The Highland Council
Comhairle na Gàidhealtachd

Please ask for:
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Your Ref:
Our Ref: AC5010_Smithton_Culloden FAS
Date: 03 April 2012

Dear Sir/Madam,

In accordance with the exceptions under Regulations 10(4)(d) and 10(5)(f) of the Environmental Information (Scotland) Regulations 2004 the Highland Council have redacted the following sections of this report:

- specific property addresses and names of residents mentioned throughout the report;
- maps and figures showing actual and modelled flood outlines in relation to properties;
- Appendix E - Properties affected and estimated flood damages; and
- Pluvial flood maps not yet released by SEPA.

Yours sincerely

MATT SMITH
Principal Engineer & Team Leader
Flood Team

On behalf of NEIL GILLIES
Director of Transport Environmental and Community Services

Inverness East
Post Flood Report

Final Report

February 2012

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Revision History

Revision Ref / Date Issued	Amendments	Issued to
Draft Report / 10 November 2011	-	Matt Smith
Final Report / 27 February 2012	Minor text amendments and corrections. Incorporation of comments from SEPA Addition of Appendices	Matt Smith

Contract

This report describes work commissioned by Matt Smith, on behalf of Highland Council, by a letter dated 23 August 2011. Highland Council's representative for the contract was Matt Smith. Angus Pettit, David Bassett, Nicola Buckley and I-Hsien Porter of JBA Consulting carried out this work.

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Purpose

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

Acknowledgements

We would like to thank the Highland Council staff that contributed and provided information to support the findings of this report including Martin Boshoff, Michelle Laurie, Mike Stephens and John Taylor. We would also like to thank Becky Thomson of SEPA for the provision of rainfall and flow data.

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Executive Summary

After a wet summer, exceptionally intense rain fell on a number of occasions to the east of Inverness. During the weekends of 16/17 July 2011 and 6/7 August 2011 the Inverness area, and in particular the Smithton and Culloden area, flooding as a result of heavy, persistent rainfall caused water levels to rise quickly within burns, resulting in flooding to properties and roads.

Highland Council responded to these flood events during the flood with assistance from emergency services. Following the emergency response phase Highland Council collated information on flood extents, impacts, causes and this report was commissioned to determine the severity and to recommend options to reduce future flood risk from the Smithton and Culloden Burn West.

Whilst flooding occurred in and around a number of watercourses in the area the most serious flooding occurred on the Smithton Burn and Culloden Burn West (also known as the Red Burn). JBA's commission was therefore to review these two burns. Highland Council has been undertaking works to the other burns affected by flooding to mitigate future flood risks on these burns.

On the 18 September a Public Meeting was held to gather the communities concerns, experiences and thoughts on flood mitigation. The Council also took this opportunity to present to the community plans to reduce risk in the area.

The community's general concerns can be split into the following key issues:

- Flooding on the burns is not a new problem with previous flooding occurring a number of times and in particular in 2002.
- The response to flooding and emergency works was reactive and poorly planned.
- The culverts and burn crossings on the burns are perceived to be under capacity.
- Surface water run-off is a major issue and is exacerbated by perceived under capacity of drainage and Sustainable Urban Drainage Systems put in as part of the new developments (particularly on the Smithton Burn).
- General concern that new developments did not provide adequate drainage or sufficiently consider flood risk management at the catchment scale.
- Erosion to banks and watercourse is a major issue that contributed to the flooding.
- Concern that flooding to properties will occur again. Improved knowledge of responsibilities and how to protect properties from flooding.

This report aims to answer these issues and provide the Council with a set of recommendations for future works to alleviate flood risk on the two burns.

Our investigations have confirmed that the summer was exceptionally wet with nearly one third of annual rainfall occurring in one month. This was exacerbated by further localised intensive rainfall on the weekends of 16/17 July 2011 and 6/7 August 2011.

The discrete events have been estimated to be equivalent to a 15 year return period rainfall event across the area for July and a 45 year return period rainfall event for August. These may have been locally higher in the two catchments generating an estimated fluvial return period of 30 and 45 years on the Culloden Burn West and Smithton Burn respectively.

The capacities of the burns, culverts and structures have been assessed. The capacities vary significantly throughout the reaches. Assessments of the structures shows that the capacities (particularly the culverts and screens) reduce when assessed against current best practice. It also confirms that this could be readily improved through adoption of best practice design for culvert screens, improved maintenance, removal of culverts, removal of old screens and stream restoration.

Flooding on the Smithton Burn has a strong link to the mobilisation and subsequent deposition of gravel either from made ground and / or recent modification to the burn. Gravel was deposited at the railway bridge above inadequate culvert screens causing significant volumes of water to leave the burn. Other flooding is associated with low banks, blockage, sedimentation, drainage and overland flow.

Culloden Burn West was more closely linked to woody debris and vegetation gathering on the inadequate screen and flowing overland.

The solutions can either be effected as FRM measures or considered in more detail as a strategic scheme. Adoption of maintenance and standoff strip from watercourses would 'make space for water' and ease maintenance requirements. Improved regulation of river structures could also reduce flood risk.

After flooding in 2002 some measures were taken to reduce flood risk and others planned. Not all of the planned measures identified within the Biennial Reports were implemented, possibly due to other higher risks/events occurring (such as the major event in Dingwall in 2006). In addition significant development upstream of a key point of flood risk on the Smithton burn was undertaken and more space could have been left for the burn. The connectivity of rural drainage at the urban fringe should be reviewed and considered in future development as overland flow can be uncontrolled and enter the urban fringe at a number of locations.

In the short term careful consideration should be given to each structure but in particular the removal of the following three culverts should be investigated:

- the culvert adjacent to Murray Terrace,
- the culvert beneath Murray Road and the park and
- the culvert beneath the garden of Redburn Avenue.

Further screen improvements and gravel traps should also be considered as a minimum, combined with enhanced catchment wide risk-based maintenance to reduce flood risk.

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Abbreviations

2D	Two Dimensional (modelling)
AP	Annual Probability
AM	Annual Maximum
BFI	Base Flow Index
BGS	British Geological Survey
CCTV	Closed Circuit Television
CIRIA	Company providing research and training in the construction industry
DDF	Depth Duration Frequency
DTM	Digital Terrain Model
EA	Environment Agency
FEH	Flood Estimation Handbook
GIS	Geographical Information System
IH	Institute of Hydrology
JBA	JBA Consulting – Engineers & Scientists
J|FLOW	2-D hydraulic modelling package developed by JBA
LiDAR	Light Detection And Ranging
mAOD	metres Above Ordnance Datum
OS	Ordnance Survey
Q100	Flow at the 100-year return period
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
RR	Rainfall-Runoff
SEPA	Scottish Environment Protection Agency
SPR	Standard percentage runoff
SUDS	Sustainable Urban Drainage Systems
TBR	Tipping Bucket Raingauge
Tp	Time to Peak
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBEXT	FEH index of fractional urban extent

1 Introduction and site description

1.1 Background

This study was commissioned by Highland Council to investigate the causes of recent flooding in the area to the east of Inverness (close to Smithton and Culloden) in July and August 2011, and to make recommendations for mitigation measures to reduce flooding.

The weekend of the 8 July saw significant rainfall in the area of Inverness that resulted in the closure of the Golf Open at Castle Stuart links course on the Moray Firth. During the weekends of 16/17 July 2011 and 6/7 August 2011 the area to the east of Inverness, and in particular the communities of Smithton and Culloden experienced flooding as a result of localised, heavy, persistent rainfall on already saturated catchments that caused water levels to rise within the burns that flow through this area.

Blockages at culvert screens and inlets caused a build-up of sediment and debris that also contributed to the flooding. Current information indicates that approximately 50 properties were directly affected by flood water in the Smithton/Culloden area and a number of other properties in the surrounding areas.

1.2 Report objectives and approach

The aim of the flood study is two-fold namely:

1. to investigate the cause of the recent flood events that have affected various urban areas within the study area including a post-flood analysis; and
2. to identify sustainable, solutions for detailed consideration to reduce flood risk within the study area.

The study will be broken down into two stages with a reporting and review process at the end of each stage. This report covers Stage 1 that represents a thorough understanding of the causes and key flood mechanisms that have played a role in causing the recent flooding. Stage 1 will also include an assessment of the capacity of the SUDS ponds. Stage 1 will be used as a scoping study for further work required to assess flood risk to the study area in detail.

Stage 2 will be a detailed Flood Risk Assessment of all the catchments in question to develop strategies developed to reduce the risk of flooding to houses, businesses and critical infrastructure to an acceptable standard in a sustainable, efficient and cost-effective manner based on the recommendations from Stage 1.

The study is restricted to the analysis of the two burns that caused the majority of flooding during the 16/17 July and 6-7 August, namely the Smithton Burn and the Culloden Burn West (also locally known as the Red Burn).

1.2.1 Scope of Stage 1

- Channel survey to ordnance datum;
- Analysis and contextualisation of rainfall event data and antecedent meteorological conditions preceding the flood events of 16/17 July 2011 and 6/7 August 2011;
- Summary and maps of the affected areas to property level including a review of impacts i.e. flood depths/extents/velocities within the study area;
- Investigation and description of the main mechanisms of flooding e.g. fluvial & surface water sources, blocked/under-capacity culverts, overwhelmed SuDS features etc within the study area;
- Estimation of peak flood flows during the recent flood events on the watercourses within the study area where possible;
- Estimation of statistical peak flood flows anticipated for return periods up to the 1:200 year plus an allowance for climate change;

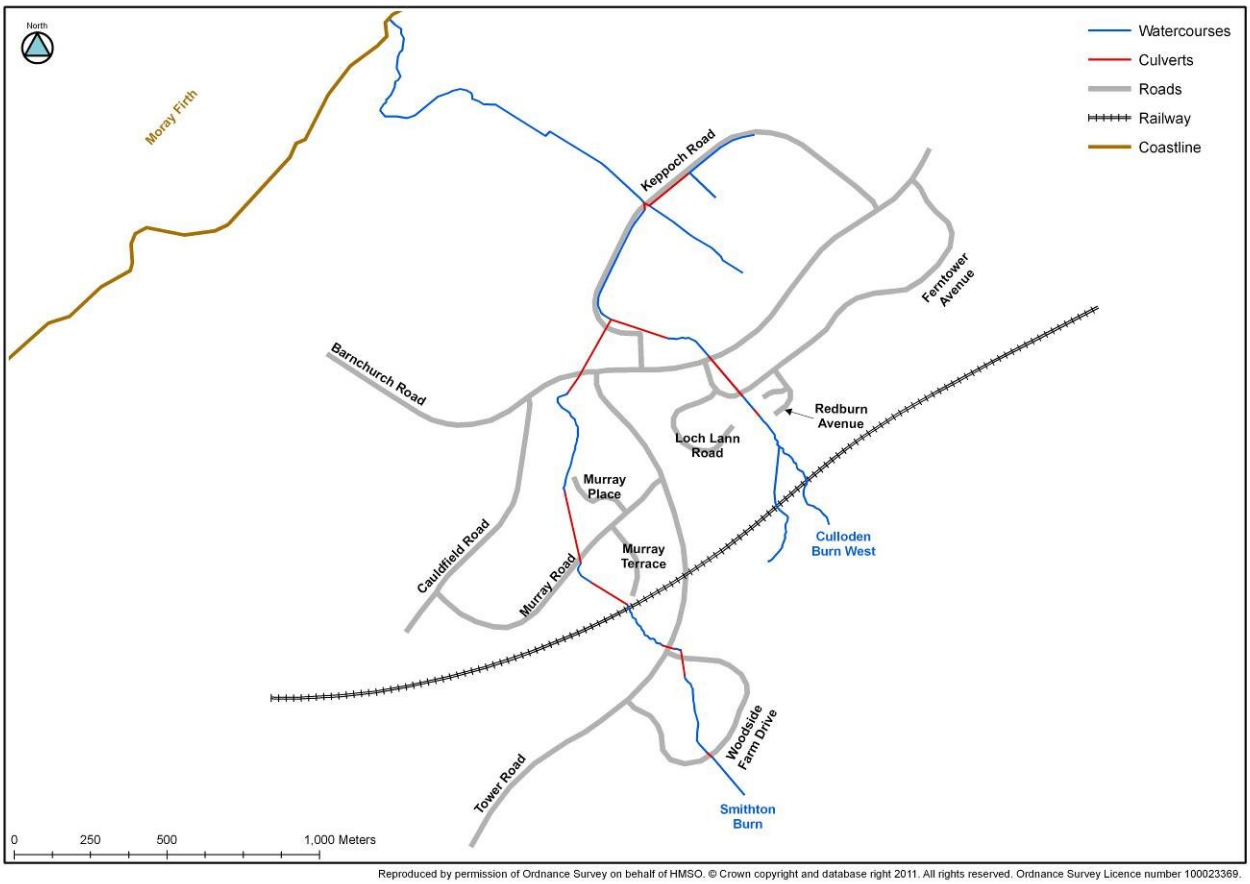
- A preliminary assessment of channel/culvert conveyance capacity within the Smithton Burn and the Red Burn at the locations where flood water came out of bank during recent flood events;
- Comment and recommendations on suitable enhanced maintenance;
- Identify any improvements to trash screens and maintenance;
- Identification and recommendation of the most appropriate industry accepted methodologies for assessing existing and future flood risk from all sources (having due regard for the SEPA pluvial flooding project for Inverness) within the study area;
- A specification of works to deliver the above assessment including a cost estimate.

1.3 Site and catchment description

A number of small burns to the east of the A9 and Inverness rise in the hillside south of the communities of Cradlehall, Westhill, Smithton, Culloden and Balloch. These burns flow roughly parallel to each other through these communities in a north westerly direction before discharging into the Moray Firth to the east of Inverness. A general schematic of the area is provided in Figure 1-1.

The burns start on the lower gradient moorland before flowing through steep sections of channel, often through built up urban areas before reaching relatively flat farmland and drainage ditches nearer to the estuary. Through the urban areas the channel can be heavily modified and in some sections are steep and erodible. Reaches are culverted, bridged, armoured, contain headwalls, gates, screens, erosion protection and other features. Urban drainage is controlled by Sustainable Urban Drainage Systems (SUDS) in the upper catchments where development is more recent, and a complex network of surface water and combined sewer drainage.

Figure 1-1: Schematic of the watercourses and key road crossings



1.4 Return Period and Probability

For flood frequency analysis, the probability of an event occurring is expressed as a return period. The return period on the annual maximum scale, T, is defined as the average interval between years containing one or more floods exceeding a flow Q (T). In the Flood Estimation Handbook (FEH), the flood with return period T is referred to as the T-year flood.

A useful term closely linked to return period is the annual probability, AP, which is the probability of a flood greater than Q(T) occurring in any year. This is simply the inverse of T:

$$AEP = 1/T$$

For example, there is a 1 in 100 chance of a flood exceeding the 100-year flood in any one year.

Table 1-1: Return period and equivalent annual probability

Return Period	Annual Probability [AP] (%)
2 year	50
5 year	20
10 year	10
25 year	4
30 year	3.33
50 year	2
75 year	1.33
100 year	1
200 year	0.5
500 year	0.2
1000 year	0.1

It is very important to realise that a flood with a return period of T years has a finite probability of occurring during any period of duration less than T years. The probability p that a T year flood will occur at least once in an N year period is given by the "risk equation":

$$p = 1 - (1 - 1/T)^N$$

This equation indicates that over the last 10 years since the last flood, the probability of a 100 year flood occurring is 10%. This increases to 34% for a 25 year flood occurring in a 10 year period.

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2 Watercourse description

2.1 Summary and introduction

The Smithton Burn and Culloden Burn West are two burns of several that drain the western slopes of Culloden Muir between Balloch to the east and the A9 and Inverness to the west before discharging into the Moray Firth. The burns in this area have similar characteristics with flatter upper catchments, steep mid sections and low gradient sections near to the coast. The catchments are all long and narrow, urbanised in the middle to lower reaches and partially wooded.

The upper catchment of the Culloden Burn West is located on the Culloden Muir with an elevation up to 150m before flowing through Culloden Wood. The middle reach is steep and passes through an urbanised section of Culloden via a number of culverts and engineered river sections. The lower reach has a shallower gradient, is less constrained and more open with fewer river crossings before discharging to the estuary. The catchment area is approximately 1.4km^2.

The upper reach of the Smithton Burn drains the upper Culloden Muir, but has been gradually developed further up the hill from Tower Road over the last 10 years. The reach through the newly developed area covering the urban areas of Westhill and Smithton is urbanised and steep, the watercourse often constrained by culverts, crossings and property fences and boundary walls. The urbanisation has left very little room for the burn and no discernible floodplain. There are a number of long culverts in the middle reach before the burn reduces in gradient and opens out in the region of Murray Place and Smithton Villas. The Burn joins the Culloden Burn West via a final long culvert.

2.2 History of flooding

The burns to the east of Inverness have a history of flooding that has been well documented by Highland Council. Indeed there are historic records[1] of high rainfall events in the area including:

- *27 August 1829 - "considerable flood damage in Inverness; crops flattened, numerous bridges lost, mills and homes damaged…"*
- *24 July 1846 - "The storms were widespread in Scotland. Around Inverness the rain poured down in torrents, flooding a good deal of the country."*
- *25 September 1890 - Rainfall observer at Loch Sheil, West Inverness, noted "Rain 3.57 in. causing an exceptionally great flood."*
- *15 August 1893 - "Thunderstorm in Strathnairn: The somewhat remarkable thunderstorm of Tuesday afternoon, which was startling but not destructive in the immediate neighborhood of Inverness."*
- *24-26 September 1915 - rainfall "totals exceeding 3.5 inches were measured, at Inverness (3.64 in), Nairn (3.78 in)…"*

More recent flooding events recorded by Highland Council on the Smithton Burn and Culloden Burn West include the following:

- 28 November 1999 - Flooding to properties on Murray Terrace (Smithton Burn).
- 8 September 2002 - Severe flooding to a number of locations in September and October resulting in overland flows and flooding to roads, houses, gardens and commercial properties (Smithton Burn and Culloden Burn West). 55mm of rain fell during the night of the 7/8 September[2].
- 3 July 2004 - Short term torrential rainfall resulting in burn overtopping and garden flooding on Redburn Avenue (Culloden Burn West).
- 4 July 2007 - "Gullies surcharging on lower section of Tower Road. Water flowing down road to junction with Barnchurch Road"

[1] Chronology of British Hydrological Events (http://www.dundee.ac.uk/geography/cbhe/)
[2] Highland Council, 4th Biennial Report (2003)

These more recent flood events are shown geographically in Figure 1.

2.3 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[3].

The channel reaches for the Culloden Burn West and Smithton Burn are presented within Figure 2-1 and Figure 2-2 respectively, with a summary of the key features of each reach presented below. Full details are presented within Appendix D.

Table 2-1: Summary of Culloden Burn West Channel Reaches

Reach	Summary	Erosion Risk Category
K	Steep, erosive reach within a steep sided densely vegetated valley. The channel has a step-pool form, with some steps formed by natural logjams. Sediment eroded from the reach would be passed downstream although much of this would be caught behind the gabion dam at the downstream extent of this reach.	High
L	Straightened and highly modified reach, with the channel lined with gabions along its length. Sediment has accumulated at various points along this reach, but is particularly observed at the downstream extent of the reach, upstream of the Ferntower Avenue culvert.	Low
M	Small, shallow sided valley with sections of both erosion and sediment accumulation.	Medium
N	Stable reach, with only a couple of localised sections of bank erosion and little evidence of sediment accumulation.	Low

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

Figure 2-1: Culloden Burn West Channel Reaches

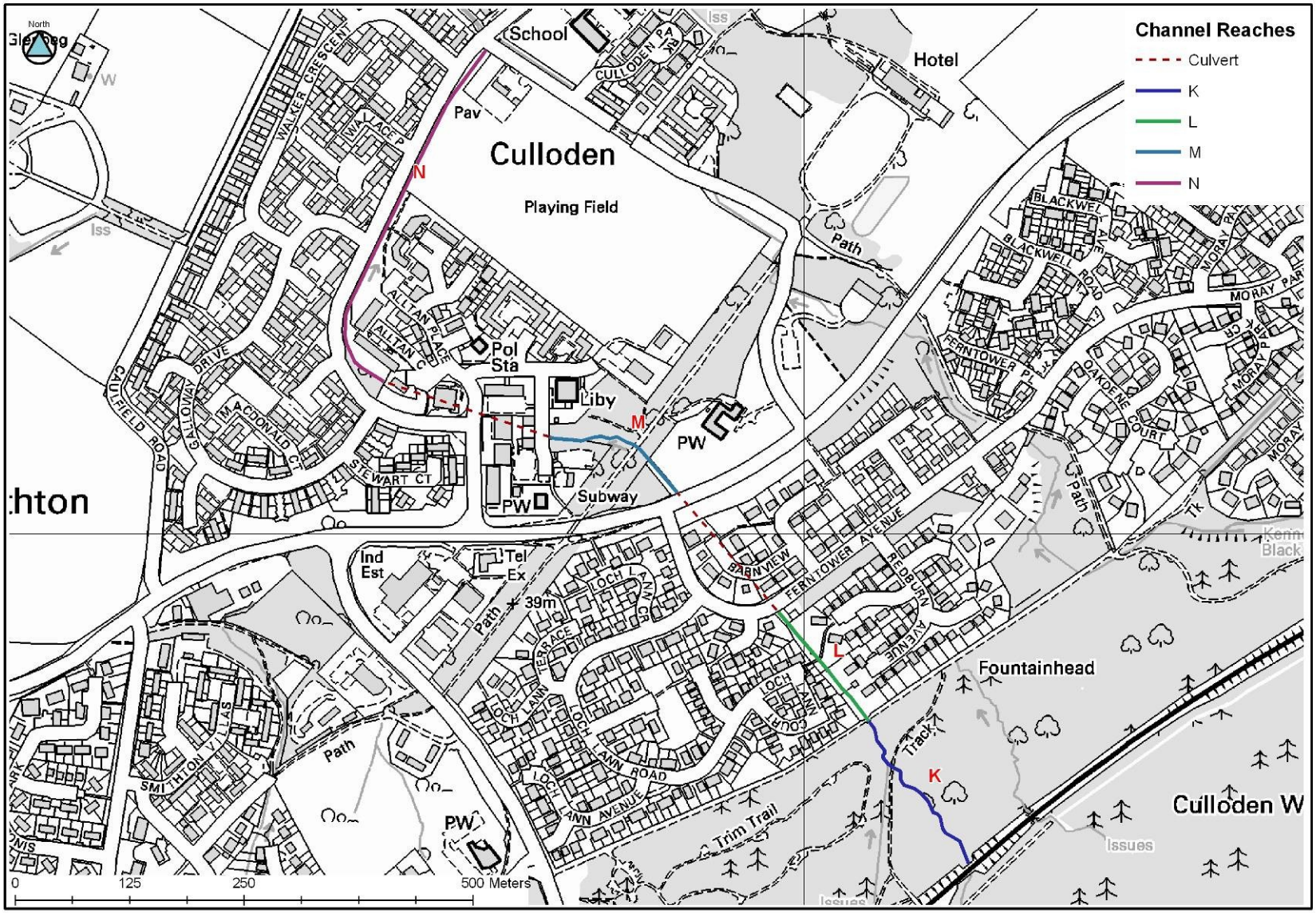

Figure 2-2: Smithton Burn Channel Reaches

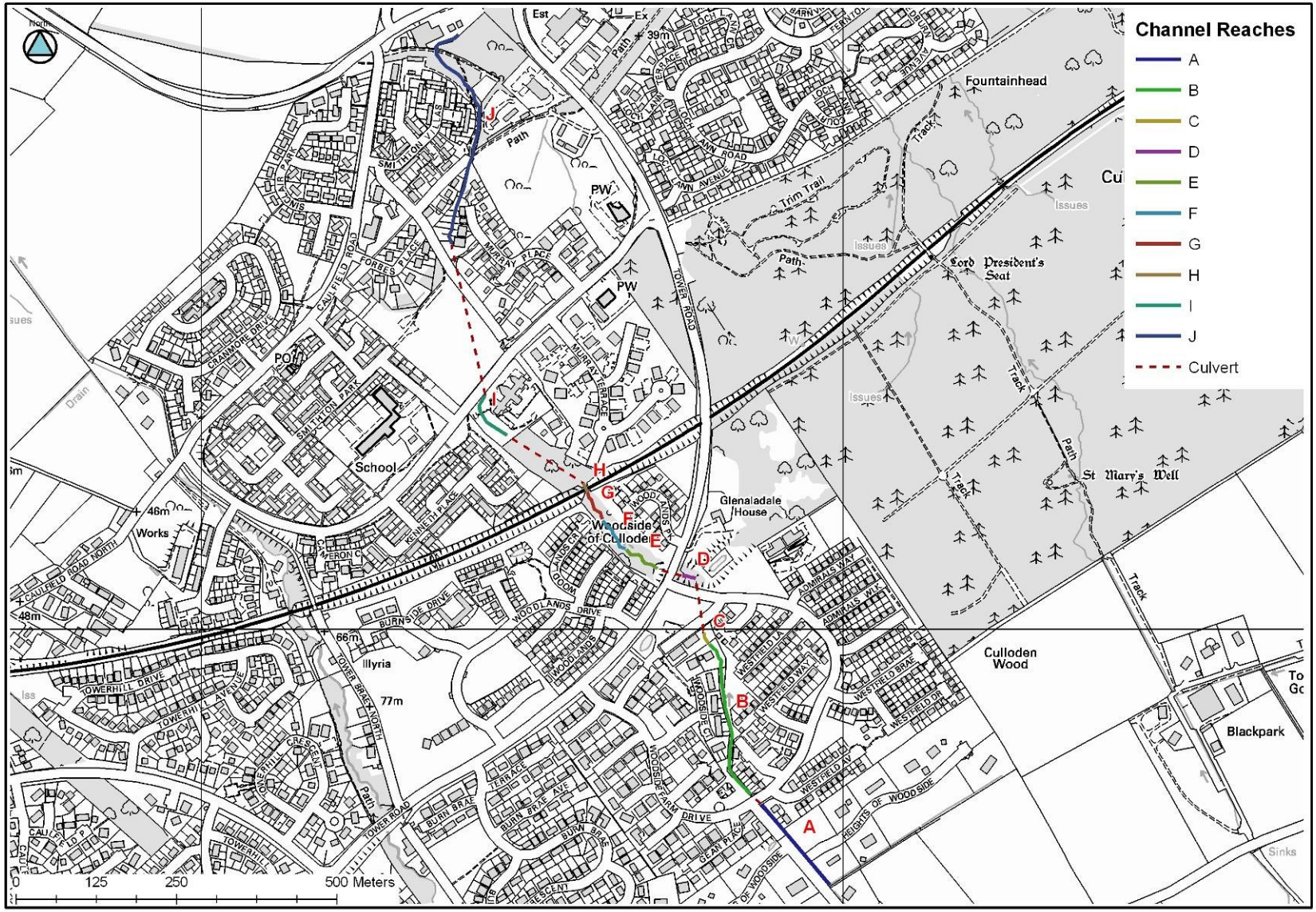

Table 2-2: Summary of Smithton Burn Channel Reaches

Reach	Summary	Erosion Risk category
A	Historic straightening and improvements to land drainage within the upper catchment. Natural sediment load from the upper catchment is low, with this reduced further by the historical lining of the channel.	Low
B	The burn has been significantly modified within this reach, with development present to the top of either bank. The banks have sporadically been reinforced to protect property and allow for structures spanning the burn. The cumulative effect of the changes is that the erosion potential of the burn has increased, with the confinement of the burn focussing the energy within the channel during flood events. The sporadic nature of the modifications results in the erosion transferring to other areas and thus releasing a significant amount of sediment downstream.	Medium
C	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.	High
D	The reach is effective at conveying sediment from upstream, and is also subject to further erosion. This is exemplified by a SUDS outfall that is sitting 0.5-1m above the bed level. However, there is also some deposition immediately upstream of Tower Road culvert.	Medium
E	A large scour pool is present at the end of Tower Road culvert, with sediment deposition downstream; the accumulation of sediment confirms the ability of the culverts upstream to convey sediment from the upper reaches. Downstream of the pool the burn is relatively natural. It is subject to erosion and is effective at conveying sediment downstream through a step-pool system.	High
F	The reach is steep and has undergone extensive recent erosion. This may have resulted from the historical clearing of sediment in the vicinity of the railway bridge, which created a nick-point that then spread upstream during a subsequent flood. A series of boulder weirs have recently been installed in an attempt to stabilise the channel and control the bed level through the reach.	High
G	The channel gradient decreases and the burn widens upstream of the railway bridge, thus resulting in sediment deposition. Significant alteration of the channel at this location has taken place following the recent flood events. This is demonstrated in the photographs below. **Pre flood (March 2010)**  **Post flood (September 2011)** 	High
H	A large volume of sediment accumulates in the vicinity of the railway bridge and upstream of Murray Terrace culvert, with the trash screen upstream of the culvert believed to act as a significant blockage to sediment and flow.	High
I	There are small amounts of deposited sediment present within the channel, thus suggesting that sediment is able to be conveyed through the long culvert downstream of the railway bridge.	Low
J	The reach downstream of the Murray Place culvert is stable. The culvert itself is partially blocked at the downstream end. The size of sediment is much smaller than that observed in the upper reaches suggesting that the larger sediment may not be actively transferred through the long culvert.	Low

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