Appendices

A Summary of Biennial Report information relating to burns

A.1 Biennial Report No. 3, November 2001 - Minor Flood Prevention Measures

A.1.1 Murray Terrace, Smithton, Inverness

Primary and secondary culvert screens with alterations to the access are proposed to Smithton Burn.

A.1.2 Murray Road, Smithton, Inverness

Primary and secondary culvert screens with alterations to the access are proposed to Smithton Burn.

A.1.3 Ferntower Avenue, Culloden, Inverness

Tree felling operations have increased the flood risk, this coupled with the ongoing construction of an adjacent housing development prompted a watercourse assessment to be undertaken, Culloden North Burn is to be cleared and culvert dimensions surveyed, prior to the installation of primary and secondary culvert screens.

A.1.4 Redburn Avenue/Forestry Road, Culloden, Inverness

Primary and secondary screens to Culloden Burn are proposed.

A.1.5 Keppoch Road, Culloden, Inverness

On Culloden Burn and Culloden Burn North, there are two box culverts, around 50 tonnes of deposited material is required to be removed and disposed of, primary screens are then proposed for the culverts. The watercourse channel also required to be regraded.

A.2 Biennial Report No. 4, November 2003 - Major Flood Prevention Schemes

Details of work in Smithton, Culloden and Balloch.

A.3 Biennial Report No. 4, November 2003 - Minor Flood Prevention Measures

Inverness TEC Services are pursuing a programme of regular waterway inspections aimed at establishing a suitable schedule of regular maintenance. There is significant association with consultants, Scottish Water, SEPA and the Forestry Commission in seeking to resolve flooding problems.

A.4 Biennial Report No. 4, November 2003 - Minor Reported Works Relating to Flooding

A.4.6 Smithton Burn

A temporary screen has been installed at the top of Murray Terrace but there have been no further screen modifications since the last report. A CCTV survey has been carried out on all significant lengths of culvert in this watercourse to check for detritus/blockages and broken pipes or illegal connections. A manhole has been constructed over the culvert in the middle of the Smithton playing fields, to enable removal of large obstruction and facilitate future maintenance. Culverts haven been jet cleaned as required.

Funding has been committed to implementing a solution to a problem at Loch Lann Avenue, in co-operation with the Forestry Commission.

Improvements to the road drainage system on Caulifield Road North at Sinclair Terrace are being monitored and further changes will be investigated.

Work to counteract overflow into a house garden from uphill ground including a car park at Culloden has been only partially successful, and further investigation is proceeding in association with Housing Service.

A.4.7 Culloden Burn

In co-operation with the Forestry Commission and Barratt Construction Ltd an open channel has been excavated on a tributary watercourse to divert water away from a sub-standard pipeline and alleviate a flooding problem at Redburn Avenue.

The Forestry Commission has constructed a debris trap on the main burn upstream of Redburn Avenue, and detritus has been removed from the burn with garden grounds to improve and maintain channel capacity. Consultant surveyors have completed a detailed survey of the burn at this location, and measures will be investigated to control scour and bank erosion. A primary screen has been positioned at Ferntower Avenue.

Culverts have been CCTV surveyed and jet cleaned as necessary. Additional manholes have been constructed as required. Open channel improvements have been completed where necessary.

A.5 Biennial Report No. 5, November 2005 - Major Flood Prevention Schemes

Details of work in Smithton, Culloden and Balloch.

A.6 Biennial Report No. 5, November 2005 - Minor Flood Prevention Measures

During the summer of 2005, Inverness TECS carried out inspections of all urban watercourses in the area and for the first time a comprehensive record of this was created. A numbering system was established and details of potential problems were noted. Using this information a revised formal inspection regime is currently being set up.

A.7 Biennial Report No. 6, November 2007 - Minor Flood Prevention Measures

Inverness TECS carried out annual inspections of all urban watercourses in the area and maintained/updated the comprehensive photographic record.

Maintenance of ditches and debris screens, or a straightforward Council response to reported blocked gullies and/or gully connections are excluded from the record in the Inverness area.

A.8 Biennial Report No. 7, November 2009

Watercourse Reference Schedule Example – notes Smithton Burn and Culloden Burn West as having priority rating of 3.

B Watercourse crossing register

B.1 Culloden Burn West

Name: Railway Bridge	
 *Upstream face of bridge*	**Description**: Single span arch bridge Network Rail Line Reference Number: HGL2 Network Rail Structure Number: 290/332 **OS NGR**: NH **Opening area**: Not assessed but estimated to be at least 10m^2. **Screen?**: No **Blockage Risk**: Low **Access**: In steep channel. Access by foot possible from forestry track on U/S side of bridge. Maintenance: **Other**: Bed rock upstream, concrete scour protection visible. Large boulders and debris located within U/S and D/S of structure.

Name: Railway Culvert (tributary of Culloden Burn West)	
 *Upstream face of culvert*	**Description**: Double circular steel culvert beneath railway Network Rail Line Reference Number: HGL2 Network Rail Structure Number: 290/333 **OS NGR**: NH **Opening area**: Not surveyed **Screen?**: Yes – full height screen. **Blockage Risk**: Medium **Access**: Railway access only. Maintenance: Network Rail responsibility. **Other**: Trash built up on screen.

Name: Forestry Track Bridge

Upstream face of bridge

Description: Single span concrete bridge
OS NGR: NH
Opening area: 3.18 m^2
Screen?: Swinging gate on downstream side
Blockage Risk: Medium
Access: Access from forestry track and forestry car park to the west off Tower Road.
Maintenance: Maintenance during flooding is difficult and complicated by water gate on downstream side.
Other: Gate was moved from upstream side to downstream side after 2002 floods.

Name: Third party boundary fence and water gate

Upstream face of bridge

Description: Property boundary fence
OS NGR: NH
Opening area: 5.10 m^2
Screen?: Water gate, but clearance is relatively low.
Blockage Risk: Medium
Access: Access through gardens off Redburn Avenue
Maintenance: Steep sided grassy banks constrained on upstream side by sheds. Potentially high risk for maintenance during flood.
Other:

Name: Culvert beneath garden of [redacted] Redburn Avenue

Upstream face of culvert

Description: Circular concrete culvert - 1040mm diameter
OS NGR: NH
Opening area: 0.85 m^2
Screen?: Yes
Blockage Risk: High
Access: Access through gardens off Redburn Avenue
Maintenance: Garden access bridge over culvert restricts maintenance. Potentially high risk for maintenance during flood.
Other: Screen replaced after 2009.

Name: Culvert beneath Ferntower Avenue, Barnview and main road	
 ***Upstream face of culvert***	**Description**: Circular concrete culvert - 1050mm diameter **OS NGR**: NH **Opening area**: 0.87 m^2 **Screen?**: Yes – half height screen **Blockage Risk**: Medium **Access**: Restricted. No vehicular access. Access over fence. Burn fenced in either side. Maintenance: Difficult to maintain. Poor access. Nowhere to place material once removed from screen. **Other**: Screen completely blocked during July flood and acting as a weir – water below top of headwall. Culvert shape is different at downstream end suggesting culverts abutted to each other. Potential for internal blockage.

Name: Culloden walkway culvert	
 ***Upstream face of culvert***	**Description**: Circular concrete culvert - 1050mm diameter **OS NGR**: NH **Opening area**: 0.87 m^2 **Screen?**: No **Blockage Risk**: Medium – due to pipe crossing upstream. **Access**: Unrestricted access via walkway. Maintenance: Open access but no safety or areas to store material once removed. **Other**: Relatively short section of channel upstream. Maintenance of channel and bank upstream could reduce blockage at this culvert.

Name: Culloden Centre Culvert	
 ***Upstream face of culvert***	**Description**: Circular concrete culvert - 1400mm diameter **OS NGR**: NH **Opening area**: 1.54 m^2 **Screen?**: Yes – fine square mesh **Blockage Risk**: High **Access**: Unrestricted access from Culloden Centre. Maintenance: Easy access, but loose ground surrounding inlet and screen. Safety of operatives for screen clearance during flood conditions could be improved due to lack of appropriate working positions, handrails and harness points. **Other**:

Name: Footbridge upstream of Culloden Recreation Ground	
 ***Downstream face of culvert***	**Description**: Wooden foot bridge **OS NGR**: NH **Opening area**: 2.70 m^2 **Screen?**: No **Blockage Risk**: Low **Access**: Access via Keppoch Road. Maintenance: Access to channel is difficult and banks overgrown. **Other**:

Name: Culvert beneath Keppoch Road	
 ***Upstream face of culvert***  Gravel bed through culvert	**Description**: Rectangular concrete culvert **OS NGR**: NH **Opening area**: Not surveyed **Screen?**: No. **Blockage Risk**: Low **Access**: Access from Keppoch Road Maintenance: **Other**: A small weir is located upstream. The culvert has a gravel bed to an approximate depth of 100mm and a gravel bar throughout the culvert.

B.2 Smithton Burn

Name: Culvert beneath Heights of Woodside

Upstream ***face of culvert***

Description: Circular concrete culvert - 800mm diameter
OS NGR: NH
Opening area: 0.50 m^2
Screen?: No
Blockage Risk: Low
Access: Access from Heights of Woodside
Maintenance: Maintenance access is good. Safety of operatives could be improved.
Other: Channel heavily overgrown upstream.

Name: Culvert beneath Woodside Farm Drive

Channel upstream of culvert

Upstream face of culvert

Description: Circular concrete culvert - 1050mm diameter
OS NGR: NH
Opening area: 0.87 m^2
Screen?: No
Blockage Risk: Low
Access: Access from Woodside Farm Drive
Maintenance: Maintenance access is good. Safety of operatives could be improved.
Other: Channel heavily overgrown upstream.

Name: Boundary fence restricting access to burn

Upstream face of fence

Description: Boundary fence
OS NGR: NH
Opening area: 1.18 m^2
Screen?: No
Blockage Risk: Medium
Access: Access to upstream side possible adjacent SUDS pond off Woodside Farm Drive
Maintenance: Maintenance during flood conditions is not possible due to unsafe and restricted access.
Other:

Name: Property decking extending over burn

Upstream face of decking "bridge"

Description: Patio decking over river
OS NGR: NH
Opening area: Not surveyed
Screen?: No
Blockage Risk: Medium
Access: No access other than via channel during low flow conditions (via Westfield Lane).
Maintenance: Access during flood conditions via riparian properties only. Maintenance during flood conditions is not possible due to restricted access.
Other: Banks and gabion baskets beneath decking are in poor condition and eroding due to lack of bank vegetation.
Banks upstream have been lined with rock to stabilise channel.
Not surveyed or modelled

Name: Property decking extending over burn

Upstream face of decking "bridge"

Description: Patio decking over river
OS NGR: NH
Opening area: Not surveyed
Screen?: No
Blockage Risk: Medium
Access: No access other than via channel during low flow conditions (via Westfield Lane). Maintenance during flood conditions is not possible due to restricted access.
Maintenance: Access during flood conditions via riparian properties only.
Other:
Not surveyed or modelled

Name: Property boundary fence

Downstream face of fence

Description: Boundary fence with water gate
OS NGR: NH
Opening area: Not surveyed
Screen?: No
Blockage Risk: Medium
Access: Access via garden of No. [redacted] Woodside Court
Maintenance: Access to downstream side available. Access to upstream side is restricted as channel is fenced in behind property boundary fences.
Other: The recent floods did not remove or wash away the water gate suggesting that very little material or debris was washed down the channel to this point.
Not surveyed or modelled

Name: Property boundary fence

Upstream face of fence

Description: Property access bridge over channel
OS NGR: NH
Opening area: 1.48 m^2
Screen?: No
Blockage Risk: Low
Access: Access via garden of No. [redacted] Woodside Court
Maintenance:
Other:

Name: Culvert beneath ?? and Woodside Farm Drive

Upstream face of culvert

Description: Circular concrete culvert - 1050mm diameter
OS NGR: NH
Opening area: 0.87 m^2
Screen?: No
Blockage Risk: Medium
Access: Access from Woodside Village
Maintenance: Culvert inlet is fenced off. Difficult to access inlet. Maintenance during flood conditions is difficult due to restricted access and lack of appropriate working positions handrails and harness points.
Other: Channel bed upstream is highly mobile and eroding providing substantial debris and material that could block culvert inlet.

Name: Culvert beneath Tower Road	
 ***Upstream face of culvert***	**Description**: Circular concrete culvert - 1500mm diameter **OS NGR**: NH **Opening area**: 1.77 m^2 **Screen?**: No **Blockage Risk**: Medium **Access**: Difficult access from Woodside Farm Drive. Maintenance: Situated in steep channel. Maintenance during flood conditions is difficult due to restricted access and lack of appropriate working positions handrails and harness points. **Other**: A temporary access track from Woodside Farm Drive to the right side of the burn has been provided for post flood works/maintenance. This material is at risk of being undermined and causing further channel/culvert blockage. Works to protect the toe of this slope are recommended.

Name: Railway culvert	
 ***Upstream face of culvert***	**Description**: Single span stone arch bridge Network Rail Line Reference Number: HGL2 Network Rail Structure Number: 290/334 **OS NGR**: NH **Opening area**: 4.38 m^2 **Screen?**: No **Blockage Risk**: Low **Access**: Access from Woodlands Park. Maintenance: Maintenance during flood conditions is restricted by railway and uncontained channel upstream. **Other**: Significant sediment accretion and deposition witnessed before and after recent floods. Significant bed load is available in reach upstream. Post flood works have taken place in reach upstream to create boulder dams to limit gravel movement.

Name: Culvert beneath high ground adjacent to Murray Terrace

Downstream face of culvert

Description: Circular concrete culvert - 900mm diameter
OS NGR: NH
Opening area: 0.64 m^2
Screen?: Yes No. 2: fine square mesh located 2m upstream and further screen over inlet.
Blockage Risk: High
Access: Access from Murray Terrace [redacted]
Maintenance: Maintenance is unsafe during flood conditions due to lack of appropriate screens, handrails and harness points.
Other: In-channel gabion protection on left bank reduces channel capacity. Initial screen is at the height of the headwall which if completely blocked could lead to bypassing flows.
Material removed from the channel during the recent floods has been piled up on the left bank and is at risk of mobilisation/re-entering the river.

Name: Footbridge in grounds of burnt out retirement home

Upstream face of bridge

Description: Concrete bridge with metal railings
OS NGR: NH
Opening area: 2.22 m^2
Screen?: No
Blockage Risk: Low
Access: Access via burnt out old people's home off Murray Road.
Maintenance:
Other: Channel is heavily overgrown upstream and downstream of channel.

Name: Culvert beneath Murray Road

Upstream culvert inlet and channel

Description: Circular concrete culvert - 900mm diameter
OS NGR: NH
Opening area: 0.64 m^2
Screen?: Yes – fine square mesh in poor condition.
Blockage Risk: Culvert is currently blocked by 50% at downstream end. High blockage risk.
Access: Access from Murray Road.
Maintenance: Restricted access over fence. Heavily overgrown channel upstream. Screen slopes towards the culvert inlet at the base making screen clearance during flood conditions difficult and unsafe.
Other: Screen is in poor condition.

Name: Numerous property boundary fences, bridges and culverts at rear of Murray Place

1037

1038

1039

Upstream faces of structures

Description: Various
OS NGR: NH
Opening area: As small as 0.41 m^2
Screen?: No
Blockage Risk: High
Access: Access from Murray Place
Maintenance: Maintenance during flood conditions is difficult due to restricted access.
Other: Numerous structures present. Key structures were surveyed and included within the model.

Name: Property fence on boundary of Murray Place

Downstream face of fence

Description: Property boundary fence
OS NGR: NH
Opening area: Not surveyed
Screen?: No
Blockage Risk: High
Access: Access from footpath between Smithton Road and Tower Road or via garden of No. [redacted] Murray Place.
Maintenance:
Other:
Not surveyed or modelled

Name: Footbridge on footpath leading to Forbes Plan

Downstream face of footbridge

Description: Single span footbridge
OS NGR: NH
Opening area: 4.34 m^2
Screen?: No
Blockage Risk: Low
Access: Access from footpath between Smithton Road and Tower Road.
Maintenance:
Other: Post flood bank reconstruction has taken place on the downstream left bank.
Pipe crossing located immediately upstream of bridge. Invert below bridge soffit.

Name: Footbridge at rear of Smithton Villas

Upstream face of footbridge

Description: Single span wooden footbridge
OS NGR: NH
Opening area: 1.79 m^2
Screen?: No
Blockage Risk: Low
Access: Access from footpath/rough ground behind Smithton Villas.
Maintenance:
Other: Bridge being replaced as part of new development off Tower Road.

Name: Culvert beneath access road

Upstream face of culvert

Description: Single span stone arch culvert
OS NGR: NH
Opening area: 2.19 m^2
Screen?: No
Blockage Risk: Medium
Access: Access from rough ground / footpath behind Smithton Villas.
Maintenance: Maintenance of the inlet is difficult due to pipe crossing upstream.
Other: A concrete block work headwall has been constructed on the upstream side. A pipe crosses the inlet that may accumulate debris during flood conditions.

Name: Culvert beneath garage on main road	
 ***Upstream face of culvert***	**Description**: Double corrugated metal culvert - 900mm diameter **OS NGR**: NH **Opening area**: 1.27 m^2 **Screen?**: No **Blockage Risk**: Medium **Access**: Access from Garage off Barn Church Road. Maintenance: Banks are overgrown. Access restricted by concrete wall. Material removed from channel cannot be stored locally, but is unlikely to re-enter the channel. **Other**: A small weir is located upstream of the inlet.

Name: Culvert beneath Barn Church Road leading to Culloden Burn West	
 ***Upstream face of culvert***	**Description**: Circular concrete culvert - 1200mm diameter **OS NGR**: NH **Opening area**: 1.13 m^2 **Screen?**: No **Blockage Risk**: Medium **Access**: Access from Barn Church Road Maintenance: Access to culvert opening is difficult. Banks are overgrown. Fence that restricts access is in poor condition. Material removed from channel cannot be stored locally. **Other**: Outlet joins Culloden Burn West culvert beneath Culloden Centre. A small weir is located upstream.

C Watercourse asset issues

A complete asset record for the two burns is provided here.

Table 12-1: Culloden Burn West

Action	Location (from downstream end of reach)	Flood impact / risk	Response
Sediment deposition through culvert	Keppoch Road Culvert	Reduced culvert capacity, although may have been designed for ecological reasons.	Check capacity.
Minor bank erosion (various)	Reach adjacent Keppoch Road	Further erosion/debris material	Continue to monitor and repair if erosions worsens.
Gabion basket undercutting and slippage into channel	Keppoch Road	Blockage risk	Continue to monitor or repair.
Erosion and deposition upstream of culvert	Upstream of Culloden Centre	Blockage risk	Continue to monitor and inspect.
Sediment deposition and in-channel vegetation	Upstream of Ferntower Avenue culvert	Reduced channel capacity	Continue to monitor and remove if this starts to impact on flood capacities.
Culvert headwall undercutting/scour	Culvert inlet in garden of [redacted] Redburn Avenue	Culvert failure	Repair or remove culvert.
Source of active and mobile sediment and debris	Woodland upstream of urban area	Blockage risk	Add additional screens and formalise debris dams.

Table 12-2: Smithton Burn

Action	Location	Flood impact / risk	Response
Some sediment deposition through culvert	Track off Smithton Road	Reduced culvert capacity	Continue to monitor and inspect.
Undercutting of footbridge sidewall	Behind Smithton Villas	Bridge failure	Continue to monitor and inspect.
Recent bank repair	Footbridge behind Smithton Villas	Possible risk of failure until bank/toe is stabilised by vegetation.	Continue to monitor and inspect.
Screen in poor condition and sloping towards invert at base.	Murray Road	Difficult to clear during flood conditions.	Replace screen.
Heavily overgrown channel	Upstream of Murray Road	Decrease in channel capacity	
Post flood debris stored on left bank.	Downstream of Railway Culvert	Possible re-entry into channel.	Remove debris and sediment.
Culvert inlet screen in poor condition	Downstream of Railway Culvert	Difficult to clear during flood conditions.	
Gabion basket and secondary screen	Downstream of Railway Culvert	Difficult to clear during flood conditions.	
Highly eroded bed and banks. Source of active and mobile sediment and debris.	Upstream of Railway Culvert	Blockage risk	
Access ramp to culvert inlet at risk of undercutting and	Upstream of Tower Road Culvert	Blockage risk	Stabilise toe of bank / access ramp.

Action	Location	Flood impact / risk	Response
failure			
Highly eroded bed and banks. Source of active and mobile sediment and debris	Upstream of Woodside Village	Blockage risk	
Bank erosion and failure beneath riparian property decking.	Behind Woodside Court	Blockage risk	
Heavily overgrown channel	Upstream of Woodside Farm Drive	Decrease in channel capacity	

D Watercourse condition and sediment erosion review

D. Channel Assessment

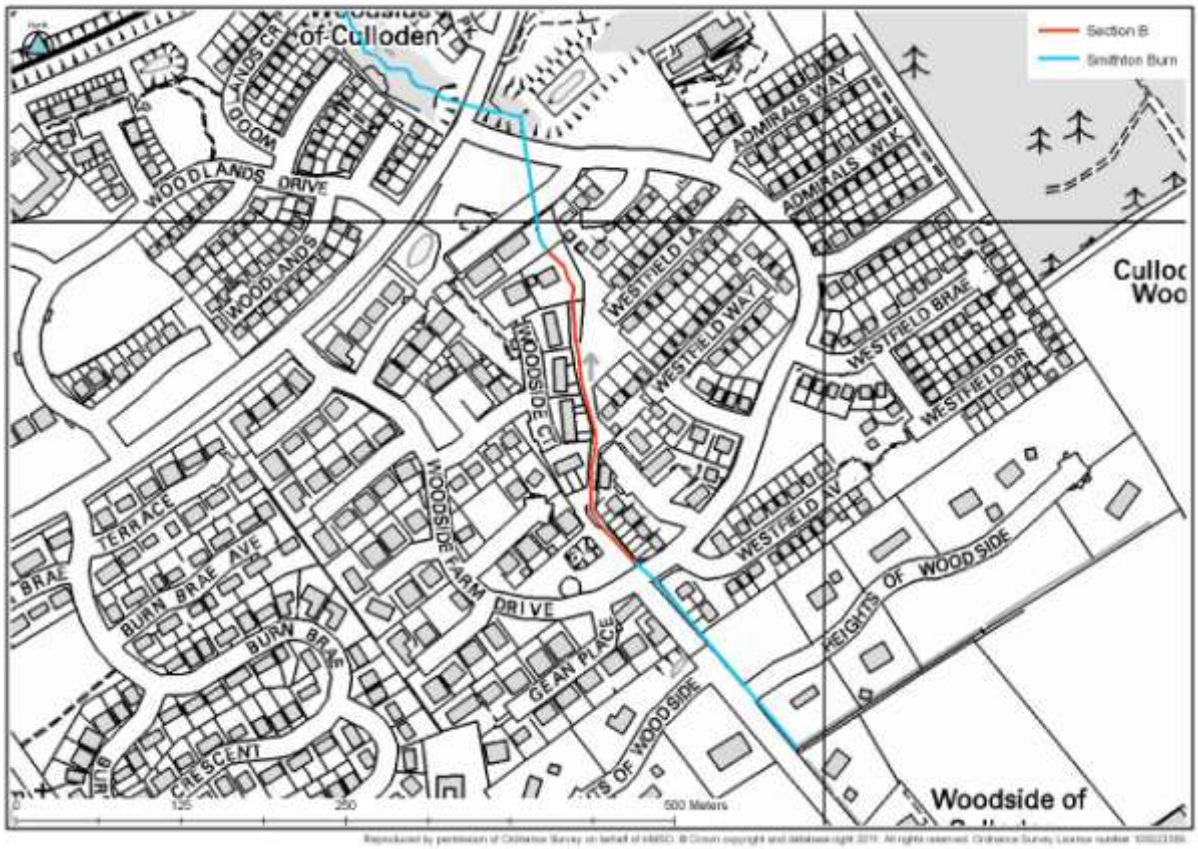
D.1 Smithton Burn

Section A

Nature of Channel
Channel narrow (0.3-0.5m wide), very straight and no natural valley.
Bed Material
Some sections of the bed are lined with stone pitching. Only small accumulations of sediment, which is mostly gravel sized.
Bank Material
Banks lined with stone pitching – this is very old and there are small isolated pockets of bank erosion where the pitching has failed.

Photographs

Section B



Nature of Channel

Narrow and deep with steep banks and obvious recent bed incision at the base of either bank – in some places this has resulted in full bank collapse. A step in bed level is formed by a logjam at approximately NH 71809 44920, with a large pool and severe bank erosion downstream of the jam.

The channel is confined by development, and there is evidence of modifications since the development was completed, including the construction of decking and bridges over the channel and ad-hoc reinforcement of the banks.

Bed Material

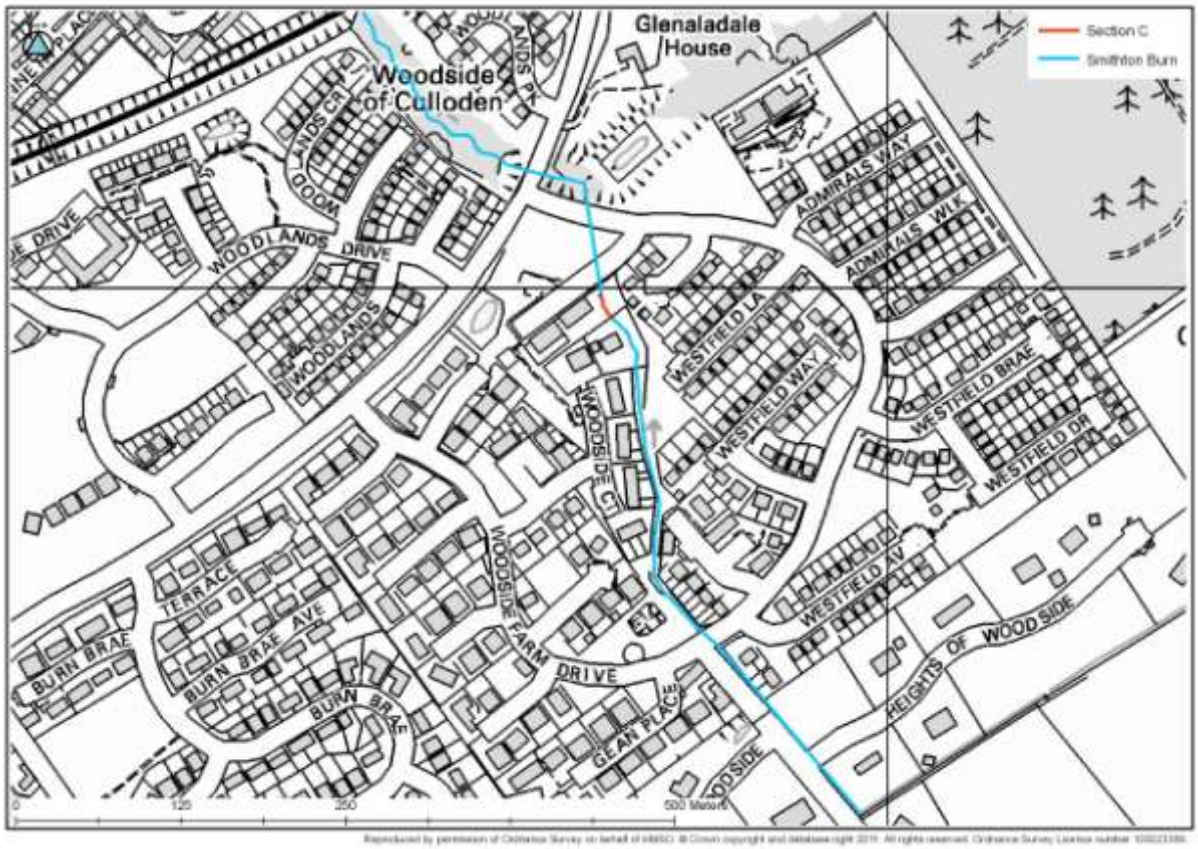
Poorly sorted sand, gravel, cobbles and small boulders.

Bank Material

Banks are a mixture of natural and reinforced sections. Undermining and subsequent failure of the banks is common. Reinforcement of some sections using rip-rap had recently been undertaken.

Photographs

Section C



Nature of Channel

Narrow with evidence of recent sediment deposition immediately upstream of the culvert inlet. Upstream the bed level rises steeply with severe erosion of the left bank and minor erosion in the channel bed at the base of the slope.

Bed Material

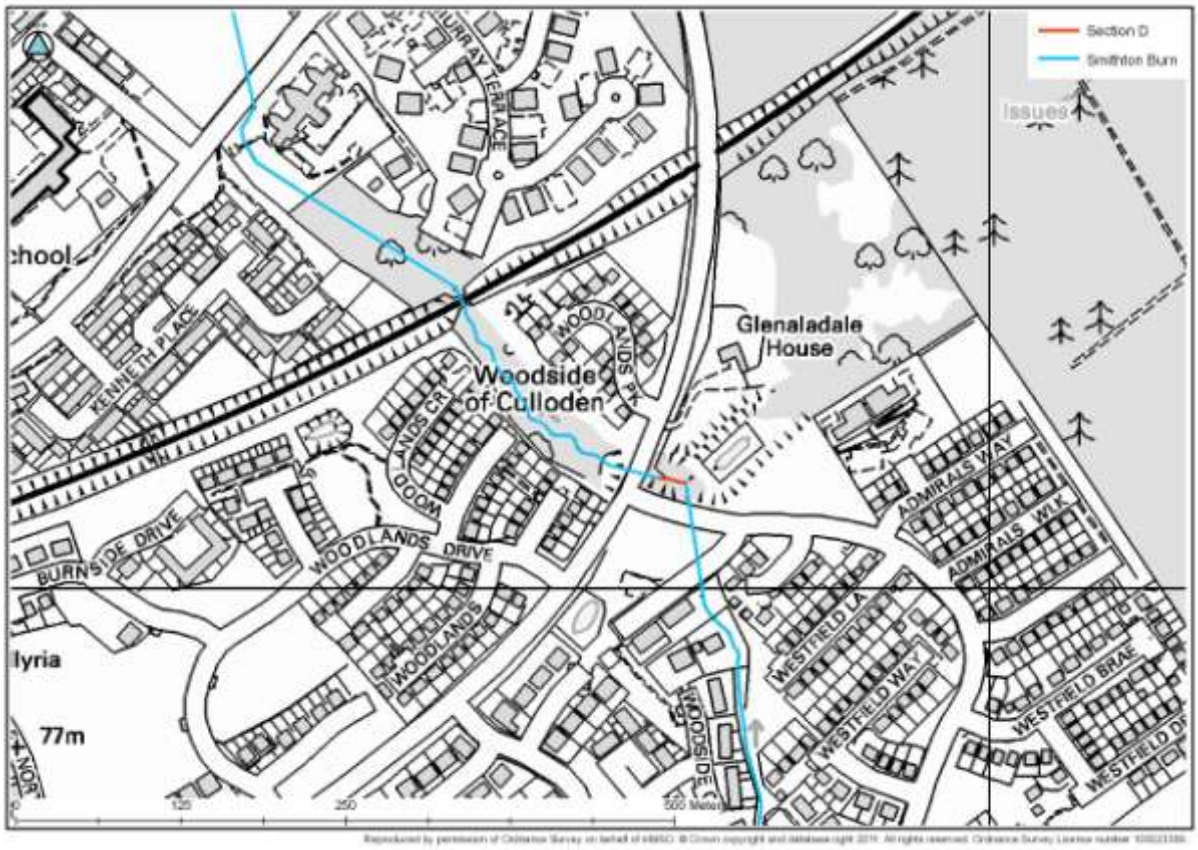
Upstream of the culvert inlet the bed is comprised of very poorly sorted sand, gravel and cobble. Upstream of this, where the bed rises the channel is formed of large sub-angular cobbles, boulders, concrete, bitumen and timber.

Bank Material

The left bank is reinforced with gabion baskets. The right bank is formed by a steep grass slope – this is eroded in places and is comprised of till.

Photographs

Section D



Nature of Channel

Channel at base of steep sided densely vegetated valley. Signs of extensive recent bed and bank erosion – SUDS outfall on right hand bank sitting 0.5-1m above bed level.

Bed Material

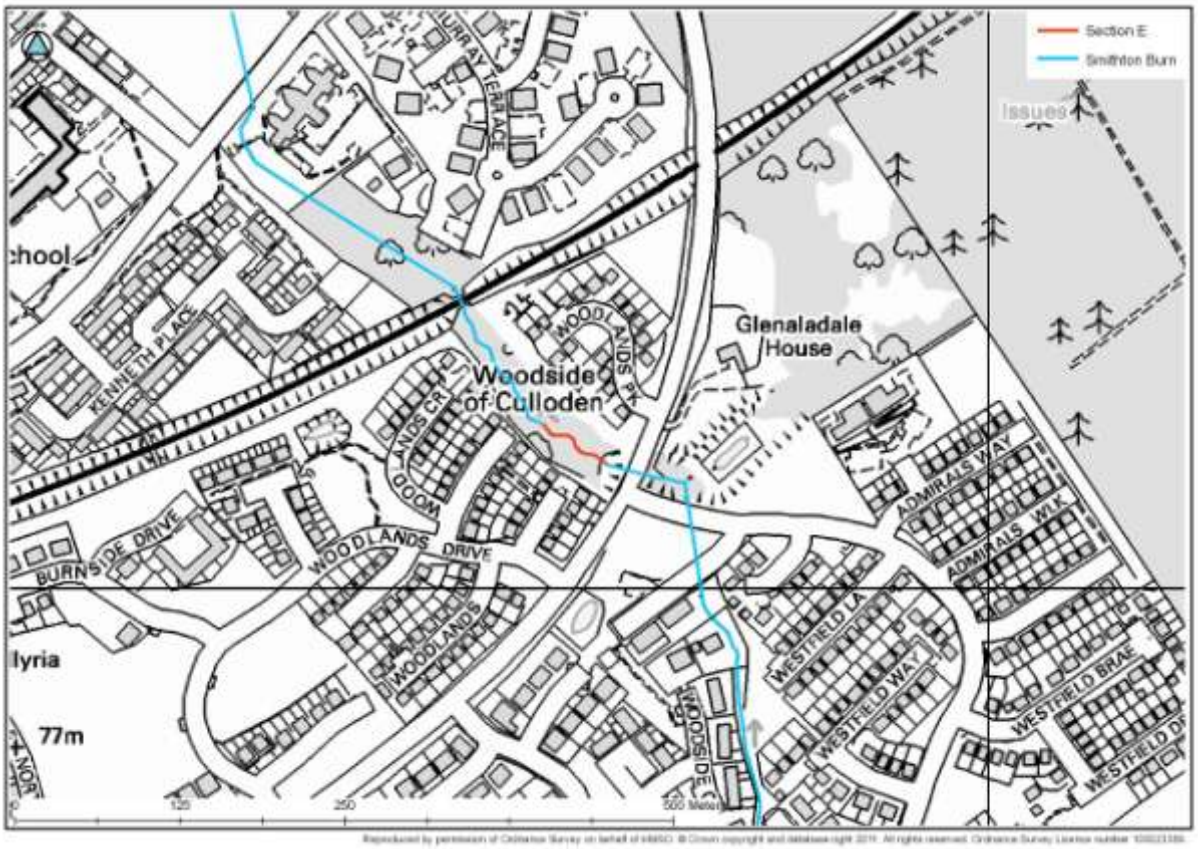
Poorly sorted sand, gravel and cobbles.

Bank Material

Steep, vegetated banks with eroded till at base of either bank.

Photographs

Section E



Nature of Channel

Narrow step-pool channel in base of steep sided valley. Significant deposits of sediment in channel and on narrow floodplain, as well as signs of bed incision of up to 0.5m.

There is a large scour pool immediately downstream of Tower Road culvert, with the culvert hanging above the pool by approximately 0.3m. A large accumulation of sediment is present downstream of this pool.

Bed Material

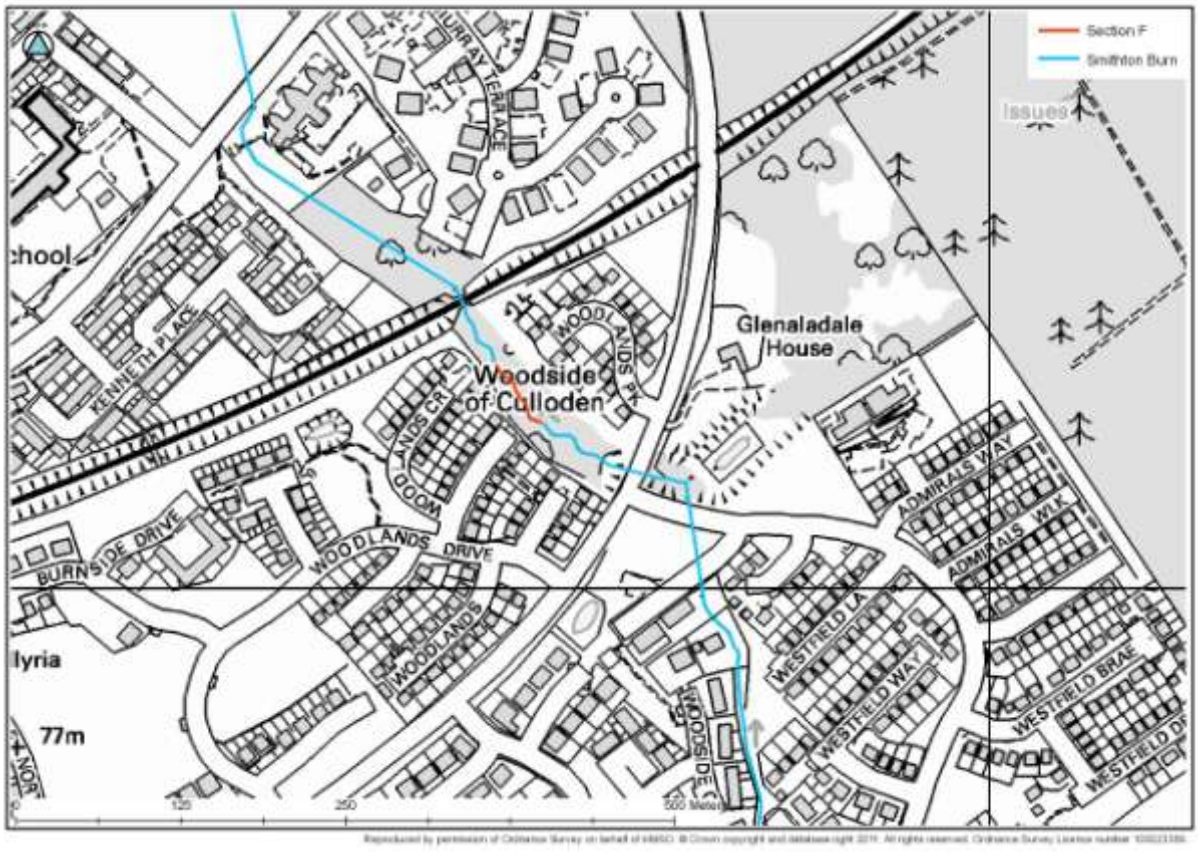
Very poorly sorted silt, sand, gravel, cobbles and boulders.

Bank Material

Steep till banks – eroded at the base of either bank. Significant erosion on the left bank downstream of the pool at the end of Tower Road culvert.

Photographs

Section F



Nature of Channel

Channel has a steep gradient, with three boulder weirs constructed at 20-25m intervals – the weirs are porous and have not formed pools on their upstream side. Upstream a natural logjam is present across the channel, creating a drop in bed level of approximately 1m and a small pool to the downstream.

Bed Material

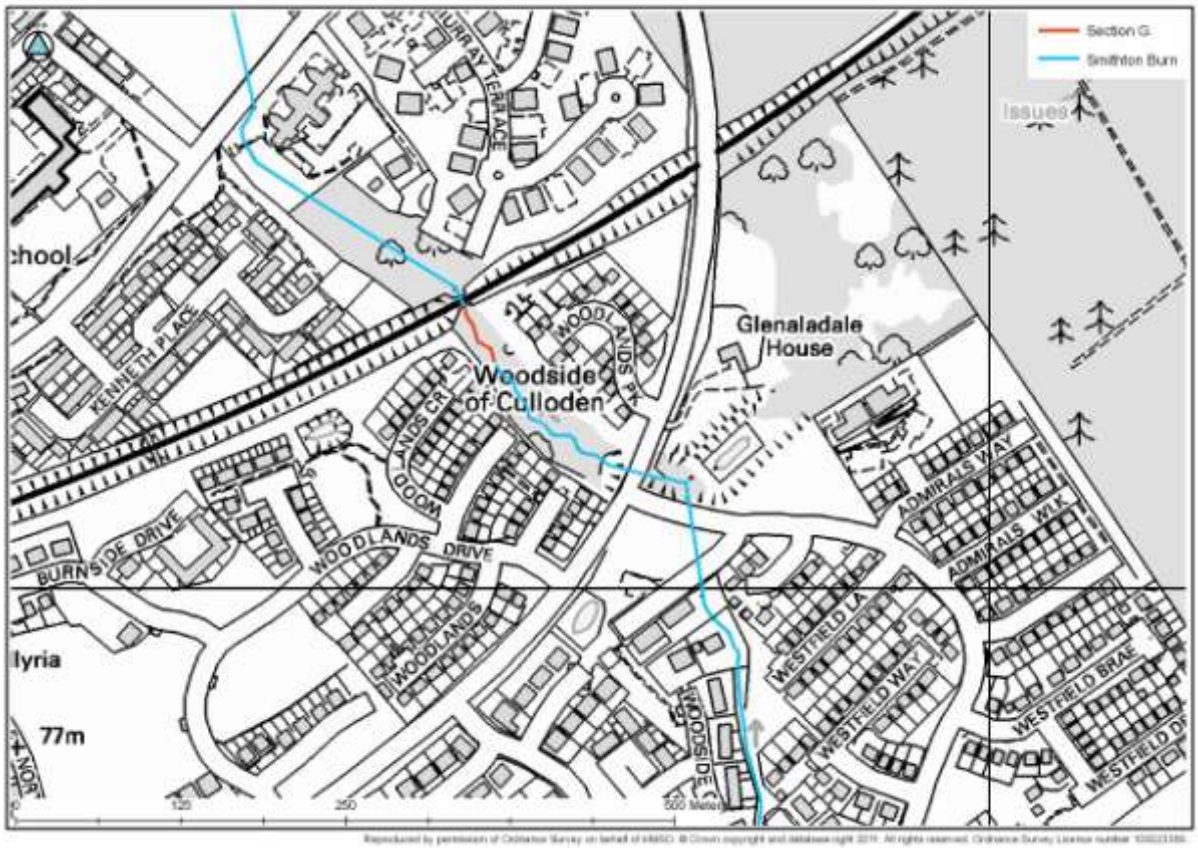
Poorly sorted sand, gravel and cobbles.

Bank Material

Steep, vegetated till banks – eroded along reach length.

Photographs

Section G



Nature of Channel

Channel is wide and poorly defined in base of steep sided valley. The gradient of the channel decreases from this reach downstream, with this area seeing significant sediment accumulation. This is exemplified by the buried surface water drain visible.

Bed Material

Poorly sorted silt, sand, gravel and cobbles.

Bank Material

Steep, densely vegetated banks. Sediment has also accumulated on the banks within the narrow floodplain.

Photographs

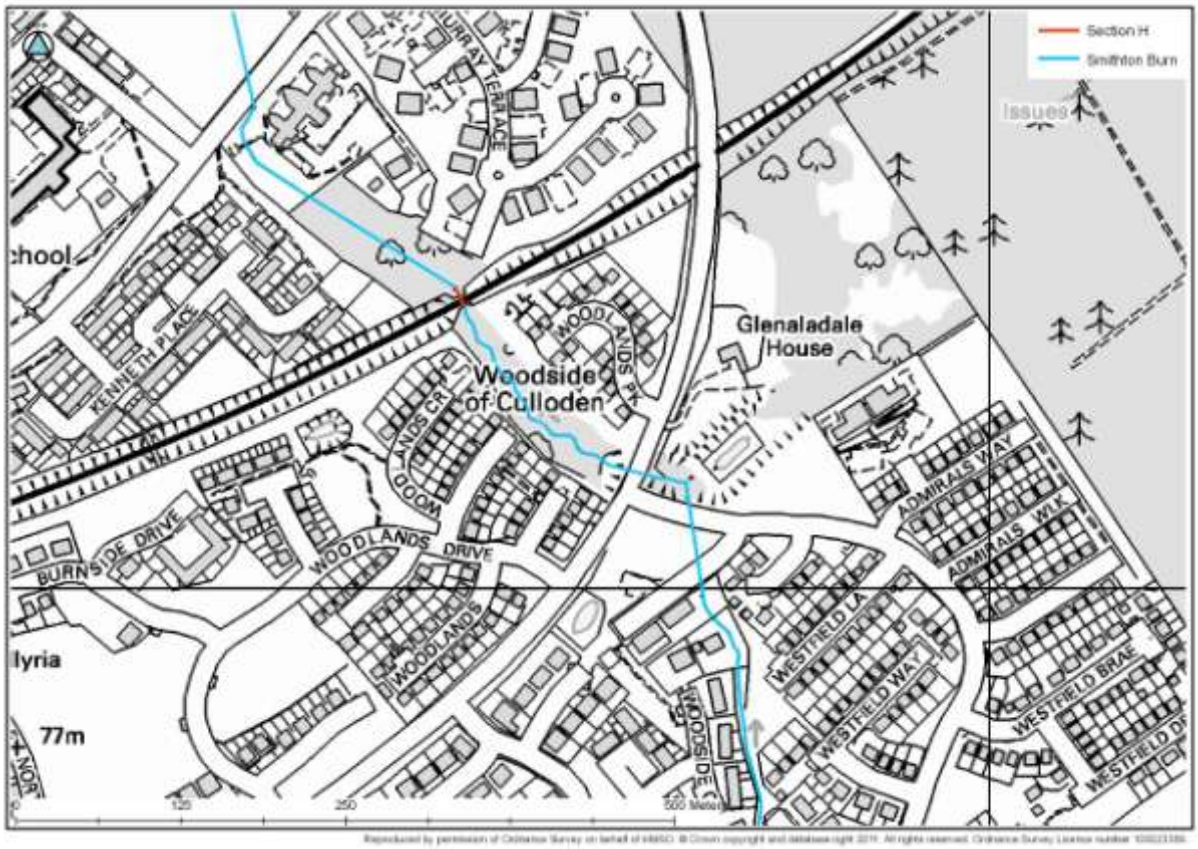
12 March 2010

7 September 2011

12 March 2010

7 September 2011

Section H



Nature of Channel

The reach is highly modified, with the channel having been straightened and progressively narrowed, as well as the banks being reinforced. Beneath underbridge HGL2/590/334 the channel measures approximately 3 m in width between the bridge abutments; however, at bed level this is narrowed to approximately 2 m by the presence of concrete armour encasing a pipe. Downstream of the bridge the channel progressively narrows to approximately 1 m at the primary trash screen and this is then further reduced by the presence of a gabion basket within the channel just upstream of the culvert inlet.

Bed Material

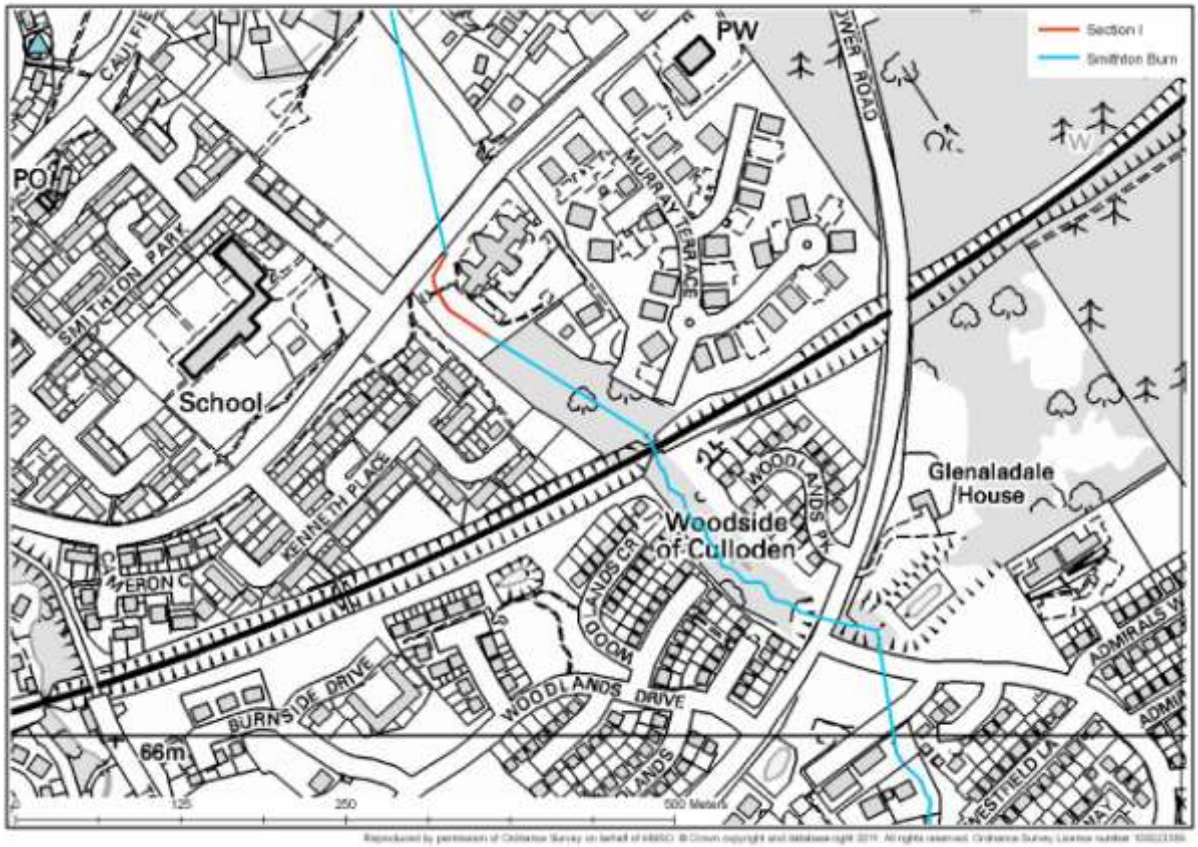
The reach saw significant sediment accumulation in the recent floods, with large amounts of the sediment now removed. This consists of a poorly sorted mixture of silt, sand, gravel and cobbles. The channel beneath the railway bridge is stone pitched.

Bank Material

The channel banks are reinforced by a combination of concrete, gabions baskets and masonry.

Photographs

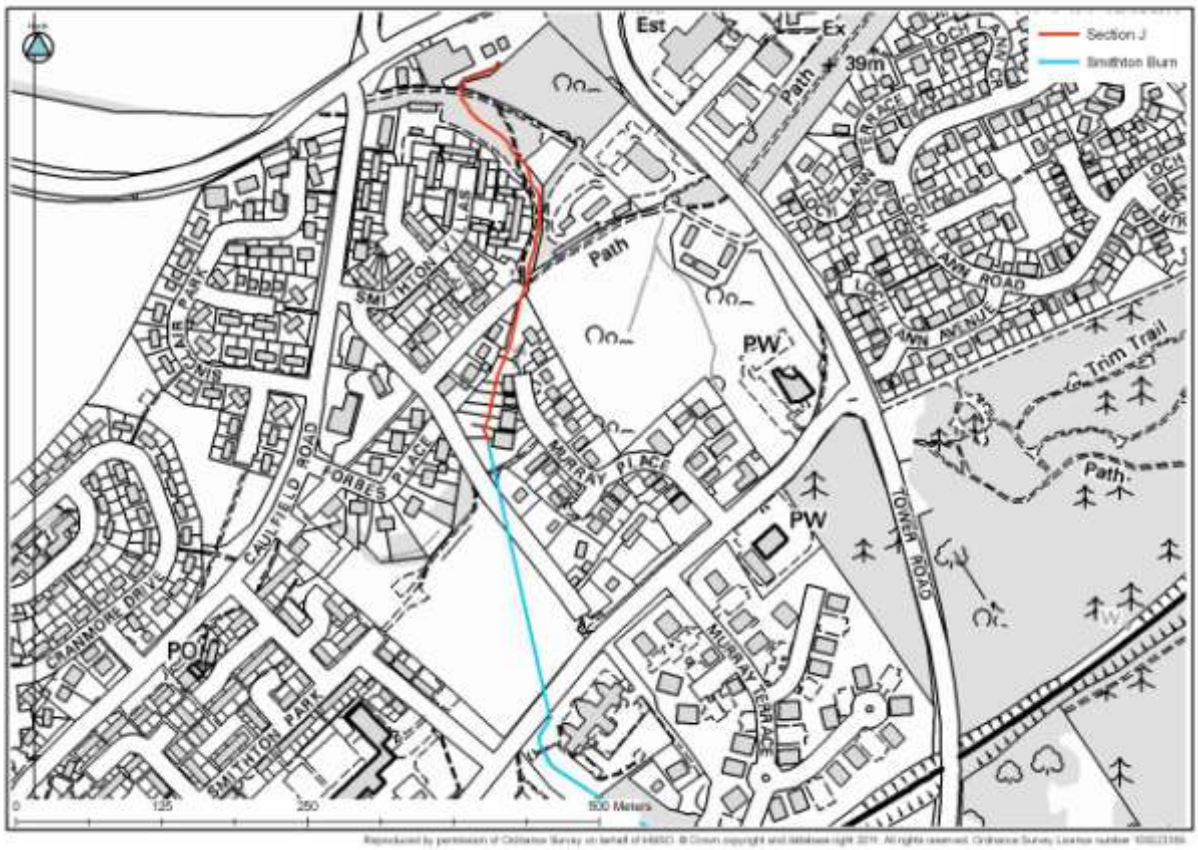
Section I



Nature of Channel
Narrow and fairly deep channel with evidence of small areas of sediment deposition. This confirms that some sediment can pass through the Murray Terrace culvert upstream.
Bed Material
Mixture of sand, gravel and small cobbles.
Bank Material
Densely vegetated, steep banks with till evident at the base of the banks.

Photographs

Section J



Nature of Channel

Stable reach with little evidence of erosion of deposition. The channel varies in width between 0.5 and 2m, and is largely confined by development.

Bed Material

Mainly silt, sand and fine gravel with occasional cobbles.

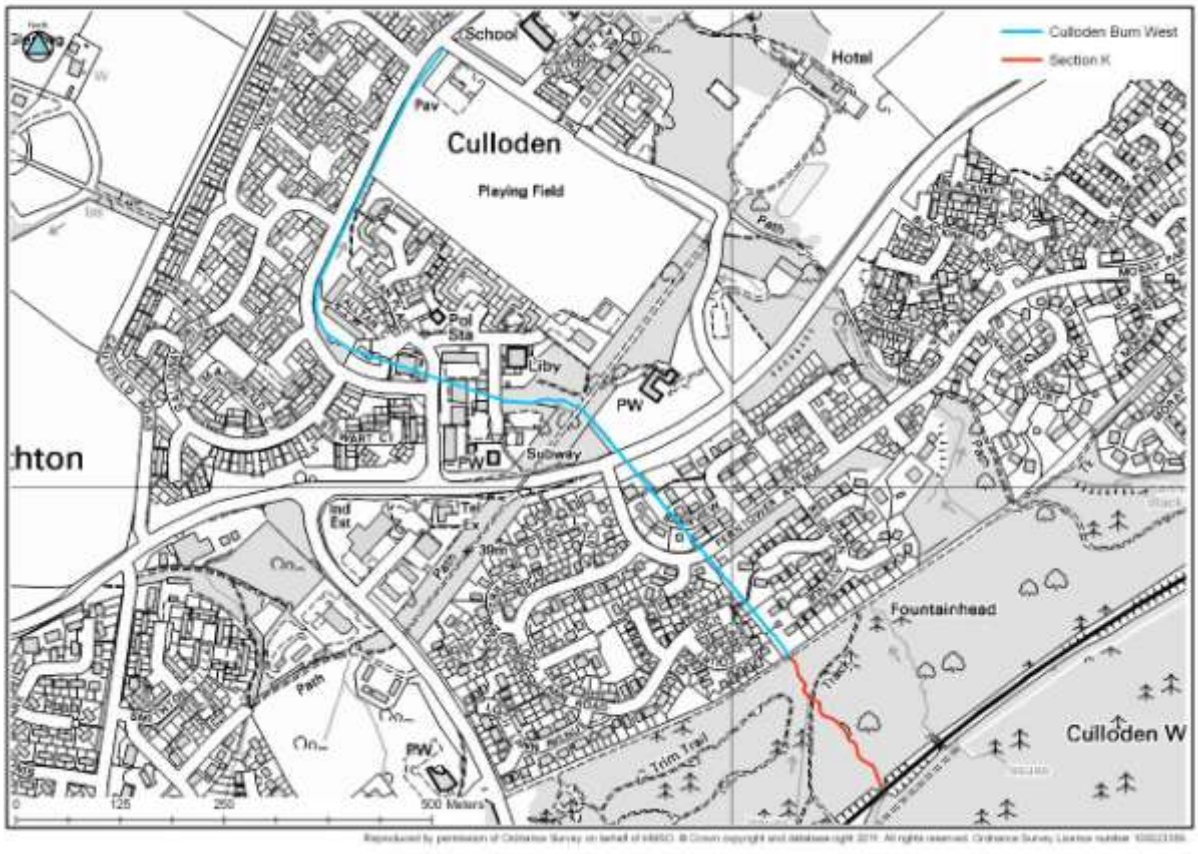
Bank Material

Banks vary between grassland, vegetated slopes and man-made surfaces including concrete and masonry.

Photographs

E.1 Culloden Burn West

Section K



Nature of Channel

The channel flows through dense woodland and has a steep gradient. The reach takes a step-pool form, with a number of the steps formed by natural logjams across the channel. Sediment is accumulated upstream of these jams, and would therefore be released downstream should the logjams fail. Overall the reach is erosive, with sediment passing downstream.

Bed Material

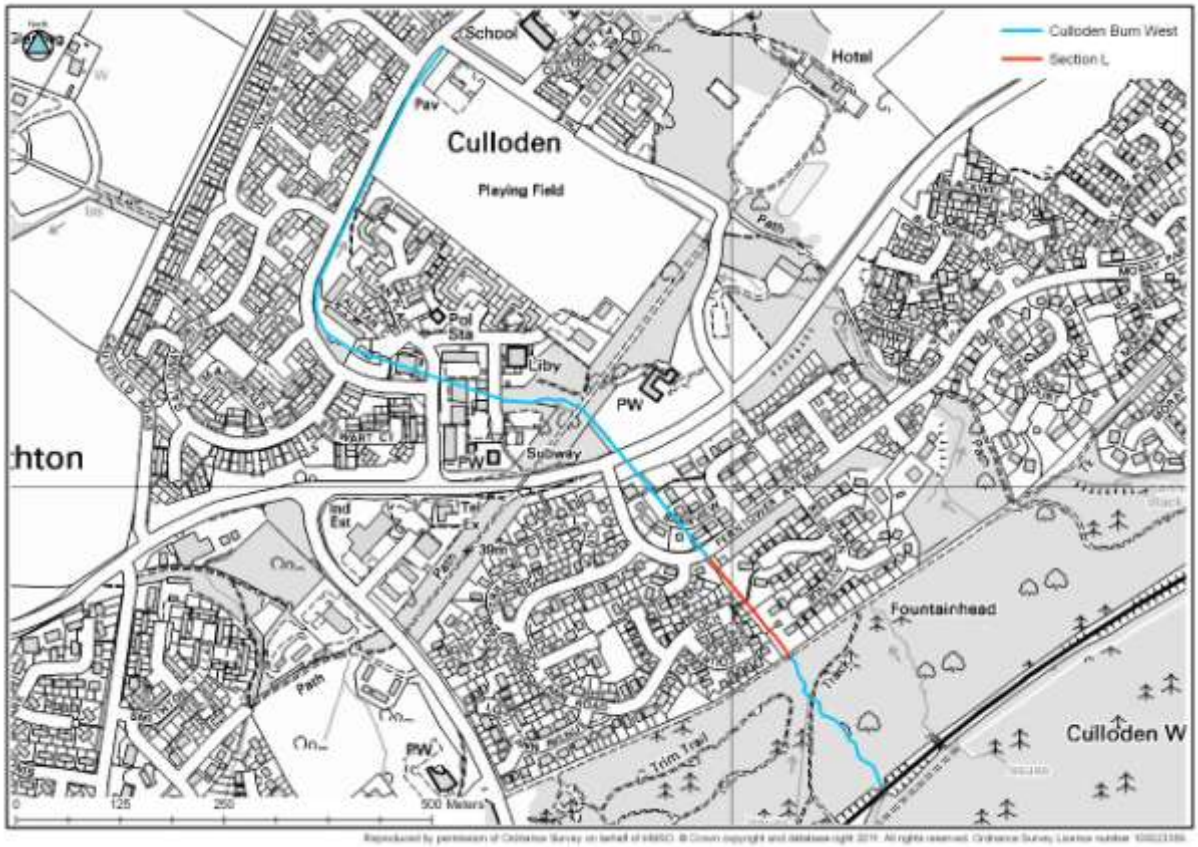
Poorly sorted sand, gravel and cobbles. Clay rich till is visible where erosion has occurred.

Bank Material

The banks are generally steep and vegetated. However, where erosion has taken place till is evident within the channel banks.

Photographs

Section L



Nature of Channel

The channel is highly modified throughout the reach, and is straightened and lined with gabion baskets along the reach length. The form of the channel varies between a rectangular form and a trapezoidal channel. There is evidence of sediment accumulation, particularly at the downstream extent of the reach, upstream of Ferntower Avenue culvert. In addition, there is vegetation (grass) growing within the channel.

Bed Material

The channel bed is lined with a gabion mattress along much of the reach length, with little sediment accumulated on top until just upstream of Ferntower Avenue culvert. At this point there is a poorly sorted accumulation of sediment comprised of gravel and cobbles.

Bank Material

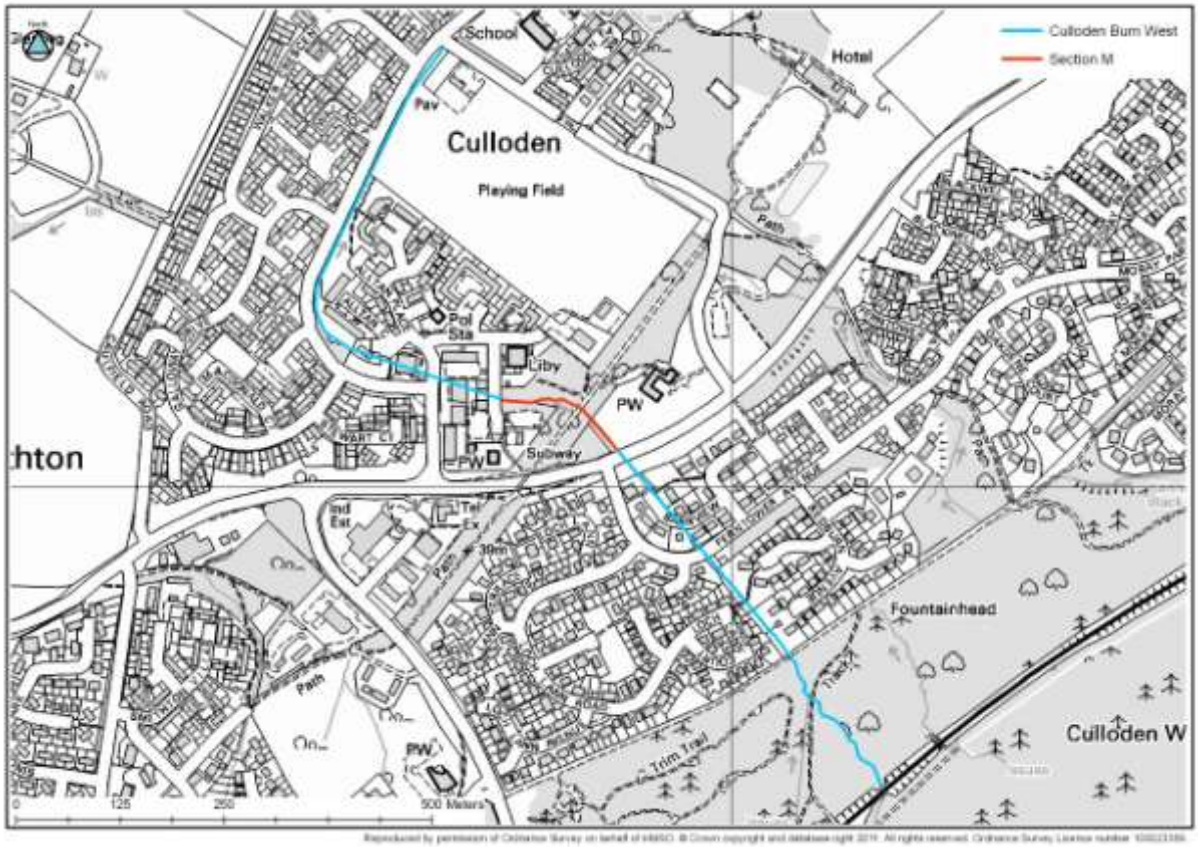
The banks are lined by gabions along much of the reach length, with a short section at the upstream of the reach with sloped grass banks.

Photographs






Section M



Nature of Channel

The channel is located within a small, fairly shallow sided and vegetated valley. There are sections of erosion (particularly bank erosion) present within the reach, as well as sediment accumulation within the channel bed.

Bed Material

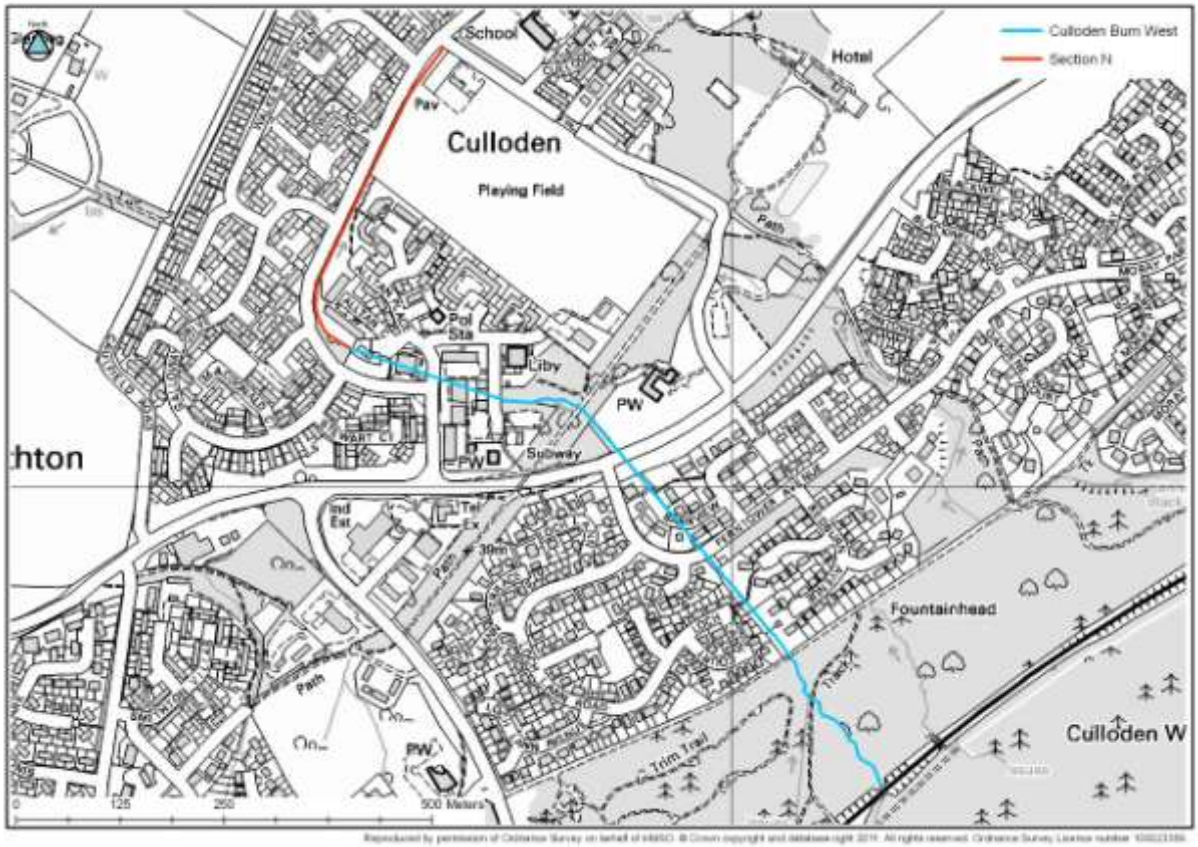
Poorly sorted mixture of silt, sand, gravel and cobbles.

Bank Material

The banks are well vegetated and are comprised of till. There are ad-hoc areas of severe bank erosion.

Photographs

Section N



Nature of Channel

The channel is comprised of a shallow, narrow channel at the base of a small, localised valley. The reach is relatively stable and there is little evidence of sediment accumulation, and only a couple of small areas of bank erosion.

Bed Material

Bed material is largely finely grained, with a mixture of silt, sand and gravel.

Bank Material

The channel banks are comprised of till, with grass slopes above.

Photographs

E Flood damage estimates

F Flood hydrology summaries

1 PROJECT

1.1 PROJECT

Internal Reviewer	Caroline Anderton
Office	Edinburgh
Project Manager	Angus Pettit
Project Title	Inverness East Post Flood
Client Name	Highland Council
Client Contact	Matt Smith

2 SITE

2.1 SITE DETAILS

FEH Version	3.0
Site Code	ANGUSPETTIT_23/09/2011 14:05:39
Site Name	Culloden Burn West adj Final
Site Description	SPR and area adjusted but no change to Tp or duration.
Watercourse Catchment	Inverness East
Watercourse Name	Culloden Burn West

2.2 CATCHMENT

Easting	271600
Northing	846500
Centroid Easting	272495
Centroid Northing	845073
AREA (km2)	1.835
SAAR (mm)	748
SAAR4170 (mm)	775

FARL	1
FPEXT	0.086
BFIHOST	0.62
SPRHOST (%)	33.06
DPLBAR	2.04
DPSBAR (m/km)	41.2
PROPWET	0.42
ALTBAR	111
ASPBAR	332
ASPVAR	0.84
C	-0.02
D1	0.38778
D2	0.45274
D3	0.30664
E	0.2637
F	2.26132
C1km	-0.021
D11km	0.387
D21km	0.457
D31km	0.3
E1km	0.265
F1km	2.24
Adapted URBEXT Year	2011
URBEXT1990	0.0559
URBEXT1990 AREA Notes	URBEXT1990 value 0.0559 updated to 2011 value of 0.0597
Adapted URBEXT1990	0.0597
URBEXT2000	0.0989
URBEXT2000 AREA Notes	URBEXT2000 value 0.0989 updated to 2011 value of 0.1014
Adapted URBEXT2000	0.1015

3 FEH RAINFALL RUNOFF

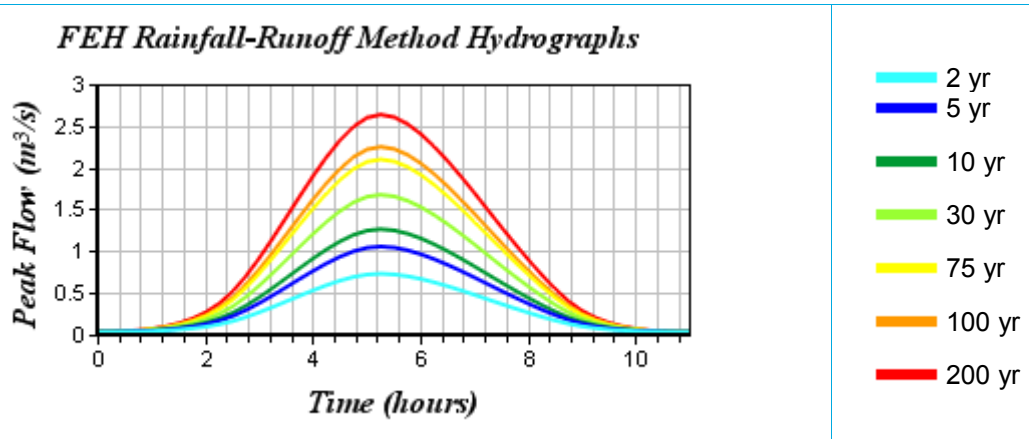
3.1 PARAMETERS

Pumped Catchment	FALSE
Instantaneous unit hydrograph time-to peak (hours)	2.45
Timestep (hours)	0.25
Standard Percentage Runoff (%)	33.060
Baseflow (m3/s)	0.032
Comments	
Storm Duration (hours)	4.75
Profile	Winter
Catchment wetness index (mm)	109.65
Areal reduction factor (hours)	0.973

3.2 RESULTS

Flow return period (years)	Rainfall return period (years)	Rainfall Depth (mm)	Peak Flow (m3/s)	Volume (m3)	Specific Discharge (l/s/ha)	Growth Factor
2	2	19.1	0.73	12	3.97	1
5	8	28	1.05	17	5.71	1.44
10	17	33.7	1.26	20	6.85	1.73
30	50	43.5	1.67	26	9.08	2.29
75	110	52.3	2.1	32	11.41	2.88
100	140	55.4	2.25	34	12.23	3.08
200	247	63.2	2.63	40	14.29	3.6

Figure 3-1: FEH Rainfall Runoff Results Chart



4 REVITALISED FLOOD HYDROGRAPH

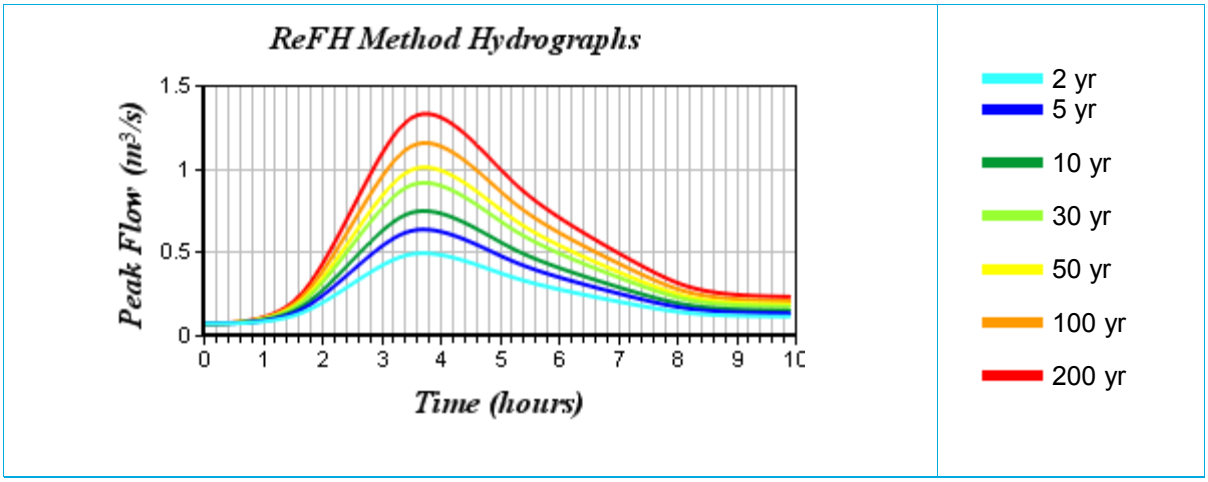
4.1 PARAMETERS

Instantaneous unit hydrograph time-to-peak (hours)	1.795
Timestep (hours)	0.1
Maximum Soil Moisture Capacity (mm)	466.604
Initial Soil Moisture Content (mm)	114.411
Baseflow Lag (hours)	31.431
Baseflow Recharge	1.638
Comments	
Storm Duration (hours)	3.3
Profile	Winter
Seasonal Correction Factor	0.665
Areal reduction factor (hours)	0.969
Hydrograph End Point	where Surface Runoff = 0

4.2 RESULTS

Flow return period (years)	Rainfall Depth (mm)	Peak Flow (m3/s)	Volume (m3)
2	16.646	0.491	8.499
5	21.846	0.633	10.608
10	26.154	0.744	12.259
30	34.327	0.913	14.764
50	38.864	1.006	16.143
100	45.948	1.152	18.306
200	54.291	1.326	20.892

Figure 4-1: ReFH Results Chart



5 SUMMARY TABLES

5.1 PEAK FLOWS

Return Period	Peak Flows (m3/s)	
	FEH RR	ReFH
2	0.73	0.49
5	1.05	0.63
10	1.26	0.74
30	1.67	0.91
50		1.01
75	2.10	
100	2.25	1.15
200	2.63	1.33

5.2 SPECIFIC DISCHARGES

Return Period	Specific Discharges (l/s/ha)	
	FEH RR	ReFH
2	3.97	2.67
5	5.71	3.45
10	6.85	4.05
30	9.08	4.97
50		5.48
75	11.41	
100	12.23	6.28
200	14.29	7.23

5.3 GROWTH FACTORS

Return Period	Growth Factors	
	FEH RR	ReFH
2	1.00	1.00
5	1.44	1.29
10	1.73	1.52
30	2.29	1.86
50		2.05
75	2.88	
100	3.08	2.35
200	3.60	2.70

1 PROJECT

1.1 PROJECT

Internal Reviewer	Caroline Anderton
Office	Edinburgh
Project Manager	Angus Pettit
Project Title	Inverness East Post Flood
Client Name	Highland Council
Client Contact	Matt Smith

2 SITE

2.1 SITE DETAILS

FEH Version	3.0
Site Code	ANGUSPETTIT_23/09/2011 14:14:03
Site Name	Smithton Burn Final
Site Description	SPR and area adjusted but no change to Tp or duration.
Watercourse Catchment	Inverness East
Watercourse Name	Smithton Burn

2.2 CATCHMENT

Easting	271400
Northing	846050
Centroid Easting	272188
Centroid Northing	844804
AREA (km2)	1.438
SAAR (mm)	750
SAAR4170 (mm)	772

FARL	1
FPEXT	0.0425
BFIHOST	0.635
SPRHOST (%)	30.41
DPLBAR	1.71
DPSBAR (m/km)	57.8
PROPWET	0.42
ALTBAR	115
ASPBAR	325
ASPVAR	0.9
C	-0.02
D1	0.38717
D2	0.45244
D3	0.30816
E	0.26328
F	2.26147
C1km	-0.02
D11km	0.386
D21km	0.452
D31km	0.319
E1km	0.263
F1km	2.249
Adapted URBEXT Year	2011
URBEXT1990	0.0482
URBEXT1990 AREA Notes	URBEXT1990 value 0.0482 updated to 2011 value of 0.0514
Adapted URBEXT1990	0.0515
URBEXT2000	0.07
URBEXT2000 AREA Notes	URBEXT2000 value 0.07 updated to 2011 value of 0.0718
Adapted URBEXT2000	0.0718

3 FEH RAINFALL RUNOFF

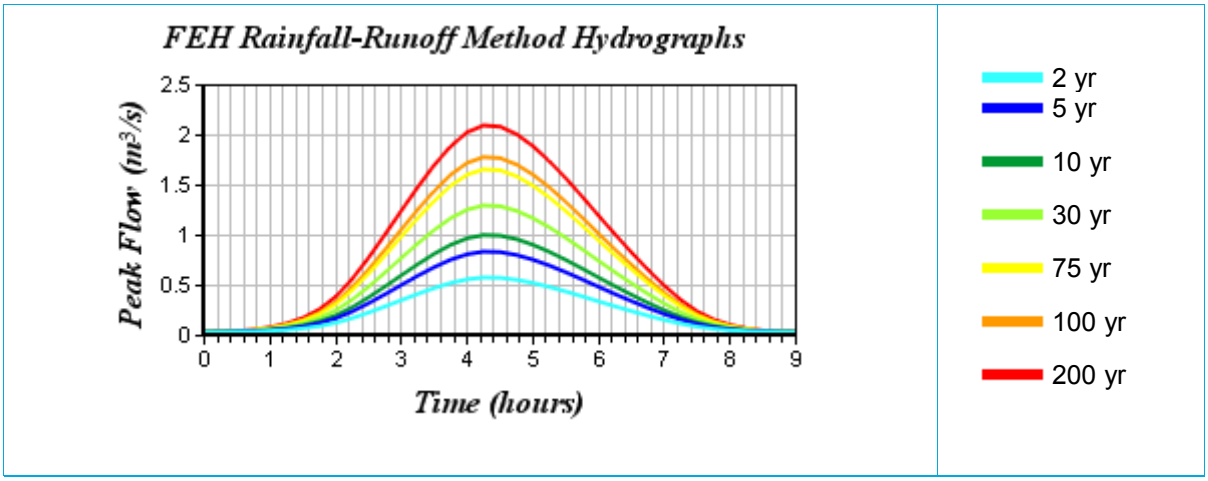
3.1 PARAMETERS

Pumped Catchment	FALSE
Instantaneous unit hydrograph time-to-peak (hours)	2.066
Timestep (hours)	0.25
Standard Percentage Runoff (%)	30.410
Baseflow (m3/s)	0.025
Comments	
Storm Duration (hours)	3.75
Profile	Winter
Catchment wetness index (mm)	110
Areal reduction factor (hours)	0.973

3.2 RESULTS

Flow return period (years)	Rainfall return period (years)	Rainfall Depth (mm)	Peak Flow (m3/s)	Volume (m3)	Specific Discharge (l/s/ha)	Growth Factor
2	2	17.5	0.57	8	3.96	1
5	8	25.8	0.83	11	5.76	1.46
10	17	31.1	0.99	13	6.88	1.74
30	50	40.3	1.29	17	8.96	2.26
75	110	48.7	1.65	21	11.46	2.89
100	140	51.6	1.77	23	12.29	3.11
200	247	59	2.09	27	14.51	3.67

Figure 3-1: FEH Rainfall Runoff Results Chart



4 REVITALISED FLOOD HYDROGRAPH

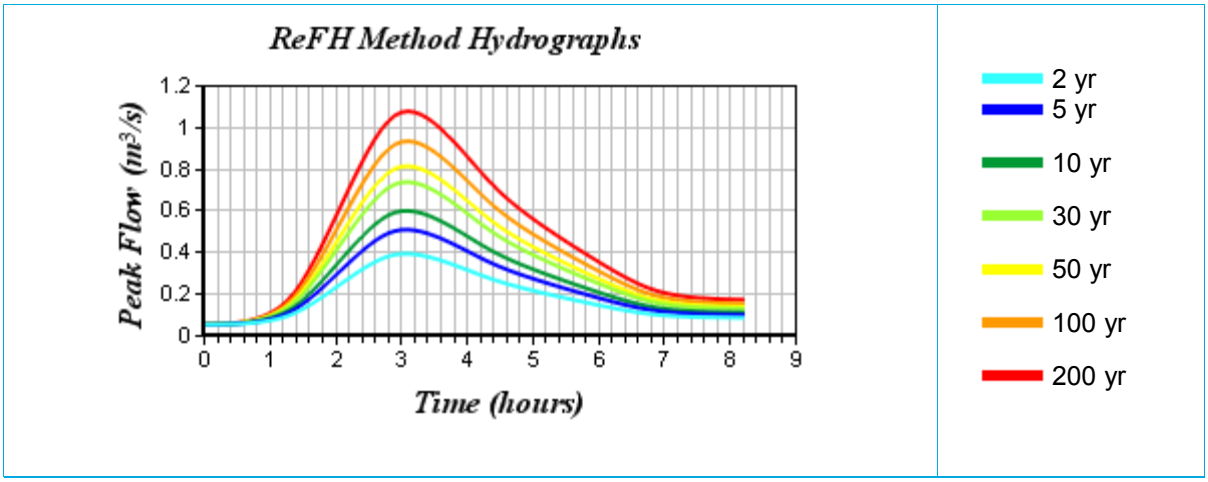
4.1 PARAMETERS

Instantaneous unit hydrograph time-to-peak (hours)	1.507
Timestep (hours)	0.1
Maximum Soil Moisture Capacity (mm)	477.322
Initial Soil Moisture Content (mm)	110.953
Baseflow Lag (hours)	31.354
Baseflow Recharge	1.681
Comments	
Storm Duration (hours)	2.7
Profile	Winter
Seasonal Correction Factor	0.653
Areal reduction factor (hours)	0.969
Hydrograph End Point	where Surface Runoff = 0

4.2 RESULTS

Flow return period (years)	Rainfall Depth (mm)	Peak Flow (m3/s)	Volume (m3)
2	15.413	0.390	5.529
5	20.310	0.505	6.935
10	24.381	0.596	8.040
30	32.131	0.734	9.723
50	36.445	0.810	10.651
100	43.197	0.930	12.108
200	51.168	1.074	13.852

Figure 4-1: ReFH Results Chart



5 SUMMARY TABLES

5.1 PEAK FLOWS

Return Period	Peak Flows (m3/s)	
	FEH RR	ReFH
2	0.57	0.39
5	0.83	0.51
10	0.99	0.60
30	1.29	0.73
50		0.81
75	1.65	
100	1.77	0.93
200	2.09	1.07

5.2 SPECIFIC DISCHARGES

Return Period	Specific Discharges (l/s/ha)	
	FEH RR	ReFH
2	3.96	2.71
5	5.76	3.51
10	6.88	4.14
30	8.96	5.10
50		5.63
75	11.46	
100	12.29	6.47
200	14.51	7.47

5.3 GROWTH FACTORS

Return Period	Growth Factors	
	FEH RR	ReFH
2	1.00	1.00
5	1.46	1.30
10	1.74	1.53
30	2.26	1.88
50		2.08
75	2.89	
100	3.11	2.39
200	3.67	2.75

G Recommended industry standard methodologies and best practice

The following section provides background to best practice and recommendation for watercourse inspection, culvert and screen maintenance and bank/channel erosion. This will be essential to review these industry standards for the next stage of the work.

G.1 Flood Risk Assessment

Generic flood risk assessment guidance for use in Scotland is provided by SEPA and includes the technical guidance for stakeholders. Whilst this is primarily aimed at strategic flood risk assessments (SFRA's) and flood risk assessments (FRA) for developments and planning purposes the general guidance is appropriate for all flood studies in Scotland. A copy of the guidance is available here:

http://www.sepa.org.uk/flooding/planning__flooding.aspx

This guidance covers aspects such as hydrology, hydraulic modelling and (although not relevant for this study) land raising and compensatory storage. Details on the use of the FEH methodologies (used in this study) are provided although further work should refer back to the FEH documents. Further guidance is likely to be issued over the coming months and years at SEPA take on more responsibility for flood risk management in Scotland.

Further more specific guidance relating to Highland Council is provided in their Interim Supplementary Guidance: Flood Risk & Drainage Impact Assessment.

G.2 CAR licensing

Water Environment and Water Services (Scotland) Act 2003 (WEWS Act) transposed the Water Framework Directive (WFD) in to law in Scotland. The WEWS Act gives Scottish ministers powers to introduce regulatory controls over water activities, in order to protect, improve and promote sustainable use of Scotland's water environment. This includes wetlands, rivers, lochs, transitional waters (estuaries), coastal waters and groundwater.

Under the Water Environment (Controlled Activities) (Scotland) Regulations 2011 (more commonly known as the Controlled Activity Regulations (CAR)) anyone intending to carry out any activity which may affect Scotland's water environment must be authorised to do so. Discharges, disposal to land, abstractions, impoundments and engineering works are all regulated by SEPA under CAR licences. Full details are available on SEPA's website:

http://www.sepa.org.uk/water/water_regulation.aspx

G.3 Flood Protection Scheme guidance

The guidance is a series of technical documents, aimed at local authorities and their professional advisors, on best practice for the promotion of flood prevention schemes under the current statutory framework. The current guidance documents are located here:

http://www.scotland.gov.uk/Topics/Environment/Water/Flooding/Flood-prevention/guidance-la

The guidance aimed to provide 10 chapters in total to provide an integrated series of guidance documents with each chapter concentrating on specific aspects of identifying and evaluating flood prevention options. Although only 2 were originally published they are in the process of being updated for use under the Flood Risk Management (Scotland) 2009 Act.

G.4 Benefit cost appraisal

Although benefit-cost and economic appraisals are covered in the above set of Scottish Government guidance documents, the procedures for economic appraisals in the UK is well established by the following documents:

- HM Treasury Green Book for general economic and risk methodologies and guidance.

- Defra FCDPAG replaced by the Environment Agency FCERM Appraisal Guidance for economic appraisal methodologies.
- FHRC's Multi-Coloured Manual for flood damage calculations.

These are available here:

http://www.hm-treasury.gov.uk/data_greenbook_index.htm

http://www.environment-agency.gov.uk/research/planning/116705.aspx

http://www.mdx.ac.uk/research/areas/geography/flood-hazard/publications/index.aspx

G.5 Condition assessment surveys

The Environment Agency condition assessment manual is the best practice for condition surveys. The guidance refers specifically to the initial visual inspection and condition grading of assets and watercourses. This initial visual grading may serve as the catalyst for further, more specialist inspections to be undertaken. A copy of the manual is available here:

http://www.ada.org.uk/documents/eacondassessment.pdf

Condition surveys are essential to periodically assess and review the watercourse and to understand watercourse and asset performance which is essential for effective flood risk management. This information can support effective decision making for the management of flood risk.

G.6 Culvert design and maintenance

Best practice on design and maintenance of culverts is provided in the CIRIA Culvert design and operation guide (CDOG)[21]. This is available here:

http://www.ciria.org/service/AM/ContentManagerNet/ContentDisplay.aspx?Section=knowledgebase&ContentID=16202

During a culverts life it's performance will deteriorate and intervention will be required to maintain a minimum level of performance to convey the designated flow, reduce flood risk, maintain good ecological conditions and to maintain operatives health and safety.

Consideration of the following inspection and maintenance aspects are covered by the guidance and include the following:

- Hydraulic performance inspections (blockage or silt levels through a culvert)
- Periodic structural assessments
- Ensuring sufficient health and safety requirements for operative and maintenance staff
- Public safety (safe egress points, screens, barriers and signage).

G.7 Trash & security screens

Best practice guidance is EA Trash & Security Screen Guide for Flood Risk Management[22] which is available here: http://publications.environment-agency.gov.uk/pdf/SCHO1109BRHF-e-e.pdf

The following considerations are required and recommended for the adequate functioning and safe maintenance of culvert screens:

- Routine inspection and clearance of screens is required preferably on a risk based (probability x consequence) basis.
- Procedures to deal with non routine clearance during flood events when routine clearance is unable to cope with additional debris loading on a screen.
- Suitable design of screens including the consideration of screen position, bar spacing and alignment, screen area and layout, method of screen cleaning, screen height and angle of screen.
- Safe clearance of debris is key. This may require the following:

[21] CIRIA (2010), Culvert design and operation guide. CIRIA C689. London.
[22] Environment Agency (July 2007). Trash & Security Screen Guide for Flood Risk Management. Final Report (9R8901).

- safe access,
- working platforms including health and safety provisions (e.g. hand railing, fencing, ladders safety harnesses and suitable anchoring points for operatives),
- warning notices,
- lighting, and
- water depth indicators.
- Temporary storage of debris removed on site prior to disposal. Access to the storage zone and transfer from screen to storage and removal must be allowed for. Sufficient storage capacity should be available and reflect the likely volume of debris.
- Removal and disposal at an appropriate licensed waste disposal site is required.

Other considerations for safe culvert operation include the need for telemetry, CCTV and security arrangements.

G.8 Watercourse and bank erosion management

Bank Erosion Management guidance is provided by SEPA on their website:

www.sepa.org.uk/water/water_publications.aspx

G.9 SUDS design

Details on Highland Councils controls on SUDS design is provided in their Interim Supplementary Guidance: Flood Risk and Drainage Impact Assessment documents. This document puts the Council's general planning policy on flooding and development into detailed planning, construction and maintenance practice. A copy is available on the Highland Council website:

http://www.highland.gov.uk/NR/rdonlyres/B5C830EE-4CCA-42CA-80FC-F79AE92A07F1/0/flooding_cons_draft.pdf

The Council recommends that SuDS principles and specifications are provided in accordance with current legislation and guidelines such as the CIRIA Publication C697 - The SUDS Manual.

G.10 Asset Management

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[23], 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.

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

H Specification of Works to Assess Flood Risk

This document aims to provide an overview of the accepted methodologies, data required and specification of works for assessing existing and future flood risk. It is intended for use in areas where flood risk is poorly understood or where further assessment is required. It is broken down into the following categories:

- Data review and Scoping
- Topographic data
- Hydrology
- Hydraulic Modelling
- Flood Mapping
- Assessment of risk

General guidance on the preparation of flood risk assessments is provided within SEPA's document 'Technical Flood Risk Guidance for Stakeholders', which can be found here http://www.sepa.org.uk/flooding/planning__flooding.aspx

H.1 Data Review and Scoping

The first stage of undertaking a flood risk assessment is to review any existing data in order to understand the potential sources of risk that could affect the area in question. Sources of existing data include:

- SEPA's Indicative Fluvial and Costal Flood Map (Scotland)
- SEPA's National Flood Risk Assessment (NFRA)
- Any existing pluvial modelling
- SEPA's Level 1 groundwater hazard map
- Historical data

Historical data may either be in relation to specific events or be general knowledge about a known source of risk to an area, and can be obtained through consultation with the Council, SEPA, Scottish Water and the general public as well as through searches of newspaper archives and the internet. An understanding of historical flood risk is also important as it can aid in the calibration and validation of modelling, as well as providing a context to the study for stakeholders and members of the public.

Undertaking a site visit is also key to understanding the flood mechanisms in operation within an area.

Data Sources/ Guidance Documents	SEPA's Indicative Fluvial and Coastal Map (Scotland): http://www.sepa.org.uk/flooding/flood_map.aspx SEPA's National Flood Risk Assessment: http://www.sepa.org.uk/flooding/flood_risk_management/national_flood_risk_assessment.aspx
Typical Activities	- Undertake site walkover - Review existing sources of information including historical flooding data - Consultation with Council, SEPA and Scottish Water

H.2 Topographic Data

Topographic data is often required in order to undertake an assessment of flood risk. This can vary in terms of the type of data and level of detail required depending upon the source(s) of flooding being investigated, the modelling methods required and the receptors to flooding that are present. Different types of topographic data that may be required are summarised below:

- DTM (Digital Terrain Model) – a raster that represents the topography in terms of digital elevations. This is often in the form of LiDAR data, and can either include or exclude buildings. It can be processed to, for example, remove false blockages or lower roads in order to better represent overland flow paths. A DTM is required to undertaken 2D hydraulic modelling.
- Channel cross sections – cross sections across a channel are required for the development of a 1D hydraulic model, and should include any structures present within the reach to be modelled.
- Threshold survey – a threshold survey can be useful in 2D modelling to provide a better representation of the number of properties flooding and the flood depths occurring.
- Defence survey – this can include the survey of lateral defences along the side of a watercourse or survey of coastal defences, where a section can be taken perpendicular to the defence to allow wave overtopping analysis to be undertaken.
- Bathymetric survey – survey of the offshore bathymetry may, in some instance, be required to undertake detailed wave transformation modelling.

Data Sources/ Guidance Documents	• RICS Guidance Note, 2nd Edition – Guidelines for the use of GNSS in land surveying and mapping • JBA Training Course: *Survey for River Models*
Typical Activities	• Determine type and extent of survey required • Prepare a detailed specification for the commission of the survey • Survey check/audit

H.3 Hydrology

Hydrological estimations are required to provide inputs to the hydraulic modelling; this includes the derivation of fluvial flows, rainfall hyetographs, still water levels and waves. Consideration may also be given to the assessment of the potential effects of climate change.

Fluvial Flow Estimation

The estimation of fluvial flows is typically undertaking using methods from the Flood Estimation Handbook (FEH). The FEH presents two main methods for the estimation of fluvial flows; the statistical and the rainfall runoff method. The statistical method was updated in 2008 and the rainfall runoff superseded by the revitalised flood hydrograph method (ReFH) in 2006; however, it should be noted that the ReFH method is not accepted by SEPA for use in Scotland. Further details of these methods can be obtained from the references provided below. Alternative methods are available for catchments with particular characteristics, e.g. small, urban, permeable or snow melt dominated catchments. For small catchments methods include the rational method, IH Report 124, ADAS Reference Book 345 or the scaling down of FEH estimates. For urban catchments the modified rational method is often utilised.

Pluvial Rainfall Estimation

Pluvial depths and hyetographs can be derived through the analysis of rain gauge data or by using the Depth Duration Frequency model within the FEH. This can be edited to allow for different local drainage capacities, winter/summer profiles and storm durations. Further detailed specifications are provided in the hydraulic modelling section of this report.

Tidal - Still Water Levels and Waves

With regard to coastal flood risk, consideration should be given to risk from both extreme still water levels and wave run-up and overtopping. Extreme sea levels around much of the UK coastline are available from the Defra dataset released in February 2011. Methods used to derive wave heights within area vary greatly depending upon the requirements of the study. The process involves the initial consideration of offshore wave heights, with these then transferred into nearshore wave characteristics.

Climate Change

As well as assessing current flood risk, it is important to consider how the climate may change in the future, especially if this could result in an increase in risk. The current guidance on allowing for climate change is summarised below:

- Fluvial flows – peak flow uplifted by 20%, as advised within SEPA's FRA guidance
- Pluvial – increased by 20% as standard practice.
- Extreme sea levels – Changes in sea levels can be obtained from UKCP09, with further guidance provided by the Environment Agency (2011) report (see below).
- Wave heights – Wave heights are typically increased by 10%, as recommended in Planning Policy Statement 25

Data Sources/ Guidance Documents	• Flood Estimation Handbook: *Flood Estimation Handbook, Volume 3* • Statistical method update report: *Environment Agency Science Report SC050050, 2008* • Revitalised flood hydrograph method report: *Revitalisation of the FSR/FEH Rainfall Runoff Method: R&D Technical Report FD1913/TR* • Environment Agency Fluvial Design Guide - Chapter 2: Hydrology http://evidence.environment-agency.gov.uk/FCERM/en/FluvialDesignGuide/Chapter_2_Background.aspx • Defra coastal level dataset: *Coastal Flood Boundary Conditions for UK Mainland and Islands. Project SC060064/TR2: Design Sea Levels, February 2011* • SEPA's FRA guidance: *Technical Flood Risk Guidance for Stakeholders* http://www.sepa.org.uk/flooding/planning__flooding.aspx • UKCP09: http://ukclimateprojections-ui.defra.gov.uk/ui/admin/login.php • Environment Agency, 2011. Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities: http://publications.environment-agency.gov.uk/dispay.php?name=GEHO0711BTZU-E-E • Planning Policy Statement 25: *Planning Policy Statement 25: Development and Flood Risk. Report by Communities and Local Government, 2006.* JBA Training Courses: - Introduction to Flood Hydrology: Processes and Practices - Urban Hydrology - Flood Estimation Handbook (FEH) - Coastal Flood Modelling and Extremes Analysis
Typical Activities	• Determine the hydrological estimations required • Obtain data and review. Undertake rating reviews (if required) • Derive estimations of fluvial flow, rainfall, still water levels and waves heights at the locations required • Consider joint probability (if required) • Consider climate change

H.4 Hydraulic Modelling

Hydraulic modelling is required to translate the flow or rainfall, etc. into a flood level on the ground. Modelling can be 1D, 2D, or a combination of the two. Details for the modelling of each flooding source are summarised below:

Fluvial

Fluvial modelling can be undertaken in 1D, 2D or through linked or non-linked 1D-2D modelling. 1D software is typically used to model the main channel of a watercourse, but can

also be extended across a floodplain to represent simple situations. 2D modelling is typically utilised to model areas of floodplain or overland flow, but can also be used to model watercourses where the channel is wide enough to be realistically represented in 2D. A combination of 1D-2D modelling can either be linked, where the model automatically passes flow between the 1D and 2D domains of a model, or cannot be linked, where the out of bank flow from a 1D model is used as the input to a 2D domain to represent overland flow.

Coastal

Coastal modelling is comprised of two parts; the assessment of still water levels and wave run-up/overtopping. Still water levels for a range of return periods are available from the Defra dataset; however, the levels do not extend to all locations, e.g. up estuaries, and modelling may therefore be required. This could range from the simple interpolation of levels to detailed 2D modelling of the area. Once the nearshore wave characteristics have been determined wave run-up and overtopping rates and volumes can be derived using the methods detailed within the EuroTop manual.

Pluvial

Pluvial modelling uses a 2D raster approach to simulate rainfall runoff over the topography of an area. The DTM of the area can be edited to, for example, remove false blockages, represent buildings and lower roads. Roughness values can be applied as a blanket value or varied according to land use. Outputs from pluvial modelling can include flood depths, velocities and outlines, as well as hazard index and flow direction arrows.

Integrated Sewer Modelling

Integrated sewer modelling can represent a number of different elements in an integrated manner, with the models linked together and able to interact with one another dynamically. This can consider the interactions between pluvial events and the sewer network, or more recent developments have lead to 'integrated catchment modelling', which can also include the interaction of pluvial events, the sewer network and local watercourses.

Model Calibration

Calibration is necessary to develop confidence in the hydraulic model's predictions of flood depths and extents and to test levels of uncertainty and confidence in the parameters used. Calibration is achieved through the use of historic flood data; ideally, this information is primarily in the form of peak water levels at specific locations, which correspond to peak recorded river flows. However, if no data is available to allow calibration of the model, sensitivity analysis should be undertaken so as to determine the effect of uncertainty of the different parameters used. Consideration should also be given to the likelihood and potential effects of bridge blockage.

Flood Mapping

Flood mapping allows the visualisation of flood risk within an area. Most 2D modelling software can automatically produce outputs including flood extents, depths, velocities and hazard index, whereas outputs from 1D models generally require further manipulation, e.g. interpolation between cross sections.

Data Sources/ Guidance Documents	• Environment Agency Fluvial Design Guide - Chapter 7: Hydraulic Analysis and Design http://evidence.environment-agency.gov.uk/FCERM/en/FluvialDesignGuide/Chapter_7_Background.aspx • EuroTop manual: *EuroTop - Wave Overtopping of Sea Defence and Related Structures: Assessment Manual, August 2007* • Annexes to Surface Water Management Plan Technical Guidance, March 2010 http://www.defra.gov.uk/publications/files/pb13546-swmp-guidance-annex-100319.pdf • Software User Manuals JBA Training Courses: - River Modelling Methods - 2D River Modelling Overview - Software courses in HEC-RAS, ISIS and TuFlow
Typical Activities	**Fluvial** • Construct 1D, 2D or linked 1D-2D hydraulic model as required • Run model for the required design events and scenarios • Undertaken model calibration and validation if data is available • Undertake sensitivity analysis and consider blockage scenarios • Produce flood maps • **Coastal** • Determine if still water levels are readily available within the Defra dataset, and derive if necessary. • Determine flood risk due to still water levels • Consider whether waves may pose an additional element of risk • Determine wave run-up and overtopping volumes and rates. Further 2D modelling can be undertaken to determine flow routes and/or ponding if applicable. • Produce flood maps • **Pluvial** • Edit DTM to account for false blockages, buildings, roads, etc as required. • Run model for the required design events and scenarios • Produce flood maps

H.5 Assessment of Flood Risk

Hydrology and hydraulic modelling can be used to determine flood hazard from different sources within and area. This is then converted to risk through the consideration of the potential implications of the hazard. Risk is most often associated with both the probability of flooding and the consequence of flooding. The assessment of probability is determined by the hydrological, hydraulic and flood mapping undertaken. The consequence of flooding will relate to the type receptors at risk, vulnerability of households at risk and the presence of critical infrastructure. Further analysis may therefore be required to quantify this risk such as:

- Property counts
- Multi-criteria assessments
- Risk to life or social appraisals
- Flood damage or economic appraisals

The above assessments may require simple GIS queries or more specialist tasks and advice.

I Survey cross section drawings

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