events.

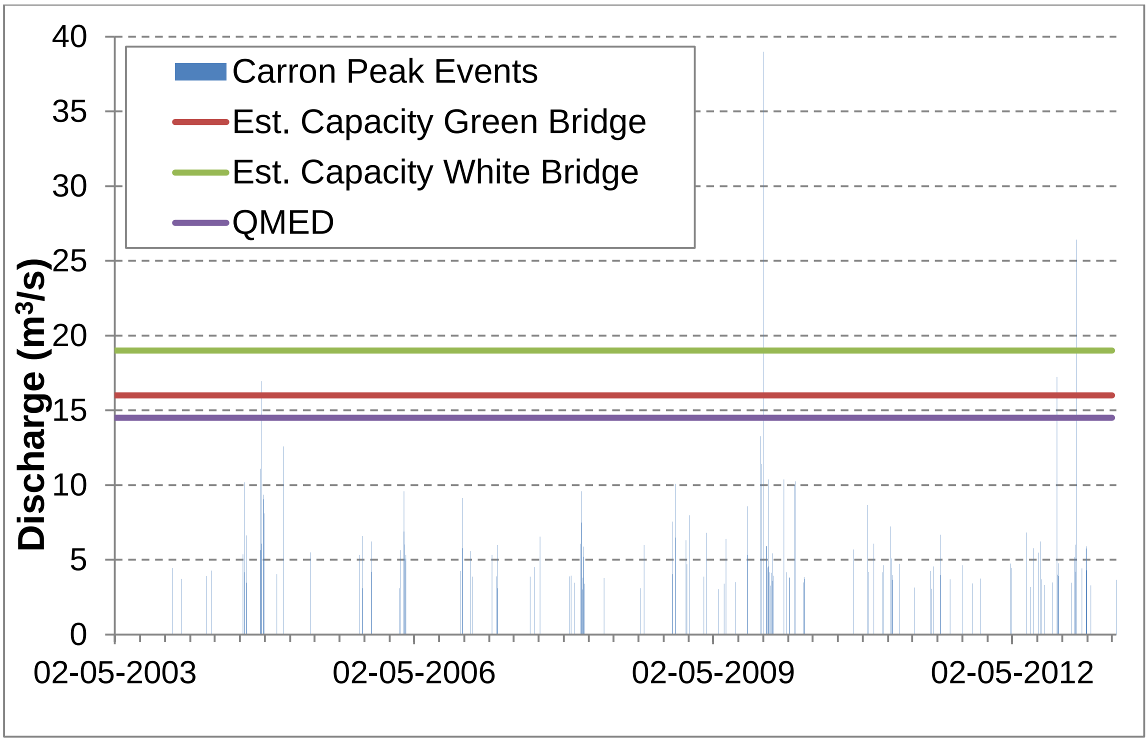


Figure 4-10: Event analysis peak flows (Carron gauge data only)

Table 4-2: Exceedances during 10 year period

Flow (m^3/s)	No of exceedance events
16	4
14.5	4
13	5
12	6
11	8
10	14
9	19
8	22
7	26
6	45
5	68
4	95
3	142

4.2 Shear Stress

The hydraulic variable outputs from the 2D model were used to predict the probable development of channel and gravel / bar deposit composed of coarse gravels (intermediate axis averaging 90 mm (ranging from 65mm to 167mm). The modelled velocity output has been converted to a depth averaged shear stress for comparison with the critical shear stress required to mobilise the bed sediment present.

Shear stress is calculated as:

$$\tau = C_f \rho_w U^2$$

τ= Shear stress (M/m^2)

C_f= Coefficient (0.125 used)

ρ_w= Density of water (1000 kg/m^2)

U = Depth averaged point velocity (m/s)

Critical shear is calculated as:

$$\tau_{cr} = 0.045(\rho_s - \rho_w)gD_g$$

τ_{cr}= Critical shear stress (M/m^2)

ρ_s= Density of sediment (2650 kg/m^2)

ρ_w= Density of water (1000 kg/m^2)

g = gravitational acceleration (9.81 m/s^2)

D_g= Sediment size (intermediate axis) (m)

Critical shear stress ranges from 47 to 122 Nm$^{-2,}$ with a threshold of 66 Nm^{-2} calculated based on the average 90mm sediment size (using the equation above) for each modelled flow. Mapping of critical shear indicates areas where this threshold is exceeded therefore showing higher energy zones where sediment is likely to become mobilised (Figure 4-11 and Figure 4-12). The maps show that for flows around Q95 there is likely to be a little movement of sediments. However, the majority of the modelled section of channel would experience the mobilisation of sediment for flows at QMED. On the receding limb of flood events or during events up to 4 m^3/s, deposition of sediments is likely to be dominant. Comparison of the existing conditions and those as a result of the FPS suggest that the sections of river downstream of White Bridge and the mouth of the river would have a greater width of channel that would be above the critical shear stress level.

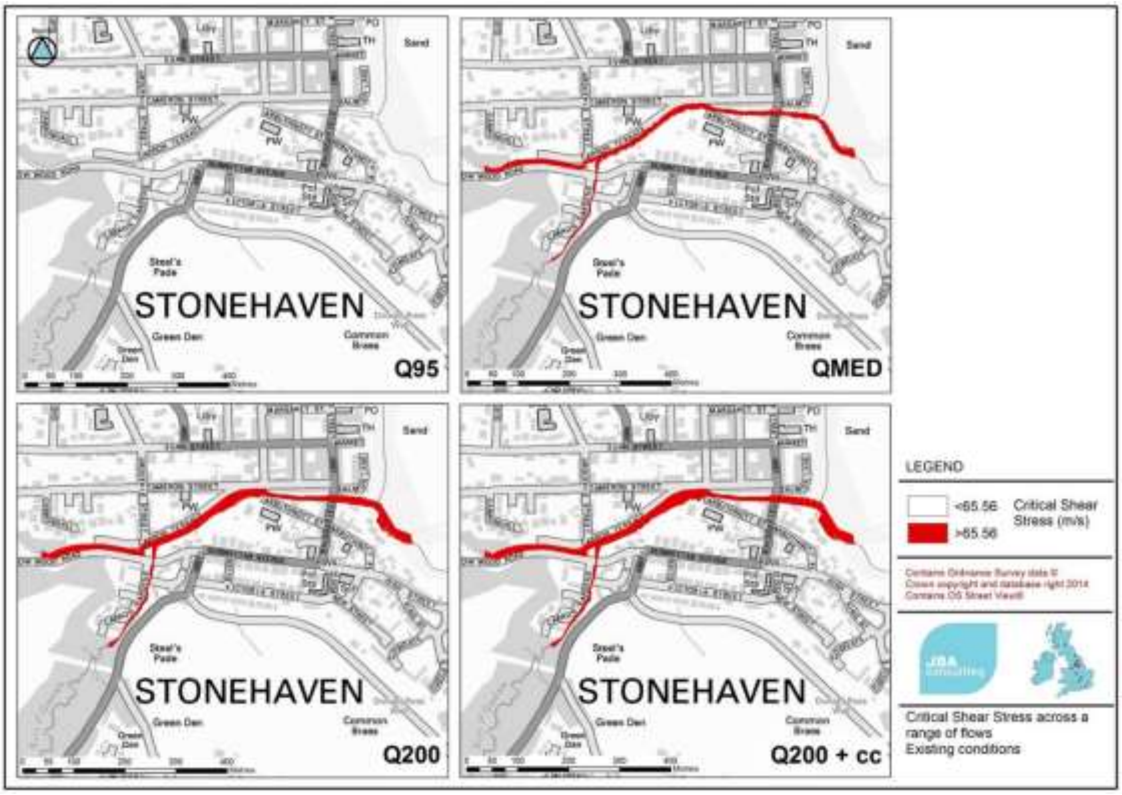


Figure 4-11: Existing critical shear stress

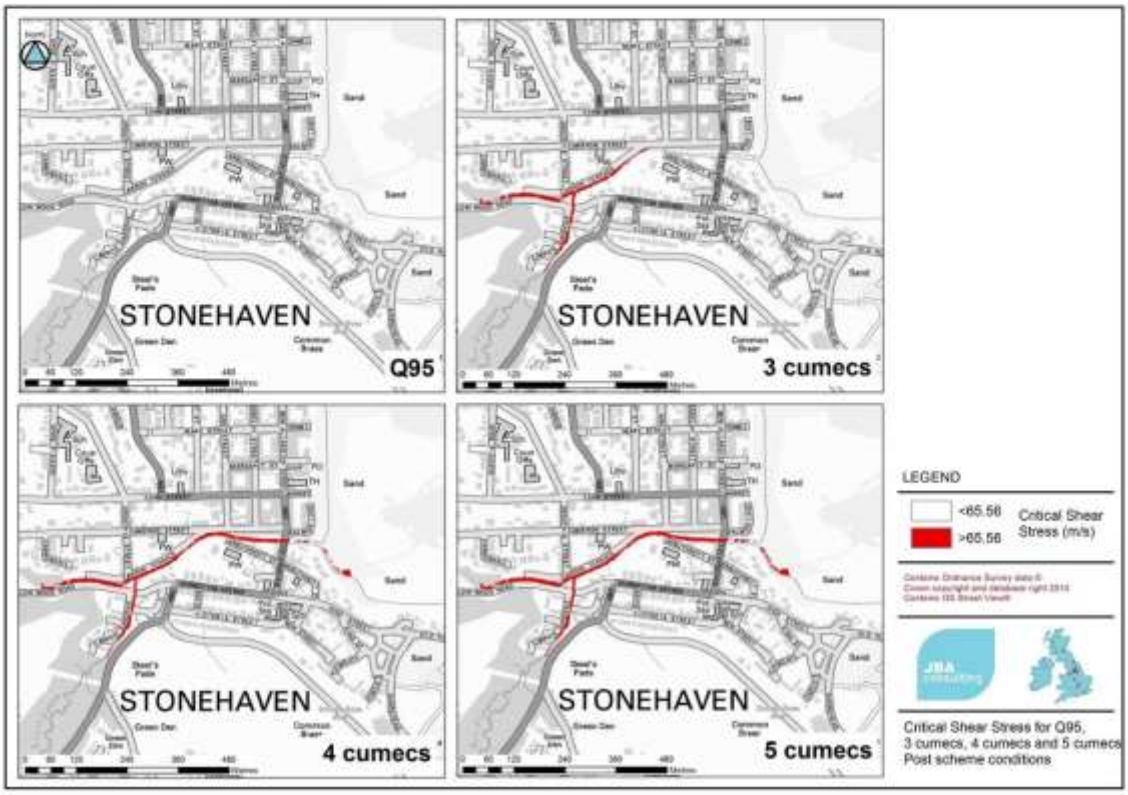


Figure 4-12: Post-scheme critical shear stress for Q95 and 3, 4 and 5 cumecs

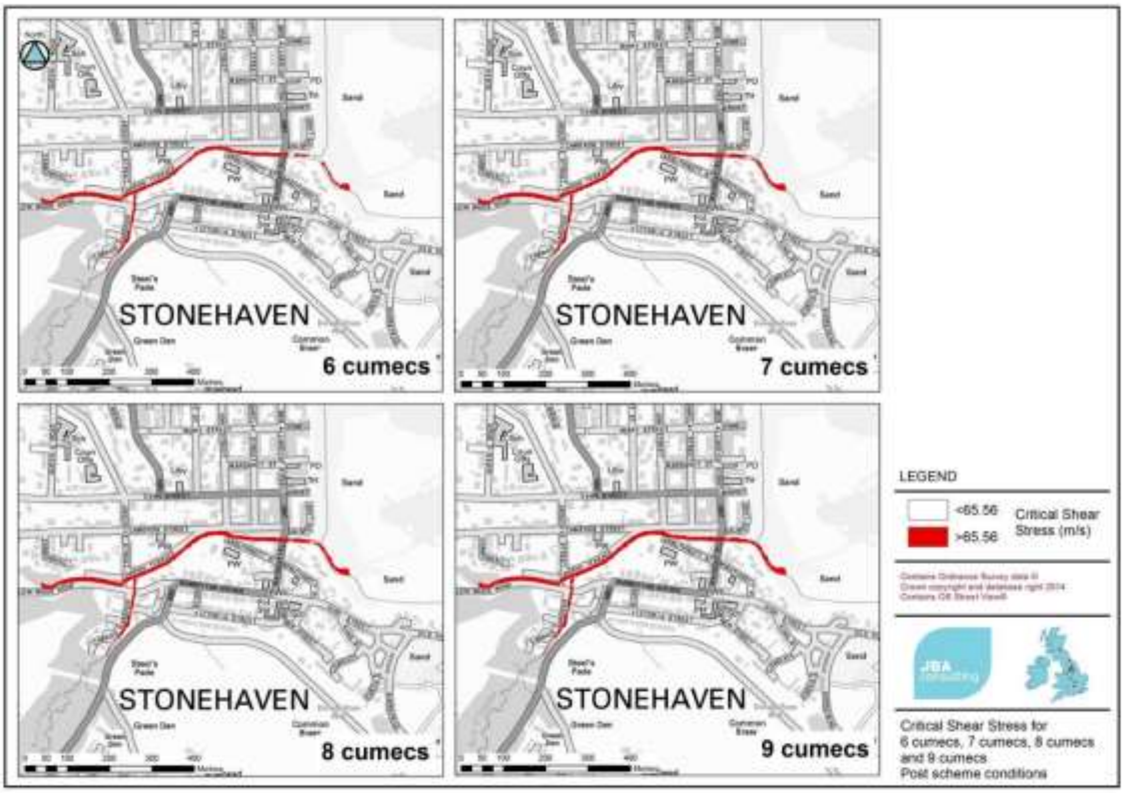


Figure 4-13: Post-scheme critical shear stress for 6, 7, 8, and 9 cumecs

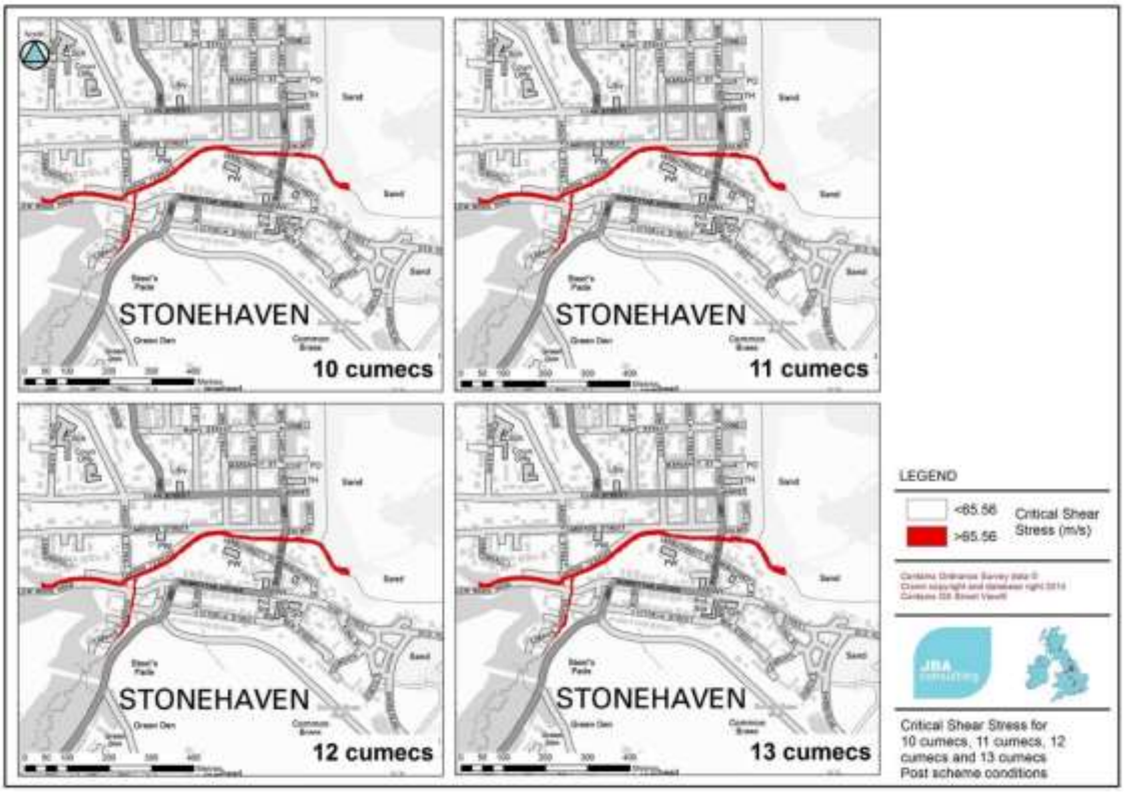


Figure 4-14: Post-scheme critical shear stress for 10, 11, 12 and 13 cumecs

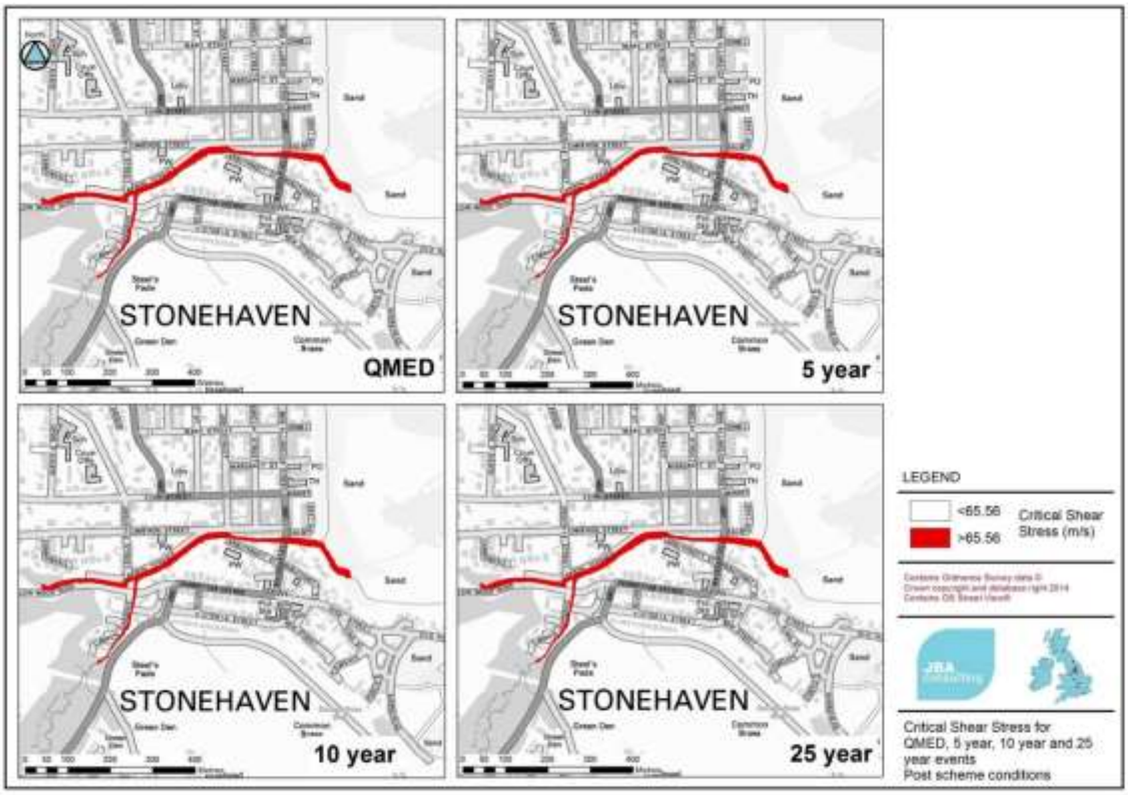


Figure 4-15: Post-scheme critical shear stress for QMED and 5, 10 and 25 year events

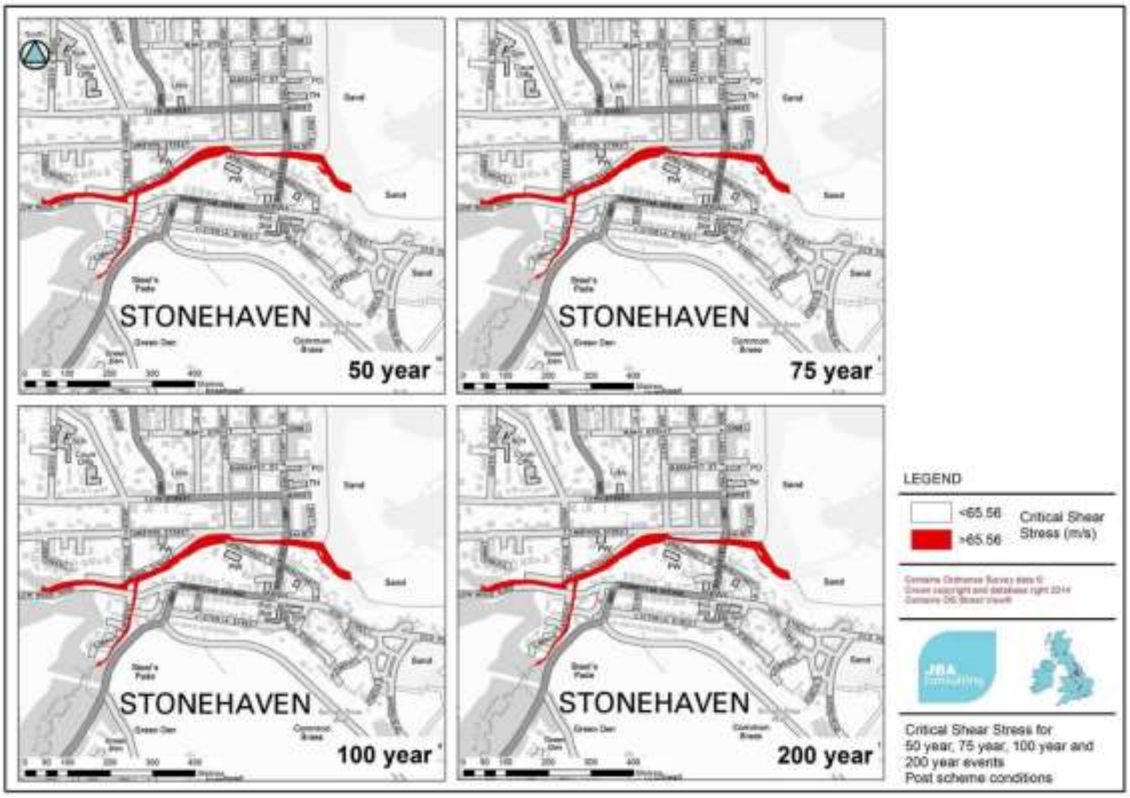


Figure 4-16: Post-scheme critical shear stress for 50, 75, 100 and 200 year events

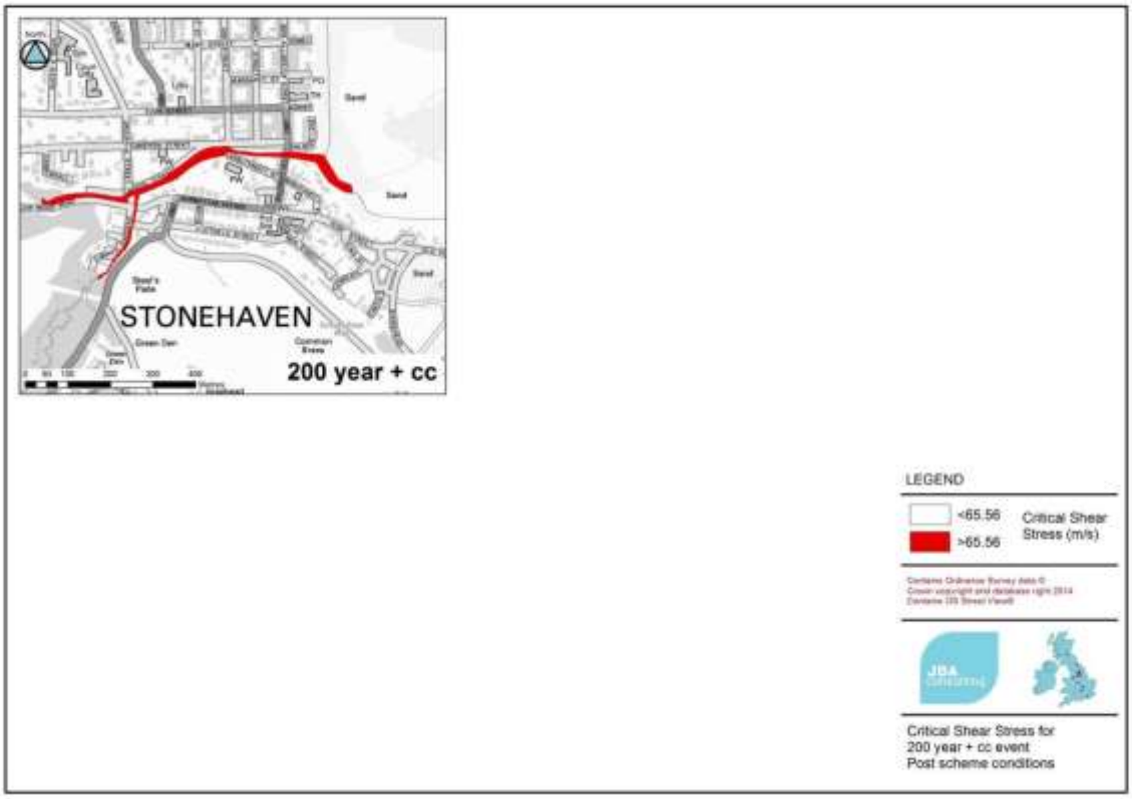


Figure 4-17: Post-scheme critical shear stress for 200 year + cc event

5 Conclusions

The study reach of the River Carron and Glaslaw Burn at Stonehaven has been examined for the effect which the proposed FPS will have on the hydromorphology of the watercourses.

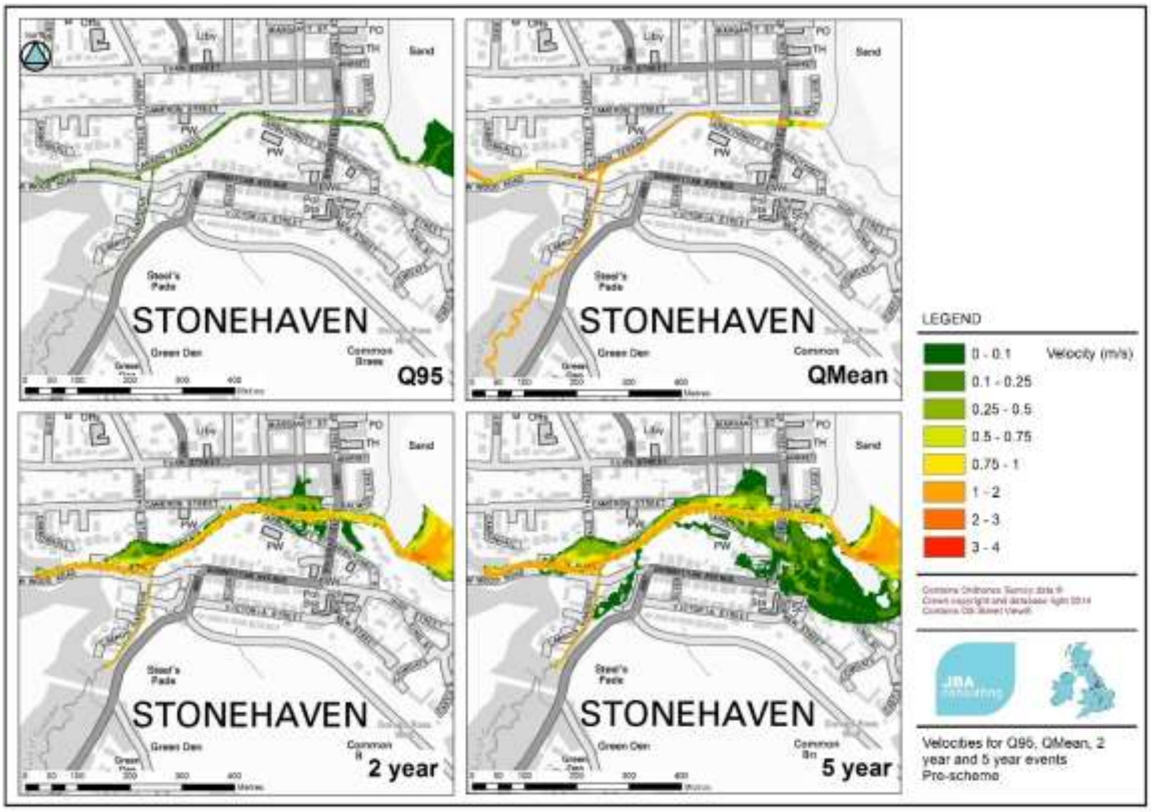
The DTM and input hydrographs were used to produce results for flows including Q95, 2 year, 200 year and 200 year plus climate change. The depths and velocities for each of these flows were compared for the existing channel conditions and the estimated conditions after the installation of the FPS.

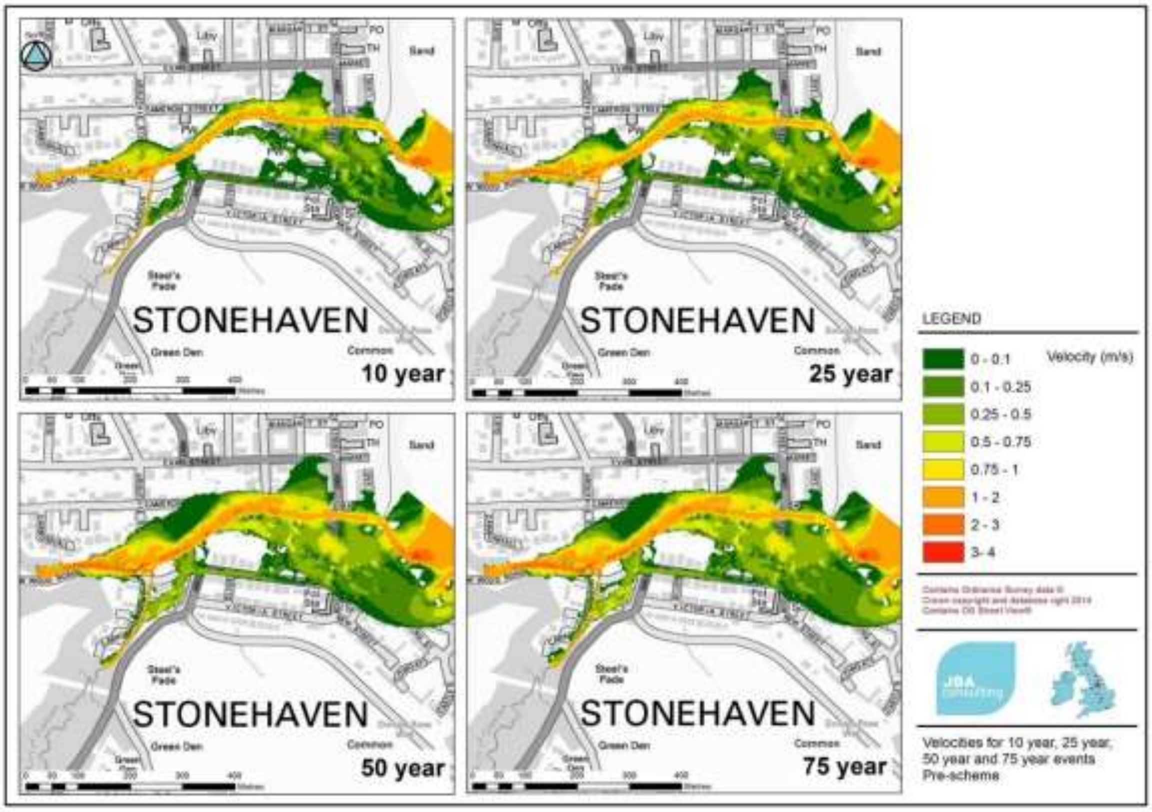
Maps produced from the results showed that as per the design, water would be contained within the channel during high flow events, the velocity and depths within the channel would hence increase. Calculation of critical shear stress indicated that after the installation of the FPS, sedimentation is dependent on the delivery of sediment from upstream and would continue to only occur during events of flows lower than QMED (14.5 m^3/s). For higher flows there would be a mobilisation of sediment down the study reach as a result of increased energy levels. Areas where sediment movement would be highest is between the White Bridge and Bridgefield Bridge, and such significant increases in estimated velocities of up to 4.5 m/s will result in scour along this reach. The maximum modelled velocities range from 4.1 m/s to 5.9 m/s during the post scheme model scenario from the QMED to 200 year events respectively, such velocities are related to the erosion of consolidated bed materials.

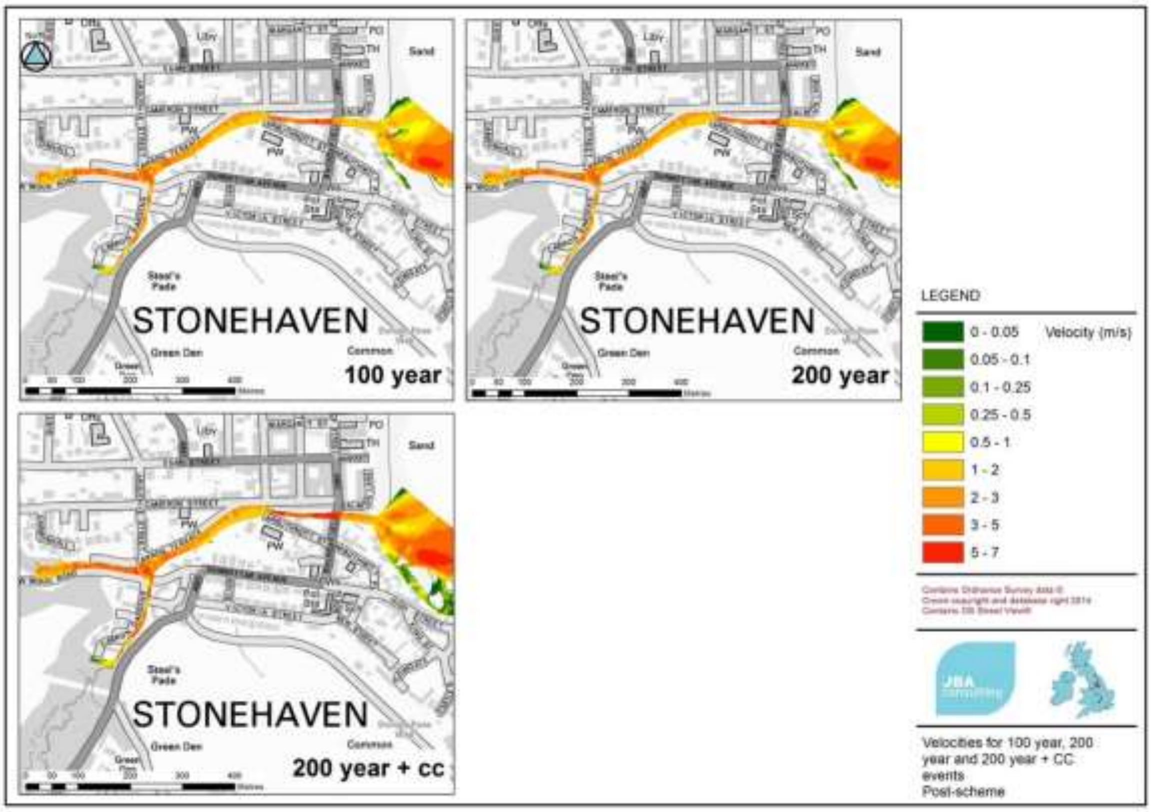
Sediment load information has not been collected within this catchment or modelled reach and hence a dynamic system model could not be created. Thus there is limited information available to allow for the assessment of the input / flux of sediment during less extreme events, which may counteract the scour experienced during the rarer extreme events. Given that the watercourse flows over a raised beach and there is no bedrock present at depths of up to c. 8.5m along the reach between White Bridge and Bridgefield Bridge, armouring of the channel bed will therefore be required. Armouring of the bed will also need to be considered on the Glaslaw Burn and reach of the Carron Water immediately upstream and downstream of the Glaslaw Burn confluence.

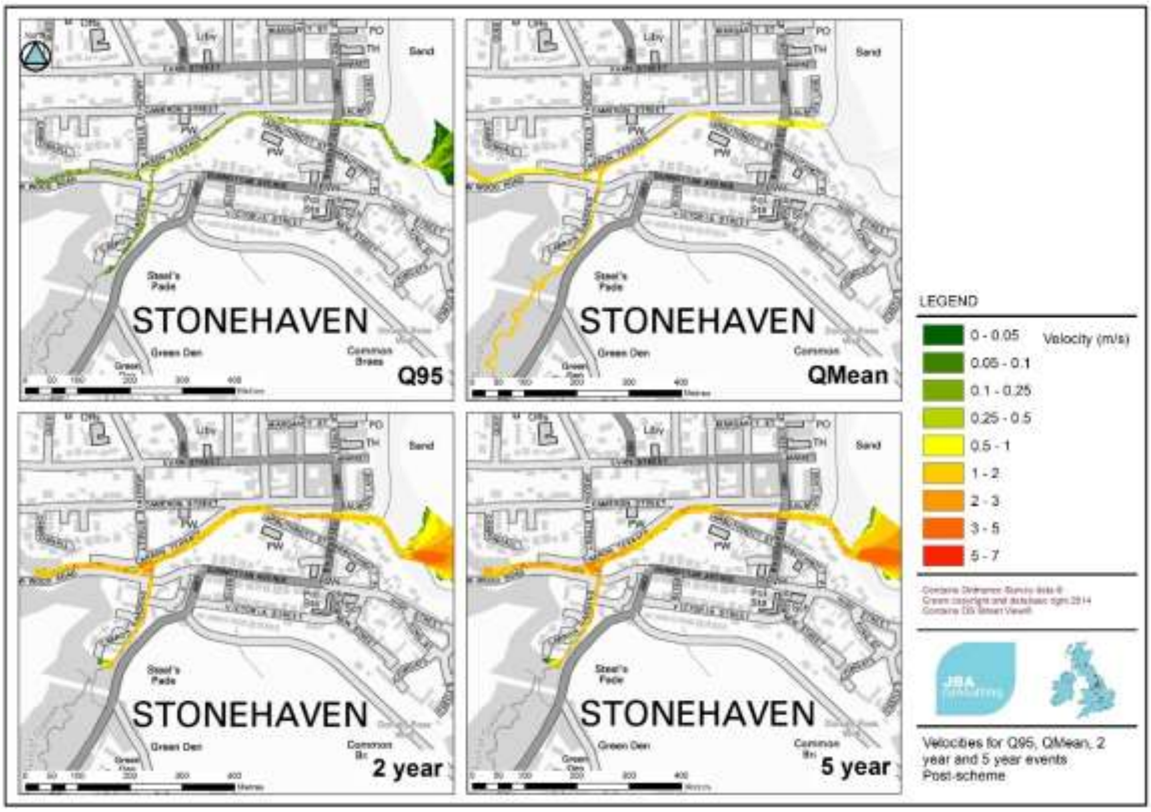
Appendices

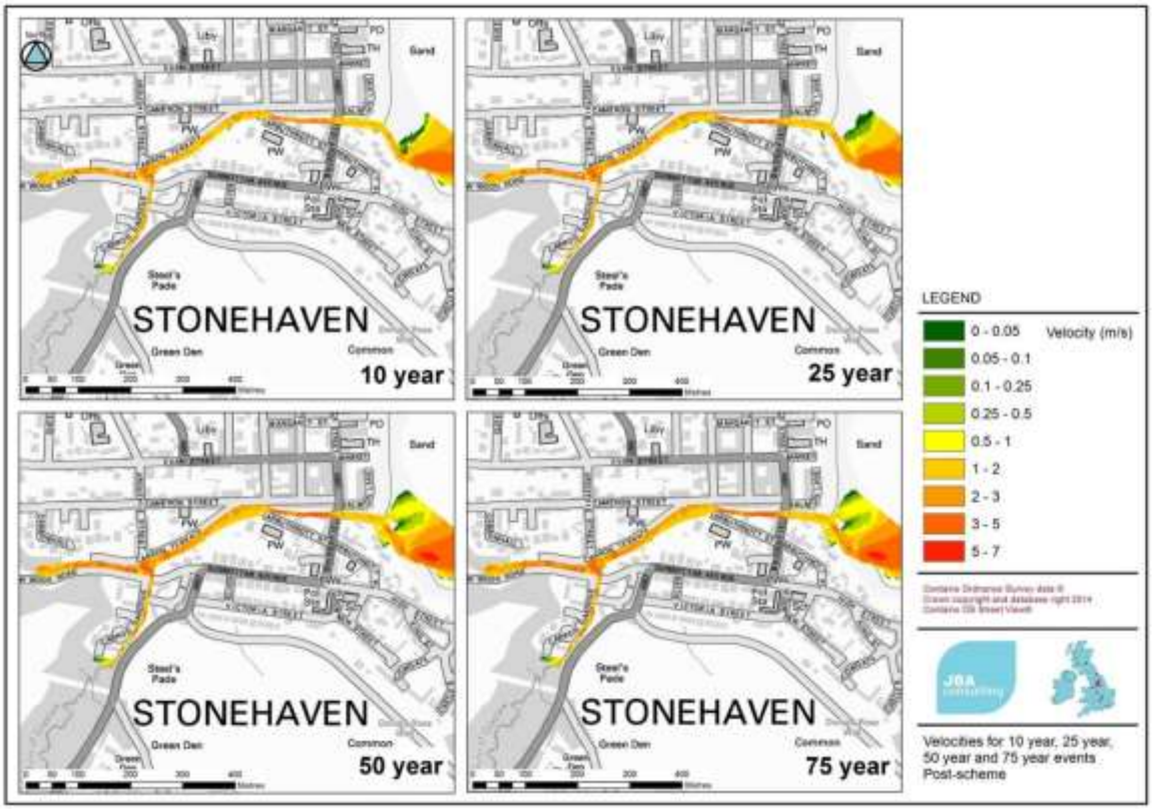
A Velocity and shear stress maps for additional return periods

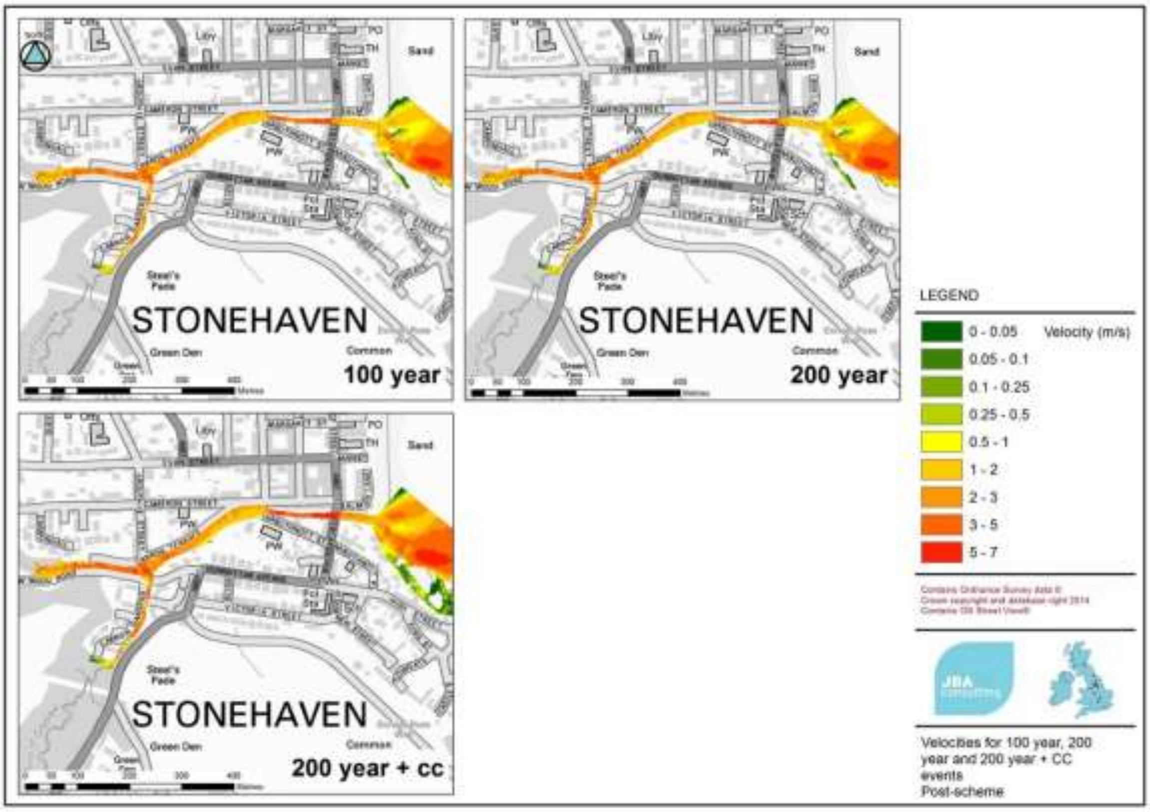


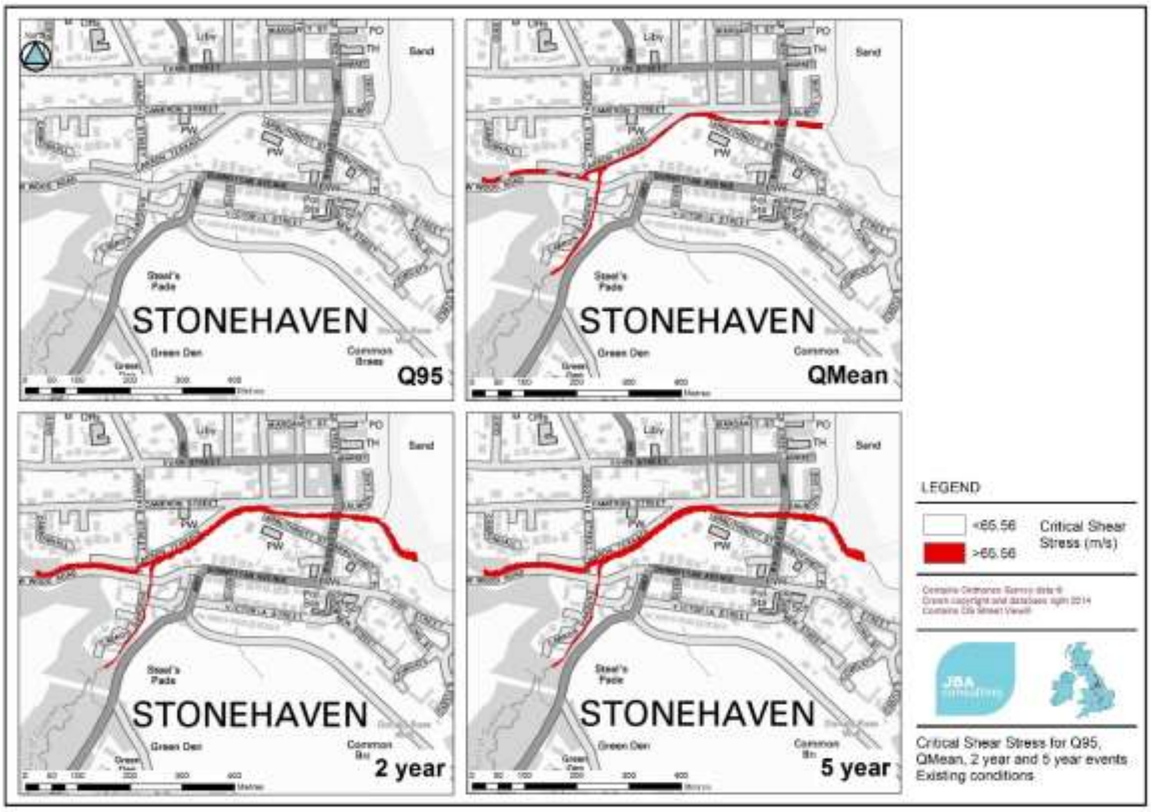


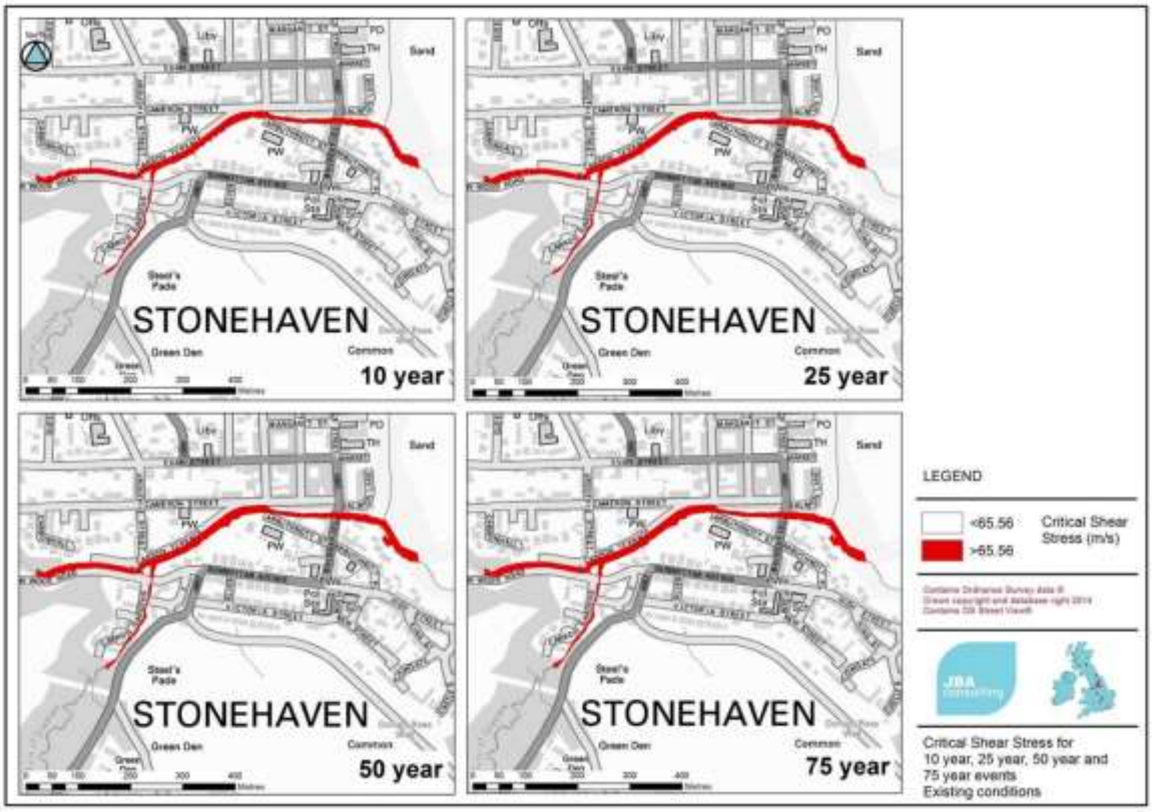

STONEHAVEN
100 year
STONEHAVEN
200 year
STONEHAVEN
200 year + cc
LEGEND
Velocity (m/s)
0 - 0.05
0.05 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 5
5 - 7
Velocities for 100 year, 200 year and 200 year + CC events
Post-scheme

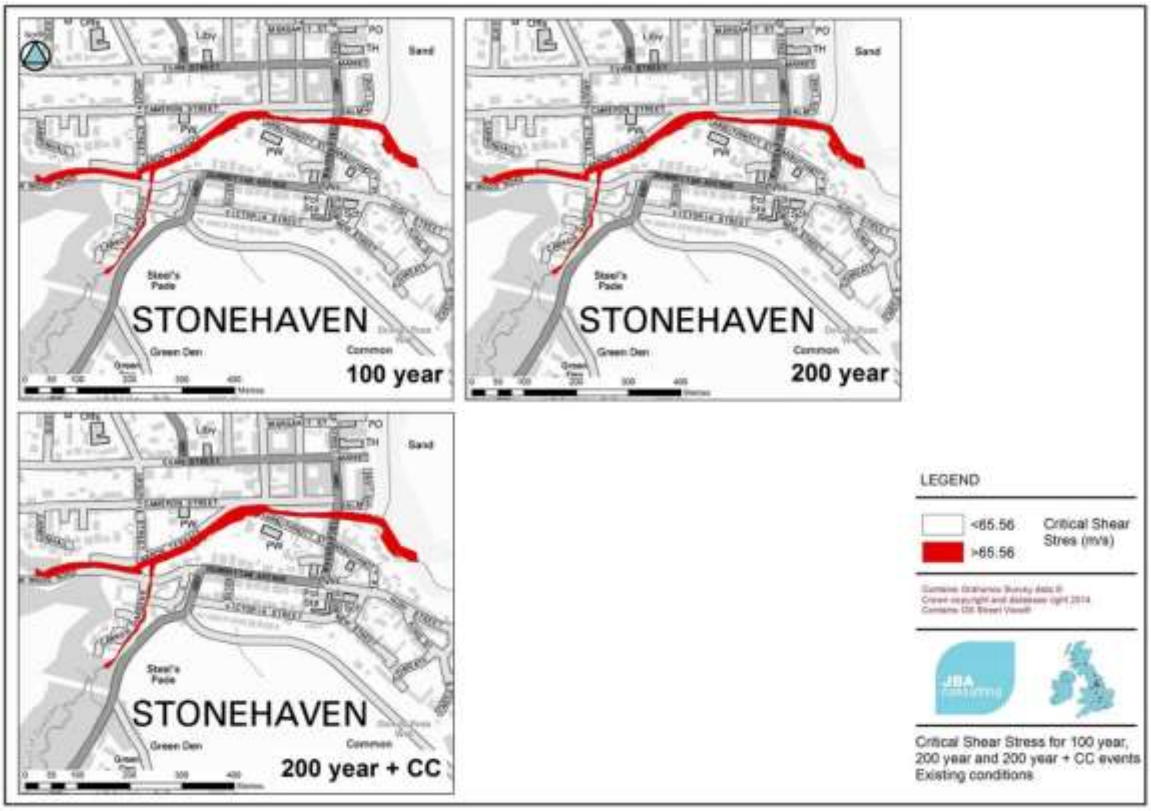

STONEHAVEN
Q95
STONEHAVEN
QMean
STONEHAVEN
2 year
STONEHAVEN
5 year
LEGEND
Velocity (m/s)
0 - 0.05
0.05 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 5
5 - 7
Velocities for Q95, QMean, 2 year and 5 year events
Post-scheme

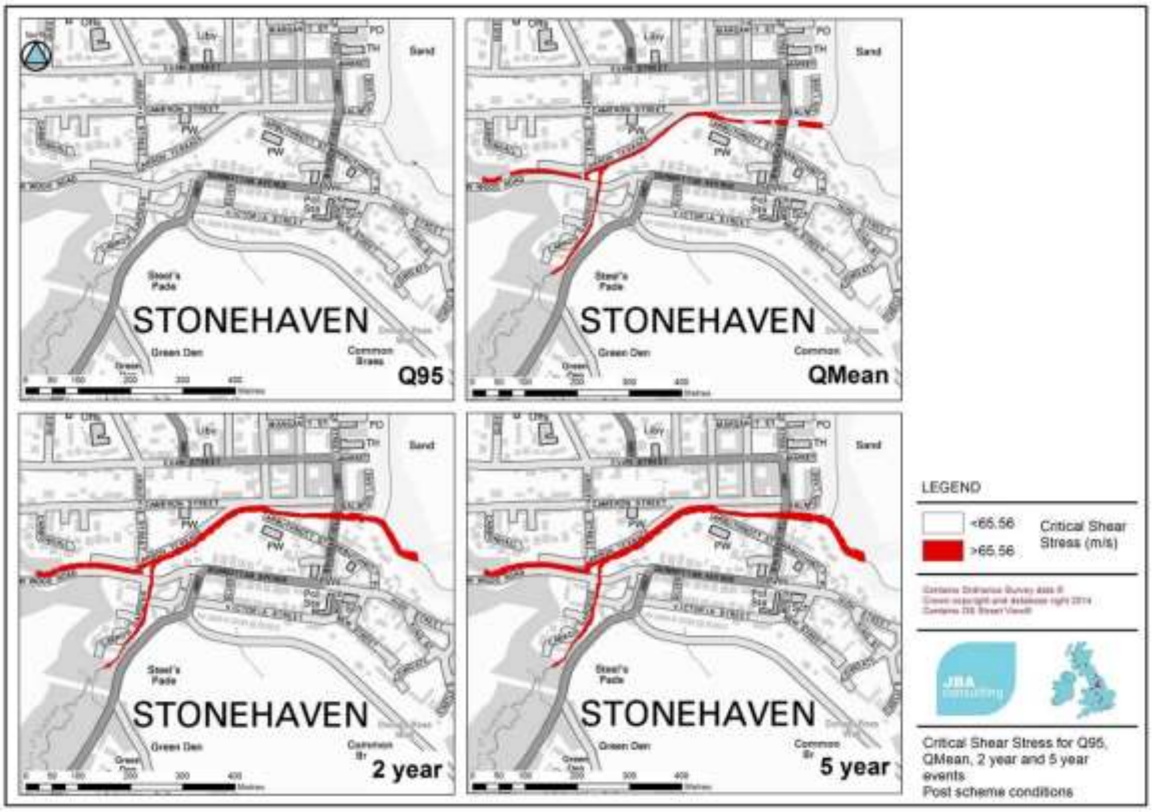

STONEHAVEN
10 year
25 year
50 year
75 year
LEGEND
Velocity (m/s)
0 - 0.05
0.05 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 5
5 - 7
Velocities for 10 year, 25 year, 50 year and 75 year events
Post-scheme

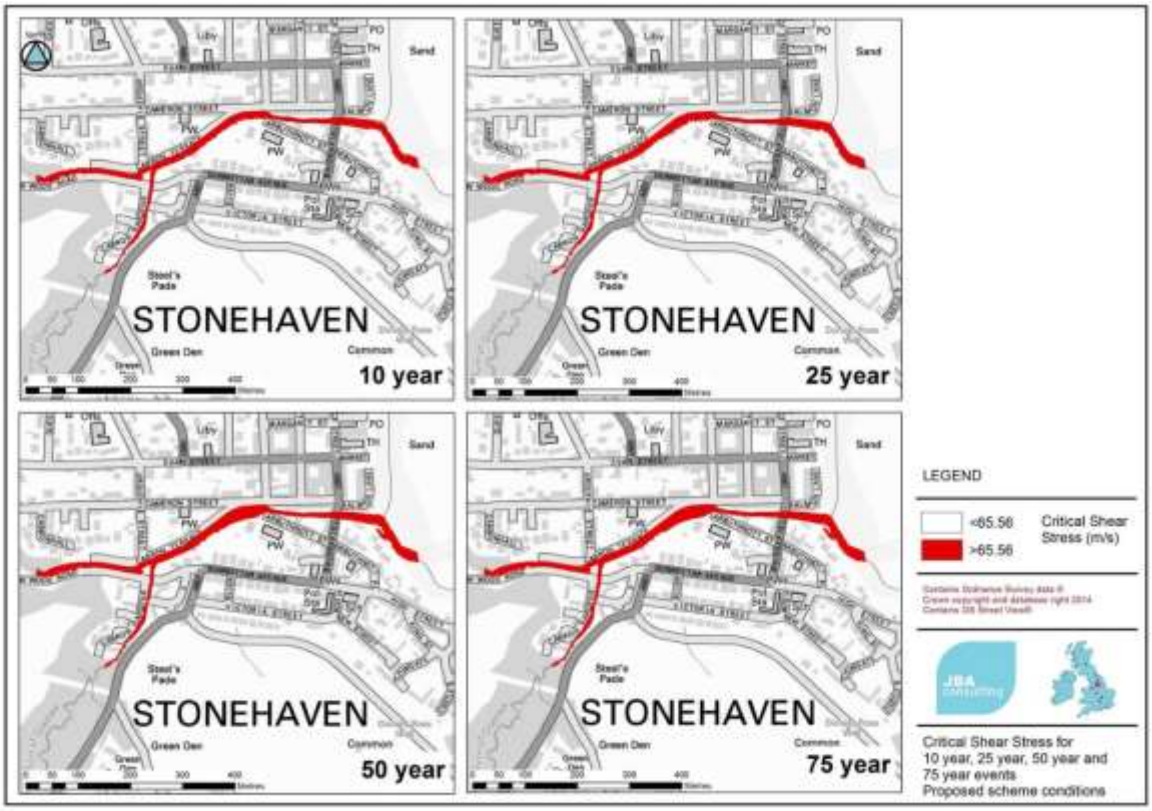

STONEHAVEN
100 year
200 year
200 year + cc
LEGEND
Velocity (m/s)
0 - 0.05
0.05 - 0.1
0.1 - 0.25
0.25 - 0.5
0.5 - 1
1 - 2
2 - 3
3 - 5
5 - 7
Velocities for 100 year, 200 year and 200 year + CC events
Post-scheme

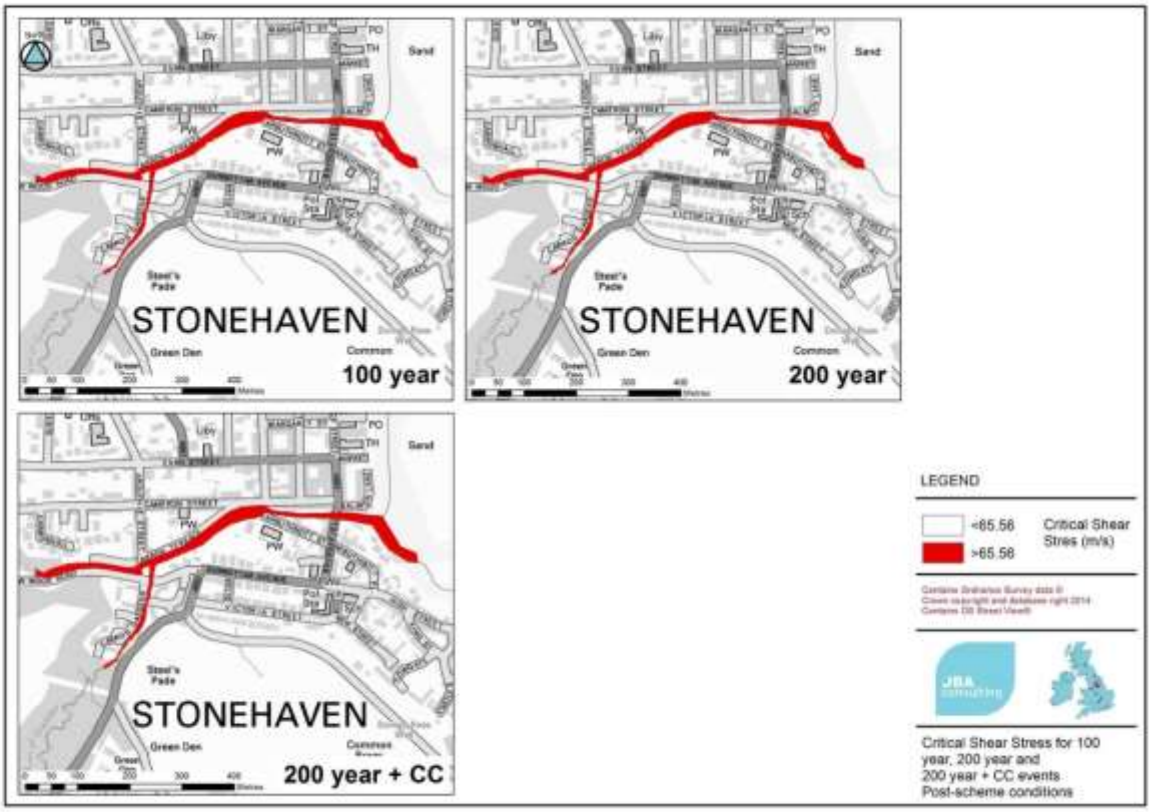

STONEHAVEN
Q95
STONEHAVEN
QMean
STONEHAVEN
2 year
STONEHAVEN
5 year
LEGEND
<65.56
>65.56
Critical Shear Stress (m/s)
Critical Shear Stress for Q95, QMean, 2 year and 5 year events
Existing conditions


STONEHAVEN
10 year
STONEHAVEN
25 year
STONEHAVEN
50 year
STONEHAVEN
75 year
LEGEND
<65.56
>65.56
Critical Shear Stress (m/s)
Critical Shear Stress for 10 year, 25 year, 50 year and 75 year events
Existing conditions


STONEHAVEN
100 year
STONEHAVEN
200 year
STONEHAVEN
200 year + CC
LEGEND
<65.56
>65.56
Critical Shear Stres (m/s)
Critical Shear Stress for 100 year, 200 year and 200 year + CC events
Existing conditions


STONEHAVEN
Q95
STONEHAVEN
QMean
STONEHAVEN
2 year
STONEHAVEN
5 year
LEGEND
<65.56
>65.56
Critical Shear Stress (m/s)
Critical Shear Stress for Q95, QMean, 2 year and 5 year events
Post scheme conditions


STONEHAVEN
10 year
STONEHAVEN
25 year
STONEHAVEN
50 year
STONEHAVEN
75 year
LEGEND
<65.56
>65.56
Critical Shear Stress (m/s)
Critical Shear Stress for 10 year, 25 year, 50 year and 75 year events
Proposed scheme conditions


STONEHAVEN
100 year
STONEHAVEN
200 year
STONEHAVEN
200 year + CC
LEGEND
<65.56
>65.56
Critical Shear Stres (m/s)
Critical Shear Stress for 100 year, 200 year and 200 year + CC events
Post-scheme conditions

Offices at

Coleshill
Doncaster
Edinburgh
Haywards Heath
Limerick
Newcastle upon Tyne
Newport
Saltaire
Skipton
Tadcaster
Thirsk
Wallingford
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