# LT000052-SLR-CIV-RPT-007 Flood Risk Optioneering Report

## Flushing Flood Alleviation Scheme

### SSEN Transmission

200 Dunkeld Road, Perth, PH1 3AQ

Prepared by:

**SLR Consulting Limited**

Cubo, Standard Court, Park Row, Nottingham, NG1 6GN

SLR Project No.: 403.065425.00001

Client Reference No: 069000

28 January 2025

Revision: 06

## Revision Record

| Revision | Date | Prepared By | Checked By | Authorised By |
|---|---|---|---|---|
| 01 | 20 September 2024 | SCB | RW | RW |
| 02 | 27 November 2024 | SCB | RW | RW |
| 03 | 5 December 2024 | SCB | RW | RW |
| 04 | 10 January 2025 | SCB | RW | RW |
| 05 | 15 January 2025 | SCB | RW | RW |
| 06 | 28 January 2025 | SCB | RW | RW |

# Basis of Report

# Executive Summary

SLR Consulting Ltd (SLR) has been appointed by SSEN Transmission to undertake an optioneering study for a proposed Flood Alleviation Scheme around the hamlet of Flushing, Aberdeenshire (centred at National Grid Reference: NK 05338 46867) to understand the extent of the existing flood risk to the local area and the potential options for reducing the effects of flooding.

The study utilised the latest Flood Estimation Handbook (FEH22) rainfall data and Scottish Environmental Protection Agency (SEPA) climate change allowances to develop a robust understanding of the flood risks associated with the site. The hydraulic model incorporated 2D floodplain topography based upon survey data and used the ReFH2.3 software to simulate peak rainfall hydrological model inputs.

The results demonstrate that, due to the volume of surface water runoff from the upstream catchment, the only tested mitigation options which resulted in a substantial betterment were those that provided significant attenuation of surface water volumes. Given that the majority of the upstream catchment falls within the Netherton Hub site boundary, significant storage volumes are required upstream (south) of the A950 to retain flood water before it is able to spill over the A950 and impact Flushing. Due to the fact that a Drainage Impact Assessment (DIA, ref.: LT000052-SLR-CIV-LAY-007-01) is intended to store rainfall runoff for all events up to and including the 1 in 200-year (0.5% AEP) with an allowance for climate change, while restricting surface water discharge to a low greenfield rate, implementing the DIA detention basins would likely be the most practicable method for removing the risk of flooding from Flushing. The results also demonstrate some comparatively low volume flooding to properties in Flushing due to sheet rainfall runoff from elevated land to the north which cannot be mitigated by interventions within the Netherton Hub land. Therefore, this flood risk can be addressed through the implementation of a low-level bund running adjacent to the north of the road running through Flushing.

# Table of Contents

# Acronyms and Abbreviations

| | |
|---|---|
| NGR | National Grid Reference |
| SEPA | Scottish Environmental Protection Agency |
| NPF4 | National Planning Framework 4 |
| DIA | Drainage Impact Assessment |
| DTM | Digital Terrain Model |
| LiDAR | Light Detection and Ranging |
| AEP | Annual Exceedance Probability |
| CC | Climate Change (Uplift of 37%) |
| AOD | Above Ordnance Datum |

# 1.0 Introduction

## 1.1 Background and Purpose of Services

The hamlet of Flushing in Aberdeenshire is indicated on the SEPA surface water flood mapping as being at high risk of flooding during the 1 in 200-year (0.5% AEP) plus 37% climate change event. This Flood Alleviation Study aims to provide an understanding of the current baseline flooding extents and its mechanisms within the development area and surrounding area of Flushing. The secondary aim of this study is to test potential solutions for alleviating flooding to the hamlet of Flushing as a whole. Any solution which is found to completely alleviate Flushing from flooding, which goes beyond the mitigation measures and flooding betterment detailed within the Netherton Hub PPiP Drainage Strategy report LT000052-SLR-CIV-RPT-005, may be considered to be taken forward for discussion with Aberdeenshire Council and relevant stakeholders.

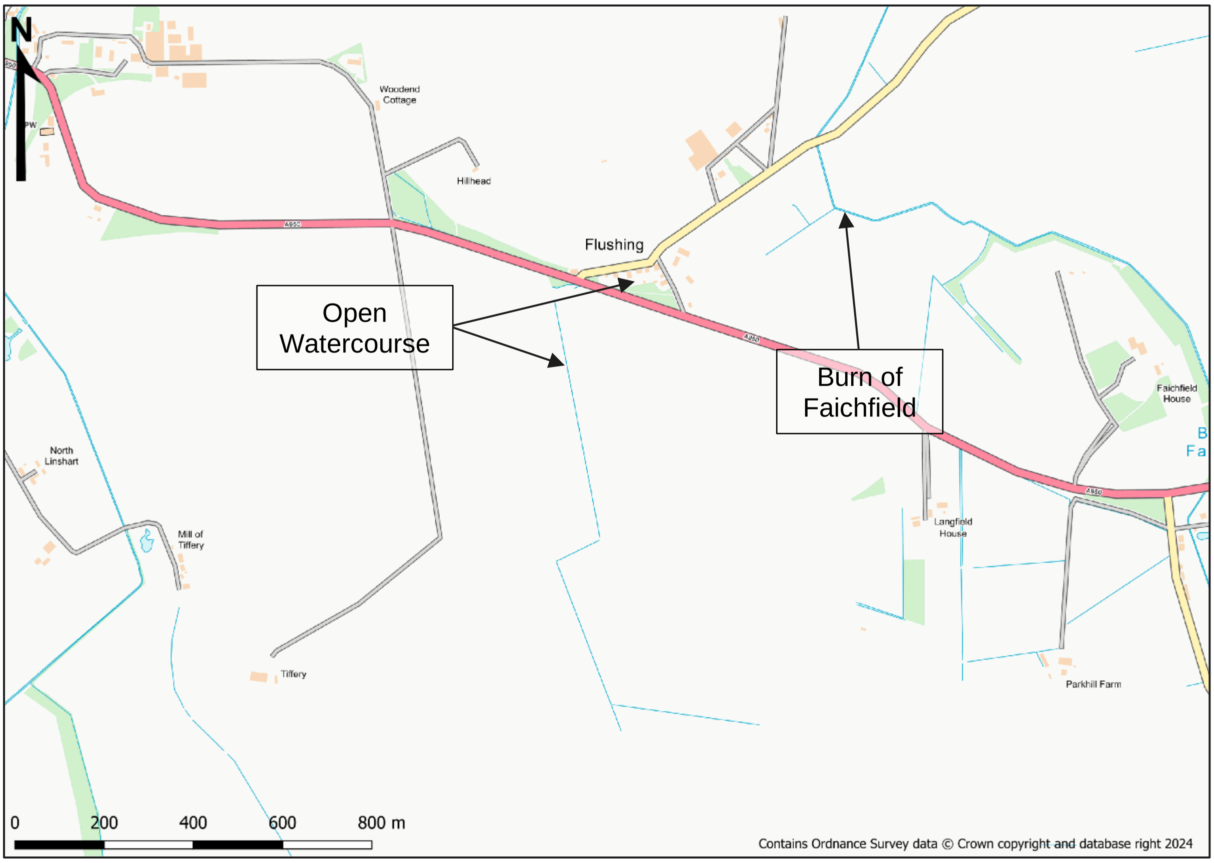
This Flood Risk Modelling report has been prepared under the direction of a Principal Flood Risk Consultant at SLR who specialises in flood risk modelling and associated planning matters. Reporting has been completed in accordance with guidance from both Scotland's National Planning Framework 4 (NPF4) and the Scottish Environmental Protection Agency (SEPA).

## 1.2 Study Location

Situated within Aberdeenshire, Scotland, the study area comprises largely agricultural land, with the small hamlet of Flushing situated immediately to the north of the A950. Flushing is centred on National Grid Reference (NGR) NK 05338 46867.

The study location, including the hamlet of Flushing, the open watercourse and its point of discharge to the Burn of Faichfield, are shown below in Figure 1-1.

**Figure 1-1: Study Location, Including Ditch and Burn of Faichfield**




# 2.0 Methodology

## 2.1 Hydrology

The site sits within a catchment area of approximately 1.18km$^2$. Peak rainfall hydrological inputs, in the form of rainfall hyetographs, for the catchment have been estimated using the latest FEH22 rainfall data available within the ReFH2 model.

The rainfall hyetographs have been developed using the latest Flood Estimation Handbook[1] (FEH) Rainfall Runoff methods.

The Rainfall Runoff methods are those first published by Kjeldsen[2], which were subsequently updated in 2015 and implemented within the ReFH2 software[3]. The latest ReFH2.3 model was released in 2023 and calibrated for the FEH22 depth duration frequency (DDF) rainfall model.

Rainfall data was obtained using the FEH Webservice to obtain the point FEH22 DDF rainfall for the site. The rainfall model is produced at a 1km resolution. The analysis has been based upon the FEH catchment descriptors.

The ReFH2.3 model uses the catchment descriptor data to calculate the rainfall, and loss parameters, which are used to derive net rainfall and flow hydrographs. This assumes that

[1] Flood Estimation Handbook, Centre for Ecology and Hydrology. 1999

[2] The revitalised FSR/FEH rainfall-runoff method. Supplementary Report No.1. Kjeldsen, T. R. Centre for Ecology and Hydrology. 2007.

[3] https://www.hydrosolutions.co.uk/software/refh-2/

rainfall, infiltration and other losses are modelled in ReFH2 and that the resultant net rainfall (runoff) is applied to hydraulic model. Additionally, sewer losses have not been modelled in ReFH2.

The FEH data and methods are the regulatory recommended methods for estimating design rainfall in England, Scotland and Wales.

### 2.1.1 Climate Change

The most recent advice on climate change is provided by the Scottish Environment Protection Agency[4] (SEPA). The catchment is located within the North-East Scotland river basin region where an allowance of 37% is applied to peak rainfall intensity to represent the anticipated impact of climate change up to the year 2100.

### 2.1.2 Rainfall Runoff Method

The FEH rainfall runoff method analysis has been undertaken using the ReFH2.3 model.

The hyetographs are defined over the 1.18km² catchment. The Areal Reduction Factor (ARF) and Seasonal Correction Factor (SCF) were kept at the default values defined by the ReFH2.3 software. These are 0.97 (ARF) and 0.98 (SCF) respectively.

## 2.2 Hydraulics

### 2.2.1 Model Development

A review of the catchment and SEPA flood mapping was undertaken in order to determine the primary causes and influences on flood risk to Flushing. The nearest fluvial watercourse to Flushing is the Burn of Faichfield, located running in a general south to north direction approximately 400m to the northeast of Flushing. This watercourse is situated downstream of the hamlet and, as such, is not considered a primary source of flood risk. The burn does, however, ultimately act as the primary receptor for a number of drainage ditches throughout the local area.

Based on the requirements of this analysis, available data at the time, and hydraulic structures within the area of interest, a 2-dimensional (2D) Rain-on-Grid model was considered appropriate for determining flood extent. The type of model is best suited for simulating and predicting the risk of flooding from surface water sources as generated/synthetic or gauged/recorded rainfall can be evenly distributed across the model domain and applied at each individual cell. In additional, rainfall-runoff characteristics are defined, with the resulting exceedance flows simulated to follow the topographic represented by the DTM.

The construction of the 2D hydraulic model requires several datasets and parameters as input. These are summarised below:

- Floodplain topography derived from the topographic survey;
- Hydraulic structures;
- Hydraulic boundaries;
- Roughness across study area (Manning's n); and,
- Appropriate model cell size.

[4] https://www.sepa.org.uk/media/gq3c2xyb/climate-change-allowances-guidance-v4-final_nov23.pdf

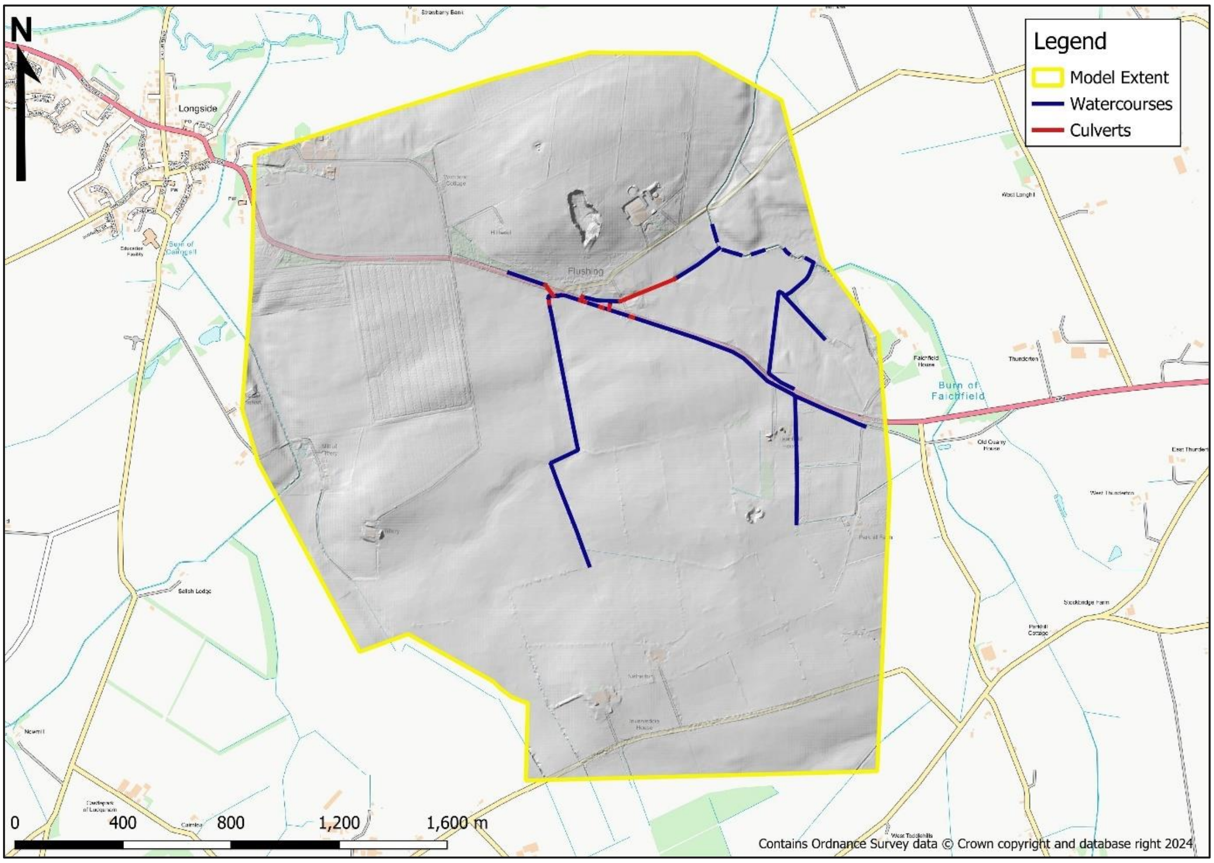
### 2.2.2 Model Topography

As only limited LiDAR data is available for parts of the study area, the topography of the contributing catchment has been represented using a DTM generated using topographic survey data of ground elevations. The use of topographic survey is generally preferred to the use of LiDAR data regardless, due to its greater level of accuracy.

The full extent of the model domain has been based upon the FEH catchment to ensure the rainfall calculated for the catchment is currently and even distributed. The result is that some surface water runoff flow paths are generated that run away from the study area and towards the edge of the model domain where they can become trapped. In some instances this may result instabilities that result in simulation failure. However, given that these flow paths have no interaction with the study area, and due to the use of TUFLOW HPC to continually solve shallow water equations without instabilities occurring, this does not result in any issues for this model. As such, these surface water flow paths at the model edges can be discredited/ignored.

The hydraulic model extents and topographic fix are shown within Figure 2-1 below.

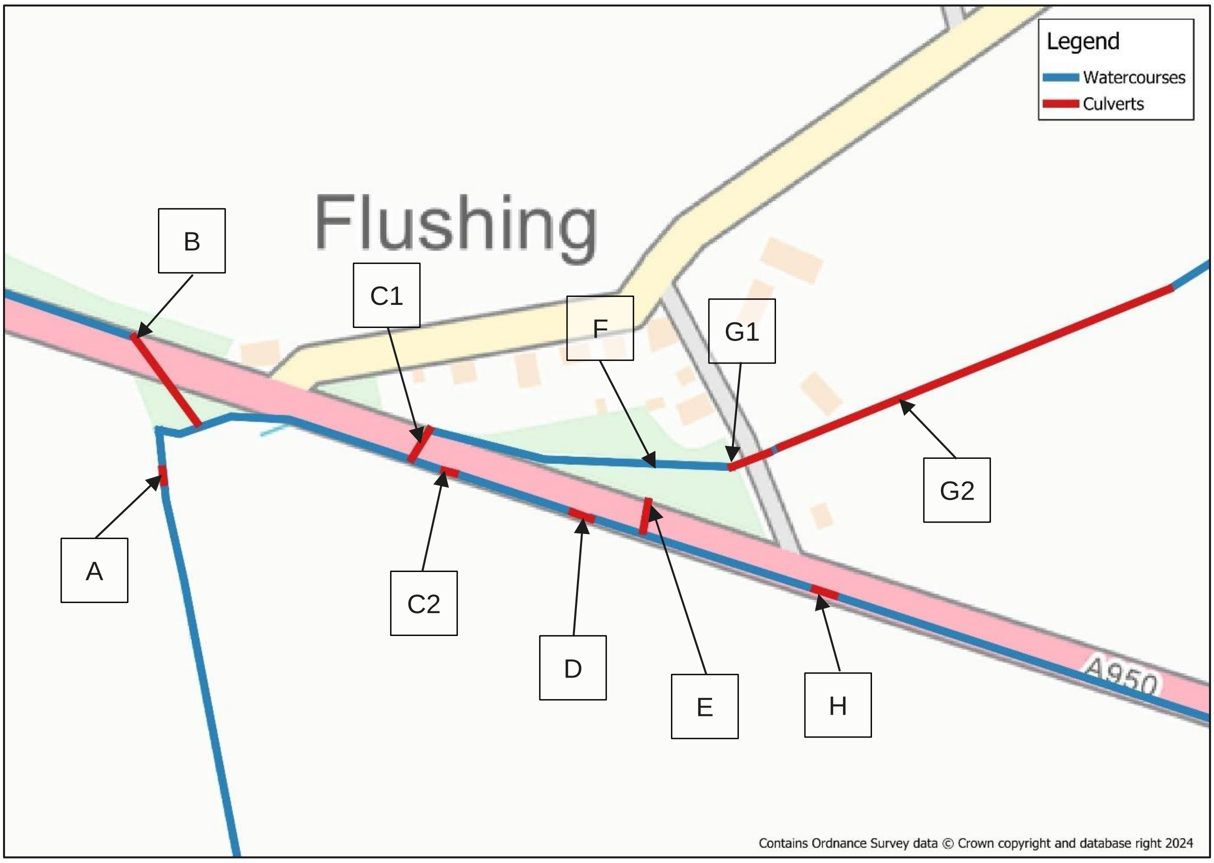
**Figure 2-1: Hydraulic Model Extent and Culverts**




### 2.2.3 Hydraulic Structures

The local drainage channels and features were visually assessed during the site inspection. The locations of the notable features are shown on Figure 2-2.

**Figure 2-2 : Structure Locations**




## Location A

The structure at Location A was not initially located due to dense vegetative overgrowth in and around the channel. Deep mud was noted at the location of the expected inlet/outlet and it is possible that the culvert opening was submerged at the time of the site inspection.

Upon a second survey visit, the strucutre was located with the upstream channel invert level was recorded to be 28.8 m above Ordnance Datum (AOD), and the downstream invert level was noted to be 28.5 m AOD. The deck level above the culvert was recorded at 30.2 m AOD.

**Photograph 1 : Expected culvert inlet location at Location A**

**Location B**

The inlet of Culvert B was located and appeared to be in a state of disrepair (Photograph 2). The culvert appears to be a stone box culvert, but the true dimensions were unclear due to the condition. The width of the culvert was measured to be approximately 800 mm. There was no active flow observed through the culvert, though standing water was noted at the inlet and at the outlet downstream.

The channel downstream of Culvert B was noted to be overgrown and was not accessible at the time of the site inspection (Photograph 3).

The upstream invert level was recorded to be 29.35 m AOD, and the downstream invert level was recorded to be 28.2 m AOD.

**Photograph 2 : Culvert B**

**Photograph 3 : Channel downstream of Culvert B**

**Locations C & D**

At the time of the site visit, Culvert C1 could not be located due to heavy vegetation growth. However, Culvert C1 was located during a site visit undertaken by WSP in December 2024, which confirmed an approximately 1,200 mm by 1,000 mm box culvert connecting the watercourse south of the A950 to the north, as indicated in Figure 2-2. Culverts C2 and D were both noted to be 450 mm diameter circular culverts. Culvert D is shown in Photograph 4. Very low flows travelling south-eastwards were noted in both culverts.

The upstream invert level at Culvert C2 was recorded at 28.7 m AOD, and the downstream was recorded at 28.9 m AOD, though the downstream end was inaccessible at the outlet itself.

The upstream invert level at Culvert D was recorded to be 28.75 m AOD, and the downstream level was recorded to be 28.85 m AOD, though the downstream end was inaccessible at the culvert outlet itself.

**Photograph 4 : Culvert D**

**Location E**

A culvert outlet was located draining towards the watercourse in the area of woodland north of the A950 road. The culvert was noted to be a stone box culvert of dimensions 400 mm x 400 mm. Low flow was noted through the culvert at the time of the site inspection. The outlet invert level was recorded to be 28.5 m AOD.

The culvert inlet across the road was not located due to dense vegetation in the ditch channel.

**Photograph 5 : Culvert E**

**Location F**

The approximate dimensions of the burn channel in the wooded area were recorded. The channel was measured to be approximately 1.7 m wide, with active flow up to 200 mm deep at the time of inspection.

The channel invert level was recorded to be 28.15 m AOD at the time of inspection, with a southern bank level of 29.55 m AOD and a northern bank level of 29.25 m AOD.

Ground levels in the area surrounding the watercourse generally slope down from the road towards the watercourse. The road level was measured at approximately 30.15 m AOD, dropping steeply northwards from the road to a level of 29.3 m AOD, and levels of 28.6 m AOD in the vicinity of the watercourse.

**Photograph 6 : Burn channel at Location F**

**Location G**

The dimensions of Culvert G1, a short culvert beneath an unnamed road, was located during the site inspection and was noted to be a stone box culvert with dimensions 800 mm x 800 mm (Photograph 7). Low flow was noted in the culvert at the time of the site inspection. The culvert invert level was recorded at 27.7 m AOD, with a headwall elevation of 29.8 m AOD.

An additional culvert opening perpendicular to Culvert G was noted during the site inspection (Photograph 8). No flow appeared to be discharging from the culvert.

Culvert G1 has an outlet to the east of the unnamed road, discharging to a brief section of open watercourse before entering culvert G2 within the grounds of a private residential property. Culvert G2 has been confirmed to comprise two parallel 600 mm circular pipes by CCTV completed by Underground Maintenance Systems (UMS) Ltd on behalf of Aberdeenshire Council in November 2017.

**Photograph 7 : Culvert G**

**Photograph 8 : Additional culvert opening**

**Location H**

The culvert at Location H was visually assessed at the time of the site inspection. The culvert is a circular steel pipe, which appears to have been crushed. It is expected that the pipe was originally a 450 mm diameter circular pipe. Very low flow was noted through the culvert at the time of the site inspection.

The upstream invert level was recorded to be 29.1 m AOD, and the downstream invert level was recorded to be 29.3 m AOD.

**Photograph 9 : Culvert H**

### 2.2.4 Model Roughness (Manning's n)

The material roughness across the model domain has been read into the hydraulic model using a CSV file, correctly formatted to be read by TUFLOW. Manning's values for each land classification were derived from texts such as Chow[5].

Land classification across the model domain were taken from the freely available UK Centre for Ecology and Hydrology land cover maps[6] and further manually processed and annotated to incorporate buildings and roads.

5 Chow, V.T. (1959) Open Channel Hydraulics. McGraw-Hill, New York.

6 Land Cover Map 2021: https://www.ceh.ac.uk/data/ukceh-land-cover-maps

# 3.0 Model Scenarios & Results

## 3.1 Baseline

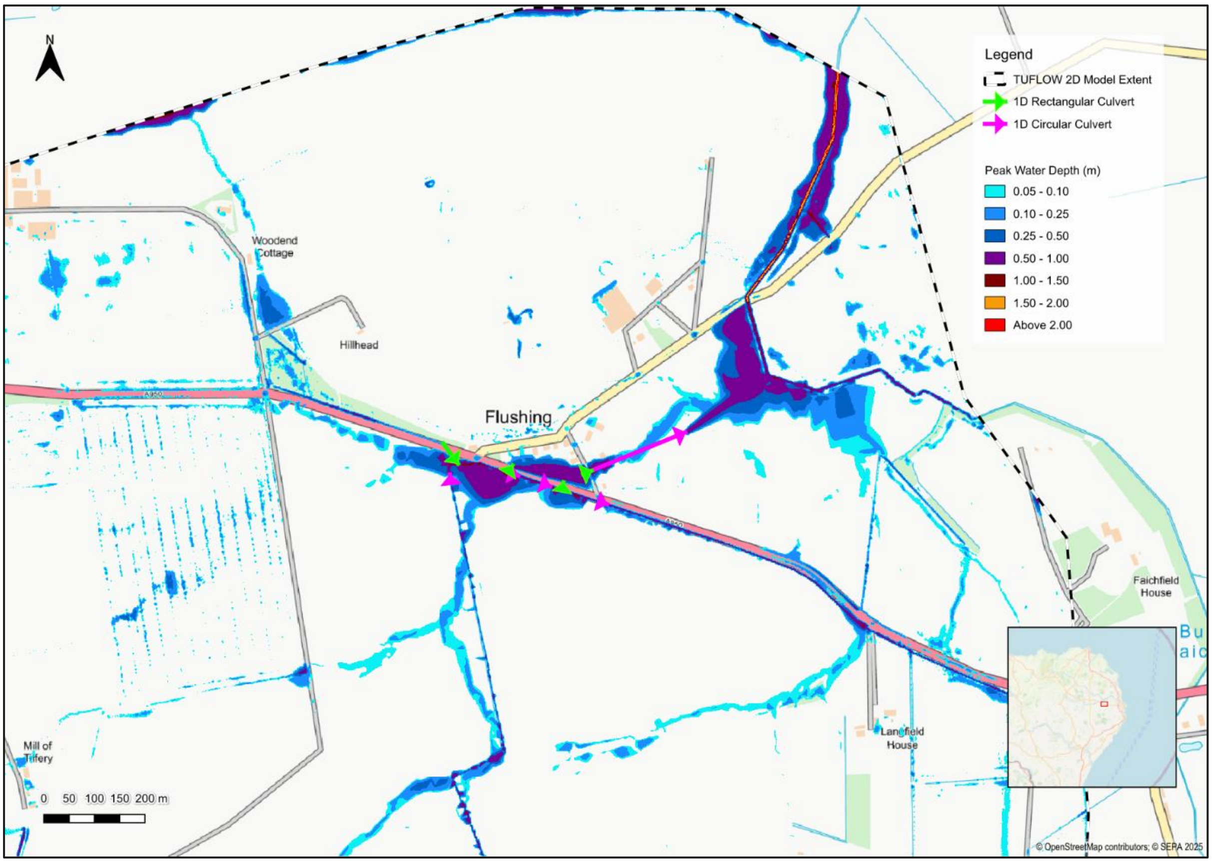
The baseline scenario represents the current conditions of the local area around Flushing, including the current alignment of the watercourse and its associated culverts. Following a site visit and topographical survey not being able to locate the exact position of culvert E beneath the A950 (the assumed outlet to the north was located but an inlet could not be located), the dimensions of this culvert have been assumed to be 0.4m in diameter. All of the culverts have been assumed to be in fully operational condition in order to represent a “best case” for the local drainage network.

### 3.1.1 Baseline Results

The peak depth results for the baseline model scenario during the 1 in 200-year (0.5% AEP) plus 37% climate change event are shown in Figure 2-3 below. These results show significant predicted flooding to occur immediately upstream (south) of the A950 before flows spill across the A950 and combine with out-of-channel flows to the north of the road to the rear of the residential properties in Flushing, exacerbating flooding further. Combined, this results in indicated flooding primarily to the rear gardens of existing residential properties within Flushing but also indicates one property itself being impacted.

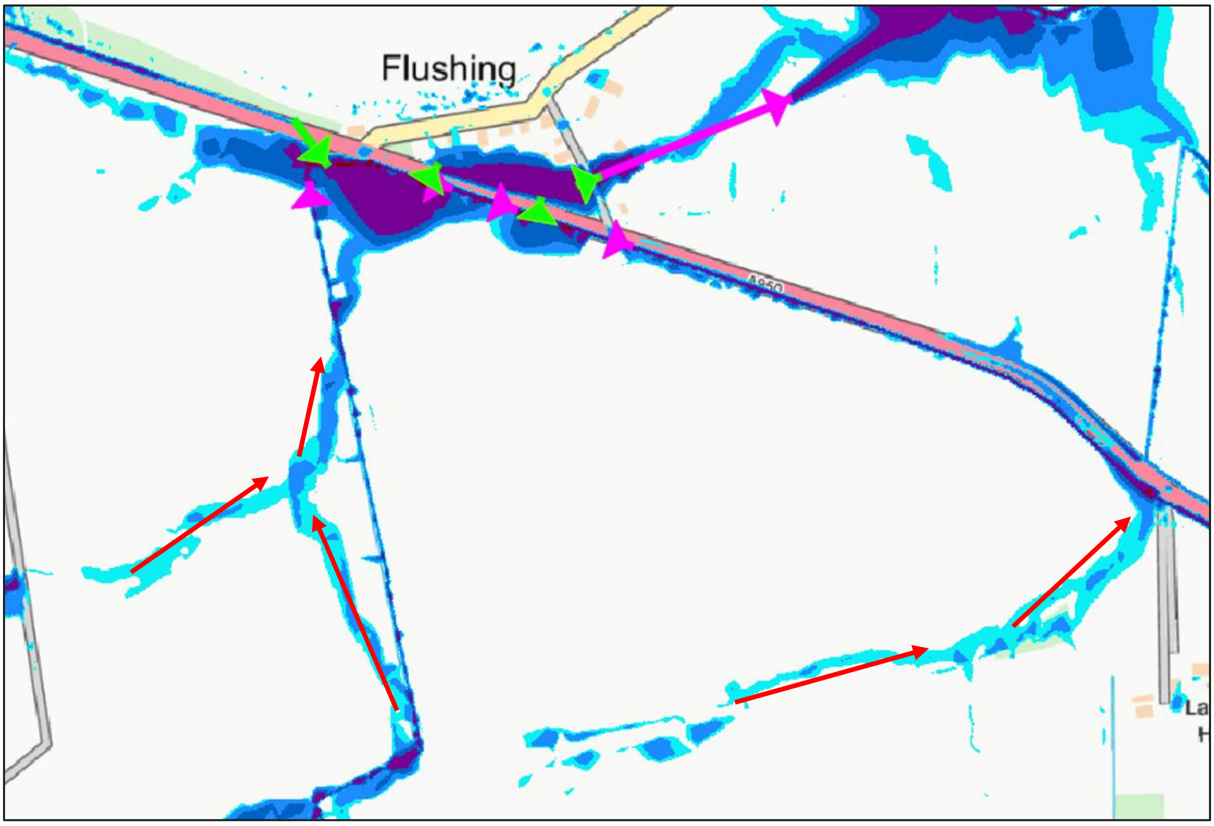
A floodplain flow path is also apparent within Figure 2-3 below to the immediate east of Flushing bypassing the final culverts (culverts G1 and G2) along the ditch course. Flow of between 0.05 and 0.1m are seen to flow out-of-channel and over culvert G before following a topographic depression northeast and then subsequently turning back towards the open watercourse channel immediately downstream of the culvert. As the culvert has been modelled without any operational issues assumed, this suggests that the culvert lacks capacity to convey flows sufficiently downstream.

**Figure 2-3: Baseline peak flood depths (0.5% AEP+37% climate change)**




In the upper reach of the open watercourse, to the south and upstream of the worst indicated flood risk adjacent to the A950, flows can be seen to break out-of-channel, forming a floodplain flow path running north alongside the open watercourse itself. This flow path is then seen to join a separate flow path of runoff from the west before rejoining the open watercourse, as highlighted in Figure 2-4 below.

**Figure 2-4: Floodplain flow mechanism**




As can be seen in the baseline results in Figure 2-3, surface water flooding occurs to the northwest of Flushing and north of the A950, as well as a number of small, isolated areas of flooding within Flushing and in the vicinity of the unnamed road running east to west within Flushing. The flows to the northwest of Flushing appear to run in a southerly direction before collecting within the open watercourse running immediately adjacent to the A950, upstream of culvert B. While this flow path does not have a direct impact of flooding in Flushing, this water will result in greater rates and volumes within the open watercourse as the culvert outfalls into the watercourse south of the A950, limiting capacity further downstream and resulting in flooding. The number of small, isolated patches of flooding in and around Flushing, however, are the result of shallow sheet runoff from the elevated land to the north (most of which is not visible in the results at depths under 0.05m). Given that there is no formal drainage system in place to receive this water before reaching Flushing, as it tries to discharge to the open watercourse, some form of mitigation will be required to prevent this runoff from compounding flooding in Flushing further.

## 3.2 Mitigation Option 1 – Scrapes & Spillway

Mitigation Option 1 comprises the incorporation of Natural Flood Management (NFM) measures designed to provide storage of floodwater within the open floodplain before the flooding presents an issue downstream, utilising only natural, generally low-maintenance techniques. This method represents a temporary solution, with the aim that it could be implemented relatively easily in the interim period before works commence on the surface water drainage system for the Netherton Hub.

The methods most appropriate to the location and context of the open watercourse, which is essentially straight before entering a series of culverts, are the use of scrapes to provide floodplain storage and a floodplain spillway, which would take advantage of an indicated surface water flood flow path in the baseline results but interrupt the flows and slow these down.

The basins have been represented in the model as three basins located either side of the drain immediately upstream of the A950. The basins comprise flow controls on the inlets to encourage the filling of the basins before flooding occurs out of channel. These basins vary in depth between 1 and 2m in order to provide sufficient storage.

Similar to the basins, the scrapes comprise the lowering of the ground but to a lesser extent, creating a shallow depression which aims to fill up and then spill out and onto the next scrape. The aim with this option is to primarily slow flows down and prevent downstream inundation. Each scrape has been represented in the model by lowering the existing ground levels by 0.6m.

Under this scenario, all culverts have been left in-situ at their existing size, with each culvert assumed to be in a fully operational state.

A schematic plan of the mitigation features above is included in Appendix A.

### 3.2.1 Mitigation Option 1 Results

Figure 2-5 below shows the peak depth results of Mitigation Option 1, incorporating attenuation basins and a floodplain spillway, during the 1 in 200-year (0.5% AEP) plus 37% climate change event. The results show that the scrapes successfully intercept the floodplain flow path and create some limited storage of floodwater, slowing and holding flows back. However, due to the limited depth of the scrapes (0.6m) they do not fill to full capacity before spilling and allowing flows to continue through the floodplain as overland flow.

The extent of flooding downstream and adjacent to the A950 (south of the properties in Flushing) is generally similar to that of the baseline results shown in Figure 2-3 above, though due to the implementation of the scrapes providing some flood volume storage there is a general reduction in peak water depth of c.200mm. While the scrapes reduce the amount of water spilling across the A950 by retaining water, thus resulting in the peak depth reduction, flooding downstream of the A950 is not prevented in its entirety and is only marginally alleviated. This suggests that the scrapes do not provide sufficient storage volume for the full rainfall event and would in fact need to be significantly larger to prevent flooding to Flushing in its entirety.

**Figure 2-5: Mitigation Option 1 peak flood depths (0.5% AEP+37% climate change)**

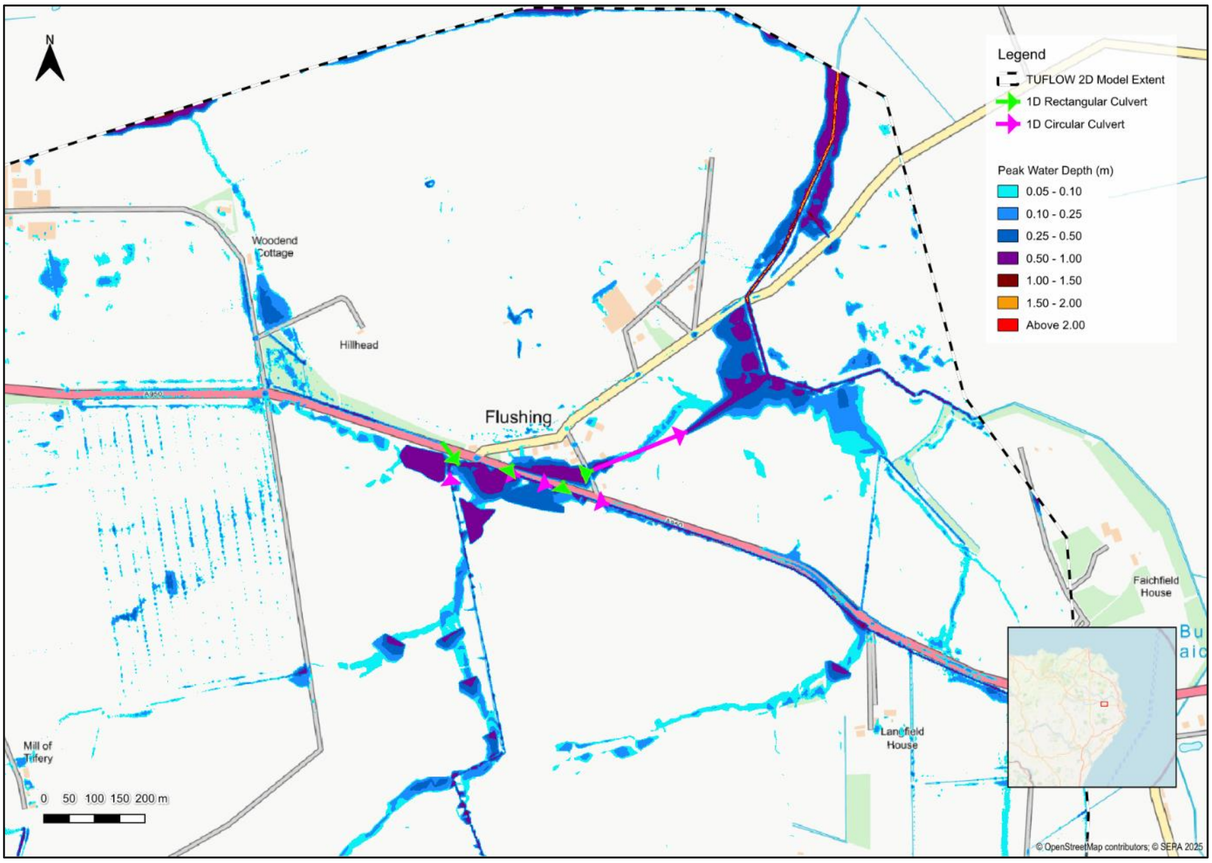
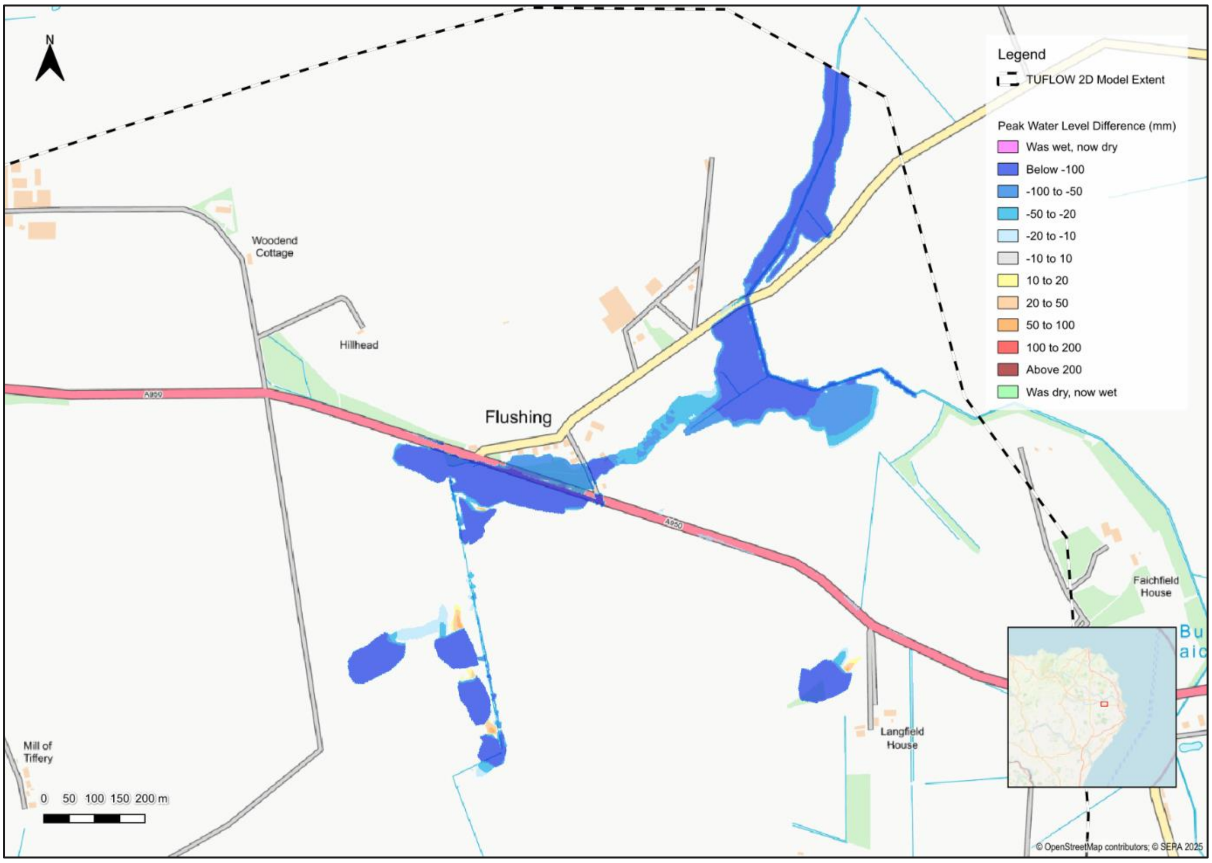



Figure 2-6 below shows the difference grid results derived by subtracting the maximum depth results of the Baseline scenario from the results of the Mitigation Option 1 scenario, highlighting increases and decreases in flooding that occur as a result of the mitigation measures being tested. These results highlight the expected peak water depth increases where basins and scrapes have been modelled to intentionally retain water and, as a consequence, a general reduction in peak flood depths of between 30mm and 100mm to the south of the A950. To the north of the A950, a significant reduction in peak depth during the 1 in 200-year plus 37% climate change event in excess of 100mm in the vicinity of the existing watercourse, culvert G and further downstream is shown.

**Figure 2-6: Peak Depth difference results between Mitigation Option 1 and Baseline**




## 3.3 Mitigation Option 2 – Culvert Upsizing

The second scenario comprises the upsizing of existing culvert C1 from 1,200mm in width to 2m in width, culvert E from 400mm in diameter to 1,200mm in diameter, culvert G1 downstream from 800mm diameter to 1,200mm diameter and culvert G2 from a dual bore 600mm culvert to a dual bore 1m culvert. This mitigation option then excluded any other interventions, with the aim to understand whether the culverts are acting as a primary cause of flooding in and around Flushing by acting as flow restrictions. With the culverts upsized it is expected that the greater flow throughput would result in a lower likelihood of water building up to the south of the A950 before spilling across the road.

A schematic plan of the mitigation features above is included in Appendix A.

### 3.3.1 Mitigation Option 2 Results

The results of the 1 in 200-year (0.5% AEP) plus 37% climate change event for Mitigation Option 2 are shown below in Figure 2-7, indicating very little change from the baseline scenario in terms of extent. While the upsizing of the culvert beneath the A950 (Culvert E) and the culvert to the east of Flushing (Culvert G) have resulted in a c.30mm reduction in peak water levels downstream of the A950 by allowing flows to be conveyed downstream faster, the relatively small reduction and minimal impact to flood extents suggests that the culverts are not the primary cause of flooding. Instead, it is understood that the sheer volume of water during the event is the primary issue, resulting in breakouts from the open watercourse channel both upstream and downstream of the A950. In particular, the out-of-channel flows to the south of the A950, couple together with the A950 acting as a raised barrier, results in significant flood volumes that ultimately overtop the road, bypassing the culvert entirely.

**Figure 2-7: Mitigation Option 2 peak flood depths (0.5% AEP+37% climate change)**

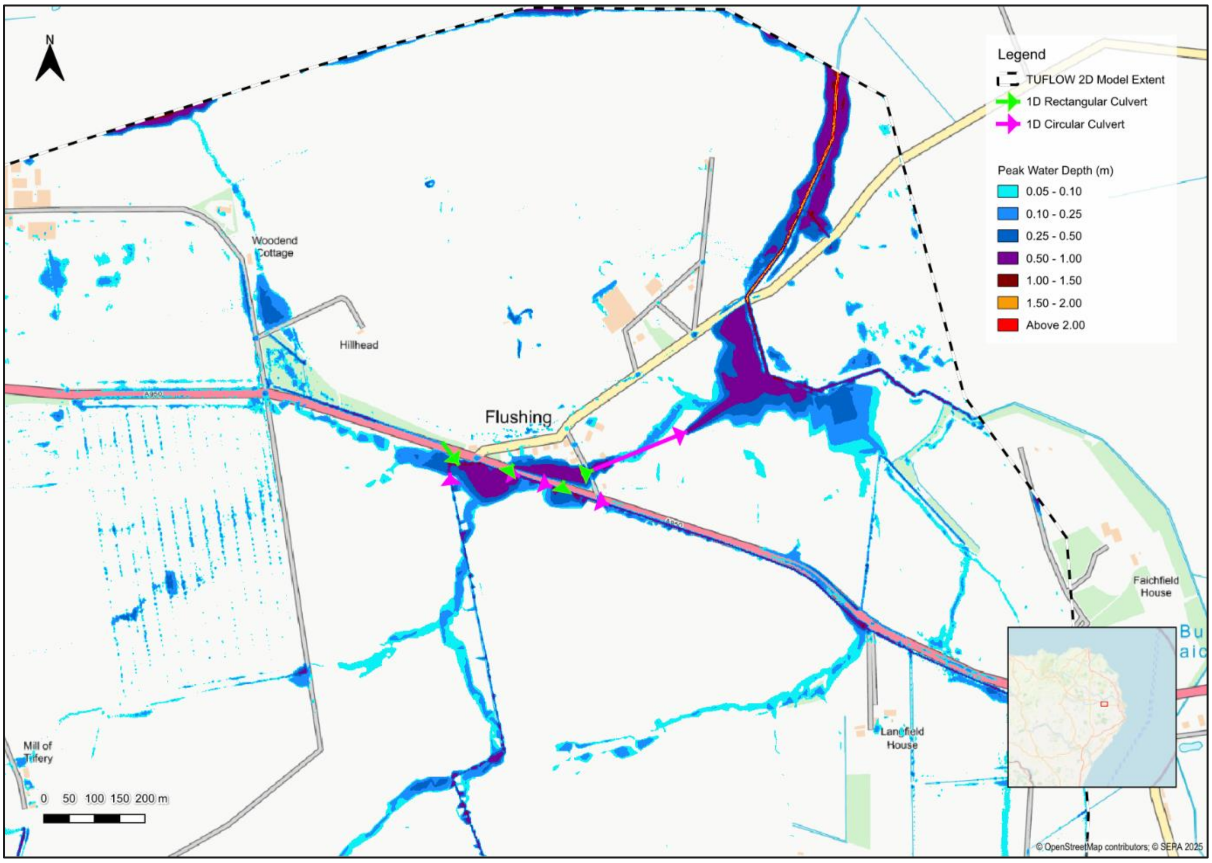
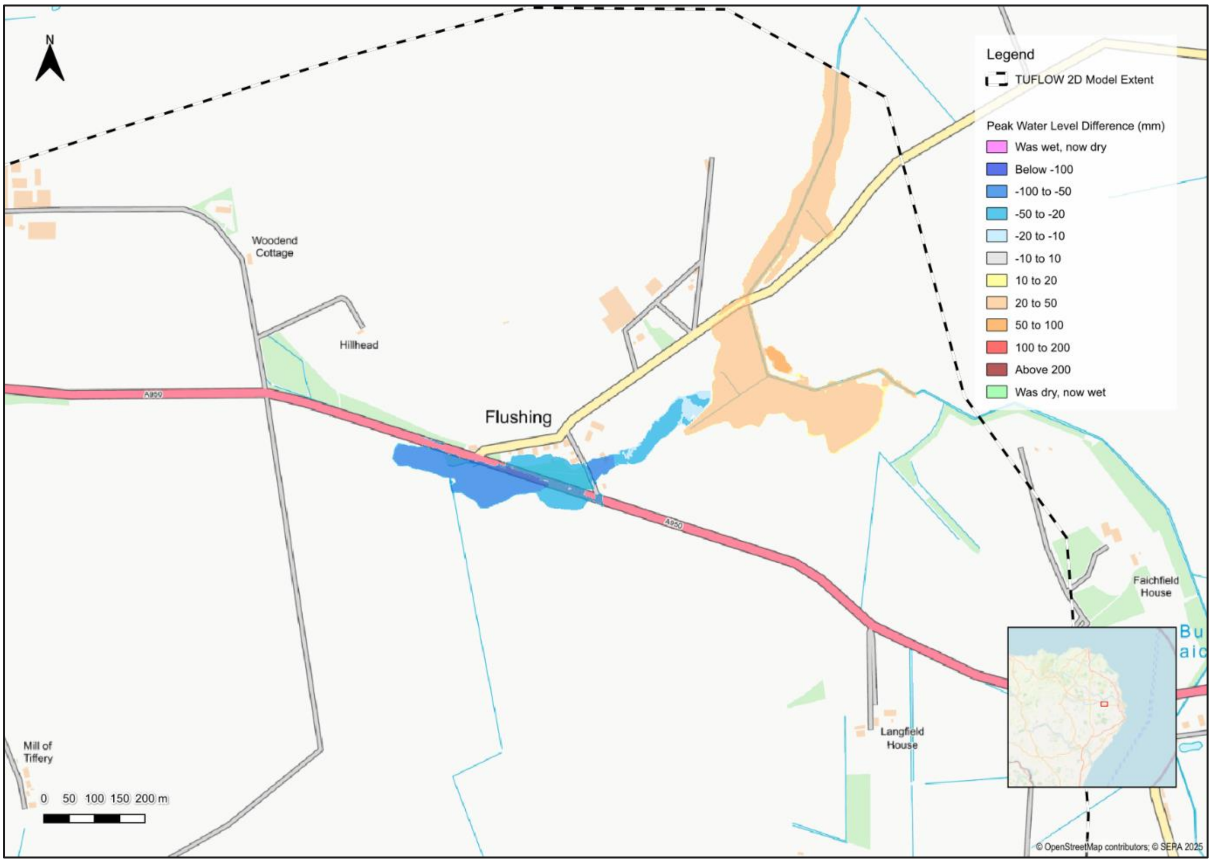



Figure 2-8 below shows the difference change between Mitigation Option 2 and the Baseline, with a general decrease of between 20mm and 50mm in peak depth to the south of the A950 due to the upsizing of the culverts. To the north of the A950, although a decrease in peak depths is still observed when compared to the baseline, this is to a lesser amount (between 20mm and 50mm decrease in peak depth). Downstream of culvert G2, a general increase in flood depths of between 20mm and 50mm is shown, suggesting that, while the upsizing of the culverts is able to allow greater flood volumes to continue downstream, this only results in minor decreases in peak flood depths around Flushing and negatively results in greater flood depths downstream of Flushing. Although the culvert sizes have been increased significantly, water is still shown to back up south of the A950 before spilling across the road.

**Figure 2-8: Difference results between Mitigation Option 2 and Baseline**




## 3.4 Mitigation Option 3 – Flow Restriction

Option 3 comprises the baseline conditions without any of the previous (Mitigation Option 1 or 2) interventions included, with a flow restriction of 320.9l/s applied to Culvert C1, which conveys the drain beneath the A950. The purpose of this option is to mimic the restricted discharge of surface water runoff from the proposed Netherton Hub development, thus demonstrating the impacts of a flow control without appropriate storage. This option does not include the on-site attenuation that would be provisioned as part of the development, and so flooding would still be expected to occur if the culverts downstream of the A950 are not the primary cause of flooding within Flushing. While this option was primarily undertaken as a sensitivity test, the results are largely superseded by Mitigation Options 4, 5 and 6 below.

A schematic plan of the mitigation features above is included in Appendix A.

### 3.4.1 Mitigation Option 3 Results

Finally, the results of the 1 in 200-year (0.5% AEP) plus 37% climate change event for Mitigation Option 3 are shown below in Figure 2-9. Similar to Mitigation Option 2, the results show little difference between the mitigation test and the baseline results. This is likely due to the fact that upstream floodwater is able to bypass the culvert beneath the A950 by overtopping the road. During this event there is effectively no change in peak flood depths/levels downstream of the A950.

**Figure 2-9: Mitigation Option 3 peak flood depths (0.5% AEP+37% climate change)**

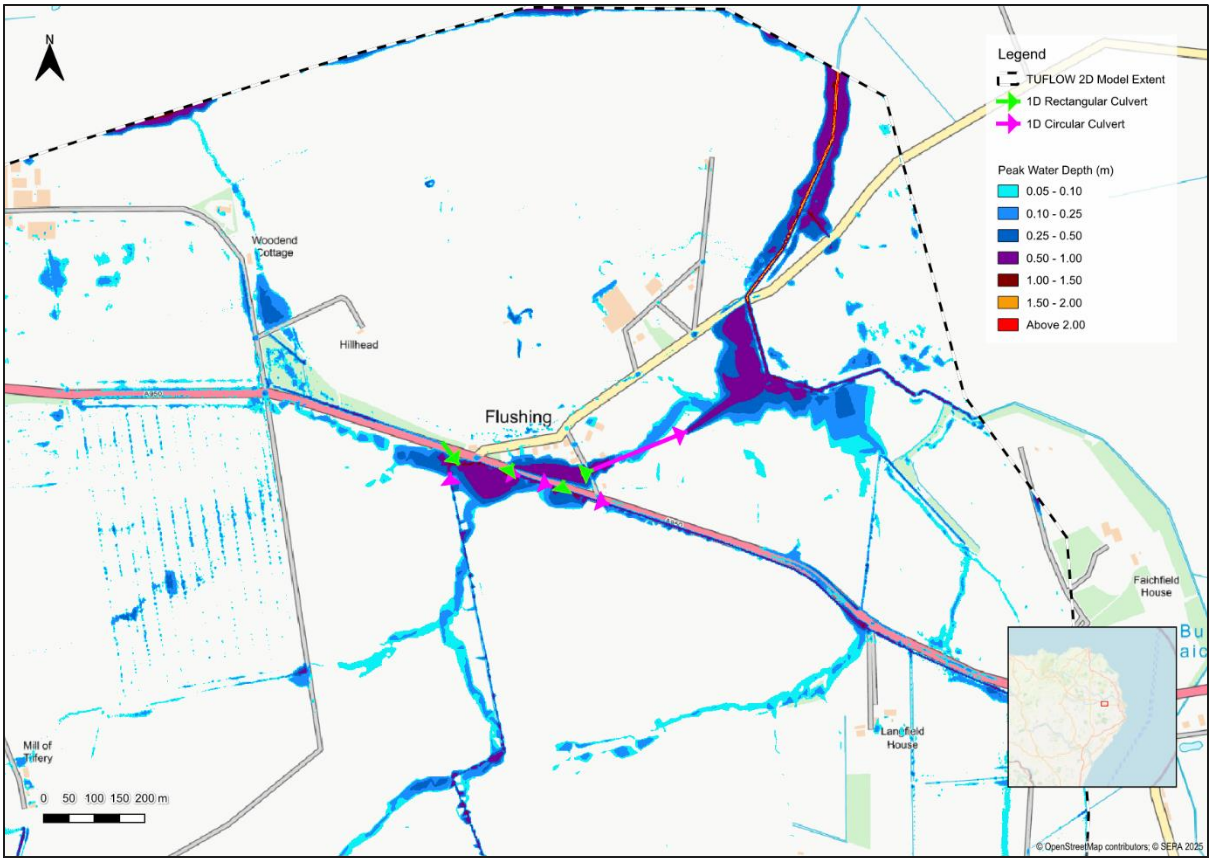
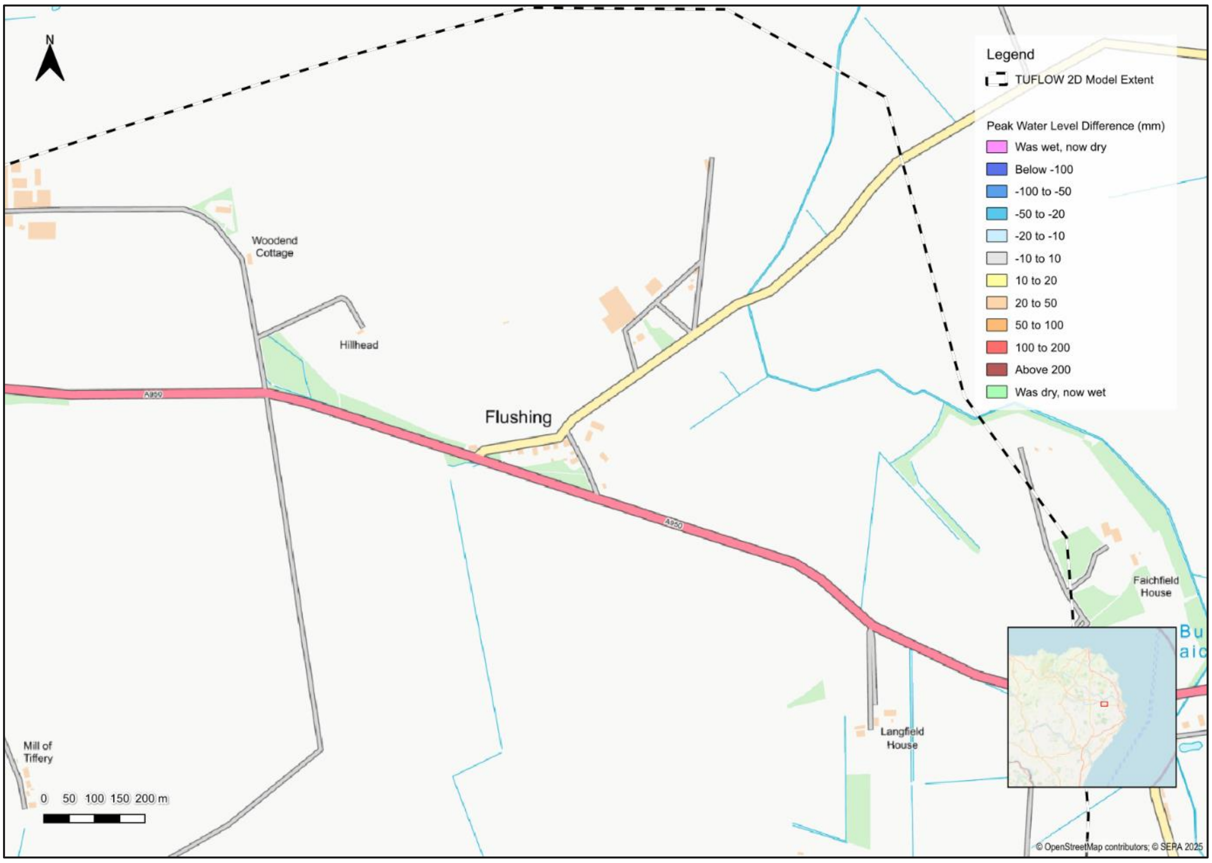



Figure 2-10 below demonstrates that there has been no change, positive or negative, between the results of Mitigation Option 3 and the Baseline. However, the results indicate a largely negligible change from the Baseline scenario. This is primarily due to the fact that, due to the significant amount of flooding expected to occur, much of the flooding is able to bypass the flow restriction and predominantly spill over the A950.

**Figure 2-10: Difference results between Mitigation Option 3 and Baseline**




## 3.5 Mitigation Option 4 – NW & NE Basins plus Bund

This mitigation option comprises the inclusion of both basins from the Netherton Hub DIA. However, where the DIA proposes an outflow from the northwest basin via an existing culvert beneath the A950, discharging to the existing watercourse and subsequently through culverts G1 and G2, this mitigation option includes a bypass discharge sewer from the northwest basin that joins with the discharge sewer from northeast basin before flows from both directly discharge to the Burn of Faichfield. The aim of this option is to test how both DIA basins would perform together in retaining surface water runoff from the upstream catchment while also bypassing Flushing downstream to remove the risk of flooding. This option also includes a bund to the north of the properties in Flushing to prevent sheet runoff from the elevated land to the north.

A schematic plan of the mitigation features above is included in Appendix A.

### 3.5.1 Mitigation Option 4 Results

The peak flood depth results for Mitigation Option 4 are shown below in Figure 2-11. While small, generally isolated patches of surface water flood with a peak depth of over 0.05m are present within Flushing, the exceedance flows that were present on the Netherton Hub site have been contained, ensuring that the downstream watercourses and the associated culverts are not overwhelmed. Sheet runoff from the elevated land to the north is also shown to be intercepted by the defensive bund, protecting the residential properties immediately to the south.

**Figure 2-11 Mitigation Option 4 peak flood depths (0.5% AEP+37% climate change)**

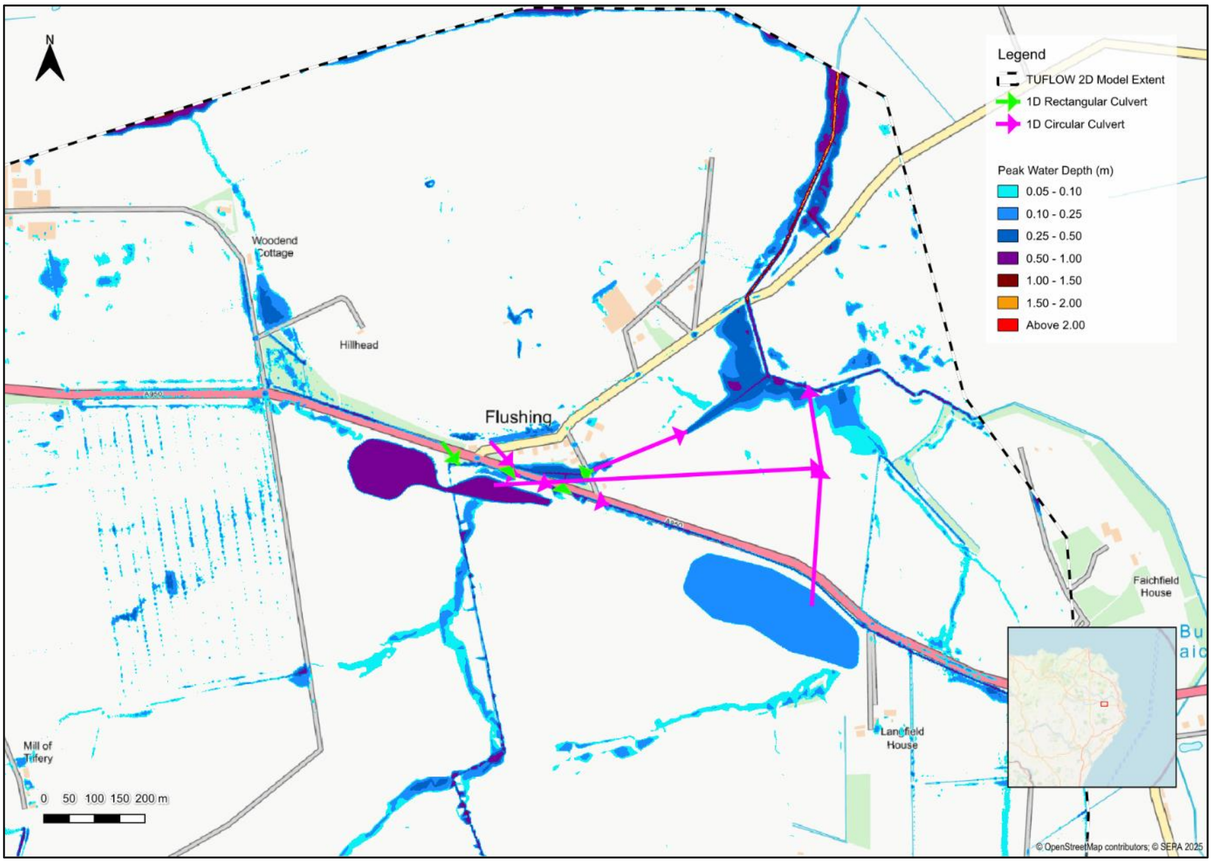
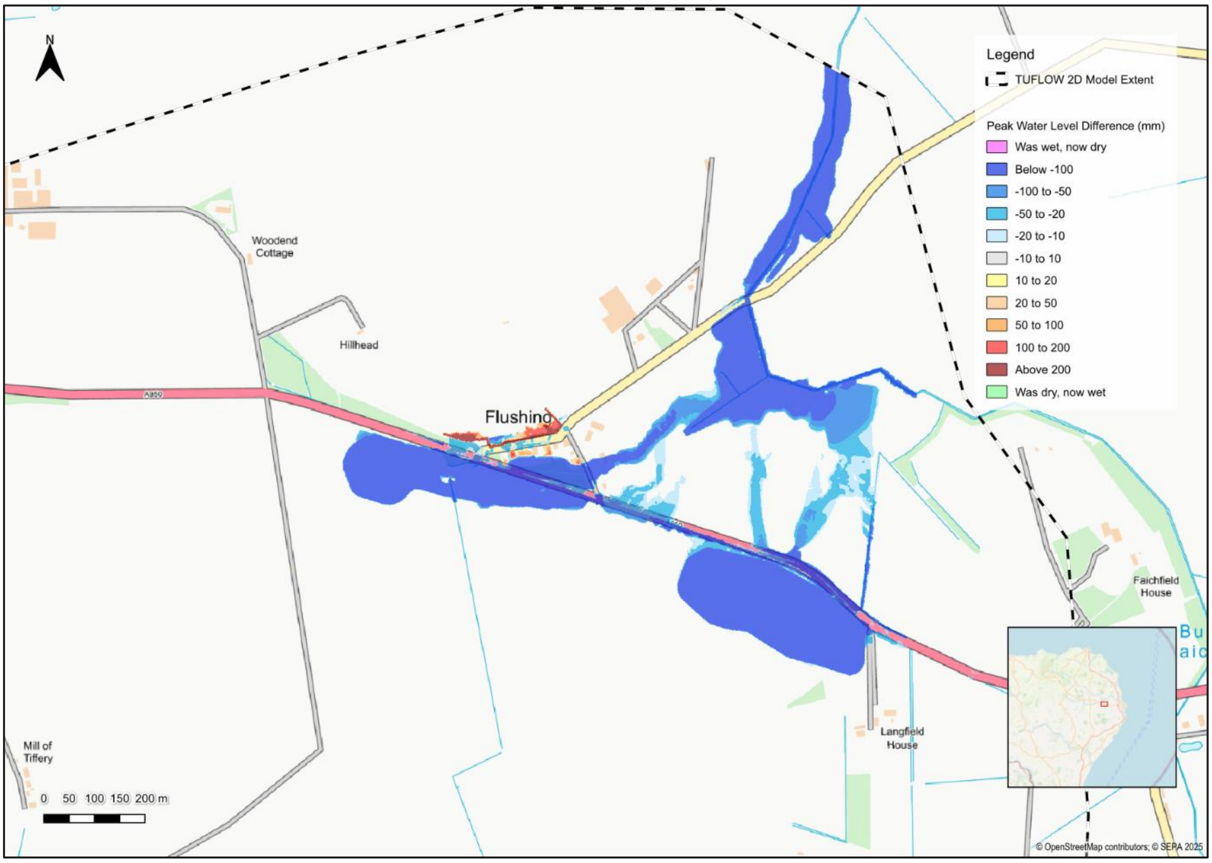



Figure 2-12 below shows the differences between Mitigation Option 4 and the Baseline, with significant peak depth increases over 100mm within the modelled basins as intended. The results also highlight the reduction in flood depths (primarily in excess of 100mm) in all areas outside of the modelled basins, demonstrating that both basins working together is highly effective as a solution for removing the risk of flooding overall.

**Figure 2-12: Difference results between Mitigation Option 4 and Baseline**




## 3.6 Mitigation Option 5 – NW Basin

This mitigation option comprises the modelling of the northwest basin from the Netherton Hub DIA with a flow restriction (320.9l/s) applied to the culvert beneath the A950. The restricted flows are then discharged to the drainage ditch running to the north of the A950 before entering culvert G. The purpose of this option is to mimic the restricted discharge of surface water runoff from the proposed Netherton Hub development, ultimately retaining floodwater upstream and within the Netherton Hub land to prevent flooding to Flushing by significantly reducing flow rates and volumes together with ensuring that culvert G does not reach its peak conveyance capacity.

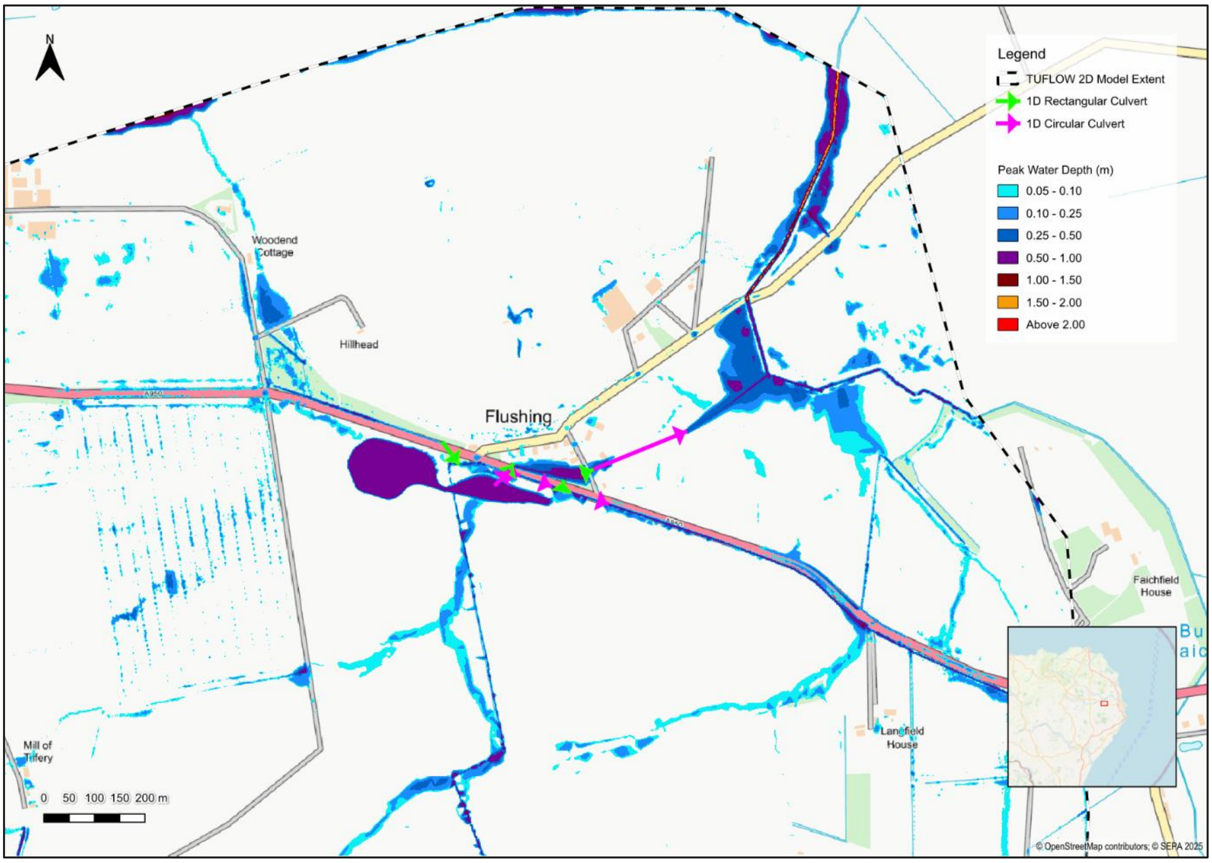
A schematic plan of the mitigation features above is included in Appendix A.

### 3.6.1 Mitigation Option 5 Results

The peak flood depth results for Mitigation Option 5 are shown below in Figure 2-13. While the DIA basin to the northwest is sufficient in greatly reducing the effects of flooding to Flushing, in particular with intercepting the significant out of channel flow path within the Netherton Hub site that runs adjacent to the watercourse, as with Mitigation Option 4 small, isolated patches of flooding are shown to occur within Flushing itself. This flooding is still attributed to sheet runoff from the higher ground to the north of Flushing.

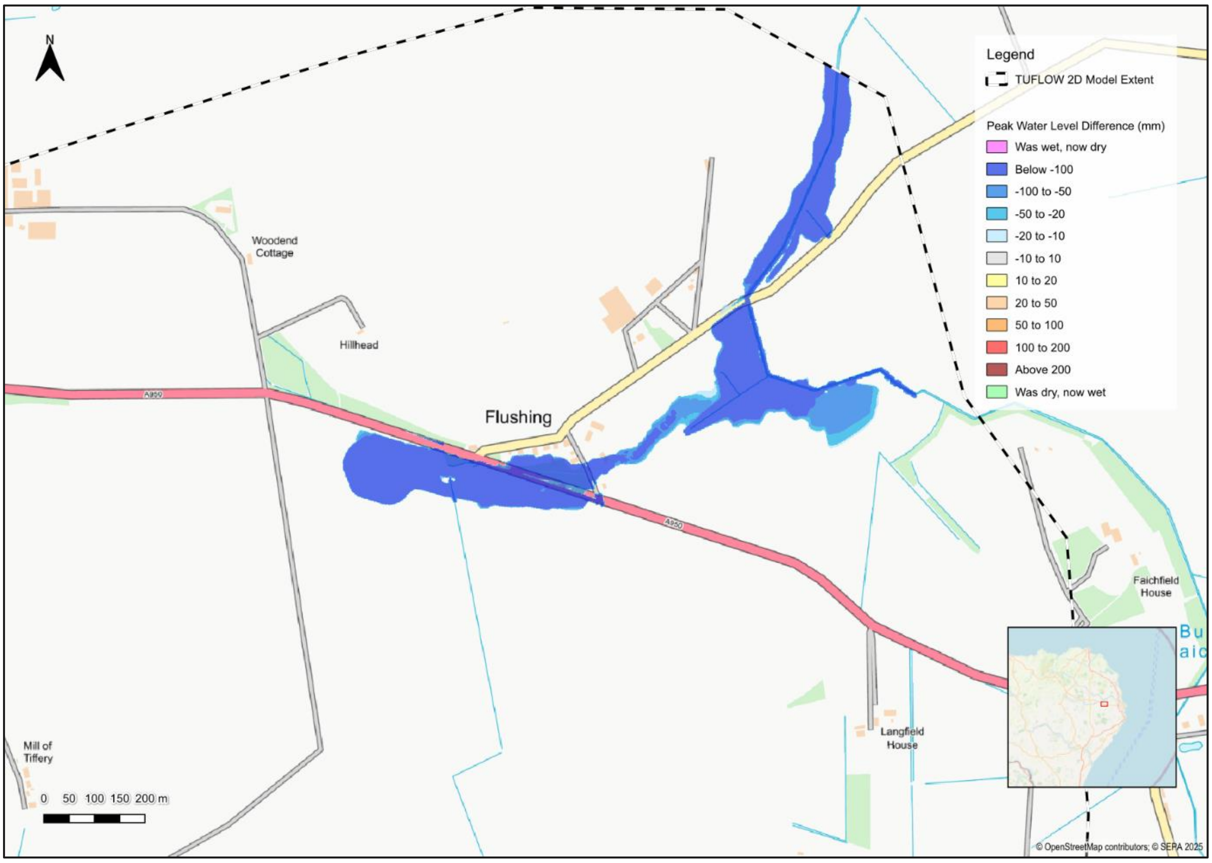
In the immediate vicinity of the watercourse running to the north of the A950, some flooding is indicated to occur and to a greater extent than with Mitigation Option 4. This is likely attributed to the fact that, without the basin to the northeast, surface water is not intercepted and continues to run within the watercourse situated immediately adjacent to the south of the A950. Though not severe, this results in a greater flow through the culvert beneath the A950 coupling with overland flow from the north. Despite this, the inclusion of the northwest basin alone offers a significant betterment over the baseline conditions.

**Figure 2-13: Mitigation Option 5 peak flood depths (0.5% AEP+37% climate change)**




The difference in peak depths between Mitigation Option 5 and the Baseline are shown in Figure 2-14 below. Similar to Mitigation Option 4, the inclusion of the basin expectedly results in the majority of flood water being retained, with reductions in peak flood depth primarily in excess of 100mm downstream. Removal of the basin to the east, without increases or decreases shown to occur to the east, highlights that flooding in that area is relatively unchanged from the Baseline. This suggests that implementing the western basin first or early (aside from any planning requirements) would be a beneficial measure for substantially reducing the risk of flooding to Flushing itself until such a time as the full Netherton Hub scheme can be completed.

**Figure 2-14: Difference results between Mitigation Option 5 and Baseline**




## 3.7 Mitigation Option 6 – Diversion to NE Basin

Similar to option 5 above, this mitigation option aims to test the performance and ability of a single DIA basin at resolving flooding downstream, with the basin to the northeast tested alone with a direct discharge to the Burn of Faichfield at a restricted rate of 242.3l/s. The watercourse within the Netherton Hub site has been diverted to the northeast basin following the existing topography as part of this scenario, ensuring that all flows propagate to the northeast basin where they can be retained and released gradually. In order to try and encourage flows to run along the diversion, an earth bund has been modelled to the immediate north across the original watercourse. During model runs of this scenario, the earth bund has been gradually increased in size but continues to be overtopped by significant flow. However, it is likely that a less rudimentary solution could be engineered in reality should this option be taken forward. With the direct discharge to the Burn of Faichfield, as with Mitigation Option 4, Flushing and its associated culverts would be completed bypassed to remove the risk of flooding.

A schematic plan of the mitigation features above is included in Appendix A.

### 3.7.1 Mitigation Option 6 Results

The peak flood depth results for Mitigation Option 6 are shown below in Figure 2-15. With only the northeast basin from the DIA and the watercourse diverted to it, some of the surface water is retained on-site. However, the results show that a significant breakout of surface water occurs at the start of the diversion before continuing in a northerly direction. The peak depth and extent of flooding is reduced, particularly to the immediate south of the A950 and along the watercourse channel to the north of the A950, though flooding is still shown to occur in these areas, highlighting that this option, while providing a slight betterment over the baseline conditions, is less effective than Mitigation Options 4 and 5.

**Figure 2-15: Mitigation Option 6 peak flood depths (0.5% AEP+37% climate change)**

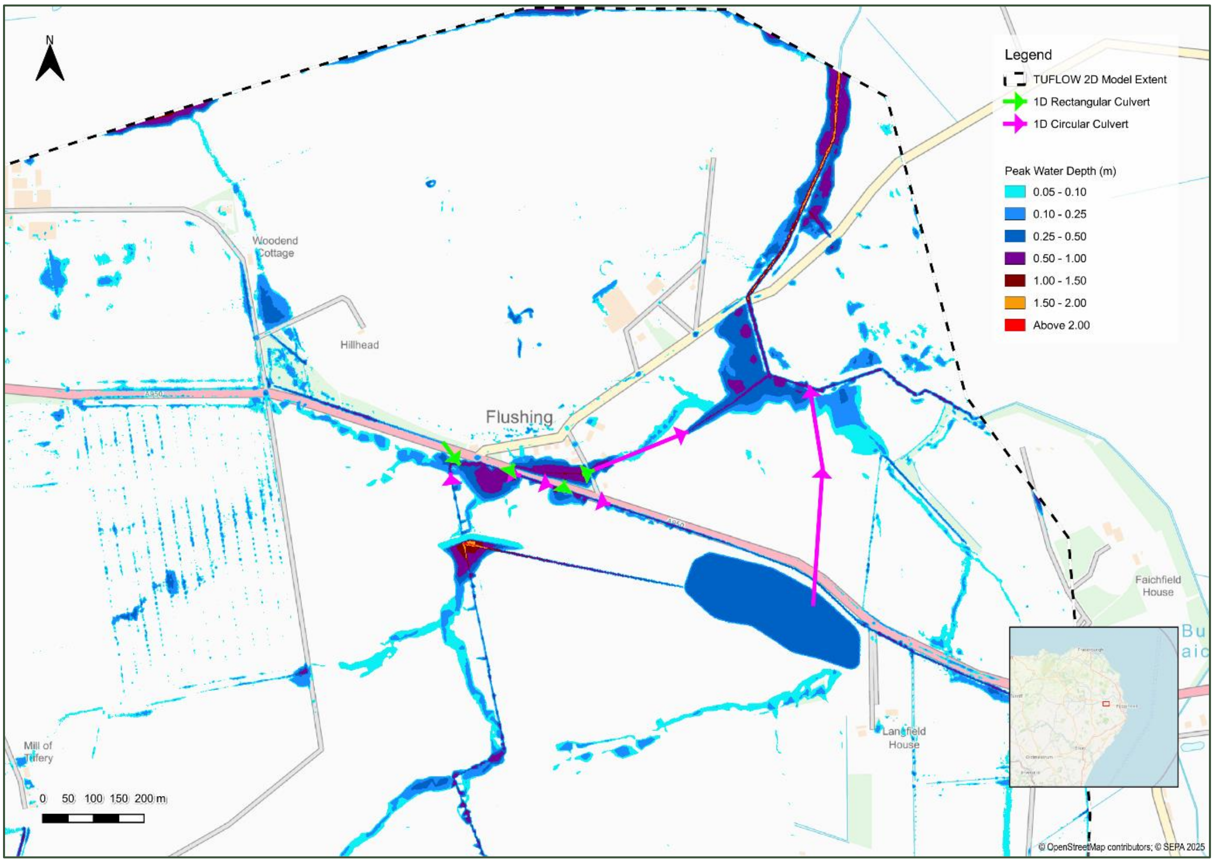
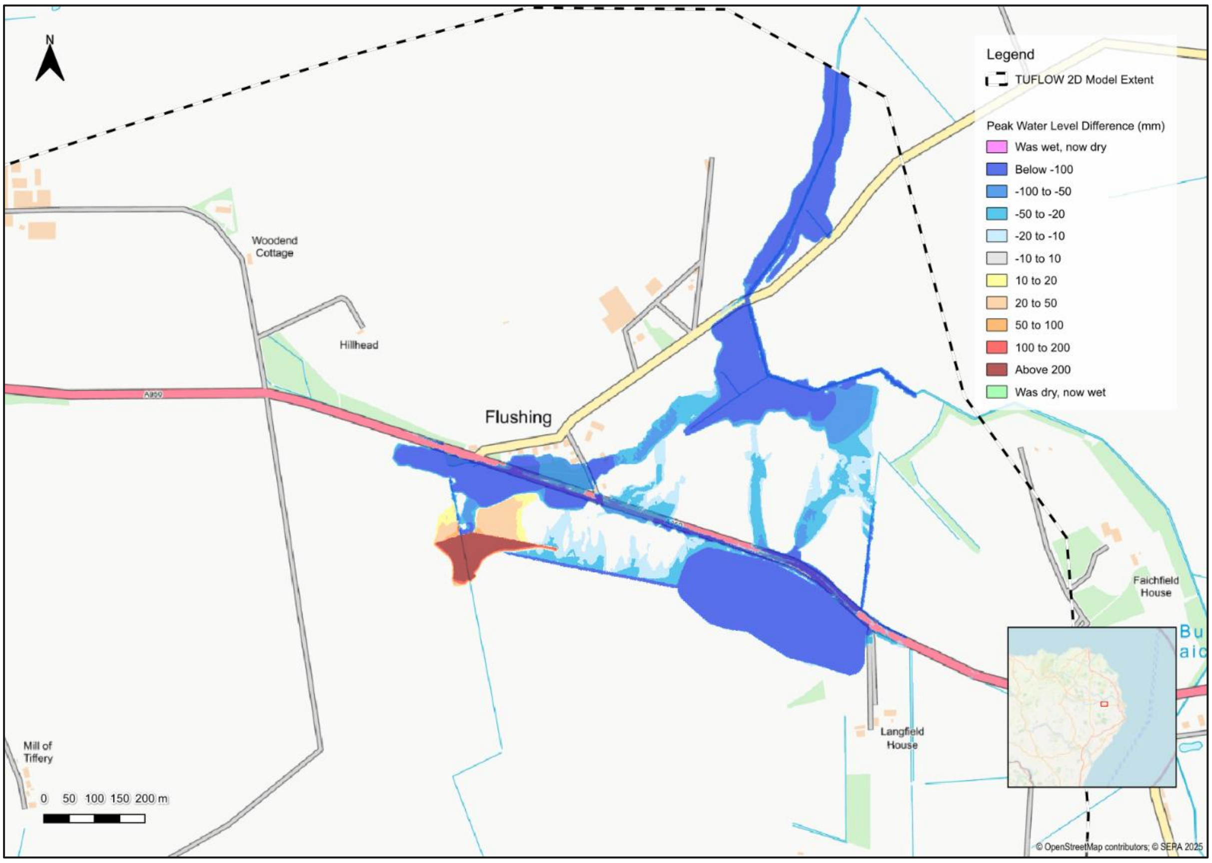



Figure 2-16 below shows the differences in peak depths between Mitigation Option 6 and the Baseline. This shows a reduction in peak flood depths to the south of the A950 of between 30mm and 100mm, with a substantial reduction exceeding 100mm to the north of the A950. A substantial increase in peak flood depths exceeding 100mm is shown within the site at the point that the diversion to the northeast basin commences, ultimately caused directly by the modelled earth bund. However, without this bund it is likely the reductions in peak flood depths immediately to the south of the A950 would be less prevalent, or potentially even be shown as an increase over the Baseline.

**Figure 2-16: Difference results between Mitigation Option 6 and Baseline**




## 3.8 Mitigation Option 7 – NW & NE Basins and Defence Bund

Similar to Mitigation Option 4, this mitigation option comprises both basins from the DIA. However, while in Mitigation Option 4 the NW basin discharges via a new sewer bypassing culverts E and G, Option 7 reverts to a restricted discharge of 320.9l/s to culvert E. This ensures a scenario which closely represents the DIA design, as per Mitigation Option 5 but with both basins represented.

In addition, due to the surface water runoff from the elevated ground to the north of Flushing resulting sheet rainfall runoff, a raised bund has been modelled adjacent to the north of the road through Flushing. This raised bund is set to a level of 32.7m AOD, ensuring an average height of approximately 1.5m. As the bund is designed to trapsurface water runoff as it flows south towards the open watercourse, a 300mm diameter culvert has been modelled to allow the water to drain directly to the open watercourse.

A schematic plan of the mitigation features above is included in Appendix A.

### 3.8.1 Mitigation Option 7 Results

The peak flood depth results for Mitigation Option 7 are shown below in Figure 2-17, indicating similar results to that of Mitigation 4 despite the direct discharge from the NW basin to culvert C1. The extent of flooding around the open watercourse between the dwellings in Flushing and the A950 is essentially the same as seen during Option 4, though peak flood depths during Option 7 are generally around 40-50mm lower. This is likely due to the fact that runoff from the north of Flushing is restricted in its entry to the open watercourse, rather than due to the NW basin discharge to culvert E.

Figure 2-17 also shows the rainfall runoff from the elevated land to the north of Flushing being intercepted and retained by the modelled raised bund which ultimately prevents a relatively small amount of flooding to residential properties in the Baseline scenario. The flooding immediately to the south of the residential dwellings that remains present within the gardens has also been prevented due to the levelling of ground levels in the floodplain.

**Figure 2-17 Mitigation Option 7 peak flood depths (0.5% AEP+37% climate change)**

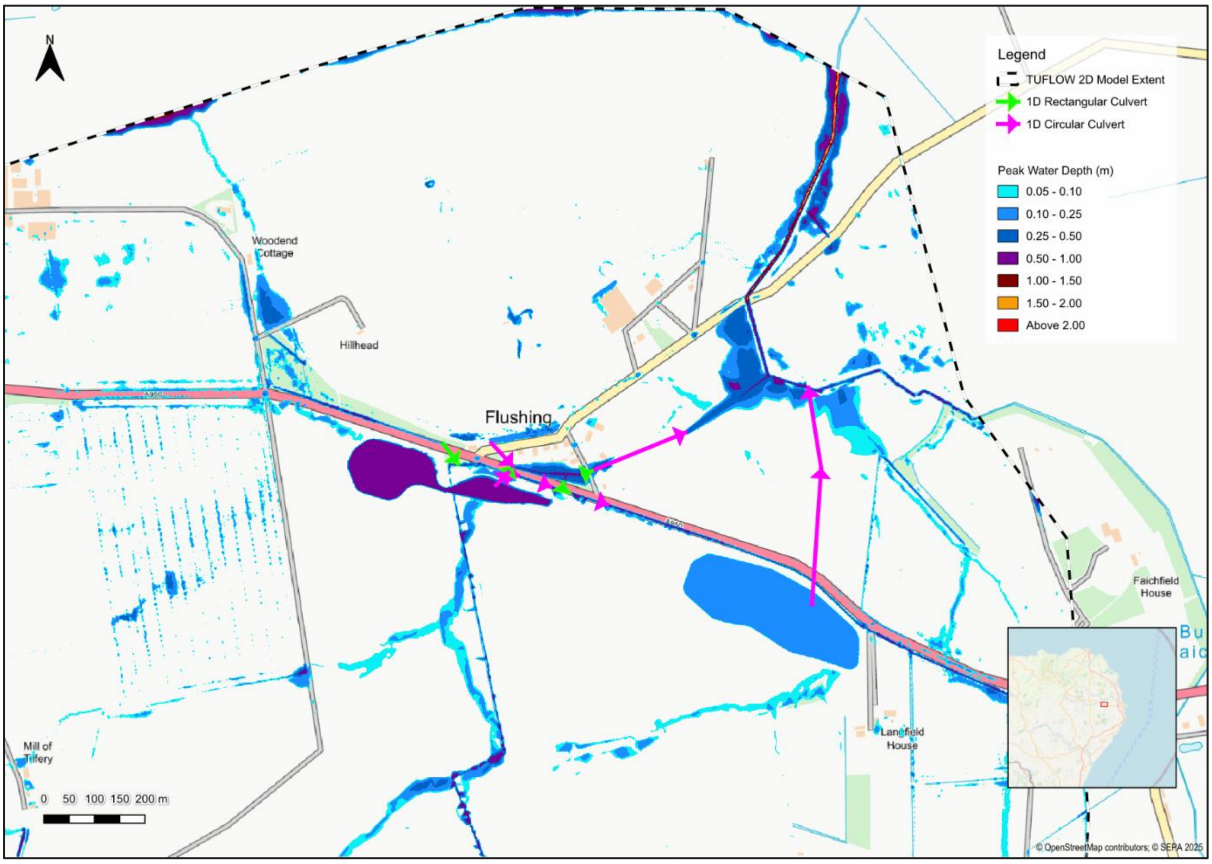
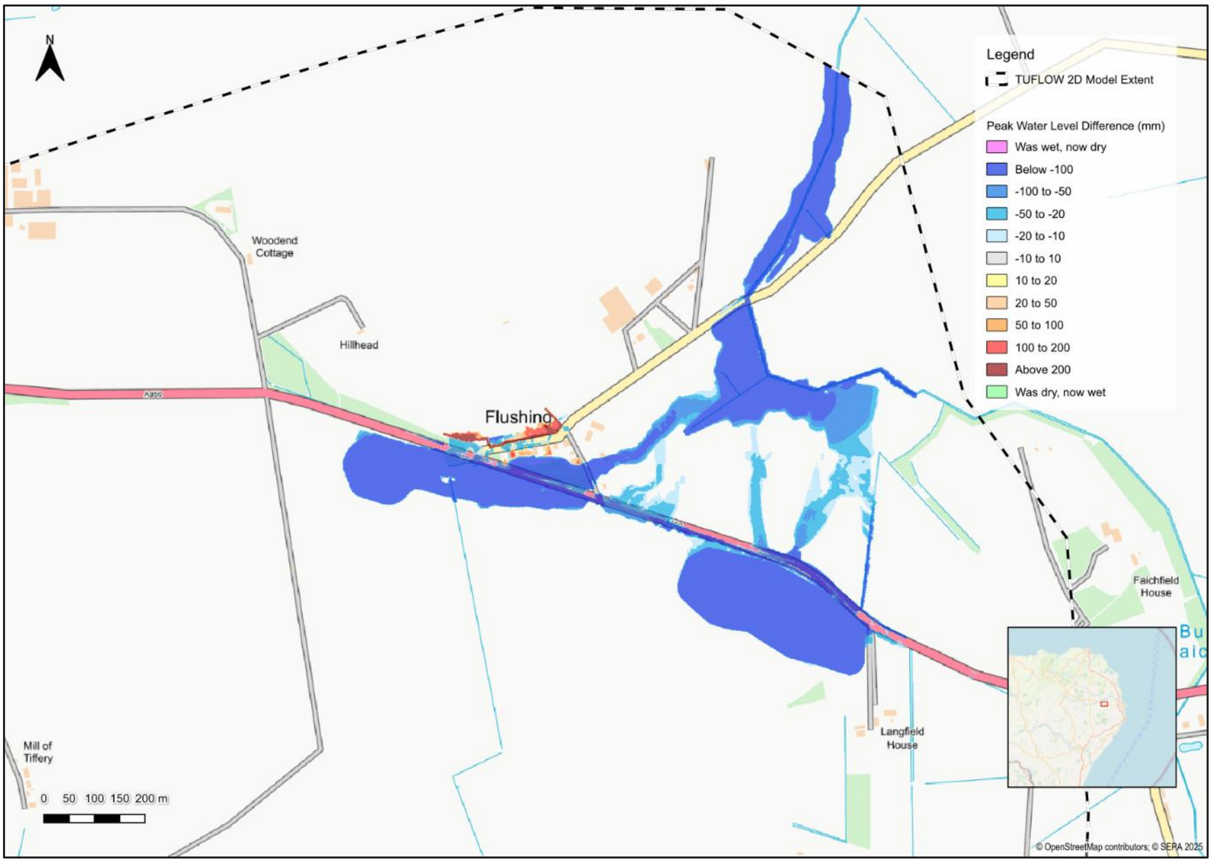



Figure 2-18 below shows the differences between Mitigation Option 7 and the Baseline, which shows that, while the flooding of the rear gardens of the residential properties discussed above has not been completely prevented, the extent has been reduced and overall peak depth of flooding in this area has been reduced by between 30 and 100mm. As with Option 4, the extent and peak depth of flooding to the north of the A950, in the vicinity of culvert G and further downstream has been significantly reduced. Increases in peak depth are observed but only in intended locations, such as the DIA basins and behind the raised bund to the north of Flushing, highlighting the effectiveness of these features.

**Figure 2-18: Difference results between Mitigation Option 7 and Baseline**




## 3.9 Mitigation Option 8 – NW & NE Basins, Defence Bund, Raised Land & Single Culvert (G)

Mitigation Option 8 comprises a copy of Mitigation Option 7, but with culverts G1 and G2 having been replaced with a single long culvert to remove the brief gap between that allows flooding out of the watercourse.

A schematic plan of the mitigation features above is included in Appendix A.

### 3.9.1 Mitigation Option 8 Results

The results of the 1 in 200-year (0.5% AEP) plus 37% climate change event for Mitigation Option 8 are shown below in Figure 2-19. These results are shown to be broadly the same as those of Mitigation Option 7. However, the single culvert replacing culverts G1 and G2 successfully prevents flooding from impacting the single residential dwelling to the eastern edge of Flushing.

**Figure 2-19: Mitigation Option 8 peak flood depths (0.5% AEP+37% climate change)**

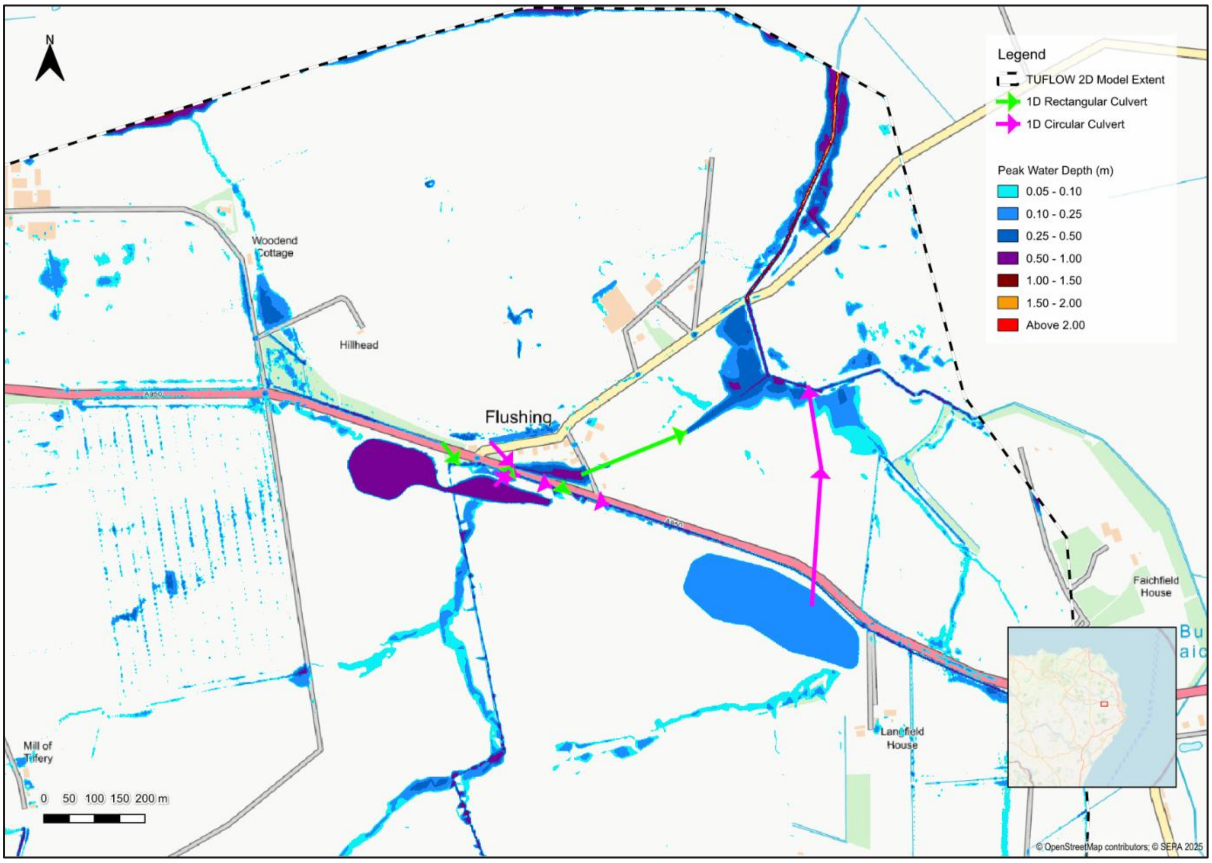
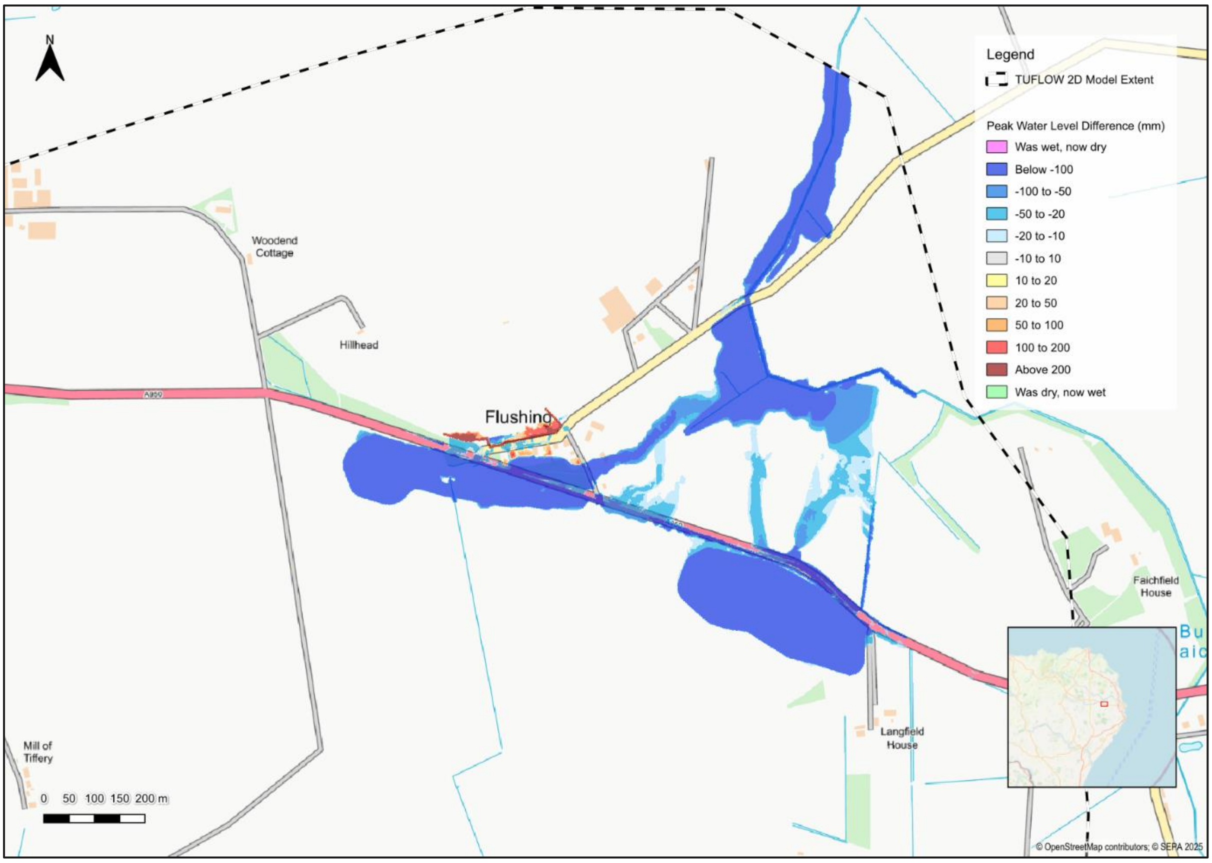



Figure 2-20 below shows the differences between the results of Mitigation Option 8 and the Baseline during the 1 in 200-year plus 37% climate change event, showing broadly the same significant reductions in flooding as in Mitigation Option 7. However, with regards to the dwelling to the east of Flushing, this simply suggests that while the reduction in flooding around this dwelling in Option 7 was greater than 100mm, the reduction for Option 8 is greater still.

**Figure 2-20: Difference results between Mitigation Option 8 and Baseline**




## 3.10 Mitigation Option 9 – NW & NE Basins, Defence Bund, Raised Land & Raised Dwelling Land

Similar to Mitigation Option 8, Mitigation Option 9 is a copy of Mitigation Option 7 which includes the ground levelling in the floodplain to the rear of the residential properties. However, instead of a single culvert replacing culverts G1 and G2 both of these have been retained along with the brief stretch of open watercourse between the two. Instead, ground raising has been added around the dwelling near these culverts in an attempt to keep it free from flooding and to deflect water downstream.

A schematic plan of the mitigation features above is included in Appendix A.

### 3.10.1 Mitigation Option 9 Results

The results of the 1 in 200-year (0.5% AEP) plus 37% climate change event for Mitigation Option 9 are shown below in Figure 2-21. The results are shown to be very similar to Mitigation Option 7. However, while flooding around the gap between culverts G1 and G2 is still present, this has essentially been pushed away from the dwelling marginally due to the raised ground.

**Figure 2-21: Mitigation Option 9 peak flood depths (0.5% AEP+37% climate change)**

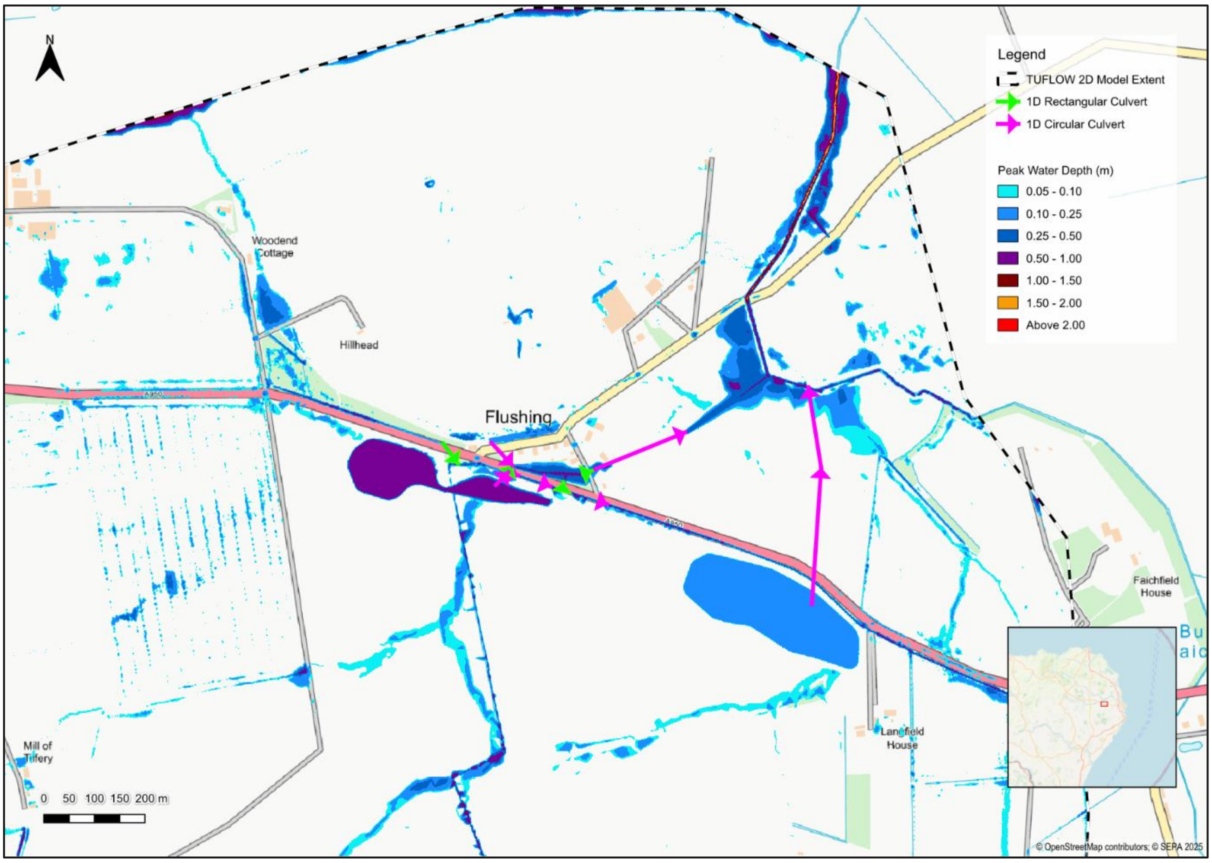
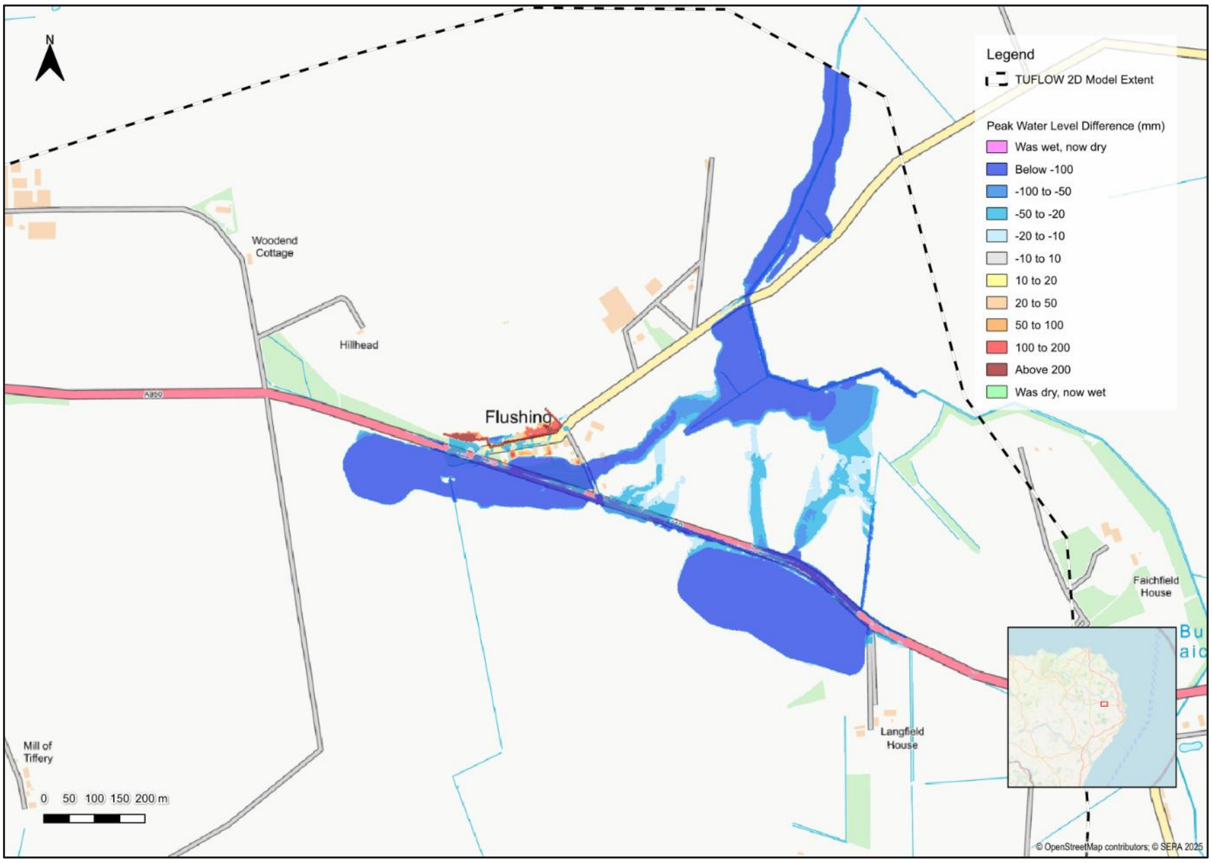



Figure 2-22 below shows the differences between the results of Mitigation Option 9 and the Baseline during the 1 in 200-year plus 37% climate change event, again showing very similar significant reductions in flooding as seen with Mitigation Option 7. As with Mitigation Option 8 above, the improvements offered by Option 9 in the vicinity of the dwelling to the eastern are marginal due an already greater than 100mm reduction being reduced further.

**Figure 2-22: Difference results between Mitigation Option 9 and Baseline**




# 4.0 Conclusions

The RAG Rating table below provides a summary of the findings from each of the tested mitigation options.

| Mitigation Option | RAG Rating | Comments |
|---|---|---|
| 1 | | This option generally performs well, though would need to be expanded further to offer a total solution to flooding from the site. It is likely that the scrapes, alongside features such as bioretention areas, could be worked into the detailed drainage design for the site running adjacent to the realigned channel. |
| 2 | | Upsizing of the culverts offers marginal improvements. Demonstrates that a significant volume of water propagates along the watercourse south of the A950 and that the watercourse lacks sufficient capacity in itself, highlighting the need for floodwater attenuation volumes. |
| 3 | | Primarily completed as a sensitivity test. This option highlights the need for attenuation volumes to storage floodwater. Otherwise, excess flood volumes are able to bypass culvert C1 and freely overtop the A950. |
| 4 | | Option 4 demonstrates that the DIA basins would suitably retain floodwater, drastically reducing flooding to the north of the A950. However, some limited flooding is still shown to occur to the area around culverts G1 and G2 due to the gap between the two. The |

| Mitigation Option | RAG Rating | Comments |
|---|---|---|
| | | addition of a bund to the north of Flushing prevents sheet surface water runoff from the elevated land to the north reaching and subsequently impacting the residential properties in Flushing. |
| 5 | | Similarly to Option 4, Option 5 demonstrates that the northwest DIA basin would be highly effective in significantly reducing/removing flood risk downstream. However, with the removal of the northeast DIA basin, the flow path through the site that runs in a north-easterly direction would not be intercepted. |
| 6 | | This option demonstrates that the northeast basin alone, with flows diverted from the watercourse, would be highly effective in reducing flood risk downstream of the A950. However, upstream of the A950, reductions are still present but to a lesser degree. As such, this option could be explored further with further considerations but should not be favoured. |
| 7 | | This option, being a close representation of the DIA, is shown to be extremely effective in retaining surface water flood volumes and preventing flooding downstream, as per Option 4. However, some limited flooding around the dwelling to the eastern edge of Flushing is shown to occur, due to the open gap between culverts G1 and G2. |
| 8 | | This option broadly demonstrates similar results to Option 7. However, the addition of the single culvert to replace culverts G1 and G2 in order to prevent flooding to the single dwelling located to the east of Flushing. |
| 9 | | Mitigation Option 9 also broadly demonstrates similar results to Mitigation Option 7, with the flooding around the dwelling to the east reduced slightly, though not as significantly as in Option 8. Furthermore, the practical feasibility of raising the land around what is an existing dwelling is likely minimal. |

In conclusion, based upon assessment and the testing completed, it is understood that the primary cause of flooding to Flushing and the local area is due to the significant volume of greenfield runoff from the upstream catchment, coupled with an existing drainage system which is insufficient in conveying the necessary flows and volumes. As such, any mitigation measures will need to address the volume of runoff before it reaches the hamlet. Mitigation Option 4, 7, 8 and 9 demonstrate that both of the DIA basins together would provide sufficient water retention and volume storage, together with flow interception, to substantially reduce the risk of flooding downstream. However, through the testing of different solutions, it was discovered that flooding also occurs from the north and from the open watercourse between culverts G1 and G2. Mitigation Options 4, 7, 8 and 9 include a bund to defend the properties within Flushing from sheet surface water runoff from the elevated land to the north, which has been demonstrated to be effective.

Mitigation Option 8 goes a step further by replacing culverts G1 and G2 with a single culvert, successfully preventing flooding to the dwelling to the east of Flushing. However, while effective in flood mitigation, these options would require the implementation of the DIA basins in advance of the development at the Netherton Hub, and while the raised bund to the north is a relatively simple measure to implement, this would require third party engagement and agreement. Similarly to the bund, the works involved in removal and replacement of the culvert would be significant and also subject to third party agreement.

Mitigation Option 8 represents the most effective solution in alleviating current flooding from residential properties in Flushing and if deemed necessary, should be considered the preferred option to be taken forward by Aberdeenshire Council for developing with the relevant stakeholders.

While the preferred solution for flood alleviation at Flushing would be to incorporate the DIA basins, they will take time to implement fully. As such, in the short-term the existing residential dwellings in the area remain at risk of flooding. It is therefore recommended that property-level flood defences be considered to help prevent internal flooding of the properties. This may include (but not be limited to) flood barriers and gates, flood fencing and providing residents with temporarily deployed flood barriers.

It should be noted that the modelling completed as part of this study assumes each culvert is in good operational condition, with no conditional defects or blockages. However, during the site visit completed by SLR, and likewise during the site visit completed by WSP, a number of defects and uncertainties have been noted. Both site visits have discovered that the culvert inlet to culvert B was significantly deformed and blocked and has likely collapsed over time. Similarly, the CCTV survey completed by UMS on behalf of Aberdeenshire Council has noted that culvert G2 was in poor structural condition. As such, it is recommended that the culverts in and around Flushing be fully checked and surveyed and, where necessary, repaired and upgraded to minimise the risk of flooding in the future in the first instance.

# Appendix A Mitigation Option Schematic Plans and Modelling Results

Making Sustainability Happen