12 Conclusions and recommendations

12.1 Rainfall events

1. High rainfall events are not uncommon and flooding in the area has been recorded in the past.
2. Almost 50% of the normal average annual rainfall for Inverness fell at the Culloden Leannach raingauge over July and August. Within this period of above average rainfall for July and August specific rainfall events occurred on the 8-10 July, 16 July and the 6-7 August. The latter two led to flooding on the Inverness East burns.
3. The July rainfall event had a uniform pattern over the region generating approximately 50-60 mm in a 24 hour period. This intense rainfall resulted in rainfall return periods in the region of 9-16 years in the area to the east of Inverness but may have been closer to a 80 year return period in the region of the Culloden gauge.
4. 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.
5. These flows are estimated to be equivalent to a return period of approximately 40 years and 30 years on the Culloden Burn West and Smithton Burn respectively.

12.2 Culvert Capacity and overland flow modelling

6. The modelling undertaken has shown that combined 1D and 2D modelling can re-create the complex flood flows observed during the event. This approach could be used as a proactive method to assess flood risk for planning purposes for other burns within the area where similar flood mechanisms occur (i.e. structure or sediment blockage, channel capacity exceedence leading to overtopping of flood flows away from the watercourse).
7. Culvert capacities do not provide a sufficient capacity based on current design standards and freeboard. Furthermore, structures and culvert inlets and screens are highly sensitive to debris blockage and poorly maintained which further exacerbates the risk of blockage and flooding. Specifically, the following structures are considered to be high risk due to their poor inlet conditions, undersized culverts, sensitivity to blockage and need for high frequency maintenance to keep screens clear:
    a. The culvert beneath the garden of [redacted] Redburn Avenue,
    b. Culvert beneath high ground adjacent to Murray Terrace,
    c. Culvert beneath Murray Road and the park.

12.3 Flood mechanisms

A number of factors contributed to the flooding and are likely to continue to exacerbate flooding unless further works are undertaken. These include:

8. High flows mobilised sediment and woody debris. It is possible that water gates could suddenly release material downstream onto blockage prone, high risk structures.
9. Many structures are poorly maintained, have non standard culvert screens and in-channel obstructions that increase the probability of sediment and debris blockage. Culverts within the reach would not be considered to have sufficient capacity if current design standards were used. One culvert is currently 50% blocked.
10. Maintenance routines or problem reaches / structures have been identified in the past. However, maintenance and inspection regimes have not provided the necessary procedures to react to flooding on these burns. Furthermore, previous works to certain reaches may have improved channel capacities and stabilised channels, but have not approached some of the root causes of flooding.
11. Riparian bridge crossings and boundary fences increase flood risk and make access to watercourses difficult and impossible to maintain or react to problems during high flows.

12. There is currently no telemetry or sufficient lead time to warn of high flows, or poor procedures to anticipate high rainfall and send operations teams out on standby to deal with flooding at known problem watercourses.
13. There may not have been sufficient maintenance prior to and during events to clear high risk structures of debris.
14. Many structures are unsafe or have poor access for Council staff. Uncontrolled public access and a lack of emergency contact details clearly labelled on structures is also an issue.
15. Blockage of culvert screens resulted in backing up of flows behind the culvert inlets and the eventual overtopping of the culvert headwalls. This lead to overland flow paths away from the burn. Once out of bank no flood management exists to divert flows back into burns, other than reactive sand bagging by the Council.
16. The entry of overland flows into surface water drainage system may have contributed to sewer and surface water flows resulting in drainage capacity exceedence elsewhere in the area particular affecting Smithton Villas. On-site knowledge of drainage connections and the possible risk of moving the flooding issues from one area to the other is not known.
17. A SUDS pond in the upper catchment filled and breached at the low point leading to flooding to properties on Gean Place and over the footpath into the Smithton Burn.
18. Although not generally a problem within the two catchments, bank overtopping and breaching contributed to the flood risk in Smithton Villas.
19. No suitable location exists to store cleared debris from culvert screens without the risk of this re-entering the channel if water levels rise further.
20. Total economic (rather than financial) costs of flooding have been estimated to be £286,000. This represents the damage that occurred due to the recent floods based on available information. The total damages may be greater than those provided due to low declaration from owners within questionnaires.

12.4 Options and recommendations

21. After flooding in 2002 some measures were taken to reduce flood risk and others planned. Not all of the Planned Measures identified in the Parkman Report and subsequent biennial reports have been implemented on site - possibly due to financial constraints or other priorities 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.
22. 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.
23. There are two general approaches to alleviating flood risk in the area: a flood protection scheme or upgraded maintenance combined with small scale measures. A capital scheme has the chance to assess and solve the catchment problems holistically by removing the key structures and the long term inspection and maintenance issued.
24. A scheme of smaller measures and enhance maintenance may significantly increase operational expenditure through the continued and ongoing requirement for maintenance and screen clearance without sufficiently removing the key elements that cause the risk such as the high risk and blockage prone culverts.
25. 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. Due to the small catchments and fast response to rainfall, there is an ongoing risk of failure for this option.
26. It is recommended that in the short term careful consideration should be given to each structure to assess the probability and consequence of flooding and whether culvert removal or improved screen design and gravel traps/watercourse maintenance is the

preferred approach. We recommend that the removal of the Murray Terrace, Murray Road and Loch Lann culverts are investigated in the first instance.

12.5 Requirements for Stage 2

This report summarises Stage 1 of the Inverness study and has provided a thorough understanding of the causes and key flood mechanisms that have played a role in causing the recent flooding. This report also provided suggested scheme and measures that need to be considered to reduce flood risk to the Smithton and Culloden Burn West.

Further work under Stage 2 will be required to determine the most appropriate strategies to reduce the risk of flooding to houses, businesses and critical infrastructure to an acceptable standard in a sustainable, efficient and cost-effective manner. This may include:

- Production of an operation and maintenance manual and schedule
- Feasibility of scheme approach
- Economic appraisal of options
- Detailed design of culvert removal
- Detailed design of screens
- Detailed design of CCTV/Telemetry
- Detailed design of gravel traps
- Detailed design of bank restoration
- Geomorphological audit of Smithton Burn

12.6 Recommended industry standard methodologies and best practice

Appendix H provides a summary of current best practice and industry standards for a number of aspects that will need to be reviewed to take forward the measures and options to mitigate flooding. This includes standards for capital and operational expenditures such as:

- Flood risk assessment,
- Benefit-cost analysis of options,
- Scheme design,
- Watercourse inspection,
- Culvert and screen maintenance,
- Bank/channel erosion works,
- SUDS design,
- Asset management planning.

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Figures Section

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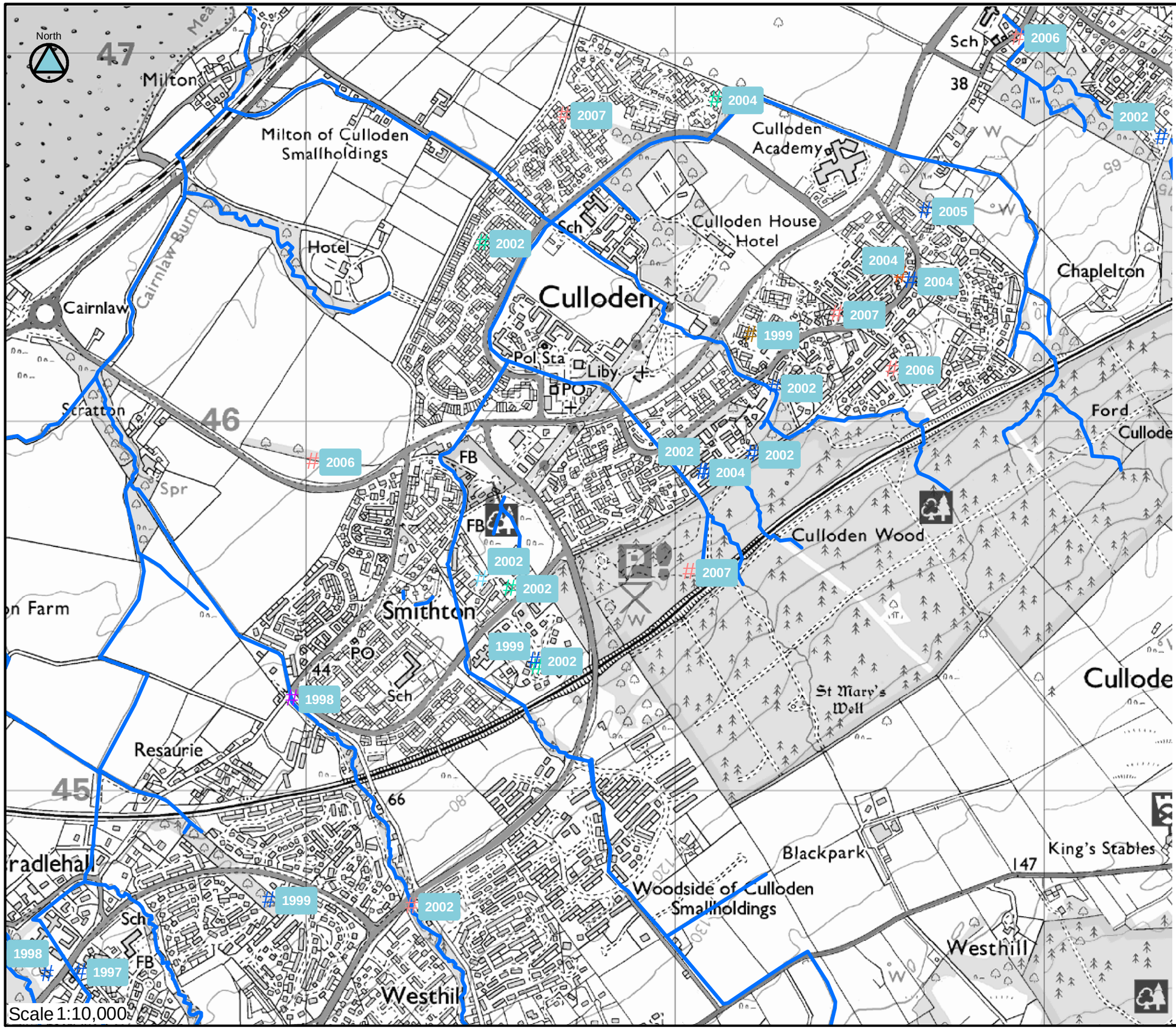

Scale 1:10,000

LEGEND

Watercourses

Flood Source

- Unknown
- Assumed Fluvial
- Fluvial
- Groundwater
- Other Artificial Structure
- Other Drainage
- Pluvial

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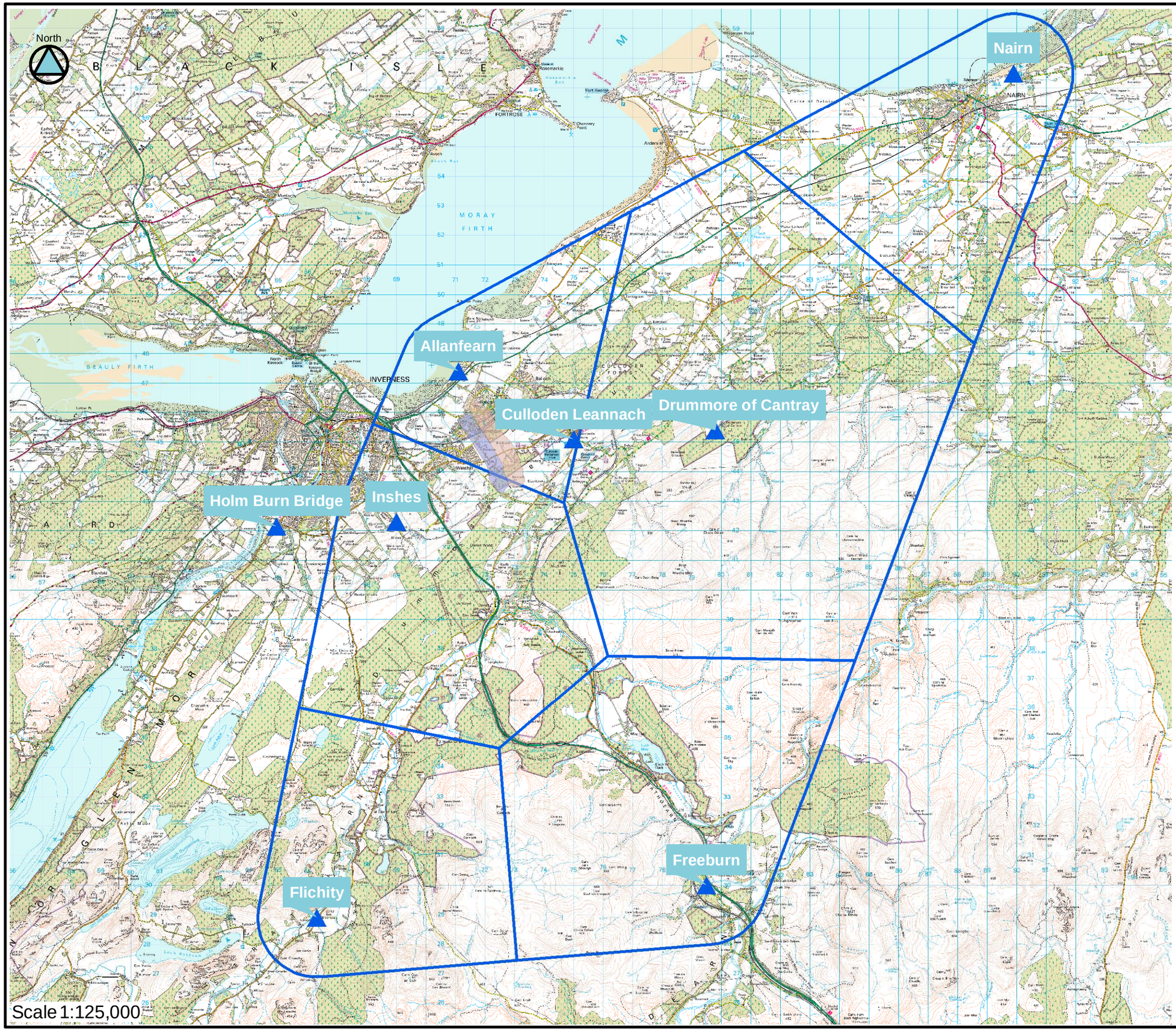
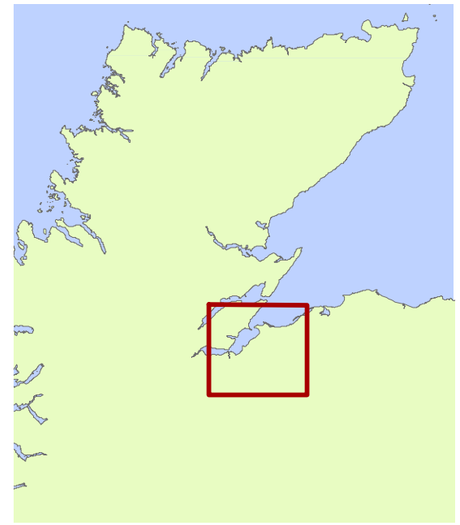
FIGURE 1

Historic Flood Records



KEYPLAN



LEGEND

- Culloden Burn West
- Smithton Burn
- \# Rain Gauges
- TBR Theissen Polygons

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FIGURE 2

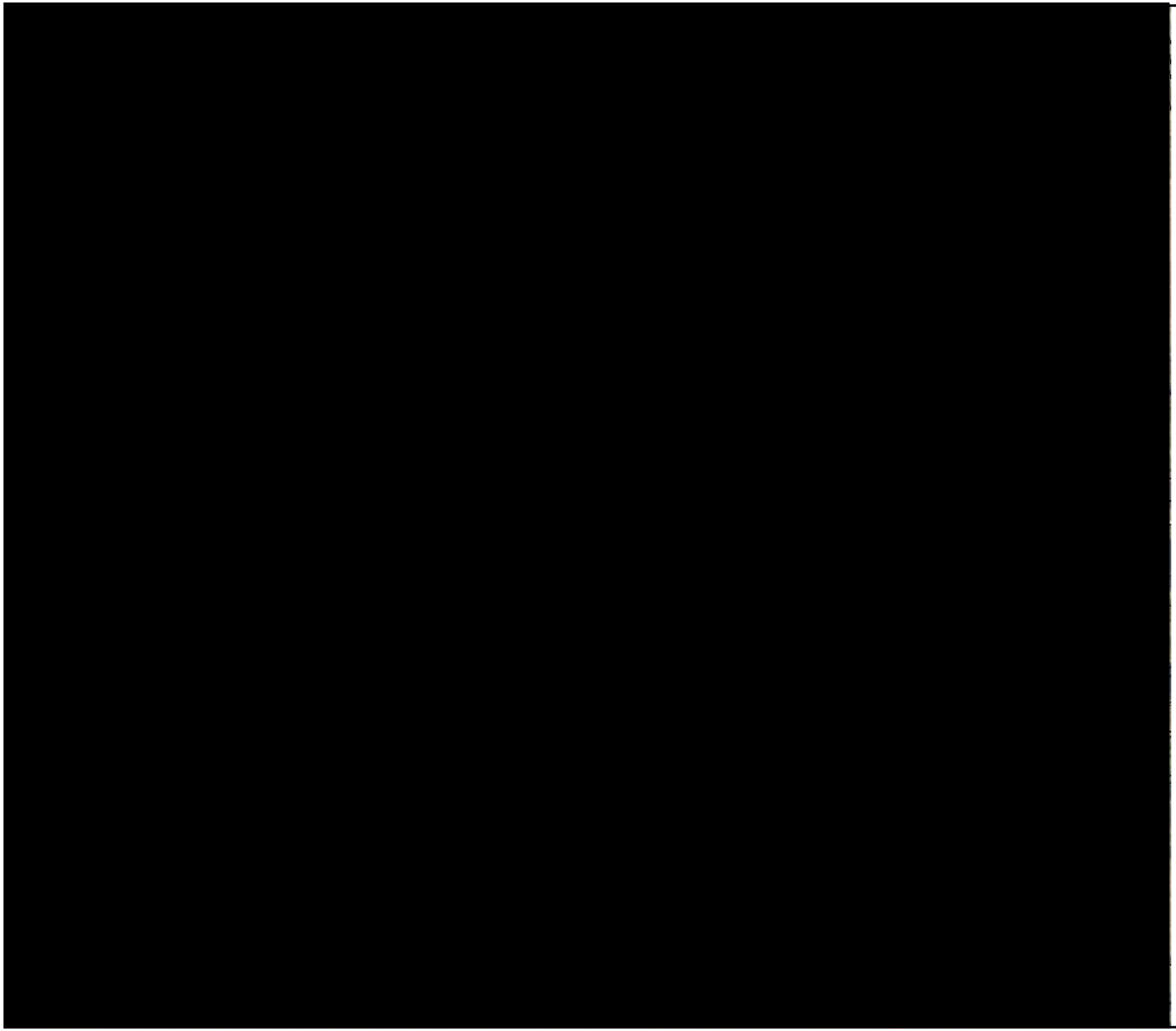
Rain Gauge Locations and Theissen Polygons for Tipping Bucket Gauges

LEGEND

- Estimated Flood Extent
- Properties Affected
- Watercourses

FIGURE 3

Culloden Burn West Estimated Flood Outline (July 2011)



LEGEND

Estimated Flood Extent

Properties Affected

Watercourses

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FIGURE 4

Smithton Burn Estimated Flood Outline (July & August 2011)

LEGEND

- Estimated Flood Extent
- Properties affected
- Watercourses

FIGURE 5

Smithton Burn Estimated Flood Outline (July & August 2011)

LEGEND

- Estimated Flood Extent
- Properties affected
- Watercourses
- Surcharged Manhole

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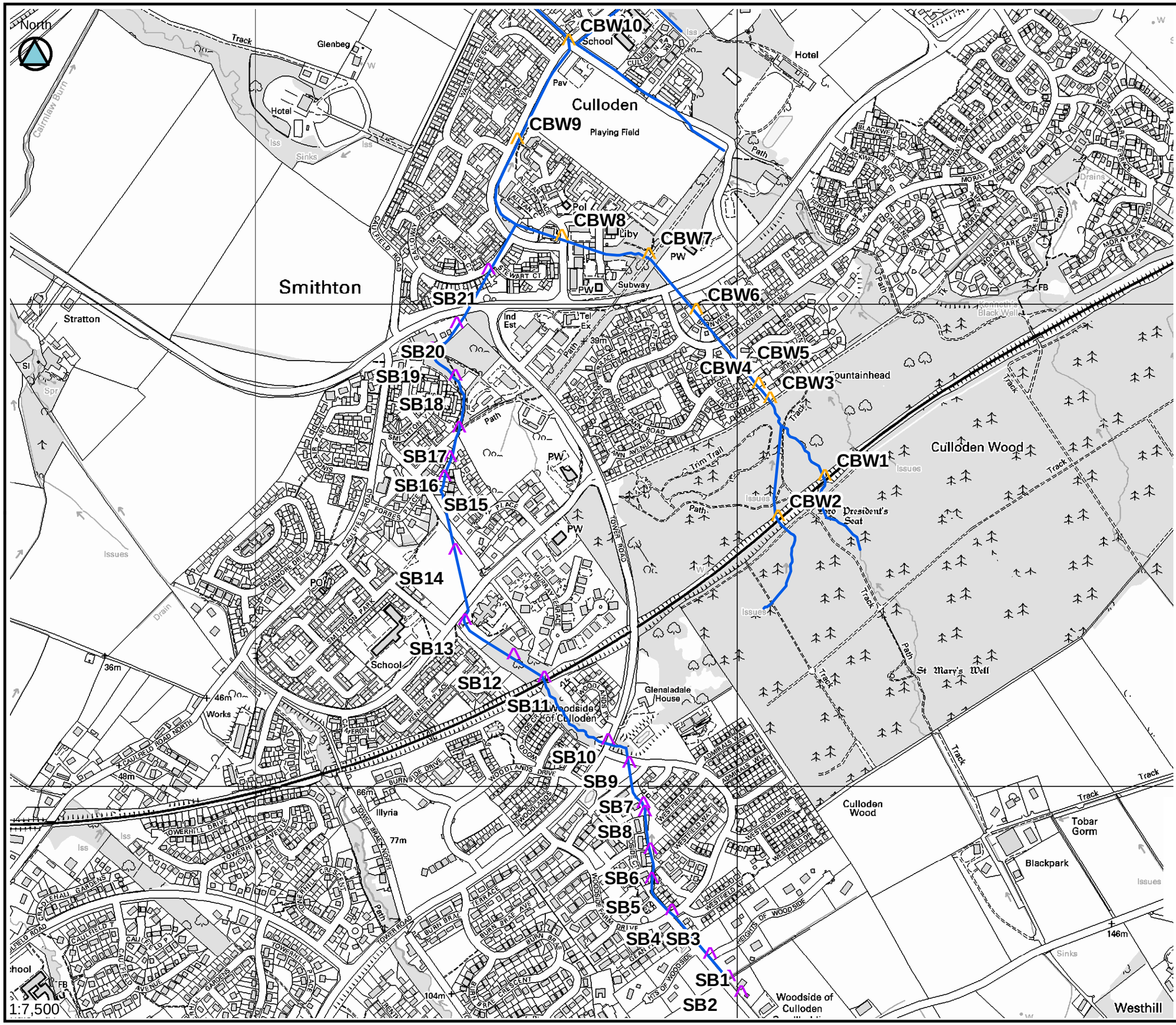
FIGURE 6

Smithton Burn Estimated Flood Outline (July & August 2011)



LEGEND

- Watercourses
- CBW Structures
- SB Structures

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FIGURE 7

Plan of Structures

North

LEGEND

- Model Sections
- Watercourses

CBW_0
CBW_269
CBW_464
CBW_557
CBW_631
CBW_801
CBW_882
CBW_980
SB_0
SB_190
SB_303
SB_453
SB_694
SB_916
SB_1020
SB_1179
SB_1333
SB_1537
SB_1677

Culloden
Playing Field
Smithton
Stratton
Culloden Wood
Fountainhead
President's Seat
St Mary's Well
Glenaladale House
Woodside of Culloden
Culloden Wood
Tobar Gorm
Blackpark
Illyria
School
Works

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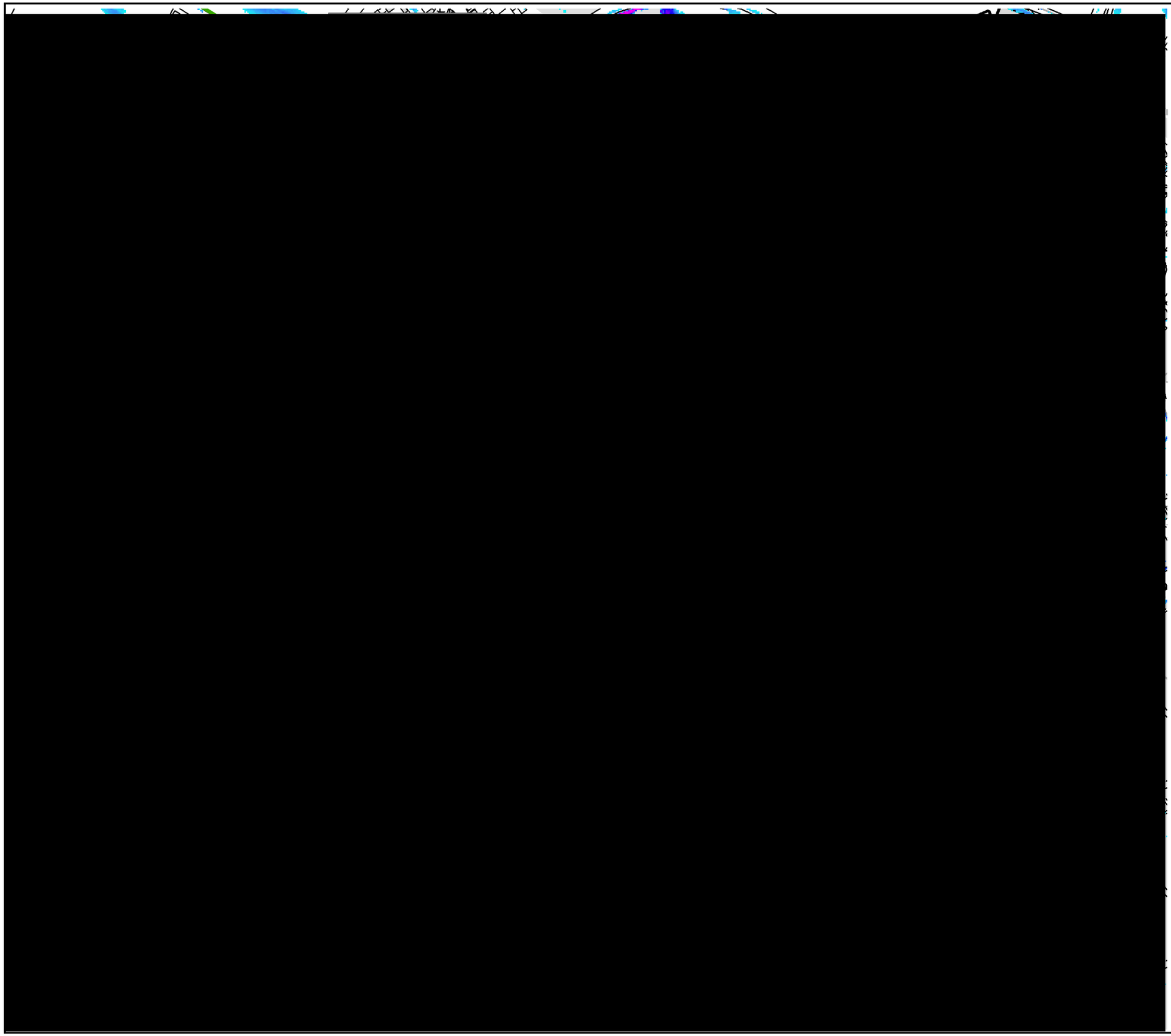
FIGURE 8

Hydraulic Model Cross Sections

1:7,000



LEGEND

0.5% AP (200yr) Depths

High : 4.1m

Low : 0.1m

Culloden Burn West

Culloden Burn West - Culverts

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FIGURE 9

Pluvial Flooding in the Culloden Burn West Catchment

LEGEND

0.5% AP (200yr) Depths

High : 4.1

Low : 0.1

Smithton Burn

Smithton Burn Culverts

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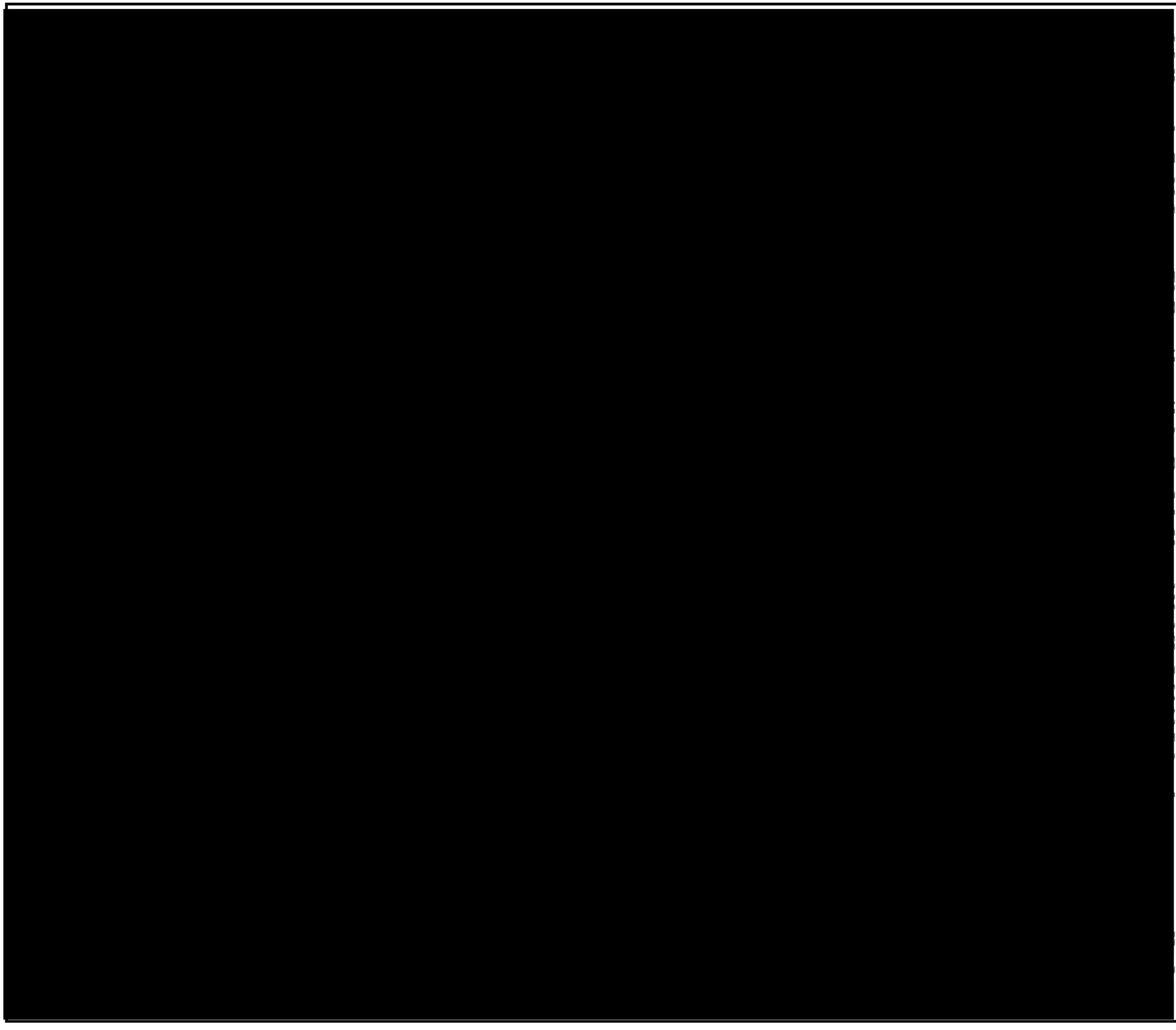
FIGURE 10

Pluvial Flooding in the Smithton Burn Catchment



LEGEND

Watercourses

Culverts

CBW Depths (m)

0.00 - 0.05

0.05 - 0.10

0.10 - 0.25

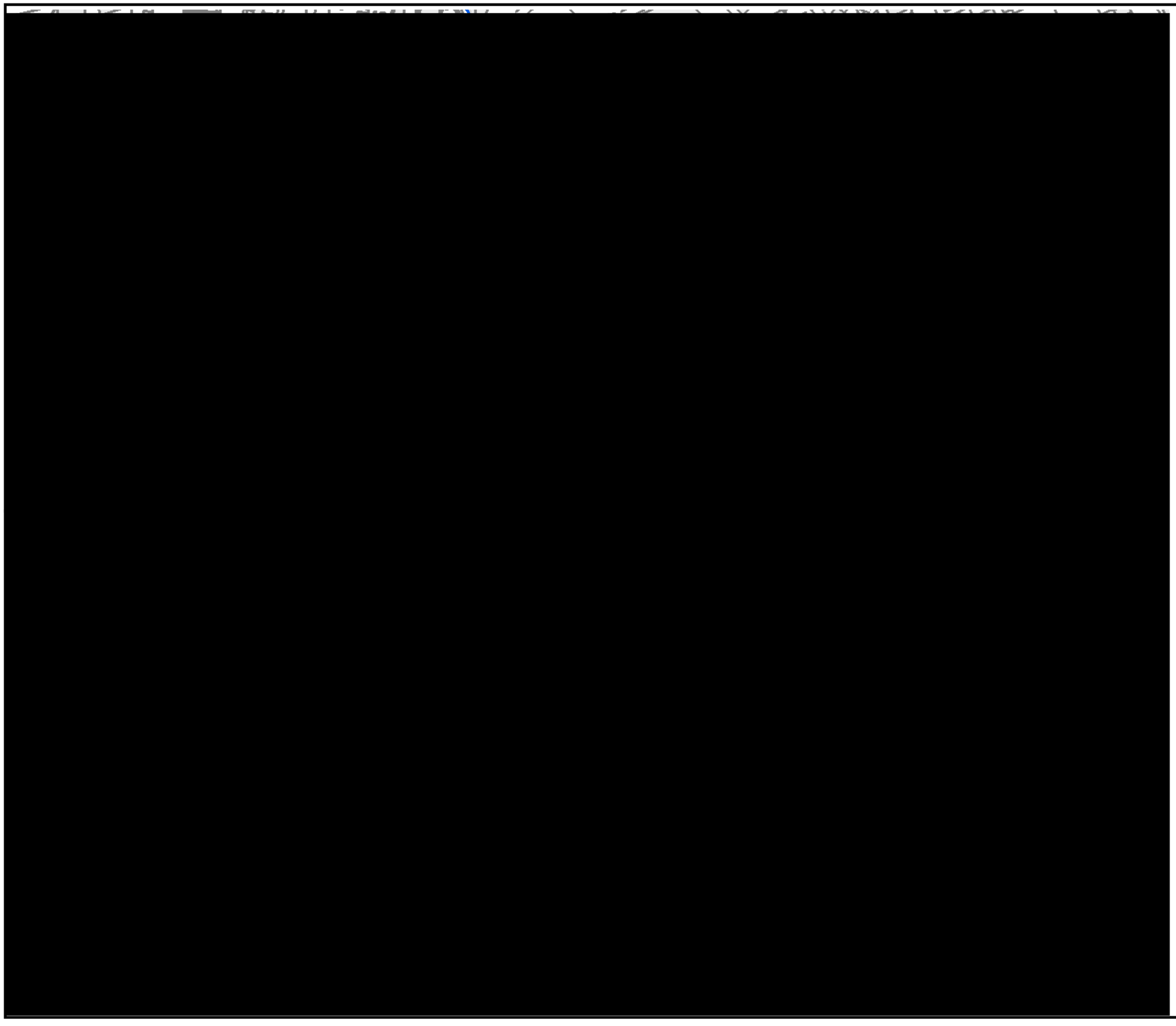
0.25 - 0.50

0.50 - 1.00

1.00 - 1.65

FIGURE 11

Overland Flood Depths from the Culloden Burn West



LEGEND

Watercourses

Culverts

SB Depths (m)

0.00 - 0.05

0.05 - 0.10

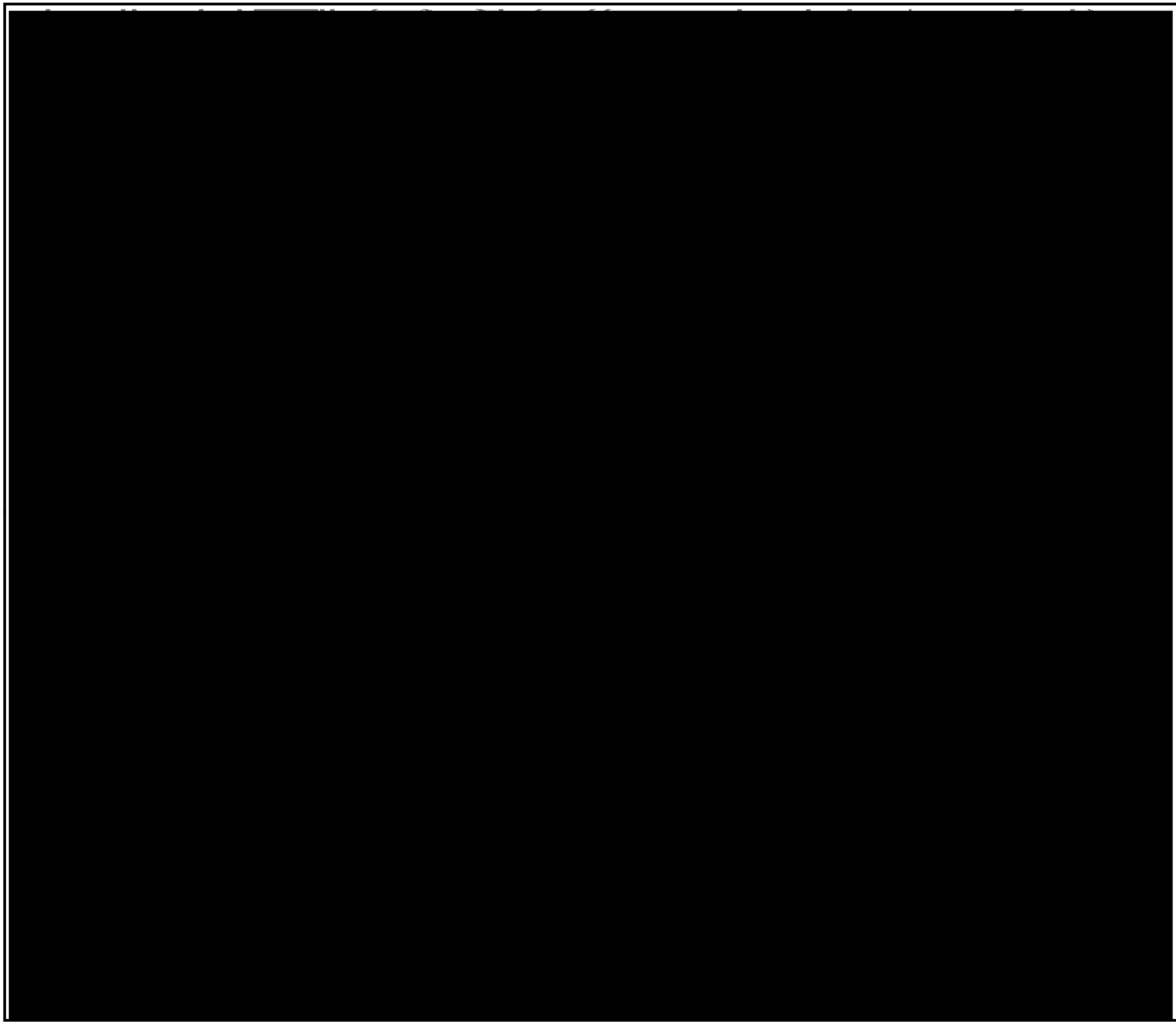
0.10 - 0.25

0.25 - 0.50

0.50 - 1.00

FIGURE 12

Overland Flood Depths from the Smithton Burn



LEGEND

Watercourses

Culverts

CBW Velocity (m/s)

0.00 - 0.05

0.05 - 0.10

0.10 - 0.15

0.15 - 0.20

0.20 - 0.25

0.25 - 0.30

0.30 - 0.50

0.50 - 0.86

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FIGURE 13

Overland Flood Velocities from the Culloden Burn West

LEGEND

Watercourses

Culverts

SB Velocity (m/s)

0.00 - 0.05

0.05 - 0.10

0.10 - 0.15

0.15 - 0.20

0.20 - 0.25

0.25 - 0.30

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FIGURE 14

Overland Flood Velocities from the Smithton Burn

LEGEND

Culloden Burn West (CBW)

CBW Culverts

High Risk / Priority

Medium Risk / Priority

Low Risk / Priority

CBW Options

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FIGURE 15

Proposed Measures to Alleviate Flood Risk on the Culloden Burn West

LEGEND

Smithton Burn

Smithton Burn Culverts

Low Risk / Priority

High Risk / Priority

Medium Risk / Priority

Smithton Burn Options

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FIGURE 16

Proposed Measures to Alleviate Flood Risk on the Smithton Burn