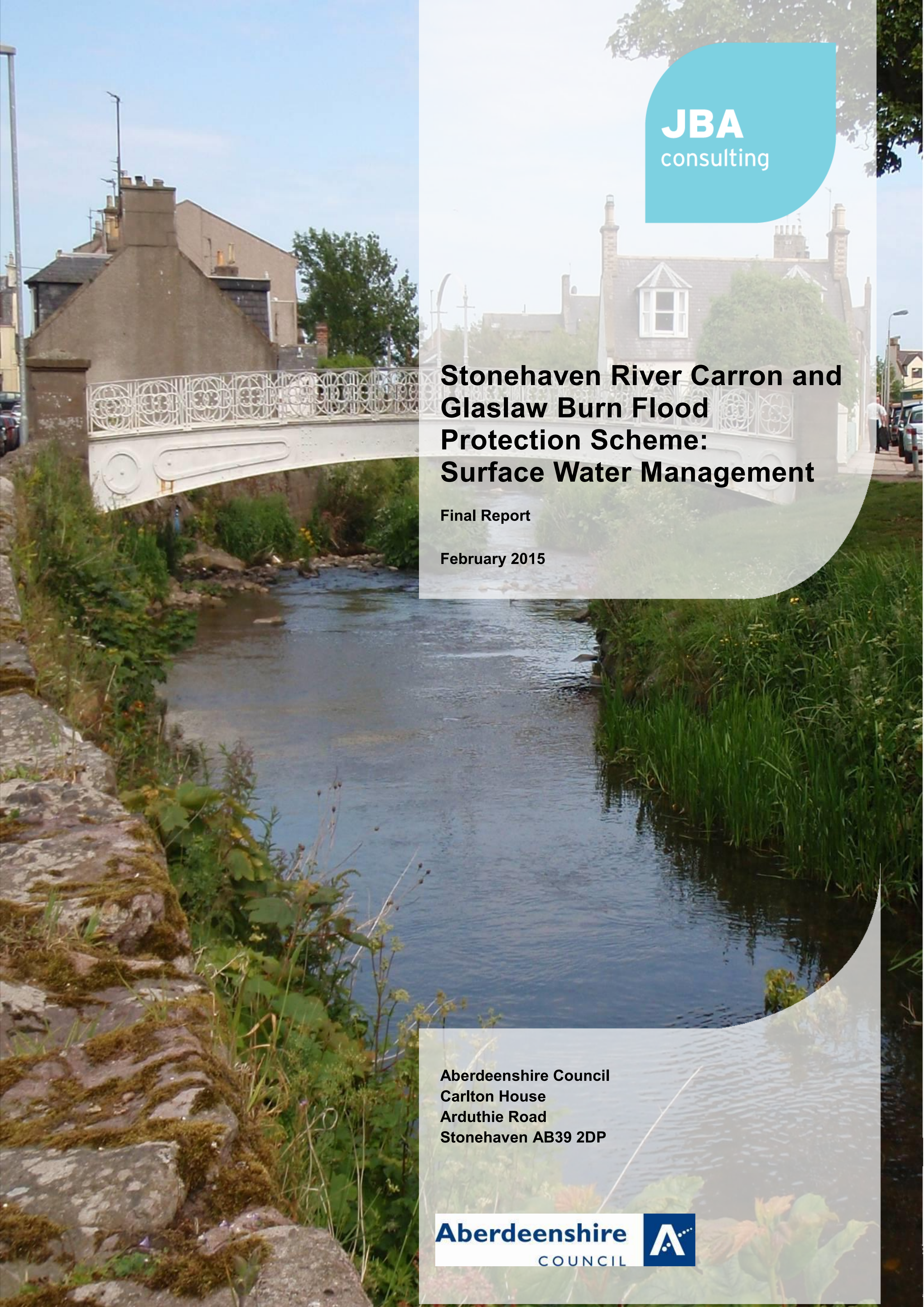


Stonehaven River Carron and Glaslaw Burn Flood Protection Scheme: Surface Water Management

Final Report

February 2015

Aberdeenshire Council
Carlton House
Arduthie Road
Stonehaven AB39 2DP

JBA Project Manager

Rene Dobson BEng CEng MICE
1 Longcraig Road
Port Neuk
South Queensferry
Edinburgh
EH30 9D

Revision History

Revision Ref / Date Issued	Amendments	Issued to
Final	n/a	Rachel Kennedy

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 of Aberdeenshire Council. Mark McMillan of JBA Consulting carried out this work.

Prepared by .... Mark McMillan MEng

Engineer

Reviewed by .... René Dobson BEng CEng MICE

Principal Engineer

Purpose

This document has been prepared as a Final Report for Aberdeenshire Council. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

JBA Consulting has no liability regarding the use of this report except to Aberdeenshire Council.

Acknowledgements

JBA Para Text

Copyright

Carbon Footprint

A printed copy of the main text in this document will result in a carbon footprint of 74g if 100% post-consumer recycled paper is used and 94g if primary-source paper is used. These figures assume the report is printed in black and white on A4 paper and in duplex.

JBA is aiming to reduce its per capita carbon emissions.

Contents

List of Figures

List of Tables

Abbreviations

FPS .... Flood Protection Scheme
FEH .... Flood Estimation Handbook
DDF .... Depth Duration Frequency
LiDAR .... Light Detection and Ranging
DTM .... Digital Terrain Model

1 Introduction

Stonehaven is located in the northeast of Scotland in Aberdeenshire. The coastal town is bordered to the North by the River Cowie. The River Carron flows through the historic centre of the town and is a major source of flood risk. On its course through the town the River Carron is joined by the Glaslaw Burn, which has its origins to the south of Stonehaven. Stonehaven is potentially at risk of flooding from these watercourses and surface water runoff, particularly from the Bervie Braes. Parts of the town are also at coastal flood risk (tidal wave flooding). The town has experienced major flooding from the River Carron and Glaslaw Burn throughout its history and most recently in November 2009 and December 2012.

As a result of the recent flooding Aberdeenshire Council have proposed a Flood Protection Scheme (FPS) to alleviate flooding from the River Carron and the Glaslaw Burn. The preferred scheme is to include direct defences on the River Carron and Glaslaw Burn through the centre of Stonehaven. However, these defences may have the effect of exacerbating surface water flood risk in the town by preventing surface water runoff draining directly to the river. Instead water that would naturally drain to the river would instead pond behind the defences.

The purpose of this report is to:

- Highlight areas with increased surface water flood risk as a result of the FPS
- Identify mitigation measures that could be incorporated into FPS.

2 Surface Water Modelling

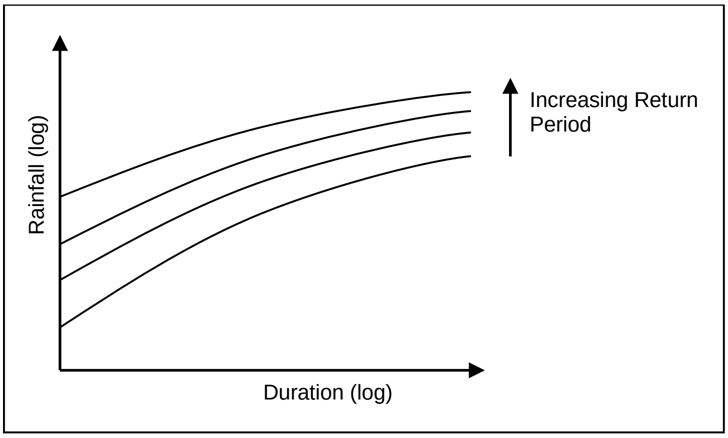
Surface water flooding is flooding as a direct result of rainfall onto the ground surface and its subsequent runoff via overland flow routes leading to ponding in topographically low-lying areas. The surface water flood risk to Stonehaven was evaluated using JFLOW+, a 2D raster-based modelling software designed by JBA Consulting. The inputs to the model are rainfall data and topographical information. The model produces a map of surface water flood grids across the study area including depth, velocity and hazard.

2.1 Rainfall Characteristics

The east coast of Scotland is in the rain shadow of the generally wetter west and the FEH-CD-ROM v3 suggests that the Standard Average Annual Rainfall (SAAR) within the study area is in the region of 870mm. For the purposes of this study rainfall estimates were generated using the Flood Estimation Handbook (FEH) and FEH Depth-Duration-Frequency (DDF) modelling was used to generate baseline rainfall.

The FEH can be used to generate 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 events as shown in Figure 2-1.

Figure 2-1: Example of DDF Curves



The design standard for the proposed FPS is the 1 in 200 year flood event, or 0.5 AP with an allowance for climate change. Rainfall inputs (hyetographs) were generated for the 200 year flood event for multiple durations. The duration of the storm event affects volume depths and overland flow paths and multiple durations are tested to determine a worst case scenario. The durations tested in this study are the following:

- 1 hours
- 2 hours
- 3 hours
- 4 hours
- 5 hours
- 10 hours

The hyetographs developed were distributed over a standard 'summer' storm which assumes a greater intensity. To allow for the effects of climate change the overland flows derived from this study will be uplifted.

2.1.1 Effect of Urban Drainage

Drainage systems in urban areas remove some runoff from the ground surface. Within urban areas, the capacity of the drainage system will vary substantially between locations and is difficult to estimate without detailed investigation of the drainage network. Research by JBA Consulting during other national pluvial mapping exercises has suggested that a standardised allowance equating to the 20% AP (5 year) event is appropriate for most UK urban areas following testing against historical datasets. This this allowance for drainage has been accounted for in overland flood routing.

2.1.2 Assumptions

The following assumptions apply to the surface water management model:

- Filtered LiDAR and contour data used in the DTM gives an accurate representation of the ground surface and presence of streamlines and low topography.
- A Manning's 'n' value of 0.04 has been applied universally to the model.
- Water is lost from the model at the edges of the DTM.
- The model run time extends beyond the end of the input hydrograph in order to allow water to continue to run off across the ground surface to create final flood depths. Each model was run for a period of 20 hours with the peak of the hyetograph at 10 hours.

2.2 Digital Terrain Model

Surface Water Modelling uses a 2D raster approach to simulate rainfall runoff over the topography of the study area. For this purpose a Digital Terrain Model (DTM) is required. The DTM for Stonehaven was created from LiDAR data (high resolution) which covers the town and main valley of the River Carron and the River Cowie. This was further augmented with topographical and channel survey of the River Carron and Glaslaw Burn. A coarser (lower resolution) DTM was created of the surrounding areas of Stonehaven from freely available Ordnance Survey contour data.

The resolution and accuracy of these two sources results in a step where the two meet and a process called 'feathering' is undertaken in GIS to smoothly transition from one dataset the other. In this way a problem of artificial ponding is avoided. The final DTM has a resolution of 2m.

2.3 Surface Water Flood Risk to Stonehaven

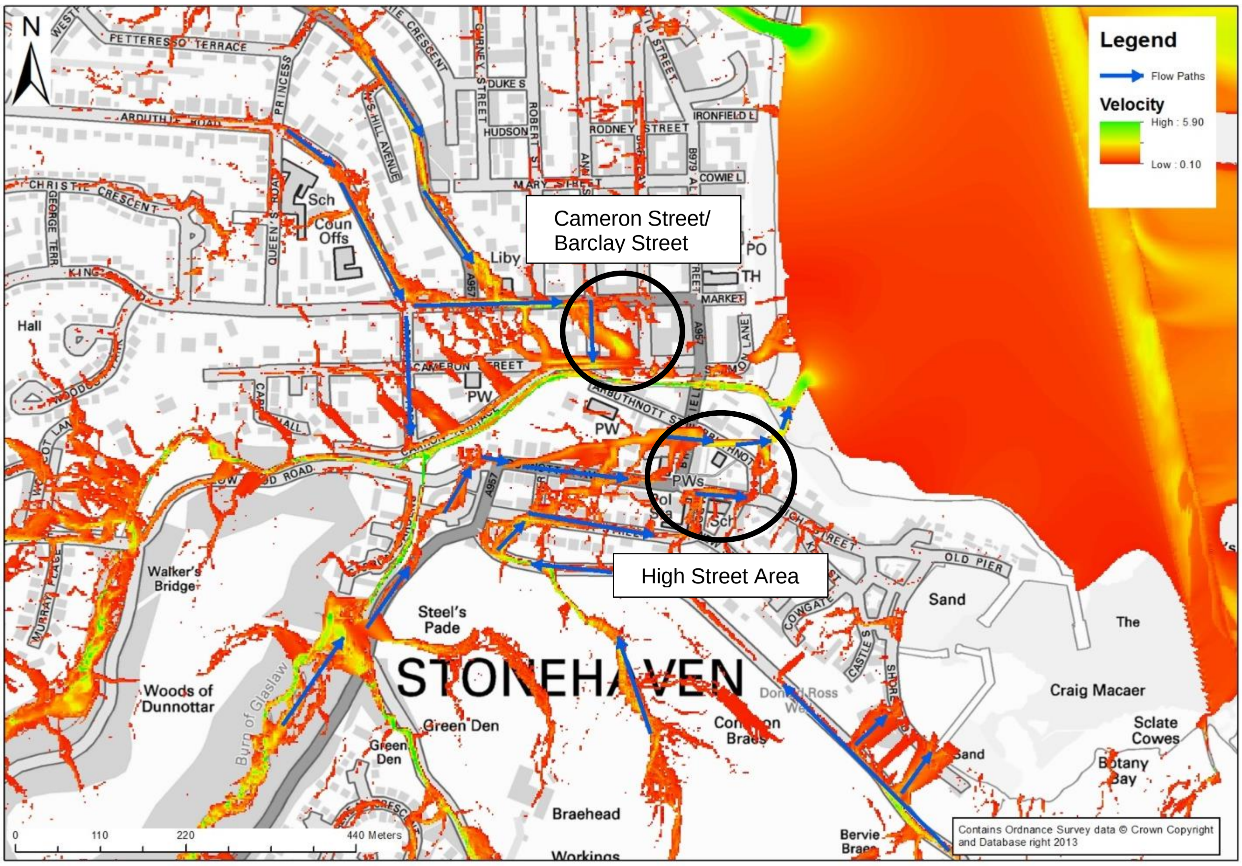
As part of the Flood Alleviation Study carried out by JBA Consulting[1] the surface water flood risk to Stonehaven was assessed for a range of return periods. It concluded that for a storm event with an AP of 0.5% (200 years) surface water flooding poses a significant risk with depths of ponding reaching approximately 0.7m in Cameron Street/ Barclay Street area and approximately 1.1m in the low lying area of High Street. Another key location which is shown to be at surface flood water

[1] Stonehaven River Carron Flood Alleviation Study, July 2012, JBA Consulting

risk is in the vicinity of the Cowie Leisure Centre and Caravan Park. These lie in a topographic depression at the coast and are therefore highly susceptible to surface water flooding.

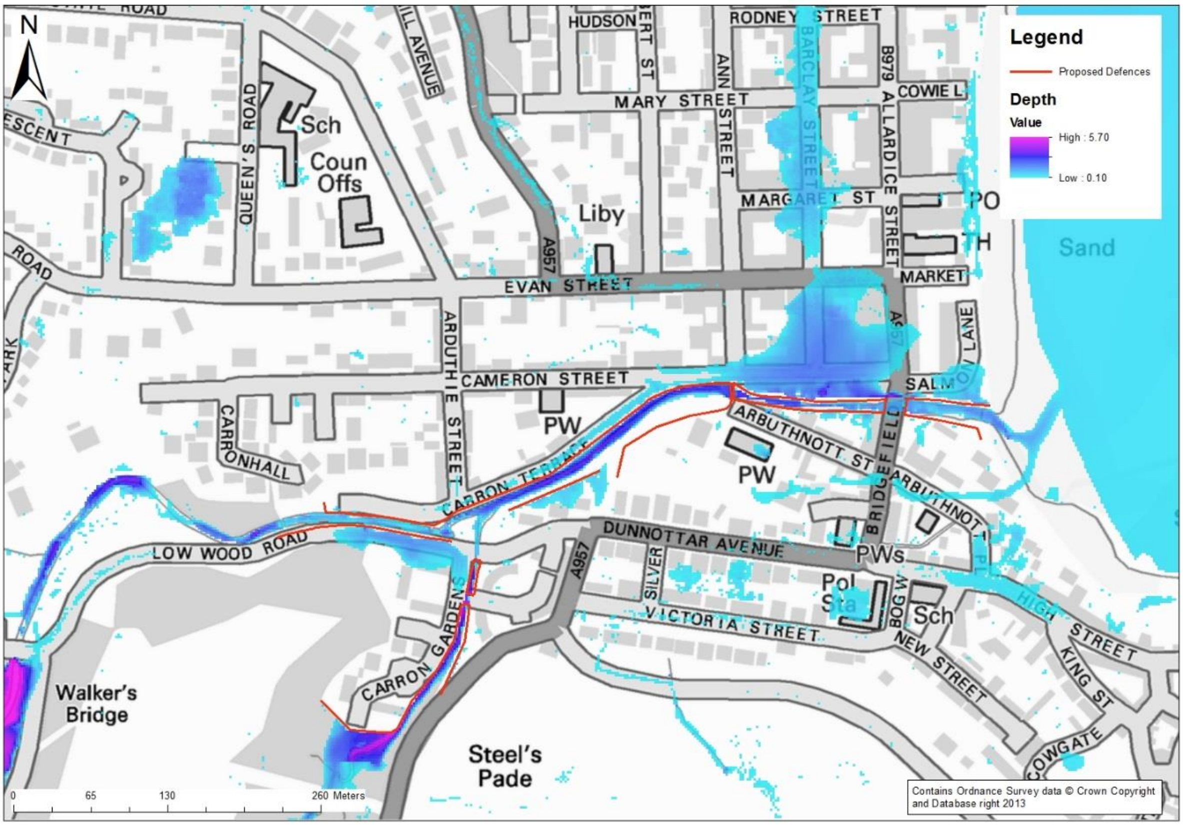
In December 2012 Stonehaven was severely affected by flooding. The analysis of the event indicated a large contribution to the observed flood depths in the High Street area to have originated from the Bervie Braes. This was looked at in a previous study which showed that that most of the surface water runoff in the area of the town south of the River Carron flows along Dunnottar Avenue, Victoria Street accumulating in the High Street area. The overland flow paths are illustrated in Figure 2-1.

Figure 2-1: Overland Flow Paths



The area of town to the north of the River Carron has prominent flow paths towards the river which include Arduthie Road, Slug Road and Barclay Street. The surface water analysis indicates that these flow paths could result in ponding water of approximately 0.8 m in depth on the 'dry' side of the proposed defences. This can be seen in Figure 2-2.

Figure 2-2: Areas of Surface Water Ponding



3 Mitigation Measures

The potential measures for decreasing surface water flood risk are:

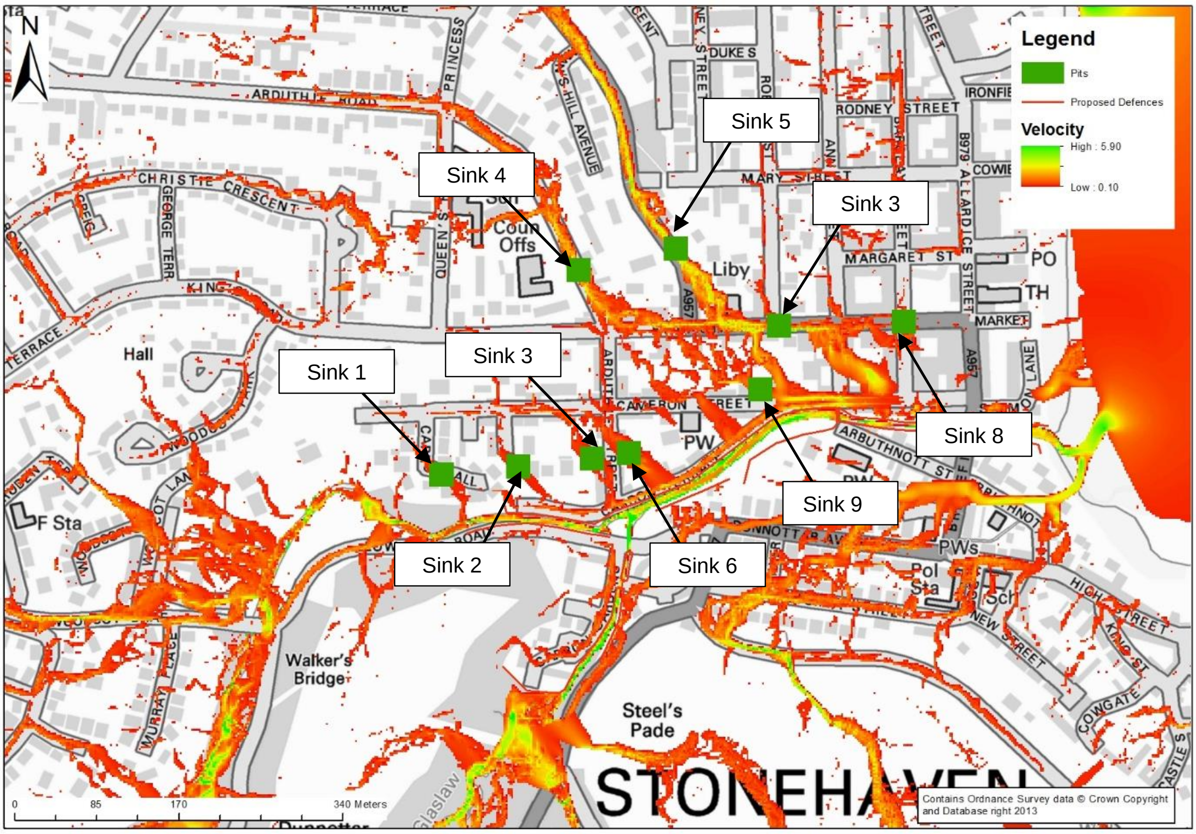
- Drainage or landscaping to intercept flows before ponding can occur.
- Installation of pumping stations to discharge water from low lying areas.

To assess the feasibility of any option the peak flow rate of the overland flow paths must be estimated. To estimate the peak flow rates the following methodology was utilised:

- Contributing overland flows paths were identified
- The DTM was altered to include large 'sinks' which would intercept all flow along the identified flow paths.
- The JFlow simulation was re-run with the altered DTM and depth data was recorded at each of the 'sinks' for each time step.
- As the area of each 'sink' is known, the increase in volume for each time step is calculated. The largest increase in volume per unit time is taken as the peak flow rate.

The DTM was altered to include numerous sinks as shown is Figure 3-1.

Figure 3-1: Location of Modelled Pits



The model was run for the 1, 2, 3, 4, 5 and 10 hour duration as a means of understanding the critical or worst case scenario. The peak flow rate for each sink can be used to identify and size discrete mitigation measures and assess the holistic affects when combined. Table 3-1 shows the recorded flow rates

Table 3-1: Estimated Peak Flow Rates (m^3/s)

Location	Duration (Hours)					
	1	2	3	4	5	10
Sink 1	0.04	0.04	0.04	0.04	0.04	0.04
Sink 2	0.05	0.05	0.06	0.06	0.05	0.04
Sink 3	0.06	0.07	0.07	0.07	0.06	0.06
Sink 4	0.28	0.35	0.37	0.37	0.37	0.35
Sink 5	0.38	0.50	0.60	0.62	0.60	0.54
Sink 6	0.09	0.10	0.10	0.10	0.10	0.09
Sink 7	0.11	0.11	0.11	0.10	0.10	0.08
Sink 8	0.05	0.06	0.07	0.07	0.06	0.07
Sink 9	0.05	0.06	0.06	0.06	0.06	0.04
Total	**1.11**	**1.34**	**1.48**	**1.49**	**1.44**	**1.31**

From Table 3-1 it can be seen that the peak flow rates are experienced during the 4 hour storm duration.

3.1 Option 1: Pumping Station

Pumps that pump against a head higher, or lower than their design range will not only be inefficient, but will encounter problems due to excessive wear and cavitiation. Therefore all design options have assumed a free discharge, so that pumps are consistently pumping at a constant head. This approach has the added advantage of not requiring flap valves on the outfalls and ensures a simple pumping arrangement free of valves and penstocks.

The surface water modelling has indicated that the low lying area most affected is the junction of Cameron Street and Barclay Street as shown in Figure 2-2. The total peak flow contributing to this area is likely to be approximately 1.5 m^3/s for the 200 year rainfall event with a duration of 4 hours as shown in Table 2-1. The design standard of the proposed scheme is the 200 year flood event with an allowance for climate change. The allowance for climate changed adopted for the scheme, in accordance with data from UKCP09, is an increase in peak flows of 33% by 2080. Therefore within the life the scheme a pumping station should have a capacity of approximately 2m^3/s. The pumping station could be designed in a manner that would allow extra capacity to be added when required and when a better understanding of the impact of climate change may be available.

The feasibility of a pumping station is dependent on the required size which is a product of the following variables,

- Peak inflow
- Capacity
- Minimum cycle time
- The number of pumps
- The configuration of pump station geometry and layout.

Additionally a pumping station design should consider the following points:

- Inflow to the pumps should have minimal turbulence
- The pump inlet should be sufficiently submerged to prevent air intake.
- Water depth in the sump should be great enough to suppress surface vortices.

The critical factor that will determine the size of the pumping station will either be the volume of stored water in the sump to operate the pumps efficiently, or the space required to house the number of pumps required. Peak inflow and pump capacity may differ due to the number and capacity of the individual pumps. A greater capacity will result in a greater volume of stored water to allow sufficient depth in the sump. Therefore the use of a smaller number of larger pumps may result in a larger station than one with more pumps with a smaller capacity. The preferred configuration will be dependent on whether width or depth poses the greater constraint.

The selection of pumps and station configuration in this study is derived from design recommendations from pump manufacturer ITT Flygt Ltd. Other manufacturer recommendations may vary. The type of pump considered the most suitable for this scenario is a submersible waste and raw water pump equipped with a shrouded, single or multi-vane impeller that runs in a volute. The shape and size of the impeller are designed to minimise clogging, which makes this pump suitable for wastewater applications. These pumps had an extensive performance range and can be used in a variety of applications including handling storm water.

A pumping station was initially sized to manage surface water from a 200 year rainfall event. The layout of the pumping station is based on submersible pump design using similar sized pumps to facilitate access and maintenance. The design inflow was 1.5 m^3/s. A maximum number of starts per hour for the proposed pumps was considered to be 15 starts per hour. Additionally it has been assumed that the pumping station be designed to house a surplus of one pump as a contingency in the event of one of the other pumps failing. Scottish Water design specification[2] for rising mains states that the diameter of the rising main should be such that the velocity of the discharge is in the range 0.75 to 1.8 m/s so that blockages are avoided. Table 3-2 outlines the details of the pump station sizing.

Table 3-2: Pumping Station Details for 200 year rainfall event

Inflow (m^3/s)	Number of Pumps	Individual Capacity (m^3/s)	Impeller diameter (mm)	Total Capacity (m^3/s)	Total Length (m)	Total Width (m)	Sump Area (m^2)	Minimum Depth (m)	Discharge Connection Diameter (mm)
1.5	1	1.494	575	1.49	8.74	9.1	35.49	2.52	1100
1.5	2	0.725	600	1.45	7.31	9.30	86.91	3.73	1100
1.5	3	0.510	400	1.53	6.41	9.00	91.96	5.11	1100
1.5	4	0.363	350	1.45	5.04	10.22	87.16	5.17	1100

When considering climate change the peak inflow, and therefore minimum capacity of the pumping station, will be increased to approximately 2m^3/s. Table 3-3 outlines the requirements for this scenario with the same assumptions as above.

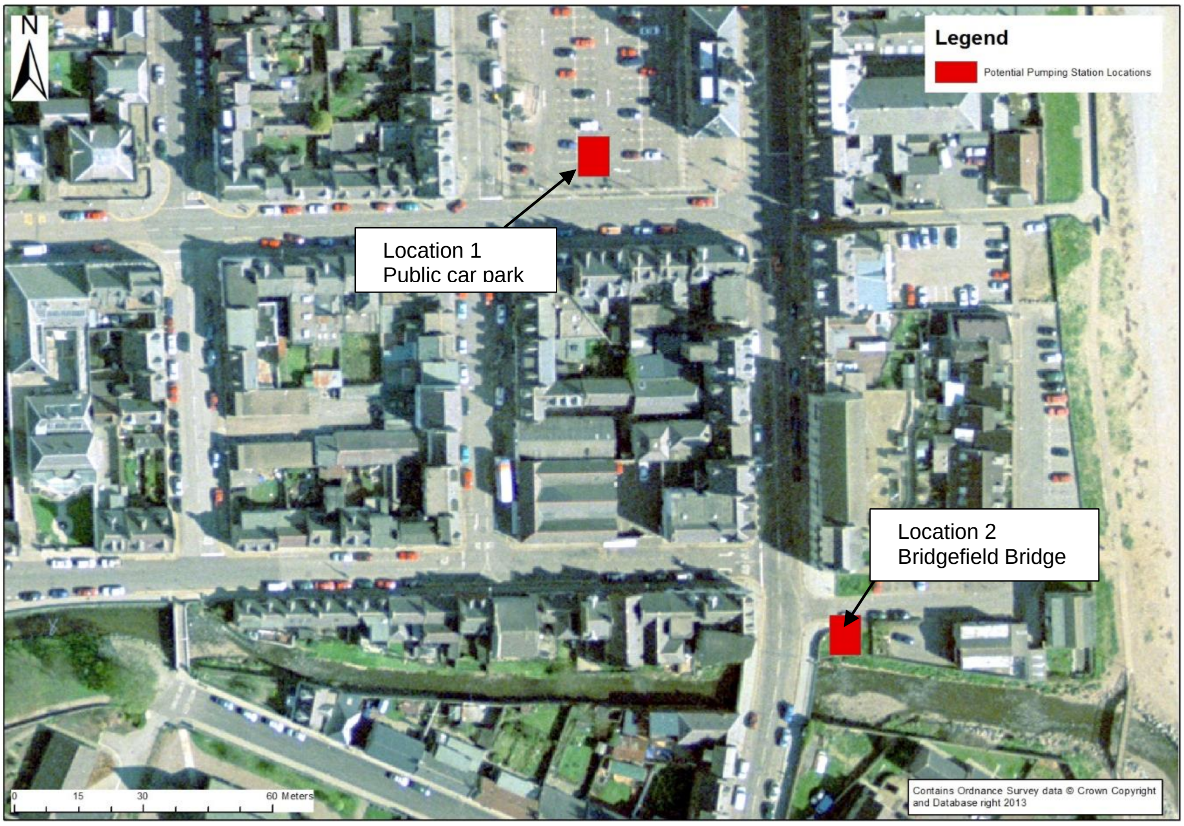
[2] Sewers for Scotland - 2nd Edition, Scottish Water, WRc, Water UK, November 2007

Table 3-3: Pumping Station Details for 200 year plus climate change rainfall event

Inflow (m^3/s)	Number of Pumps	Individual Capacity (m^3/s)	Impeller diameter (mm)	Total Capacity (m^3/s)	Total Length (m)	Total Width (m)	Sump Area (m^2)	Minimum Depth (m)	Discharge Connection Diameter (mm)
2.0	1	2.03	800	2.03	10.9	10.6	49.82	2.44	1200
2.0	2	0.96	500	1.93	7.44	10.3	29.87	3.87	1200
2.0	3	0.66	500	1.98	6.74	11.3	27.00	4.39	1200
2.0	4	0.48	500	1.93	5.84	11.1	18.94	6.12	1200

The dimensions stated in Tables 3-2 and 3-3 are based on geometries of generic pumping station layouts. Detailed design of a site specific pumping station will likely result in deviation from the initial sizing. As such Figure 3-2 illustrates the potential locations for one of these stations to be positioned.

Figure 3-2 positioning of proposed pumping stations

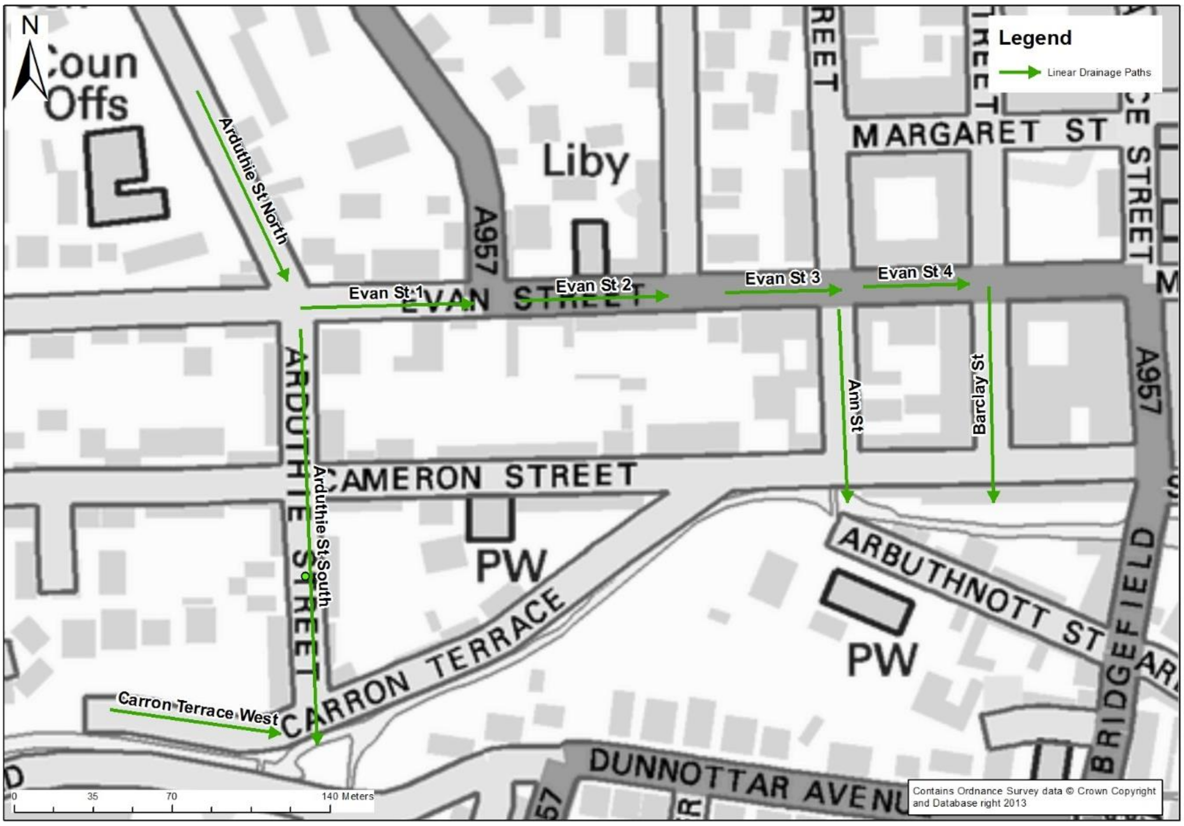


Of the two potential locations, the public car park on Evan Street would be the simplest to route intercepted water to. Linear drainage along Evan Street could intercept surface water runoff and direct it to the pumping station. However, as the discharge of the pumping station must be approximately 1m in diameter to meet design standards for velocity in a rising main discharge to the river or coast will prove problematic due to the constraint of existing surfaces in the area which include surface water and combined sewers. The existing sewers will be unlikely to have capacity beyond the 30 year rainfall event to which they are designed. The station at location 2 will be difficult to direct flows to due to the aforementioned services and unfavourable topography.

3.2 Option 2: Linear Drainage

Linear drainage may be used to intercept flows and convey them to the river through carrier drains. A plan of the proposed drainage to shown in Figure 2-4.

Figure 3-3: Proposed Linear Drainage Paths



Flow from Arduthie St, north of Evan Street can be conveyed along Arduthie Street to the South of Evan Street and to the River Carron. Flow from the west of Carron Terrace could be conveyed to this drain as well. Flow from north of Evan Street and east of Arduthie Road may be intercepted along Evan Street. These flows can then be discharged to the River Carron through Drains along Ann Street and Barclay Street.

The required sizes of the carrier drains have been estimated in Table 2-2. The pipe sizes where derived using Manning's equation with the following assumptions

- Manning's 'n' for carrier drain = 0.03
- Uplift of Flows for Climate Change = 1.33
- The carrier drains will follow the same slope as the roads.
- Drains drain by gravity and additional capacity due to surcharged pressure forces have not been included.

Table 3-4: Required Pipe Sizes

Location	Pipe Diameter (m)	Capacity (m^3/s)
Arduthie St North	0.45	0.49
Evan St 2	0.60	0.80
Evan St 3	0.60	0.63
Ann St (Outfall)	0.45	0.48
Evan St 4	0.45	0.25
Barclay St (Outfall)	0.45	0.25
Arduthie St South (Outfall)	0.60	0.96
Carron Terrace East	0.45	0.09
Carron Terrace West	0.30	0.06

Although the critical storm duration is considered to be 4 hours in terms of peak flows, it is possible that a longer storm duration, with less flows, could occur in conjunction with a flood event in the River Carron to which the linear drainage will discharge. In this event surface water will be unable to discharge as the outlet may be submerged.

It is therefore recommended that the carrier drains that discharge to the River Carron be pressurised so that sufficient head may force flows into the river. This would be achieved by allowing no means of escape for water in the pipe (a gully for example) to be level than approximately 1 m above the peak water level in the river at the location of the outfall. Table 2-4 shows the requirements for pressurised outfalls.

Table 3-5: Pressurised Outfall Requirements

Outfall	Peak Water Level (mAOD)	Minimum Head Level (mAOD)	Length of Pressurised Drainage Required (m)
Arduthie Street	7.01	8.01	75
Ann Street	5.69	6.69	70
Barclay Street	5.09	609	161

The levels on Barclay Street are insufficient to allow a pressurised outfall. The highest level on Barclay Street at Evan Street is approximately 4.60 m AOD. Therefore if the outfall at Barclay Street where to be included, it would be required to be pressurised from the junction of Ann Street and Evan Street.

For this to be an effective solution it is likely to involve streetscaping of Arduthie Street, and Evan Street to ensure the maximum potential to intercept drainage is achieved.

During the period when the drainage system is river locked, there is a residual flood risk arising from the accumulation of runoff that cannot enter the proposed pressurised drainage network. The flood walls along the River Carron have been designed to incorporate 'toe drainage' to accommodate surface water behind the defences that cannot be intercepted by the proposed linear drainage and potential seepage from the river under the defences. The toe drainage in the defences may discharge to the River Carron through the inclusion of package pumping stations with a capacity of between 50 - 100 l/s.

3.3 Option 3: Combined Linear Drainage and Pumping Station

The third option is to use a combination of the two options assessed above. This option would use linear drainage where possible to convey flows to the river to reduce the required capacity of the pumping station. Linear drainage could be used to intercept flows along Arduthie Street and convey them to the River Carron. Drainage could be used to convey flows along Evan Street to a smaller pumping station. The flow likely to be intercepted in the linear drainage along Arduthie Street will be approximately 0.64 m^3/s. This would leave 0.86 m^3/s to be pumped for the 200 year rainfall event and 1.14 m^3/s to allow for climate change.

Table 3-6: Pump station details for Option 3

Inflow (m^3/s)	Number of Pumps	Individual Capacity (m^3/s)	Impeller diameter (mm)	Total Capacity (m^3/s)	Total Length (m)	Total Width (m)	Sump Area (m^2)	Minimum Depth (m)	Discharge Connection Diameter (mm)
1.14	1	1.16	0.60	1.16	8.11	7.70	23.87	2.92	900
1.14	2	0.58	0.35	1.17	5.74	7.92	16.63	4.21	900
1.14	3	0.38	0.35	1.14	5.04	8.45	12.68	5.39	900
1.14	4	0.29	0.35	1.16	4.64	8.80	11.44	6.06	900

The size of the pumping option and the combined option is not greatly reduced. It is likely that a 900 mm outfall pipe will pose difficulty with existing services. Additionally, the drainage required to convey flows to the pumping station would be largely similar to that detailed in Option 2 but with added cost of construction.

3.4 Option 4: Property Level Protection

This option would involve no works to mitigate the scale of surface water flooding but provide protection to the individual properties affected. There are likely to be approximately 64 properties affected by surface water flood depths of up to 0.8m in the area around Cameron Street and Barclay Street.

Property Level Protection consist of the provision of flood protection products for individual local residents, designed to make the external fabric of each property resilient to flooding up to a specified level. Resistance measures may include:

- Barriers
- Automatic flood doors
- Airbrick/vent covers

Of these, automatic flood doors would be the preferred means of protecting properties as surface water flooding could occur at short notice leaving residents little time to react. Existing airbricks could be replaced with automatically closing airbricks to help prevent flood water from entering a property.

It should be noted that the provision of property level defences is unlikely to be a popular solution to the residents of Cameron Street. These properties are likely to be affected by the construction and operation the main FPS. If these properties were to remain at flood risk as a result of the scheme there is a risk that objections may be made against the FPS.

3.5 Preferred Option

The preferred option for managing surface water as part of the Stonehaven FPS is Option 2; the use of linear drainage and pressurised outfalls to drain surface water to the River Carron by gravity.

A pumping solution is considered unfeasible due to the high number of constraints. The size of pumps required result in a structure that is difficult to place efficiently. Ideally a pump station would be located at the topographical low point were water will pond however this is not possible unless the demolition of existing structures is considered. Therefore additional drainage would be required to convey flows to the pumping station. The outfall from a pumping station option will require a minimum 900mm diameter pipe that will require the costly diversion of existing services. Although this may be unavoidable, with the selection of Option 2 the outfalls to the river may be smaller in diameter and therefore less of a constraint.

The provision of property level defences would mitigate the risk to individual properties, but would not reduce the hazard caused by the flooding out with the property in a residential and commercial area.

4 Conclusions

The Stonehaven Flood Protection Scheme will include direct defences along the River Carron through the centre of the town. As a result surface water resulting from overland flow will be obstructed from entering the river.

An analysis of the impact the proposed defences would have on surface water flooding in Stonehaven was undertaken using JFlow+, a raster based simulation software that can produce inundation maps showing maximum depth and velocity. The modelling showed that overland flow will be obstructed from entering the River Carron along its northern bank. Overland flow in the south of the town follows natural topography towards the coast and will be largely unaffected by the proposed defences.

The most affected area is the junction of Barclay Street and Cameron Street as this is a topographical low point at which considerable ponding of water is likely to occur. Peak flow to this location is likely to be in the order 1.5 m^3/s for a 200 year rainfall event with a duration of 4 hours and an allowance for climate change

Three potential options were investigated to determine the most appropriate for managing the additional surface water flood risk

Option 1: Pumping station and rising main

Option 2: Linear Drainage and Pressurised Outfalls

Option 3: Combined Pumping Station and Linear Drainage

Option 4: Provision of Property Level Defences

A standalone pumping solution would be a minimum of 5.84 m by 11.10 m in dimension. By altering the number of pumps and arrangement these dimensions are subject to change but are considered a significant constraint to the feasibility of a pumping solution. Additionally the design requirements of rising main require that the velocity in the discharge pipe be less than 1.8 m/s. This would require a minimum pipe diameter of 1m. Discharge to the river or coast would therefore be further constrained by the concentration of services within the area.

Although the provision of property level defences to individual properties may be feasible it is unlikely to be a popular solution to the increased flood risk as many of these properties will be affected by the construction of the FPS. Additionally this option would leave a flood risk hazard within the centre of the town.

The preferred solution is the use of linear drainage and pressurised outfalls. Flow from Arduthie St north of Evan Street can be conveyed along Arduthie Street to the South of Evan Street and to the River Carron. Flow from the west of Carron Terrace could conveyed to this drain as well. Flow from north of Evan Street and east of Arduthie Road may be intercepted along Evan Street. These flows can then be discharged to the River Carron through Drains along Ann Street and Barclay Street.

It is possible that a long storm event could occur in conjunction with a flood event in the River Carron to which the linear drainage will discharge. In this event surface water will be unable to discharge as the outlet may be submerged. It is therefore recommended that the carrier drains that discharge to the River Carron be pressurised so that sufficient head may force flows into the river. This would be achieved by allowing no means of escape for water in the type (a gully for example) to be level than approximately 1 m above the peak water level in the river at the location of the outfall. Surface water resulting in areas where the proposed linear drainage is to be pressurised may be drained through the 'toe drainage' incorporated into the proposed defences.

Offices at

Coleshill

Doncaster

Dublin

Edinburgh

Exeter

Haywards Heath

Limerick

Newcastle upon Tyne

Newport

Saltaire

Skipton

Tadcaster

Thirsk

Wallingford

Warrington

Registered Office
South Barn
Broughton Hall
SKIPTON
North Yorkshire
BD23 3AE

t:+44(0)1756 799919
e:info@jbaconsulting.com

Jeremy Benn Associates Ltd
Registered in England
3246693