7 Groundwater flood risk

During and following the flooding to the area there were reports that some of the flooding witnessed may have been from groundwater sources. Whilst groundwater flooding is not commonly seen in Scotland as a flood mechanism in its own right, it can exacerbate flooding from other sources. This section aims to discuss the wider geology of the area with a view to determining the potential for groundwater flooding in the area and to discuss the factors that may contribute to this flood risk type.

The British Geological Survey (BGS) geology maps suggest that the underlying bedrock is moderately permeable Devonian old red sandstone sedimentary rocks. The overlying superficial geology consists of glacial sand and gravel in the lower catchments and Glacial Till and Diamicton (very poorly sorted sediment) in the upper catchments.

Groundwater flooding is flooding caused by unusually high groundwater levels or flow rates. During flooding, groundwater emerges at the ground surface or within man-made underground structures such as basements. It may emerge as one or more point discharges (springs) or as diffuse discharge/seepage over an extended area. Groundwater flooding can be more persistent than surface water flooding, typically lasting for weeks or months rather than for hours or days.

There are various mechanisms of groundwater flooding, including:

- clearwater flooding (due to prolonged heavy rainfall and mainly associated with Cretaceous Chalk, which is not present in Scotland),
- alluvial groundwater flooding,
- coastal groundwater flooding,
- groundwater/minewater rebound,
- ground subsidence and development-related mechanisms (in which artificial structures act to dam groundwater, or provide a pathway for flow).

It is likely that in Scotland the most important groundwater flooding mechanism is alluvial groundwater flooding, in which high river levels cause the water table in an adjacent alluvial sand/gravel aquifer to rise. The conditions necessary for this type of flooding are widespread in Scotland, and there are examples of the mechanism having operated in the past.

7.1 Scottish Government Groundwater flood hazard study (2011)

In 2011 JBA Consulting undertook a groundwater flooding scoping and screening study[14] to create flood hazard maps to allow an assessment of the potential risk posed and to identify vulnerable areas.

The report developed a methodology for groundwater flood hazard mapping in Scotland and uses a hierarchical approach in which different levels of analysis are employed depending on the scale of the assessment required and the availability of data:

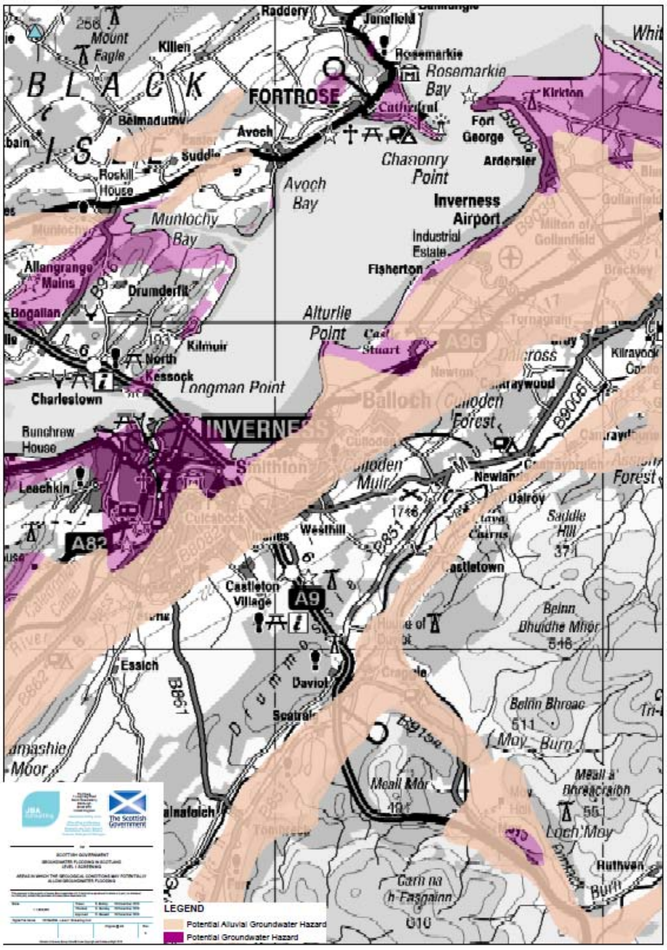
- **Level 1 (national or regional screening)** uses existing national-scale geological mapping to separate areas potentially susceptible to groundwater flooding from those unlikely to be susceptible.
- **Level 2 (hazard assessment)** generates a regional hazard map showing areas potentially susceptible to groundwater flooding and classifies them by mechanism.
- **Level 3 (detailed hazard assessment)** goes a stage further and generates a map showing flood outlines for events of specified return periods.

Level 1 screening has been carried out for the whole of Scotland. Level 2 assessments were undertaken for a pilot catchment in Angus and are programmed for completion by SEPA for all other. These have yet to be completed for the Inverness region although SEPA hope that these will be completed in 2012[15].

[14] Scottish Government (2011). Exploring the causes and potential extent of groundwater flooding in Scotland - scoping and screening study. Commission Number CR/2008/35. Final Report, March 2011).
[15] Pers. Comm. Elaine Simpson (SEPA).

An image of the Level 1 screening map is presented in Figure 7-1 below and highlights zones potentially susceptible to groundwater flooding and potential groundwater hazards that includes permeable superficial deposits (e.g. alluvium and glacial sand and gravel) within existing river valleys. However, it should be noted that this level 1 assessment is broad scale and based solely on pre-existing geological mapping.

Figure 7-1: Level 1 groundwater screening map for Inverness

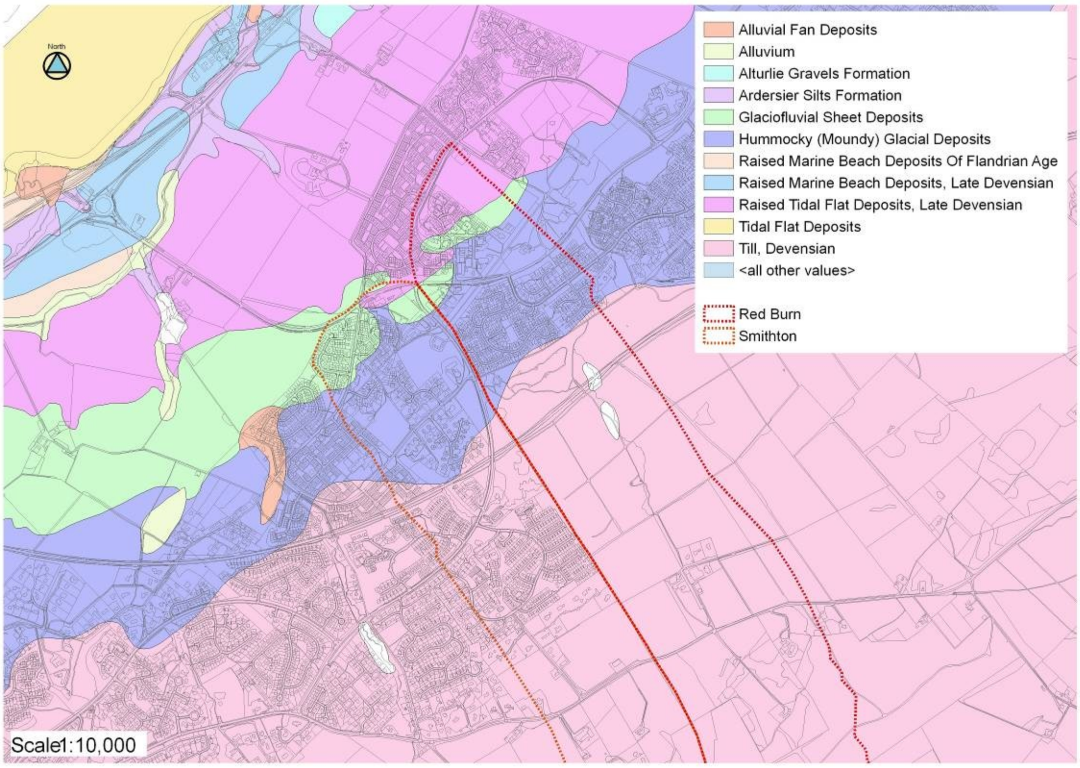


It is recommended that Highland Council collates and reviews all available borehole information in the area of Culloden and Smithton with a view to providing this to SEPA in order for this to be used as part of the Level 2 assessments. Output from these Level 2 studies should be reviewed prior to any more detailed assessment of groundwater hazards in the area.

7.2 Groundwater flood risk

The 1:50,000 BGS data provides greater spatial detail of the overlying drift map and is shown in Figure 7-2 below. This shows that the upper portions of the catchments are overlain by Till deposits. The middle reaches are characterised by hummocky glacial deposits (indicative of ice-margin areas) and fluvial-glacial deposits. The flatter downstream end of the catchments are overlain by raised tidal flat deposits.

Figure 7-2: BGS 1:50,000 superficial deposits map



Analysis on site suggests that the depth of this overlying material varies greatly through the catchments, with bedrock witnessed in the upper catchment of the Culloden Burn West at the railway culvert and much deeper actively eroded sections of glacial sand, gravel and till material in the middle of both reaches (particularly in the forestry area of the Culloden Burn West and the reach upstream of the railway culvert on the Smithton Burn).

There may also be zones of sand and gravel located within both reaches. These may be highly permeable and laterally connected to the river providing a mechanism of groundwater inundation to properties adjacent to rivers but disconnected directly from the river by banks or defences.

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8 Hydraulic analysis

8.1 Introduction and conceptual modelling approach

This section describes how two watercourses in Culloden were modelled in order to estimate culvert capacity and the impact of blockages. Three general approaches have been used:

- 1D hydraulic modelling to assess channel and structures capacities.
- 2D hydraulic modelling to determine and confirm overland flow paths observed on site.
- pluvial modelling to determine surface water flood risks in the area.

Both watercourses were modelled using HEC-RAS (Hydraulic Engineering Center - River Analysis System). HEC-RAS is a one dimensional model software package developed by the US Army Corps of Engineers and is a standard tool for hydraulic modelling in the UK. There are a number of structures on both watercourses and HEC-RAS is particularly well suited to modelling these.

The 2D overland flow and pluvial modelling has been undertaken using JBA's in-house 2D modelling package J|FLOW. J|FLOW is a software package developed by JBA Consulting to meet the needs of clients who require a large scale floodplain mapping model. It provides fast, cost effective estimates of flood depth, velocity and extent. The model can be used for both small-scale breach/overflow analysis and large scale catchment modelling.

8.2 Topographic survey of watercourse and structures

A survey of river channel cross sections and structures was carried out by JBA in September and October 2011. These drawings are provided in Appendix I. A summary of this is given in Table 8-1. The location of the surveyed cross sections and other information are shown in Figure 8-1 (Culloden Burn West) and Figure 8-2 (Smithton Burn). In addition, the levels of wrack marks (debris left during the August 2011 high flow event) were surveyed.

Table 8-1: Number of cross sections and structures surveyed

Watercourse	Number of cross sections	Bridges	Culverts	Other crossings (pipes fences etc)
Culloden Burn West	21	3	4	2
Smithton Burn	39	10	8	1

8.3 Key bridges and culverts

The following key bridges and culverts have been identified as part of this study. Onsite inspection and assessment of each structure has been undertaken and an indicative assessment of blockage risks, ease of access (for the purposes of Council inspection and maintenance) and ease of maintenance has been undertaken and is presented in the Tables below.

Factors that contribute to blockage risks include the opening size, capacity, presence and type of screen and type and condition of upstream channel/catchment contributing reaches. The ownership has been defined where these are road or railway crossings. All other crossings may be the responsibility of riparian owners, although this would need to be confirmed.

A complete record of watercourse crossings, together with photographs and additional information is provided in Appendix B. A summary of the structures is provided below.

Table 8-2: Culloden Burn West

Ref	Name	Assumed ownership / responsibility	Screen (& condition)	Blockage risk	Ease of access	Ease of maintenance	Overall Risk
CWB1	Railway Bridge	Network Rail	No	Low	Fair	Fair	Low
CWB2	Railway culvert on tributary	Network Rail	Yes (Good)	Medium	Poor	Poor	Low
CWB3	Forestry Track Bridge	Highland Council	Yes (Fair but poorly sited)	Medium	Good	Fair	Low
CWB4	Boundary fence and water gate	Third party	No	Medium	Poor	Poor	Medium
CWB5	Culvert beneath garden of [redacted] Redburn Avenue	Riparian owner	Yes (Poor)	High	Fair	Poor	High
CWB6	Culvert beneath Ferntower Avenue	Highland Council	Yes (Good)	Medium	Poor	Poor	Medium
CWB7	Culloden walkway culvert	Highland Council	No	Medium	Good	Fair	Low
CWB8	Culloden Centre Culvert	Highland Council	Yes (Good)	High	Good	Fair	Medium
CWB9	Footbridge U/S of Culloden Recreation Ground	Highland Council	No	Low	Poor	Poor	Low
CWB10	Culvert beneath Keppoch Road	Highland Council	No	Low	Good	Fair	Low

Table 8-3: Smithton Burn

Ref	Name	Ownership / responsibility	Screen (& condition)	Blockage risk	Ease of access	Ease of maintenance	Overall Risk
S1	Property access culvert	Riparian owner	No	Low	Good	Good	Low
S2	Property access culvert	Riparian owner	No	Low	Good	Good	Low
S3	Culvert beneath Heights of Woodside	Highland Council	No	Low	Good	Good	Low
S4	Culvert beneath Woodside Farm Drive	Highland Council	No	Low	Good	Good	Low
S5	Boundary fence	Riparian owner	No	Medium	Poor	Poor	Medium
S6	Property decking over burn (multiple)	Riparian owner	No	Medium	Poor	Poor	Medium
S7	Property boundary fence	Riparian owner	No	Medium	Fair	Fair	Low
S8	Garden access bridge	Riparian owner	No	Low	Good	Good	Low
S9	Culvert beneath Woodside Village and Woodside Farm Drive	Highland Council	No	Medium *	Poor	Poor	Medium
S10	Culvert beneath Tower Road	Highland Council	No	Medium *	Poor	Poor	Medium
S11	Railway culvert	Network Rail	No	Low	Fair	Fair	Low
S12	Culvert adjacent to Murray Terrace	Riparian owner	Yes (Poor)	High	Fair	Poor	High

Ref	Name	Ownership / responsibility	Screen (& condition)	Blockage risk	Ease of access	Ease of maintenance	Overall Risk
S13	Footbridge adjacent to retirement home	Riparian owner	No	Low	Fair	Fair	Low
S14	Culvert beneath Murray Road	Highland Council	Yes (Poor - culvert blocked at D/S end)	High	Poor	Poor	High
S15	Numerous property boundary fences/bridges	Riparian owners	No	High	Fair	Fair	Medium
S16	Property fence on boundary of [redacted] Murray Place	Riparian owner	No	High	Good	Fair	Low
S17	Footbridge to Forbes Place	Highland Council	No	Low	Good	Good	Low
S18	Footbridge at rear of Smithton Villas	Riparian owner	No	Low	Good	Good	Low
S19	Culvert beneath access road to Forestry depot	Highland Council	No	Medium	Good	Fair	Medium
S20	Culvert beneath garage on main road	Highland Council	No	Medium	Good	Poor	Medium
S21	Culvert beneath Barn Church Road leading to Culloden Burn West	Highland Council	No	Medium	Fair	Poor	Medium
* S9 & S10 structures have a medium blockage risk due to the currently poor channel and bank conditions upstream. Whilst they both have wide diameters, decent gradient and no screens and showed good transportation of sediment during the recent floods, the channel erosion and presence of wooded banks upstream means that a medium blockage risk has been given. This could be reduced to low risk following works to stabilise the channel and bank erosion upstream.							

During the inspections undertaken following the flood events, none of the above structures or culverts was identified as blocked on either watercourse, other than the culvert beneath Murray Road (Smithton Burn) that is approximately 50% blocked at the downstream end.

8.4 Culvert capacity modelling

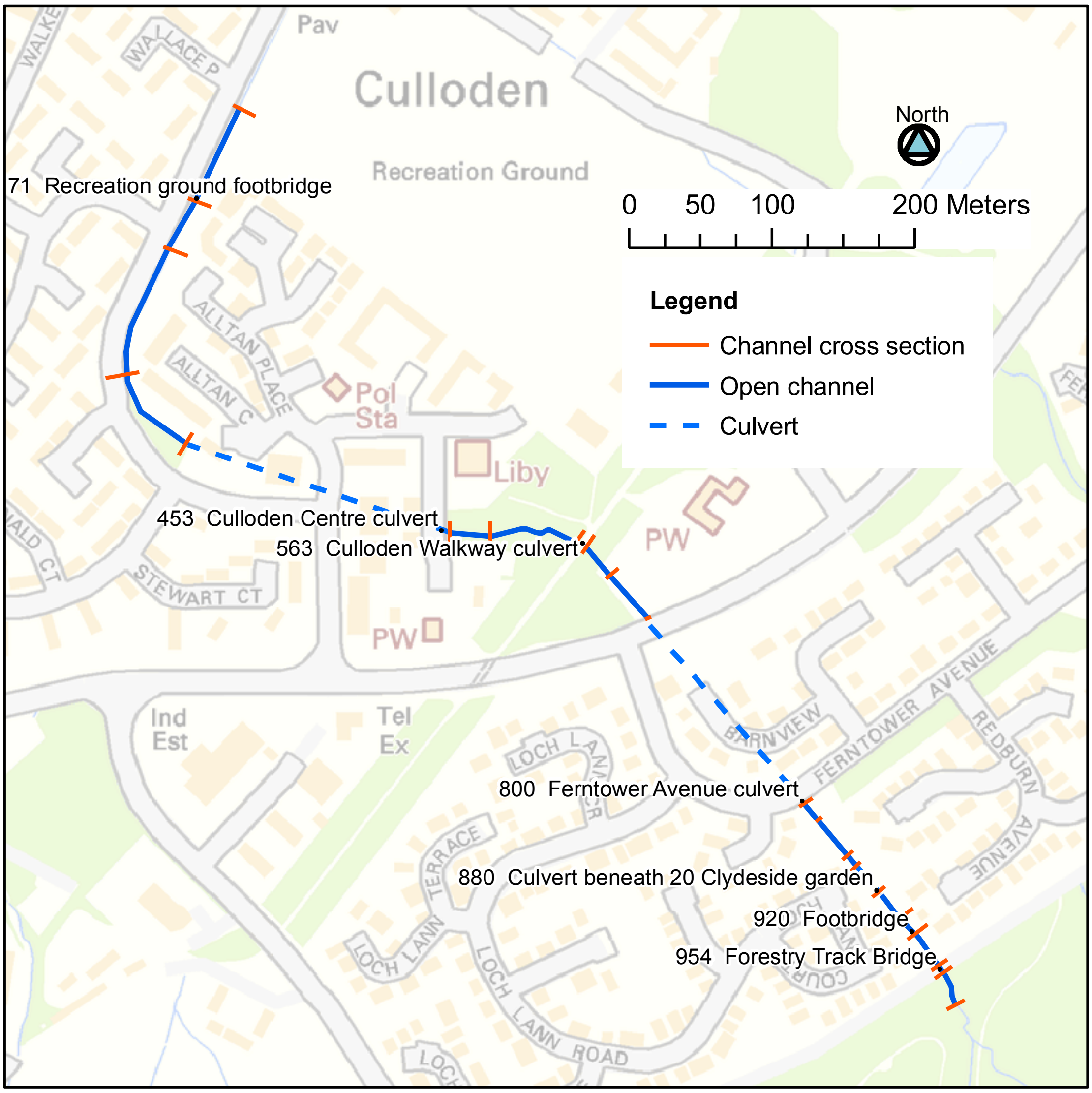
1D modelling was undertaken to determine the capacity of the culverts and burn crossings on each burn. The description of the model, the modelling methodologies and results are provided in the sections below.

8.4.1 Culloden Burn West

The modelled reach is 980m long, beginning approximately 25m upstream of the Forestry Track Bridge to the south-west of Culloden and ending alongside Keppoch Road at Culloden Recreation Ground. At the downstream boundary of the model, the catchment has an area of approximately 0.7 km^2. The modelled reach is very steep, with a drop in bed level of 32.5 m along its length.

There are four culverts and three bridges present in the modelled reach. Details of how these were modelled are given in Section 8.5. The modelled reach and key structures are shown in Figure 8-1, below.

Figure 8-1: Culloden Burn West overview map (chainage and structures shown)

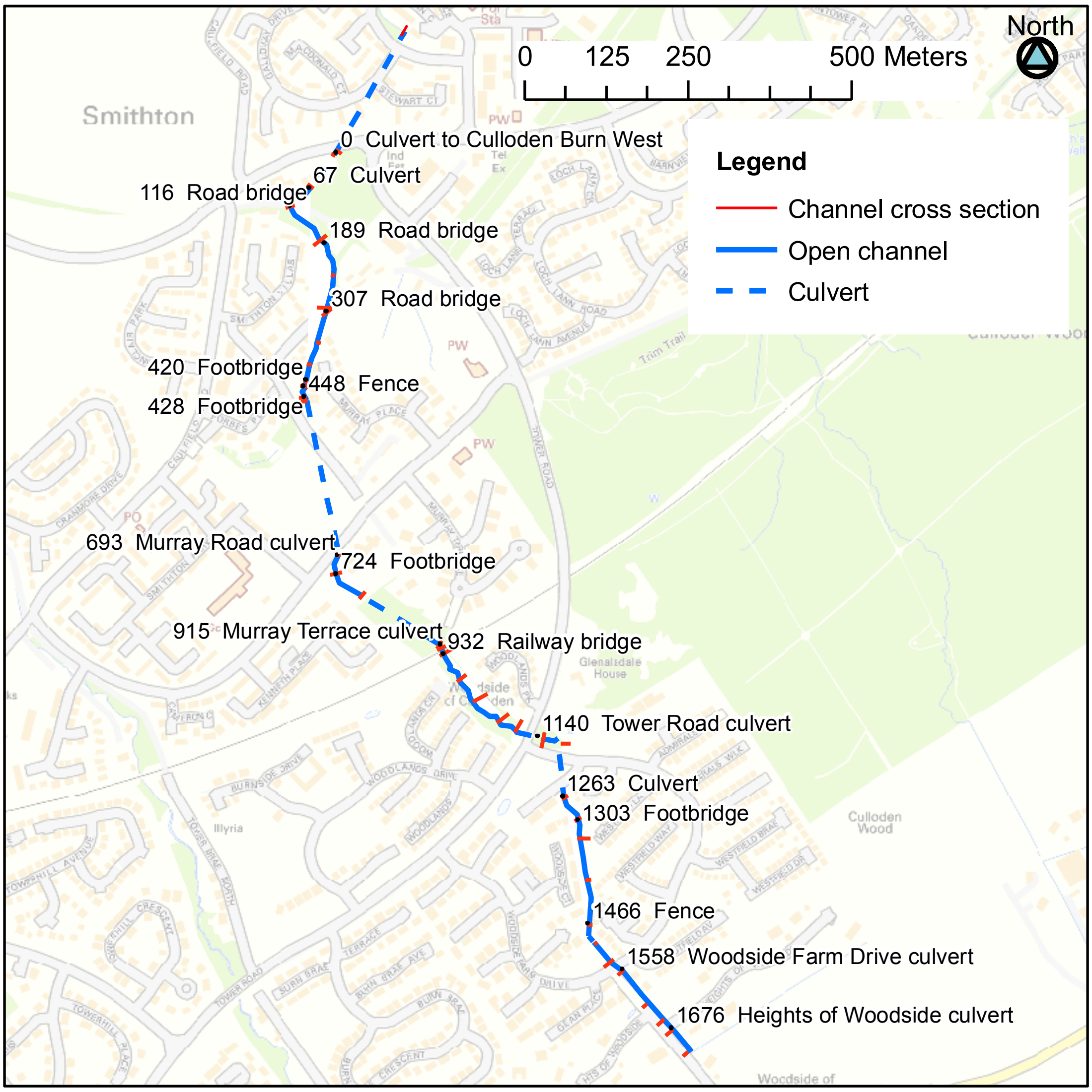


8.4.2 Smithton Burn

The modelled reach is approximately 1,940 m long, beginning alongside the Heights of Woodside (road) and ending at its confluence with Culloden Burn West. At the downstream boundary of the model, the catchment has an area of approximately 1.8 km^2. The modelled reach is very steep, with a drop in bed level of 98.9 m along its length.

There are eight culverts and eight bridges present in the modelled reach. Details of how these were modelled are given in Section 8.5. The modelled reach and key structures are shown in Figure 8-2 below.

Figure 8-2: Smithton Burn overview map



8.5 Key structures and trash screen modelling

There are a number of bridges, culverts and other burn crossing structures in the modelled reaches. There is no default method for modelling culvert screens in HEC-RAS. Two different methods, depending on the nature of the screen were used:

- A weir unit inserted immediately upstream of the culvert. Setting the weir crest to the height of the top of the screen represented complete blockage of the screen. This models screen blockage correctly when screens block and water effectively weirs over the top of the screen. This is not appropriate when a screen is flush with the inlet.
- 'Blocking' the culvert. The 'depth blocked' parameter of the culvert was set to the desired level of blockage. This is appropriate for screens when they are flush with an inlet as water cannot weir over the top of the screen once completely blocked. Therefore, whilst the culvert barrel is not blocked itself, complete blockage of the inlet can effectively completely block the inlet.

Table 8-4and Table 8-5 give details of each of the structures modelled.

Table 8-4: Modelled structures on Culloden Burn West

Chain-age (m)	Type	Description	Opening area (m^2)	Screen and method of blockage
954	Bridge	Forestry Track Bridge	3.18	Screen, but not modelled as not fixed.
920	Bridge	Footbridge in garden off Redburn Avenue	5.10	Water gate.
880	Culvert	Culvert beneath garden of [redacted] Redburn Avenue	0.85	Screen flush with inlet. Culvert blocked.
800	Culvert	Culvert beneath Ferntower Avenue, Barnview and main road	0.87	Screen placed upstream of inlet. Modelled as a weir.
563	Culvert	Culloden walkway culvert	0.87	No screen.
463	Culvert	Culloden Centre Culvert	1.54	Screen. Modelled as a weir.
71	Bridge	Footbridge upstream of Culloden Recreation Ground	2.70	No Screen

Table 8-5: Modelled structures on Smithton Burn

Chain-age (m)	Type	Description	Opening area (m2)	Screen and method of blockage
1,676	Culvert	Culvert beneath heights of Woodside	0.50	None present.
1,558	Culvert	Culvert beneath Woodside Farm Drive	0.87	None present.
1,466	Fence	Boundary fence restricting access to burn	1.18	Boundary fence may block.
1,303	Culvert	Footbridge in Garden of [redacted] Woodside Court	1.48	None present.
1,263	Culvert	Culvert beneath Woodside Village and Woodside Farm Drive	0.87	None present.
1,140	Culvert	Culvert beneath Tower Road	1.77	None present.
931	Bridge	Railway bridge	4.38	None present.
915	Culvert	Culvert beneath high ground adjacent to Murray Terrace	0.64	Two screens, one flush with inlet. Modelled using culvert blockage.
724	Bridge	Footbridge in grounds of burnt out retirement home	2.22	None present.
693	Culvert	Culvert beneath Murray Road	0.64	Screen. Modelled using culvert blockage.
447.5	Fence	Property boundary fence at rear of Murray Place	0.89	None present.
428	Bridge	Footbridge	0.98	None present.
420	Bridge	Footbridge	0.41	None present.
308.5	Pipe	Pipe upstream of bridge at 0.307	4.34	None present.
307	Bridge	Footbridge Walkway	1.79	None present.
189	Bridge	Footbridge at rear of Smithton Villas	2.19	None present.
118.5	Pipe	Pipe upstream of bridge at 0.116	1.27	None present.
116	Bridge	Access road bridge to forestry depot	1.13	None present.
67	Culvert	Culvert beneath garage on main road	0.50	None present.
0	Culvert	Culvert beneath Barn Church Road leading to Culloden Burn West	0.87	None present.

8.6 Model calibration

A number of wrack mark levels were collected during the site survey. The location of the wrack marks and the return periods to which those levels correspond are given in Table 8-6.

Whilst it is uncertain which events these wrack marks relate to and general uncertainties associated with wrack marks, the wrack marks suggest a flow on the lower Culloden Burn West of up to a 30 year return period flow. The lower wrack marks at the footbridge (XS 72) were less defined and have a lower confidence applied to these. This assessment of a 30 year flood broadly matches the estimate of flood flows from the hydrological assessment on the Culloden Burn West.

The wrack mark on the Smithton Burn is located upstream of the area of significant erosion on Woodside Place. It is also upstream of a small footbridge. The level and modelling at this location suggest a very significant flood in excess of the 200 year flow. However, blockage to the footbridge or changes to the reach downstream may be a reason why this wrack mark and the current (post flood) model suggest such a high flow. Due to these changes in the watercourse during the flood, estimation of peak flows in the channel based on this wrack mark cannot be given any confidence and have been disregarded.

Table 8-6: Wrack marks and corresponding modelled return periods

Burn	Model chainage (m)	Level of wrack (mAOD)	Return period (yr) of the flow corresponding to level	Photograph
Culloden Burn West (DS of conf with Smithton Burn)	37	24.46	30	
	72	24.74	5	
	72	24.80	5	
	204	26.70	30	
Smithton Burn	1,309	100.52	N/A	
	1,309	100.37	N/A	

8.7 Results: Culloden Burn West

Initially, the model was run assuming no culvert blockage. Table 8-7 below, shows the maximum predicted capacity of each culvert for the design flows that were modelled. 'Capacity' refers to the maximum modelled discharge before overtopping of the culvert occurred based on the minimum ground spill (deck) level.

Current culvert design best practice recommends that design flows should have an additional freeboard to the culvert soffit to take into account uncertainties. Therefore, an alternative measure of capacity with freeboard was also modelled. This indicates the culvert capacity allowing for a 300 mm margin between the water level and top of the culvert. This higher standard is what would be required for a new culvert and highlights those screens that would be considered under designed under current best practice.

Table 8-7: Modelled structure capacities, Culloden Burn West

Culvert	Model chainage (m)	Opening area (m^2)	Existing Capacity (m^3/s) (return period)	Capacity with freeboard (m^3/s) (return period)
Forestry track bridge	950	3.18	3.25 (500)	3.25 (500)
Garden footbridge	920	5.10	3.25 (500)	3.25 (500)
Beneath garden of [redacted] Redburn Avenue	880	0.85	2.25 (100)	1.67 (30)
Beneath Ferntower Avenue, Barnview and main road	800	0.87	2.63 (200)	2.10 (75)
Culloden Walkway	563	0.87	2.25 (100)	1.67 (30)
Culloden Centre	463	1.54	3.25 (500)	3.25 (500)
Footbridge	70	2.70	3.25 (500)	1.93 (50)
NOTE: The capacity is reported in terms of a modelled flow (m^3/s) and, in brackets, the return period in years to which this flow corresponds.				

The culverts with the smallest capacities are therefore:

- The culvert beneath the garden of [redacted] Redburn Avenue,
- Culvert beneath Ferntower Avenue,
- The Culloden Walkway culvert.

The above analysis suggests that if the culverts and any associated screen were clear and unblocked, the capacity of the culverts could convey flows up to the 1% AP (100 year) flood. However, if one assumes current design standards and a sufficient freeboard (to take account of hydrological uncertainties and debris) the above culverts would be considered as under capacity.

8.7.1 Culvert blockage scenarios

We also tested model sensitivity to the level of blockage of each culvert screen. Each screen in turn was blocked to 0%, 25%, 50% and 75% of the screen height. HEC-RAS does not allow culverts to be 100% blocked and in this situation, the culvert capacity would be zero.

In each scenario we applied the levels to all the culverts at once, rather than each culvert in turn. This was because the steepness of the channel limits backwater effects. The results of the testing to blockage are reported in Table 8-8. In reality, if a culvert became blocked during a flood, the culvert would continue to accumulate debris and prevent culverts further downstream from becoming blocked.

Table 8-8: Culloden Burn West - modelled culvert capacities in response to blockage

Culvert	Model chainage (m)	Maximum discharge before which overtopping occurs (m^3/s)		
		25% blockage	50% blockage	75% blockage
Beneath garden of [redacted] Redburn Avenue	881	1.67 (30yr)	1.05 (5yr)	<0.73 (<2yr)
Beneath Ferntower Avenue, Barnview and main road	800	2.63 (200yr)	2.63 (200yr)	2.63 (200yr)
Culloden walkway	564	1.26 (10yr)	0.73 (2yr)	<0.73 (<2yr)
Culloden Centre	463	3.25 (500yr)	3.25 (500yr)	3.25 (500yr)

Water levels are sensitive to the level of culvert blockage at all culverts. However, this results in a reduction in the return period associated with culvert capacity at only two of the culverts:

- the Redburn Avenue garden (881m) and

- Culloden Walkway (564m).

Whilst blockage is therefore likely to increase the probability of overtopping of these two structures, the consequence of overtopping must also be considered. Overtopping of the Redburn Avenue culvert will result in property flooding whereas overtopping of the Culloden Walkway culvert is lower risk as water will most likely flow directly into the channel downstream.

This effect of blockage is less noticeable for the culverts at Ferntower Avenue (800m) and Culloden centre (463m) because the design of these screens is such that they are less likely to completely block as they are set back from the culvert inlet.

8.8 Results: Smithton Burn

Initially, the model was run assuming no culvert blockage. Table 8-9, below, shows the maximum predicted capacity of each culvert for the design flows that were modelled.

'Capacity' refers to the maximum modelled discharge before overtopping of the culvert occurred. 'Capacity with freeboard' indicates the culvert capacity allowing for a 300 mm margin between the water level and top of the culvert.

Table 8-9: Modelled structure capacities, Smithton Burn

Culvert	Model chainage (m)	Opening area (m^2)	Capacity (m^3/s) (return period)	Capacity with freeboard (m^3/s) (return period)
Culvert beneath Heights of Woodside	1,676	0.50	1.29 (30)	0.57 (2)
Culvert beneath Woodside Farm Drive	1,558	0.87	1.77 (100)	1.65 (75)
Boundary fence restricting access to burn	1,466	1.18	2.59 (500)	<0.57 (<2)
Footbridge in Garden of [redacted] Woodside Court	1,303	1.48	2.59 (500)	0.57 (2)
Culvert beneath Woodside Village and Woodside Farm Drive	1,263	0.87	2.59 (500)	1.65 (75)
Culvert beneath Tower Road	1,140	1.77	2.59 (500)	2.59 (500)
Railway bridge	931	4.38	2.59 (500)	2.59 (500)
Culvert beneath high ground adjacent to Murray Terrace	915	0.64	2.09 (200)	0.99 (10)
Footbridge in grounds of burnt out retirement home	724	2.22	2.59 (500)	2.59 (75)
Culvert beneath Murray Road	693	0.64	1.51 (50)	0.57 (2)
Property boundary fence at rear of Murray Place	447.5	0.89	2.09 (200)	0.57 (2)
Footbridge	428	0.98	0.57 (5)	<0.57 (<2)
Footbridge	420	0.41	0.83 (10)	<0.57 (<2)
Walkway Footbridge	307	4.34	2.59 (500)	2.59 (500)
Footbridge at rear of Smithton Villas	189	1.79	2.59 (500)	1.29 (30)
Access road bridge to forestry depot	116	2.19	2.59 (500)	2.51 (200+CC)
Culvert beneath garage on main road	67	1.27	2.59 (500)	2.09 (200)
Culvert beneath Barn Church Road leading to Culloden Burn West	0	1.13	2.59 (500)	2.09 (200)

NOTE: The capacity is reported in terms of a modelled flow (m^3/s) and, in brackets, the return period in years to which this flow corresponds.
* During the site survey it was noted that the culvert beneath Murray Road (model chainage 693m) was approximately 50% blocked with stones and silt. The results show the culvert capacity for the situation with no blockage.

The culverts with the smallest capacities are therefore:

- Culvert beneath Heights of Woodside
- Culvert beneath Murray Road
- Property boundary fences and access bridges crossing burn on Murray Place

The above analysis suggests that if the culverts and any associated screen were clear and unblocked, the majority of the culverts could convey flows up to the 1% AP (100 year) flood. However, if one assumes current design standards and a sufficient freeboard (to take account of hydrological uncertainties and debris) many more structures within the reach would be considered as under capacity. This is further compounded by culvert blockage.

8.8.1 Culvert blockage

We tested model sensitivity to the level of blockage of selected culverts and screens. Each screen in turn was blocked to 0%, 25%, 50% and 75% of the screen height. HEC-RAS does not allow culverts to be 100% blocked and in this situation, the culvert capacity would be zero.

In each scenario we applied the levels to all the culverts at once, rather than each culvert in turn. This was because the steepness of the channel limits backwater effects. The results of the testing of blockage are reported in Table 8-10.

Table 8-10: Smithton Burn - modelled culvert capacities in response to blockage

Culvert	Model chainage (m)	Maximum discharge before which overtopping occurs (m^3/s)		
		25% blockage	50% blockage	75% blockage
Culvert beneath Woodside Village and Woodside Farm Drive	1,263	2.59 (500)	1.29 (30)	<0.57 (<2)
Culvert beneath Tower Road	1,140	2.59 (500)	2.59 (500)	1.29 (30)
Culvert beneath high ground adjacent to Murray Terrace	915	1.77 (100)	0.83 (5)	<0.57 (<2)
Culvert beneath Murray Road	693	0.99 (10)	0.57 (2)	<0.57 (<2)
Access road bridge to forestry depot	116	1.77 (100)	0.99 (10)	<0.57 (<2)
Culvert beneath garage on main road	67	1.77 (100)	0.83 (5)	<0.57 (<2)
Culvert beneath Barn Church Road leading to Culloden Burn West	0	1.77 (100)	0.83 (5)	<0.57 (<2)

Water levels are sensitive to the level of culvert blockage at of the selected culverts, resulting in a reduction in flow capacity at all of the structures. Structures most sensitive to blockage are:

- Culvert beneath high ground adjacent to Murray Terrace
- Culvert beneath Murray Road
- Access road bridge to forestry depot
- Culvert beneath garage on main road
- Culvert beneath Barn Church Road leading to Culloden Burn West

Whilst blockage is therefore likely to increase the probability of overtopping of these two structures, the consequence of overtopping must also be considered. Overtopping of the Murray Terrace and Murray Road are most likely to flood properties.

8.9 Summary of channel capacity modelling

A secondary test was undertaken to review the capacity of the watercourse to the estimated design flows to check for poor channel conveyance and the need for additional flood defence works. Generally the two watercourses seem to be able to convey flood flows although the recent flood event suggests that some out of bank flows may have occurred on the Smithton Burn (flooding Smithton Villas) and onto Keppoch Road (although the latter may have been due to surface water). The location of channel capacity exceedence on the Smithton Burn is shown in the photograph below.

Figure 8-3: Repaired bank at location of bank overtopping into Smithton Villas

Analysis of the modelled output suggests the following reaches are under capacity and at risk of overtopping. These reaches should be reviewed to see if additional bank raising or flood defence works are required. In many cases the capacity is controlled by structures crossing the burns downstream and the removal of these would improve the channel capacity.

Table 8-11: Reaches potentially under capacity (does not assume any freeboard to top of bank)

Burn	Location	Chainage (km)	Maximum channel capacity (return period)
Culloden Burn West	Upstream of culvert beneath garden of Redburn Avenue	0.882	100 year
Culloden Burn West	Upstream of culvert beneath Ferntower Avenue	0.800	200 year
Culloden Burn West	Upstream of Culloden Walkway culvert	0.564	75 year
Culloden Burn West	Adjacent to Keppoch Road	0.110	100 year
Culloden Burn West	Footbridge on Keppoch Road	0.72	200 year + CC
Culloden Burn West	Park adjacent to Keppoch Road	0.000	200 year
Smithton Burn	Upstream of Culvert beneath Heights of Woodside	1.676	200 year + CC
Smithton Burn	Upstream of Murray Terrace culvert	0.916	200 year
Smithton Burn	Upstream of Murray Road culvert	0694	50 year
Smithton Burn	Gardens of Murray Place	0.453 - 0.309	30 year
Smithton Burn	Upstream of access bridge to forestry depot	0.119	200 year
Anecdotal evidence suggests that out of bank flows may have occurred on the Smithton Burn at chainage 303 (as shown in Figure 8-3. The top of bank was surveyed after remedial works and suggests that the current bank level is suitable high to avoid out of bank flows. The pre-flood bank level is not known.			

8.10 Overland flow modelling (J|Flow)

This section describes how overland flow routes were modelled. Overbank areas were modelled using J|Flow; a two dimensional raster based model, developed by JBA Consulting.

Two key culverts were modelled. The analysis predicts routes that flow is likely to take, in the event that the culverts are overtopped.

8.10.1 Model construction

LiDAR grids of the risk areas were supplied by the Highland Council. The LiDAR has a resolution of 1m.

The LiDAR was provided as a Digital Terrain Model (DTM), so it has been filtered to remove buildings. However, buildings will impact on flow routes, so we added these back in to the DTM. Buildings were identified using Ordnance Survey Mastermap data and ground levels of the DTM were raised by 3m where buildings were present.

8.10.2 Model inflows

We ran the models for the 25 year event, with hydrographs calculated using the FEH Rainfall Runoff method. Inflows to the J|Flow model were applied at the upstream face of each culvert. Overtopping from three culverts was modelled. It has been assumed for modelling purposes that the 2 year flow was conveyed through the culverts and all flows above this routed via the 2D model.

Table 8-12: Key culverts for which overland flow routes were modelled

Watercourse	Culvert	HEC-RAS model chainage, m	OS Grid Ref
Culloden Burn West	Beneath garden	880	272024 845852
Smithton Burn	Murray Terrace	915	271592 845227

8.10.3 Results

The maximum flood outlines for overtopping of each culvert are shown in Figures 8-3 to 8-5. Larger plans of the flood depths and flood velocities are shown in Figures 11 to 14 in the Figures Section of the report.

Flood outlines have been clipped at the point at which flows would re-enter the channel (at Murray Place (for the Smithton Burn) and Ferntower Avenue (for the Culloden Burn West).

The overland flow routes compare with the observed flood outlines well. The differences in the outlines may be due to overland flow routes being constrained by curb levels which were are not included in the 2D modelling.

The results suggest that event for a small flow, the potential flow paths are extensive and could cover large proportion of the urban areas of Smithton and Culloden.

Figure 8-4: Flood outline for overtopping at the culvert beneath the garden of [redacted] Redburn Avenue (HEC-RAS chainage 880m)

[redacted]

Figure 8-5: Flood outline for overtopping at Murray Terrace culvert (HEC-RAS chainage 915m)

[redacted]

8.11 Pluvial flood risk mapping

Pluvial flooding is flooding as a direct result of rainfall onto the ground surface and its subsequent runoff via overland flow routes leading to pooling in topographically low-lying areas. The flooding often also referred to as surface water flooding poses a hazard as it flows over land and in the pooling in low lying areas or behind barriers.

Pluvial flood risk has recently been mapped by JBA for SEPA using JBA's in-house 2-D fully hydrodynamic modelling software J|FLOW+. pluvial modelling uses a 2-D raster approach to simulate rainfall runoff over the topography of the study area. The inputs to the model are rainfall data and raster topographical information. The model produces a map of pluvial flood depths across a study area which can assist with the identification of drainage issues within a study area and assist with future planning.

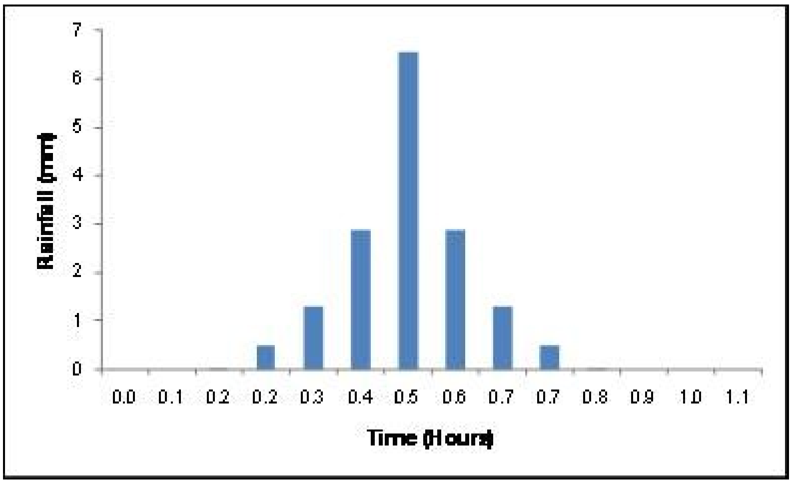
8.11.1 Pluvial modelling assumptions

The same approach used by SEPA has been repeated for this study. The following assumptions were made:

- LiDAR (light detection and ranging) data with a resolution of 1m was used.
- The LiDAR data was edited to allow more realistic flow paths through embankments, culverts, underpasses, tunnels and bridges.
- Buildings have been added to the LiDAR using OS Mastermap building polygons data to recreate realistic flow paths within the model.
- Roads have been stamped onto the DTM at a height reduced by 0.1m to provide a clear flow route which is constrained by kerbstones.
- A Manning's 'n' coefficient of 0.1 is used as a blanket surface roughness;
- Design rainfall depths were abstracted from the Flood Estimation Handbook dataset by extracting Depth-Duration-Frequency model parameters for the centre point of each model run area.
- A design rainfall hyetograph was generated based on the FEH 'summer' profile which is more representative of the convective storms more common in summer, and is recommended for application to urban catchments where a shorter period of high intensity rainfall is generally more critical.
- Urban percentage runoff values of 70% were assumed.
- The removal of 12 mm/hr within the design hyetograph was assumed to represent the effect of drainage systems in urban areas that remove some pluvial runoff volume from the ground surface.
- A 1.1 hour storm duration was used (with the rainfall profile divided into ordinates of 0.1 hours). Recent research by JBA Consulting[16] also suggests that shorter rainfall event durations are more critical for steeper topography.
- For the purposes of this assessment a 0.5% AP flood event was modelled.
- Depths of less than 0.1m removed from the results and isolated areas of pluvial flooding of less than 200 m^2 in size were also removed from flood outlines.

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

Figure 8-6: Example rainfall hyetograph (0.5% AP, 1 hour duration for an urban area)



8.11.2 Pluvial modelling results - Culloden Burn West

Pluvial maps are provided in Figure 9 and Figure 10. Key findings from the pluvial mapping are summarised below:

- The historic flood path (occurred in 2002) over the forestry track to Redburn Avenue from the western tributary of the Culloden Burn West in the forest is picked up by the pluvial flood extents. This was present before alterations to this burn and most flows should now be diverted to the main burn.
- The recent flow path into Loch Lann Court has not been recreated by the pluvial flood extents, although local depressions in the areas affected have.
- The pluvial flood extends and depths highlight a number of areas of potentially significant flood depths particularly in the area of Galloway Drive (recorded as flooded in July), Walker Crescent and Wallace Place, Keppoch Road, the Duncan Forbes Primary School and around the Culloden Centre.

8.11.3 Pluvial modelling results - Smithton Burn

Key findings from the pluvial mapping are summarised below:

- An area of ponding of flood waters around a number of properties on Westfield Avenue has been identified but was not experienced during the July and August flood events. This area should be investigated further through discussions with homeowners and site visits.
- Potential overland flow routes and ponding along Woodside Farm Drive, Woodside Place and Westfield Way. These may result in localised flooding to properties located immediate in the path of these flow routes and should be investigated on site to see if adequate drainage and flow routes back to the river are available.
- A possible flood route over Woodside Village should the adjacent culvert completely block is identified by the pluvial mapping.
- A possible low point in the railway embankment and flow path onto Murray Terrace has been identified. This occurred in 2002 and is illustrated by the photograph below.
- The ponding of surface water on Murray Road is very similar to that witnessed during the recent floods.
- The overland flow route down Murray Terrace and Murray Place is very similar to that observed during the recent floods.
- The ponding and surface water issues in Smithton Villas is identified by the pluvial mapping.
- Potentially significant flood depths are predicted by the pluvial mapping on Barn Church Road.

Figure 8-7: Flood from the Railway in September 2002 to Murray Terrace

Photo provided by [redacted]

9 Review of flood events and causes

9.1 Summary of flood events

The following rainfall events resulted in the flooding of the Culloden Burn West and Smithton Burn during July and August 2011.

- The July rainfall event had a uniform pattern over the region generating approximately 50-60 mm in a 24 hour period over the Inverness East area, but with locally intense cells that increased rainfall totals.
- The rainfall return period locally in the region of the Culloden gauge is estimated to be approximately 80 years.
- The August rainfall event saw more intense rainfall distributed to the north and west of the Inverness East area with 50-60 mm rainfall depth occurring in a 15 hour period.
- The August rainfall event is estimated to have generated a rainfall return period in the region of 30-45 years, but may have been up to 63 years locally over the Culloden rain gauge.
- Rainfall over the two catchments resulted in an estimated peak flows equivalent to 30-45 years.

9.2 Review of flood mechanisms

The following mechanisms contributed to the flooding on the Culloden Burn West.

- High flows in the upper catchment mobilised sediment and woody debris in the forested portion of the Culloden Burn West catchment. Whilst the sediment was held back by natural woody debris dams and the artificial gabion basket, woody debris was picked up and passed downstream.
- Woody debris may have been temporarily held back by the water gates in the gardens of Redburn Avenue. These partial barriers may have caused debris to be held back and released in one surge before blocking the culvert screen downstream.
- Whilst the culvert screen may have been clear the rapid blockage and short time to peak for flood flows on the burn would have rapidly blocked the screen.
- No automated telemetry or risk based frequency for screen clearance is provided by the Council. Even so, the response rate required to keep the screen clear during high flows may not be possible for this watercourse. There is also at present a safety and accessibility issue for Council Staff on some screens and inlets.
- Blockage of the culvert screen resulted in backing up of flows behind the culvert inlet and overtopping of the culvert headwall leading to flows through gardens onto the footpath that connects to Loch Lann Court, Loch Lann Court itself and Redburn Avenue. A direct flood route back into the channel is not present.
- A flow path away from the channel developed towards Ferntower Avenue flooding additional properties in the process.

The following mechanisms contributed to the flooding on the Smithton Burn.

- High rainfall in the Smithton Burn catchment resulted in significant surface water and high flows in the Burn. These high flows mobilised bed and bank sediment and caused significant erosion in specific locations within the reach including:
    - Behind Woodside Court
    - Between Woodside Village and Woodside Court
    - Upstream of the railway culvert
- In some locations this resulted in significant bank erosion but no direct flooding.
- In the reach upstream of the railway culvert significant erosion and sediment movement occurred resulting in sediment deposition at the culvert inlet and beneath

the railway culvert. This was probably as a result of the presence of a secondary screen, an in-channel gabion basket, the primary screen flush with the culvert inlet and the sheer volume of sediment mobilised. It is likely that woody debris also helped to initially block the two culvert screens and make the inlet more prone to sediment deposition.

- The blockage reduced the culvert capacity and overland flow onto Murray Terrace, Murray Road and Murray Place resulted.
- Existing blockage of the culvert downstream of Murray Road reduced the capacity of this culvert and may have contributed to flooding on Murray Road.
- The entry of overland flows into surface water drainage system contributed to sewer and surface water flows resulting in drainage capacity exceedence elsewhere in the area including Smithton Villas. A flood route to Smithton Villas via footpath near Forbes Place from a surcharged manhole was observed.
- The flooding to Smithton Villas may also have been as a result of surface water flooding.
- Overland flow directly from the burn contributed to flooding to Smithton Villas.
- A SUDS pond in the upper catchment filled and breached at the low point leading to flooding to properties on Gean Place and over footpath into the Smithton Burn channel.
- Sudden blockage or un-blockage of culverts and screens during the flood may have rapidly altered flows downstream. This has been suggested by Council staff with flooding from different sources at different times. I.e. the clearance of a culvert or screen may have reduced the overland flow path, but increased flows in the channel downstream resulting in culvert capacity exceedence downstream. Similarly the opening of manholes in the overland flow path may have added additional flows to the sewer system resulting in sewer surcharging elsewhere.

9.3 Aspects that contributed to flooding on the Culloden Burn West

Key findings from the hydraulic modelling and hydrological analysis suggest the following aspects of the catchments and flood events contributed to the flooding on the Culloden Burn West:

- Woody debris material was brought down from the forestry reach.
- Whilst sediment is caught in the gabion dam in the forestry reach, there were inadequate controls (such as in-channel screens) to catch woody debris material prior to reaching high risk structures downstream.
- Poor culvert screen design and inadequate clearance of debris material during the flood event. No suitable location exists to store cleared debris without the risk of this re-entering the channel if water levels rise further.
- Poor sighting of the culvert entrance and screen (screen cannot be viewed easily by maintenance teams).
- Fast responding catchments and debris being temporarily held back by water gates upstream means that the screens on structures can block rapidly making response times and clearance of these by Highland Council staff almost impossible during flood events.
- Once overtopped, flow paths do not redirect flow back into the burn channel, but naturally divert flows towards properties and roads.

9.4 Aspects that contributed to flooding on the Smithton Burn

Key findings from the hydraulic modelling and hydrological analysis suggest the following aspects of the catchments and flood events contributed to the flooding on the Smithton Burn:

- Channel and bank erosion in the upper reach (upstream of Tower Road) transported a lot of sediment downstream. Whilst this did not directly result in property flood damages it did contribute to emergency response and inspection and maintenance of the watercourse during the flood event by Highland Council.

- Channel and bank erosion in the middle reach (downstream of Tower Road) resulted in screen and culvert blockage adjacent to Murray Terrace.
- Raised ground to the north of the Murray Terrace culvert results in a flood route directly towards properties and land on Murray Terrace and Murray Place.
- Poor siting, condition, partial blockage and undersized culverts contributed to the probability of this culvert blocking. The screens in place may have also increased the probability of the inlet blocking with debris and sediment.
- Poor culvert screen design and inadequate clearance of debris material during the flood event. No suitable location exists to store cleared debris without the risk of this re-entering the channel if water levels rise further.
- Partial blockage of the culvert beneath Murray Road may have contributed to ponding of water on Murray Road.
- Road drainage and Scottish Water sewers had insufficient capacity to cope with the additional overland flows and resulted in a number of surcharging manholes on Murray Road, Murray Terrace, Murray Place, the walkway near Forbes Place and in Smithton Villas.
- Scottish Water sewer and surface water drainage follow the main overland flow paths contributing to the problems and links between surface flows and sewer flows.
- Bank overtopping and breaching contributed to the flood risk in Smithton Villas.
- Anecdotal evidence suggests that the capacity of SUDS ponds may not have been sufficient to store the required surface water drainage which led to overtopping of some of these ponds.

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10 Watercourse assets, condition & maintenance

10.1 Key assets

Both of the burns assessed have a number of bridge and culvert crossings as well as third party or privately installed structures that have an impact on channel maintenance and watercourse capacities. In addition to these structures there are a number of erosion and scour protection measures and reaches where severe erosion and bed/bank mobilisation is taking place. Each of these assets and their likely impact on watercourse stability and flood risk has been discussed within this report. This section draws this information together to inform the measures required to reduce flood risk.

10.1.1 Key bridges and culverts

A number of key bridges and culverts have been identified as part of this study. Onsite inspection and assessment of each structure has been undertaken and an indicative assessment of blockage risks, ease of access (for the purposes of Council inspection and maintenance) and ease of maintenance has been undertaken and is presented in Section 8.3.

Factors that contribute to blockage risks include the opening size, capacity, presence and type of screen and type and condition of upstream channel/catchment contributing reaches. A complete record of watercourse crossings, together with photographs and additional information is provided in Appendix B. A summary of the structures is provided below.

- Culvert beneath garden of [redacted] Redburn Avenue (Culloden Burn West). Poorly designed screen and in poor condition, difficult access and unsafe for maintenance.
- Culvert beneath Woodside Village and Woodside Farm Drive (Smithton Burn). Highly eroded and currently unstable channel and banks upstream risking further erosion, sediment movement and culvert blockage downstream.
- Culvert adjacent to Murray Terrace (Smithton Burn). Highly eroded channel upstream and downstream movement of sediment. Poor inlet to culvert including screens and in-channel gabion baskets increasing the probability of blockage and difficulties in clearance during flood conditions.
- Culvert beneath Murray Road (Smithton Burn). This is currently 50% blocked at the downstream end.

10.1.2 Other structural assets

A complete asset record for the two burns is provided in Appendix C that provides additional information on other assets or watercourse reaches that may require maintenance or works to reduce further flood risks. Key urgent concerns for the two burns are summarised below:

- Sediment deposition through the Keppoch Road culvert on the Culloden Burn.
- Gabion basket undercutting adjacent to Keppoch Road.
- Culvert headwall undercutting on the culvert beneath garden of Redburn Avenue.
- Post flood debris dumped next to river and not removed from inlet adjacent to Murray Terrace. Flooding could reactivate this material.
- Access ramp to river upstream of Tower Road at risk of undercutting.
- Bank erosion and failure beneath riparian property decking adjacent to Smithton Place.

10.2 Current watercourse condition and erosion

This section considers the nature of the Smithton and Culloden Burn West channels, including their existing condition, channel form and the known issues of erosion and sediment accumulation. The watercourses are considered as a number of different reaches, thus highlighting any changes in the nature of the burns that occur along their length. The details presented within this section are compiled from site observations as well as SEPA's Hydromorphology File Note[17].

The channel reaches for the Smithton Burn and Culloden Burn West are presented within Appendix D. Key reaches of concern and in need of emergency stabilisation works are:

- **Culloden Burn West woodland reach** - steep, erosive reach within a steep sided densely vegetated valley. Although some sediment management is in place, natural woody debris is at risk of failure leading to risk of sediment and debris mobilisation.
- **Smithton Burn upstream of Smithton Village** - sediment is transferred through this reach and there is no form of sediment management to prevent the material from upstream continuing on into Woodside Farm Drive culvert.
- **Smithton Burn upstream of Tower Road** - a relatively natural channel subject to erosion and is effective at conveying sediment downstream through a step-pool system.
- **Smithton Burn upstream of Railway Culvert** - a steep reach that has undergone extensive recent erosion. A series of boulder weirs have recently been installed in an attempt to stabilise the channel and control the bed level through the reach. A large volume of sediment accumulated in the vicinity of the railway bridge and upstream of Murray Terrace culvert causing extensive flooding.

10.3 Council maintenance responsibilities

The legislative context for the delivery of flood risk management, watercourse maintenance and asset management in Scotland is currently primarily determined by the Flood Risk Management (Scotland) Act 2009 following on from the 1997 act that placed a duty for inspection and maintenance of watercourses, the reporting and production of a schedule and biennial reporting.

The Flood Risk Management (Scotland) Act 2009 places a duty on local authorities to undertake assessments. Every local authority must, from time to time (or when directed to so by the Scottish Ministers):

> a) assess the relevant bodies of water (other than canals) in its area for the purpose of ascertaining whether the condition of any such body of water gives rise to a risk of flooding of land within or outwith its area, and
>
> b) where a body of water gives rise to such a risk, and the authority considers that clearance and repair works would substantially reduce that risk.

10.4 Summary of watercourse assets and condition

From the information and data provided, the following key findings are provided:

- A number of culverts have inadequate trash and security screens in place.
- Many of the trash screens are not designed to be easily cleaned and cleared particularly during flood events.
- Access to screens and culvert inlets is difficult with inadequate safety measures for Council personnel to clean and clear structures.
- Access to screens and culvert inlets during flood conditions are not restricted in terms of public safety and security with no warning or emergency contact details.
- The steep channel gradients in the middle reaches of the watercourses are prone to significant erosion and sediment movement.
- Access to some reaches to inspect and maintain channels are limited and becoming more restricted by property fencing (particularly on the Smithton Burn).
- Analysis of sediment types and channel bed material suggests that the majority of the larger moveable sediment in the active middle reaches of the watercourses is not

[17] SEPA Hydromorphology File Note, 1 September 2011. Ref: 110901_AM_Smithton Burn_Culloden

actively transferred downstream to the lower reaches and is either blocking culverts or has historically been removed from the channel.

10.5 Current maintenance regime

Current maintenance and inspection of the watercourses are undertaken by the Council as part of their responsibilities under the Flood Risk Management (Scotland) Act 2009. The Council do not have a defined inspection frequency for the burns in the Inverness East area although correspondence with the operations team[18] suggested that screens and culverts were inspected twice a year. The Council are in the process of establishing a risk based priority inspection regime.

The Council do however have records of the inspection and maintenance carried out on these Burns and reported in the Biennial reports and the most recent 2009 inspection report. These are discussed further below.

Ownership of assets is important and this will determine who has the responsibility of maintaining the assets. It is likely that not all assets and burn crossings are owned by the Council and a review of this aspect may be required.

10.5.1 Biennial reports

Biennial reports are a statutory requirement for Local Authorities to demonstrate and record actions taken to inspect and maintain watercourses. The Biennial reports from the Highland Council were reviewed to check for inspection and maintenance records for the Culloden Burn West and Smithton Burns. A summary of the information collated for these two burns is provided in Appendix A.

Based on this evidence it is clear that structures have been identified as being at risk of blockage and in need of screens to prevent culvert blockages. The records also suggest that culvert blockage has occurred in the past and that material was removed from culverts over the last 10 years. CCTV inspection of culverts has also been undertaken to determine culvert blockage.

The reports also demonstrate that the Highland Council TEC Services pursued a programme of regular waterway inspections aimed at establishing a suitable schedule of regular maintenance.

A number of works have been undertaken since the 2002 flooding to provide trash screens to culvert inlets, provide debris dams, to improve channel conveyance on the Culloden Burn West and to control scour and channel erosion.

10.5.2 2009 Flood Inspection report

The 2009 Flood Inspection Report identifies the inspection carried out on the Culloden Burn West and Smithton Burn in 2009. Inspectors visited all reaches of these two watercourses and took detailed notes and photographs of the burns. The following key aspects were noted in the report:

10.5.3 Culloden Burn West

The following key points of interest were collated or are observable from the photographs:

- Burn and culverts were largely clear at the time of inspection
- The channel leading to the culvert beneath the Culloden Centre was heavily overgrown.
- The screen on the culvert inlet beneath the garden of Redburn Avenue was not present at the time of the inspection (this was present during the July flood event).
- A wooden pallet is observed in culvert inlet of the culvert beneath the footpath.

[18] Pers. Comm. with John Taylor (Highland Council)

10.5.4 Smithton Burn

The following key points of interest were collated or are observable from the photographs:

- The reaches through the new development were heavily overgrown
- Culvert inlets were clear at the time of inspection and appeared to have adequate capacity
- Riparian homeowners through the Westfield/Woodside housing development had made modifications to the watercourse with the potential for future problems.
- Culvert upstream of Murray Terrace is identified as a bottleneck and it is essential that this is kept clear.
- All other inlets were clear at the time of inspection.

10.6 Summary of watercourse maintenance

From the information and data provided, the following key findings are provided:

- The Highland Council aims to prioritise and inspect watercourse and structures on the two burns on a risk based process. The 2009 inspection report provided a baseline record of the key watercourse features and recommendations for at least annual inspection.
- Inspection and clearance during flood events is more informal, ad hoc and undocumented. The staff responsible are aware of which assets cause the greatest problems and can be checked during flood events, but there is no defined frequency for event inspections.
- The Highland Council aims to prioritise maintenance on key assets which have known maintenance problems or difficulties.
- A number of measures have been undertaken to respond to previous flood events to try to improve channel conveyance, reduce culvert blockage and to stabilise channels.
- Various landowners along the route of the watercourses are also fulfilling their riparian duties to a greater or lesser degree by carrying out ‘ad hoc’ maintenance.
- It is recommended that the Council reviews the ownership of watercourse assets to determine who has maintenance requirements.
- Despite the above pro-active inspection and maintenance regime the most recent flood events resulted in significant channel erosion, sediment movement and structure blockage that caused significant flooding.

11 Proposed measures to alleviate flood risk

There are two general approaches to alleviating flood risk in the area:

1. a flood protection scheme or
2. upgraded maintenance combined with small scale measures.

There are pros and cons to each and a number of options within each of the above categories are discussed below. In addition to the above flood warning and forecasting can also help to reduce risk to life and flood damages by providing advanced warning to communities at risk. This is discussed further in Section 11.5 below.

11.1 Scheme versus maintenance and measures

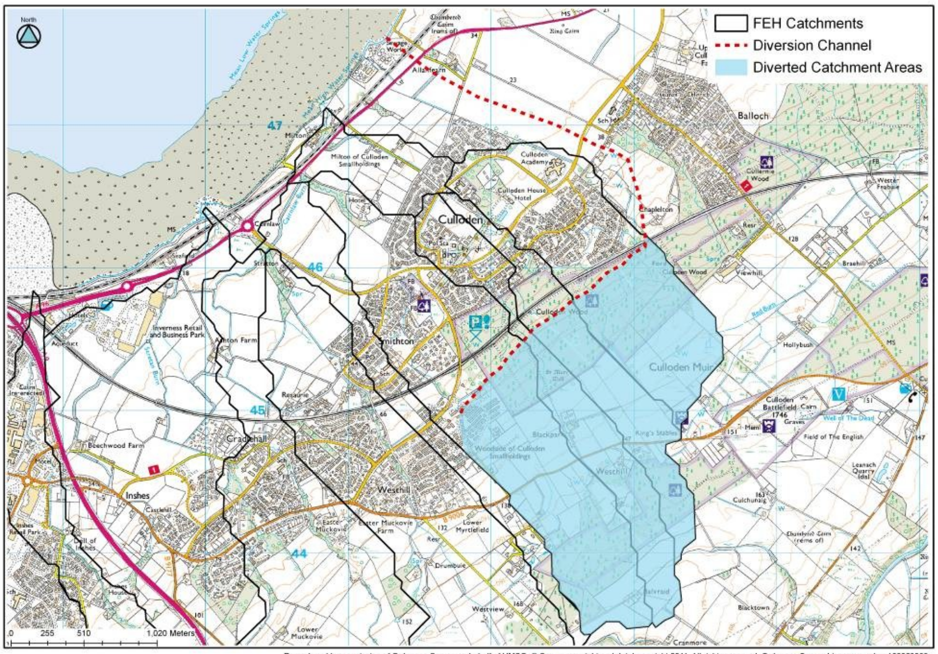
A number of flood mitigation scheme solutions have been identified and their viability discussed below. These options may be associated with significantly higher capital costs but may ultimately reduce Council revenue spending on inspections and maintenance. Further assessments on these solutions are required to determine their viability and cost effectiveness.

11.1.1 Diversion channel

A diversion channel similar to the South West Diversion Channel to the south and west of Inverness could divert flows from the upper catchment reaches and divert these away from the flood risk locations, thus reducing the flows in the urban reaches of the watercourses.

Whilst the key benefit of such an option could also divert flows from other burns in the area such as the Tower Burn and Culloden Burns, this option is complicated by the fact that the new housing development around Woodside Farm Drive is located relatively high in the catchment of the Smithton Burn. This reduces the flows that could be caught in the upper catchment.

Diversion to the west is not possible without worsening flows in the watercourses to the west. Diversion to the east is possible probably via a new channel between Culloden and Balloch as shown in the figure below. Other burns in the area would be unlikely to cope/have sufficient capacity for additional inflows. This option is further complicated by the need to cross two railway lines and additional roads.



11.1.2 Upstream storage

Upstream storage may be an option but would be needed on each burn where flow capacities need to be reduced. The upper reaches above the development areas do not lend themselves to storage due to the uniform sloping ground profile and no natural valleys. The only option would be via substantial earth moving for cut and fill storage options. An alternative option may be to consider natural flood management practices such as large woody debris dams, field scrapes and other in-channel barriers although these would have to be robust enough to prevent the risk of barriers giving way and causing pulses of flooding downstream.

11.1.3 Disconnection of Smithton Burn from Culloden Burn West

Although flood risks associated with the culvert linking Smithton Burn to Culloden Burn West have not been reported, this last culvert is sensitive to blockage and may be a future flood risk. A longer term option may be to consider diversion of this watercourse directly to the Cairnlaw Burn to the north. Whilst this does not solve the problem in the upper/mid reach of the Smithton Burn it may be a proactive approach to deal with climate change and increased flood flows.

11.1.4 Making space for water

A proactive approach to the long term flood management of these and adjacent burns may be to design for watercourse exceedence scenarios. At the moment, once burns overtop the water naturally follows the topography of the adjacent land, typically following road constrained or directed by kerbstones. The use of the overland flow and surface water mapping can help to anticipate these flow routes and to help manage these overland flow routes. Options such as general landscaping, raising kerbstones, redirecting flows back into channels and two stage channels may help to reduce the impact of overland flows.

11.2 Measures and maintenance

A number of measures have been identified that will help to alleviate future flooding from the two burns. A number of different types of measures have been identified that cover a range of aspects from capital project to maintenance works as well as some generic measures that cover both burns. These are discussed further and presented below.

11.2.1 Generic measures

The aspects cover both burns and could be extended to all burns in the area as they are generally good flood management practices for small watercourses.

Ref	Problem	Solution	Location or example
G1	Culvert blockage.	CCTV long culverted watercourses and identify connectivity. May require Scottish Water involvement.	
G2	Unauthorised access to high risk inlets / structures.	Signage to be added to all screens/culverts/structures with H.C. contact details to ensure direct link to emergency or operation teams to clear structures. Intermittent maintenance / checking of signage.	
G3	Lack of sufficient lead time to respond to increased flow and screen blockage.	Extension of Hydro-Logic Telemetry to all high risk screens and structures to identify rising levels at structures and improved screen/culvert clearance during high flows. Costs associated with telemetry installation and maintenance.	
G4	Riparian debris / waste in channel.	Education on littering and fly tipping to the community and riparian owners. Needs to be ongoing rather than once off.	

Ref	Problem	Solution	Location or example
G5	Poor bank conditions.	Education to riparian owners on their responsibilities for bank maintenance. Needs to be ongoing rather than once off.	
G6	Insufficient screen and structure inspection frequencies or emergency response planning.	Determine a screen and culvert inspection and maintenance regime for the watercourses. It is recommended that a more frequent inspection and clearance rota is required and that this should be determined on a risk based assessment of the watercourse crossings. May increase operational expenditure for the Council.	
G7	Poor emergency and maintenance access to watercourses.	Review land ownership and assess arrangements for watercourses in the area and remove boundary fences where possible to improve access for maintenance or emergency work purposes.	
G8	Lack of sufficient buffer / floodplain between watercourse and housing developments.	Review planning requirements for new developments that are adjacent to watercourses in the area and retain a buffer either side of watercourses to allow channel and bank maintenance and Council access to all watercourse reaches.	
G9	Poor drainage capacity and overtopping of SUDS	Review SUDS and drainage in new development area of Smithton Burn. Increase attenuation and sediment traps.	
G10	Recorded manhole surcharging.	Review surface water and sewer capacity. Consider capacity and options for removal or upgrades. Requires Scottish Water involvement.	
G11	Unauthorised burn crossing structures.	Prevent riparian channel modification and bridge and weir building. SEPA requirement via CAR licensing.	
G12	Uncertain hydrology for design purpose.	It is recommended that some flow and rainfall data is recorded locally prior to any design works to improve the hydrological assessments.	
G13	Poor lead time between rainfall and flood on small catchments.	Procedures and warning to anticipate high rainfall and send operations teams out on standby to deal with flooding at known high risk locations.	
G14	Properties at risk from overland flows.	Consider options for the provision of air brick covers, door guards and other property protection measures. Provision of grants or subsidised purchase schemes may also be beneficial.	

11.2.2 Culloden Burn West measures

A plan showing the location of the measures is provided in Figure 15 in the Figures section of the report.

Ref.	Problem	Action	Location / photograph
CBW1	Woody debris movement downstream.	Provision of in-stream screen upstream of forestry track culvert. This will help to reduce woody debris movement downstream and enable trash material removal from channel where access is good. Proactive and regular maintenance regime required.	
CBW1a	Sudden release of woody debris held back by water gates.	Remove water gates. Consider screen on upstream side of forestry track bridge. Remove water gate on property boundary fence.	

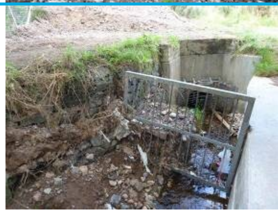
Ref.	Problem	Action	Location / photograph
CBW2	Poor capacity culvert prone to and vulnerable to blockage.	Remove culvert beneath garden of [redacted] Redburn Avenue. This will improve channel capacity and eliminate blockage and overland flow risks from this culvert. Reduction in property flat ground, but gain watercourse and environmental benefits. There is a need to understand the impact of this measure more fully before this can be taken forward.	
CBW3	Poor access for maintenance and storage of debris.	Improve screen to current design standards and maintenance access to culvert inlet on Ferntower Avenue. Provide area to store material removed from culvert. This will help to reduce blockage risk and overtopping risks. Provision of debris storage area. Proactive and regular maintenance regime required.	
CBW4	Possible risk of sediment mobilisation to screen downstream.	Consider maintenance to channel to improve access and reduce blockage risks to downstream culvert. Intermittent maintenance regime required.	
CBW5	Unsafe for screen clearance and lack of suitable area for debris storage.	Check screen capacity and improve screen to current design standards. Improve maintenance access to screen. This will help to reduce culvert blockage risks. Provision of debris storage area. Proactive and regular maintenance regime required.	
CBW6	Addition of woody debris to channel downstream.	Forestry maintenance to remove brash material deposited on floodplain that could enter channel and increase material available for screen blockage. Long term maintenance and education required.	
CBW7	Risk of sudden sediment and material mobilisation during high flows.	Formalise debris dams in forestry reach to reduce sediment and debris movement. Long term maintenance required.	
CBW8	Risk of gabion failure and channel blockage.	Repair gabion basket and scour on Keppoch Road to mitigate failure and channel blockage.	
CBW9	Reported flooding on Galloway Drive	Investigate sewer flooding to Galloway Drive.	No photo available. Reported in questionnaire.
CBW10	Under capacity culvert	Increase capacity of Culloden Walkway culvert	

Ref.	Problem	Action	Location / photograph
CBW11	Under capacity footbridge	Remove or raise footbridge	

11.2.3 Smithton Burn

A plan showing the location of the measures is provided in Figure 16 in the Figures section of the report.

Ref.	Problem	Action	Location / photograph
S1	Reduction in channel capacity. Increased risk of channel blockage.	Bank and channel vegetation management to maintain channel capacity in reach upstream of Woodside Farm Drive culvert. Ongoing maintenance requirements.	
S2	Source of bank instability and bank erosion / sediment mobilisation.	Repair banks upstream of culvert beneath Woodside Farm Drive. This occurred between the 7 September and the 14 October.	
S3	Source of bank instability and bank erosion / sediment mobilisation.	Stabilise banks in reach adjacent to Woodside Court. The aim of this is to reduce bank failure and further erosion and along this reach and to reduce the risk of further erosion and culvert blockage downstream. Riparian owner responsible for works and to apply for CAR	
S4	Poor emergency and maintenance access to watercourses.	Improve maintenance access to channel adjacent to Woodside Court (via Woodside Farm Drive, Woodside Place and Westfield Lane).	
S5	Source of bank instability and bank erosion / sediment mobilisation.	Emergency works to stabilise erosion in the garden of No. [redacted] Woodside Court to prevent further erosion and culvert blockage downstream.	
S6	High risk of culvert blockage due to unstable channel upstream. Poor access arrangements for clearance during floods.	Consider culvert screen and access for maintenance to culvert inlet upstream of Woodside Village. Long term inspection and maintenance requirements.	
S7	Risk of headwall failure.	Improve erosion protection to SUDS headwall upstream of Tower Road.	

Ref.	Problem	Action	Location / photograph
S8	Risk of failure and culvert blockage.	Remove surplus gravel on access track and stabilise toe of track upstream of Tower Road culvert, to prevent erosion and the addition of debris into channel.	
S9	Unstable channel and sediment mobilisation during high flows.	Consider gravel trap and further channel designs to stabilise gravel in the reach between Tower Road and the Railway. Some works have already been undertaken, but further stabilisation is required. Improved access to burn also required for further inspection and maintenance.	
S10	High probability of culvert blockage and major consequences if overtopping occurs.	Deculvert and design new reach from railway to Murray Road adjacent to Murray Terrace. Remove screens and gabion baskets and stabilise channel and banks. This would negate the need for a short term alternative for a trash screen on the culvert inlet. Assessment of hydromorphological impact to sediment movement required. Also need to remove extracted sediment currently lying next to burn. Landscaping to help retain or divert flows away from properties.	
S11	Poor access for maintenance and storage of debris.	Improve Murray Road entry screen to culvert to current design guidance and improved access to screen for maintenance aspects.	
S12	High risk of culvert and screen blockage.	In-channel screen upstream of Murray Road culvert inlet and allowance for maintenance access to channel and screen. This would help to reduce the blockage of the main screen.	
S13	Bottom end of culvert is approximately 50% blocked.	CCTV culvert in first instance to determine blockage of culvert. Deculvert between Murray Road and Murray Terrace. Hydromorphological impact to sediment movement required.	
S14	Poor capacity of many structures crossing burn.	Remove or improve crossings in gardens of Murray Place [redacted] Complicated access and crossings for riparian owners.	
S15	Complicated sewer / burn interaction.	Investigate drainage system further. Consider pumps or improved drainage. Check flood levels/drainage in Smithton Villas. CCTV culvert upstream to determine if root ingress and connection to sewer system. Assistance from Scottish Water essential.	
S16	Wall surrounding garage off Barn Church Road was built by land owner and is not a designed flood wall.	Check and maintain flood wall surrounding garage off Barn Church Road.	

Ref.	Problem	Action	Location / photograph
S17	Sensitive to blockage and poor access arrangements during flood. Overtopping would flood main road.	Consider removal of twin culvert adjacent to Barn Church Road or improved safe access for maintenance.	
S18	Sensitive to blockage and poor access arrangements during flood. Overtopping would flood main road.	Consider improved safe access for maintenance of culvert inlet upstream of Barn Church Road culvert.	

11.3 Relative costs, urgency and responsibilities for measures

An indicative assessment of the relative costs and urgency for the above measures is proposed in the following sections.

11.3.1 Generic measures

Ref.	Action	Relative capital cost	Relative operational cost	Risk / Urgency	Respon-sibility
G1	CCTV culverts and upgrades.	High	Low	High	HC
G2	Signage to all screens / culverts / structures.	Low	Low	High	HC
G3	Extension of Hydro-Logic Telemetry to high risk screens.	Medium	Medium	Medium	HC
G4	Education on littering and fly tipping.	Low	Low	Medium	HC / SEPA
G5	Education on owners responsibilities for bank maintenance.	Low	Low	Medium	HC / SEPA
G6	Determine a screen and culvert inspection and maintenance regime for the watercourses.	Low	High	High	HC
G7	Review access and remove boundary fences to improve maintenance or emergency work access.	Low	Low	Medium	HC / third party
G8	Review planning requirements.	Low	Low	High	HC
G9	Review SUDS and drainage capacity and upgrade if necessary.	High	Low	High	HC / vested third party
G10	Review surface water and sewer capacity and upgrade if necessary.	High	Low	High	HC / SW
G11	Prevent riparian channel modification.	Low	Low	Medium	HC / SEPA
G12	Installation of flow and rainfall recorders locally to improve future hydrological assessments.	Low	Low	High	HC / SEPA
G13	Procedures and warning of high rainfall events.	Low	Medium	High	HC / SEPA
Note. HC - Highland Council, RO - Riparian Owner, SW - Scottish Water					

11.3.2 Culloden Burn West measures

The measures below are ranked by risk/priority and colour coded in Figure 15 in the Figures section of this report. The following risk categories are given:

- Red: Under capacity culverts / inefficient designs that require urgent investment or are complex and likely to require further investigation.
- Medium: Under capacity culverts / inefficient designs that are less urgent or are relatively easy actions to ameliorate.
- Low: Structures/actions that are suggested but are low risk and non urgent, can be incorporated into Council maintenance regimes or are low cost and easy to implement.

Ref.	Action	Relative capital cost	Relative operational cost	Risk / Urgency	Respon-sibility
CBW1	Provision of gravel trap and in-stream screen upstream of forestry track culvert.	Medium	Medium	Medium	HC
CBW1a	Remove water gates.	Low	Low	Medium	HC / RO
CBW2	Remove culvert beneath garden of [redacted] Redburn Avenue.	High	Low	High	HC
CBW3	Improve screen and maintenance access to culvert inlet on Ferntower Avenue. Implement inspection and clearance regime.	Medium	High	Medium	HC
CBW4	Channel maintenance in reach downstream of Ferntower Avenue.	Low	Low	Low	HC
CBW5	Improve screen and maintenance access upstream of Culloden Centre. Implement inspection and clearance regime.	Medium	High	Medium	HC
CBW6	Remove brash material in forestry reach.	Low	Medium	Medium	HC / Forestry
CBW7	Formalise debris dams in forestry reach.	Low	Low	Medium	HC / Forestry
CBW8	Repair gabion basket and scour on Keppoch Road.	Medium	Low	Low	HC
CBW9	Investigate sewer flooding to Galloway Drive.	High	Low	Medium	HC / SW
CBW10	Increase capacity of Culloden Walkway culvert	Medium	Low	Medium	HC
CBW11	Remove or raise footbridge	Medium	Low	Medium	HC
Note. HC - Highland Council, RO - Riparian Owner, SW - Scottish Water					

11.3.3 Smithton Burn measures

The measures below are ranked by risk/priority and colour coded in Figure 16 in the Figures section of this report. The following risk categories are given:

- Red: Under capacity culverts / inefficient designs that require urgent investment or are complex and likely to require further investigation.
- Medium: Under capacity culverts / inefficient designs that are less urgent or are relatively easy actions to ameliorate.
- Low: Structures/actions that are suggested but are low risk and non urgent, can be incorporated into Council maintenance regimes or are low cost and easy to implement.

Ref.	Action	Relative capital cost	Relative operational cost	Risk / Urgency	Respon-sibility
S1	Bank and channel vegetation removal upstream of Woodside Farm Drive culvert.	Low	Medium	Low	HC / RO
S2	Repair banks upstream of culvert beneath Woodside Farm Drive.	Medium	Low	Medium	HC / RO
S3	Stabilise banks in reach adjacent to Woodside Court.	Medium	Low	Medium	HC / RO
S4	Improve maintenance access to channel adjacent to Woodside Court. Remove boundary fences and fences/water gates crossing channel.	Medium	Low	Medium	HC / RO
S5	Emergency works to stabilise erosion in the garden of [redacted] Woodside Court.	High	Low	High	HC / RO
S6	Consider culvert screen and access for maintenance to culvert inlet upstream of Woodside Village.	Medium	Medium	Medium	HC / RO
S7	Improve erosion protection to SUDS headwall upstream of Tower Road.	Medium	Low	Medium	SUDS owner
S8	Stabilise access track upstream of Tower Road culvert.	Medium	Low	Medium	HC
S9	Consider gravel trap and further channel designs to stabilise gravel in the reach between Tower Road and the Railway.	Medium	Medium	High	HC
S10	Deculvert and design new reach from railway to Murray Road adjacent to Murray Terrace.	High	Low	High	HC / RO
S11	Improve Murray Road entry screen to culvert.	Medium	High	High	HC / RO
S12	In-channel screen upstream of Murray Road culvert inlet.	Medium	High	High	HC / RO
S13	Deculvert between Murray Road and Murray Terrace.	High	Low	High	HC
S14	Remove or improve crossings in gardens of Murray Place [redacted]	Medium	Low	Low	HC / RO
S15	Consider pumps or improved drainage and check flood levels/drainage in Smithton Villas.	High	Medium	High	HC
S16	Check and maintain flood wall surrounding garage off Barn Church Road.	Low	Low	Low	HC
S17	Consider removal of twin culvert adjacent to Barn Church Road or improved safe access for maintenance.	High	Low	Low	HC
S18	Consider improved safe access for maintenance of culvert inlet upstream of Barn Church Road culvert and implement inspection and clearance regime.	Medium	Medium	Low	HC
Note. HC - Highland Council, RO - Riparian Owner, SW - Scottish Water					

11.4 Flood warning and forecasting

Flood warning and forecasting are an important element of an holistic approach to the reduction in tangible and intangible damage due to flooding. Whilst the tangible economic reduction in damages as a result of flood warning is small[19] the reduction in potential loss of life and health and social impacts is significant.

[19] Estimated to the approximately 5%. Penning-Rowsell et. al. (2005). The benefits of flood and coastal risk

SEPA is responsible for the provision of flood warnings and forecasting in Scotland. SEPA has set up a new direct flood warning service that the communities at risk in this area should be encouraged to sign up to. Although both Flood Alert and Flood Warnings are provided across Scotland, Culloden and Smithton are only covered by Flood Alerts issued against geographical areas, in the case of Highland this matches the local authority boundary.

Warnings are only provided where SEPA can accurately predict the timing and location of local flooding. This is based on analysis of historical flooding information defined alarm levels for local monitoring stations on rivers and coastal areas across Scotland. A defined flood warning target area has not been defined for the areas to the east of Inverness. Currently, insufficient gauging or technology is available to provide sufficient accuracy for targeted Flood Warning messages for properties located in this area.

The Scottish Flood Forecasting Service provides additional information to Highland Council to help plan and respond to flooding. This includes a daily Flood Guidance Statement that provides Highland Council with an assessment of the risk of flooding for the next five days from rivers, coastal and tidal areas and also surface water.

Although the area is covered by flood alert warning, improvements in flood warnings are required to increase the lead time and accuracy of warnings for this area. Due to the size of the catchment areas and the lack of sufficiently accurate rainfall radar, the ability of flood forecasting models to provide the necessary lead times is unlikely to be available in the short or medium term. We therefore make the following recommendations:

1. Improved signup of homeowners at risk to the SEPA flood alerts and maintaining this. It is suggested that this is taken forward by SEPA with assistance from the Scottish Flood Forum (SFF).
2. Public access to the Council telemetry gauges and warning messages sent to SFF flood groups/flood wardens (if set up) for further dissemination.
3. Consideration of the provision of connection of the Hydro-Logic telemetry into SEPA and the use of this for targeted flood warnings. Historical or predicted flood mapping would be needed to set target areas. Collaboration with SEPA (Mike Cranston) recommended to take this forward.
4. Longer term use of rainfall depth-duration look-up tables to provide more targeted warning of flood warning based on predicted rainfall. This is currently being undertaken by SEPA, but may not be applicable for this area due to the lack of suitably accurate rainfall radar data.
5. Consideration of gauged flows or rainfall together with warning sirens for communities at risk. Consideration should also be given to upgrading the daily rainfall recorder at Culloden to a 15 min tipping bucket rain-gauge.
6. Consideration of the use of existing gauging stations on the Holm Burn and Inverness diversion channel for more localised warnings to donor catchments.

11.5 Asset management and inspection

Asset Management enables business with physical assets to achieve their stated business goals in the most cost effective and economical way. It combines engineering and mathematical analyses with sound business practice and economic theory. When a business is reliant upon assets the more vital the reliability, availability, maintenance and safety of those assets is to its performance. The rationale for the adoption of asset management is based on optimising operational and capital expenditures and the standardisation of processes and competences.

The optimisation of the life of physical assets is vital for organisations relying on such assets to deliver its strategic policies and goals. There is currently a publicly available specification, PAS 55[20], first drafted in 2004 and updated in 2008, which provides thorough guidance on Asset Management Plans and the associated structure, information and management that should accompany such a plan.

management: A manual of assessment techniques.

[20] Publicly Available Specification 55-1:2008. Asset Management. Part 1: Specification for the optimised management of physical assets. British Standards Institution.

Asset management is often defined as the optimised management of physical assets, which enables the delivery of strategic objectives through managing assets over their whole life cycles. This can include the creation of assets, how best to operate and maintain them, and the adoption of optimal renewal or disposal of assets.

Asset management and risk based prioritisation of resources can help with the management of watercourses, flood defence assets and other watercourse structures and can provide the following benefits:

- Assurance that the reliance on watercourse assets can achieve wider policies & organisational objectives and deliver quality service to communities,
- Ensure long term watercourse asset reliability, availability, maintenance and operative safety,
- Help secure long-term funding / resources to manage watercourse assets,
- Demonstration of the economic and effective use of funds, and
- Ability to reduce resources without detriment to asset stewardship or an increase in overall organisational risk.

11.5.1 Recommendations for inspection and maintenance regime

A complete understanding of the number, condition and impact of asset failure can help to reduce flood risk in the long term. This report helps to identify the causes of the recent flooding and the wider responsibilities in terms of watercourse and asset maintenance. However in order to ensure that culverts and structures remain fit for purpose a risk based maintenance regime is recommended.

A typical risk based maintenance regime would consider both the probability and consequence of insufficient inspection, maintenance and clearance of screens and blockage prone structures. The aim is to ensure that a sufficient frequency of inspection is in place to ensure structures are clear, with those more prone to blockage or with a higher consequence of overtopping to be inspected more frequently than those less likely to block or if overtopped would not cause any flood damage.

The probability could be based on the factors considered in Section 8.3 of this report. The consequence would need to be based on the number of properties at risk (based on overland flow modelling or local knowledge for example). A simple ranking approach as shown below and used by the Environment Agency demonstrates the range in inspection frequency for assets based on probability and frequency.

Figure 11-1: Example inspection frequencies for assets

Inspection frequency in months

Consequence of failure within the reach	Low	Medium	High
High	24	12	6
Medium	36	24	6
Low	60	36	18

Probability of failure within the reach

Source: Environment Agency

It should be noted that the matrix above is used for flood defence assets; high risk screens may need a much higher frequency of inspection, particularly during autumn and winter flows. In some instances the use of weekly inspections prior to and during periods of heavy or forecast rainfall may be a more appropriate option. The use of telemetry may help to reduce staff revenue or operational expenditures for high risk or frequently visited locations.