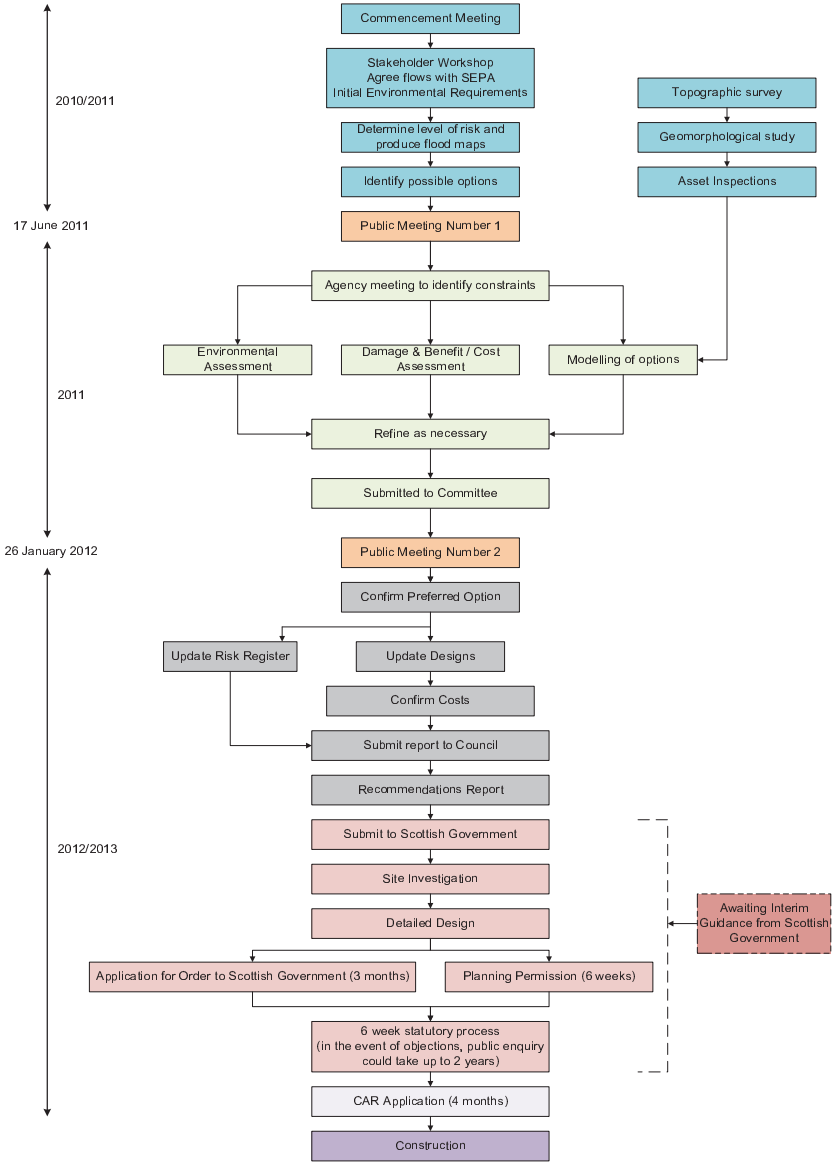
1 - SCHEME DEVELOPMENT & PROCESS

Scheme of Works / Programme



Scheme Objective

- To provide a long term flood alleviation scheme in Stonehaven.
- To reduce the likelihood and impact of fluvial flooding from the River Carron.
- To enhance or maintain the existing environment.
- To avoid adverse environmental or geomorphological impacts.

Standard of Protection (SoP)

- Scottish Government guidance relating to Flood Protection Schemes recommends that they should be designed to protect against flows up to a 1% AP (100 year) flood.
- However, the design event for planning purposes in Scotland is the 0.5% AP (200 year) flood. A consideration of climate change is also appropriate.
- A **target SoP** for the flood alleviation measures of the **0.5% AP (200 year) event** has been used for this study.

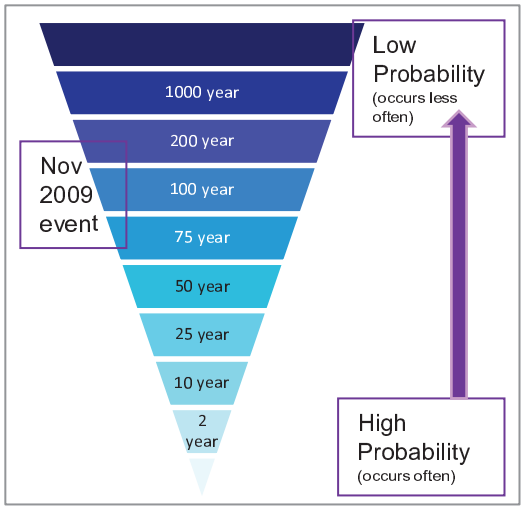
Definitions

- **Annual Probability (AP)** – % chance of being equalled or exceeded in any one year.
- **Return Period (years)** – denotes the average recurrence interval over an extended period of time.
    - e.g. 0.5% AP is equal to a 1 in 200 year return period
- **Geomorphology** – the study of landform and the processes that shape them.
- **1D hydraulic modelling** – one dimensional computer model which represents the channel dimension and used to model channel capacity.
- **2D hydraulic modelling** – two dimensional computer modelling allowing flood flows to be modelled as they pass out of channel and across the floodplain, thus representing overland flow routes.

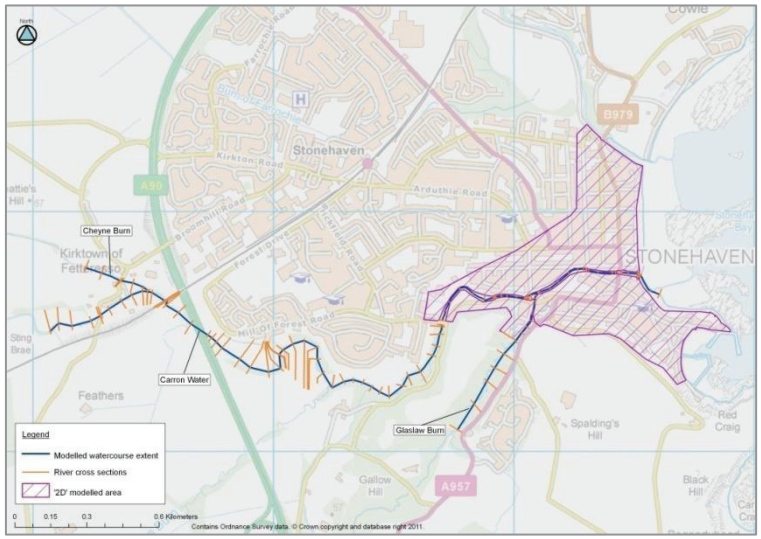
2 - STONEHAVEN FLOOD ALLEVIATION STUDY: INTRODUCTION

What are the aims of the study?

- Collate data on Stonehaven's flood history.
- Simulate different scenarios of flooding from the River Carron and Burn of Glaslaw.
- Identify where water flows across the floodplain.
- Estimate the potential impact of climate change on flooding.
- Consider the wider catchment environment.
- Develop long-term, sustainable options for flood mitigation.



Flood return periods



The extent of the River Carron model

What IS included in the study?

- Construct a detailed 2D hydraulic model of the River Carron at Stonehaven to assess extent of overland flow and calibrate it to the November 2009 event.
- Derive a range of 'design' river flows to assess the flood risk for a number of scenarios.
- Identify the key mechanisms of fluvial flooding from the River Carron and Glaslaw Burn.
- Assess existing level of flood risk and flood mapping.
- Appraise options by considering engineering feasibility, environmental constraints, benefit-cost analysis, sustainability and public opinion.
- Identify a preferred option to inform outline design.

What is NOT included in the study?

- Flood risk from the River Cowie.
- Flood risk from the sea.
- Drainage and sewer capacity.

3 - PAST FLOOD EVENTS IN STONEHAVEN

November 1873
Houses flooded to considerable depth.
The Scotsman, 8th November 1873

October 1906
Houses at the top of High Street and Arbuthnott Place flooded.
Means Leader, 25th October 1906

November 1946 & March 1947
River Carron out of bank but flooding of properties averted.
The Scotsman, 22nd November 1946 & 22nd March 1947

June 1938
Rivers Carron and Cowie in spate but no flooding to property.
The Scotsman, 3rd June 1938

October 1979
Severe flooding from the River Carron caused damage to properties in the town centre.
Press & Journal, 5th October 1979

April 1998
River Carron caused flooding to gardens along Cameron Street.

1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010

December 1882
Many houses in Stonehaven flooded to a depth of two to three feet.
The Scotsman, 18th December 1882

October 1907
Barclay Street and Market Square flooded.
The Scotsman, 11th October 1907

September 1956
River Carron out of bank, with residents on Cameron Street erecting flood barriers at their doors.
Mearns Leader, 7th October 1956

December 1985
Widespread flooding following sudden thaw combined with overnight rain.
Press & Journal, 7th December 1985


It Happened In The Mearns

25 YEARS AGO
FRIDAY DECEMBER 20 1985

November 2009
River Carron burst its banks and flooded businesses and houses, causing around 50 people to be evacuated.
Mearns Leader, 5th November 2009

Flood Event

4 - STUDY TO DATE

A number of studies have been undertaken to develop options and understand flood risk

Topographic survey and LiDAR

Provide levels for model and design

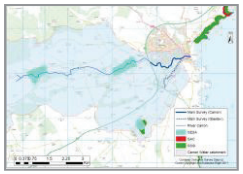
Geomorphology study

Recommended actions for the River Carron through Stonehaven:

A. Dredge bar deposits in conjunction with log weir removal
B. Remove log weir structure
C. Retain boulder weir complex
D. Create two-stage high flow channel where space allows
E. Retain gravel shoals under bridge and undertake periodic weed cutting
F. Remove in-channel structures on left bank
G. Remove in-channel structures on left bank and monitor bar sedimentation

Assess impact of gravel management on river

Environmental baseline study

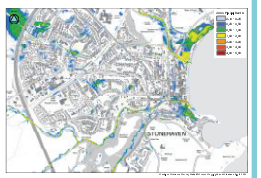


Assess environmental constraints & opportunities

Existing asset inspections

Asset inspection to confirm integrity of existing walls and structures

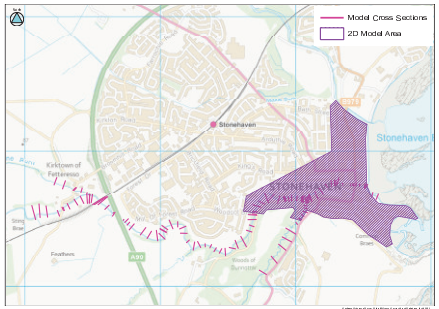
Surface water flood risk model



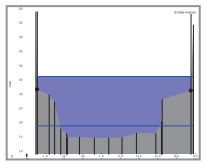
Shows areas where rain water will pond

Hydraulic (Computer) Modelling

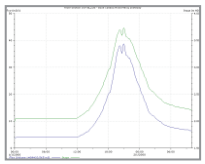
Peak water levels results at each section in the channel allow flood risk to be defined and informs feasibility.



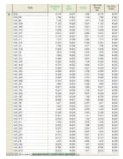
Extent of River Carron Model



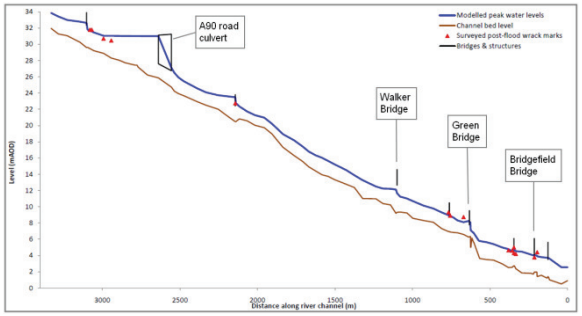
Peak water level



Time series results

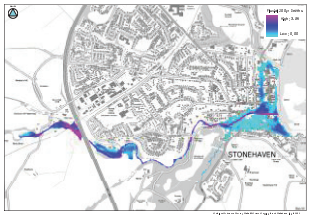


Data



Longitudinal section of water levels along the River Carron

Quantify Existing Flood Risk



Flood depths mapping on the floodplain

Define Potentially Suitable Options

Assess Option Feasibility

Present to Public Meeting No. 2

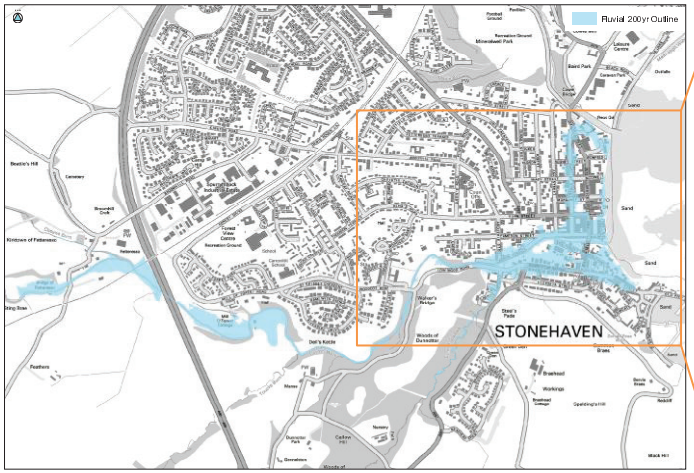
5 - FLOOD HAZARD FROM RIVER CARRON + GLASLAW

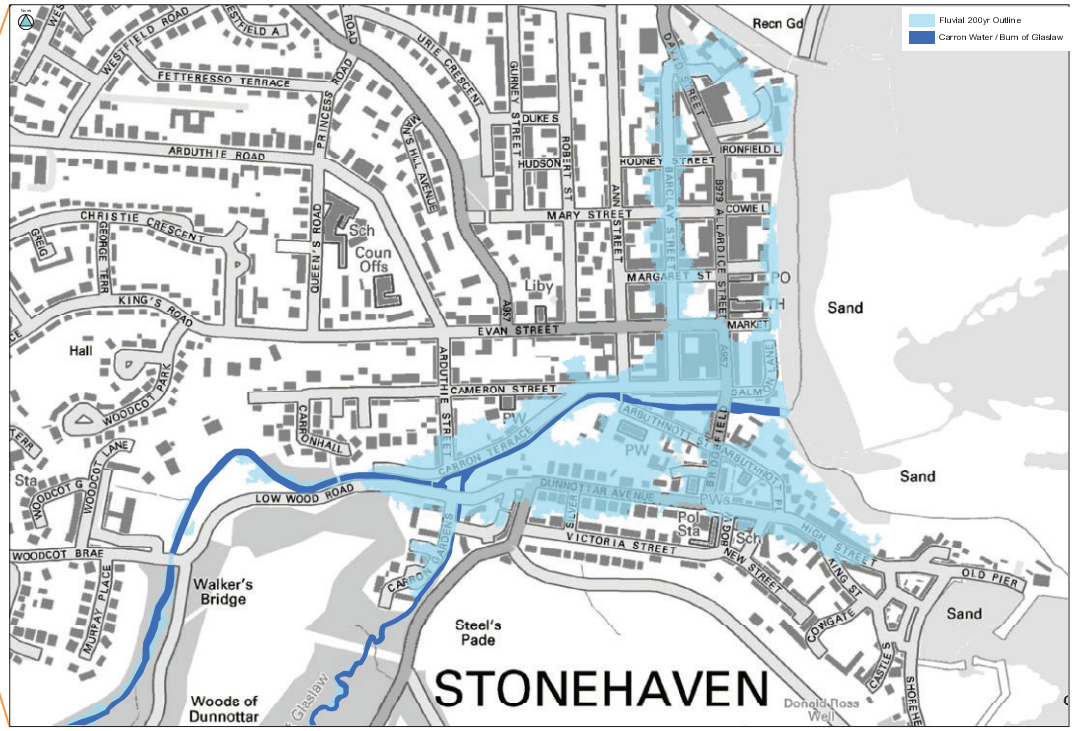
The map below shows the 0.5% AP (200 year) flood hazard area from the River Carron and lower section of the Glaslaw Burn.

Within the main town out of bank flow first commences along Low Wood Road and Carron Terrace.

In the event of a 0.5% AP (200 year) event occurring:

- 372 properties at risk
- £10.8m flood damages
- There is risk to life



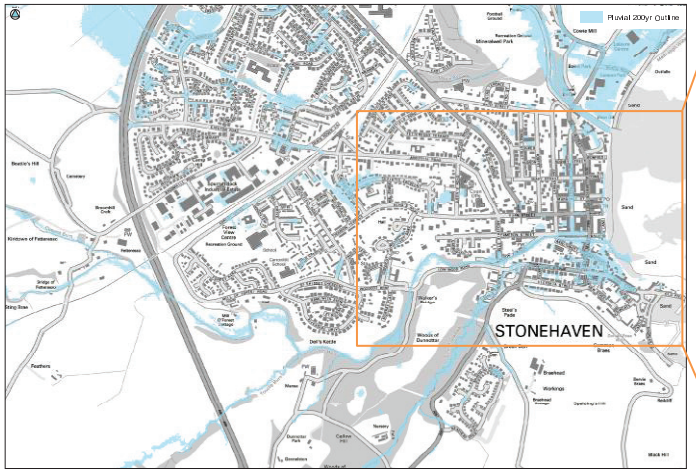


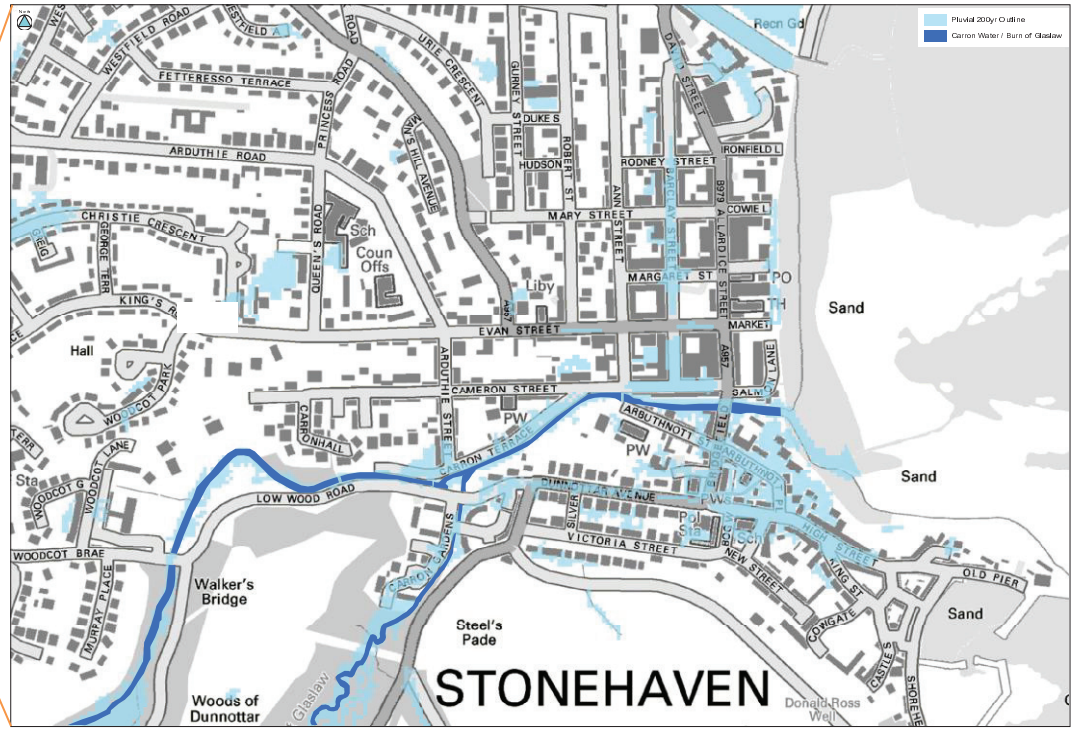
6 - FLOOD RISK FROM SURFACE WATER FLOODING

Surface water flooding is flooding as a direct result of rainfall onto the ground surface and its subsequent runoff via overland flow routes leading to ponding in topographically low-lying areas.

The map below shows the 0.5% AP (200 year) surface water flood risk area.

Identification of flood risk from this source allows this to be managed, even if flood risk from the Carron is removed.





What options have been considered?

Option 1	**Continuation of maintenance and repairs**	• Baseline scenario. • This does not significantly reduce flood risk.
Option 2	**Construction of direct defences**	• Direct defences are walls and embankments. • Provision of riverside flood walls. • In such cases it is important to make sure that any defences do not cause and impact elsewhere (i.e. Downstream).
Option 3	**Construction of direct defences combined with modifications to the channel and bridges**	• Bridges cause constrictions on the watercourse and can cause water levels to elevate upstream of the structure. It can therefore be advantageous to raise or remove bridges. • The old concrete weir at the Green Bridge causes water levels to back up and become elevated upstream. • Consideration given to raising the White Bridge.
Option 4	**Provision of upstream storage**	• Constructed storage areas upstream of the town may allow the flood peak to be stored upstream of the town and thus reduce peak flows and water levels in the town during floods. • A number of large embankments required across the valley.
Option 5	**Construction of direct defences combined with upstream storage**	• Providing a combination of direct defences and flood storage can result in the reduction in required wall heights and also the reduction of storage area required.
Option 6	**Provision of increased flood resilience**	• This option promotes the use of flood gates, vent guards, temporary flood defences and retrofitting flood resilience in buildings.

Emergency repairs in 2009

Example of direct defences

Example of upstream storage

Example of flood resilience measures

8 – PLAN SHOWING LOCATION OF DEFENCES

Within Stonehaven (Options 2/3/5)

LEGEND

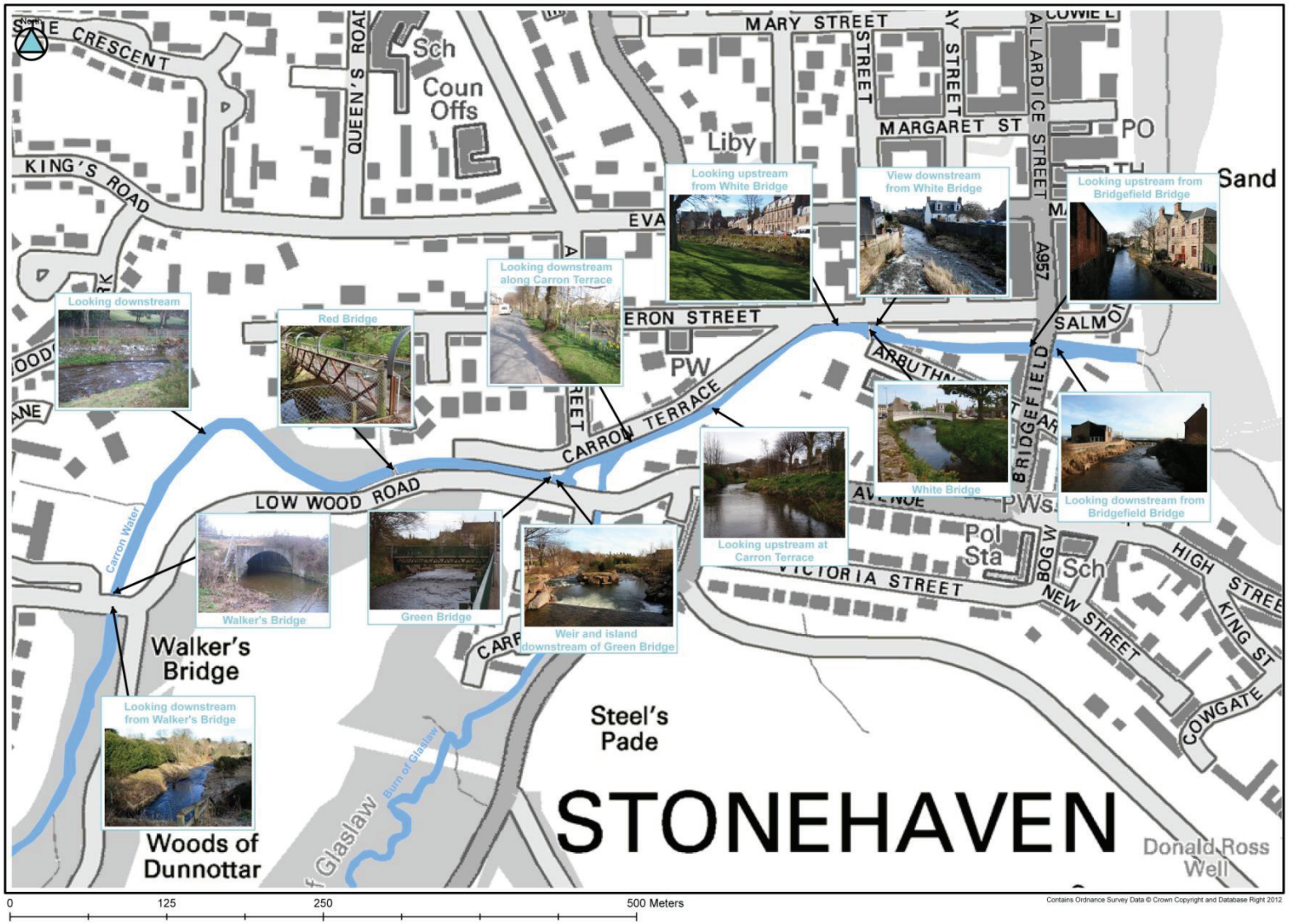
- New Wall Constructed
- Existing Wall Strengthened
- Wall / Embankment on Burn of Glaslaw
- Possible New Bridge Location
- Remove or Raise Existing Bridge
- Raise Ground Levels Locally
- Embankment
- Possible Storage Area

Upstream Storage (Options 4/5)

9 - OPTION 1: Continuation of Maintenance & Repairs

This option includes vegetation clearance, bank maintenance and tree management.

This is will not significantly reduce flood risk and is used as baseline in scheme appraisal.



10 - OPTION 2: Direct Defence as Stand Alone

This option includes the construction of riverside walls.

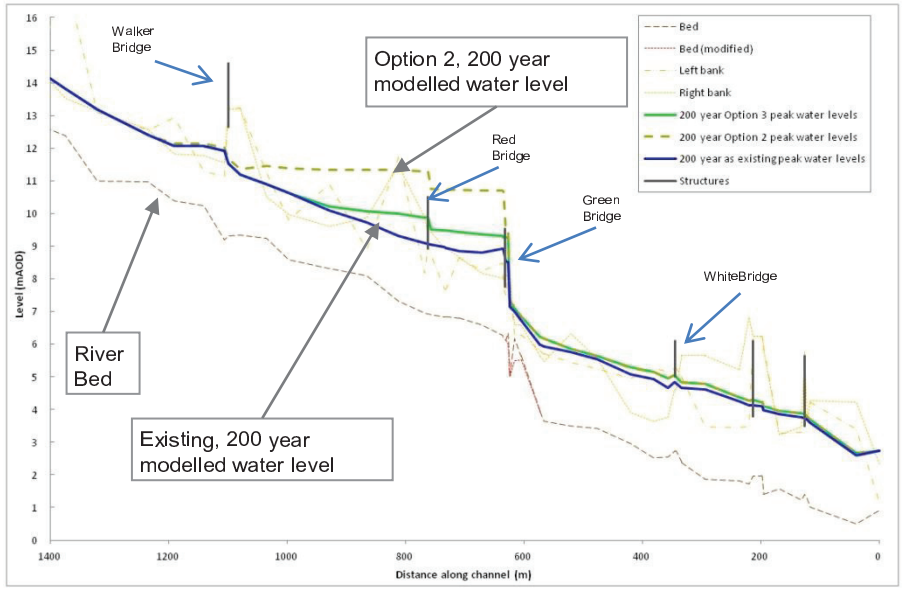
These increase channel capacity, but raise water levels in the channel against the walls and downstream.

Walls required along Low Wood Road, Carron Terrace and Cameron Street.

Locally significant wall heights required (including 300 mm freeboard).

This would provide a 0.5% AP (200 year) standard of protection.

	Average Defence Height (m)	Maximum Defence Height (m)
Carron Terrace on left bank (when looking downstream) **upstream of Green Bridge**	2.7	3.9
Low Wood Road on right bank (when looking downstream) **upstream of Green Bridge**	2.4	3.0
Carron Terrace on left bank (when looking downstream) **downstream of Green Bridge**	0.7	0.9
Cameron Street on left bank (when looking downstream) **downstream of White Bridge**	1.2	2.1



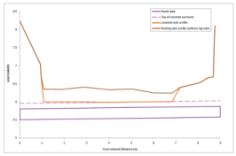
Long Section of Modelled Reach of the Carron

Example Photographs of Flood Walls

11 - OPTION 3: Defences with Channel & Bridge Modifications

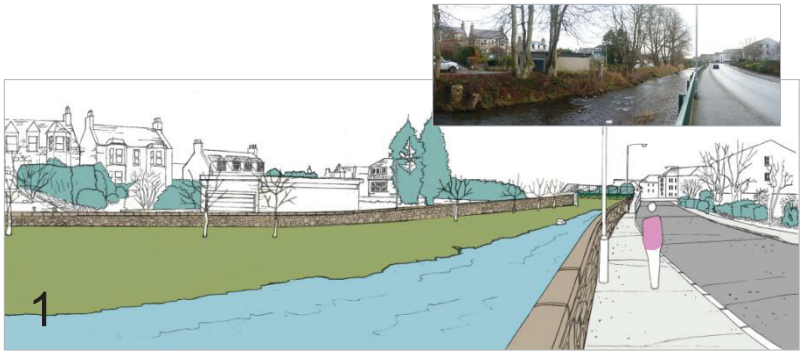
Lower Green Bridge Weir

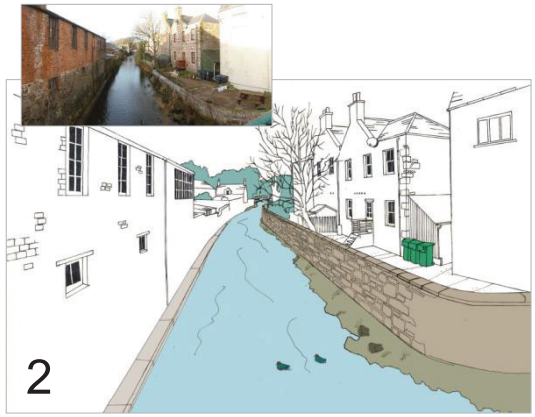
Weir

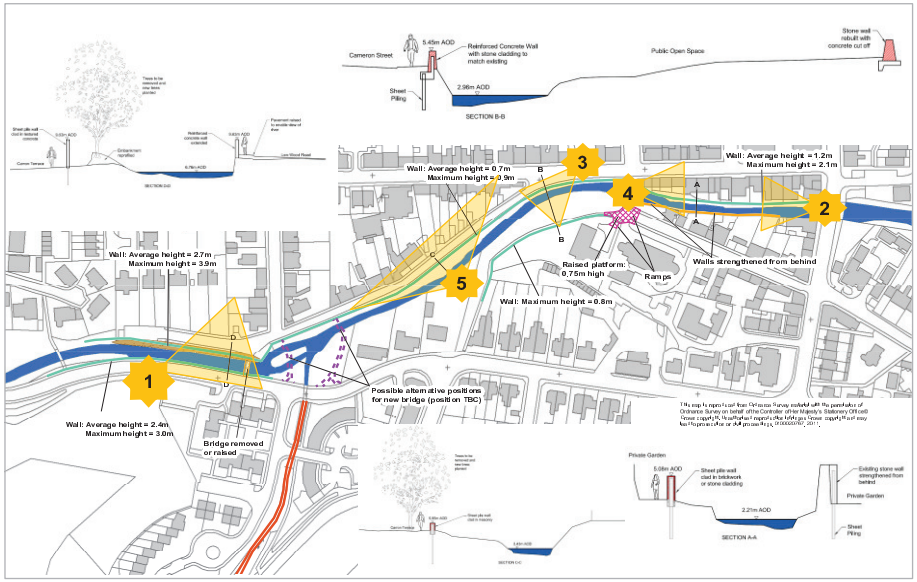


Channel Cross Section

- The Green Bridge & Weir elevate water levels upstream, therefore investigation of these structures has been undertaken combined with defences. Options include:
    - Lower the crest of the Green Bridge Weir
    - Raise the Green Bridge
    - Relocate the Green Bridge
    - Raise the White Bridge (tested although shown to have limited benefit)
- **This would reduce maximum wall heights by 1.4 m compared to Option 2.**
- Would provide a 0.5% AP (200 year) standard of protection.





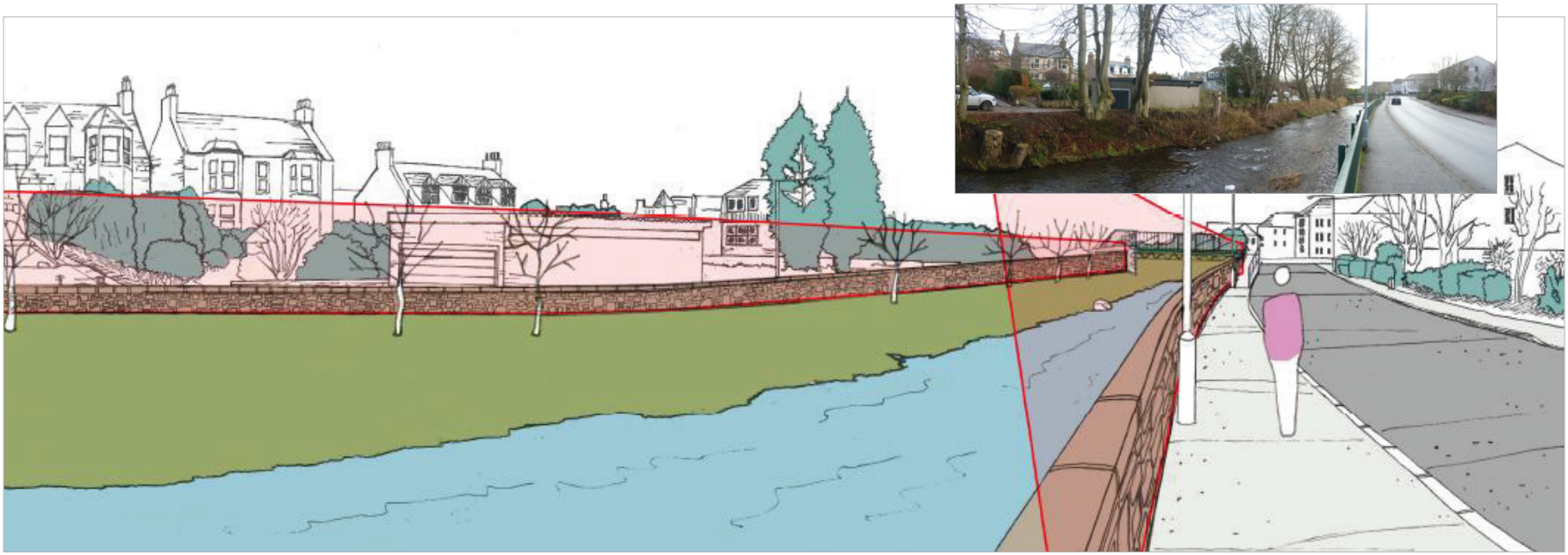


12 - COMPARISION OF OPTIONS 2 and 3

Options 2 and 3 would both provide a 0.5% AP (200 year) standard of protection.

However, stand alone direct defences (Option 2) would result in locally significant wall heights upstream of Green Bridge.

Option 3 (defences, raising of Green Bridge and lowering of weir) reduces the maximum wall heights by up to 1.4 m.



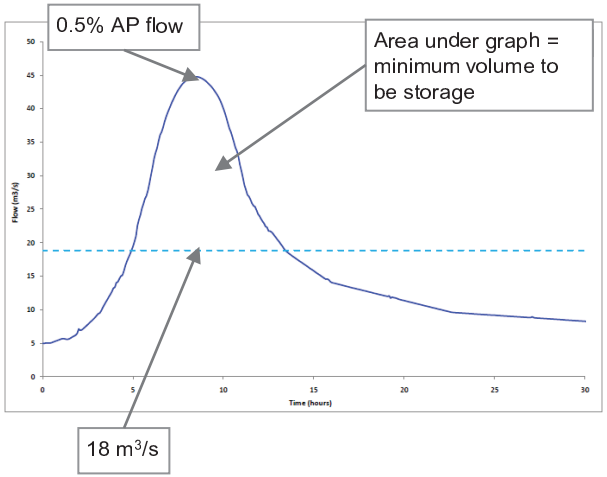
Red Line represents required wall height for Option 2 superimposed over wall heights required for Option 3

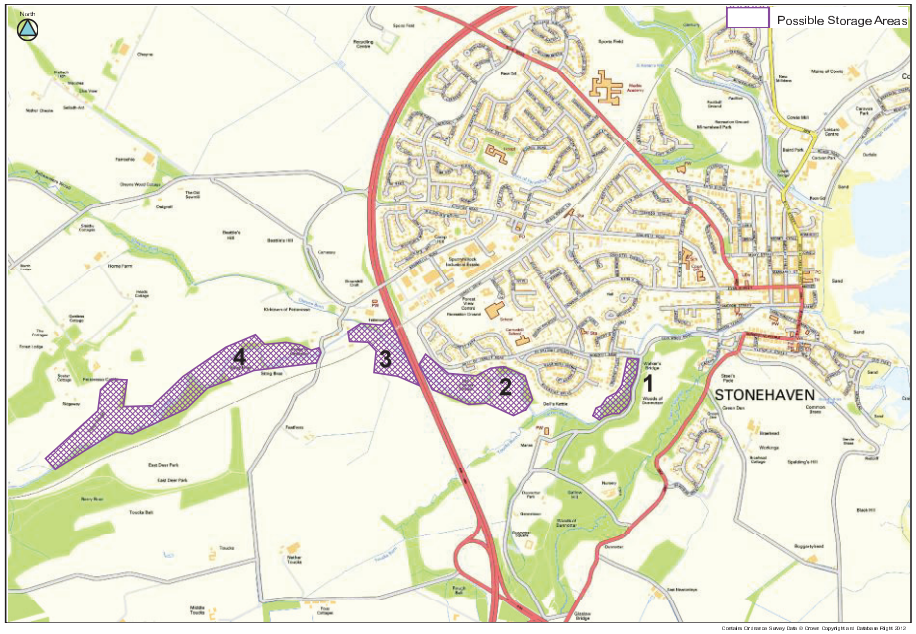
	Defence Heights Option 2		Defence Heights Option 3	
	Average Defence Height (m)	Maximum Defence Height (m)	Average Defence Height (m)	Maximum Defence Height (m)
Carron Terrace on left bank (when looking downstream) **upstream of Green Bridge**	2.7	3.9	1.9	2.5
Low Wood Road on right bank (when looking downstream) **upstream of Green Bridge**	2.4	3.0	1.0	1.6
Carron Terrace on left bank (when looking downstream) **downstream of Green Bridge**	0.7	0.9	0.7	0.9
Cameron Street on left bank (when looking downstream) **downstream of White Bridge**	1.2	2.1	1.2	2.1

13 - OPTION 4: Upstream Storage

How Does Upstream Storage Work?

- An estimated flow of 18 m^3/s can currently flow down the Carron without flooding out of bank.
- The 0.5% AP (200 year) flow is calculated as being (45 m^3/s)
- Storage would aim to store water upstream and then release this water once the flood peak has passed, restricting peak flows to only18 m^3/s in the town.
- The nearer the storage area is to the town the more successful it will be at attenuating the flood peak.





Plan showing possible locations of flood storage areas.

How much storage might be required to reduce the 0.5% AP flow?

- An estimated minimum volume of 0.45 Million (M) m^3 is required.
- 0.21 Mm^3 potentially available in all of the investigated areas combined.

Example: White Cart Water Flood Prevention Scheme

Blackhouse

Storage = 0.81 Mm^3
Embankment length = 350m
Crest Width = 3m
Maximum height = 15m

Kirkland Bridge

Storage = 1.08 Mm^3
Embankment length = 150m
Crest Width = 3m
Maximum height = 9m

Kittoch Bridge

Storage = 0.67 Mm^3
Embankment length = 300m
Crest Width = 3m
Maximum height = 15m

14 - OPTION 5: Upstream Storage and Defences

Option 5 is a combination of Options 3 and 4 to optimise wall heights and storage.

Option 3

Walls heights required for Option 3 range between a maximum of 0.9m and 2.5m.

Provides a 0.5% AP (200 year) standard of protection.

Option 4

Potentially 0.21 Million (M) m^3 of storage could be provided upstream. This would be in a number of large storage basins (0.21 Mm^3 is equivalent to 84 Olympic sized swimming pools).

This is estimated to be equivalent to the 2% AP (50 year) flow.

Therefore, this option alone is unlikely to provide a 0.5% AP (200 year) standard of protection.

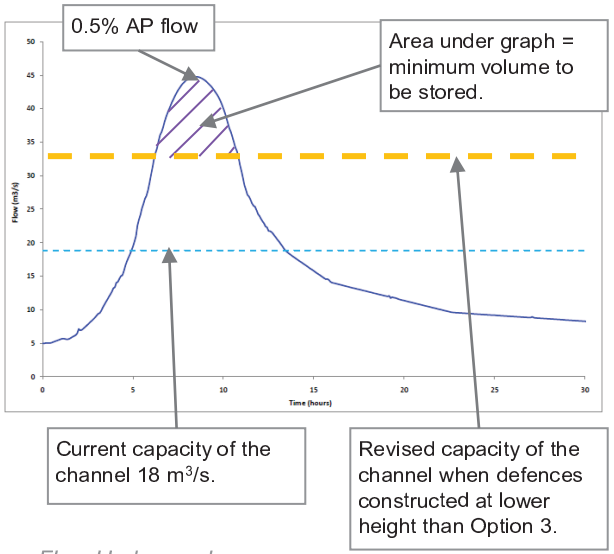
By combining storage and direct defences:

- The required defence heights within the town could be reduced.
- This may also reduce the size of the required storage areas.

Example Photograph of Flood Defence - Galashiels

Further Assessment Required

- Determine acceptable wall heights within the town.
- What standard of protection would these walls achieve?
- Can storage be found upstream to reduce the flows within the town to match that provided by the direct defences.



Flow Hydrograph

15 - OPTION 6: Increased Flood Resilience

This option promotes the use of flood gates, vent guards, temporary flood defences and retrofitting flood resilience in buildings.

Effective only up to moderate events and high risk of failures in systems due to short period of flood warning available on small catchments.

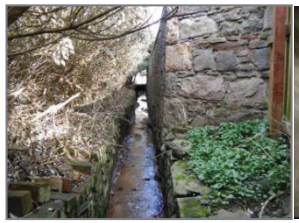
Does not provide a 0.5% AP (200 year) standard of protection.

SEPA:

- Are looking to develop improved flood warning on the Carron.
- Have installed a new river level gauge upstream of the town at Fetteresso.

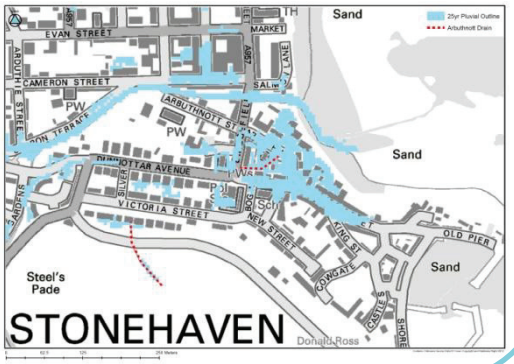
Supplementary Options have also been considered:

a. Open the Mill Lade under Arbuthnott Court (to act as flood relief drain)



Open section of Arbuthnott Drain *Under Arbuthnott Court*

- The old mill lade passes beneath Arbothnott Court and flows into a soakaway at the edge of the beach.
- The area between the open section of drain and the coast represents a topographical low and as such is subject to ponding during a rainfall event.
- Opening up end of the culvert / soakaway or pumping would allow water to be evacuated more rapidly.



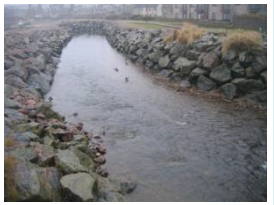
b. Promote land use changes in upper catchment to reduce run-off in extreme events

Cat Gill Wood, Yorkshire – Planted & Maintained on behalf of JBA

- Planting trees or other forms of land management practices to reduce runoff into the river.
- Peak flows could be reduced by 5-10% but large uncertainty in the effectiveness of the option.
- This could offer benefits in reducing the long term impacts of climate change to Stonehaven; but would not be sufficient enough to reduce the flood peak as a stand alone solution.

Cat Gill Wood, Yorkshire – Planted & Maintained on behalf of JBA

c. Modify / remove rock at coastal outfall



Rock armour along River Carron at its outfall into the North Sea

- The rock armour performs an important task in reducing direct wave action penetrating up the Carron from the open sea.
- Investigation shows that there is no benefit to be gained from undertaking further modifications here.

17 - SUPPLEMENTARY OPTIONS (2)

d. Modify island / twin channel structure downstream of Green Bridge

Island downstream of the Green Bridge

- Both the river modelling and direct observations on the night of the 1st November 2009 suggest that the island does not form a constriction in the current configuration.
- Modifications or removal would produce no flood alleviation benefits.
- However, modification to this area may be beneficial alongside channel modifications that are being investigated at the weir below Green Bridge.

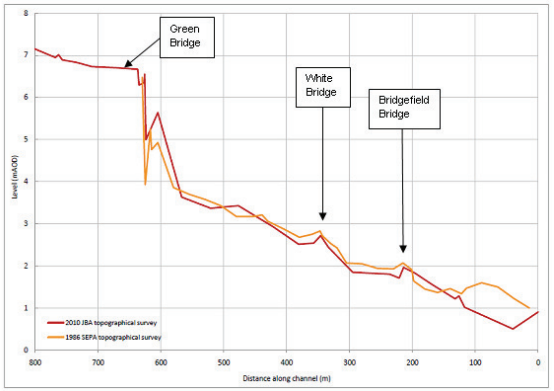
e. Modify gardens which encroach into river at Cameron Street

Looking upstream from Bridgefield Bridge

- Reference to old maps show that over a period of time, gardens in Cameron Street have encroached into the river channel and reduced the natural capacity of the river to cope with high flows.
- However, analysis demonstrates that the adverse impacts of this are limited to the river downstream of the White Bridge.
- Consider modifications to the gardens along with alleviation options.
- Further future encroachment should be avoided.

Looking downstream from White Bridge

f. Dredge the bed of the burn



Surveyed long section of the river bed in 1986 and 2010

- Dredging involves lowering the river bed by removing sediment.
- This is not sediment and vegetation management.
- Comparison with a detailed topographic survey shows that the bed of the Carron itself has not changed much over the years.
- When in spate the river transports a large quantity of sediment and on 1st November 2009, the river effectively dredged itself as demonstrated by the low bed levels post spate.
- Dredging can de-stabilise river banks and increase erosion of the river bed elsewhere.

18 - OPTION SUMMARY

The table below summarises each of the options considered with respect to the economic analysis undertaken to assess the cost effectiveness of each of the options.

Option	Effectiveness of Option	Estimated Cost (£ million)	Damages Avoided (£ million)	Residual Damages (£ million)	Benefit Cost Ratio	Standard of Protection	General Comments
1. Maintenance Only (baseline situation for assessments)	N/A	N/A	N/A	15.2	N/A	10 year	• Continuation of the present situation with minor works of maintenance and repair such as vegetation and sediment bank removal at choke points.
2. Direct Defences (Riverside walls only)	Effective	3.4	14.1	1.1	4.2	200 year	• Walls are raised to the required standard (1 in 200 year). • Containing water in channel raises water levels so maximum wall heights range from 0.9 to 3.9m. • Highly visible and disruptive to built and natural environment. • Enhanced risk if walls fail during flood event.
3. Direct Defences plus Channel and Bridges	Effective	3.4	14.1	1.1	4.2	200 year	• Walls are raised to required standard (1 in 200 year). • Including channel modification and bridge relocation allows wall heights to be reduced to maximum levels of between 0.9 and 2.5m. • Visible and disruptive to built and natural environment.
4. Upstream Storage	Moderately Effective	4.6	13.3	1.9	2.9	50 year	• Increased use of floodplain to store water upstream of Stonehaven reduces flows through town. • Effective against moderate flood events but insufficient available storage means this is only potentially effective up to 1 in 50 year.
5. Upstream Storage plus direct defences	Effective	6.1	14.1	1.1	2.3	200 year	• Using a combination of upstream storage, direct defences and channel / bridge modifications. • Allows wall heights in the town to be reduced further whilst still achieving the 1 in 200 year standard. • Further analysis required on upstream storage potential and wall heights in town.
6. Improved Resilience	Limited Effectiveness	3.7	3.5	11.7	0.9	10 year	• Promotes use of flood gates, vent guards, temporary flood defences and retrofitting flood resilience in buildings. • Effective only up to moderate events. • High risk of failures in systems due to short period of flood warning available on small catchment. • Important option as part of long term strategy as flood risk remains under all options, but not suitable as a stand alone solution to long term flood risk.
Benefit Cost Ratio is the ration of the benefits of the scheme relative to its costs. A benefit cost ration greater than 1 suggests that the scheme is cost effective.							

19 - MULTI-CRITERIA ANALYSIS OF THE OPTIONS

At this stage in the assessment each option is considered against a range of criteria.

This assessment is subjective and will be refined as the scheme progresses.

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

Colour	Result
	Positive result / no negative impact
	Intermediate / neutral result
	Negative result

20 - SUMMARY

Flood History: There is a long history of flooding from the River Carron in Stonehaven, with the most recent significant event occurring in 2009

Scheme Objective: To provide a long term, sustainable flood alleviation scheme for Stonehaven

There are a number of potential options to achieve this:

Option 1

Continuation of maintenance and repairs


Pros	Cons
• Low short term expenditure	• No real flood alleviation • Recurring or long term costs can add up • Potential environmental impacts

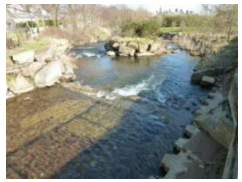
Option 2

Construction of direct defences


Pros	Cons
• Good benefit:cost ratio • Low operational requirements during flood event • Low maintenance costs	• Very high walls in town and increased damages if failure • Significant impact on amenity value of river • Impact on cultural heritage

Option 3

Construction of direct defences combined with modifications to the channel and bridges




Pros	Cons
• Good benefit:cost ratio • Potential to improve footbridge access • Low operational requirements during flood event • Opportunity for townscape improvements	• Raised walls in town • May impact on amenity value of river • May impact on cultural heritage

Option 4

Provision of upstream storage


Pros	Cons
• Construction outwith the town • Potential for creation of wetland areas	• Potential impact on fisheries and geomorphology • Complex design with high maintenance costs • Operational requirements during flood event

Option 5

Construction of direct defences combined with upstream storage


Pros	Cons
• Potential to improve footbridge access • Potential for creation of wetland areas • Robust scheme	• Potential impact on fisheries and geomorphology • Complex design with high maintenance costs • Operational requirements during flood event • Construction in and outwith town

Option 6

Provision of increased flood resilience


Pros	Cons
• Low short term expenditure • Community ownership of risk reduction • Limited disturbance during installation • Minimal environmental impact	• Limited effectiveness • Low benefit:cost ratio • Disruption during flood event • Provision of advanced warning may be limited

What happens next?