TECHNICAL APPENDIX 6.1: FLOOD RISK ASSESSMENT

Report

M9 Winchburgh Junction

Flood Risk Assessment

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1 Introduction

Sweco were commissioned to undertake a Flood Risk Assessment (FRA) in support of the planning application for a proposed motorway junction and access roads along the M9 at the B8020, Winchburgh, West Lothian.

The aim of this FRA is to demonstrate that the development proposal, inclusive of any mitigation elements, is compliant with Scottish Planning Policy (SPP, 2014) and the Flood Risk Management (Scotland) Act (2009). The report includes an overview of existing flood risk information for the area, as well as the detailed hydrological analysis and hydraulic modelling undertaken.

1.1 Data Sources

The study drew upon a variety of data sources, including:

- topographic survey data outlined in Appendix C;
- previous river and hydraulic structure surveys undertaken in 2005;
- 1 metre resolution LiDAR (Phase 2) from the Scottish Remote Sensing Portal[1];
- The National River Flow Archives database[2];
- The Flood Estimation Handbook Online Portal[3];
- British Geological Survey mapping[4]
- OS MasterMap data; and
- Winchburgh Future Urban Extension Flood Risk Assessment report (Carl Bro, 2005).

1.2 Site Visit

A site walkover was undertaken on the 22nd May 2019, covering sections of the Swine Burn, Craigton Burn and Beatlie Channel. Attendees were:

- James Franklin (Senior Engineer, Sweco)
- James Walker (Assistant Consultant, Sweco)

1.3 Site Location and Description

The proposed development is located in West Lothian, to the north east of the town of Winchburgh (OS grid reference NT 09575 75878). The development is composed of a proposed upgrade to the existing A9, including a new grade separated junction with Beatlie Road, as well as a SuDS pond and new access road. The only impact to the existing M9 will be localised at the 4 tie-in locations, where the proposed slip roads meet the existing motorway carriageway and hard shoulder.

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[1] Accessed https://dcenr.maps.arcgis.com/apps/webappviewer/index.html?id=b7c4b0e763964070ad69bf8c1572c9f5
[2] https://nrfa.ceh.ac.uk/data/search
[3] https://fehweb.ceh.ac.uk/
[4] BGS. Accessed http://mapapps.bgs.ac.uk/geologyofbritain/home.html?

The new access road crosses the Swine Burn and will therefore require the installation of a new culvert crossing. An overview of the scheme can be seen in Figure 1-1.

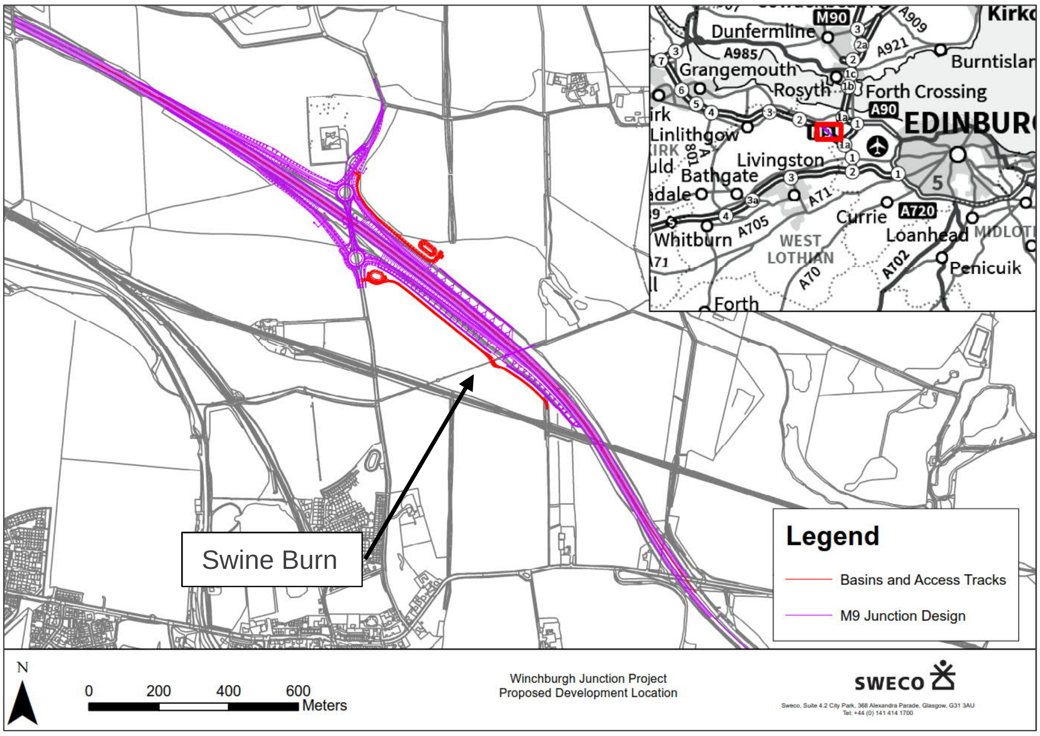

Figure 1-1 Site location and overview of the proposed development

Historical maps available from the National Library of Scotland[5] have been reviewed and indicated that the site has remained largely underdeveloped since the earliest map in the record dating to 1856, and that the surrounding land was mostly agricultural. Beatlie Road, as well as the Edinburgh to Glasgow railway are both present in the earliest map.

The Burn appears to have been modified and straightened into a land-drain prior to this map. Since 1955 there has been significant residential development within and to the north of Winchburgh.

1.4 Topography

A topographic map of the existing site is presented within the baseline modelling note provided in Appendix C and Figure 1-2. The area surrounding the proposal is generally low lying with a slight slope towards the Swine Burn. The embankments associated with the second railway and M9 provides a barrier through the floodplain.

[5] https://www.nls.uk/

Figure 1-2 Overview of site topography

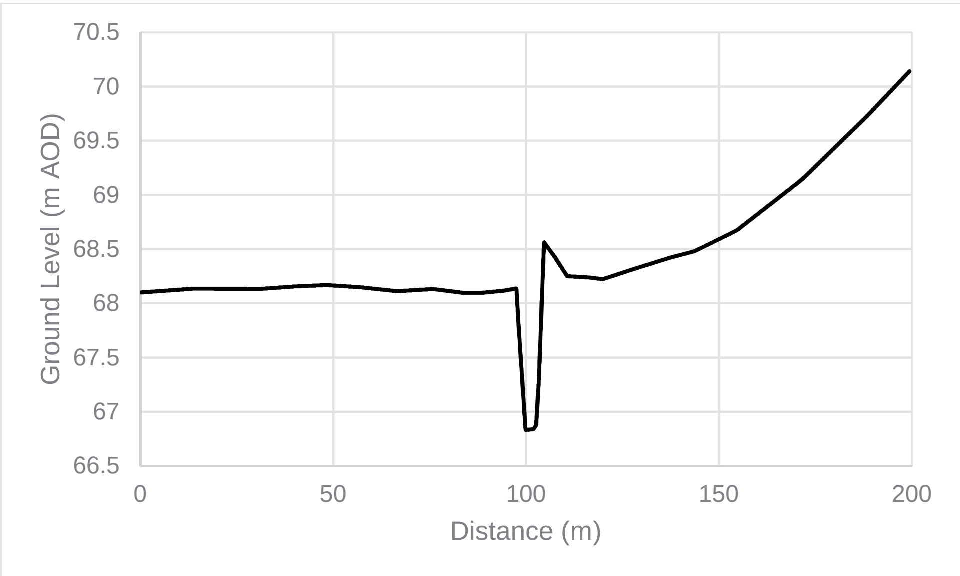

Figure 1-3 Ground profile within the area of interest

1.5 Catchment Overview

The development is within the catchment of the Swine Burn, which is an ungauged tributary of the River Almond. According to the FEH online service, this has a total catchment area of 30.64 km^2 at the confluence with the River Almond. The development sits in the catchment upstream of the M9 culvert, this catchment is estimated to have an area of 5.85 km^2. The Swine Burn is fed by two ponds located to the north west of Winchburgh and flows eastwards following the path of the Union Canal before passing under the canal just north of Winchburgh. It then flows north eastwards passing under two railway lines, the B8020 and the M9 via culverts, before connecting into the Humbie Reservoir. Floodwater from the Edinburgh to Glasgow railway are also pumped into the Swine Burn to the east of the Railway.

There are two tributaries which connect into the Swine Burn - the Beatlie Channel, which connects upstream of Beatlie Road; and the Craigton Burn, which connects immediately downstream of the culvert under the Union Canal. An overview of the watercourses and total catchment area, as defined in the FEH Online Service, are shown in Figure 1-4.

The total catchment is predominantly rural with an urban extent of 0.015. This parameter indicates that approximately 1.5% of the catchment consists of urban land cover. The base flow index (estimated from soil properties) is low to moderate at 0.404 and the FARL is 0.994, which infers a small degree of attenuation due to the presence of ponds or lakes. In particular, there is a large pre-existing clay pit south of the Beatlie Channel, between the Union Canal and the Edinburgh to Glasgow Railway, which has now been flooded and converted into a pond. Similarly, to the west of the Union Canal and north of the A7, there is a large pre-existing Quarry which is now being integrated into a new District Park.

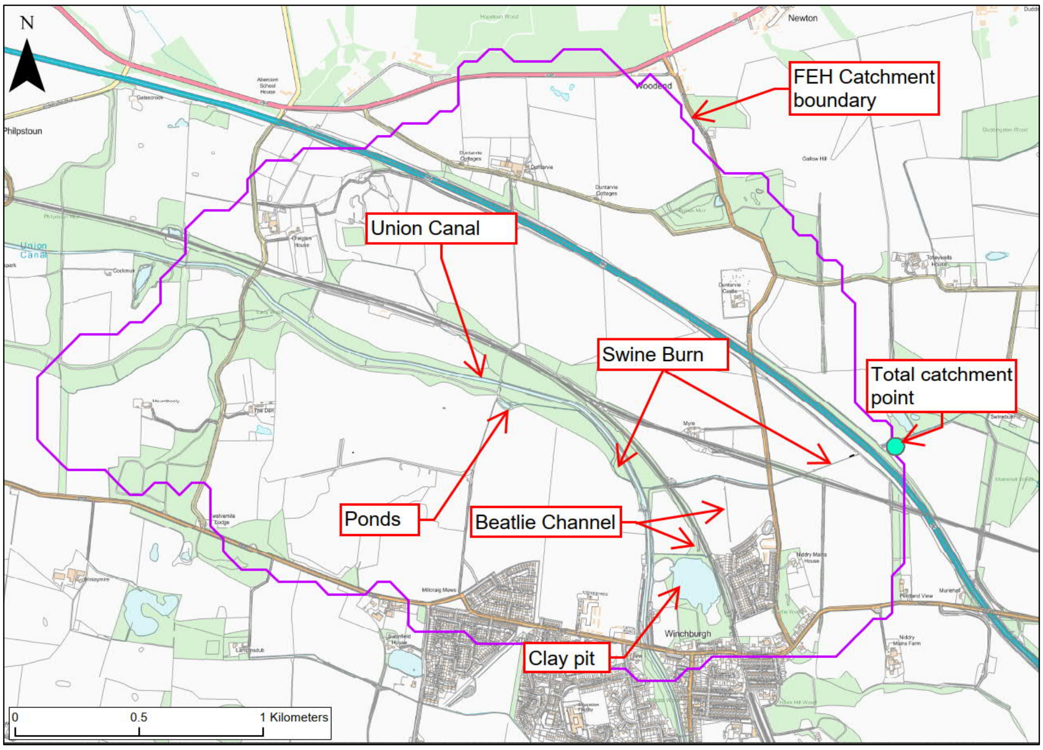

Figure 1-4 Overview of the total catchment areas as defined in the FEH online service.

1.6 Geology and Hydrogeology

The development site is underlain by Binny Sandstone which is described by the British Geological Survey[6] (BGS) as sedimentary rock of fluvial origin composed of coarse to fine grained sediment, which typically forms beds and lenses of deposits. To the west of the junction the underlying geology is classified as sedimentary rock which forms part of the Strathclyde formation. This is composed of generally fine-grained material, which form beds of carbonate rich deposits. According to the FEH Online Service both formations are moderately productive aquifers with groundwater movement primarily via fissures. The Hydrogeological Map of the UK (1:625,000 scale, 1988) shows that the underlying geology forms a moderately productive aquifer in which flow is dominantly in fissures and other discontinuities, although notes that borehole yields are generally moderate and not greater than 10l/s.

In terms of superficial geology, BGS mapping indicates that the junction and access road are underlain by lacustrine deposits of clay, silt and sand. These are typically fine grained but may include layers of coarser material. The surrounding area is largely dominated by glacial till with a varied composition. The full BGS geological mapping can be viewed in Appendix A.

A Site Investigation Report (2014)[7] undertaken to the west of the proposal notes that groundwater was encountered in twenty exploratory boreholes at depths of 1.6 to 12.25mbGL. Monitoring of boreholes within the drift recorded water levels as high as 0.4-0.7mbGL. The report notes that groundwater within the area is likely to be limited to perched groundwater in granular strata and lenses within the superficial deposits. Where present, local groundwater flow is likely to follow topography to the north, with regional groundwater flow expected to be towards the north or north east in the direction of the Firth of Forth.

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[6] http://mapapps.bgs.ac.uk/geologyofbritain/home.html?

[7] Desk Study and Ground Investigation Winchburgh BlockY. Report 761068/ACS/011214

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2 Review of Existing Flood Risk

2.1 Fluvial and Coastal Flood Risk

The SEPA fluvial flood mapping for the area indicates that the proposed development is within the low (1: 1000 year), medium (1: 200-year) and high likelihood (1: 10) zones for fluvial flooding. Flooding is predicted along both banks of the Swine Burn upstream and downstream of the existing M9 culvert. All flood risk likelihood scenarios show a very close similarity in extent with floodwaters occupying most of the area between the M9, Beatlie Road and the second railway line. For the medium and low risk scenarios floodwaters are predicted to overtop Beatlie Road to the north. Flooding is also predicted for all scenarios along both banks of the Swine Burn between the Union Canal culvert and the second railway culvert. However, the extent appears to be limited and remains close to the channel banks.

It is unclear how the culverts are represented within the SEPA modelling. In particular, both the culvert under the Union Canal, as well as an inverted syphon under the Edinbirgh to Glasgow railway, may provide a significant constraint on flows thereby affecting flood patterns within the area of interest.

The Beatlie Burn and Craigton Burns both have natural topographic catchment below $3km^2$ and are thus not included in the SEPA modelling.

2.2 Previous Studies

A previous hydraulic modelling study was undertaken for the Swine Burn as part of the Winchburgh Masterplan in 2005 by Carl Bro Group. A 1D ISIS model was developed and interviews conducted with local residents to aid in the validation of the model.

The study predicted flooding for the 1 in 200-year storm event (without an allowance for climate change) along the upper reaches of the Swine Burn, and along the Beatlie Channel, which overflows into the clay pit. No flooding was predicted along the Swine Burn in the vicinity of the proposed access road and junction.

2.3 Surface Water Flood Risk

The SEPA surface water flood risk map shows an extensive area of surface water accumulation to the east of the M9 which appears to be associated with the Humbie Reservoir. For the low and medium risk scenarios this extend westwards, crossing the M9, and intercepting the location of the proposed access road. Given the significant embankment along the M9, it is unlikely that flooding would overtop this feature and intercept the area of interest. There is also an isolated area at high risk to the west of Beatlie Road which likely relates to the fact that the existing culvert is not represented within the modelling.

The proposal will increase the area of impermeable surfaces within the Swine Burn catchment. However, the development will include a SuDS which will capture and attenuate surface water runoff for the road surfaces for the 1: 200-year storm event (with a suitable allowance for climate change). Surface water will discharge to the burn via a gravity system with outflows limited to the greenfield runoff rate. This will provide a sustainable drainage solution and ensure that the proposal will not detrimentally affect surface or fluvial flood risk downstream.

2.4 Sewer Flood Risk

A review of available information found that there is no evidence of flooding from local sewer networks having affected the proposed development site. However, the data available was relatively sparse.

2.5 Flood Risk from Reservoirs

The SEPA Reservoir Inundation Mapping indicates that the site is not at risk from the uncontrolled release of water in the event of a breach of nearby reservoirs. The Humbie Reservoir is however not registered under the Reservoirs Act 1975, and has therefore not been included in the inundation mapping.

2.6 Ground Water Flood Risk

The groundwater vulnerability maps produced by SEPA indicate that the site is not within an area where groundwater could influence the duration or extent of flooding from other sources within the area.

A review of geological information suggests that the site is underlain by a moderately productive aquifer, and that superficial deposits may have the potential to contain perched water tables.

2.7 Historical Instances of Flood Risk

As part of the previous 2005 flood study, consultation was undertaken with residents and relevant stakeholders. One resident interviewed noted several flood events on and around the railway, as well as within fields north and south of the Swine Burn (but unconnected to the Burn). A further resident reported that they had no knowledge of flooding directly from the Swine Burn with flooding largely associated with issues with surrounding land-drainage. The resident also noted that the Swine and Craigton Burn, as well as several field drains in the upper catchment, discharge to the canal during times of flooding.

2.8 Summary

A review of existing information indicates that there is a low risk of sewer flooding. There is uncertainty regarding the potential for groundwater flooding, however there are no reported instances of said flooding, and the vulnerability maps produced by SEPA suggest that there is a low risk.

There is the potential for surface water flooding within the wider area however, the development will contain a suitably designed SuDS, which will ensure that surface water is managed effectively. This will also ensure that there is no detrimental effect on flood risk downstream.

The SEPA fluvial flood mapping indicates that there is a moderate to high risk of fluvial flooding from the Swine Burn affecting the proposed development site. However, there is no evidence of previous flooding directly from the Swine Burn, and there is significant uncertainty regarding the SEPA flood modelling, particularly relating the representation of hydraulic features. Further modelling is therefore required to evaluate the existing flood risk from the burn in more detail.

3 Hydrological Analysis

The following provides a brief summary of the hydrological analysis undertaken for the Swine Burn and its associated tributaries. A more detailed overview is provided within Appendix B.

3.1 Estimation of the Index Flood (QMED)

The River Swine and its tributaries are ungauged and therefore the methods used to estimate flow rely on using catchment characteristics. A catchment descriptor for the Swine Burn at a point downstream of the M9 was purchased from the FEH Online Service (see Figure 1-4). The catchment parameters were input into WINFAP FEH (version 3; dataset version 7) to provide an initial QMED estimate of 1.953 m^3/s. The estimate of QMED was then refined through the process of data transfer using an appropriate donor site which increased the value to 1.984 m^3/s.

3.2 Peak Flows

Following the calculation of the index flood three methods were used to derive estimates of peak flows for the Swine Burn catchment upstream of the M9 as defined by the FEH Online Service: FEH Statistical, ReFH2 and FEH rainfall-runoff. Full details of these methods can be found in Appendix B.

The results indicated that all the methods provided similar peak flow values. ReFH2 produced the lowest estimate of flows and, given the uncertainty for small catchments, was not felt to be appropriate. The FEH rainfall-runoff method provides the most conservative estimate of peak flows; however, this has been largely superseded by ReFH2, which has been updated and calibrated for Scottish catchments, and is now cautiously recognised by SEPA. The FEH statistical method provide a good compromise in that the estimated flows are more conservative than those predicted using ReFH2, but lower than the FEH rainfall runoff method. It was therefore decided that the hydrograph shape would be derived using ReFH2 and the peak uplifted to match FEH statistical estimates using an adjustment factor.

3.3 Catchment delineation

Ten sub-catchments were identified which drain to points along the Swine, Beatlie and Craigton Burns (Figure 3-1). This was based on an analysis of topographical survey data (2019) and 1m resolution LiDAR using ArcGIS. A simplified direct-rainfall model was also constructed to evaluate potential flow paths and to identify areas of pooling. In particular, a large part of the area to the west was found to drain towards the canal or accumulate within a disused quarry. Similarly, an area to the south of Beatlie Channel was found to discharge into a clay pit. Hence these areas were removed from the catchment coverage.

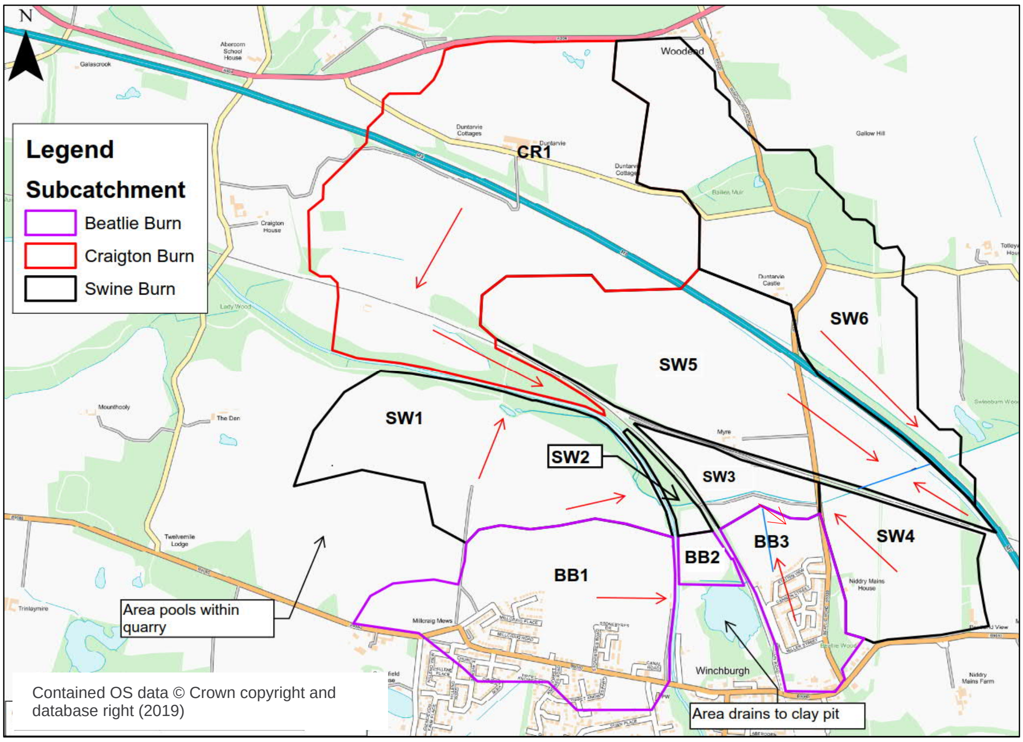


Figure 3-1 Estimated catchment areas draining into the Swine and Craigton Burns as well as the Beatlie Channel

Hydrographs were generated in ReFH2 for each of the areas shown in Figure 3-1 using sub-catchments within Infoworks ICM (version 9) and these were then uplifted by the calculated adjustment factor. The impact of the adjustment on the hydrographs is presented in Table 3-1.

Table 3-1 Estimated ReFH2 200-year flows for each sub-catchment calculated in Infoworks ICM

Sub-catchment	200-year ReFH2 peak flow (m^3/s)	200-year peak flow (m^3/s) with adj. factor applied (1.07)	35% CC
SW1	0.832	0.890	1.202
SW2	0.042	0.044	0.060
SW3	0.153	0.164	0.222
SW4	0.366	0.392	0.529
SW5	1.035	1.108	1.496
SW6	0.703	0.752	1.015
BB1	0.775	0.82	1.120
BB2	0.051	0.055	0.074
BB3	0.266	0.285	0.384
CR 1	1.270	1.358	1.834
Total	5.493	5.878	7.935

4 Fluvial Hydraulic Modelling

The following provides a summary of the hydraulic modelling as well as the baseline and post development results. A detailed overview is provided within Appendix C.

4.1 Fluvial Hydraulic Model Build

A 1D-2D model of the Swine Burn and its floodplain was created in Infoworks ICM (version 9). The model also includes a 750 m stretch of the Craigton Burn as well as Beatlie Channel. The 2D extent of the model is defined by the green polygon in Figure 4-1, which includes an overview of the model.

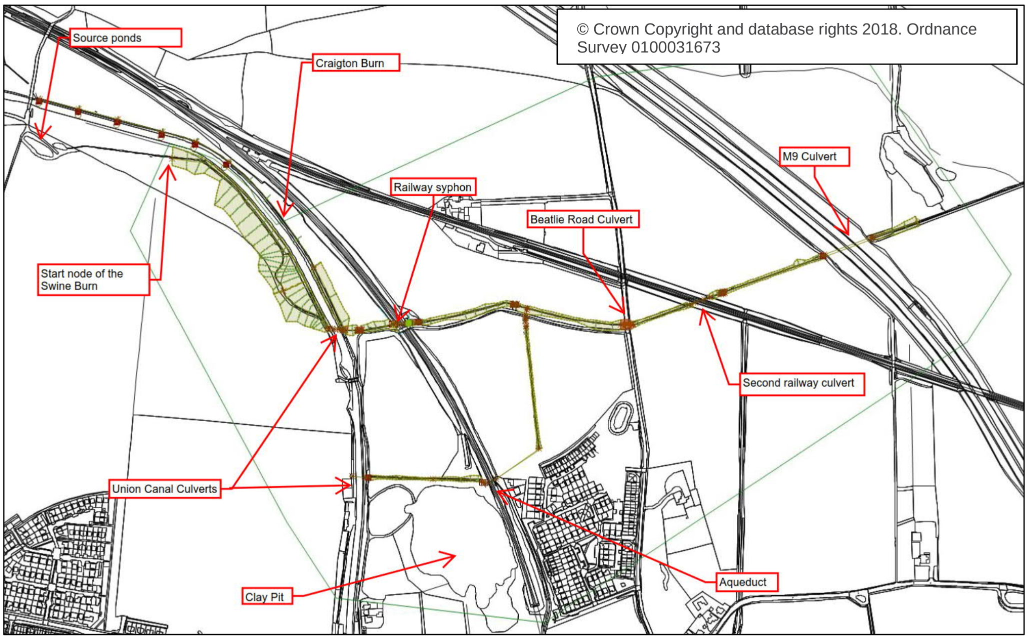


Figure 4-1 Overview of the model extent and domain

The model contains a total of 134 1D cross-sections which were cut from a ground model created using topographic survey data supplemented with 1 m resolution LiDAR. The cross-section upstream and downstream of the railway syphon along the Swine Burn were created based on cross-sectional surveys undertaken in 2005. These were thought to be more representative of the channel geometry following the site visit.

The 2D domain was meshed using the same ground model used to create the 1D river sections. The 2D zone was positioned to cover all areas where out of bank flows are expected. The 2D area is linked to the 1D river channel of the Swine and Beatlie Channels through bank lines, where flow is passed between the 1D and 2D computational model elements.

Based on the 2005 flood study Craigton Burn is known to overtop and discharge into the Union Canal within its upper reaches during flood events. Previous studies, in consultation with Scottish Canals, identified that the Union Canal maintains its level via a series of overflow weirs along its length. Therefore, to account for this process a series of irregular weirs were added to allow for the volume lost to the canal to be quantified.

4.1.1 Upstream Boundary Conditions

A detailed overview of the hydrological method used to determine the upstream boundary for the model is provided in Appendix B. The overall catchment was divided into ten sub-catchment each of which drain to specific sections of the watercourses. ReFH2 hydrographs were generated using sub-catchment objects within Infoworks ICM. These were then uplifted using an adjustment factor calculated based on the difference in peak flows estimated using ReFH2 and FEH statistical methods.

SEPAs climate change guidance (Climate change allowances for flood risk assessment in land use planning[8]) states that for small catchments (<30 km^2) the rainfall climate change allowance should be used for fluvial uplift. For the River Swine, which is within the Forth river basin region, an allowance of 35% was therefore applied to peak flows. An example of the input hydrograph can be seen in Figure 4-2.

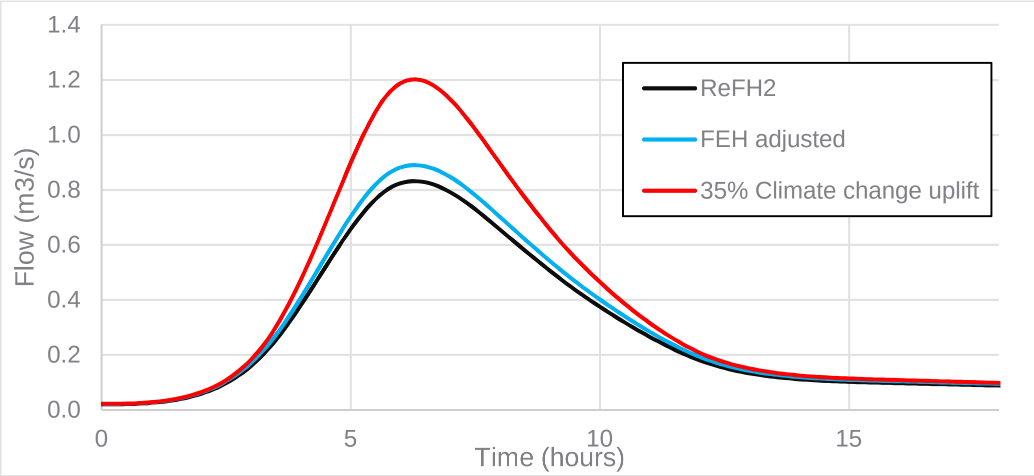


Figure 4-2 Hydrographs generated for sub-catchment SW1

The Edinburgh to Glasgow railway is served by a pumped drainage system which was accounted for by applying a constant flow rate of 0.67m^3/s to the Swine Burn, and 0.33m^3/s to the Beatlie Channel. These values were taken from the previous 2005 FRA report.

8 https://www.sepa.org.uk/media/426913/lups_cc1.pdf

4.1.2 Downstream Boundary Condition

An 1D outfall node was placed at the downstream end of the model with a normal boundary condition. Sensitivity analysis was undertaken to evaluate the impact of the downstream boundary.

4.2 Baseline Model Results

The modelling predicts flooding along both banks of the Swine Burn upstream of the Union Canal culvert for the 1:200-year event both with and without an allowance for climate change. Flooding in this location relates to the lack of capacity within the Union Canal Culvert and the sedimentation observed during the site visit. The extent of flooding is, however, limited by the sloping topography adjacent to the western bank of the watercourse, as well as the canal embankment.

The 1:200 year without climate change flood extent, which denotes the functional floodplain, is predicted to be largely contained within the channel downstream of the Union Canal Culvert to the outfall of the model (see Figure 4-3). There are small areas where floodwaters extend slightly beyond the bank, most notable upstream of Beatlie Road and the M9, however these are limited in extent. The access road and the updated junction is therefore not within the functional floodplain of the Swine Burn.

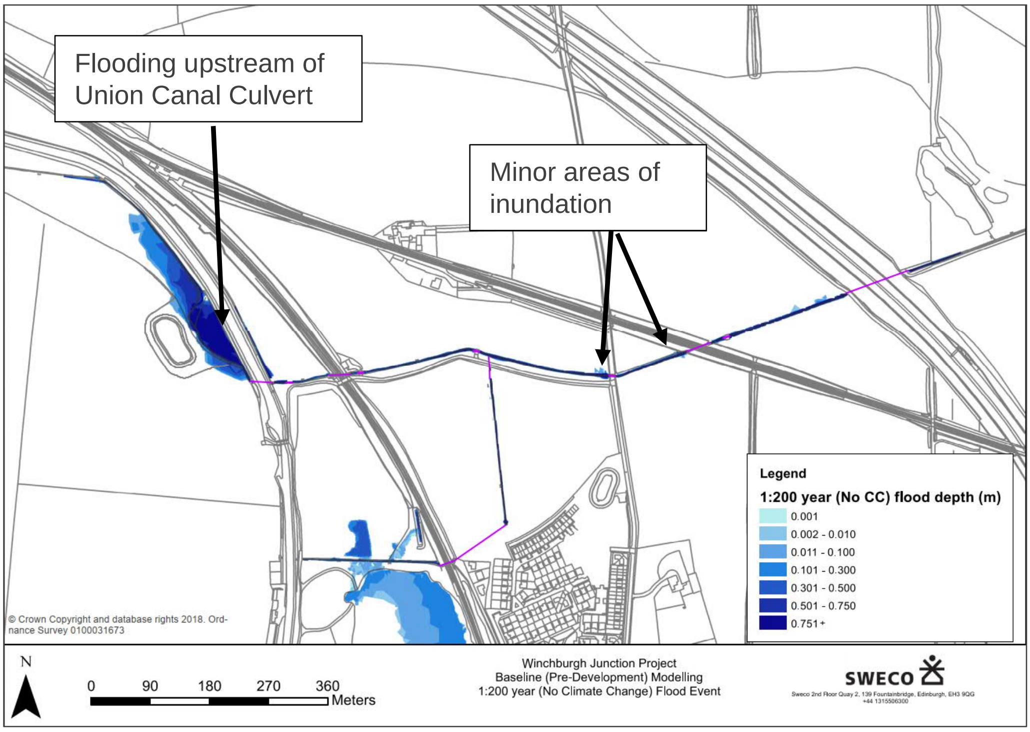


Figure 4-3 Predicted 1: 200-year (without an allowance for climate change) flood extent.

For the 1:200-year event with a 35% allowance for climate change, flooding is also predicted along the Swine Burn upstream of the Beatlie Road, as well as between the second railway and M9 culverts. This does not relate to a lack of capacity within the Beatie Road, second railway or M9 culverts, but rather low points along the channel banks. Flooding is also predicted along both banks of the Beatlie Channel which flows onto the Edinburgh to Glasgow railway line, and into the clay pit to the south.

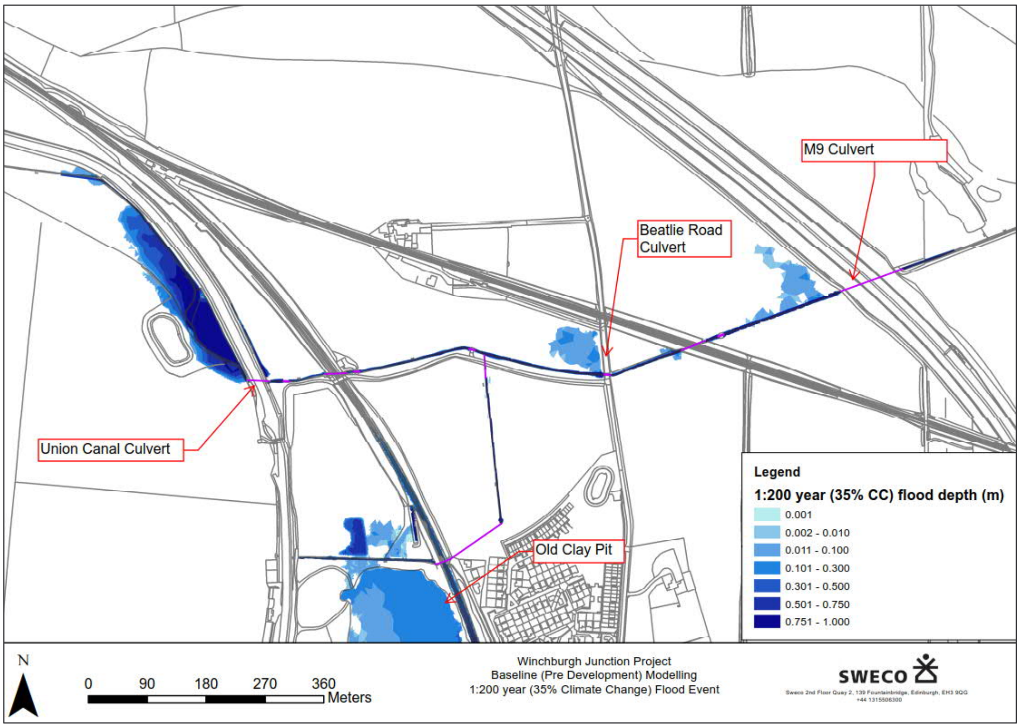


Figure 4-4 1:200-year (+35% CC) flood patterns for the baseline scenario.

4.2.1 Validation and sensitivity analysis

The Swine Burn is ungauged and information on flows or flood patterns associated with the Burn was limited, therefore it was not possible to undertake a detailed calibration and validation of the model results. However, the model results were found to be generally consistent with observations from nearby residents for the January 2005 storm event (thought to be equivalent to a 1:30-year event) noted as part of the previous FRA.

To gain a better understanding of the robustness of the model a series of additional model runs were undertaken to evaluate the sensitivity of the model to different factors including channel roughness, culvert sizes, inflows and the downstream boundary. For all scenarios the 1:200- year without an allowance for climate change hydrology was applied. The results, detailed within the node in Appendix C, indicate that the model is moderately sensitivity to changes in these parameters.

Following feedback from SEPA further sensitivity testing has been undertaken to evaluate the impact of blockages on the railway syphon upstream of the site of interest. The results indicate that this reduced peak flows within the area by approximately 22mm and reduced slightly the flood extent within the area of interest.

An additional model scenario was run in which the sediment depths within the Union Canal culvert were lowered to the surveyed bed level upstream and downstream. The predicted flood patterns are shown in Figure 4-5. The model scenario predicts greater conveyance under the Union Canal, resulting in increased flood extents between the second railway culvert and the M9, while decreasing flooding to the west of the Union Canal. These results suggest that the canal culvert provides a significant control over flood patterns downstream.

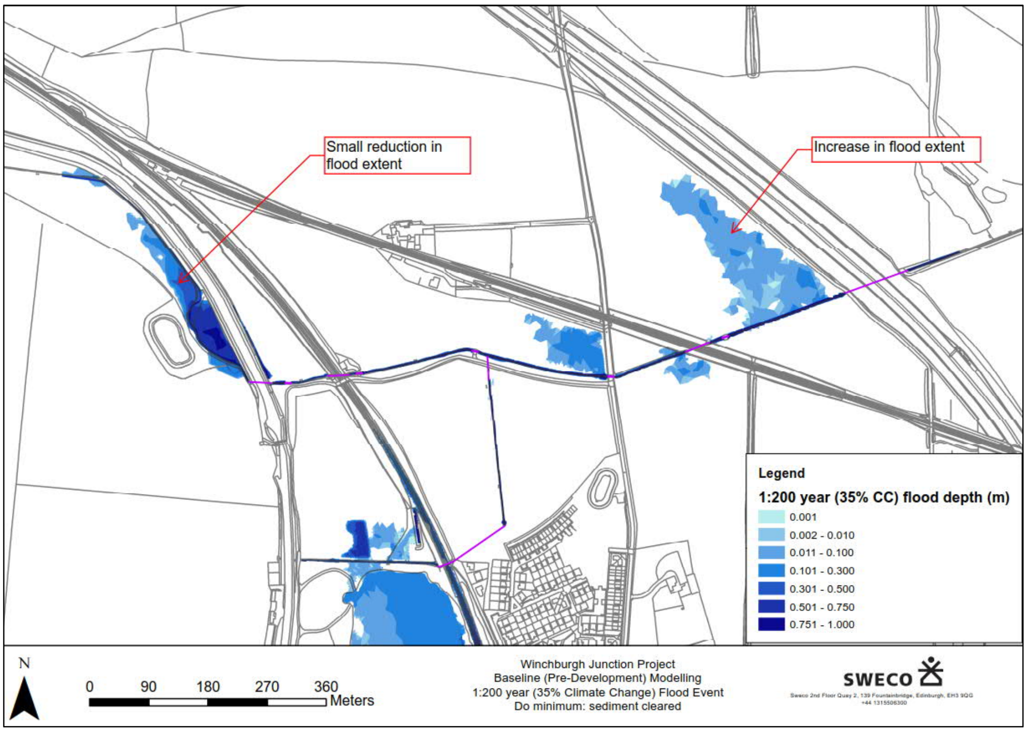


Figure 4-5 Predicted flood patterns with sediment levels reduced in the Union Canal culvert.

4.3 Post Development Modelling

As part of the development, it is proposed that a section of the Swine Burn, where the new access road crosses, will be culverted. For the post development scenario, the river reach upstream of the M9 was split and a culvert link added. The culvert was defined as rectangular, 2.4 m high and 5 m wide. The mesh parameters, cross-sectional geometry for the remaining river sections, and the hydrological input into the model remained the same as the baseline scenario (without existing SuDS scenario). An overview of the post development modelling can be found within Appendix D.

The 1:200-year flood extent (without an allowance for climate change) is predicted to remain within the channel along the section of the Swine Burn which the access road crosses. The new culvert was predicted to have a negligible impact on water levels within the vicinity (<5mm). The proposal will therefore not impinge on the functional floodplain and compensatory storage will not be required.

The model predicts that the new culvert would result in a reduction in flood extent (see Figure 4-6) and volume within the floodplain of ~ 60 m^3 for the 1:200-year flood event with a 35% climate change allowance. This reduction relates to the position of the culvert along a section of the reach where there is a drop in the northern bank, therefore slightly more water is retained within the channel.

There was predicted to result in a negligible change in water levels and velocities upstream and downstream of the proposals, with the differences well within model tolerance (<5% change). As a volume of ~160,000 m^3 is predicted over the duration of the baseline simulation the change in volume of 60m^3 has no significant impact.

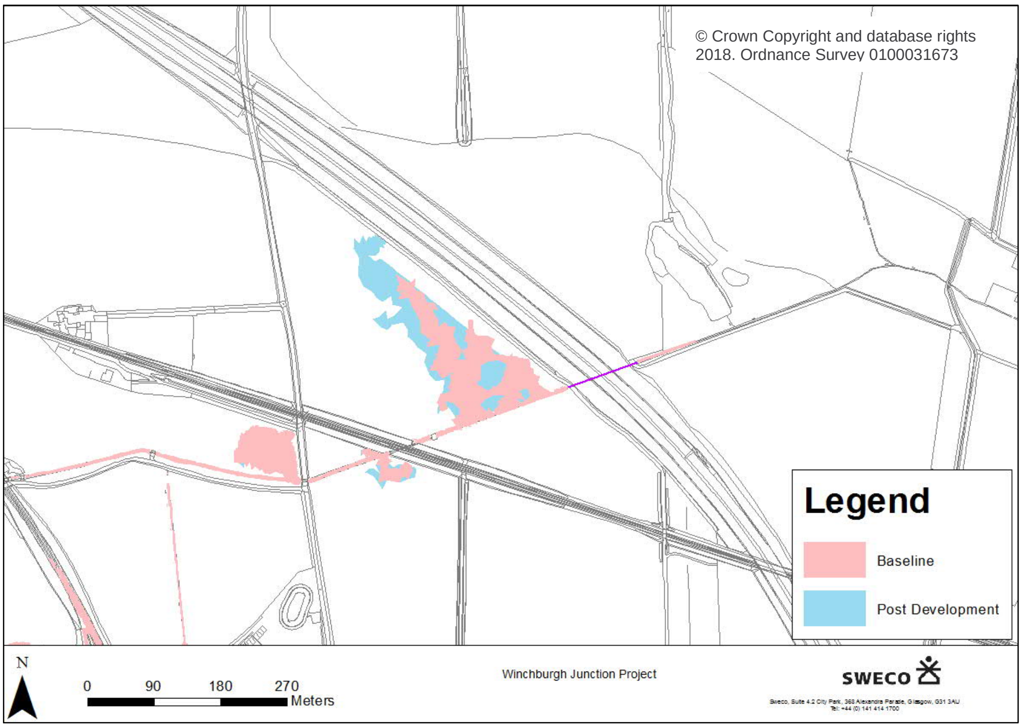


Figure 4-6 Comparison of the Baseline and Post Development flood extent upstream of the M9.

5 Conclusion

A review of existing information indicates that there is a low risk of sewer flooding affecting the site.

The groundwater vulnerability maps produced by SEPA indicate that groundwaters are not thought to affect the duration or extent of flooding from other sources within the area, and there are no reported historic instances of groundwater flooding. A review of borehole data does however suggest that perched water tables may be present within the area. The risk of groundwater flooding is therefore considered to be low.

SEPAs Reservoir Inundation Map indicates that the site would not be affected by the uncontrolled release of water in the event of a breach of nearby reservoirs. However. The SEPA mapping does not include the Humbie Reservoir.

The SEPA Surface Water Flood Mapping indicates that there is the potential for surface water flooding within the wider area. There are uncertainties with this mapping as patterns appear to be influenced by the Humbie Reservoir, and it is considered unlikely that surface water flooding could overtop the existing M9 embankment. The development will contain a suitably designed SuDS, which will ensure that surface water is managed effectively. This will also ensure that there is no detrimental effect on flood risk downstream.

SEPA flood risk maps suggested that the site is at risk from fluvial flooding. Detailed hydraulic modelling of the Swine Burn and its tributaries was undertaken to evaluate this risk. The baseline 1: 200 year without climate change flood extent is predicted to be contained within the channel downstream of the Union Canal Culvert to the outfall of the model. The proposed access road is therefore not within the functional floodplain of the Burn.

For the 1: 200-year event with a 35% allowance for climate change, flooding was predicted along the Swine Burn upstream of the Beatlie Road, as well as between the second railway and M9 culverts. This flooding was not found to relate to a lack of capacity within the Beatie Road, second railway or M9 culverts, but rather low points along the channel banks.

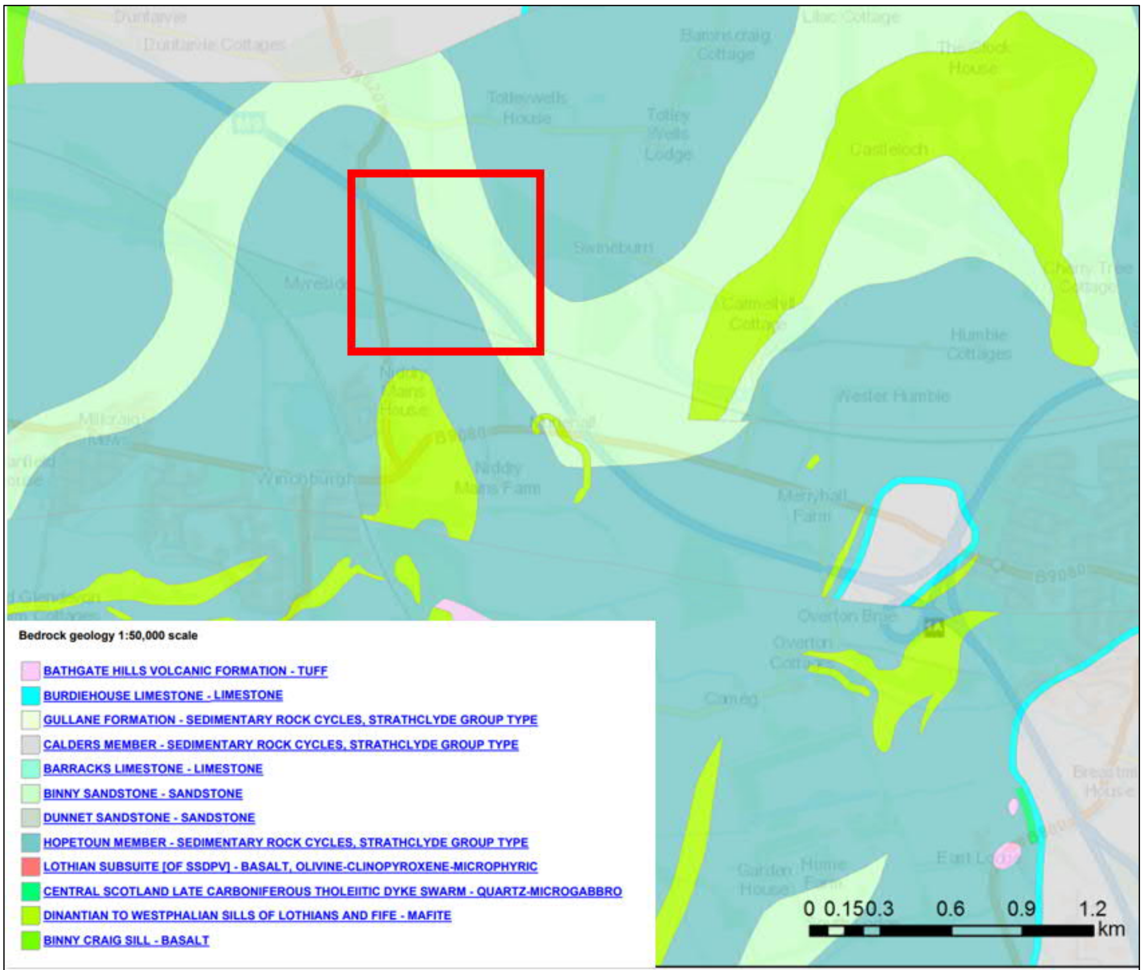
The culvert under the Union Canal was found to exert a significant influence on flooding downstream, with the removal of observed sediment increasing flood extents between the second railway culvert and the M9.

Post development modelling predicts that the 1: 200-year flood event (without an allowance for climate change), would remain within the channel in the area of interest. Similarly, the new culvert was predicted to have a negligible impact on water levels and velocities, hence compensatory storage will not be required.

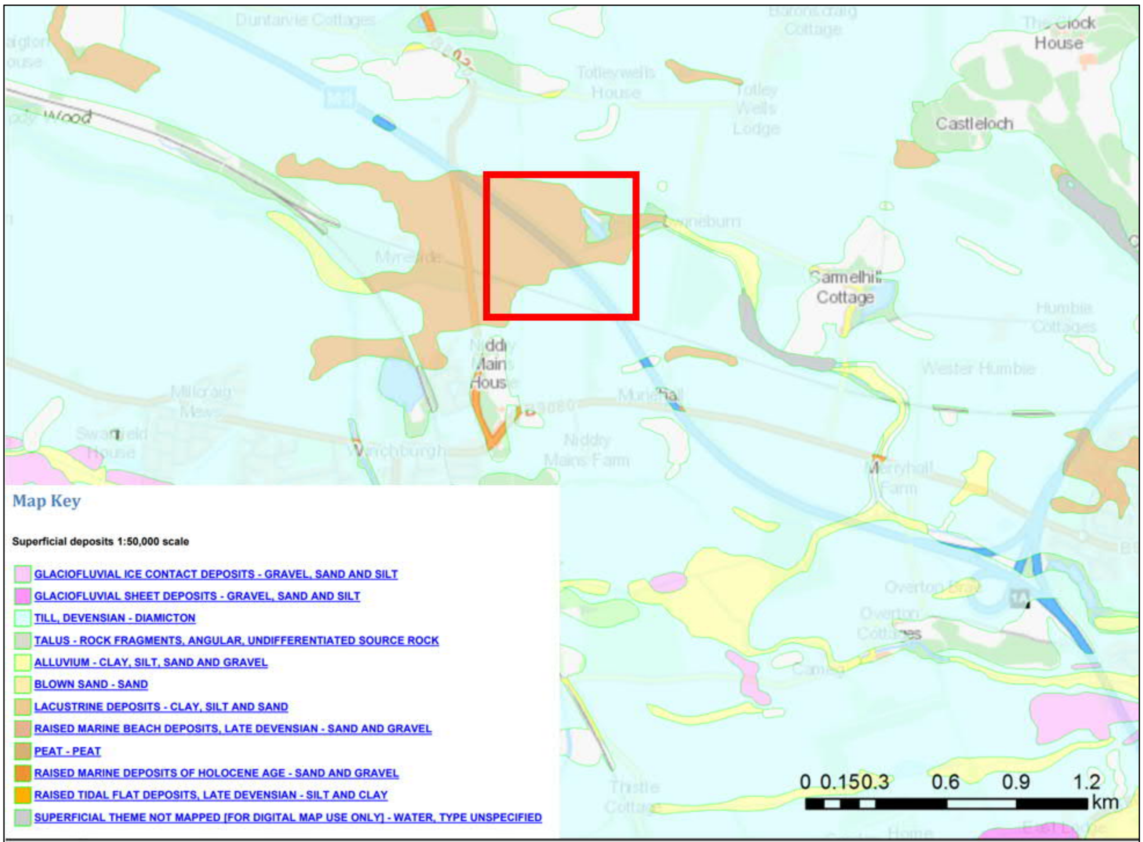
For the 1: 200-year flood extent with a 35% allowance for climate change, the post-development situation is predicted to result in a small reduction in the flood extent between the second railway culvert and the M9. This relates to the position of the new culvert along a section of the Swine Burn where there is a slight drop in the northern bank. The impact in terms of flood levels and velocities downstream is however negligible and well within model tolerance, therefore further mitigation is not required.

In conclusion, the access road and junction is not within the functional floodplain of the Swine Burn. Modelling predicts that the new culvert will have a negligible impact of peak water levels hence the development does not increase flood risk elsewhere.

Appendix A – Geological Mapping



GeoIndex Onshore Data Sources: NERC, Natural England, English Heritage and Ordnance Survey



GeoIndex Onshore Data Sources: NERC, Natural England, English Heritage and Ordnance Survey

Appendix B – Hydrological Analysis

Winchburgh Hydrology Note

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1 Introduction

This memo has been prepared to provide a summary of the analysis undertaken to determine the most suitable method for predicting the peak flow in the Swine Burn and its tributaries. The results will be used to inform the inflows into a hydraulic model of the Swine Burn to evaluate flood risk.

1.1 Catchment Overview

The development is within the catchment of the Swine Burn which is an ungauged tributary of the River Almond. According to the FEH online service this has a total catchment of 30.64 km^2 at the confluence with the River Almond. The development site sits in the catchment upstream of the M9 culvert, this catchment is estimated to have an area of 5.85 km^2. The Swine Burn is fed by two ponds located to the north west of Winchburgh and flows eastwards following the path of the Union Canal before passing under the canal just north of Winchburgh. It then flows north eastwards passing under two railway lines, the B8020 and the M9 via culverts before connecting into the Humbie Reservoir. There are two tributaries which connect into the Swine Burn - the Beatlie Channel, which connects upstream of Beatlie Road; and the Craigton Burn, which connects immediately downstream of the culvert under the Union Canal. The definition of the Beatlie Channel as a drainage ditch, and not a minor watercourse, has been previously agreed with SEPA (meeting dated 8th May 2015 between representatives of SEPA and Grontmij). An overview of the watercourses and total catchment area as defined in the FEH Online Service is shown in Figure 1-1.

The total catchment is predominantly rural with an urban extent of 0.015. The base flow index (estimated from soil properties) is low to moderate at 0.404 and the FARL is 0.994, which infers a small degree of attenuation due to the presence of pond or lakes.

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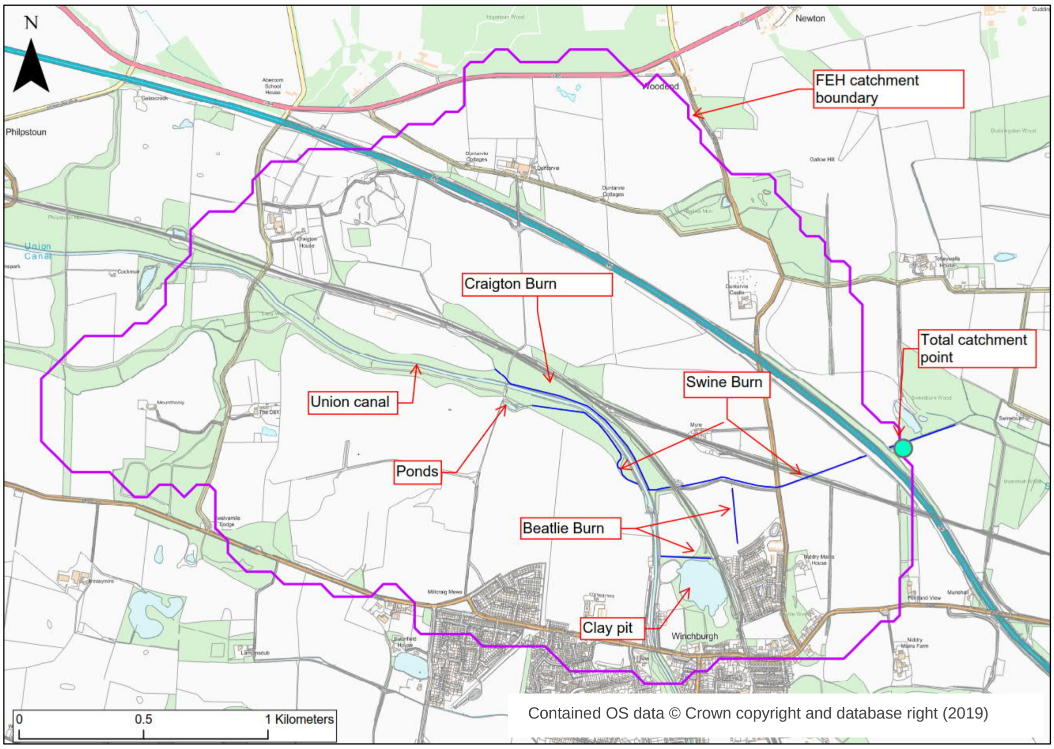

Figure 1-1 Overview of the total catchment areas as defined in the FEH online service.

2 Hydrological Assessment

2.1 Estimation of the Index Flood (QMED)

The Swine Burn and its tributaries are ungauged and therefore the methods used to estimate flow rely on using catchment characteristics. A catchment descriptor for the Swine Burn at a point immediately downstream of the M9 was purchased from the FEH Online Service (see Figure 1-1). The catchment parameters were input into WINFAP FEH (version 3; dataset version 7) to provide an initial QMED estimate of 1.953 m^3/s.

The initial estimate of QMED was then refined through the process of data transfer. This involved identifying a gauged catchment (referred to as a donor site), with data of suitable quality, to calculate an adjustment factor based on the ratio of the gauged to the ungauged estimate of QMED. This factor was then used to adjust the initial estimate of QMED at the ungauged site, assuming that the error in the QMED regression model is similar for both the subject and donor gauges.

WINFAP identified ten potential donor sites based on their hydrological similarity to the Swine Burn catchment, these have been presented in Table 2-1. The gauge at 21029 Tweed at Glenbreck was identified as being a suitable candidate in terms of area, BFIHOST and FARL. The gauge along Fruid Water also has a catchment area below 100km^2 but due to its lower value of FARL (0.779) was rejected as a donor. An additional gauge along the West Peffer Burn was also identified independently; however, as this produced a slightly lower QMED adjustment factor, it was conservatively decided that gauge 21029 would be used. The application of the donor site resulted in the QMED increasing to 1.984 m^3/s.

Table 2-1 Overview of hydrologically similar potential donor sites identified in the WINFAP FEH software

Station	AREA	Diff/ Factor	SAAR	Diff/ Factor	BFIHOST	Diff/ Factor	FARL	Diff/ Factor	URBEXT	Diff/ Factor	QMED adj
Swine Burn	5.845		772		0.404		0.994		0.015		
17001 (Carron @ Headswood)	121.14	20.7	1519	1.97	0.378	0.03	0.843	0.15	0.013	0.002	2.220
21005 (Tweed @ Lyne Ford)	377.18	64.6	1255	1.63	0.507	0.10	0.965	0.03	0.002	0.013	1.977
21015 (Leader Water @ Earlston)	239.11	40.9	853	1.10	0.563	0.16	0.999	0.01	0.001	0.014	2.119
85002 (Endrick Water @ Gaidrew)	219.07	37.5	1484	1.92	0.454	0.05	0.981	0.01	0.003	0.012	1.963
21011 (Yarrow Water @ Philiphaugh)	232.46	39.8	1347	1.74	0.443	0.04	0.875	0.12	0.000	0.015	2.005
21029 (Tweed @ Glenbreck)	34.4	5.9	1532	1.98	0.353	0.05	1.000	0.01	0.000	0.015	1.984
21001 (Fruid Water @ Fruid)	22.01	3.8	1702	2.20	0.392	0.01	0.779	0.22	0.000	0.015	2.136
21009 (Tweed @ Norham)	4398.76	753.2	955	1.24	0.495	0.09	0.981	0.01	0.003	0.012	2.014
21022 (Whiteadder Water @ Hutton Castle)	502.23	86.0	814	1.05	0.518	0.11	0.981	0.01	0.002	0.013	2.092
83013 (Irvine @ Glenfield)	211.89	36.3	1222	1.58	0.348	0.06	0.986	0.01	0.016	0.001	1.898
20002 (West Peffer Burn @ Luffness)	25.51	4.4	616	0.80	0.47	0.07	0.995	0.00	0.002	0.013	1.974

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SWECO

2.2 Peak Flows

This section details the three methods used to estimate peak flows following the calculation of the index flood. These include:

1. FEH statistical
2. ReFH2
3. FEH rainfall-runoff

2.2.1 FEH statistical

The FEH statistical method projects the estimated QMED for higher return periods using a growth curve calculated using a pooling group of suitable stations. These are identified based on a measure of hydrological similarity. A pooling group of 16 sites was selected automatically in WINFAP, which collectively contained over 500 year of recorded data. The default pooling group was then ranked and can be seen in Table 2-2.

Table 2-2 The default catchment pooling group for the Swine Burn

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
27073 (Brompton Beck @ Snainton Ings)	0.798	36	0.816	0.203	0.06	0.404
27051 (Crimple @ Burn Bridge)	1.928	45	4.564	0.221	0.144	0.093
45816 (Haddeo @ Upton)	2.079	24	3.489	0.306	0.387	0.463
26802 (Gypsey Race @ Kirby Grindalythe)	2.174	18	0.108	0.316	0.217	0.393
20002 (West Peffer Burn @ Luffness)	2.185	41	3.299	0.292	0.015	2.05
25019 (Leven @ Easby)	2.232	39	5.677	0.34	0.377	0.758
28033 (Dove @ Hollinsclough)	2.239	38	4.225	0.234	0.405	0.742
76011 (Coal Burn @ Coalburn)	2.245	40	1.84	0.166	0.31	1.069
203046 (Rathmore Burn @ Rathmore Bridge)	2.306	35	10.72	0.147	0.144	0.583
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	2.324	7	5.777	0.282	0.189	3.452
47022 (Tory Brook @ Newnham Park)	2.413	24	6.651	0.265	0.138	0.252
49006 (Camel @ Camelford)	2.444	11	11.154	0.124	-0.185	2.385
25011 (Langdon Beck @ Langdon)	2.487	28	15.878	0.238	0.318	0.561
25003 (Trout Beck @ Moor House)	2.502	44	15.142	0.168	0.294	0.76
27010 (Hodge Beck @ Bransdale Weir)	2.552	41	9.42	0.224	0.293	0.272
44008 (South Winterbourne @ Winterbourne Steepleton)	2.58	38	0.434	0.417	0.336	1.766
Total		509				

The predicted peak flows are shown in Table 2-3. For the 200-year event a peak flow of 6.996m^3/s was estimated based on the generalised logistic distribution, which is recommended due to its conservatism.

Table 2-3 Estimated flows calculated in WINFAP using the default pooling group with different distributions

Return period (1:X)	Generalised Logistic		Generalised Extreme Value	
	Peak flow (m3/s)	Growth factor	Peak flow (m3/s)	Growth factor
2	1.982	1.00	1.982	1.00
5	2.780	1.40	2.857	1.44
10	3.377	1.70	3.486	1.76
25	4.262	2.15	4.341	2.19
50	5.042	2.54	5.022	2.53
100	5.945	3.00	5.741	2.90
200	6.996	3.53	6.501	3.28
500	8.658	4.37	7.577	3.82

2.2.1.1 FEH Revised Pooling Group

The default pooling group identified in WINFAP displayed a moderate level of heterogeneity (H2=3.8, shown in Figure 2-1), indicating that a review of the pooling group sites was desirable. A high discordancy was noted for the Bolingey and Camel gauges, both catchments have relatively short record lengths compared to the group mean.

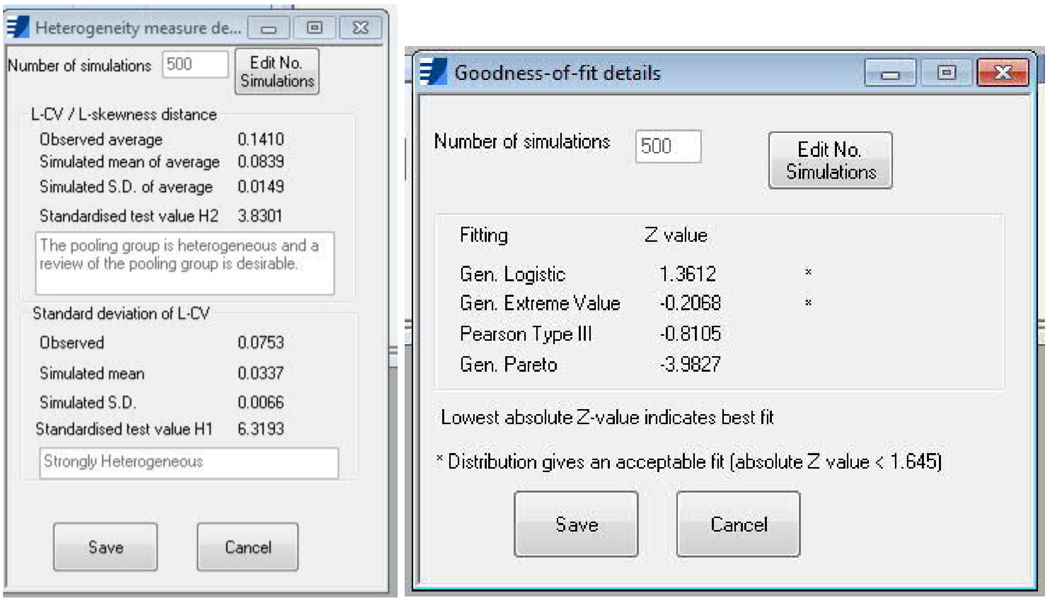

Figure 2-1 Pooling group parameters

Most of the sites, within both the default and revised pooling groups, have higher values of AREA, SAAR, DPSBAR, and FARL relative to the subject site. However, there was no preferential alternative sites, which reflects the limited range of small catchments within the database. This would likely mean that the estimated flows are conservative.

Gauging sites, type, and data quality were assessed to ensure suitability for pooling (see Table 2-4). In addition, the effect of removing sites displaying large deviations in key parameter was tested by quantifying the resultant change in pooling groups heterogeneity. Following this analysis, the following sites were removed:

- **Bollingey** – This catchment is significantly more permeable than the target site and will likely behave differently during extreme rainfall events. The gauge data appears to be good quality, but the record is short, and it is only gauged to ~0.5QMED. The high level of discordance is justified, and the site has been excluded.
- **Camel** – The gauge has a limited record length of 11 years and is only gauged to 75% QMED hence relatively high discordance is justified and site has been excluded.
- **Brompton Beck** – The gauge data appears to be good quality; however, the catchment is underlain by highly permeable bedrock (0.89 BFIHOST) and flows are potentially influenced by abstraction. The catchment will likely behave differently during extreme rainfall events with flows noted to be strongly dependent on groundwater contribution.
- **Gypsey Race** – The catchment is underlain by highly permeable bedrock with the hydrological regime dominated by groundwater contributions. Water levels subject to unexplained fluctuations due to human interference. Gauge is also reported not to perform to design and flows and results are considered suspect until further review.
- **South Winterbourne** – The gauged data appears to be good quality; however, the catchment is underlain by highly permeable chalk with the hydrological regime dominated by groundwater contributions. Flows noted to be influenced by groundwater abstraction/recharge, as well as compensatory flows upstream.
- **West Peffer Burn** – The gauged data appears to be good quality; however, appears discordant with remaining pooling group and catchment has a lower SAAR compared to subject site. Channel upstream is also noted to be dammed which is thought to affect flows.

Table 2-4 Overview of catchment characteristics for each gauge within the default pooling group

Station	Area	Factor	SAAR	Factor	BFI Host	Difference	DPSBAR	Factor	FARL	Difference	URBEXT 2000	Factor
Subject Site	5.845	-	772	-	0.404	-	24.9	-	0.994	-	0.015	-
27073 (Brompton Beck @ Snainton Ings)	8.06	1.38	721	0.93	0.89	0.49	47.7	1.92	1	0.006	0.008	0.53
27051 (Crimple @ Burn Bridge)	8.17	1.40	855	1.11	0.31	0.09	62.9	2.53	1	0.006	0.006	0.40
45816 (Haddeo @ Upton)	6.81	1.17	1210	1.57	0.59	0.19	81	3.25	1	0.006	0.005	0.33
26802 (Gypsey Race @ Kirby Grindalythe)	15.85	2.71	757	0.98	0.96	0.56	57.2	2.30	1	0.006	0	0.00
20002 (West Peffer Burn @ Luffness)	25.51	4.36	616	0.80	0.47	0.07	30.9	1.24	0.995	0.001	0.002	0.13
25019 (Leven @ Easby)	15.09	2.58	830	1.08	0.52	0.12	128	5.14	1	0.006	0.004	0.27
28033 (Dove @ Hollinsclough)	7.92	1.36	1346	1.74	0.4	0.00	166.7	6.69	1	0.006	0	0.00
76011 (Coal Burn @ Coalburn)	1.63	0.28	1096	1.42	0.2	0.20	47.2	1.90	1	0.006	0	0.00
203046 (Rathmore Burn @ Rathmore Bridge)	22.5	3.85	1043	1.35	0.43	0.03	57.9	2.33	1	0.006	0	0.00
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	16.08	2.75	1044	1.35	0.63	0.23	81.4	3.27	0.991	0.003	0.006	0.40
47022 (Tory Brook @ Newnham Park)	13.43	2.30	1403	1.82	0.43	0.03	106	4.26	0.942	0.052	0.014	0.93
49006 (Camel @ Camelford)	12.52	2.14	1418	1.84	0.57	0.17	57.5	2.31	1	0.006	0.003	0.20
25011 (Langdon Beck @ Langdon)	12.79	2.19	1463	1.90	0.24	0.16	123.4	4.96	1	0.006	0.001	0.07
25003 (Trout Beck @ Moor House)	11.4	1.95	1905	2.47	0.23	0.17	92	3.69	1	0.006	0	0.00
27010 (Hodge Beck @ Bransdale Weir)	18.82	3.22	987	1.28	0.34	0.06	149.8	6.02	1	0.006	0.001	0.07
44008 (South Winterbourne @ Winterbourne Steepleton)	20.18	3.45	1012	1.31	0.81	0.41	93.8	3.77	1	0.006	0.004	0.27

The removal of these sites reduced the number of gauged years to below 500 hence analysis was undertaken to identify suitable replacement sites. The gauges at Condor, de Lank, Keer and Hebden (shown in Table 2-5) were identified as potentially suitable based on a review of their performance and catchment similarity.

Table 2-5 Overview of the catchment characteristics for the sites added to the pooling group

Station	AREA	QMED	SAAR	BFIHOST	FPEXT	FARL	URBEXT 2000	Discordancy
Subject site (Swine Burn)	5.845	-	772	0.404	0.1796	0.994	0.015	-
72014 (Conder @ Galgate)	28.99	16.283	1183	0.44	0.082	0.975	0.006	0.492
49003 (de Lank @ de Lank)	21.61	14.324	1628	0.38	0.064	0.998	0	0.111
73015 (Keer @ High Keer Weir)	30.04	12.285	1158	0.49	0.074	0.976	0.003	0.367
27032 (Hebden Beck @ Hebden)	22.25	4.052	1433	0.252	0.0206	0.997	0	1.356

Table 2-6 shows that the revised pooling group results in a slight reduction in peak flows with the 200-year event now estimated to be 6.865 m^3/s from the generalised logistic distribution. This indicated that the predicted flows are largely insensitive to the composition of the pooling group and the default group provided slightly more conservative flow estimates.

The heterogeneity factor (H2) for the revised pooling group was much lower than the default group at 0.97 (see Figure 2-2).

Table 2-6 Estimated flows calculated in WINFAP using the revised pooling group with different distributions

Return period (1:X)	Generalised Logistic		Generalised Extreme Value	
	Peak flows	Growth factor	Peak flows	Growth Factor
2	1.982	1.000	1.982	1.000
5	2.71	1.367	2.777	1.401
10	3.271	1.650	3.369	1.700
25	4.123	2.080	4.202	2.120
50	4.889	2.467	4.887	2.465
100	5.794	2.923	5.629	2.840
200	6.865	3.464	6.436	3.247
500	8.598	4.338	7.614	3.842

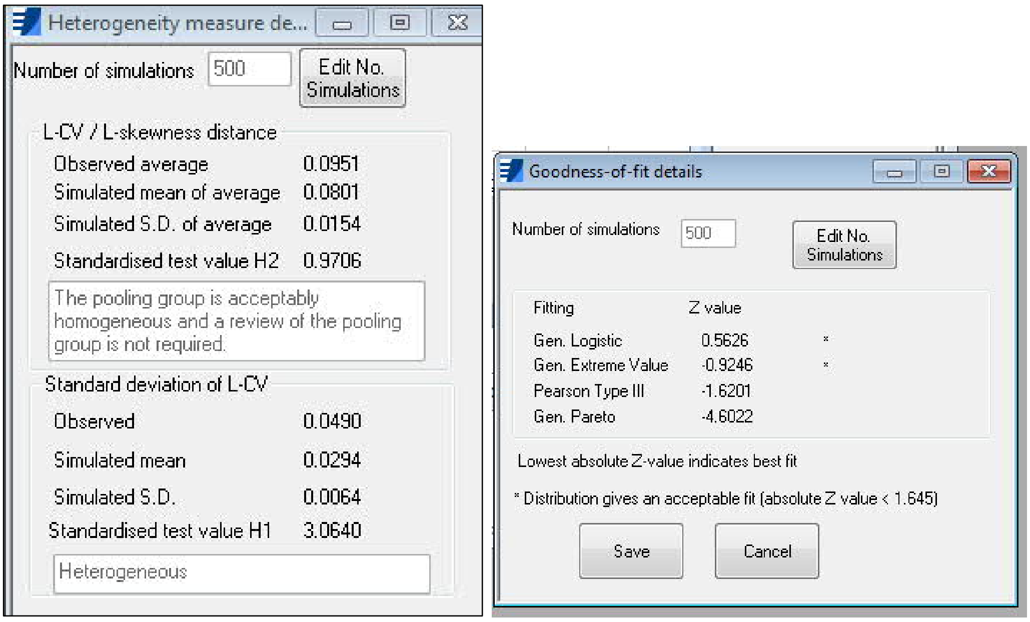

Figure 2-2 Overview of the revised pooling group characteristics

2.2.2 ReFH2 Generated Peak Flows

ReFH2 analysis was performed on the catchment to compare with the FEH statistical methods employed by WINFAP. ReFH2 was set to use the Scottish Tp equation and the area was defined as a rural catchment. The critical duration was generated automatically (6.5 hours) using ReFH2. The FEH 2013 rainfall rarity / depth data set was used and all other parameters were set to default.

Peak flows generated in ReFH2 can be found in Table 2-7 with the results showing that ReFH2 produces slightly lower values compared to the FEH statistical method. The catchment is rural and therefore only the ‘as-rural’ values will be used in this study.

Table 2-7 ReFH2 generated peak flow values

Return period (1:X)	Urbanised peak flow (m3/s)	As-rural peak flow (m3/s)
2	2.077	2.074
5	2.664	2.661
10	3.128	3.124
25	3.868	3.864
50	4.608	4.605
100	5.505	5.503
200	6.515	6.513
500	7.967	7.967

2.2.3 FEH Rainfall-Runoff

The FEH rainfall-runoff method was also applied using a boundary unit within the ISIS software package to provide an additional comparison to the ReFH2 and FEH statistical methods. The critical duration of 9 hours was calculated in ISIS, and the Winter Storm event was selected.

The results, shown in Table 2-8, indicate that the FEH rainfall-runoff method provides the highest estimation of peak flows compared to both the FEH statistical and ReFH2 methods.

Table 2-8 FEH rainfall-runoff peak flows

Return period (1:X)	Peak rural flow (m3/s)
5	3.388
10	3.973
25	5.035
50	5.889
100	6.719
200	7.703
500	9.226

2.2.4 Comparison of peak flow data

Peak flow estimates have been generated using ReFH2, FEH Rainfall-runoff and FEH statistical methods for the Swine Burn catchment upstream of the M9.

The results shown in Table 2-9 indicate that all the methods provided similar values with a small amount of variation in peak flows. The FEH rainfall-runoff method (method 4) provides the most conservative estimate of peak flows; however, this has been largely superseded by ReFH2, which has been updated and calibrated for Scottish catchments and is now cautiously recognised by SEPA. On the other hand, ReFH2 (method 3) produced the lowest estimate of flows and, given the uncertainty for small catchments, was not felt to be appropriate.

Table 2-9 Comparison of peak flows for the different hydrological techniques

Return period	Method 1 - FEH Statistical (original): GL	Method 2 - FEH Statistical (revised): GL	Method 3- ReFH2	Method 4- FEH rainfall-runoff
5	2.78	2.71	2.661	3.388
10	3.377	3.271	3.124	3.973
25	4.262	4.123	3.864	5.035
50	5.042	4.889	4.605	5.889
100	5.945	5.794	5.503	6.719
200	6.996	6.865	6.513	7.703
500	8.658	8.598	7.967	9.226

The FEH statistical methods both with (method 1) and without (method 2) revisions made to the pooling group provide a good compromise. The estimated flows are more conservative than those predicted using ReFH2, but lower than the FEH rainfall runoff method. Method 1 was selected for use in the model as it is slightly more conservative than method 2.

3 Hydrograph Generation

The catchment as defined on the FEH website (shown in Figure 1-1) was analysed and divided into ten sub-catchments which drain to specific points along the Swine Burn, Craigton Burn, and Beatlie Channel.

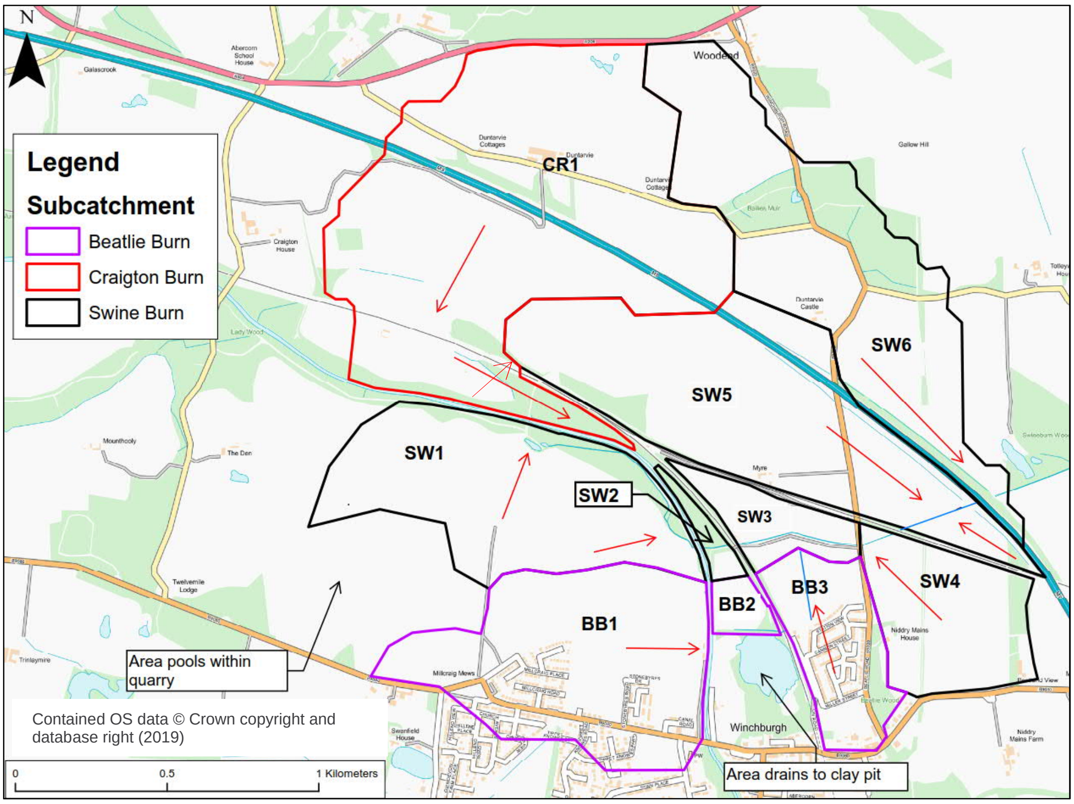

Figure 3-1 Estimated catchment areas draining into the Swine Burn, Craigton Burn, and Beatlie Channel

The sub-catchment extents were based on an analysis of topographical survey data (2019) and 1 m resolution LiDAR using ArcGIS. To aid the process of defining sub-catchments, a simplified direct-rainfall model was also constructed in Infoworks ICM to evaluate potential flow paths and identify areas of pooling. A 2-hour 200-year FEH 2019 rainfall event was applied over the mesh and a generic Manning's roughness value of 0.04 set over the model domain.

The results showed that much of the area to the west flows northwards towards the canal or accumulated within the large depression associated with the old quarry, north west of Winchburgh (See Figure 3-2). Similarly, the direct rainfall modelling indicated that the area to the south of the Beatlie Channel between the Union Canal and Edinburgh-Glasgow railway flows towards the existing clay pit (see Figure 3-3). These areas were therefore not included in the sub-catchment coverage shown in Figure 3-1.

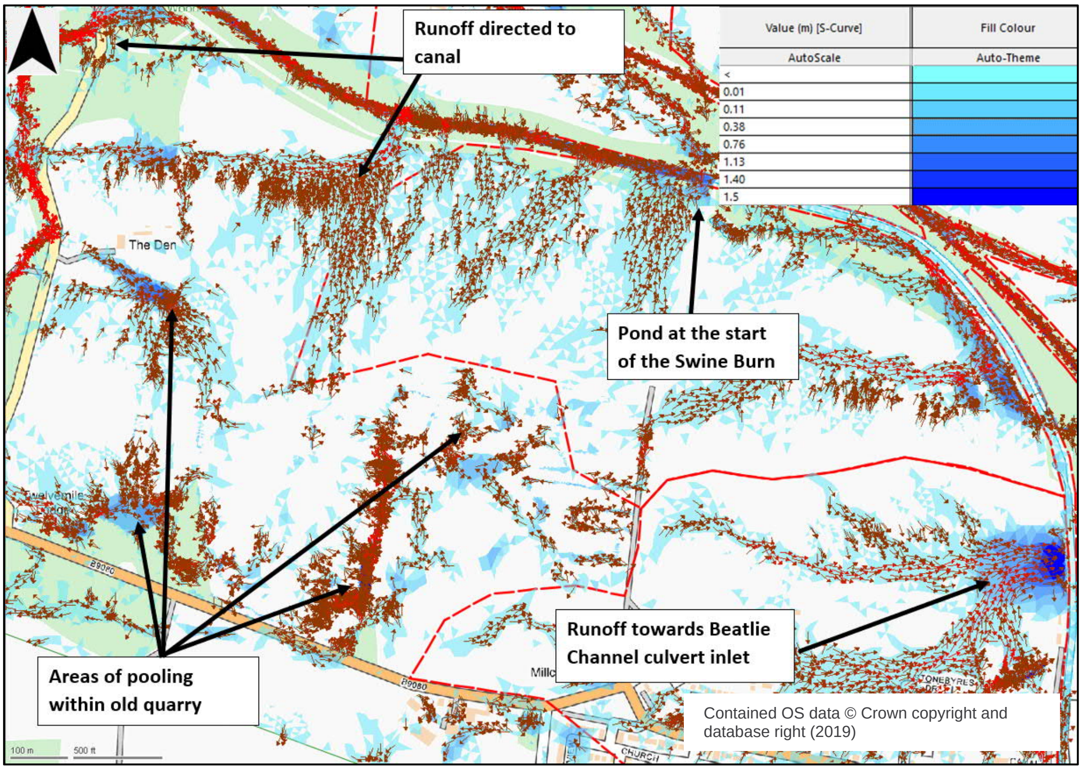

Figure 3-2 Evidence of pooling within quarry and predicted flow paths towards canal rather than to the pond at the start of the Swine Burn

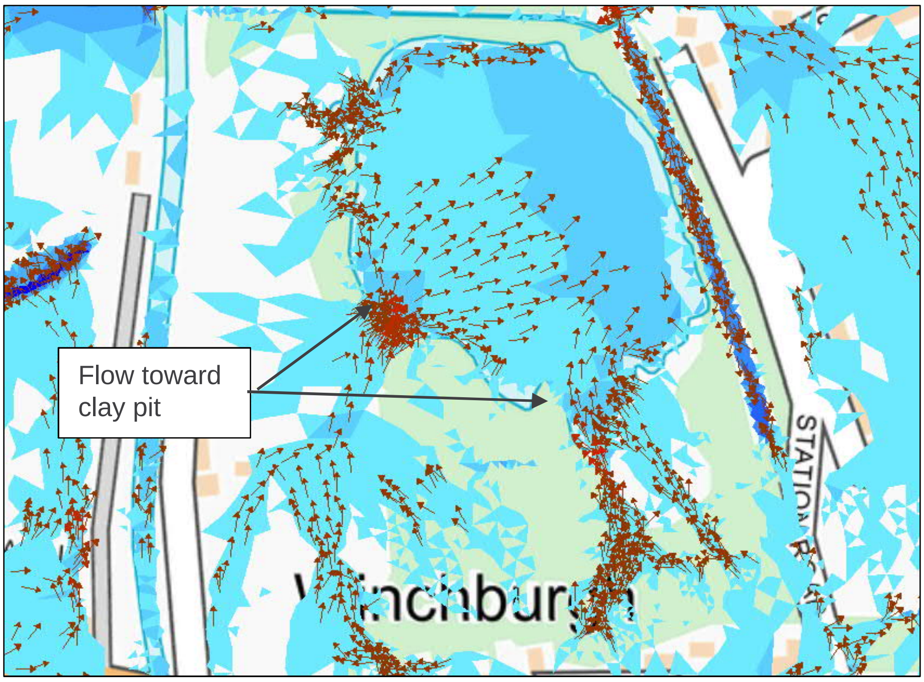

Figure 3-3 Runoff directed into the clay pit located immediately to the north of Winchburgh

The Edinburgh to Glasgow railway has a pumped system which discharges into the Swine Burn. The previous study (Carl Bro 2005) suggested that the Beatlie Channel overtops into this clay pit which is controlled by a set of pumps operated on behalf of Network Rail which discharges flows back into the Beatlie Channel during flood events. The railway and area draining into the clay pit were therefore not included in the sub-catchment coverage but will be accounted for within the modelling by applying constant point inflows set to an assumed total maximum pump capacity of 100 l/s (33 l/s to the Beatlie Channel and 67 l/s to the Swine Burn) over the duration of the simulation. This value was taken from a previous flood risk assessment undertaken in 2005 by Carl Bro. Further consultation was held with Network Rail, however further details regarding the pumping rates could not be ascertained.

Hydrographs were generated in ReFH2 for each of the areas shown in Figure 3-1 using sub-catchments within Infoworks ICM (version 9). Catchment descriptors were downloaded for the Swine and Beatlie Channel and linked to each of the sub-catchments and a winter rainfall event with a duration of 6.5 hours was applied. The resultant ReFH2 hydrographs generated were then uplifted by an adjustment factor (shown in Table 3-1) which was calculated based on the difference between the ReFH2 and FEH statistical peak flows for the total catchment (see Section 2.2.4). The impact of the adjustment on the hydrographs can be seen in Table 3-2 and Figure 3-4.

Table 3-1 FEH Statistical and ReFH2 methods for peak flow with relative adjust factor

Return period	ReFH2 Peak flows (m^3/s)	FEH Statistical Peak flows (m^3/s)	Adjustment factor
5	2.661	2.78	1.04
10	3.124	3.377	1.08
25	3.864	4.262	1.10
50	4.605	5.042	1.09
100	5.503	5.945	1.08
200	6.513	6.996	1.07
500	7.967	8.658	1.09

Table 3-2 Estimated ReFH2 200-year flows for each sub-catchment calculated in Infoworks ICM (version 9) and the resultant adjusted flows

Sub-catchment	200-year ReFH2 peak flow (m^3/s)	200-year peak flow (m^3/s) with adj. factor applied (1.07)	35% CC
SW1	0.832	0.890	1.202
SW2	0.042	0.044	0.060
SW3	0.153	0.164	0.222
SW4	0.366	0.392	0.529
SW5	1.035	1.108	1.496
SW6	0.703	0.752	1.015
BB1	0.775	0.829	1.120
BB2	0.051	0.055	0.074
BB3	0.266	0.285	0.384
CR 1	1.270	1.358	1.834
Total	5.493	5.878	7.935

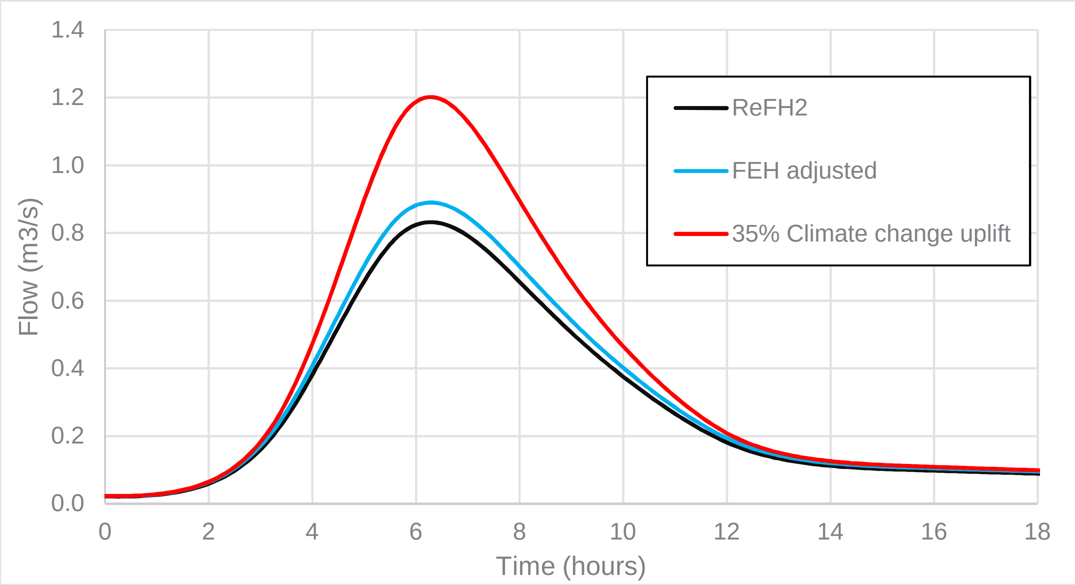

Figure 3-4 Comparison between the 200-year event's raw and adjusted hydrograph for sub-catchment SW1

It should be noted that the removal of areas which were predicted to drain to the canal, quarry or clay pit (outlined above) results in the 1: 200-year peak flows (without climate change) being reduced from 6.996m^3 (Table 2-9, based on the default FEH outline) to 5.878 m^3/s.

4 Climate Change Allowance

The West Lothian Local Development Plan (2018)[1] and Supplementary Guidance on Flooding and the Water Environment Consultation[2] states that Flood Risk Assessments being prepared for West Lothian Council must accord with the prevailing version of SEPA's Technical Flood Risk Guidance for Stakeholders (Reference: SS-NFR-P-002) Version 9.1 (June 2015).

The most recent version of SEPA's Technical Flood Risk Guidance for Stakeholders (version 10, July 2018) states that for fluvial flooding a minimum allowance of +20% should be applied, although it is noted that local authorities may require a higher standard.

SEPA have recently issued new climate change guidance (Climate change allowances for flood risk assessment in land use planning) for reference when completing FRA work in Scotland. This document states that for small catchments (<30 km^2) the rainfall climate change allowance should be used for fluvial uplift. For the Swine Burn, which is within the Forth river basin region, an allowance of 35% would therefore be relevant.

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[1] https://www.westlothian.gov.uk/media/27735/Adopted-West-Lothian-Local-Development-Plan/pdf/West_Lothian_Local_Development_Plan_-__Adopted_final.pdf
[2] https://www.westlothian.gov.uk/media/16076/Supplementary-Guidance-on-Flooding-and-the-Water-Environment-Consultation/pdf/20170206_APPENDIX_ONE_Supplementary_Guidance_Flood_Risk.pdf

5 Conclusion

Three methods of estimating peak flows were investigated: ReFH2, FEH rainfall-runoff and the FEH pooling group. The FEH statistical method using the default pooling group was found to provide a good compromise in terms of peak flows compared to both the ReFH2 and FEH rainfall-runoff techniques. As the Swine Burn is ungauged it was decided that the hydrograph shape will be obtained from ReFH2 and then this will be scaled to the FEH statistical peak flow using a calculated adjustment factor.

Catchment analysis has been undertaken using topographic data to divide the total catchment area into sub-catchments which will discharge into specific sections of the watercourses.

Appendix C – Baseline Modelling Overview

Winchburgh Baseline Hydraulic Modelling Summary

Project Name: M9 Winchburgh Junction
Project Reference: 65200072
Project Manager: Allan Mason
Author: James Walker
Date: 13/08/2019
Document Reference: 99165423/WGR/WBHMS
Revision: 3

Rev.	Date	Reason for issue	Prepared		Reviewed		Approved	
[1]	13.08.19	First issue	JJW	14.06.19	JP	02.07.19	JF	05.07.19
[2]	20.12.19	Second Issue following comment	JJW	17.12.19	JP	18.12.19	JF	19.12.19
[3]	06.03.20	Final Issue	JJW	05.03.20	AB	06.03.20	JF	06.03.20

1 Introduction

This briefing note has been prepared to provide a summary of the hydraulic modelling undertaken to support the development of a new motorway junction and access road along the M9 at the B8020, Winchburgh, West Lothian. This memo should be read in conjunction with the Winchburgh hydrological assessment memo.

1.1 Data sources

The study utilised a variety of data sources, including:

- topographic survey data contained within a CAD drawing dated March 2019;
- previous river and hydraulic structure survey undertaken in 2005;
- 1 metre resolution LiDAR (Phase 2, 29th November 2012-18th April 2014) data from the Scottish Remote Sensing Portal[1];
- The National River Flow Archives database;
- The Flood Estimation Handbook Online Portal;
- OS Mastermap data; and
- Winchburgh Future Urban Extension Flood Risk Assessment report (Carl Bro, 2005).

1.2 Site Visit

A site walkover was undertaken on the 22nd May 2019, covering sections of the Swine Burn, Craigton Burn and Beatlie Channel. Attendees were:

- James Franklin (Senior Engineer, Sweco)
- James Walker (Assistant Consultant, Sweco)

[1] Accessed https://dcenr.maps.arcgis.com/apps/webappviewer/index.html?id=b7c4b0e763964070ad69bf8c1572c9f5

2 1D-2D Model Build

A 1D-2D model of the Swine Burn and its floodplain was created in Infoworks ICM (version 9). The model extends from a point 300 m downstream of two ponds, which form the source of the Burn. The ponds are located on the south-west side of the Union Canal, north west of Winchburgh, to a point 150 m downstream of the M9 culvert. The model includes a 750 m stretch of the Craigton Burn to its confluence with the Swine Burn downstream of the Union Canal culvert. The model also includes the Beatlie Channel from the culvert inlet under the Union Canal to the inflow point to the Swine Burn between the Edinburgh-Glasgow railway and Beatlie Road. The definition of the Beatlie Channel as a drainage ditch, and not a minor watercourse, has been previously agreed with SEPA (meeting dated 8th May 2015 between representatives of SEPA and Grontmij). The 2D extent of the model is defined by the green polygon in Figure 2-1, which includes an overview of the model.

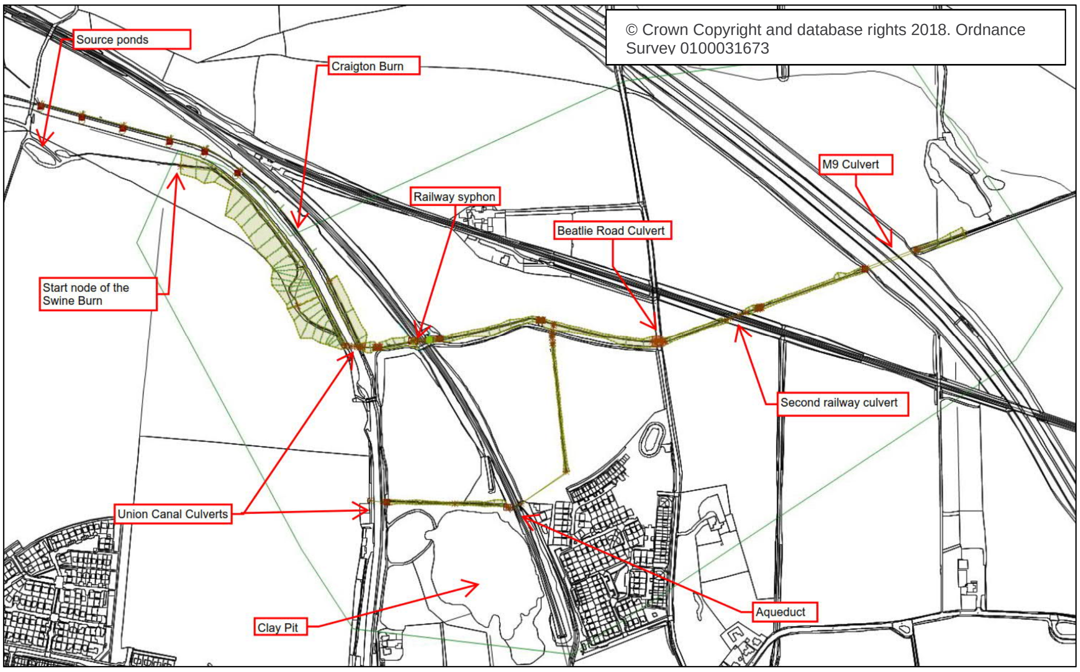

Figure 2-1 Overview of the model extent and domain

The model contains a total of 134 1D cross-sections, which are shown in Appendix C1. The cross-sections were cut from a ground model created using topographic survey (point) data supplemented with 1 m resolution LiDAR (Phase 2) where necessary. The locations where topographic survey and LiDAR were used is provided in Appendix C2. This shows that most of the watercourse was surveyed between 2017 and 2019 by Aird Geomatics, with the remaining areas surveyed at various points between 2005 and 2018.

A comparison between the topographic survey and LiDAR is presented in Appendix C3 which shows that the two datasets are similar in the area adjacent to the Swine Burn. Ground levels are generally higher in the 2019 survey along the southern bank upstream of the Union Canal Culvert and along the northern bank upstream of the M9. The topographic survey captures in greater resolution the watercourses, as well as several new developments in the surrounding area.

The cross-section upstream and downstream of the railway syphon (Swine CS39 and 40) along the Swine Burn were created from a cross-sectional survey undertaken in 2005, which were felt to be more representative of the channel geometry following the site visit. The banks of the cross-section upstream and downstream of the second railway culvert (Swine CS67 and 68) were created from LiDAR. Analysis was undertaken to ensure consistency between the datasets and prevent any erroneous changes in the longitudinal profile of the river reach.

The 2D domain was meshed using the same ground model used to create the 1D river section. The maximum meshing element size was set to a value of 100 m^2 and the smallest element area was 1 m^2. The maximum height variation between elements was 0.25 m, with terrain sensitive meshing applied to ensure that enough ground detail was captured. Break lines were enforced into the mesh using CAD files provided from the 2019 survey and MasterMap data to ensure roads and embankments were appropriately captured.

The boundaries of the 2D zone have been set to a normal depth condition. While the 2D zone has been designed to cover all areas where out-of-bank flows are expected, should any water reach the boundary this setting ensures that no glass wall effects are generated.

The 2D area is linked to the 1D river channel of the Swine Burn and Beatlie Channel through bank lines, where flow is passed between the 1D and 2D computational model elements. All river banks along the Swine and Beatlie Channel can exchange flow between domains with a discharge coefficient of 1 and a modular limit of 0.7 applied.

Based on local observations, the Craigton Burn has been known to overtop and discharge into the Union Canal within its upper reaches during flood events. Previous studies, in consultation with Scottish Canals, have identified that the Union Canal maintains its level via a series of overflow weirs along its length. Because the model only contains a short length of the Union Canal this distribution cannot be directly represented. To account for this model limitation, known flow paths from the Craigton Burn have been directed to weirs rather than 1D-2D banks. It can be seen from Figure 2-2 the upper reaches of the Burn were retained as 1D and a series of weir units were added, with the weir crests set to the level of the right-hand bank. This allows for the volume lost to the canal to be quantified without directly representing the canal. Note that the Swine Burn has a 1D-2D connection where it runs parallel to the Union Canal. The Swine Burn exchanges water across the northern bankline but it does not flow onto the Union Canal, for the events investigated.

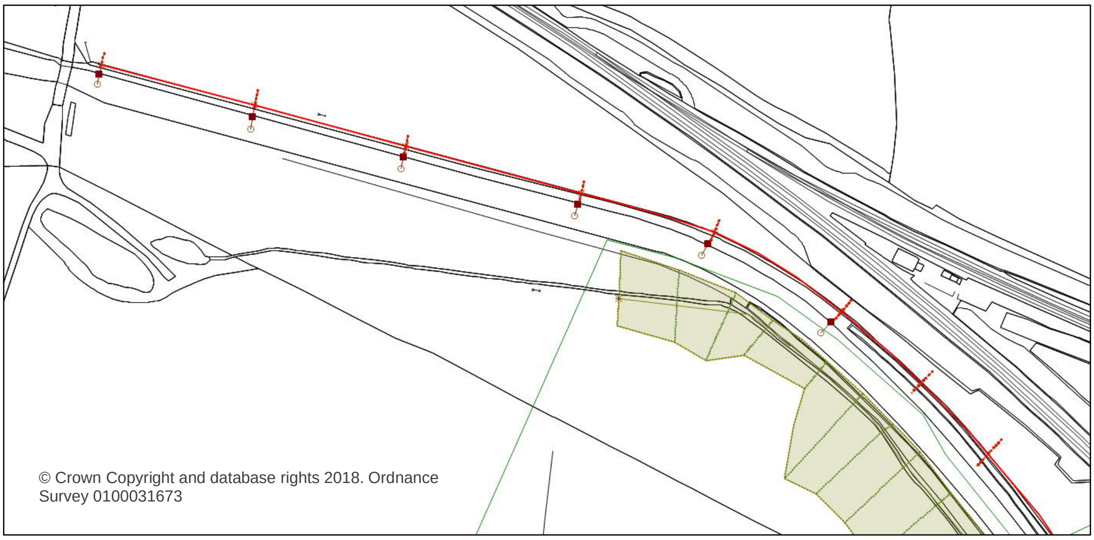

Figure 2-2 Weir units along the upper reaches of the Craigton Burn.

2.1 Hydraulic Structures

Structures considered to have an impact on the flow and flood risk within the area of interest have been represented in the model.

For the Swine Burn these are:

1. A culvert under the Union Canal;
2. Twin culverts immediately downstream of the Union Canal;
3. Inverted syphon under the Edinburgh-Glasgow railway;
4. Footbridge immediately downstream of the railway syphon;
5. Triple culvert immediately upstream of the channel discharge point;
6. Arched culvert under Beatlie Road (B8020);
7. Arched culvert under the second railway link;
8. Triple culvert downstream of second railway culvert; and
9. The box culvert and weir under the M9.

During the site visit it was determined that the Union Canal culvert suffered from severe sedimentation, which likely affects flows downstream (Figure 2-3A). Similarly, one of the twin culverts immediately downstream of the canal was observed to be approximately 50% blocked (see Figure 2-3B). To account for these constraints, an estimated sediment depth was added to both culverts based on these field observations. The baseline results are presented both with and without sediment included.

The northern inlet to the inverted syphon was observed, during the site walkover, to be operational with slight accumulation of debris within the northern inlet. For the baseline modelling the syphon was assumed to be unimpeded thereby ensuring levels within the area of interest are conservative. Sensitivity testing was undertaken to evaluate the impact of blockages on this feature as well as the Union Canal culvert (See section 4.2).

Figure 2-3 (a) Downstream of the Union Canal Culvert and (b) upstream of the two culverts along the Swine Burn

For the Beatlie Channel the following culverts are represented:

1. Culvert under the Union Canal;
2. Aqueduct crossing the Edinburgh-Glasgow railway;
3. Twin culverts from the railway aqueduct to an open channel downstream; and
4. Two culverts upstream of the discharge point to the Swine Burn.

Figure 2-4 (A) Outfall from the Union canal culvert and (B) Inlet to the railway aqueduct.

The inverts and dimensions of the culverts were informed by both the 2005 and 2019 surveys, as well as field observations. Where there was uncertainty regarding the invert levels of the culverts, the soffit levels taken from the 2005 survey were generally used as the reference point and the inverts calculated by lowering this value by the maximum opening height either upstream of downstream. Where inverts were found to be significantly below the recorded bed level, a sediment depth was added to ensure continuity in the bed profile.

2.2 Roughness Values

The roughness values used in the model is shown in Table 2-1:

Table 2-1 Manning's 'n' values used in the model

1D	Channel Bed	0.03 - 0.04
1D	Channel Banks	0.055 - 0.04
1D	Bridges	0.02
1D	Culverts	15mm (Colebrook-White)
2D	2D Mesh	0.04

The Manning's 'n' roughness values of the channel bed and banks were based on an initial site walkover. The banks of the River Swine upstream of the Union Canal culvert were set to a Manning's 'n' value of 0.055 to reflect the area of woodland and dense vegetation. The channel banks along the river reaches downstream of the railway syphon were set to a roughness of 0.04 to reflect the long grass vegetation observed. Similarly, the Beatlie Channel upstream of the railway aqueduct has a channel and bank roughness of 0.04 to reflect the tall grass and scrubland covering both the bed and banks. Pictures taken during the survey reflecting roughness zones can be seen in Figure 2-5 and Figure 2-6.

Figure 2-5 (a) The Beatlie Channel upstream of the railway aqueduct and (b) the Swine Burn channel and banks upstream of the Union Canal Culvert.

Figure 2-6 Swine Burn channel downstream of syphon and downstream of unnamed bridge 2 showing long grass along banks and straight channel.

2.3 Boundary Conditions

2.3.1 Upstream Boundary

The Swine Burn is ungauged, as a result the FEH catchment descriptors were used in the hydrological analysis. Several techniques were compared including FEH statistical, ReFH2, and FEH rainfall-runoff. The ReFH2 hydrograph shape was retained, with the peak value uplifted by 7% to bring the peak flow in line with the FEH statistical estimate.

The overall catchment was divided into ten sub-catchments, and associated inflow hydrographs, based on a review of the site topography and a simplified direct rainfall model. Peak flows were manually uplifted by 7%. The hydrograph peaks were then uplifted by a further 35% to account for climate change following the most recent SEPA guidance. The Edinburgh to Glasgow railway is served by a pumped drainage system which was accounted for by applying a constant flow rate of 67 l/s to the Swine Burn and 33 l/s to the Beatlie Channel following the 2005 FRA report. A detailed overview of the hydrological analysis undertaken can be found in Appendix B of the M9 Winchburgh Junction – Flood Risk Assessment.

2.3.2 Downstream Boundary

An 1D outfall node was placed at the downstream end of the model with a normal boundary condition. Sensitivity analysis was undertaken to evaluate the impact of the downstream boundary with the results outlined in Section 4.

2.4 Run parameters

The model was run with a 5 second timestep and a 5-minute output. The baseline model for the 200-year event (with a 35% allowance for climate change) has a total mass error of 0.0001 m^3 and a volume balance error of 0.35% ($52m^3$). The minor errors are below the recommended 1% threshold noted within SEPAs Flood Modelling Guidance for Responsible Authorities[2] .

3 Baseline Model Results

The baseline flood maps with and without a 35% allowance for climate change are shown in Figure 3-1 and Figure 3-2. The modelling predicts flooding along both banks of the Swine Burn upstream of the Union Canal culvert for the 1:200-year event (both with and without a 35% climate change allowance). Flooding in this location relates to the lack of capacity within the Union Canal Culvert and the sedimentation observed during the site visit (noted in Section 2.1). This lack of capacity throttles flows, resulting in water backing up upstream of the culvert. The extent of flooding is however limited by the sloping topography adjacent to the western bank of the watercourse as well as the canal embankment.

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[2] https://www.sepa.org.uk/media/219653/flood_model_guidance_v2.pdf

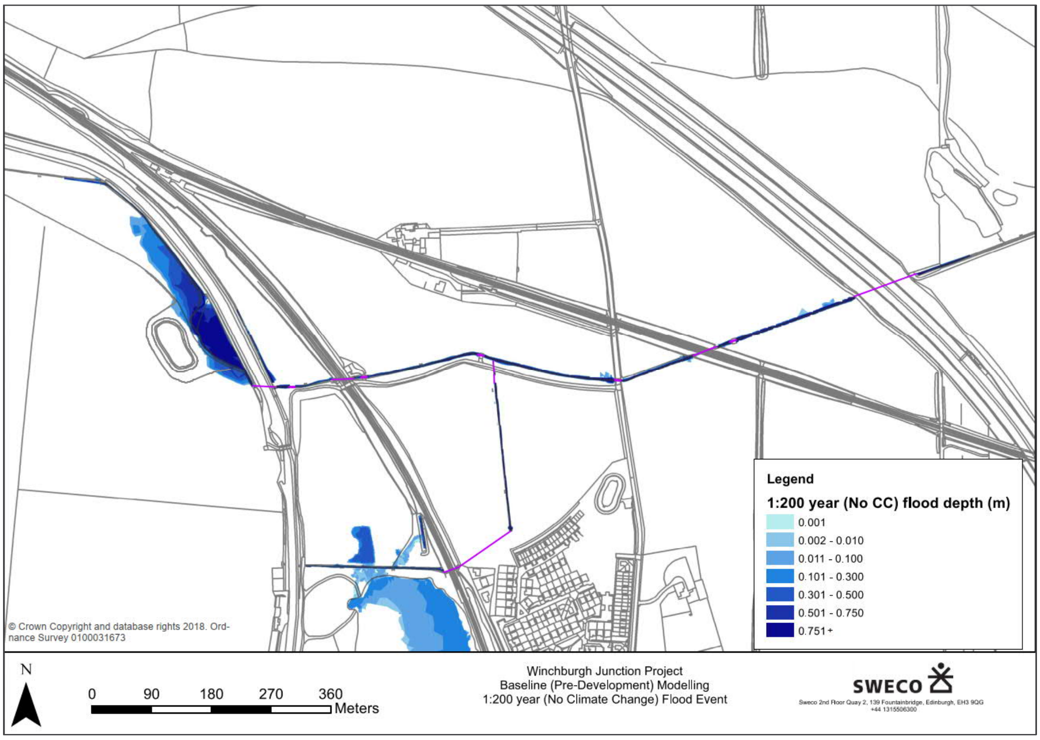


Figure 3-1 1:200-year (No CC) flood patterns for the baseline scenario.

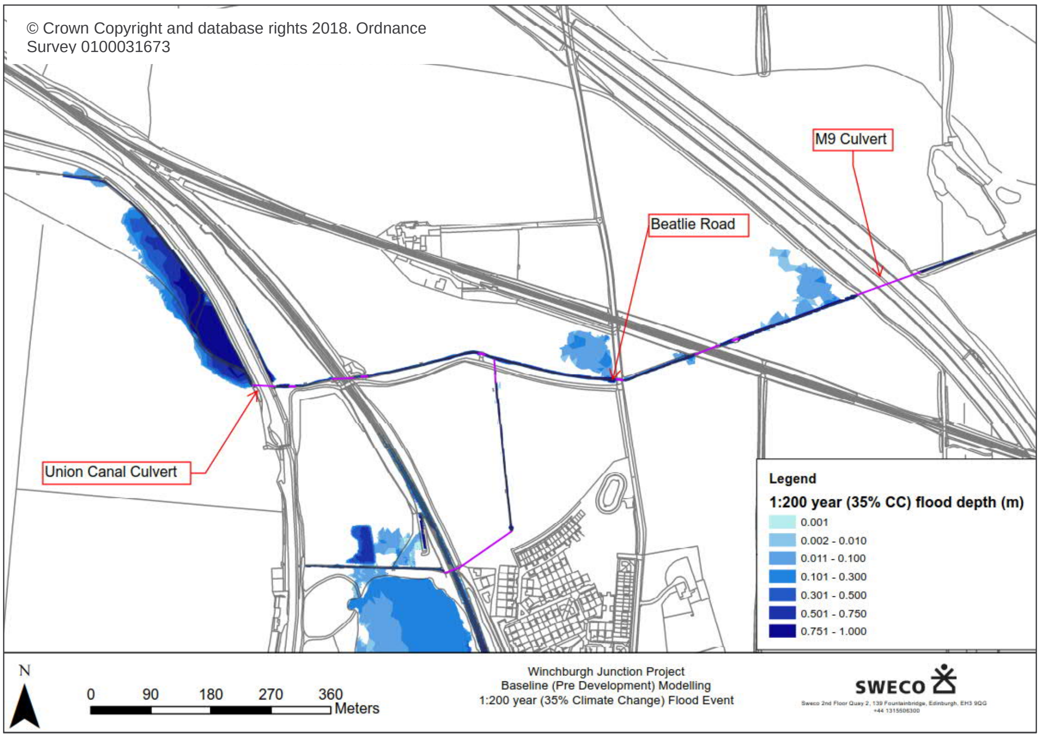


Figure 3-2 1:200-year (+35% CC) flood patterns for the baseline scenario.

The 1: 200 year without climate change flood extent, which denotes the functional floodplain, is predicted to be largely contained within the channel downstream of the Union Canal culvert to the outfall of the model. There are small areas where floodwaters extend slightly beyond the bank, most notable upstream of Beatlie Road and the M9, however these are limited in extent.

For the 1: 200-year scenario with a 35% allowance for climate change flooding was predicted along the Swine Burn upstream of the Beatlie Road, as well as between the second railway and M9 culverts. This was not found to relate to a lack of capacity within the Beatie Road, second railway or M9 culverts but rather low points along the channel banks. Flooding is also predicted along both banks of the Beatlie Channel which flows onto the Edinburgh to Glasgow railway line, and into the clay pit to the south.

An additional model scenario was run in which the sediment depths within the Union Canal culvert were lowered to the surveyed bed layer upstream and downstream. The predicted flood patterns are shown in Figure 3-3. The model scenario predicts greater conveyance under the Union Canal. This results in increased flood extents between the second railway culvert and the M9, while decreasing flooding to the west of the Union Canal. These results suggest that the canal culvert provides control over flood patterns downstream.

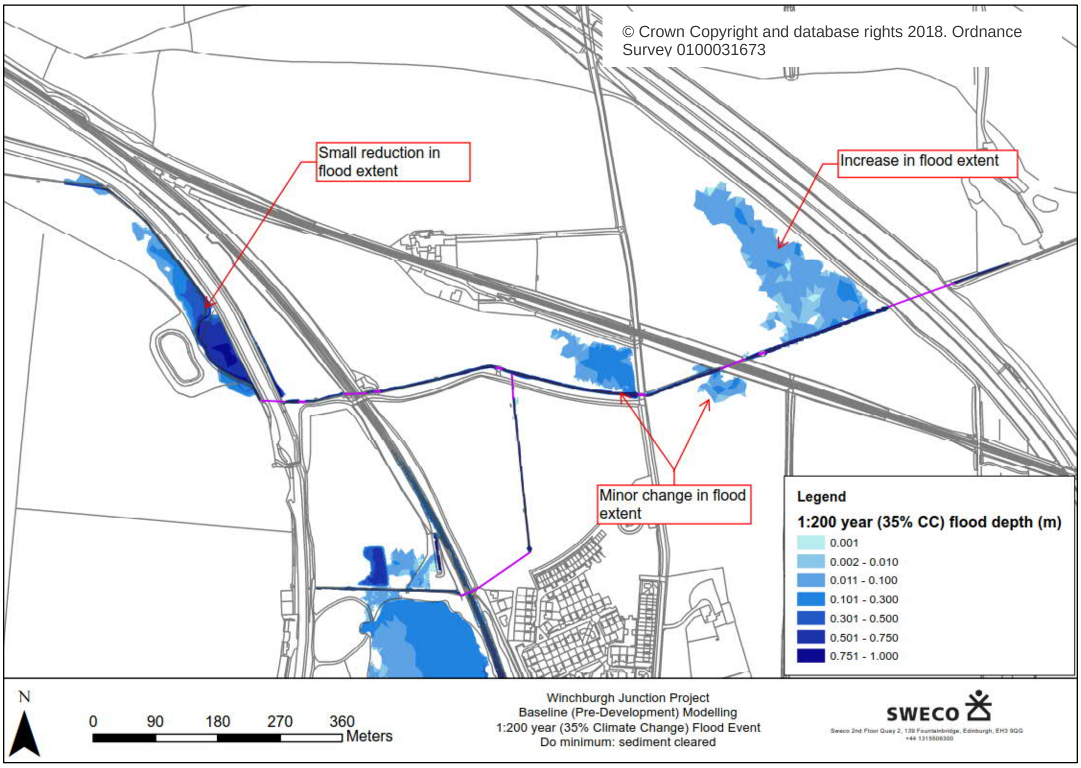


Figure 3-3 Predicted flood patterns with sediment levels reduced in the Union Canal culvert.

4 Sensitivity Analysis

A comprehensive process of calibration and validation was not possible, as the Swine Burn is ungauged. The previous FRA (Carl Bro; 2005) contains a summary of interviews conducted with local residents. Additionally, given the rural nature of the site there are few observations of previous flooding.

4.1 Validation

One resident noted that during the storm event in January 2005, the water level within the Swine Burn was approximately 70 cm below the apex of the triple culvert bridge, upstream of the discharge point from the Beatlie Channel. The resident also noted that there was no flooding from the Burn observed downstream of the Union Canal. This event was estimated by Carl Bro to be equivalent to a 1 in 30-year storm.

The baseline model was run for this return period to enable a comparison. The model predictions were found to be consistent with to the observations, with a freeboard of 0.751 m and 0.691m at the upstream and downstream of the culvert, respectively. Additionally, no out of bank flooding was predicted along the Swine Burn.

The Craigton and Swine Burns were reported to overtopping into the Union Canal in their upper reaches. It is possible that this observation relates to surface water runoff entering the canal, which is predicted by the direct rainfall model (see hydrology analysis – Appendix B).

For the 1 in 200-year (with climate change) event the model predicts that a total of 7,103 m^3 would discharge into the canal from the southern bank of the Craigton Burn, note that nothing is predicted to overflow for the 1 in 30-year event. Overflow at the 1 in 200-year event caps peak flow in the Craigton Burn, reducing peak inflow to the Swine Burn from 1.82 to 1.12 m^3/s, as shown in Figure 4-1. Floodwaters were not predicted to enter the canal from the Swine Burn.

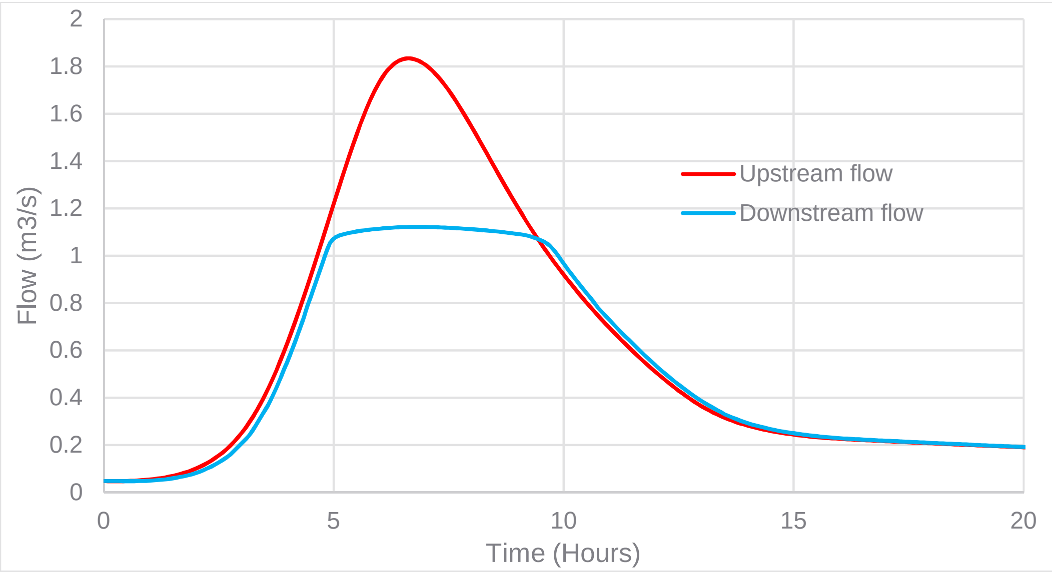


Figure 4-1 upstream and downstream flow along the Craigton Burn.

An overview of the hydrographs at selected points along the Beatlie Channel and Swine Burn are presented in Appendix C4.

During the 2005 event flooding was observed from the Beatlie Channel into the Clay Pit. The model replicated this behavior during the 1 in 30-year simulation.

4.2 Sensitivity

Sensitivity testing was undertaken for channel roughness, inflows, culvert dimensions, and downstream boundary. The results, summarised in Table 4-1 indicate that the model is most sensitive to the downstream boundary condition, which was found to increase depths by an average of 8.9% within the area of interest. The model is also moderately sensitive to changes in inflows, as well as channel roughness and the removal of sediment within the Union Canal culvert. A detailed overview of sensitivity analysis can be found in Appendix C5.

Table 4-1 Results of varying channel roughness on predicted flood extents and peak water depths in the area of interest

Scenario	Maximum change in peak water levels (m)	Average Change in water level (m)	Average % Change in depth
+20% roughness	0.051	0.033	3.3
-20% roughness	-0.069	-0.045	-4.5
SEPA roughness Test	0.051	0.033	3.3
+20% inflows	0.064	0.058	5.5
-20% Inflows	-0.079	-0.073	-6.9
+20% conduit dimension	0.026	0.002	0.3
-20% conduit dimension	0.053	0.016	1.4
Bank full downstream boundary	0.148	0.096	8.9
Sediment removed from canal culvert	0.045	0.041	3.9
50% blockage to railway syphon	-0.022	-0.02	-1.9

Following feedback from SEPA bank roughness values upstream of the Union Canal culvert were further increased to 0.08 to reflect the dense vegetation. This was found to have the same impact as the scenario in which roughness values were all increased by 20%, due to the throttling effect of the Union Canal culvert.

Further sensitivity testing was undertaken to evaluate the impact of blockages on the railway syphon upstream of the site of interest. The results indicate that this reduces peak flows within the area by approximately 22 mm and reduced slightly the flood extent within the area of interest.

5 Summary

This briefing note has been prepared to provide a summary of the hydraulic modelling undertaken to support the development of a new motorway and access infrastructure along the M9 at Winchburgh, west of Edinburgh. The model was constructed using topographic survey data, as well as 1 m resolution LiDAR. Pumps for the Edinburgh to Glasgow Railway were accounted for by applying a constant 100 l/s inflow distributed between the Swine Burn and Beatlie Channel.

The baseline results are presented both with and without a 35% allowance for climate change. Both scenarios predict flooding for the 1:200-year event (with a 35% climate change allowance) along the Swine Burn upstream of the Union Canal.

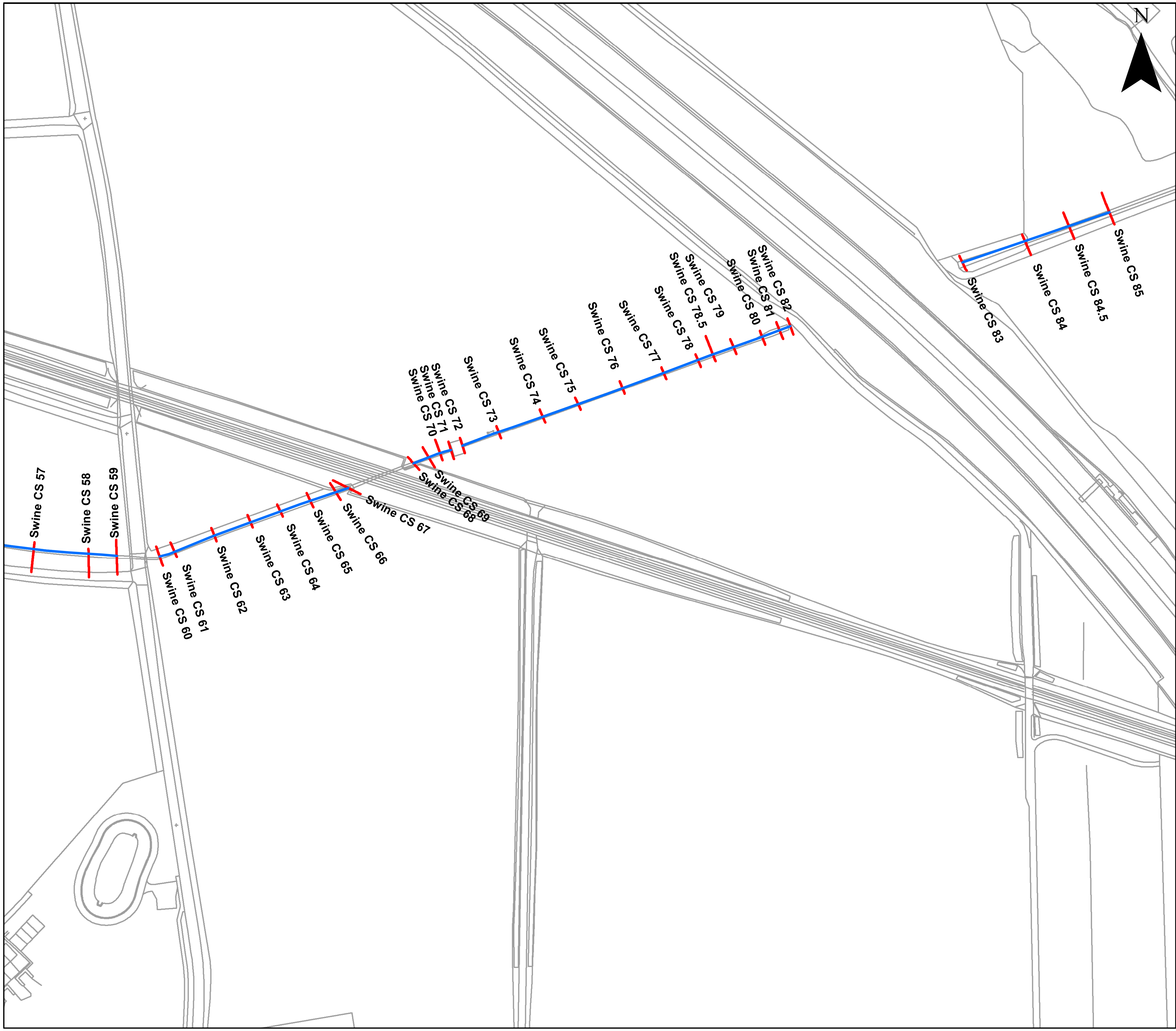
The 1: 200-year without climate change flood extent is predicted to be contained within the channel downstream of the Canal Culvert to the outfall of the model. The proposed development is therefore not within the functional floodplain of the Swine Burn.

For the 1: 200-year event with a 35% allowance for climate change, flooding was predicted along the Swine Burn upstream of the Beatlie Road, as well as between the second railway and M9 culverts.

The culvert under the Union Canal was found to exert a significant impact on flooding downstream with the removal of observed sediment increasing flood extents between the second railway culvert and the M9.

The model results were comparable with previously observed flooding; however, it is noted that there is uncertainty regarding the flood history of the site. Sensitivity testing was undertaken with water levels found to be moderately sensitive to changes to inflows and downstream boundary.

Appendix C1 - Overview of cross-section locations



Legend

- River reach
- River reach Section Lines

0 25 50 100 Meters

Rev.	Rev. Date	Drawing Status	Drawn	Appr'd
0	V1	First Issue	JJW	JPF

Sweco,
2nd Floor Quay 2
139 Fountainbridge,
Edinburgh, EH3 9QG,
Tel: +44 (0) 131 550 6300
Web: www.sweco.co.uk

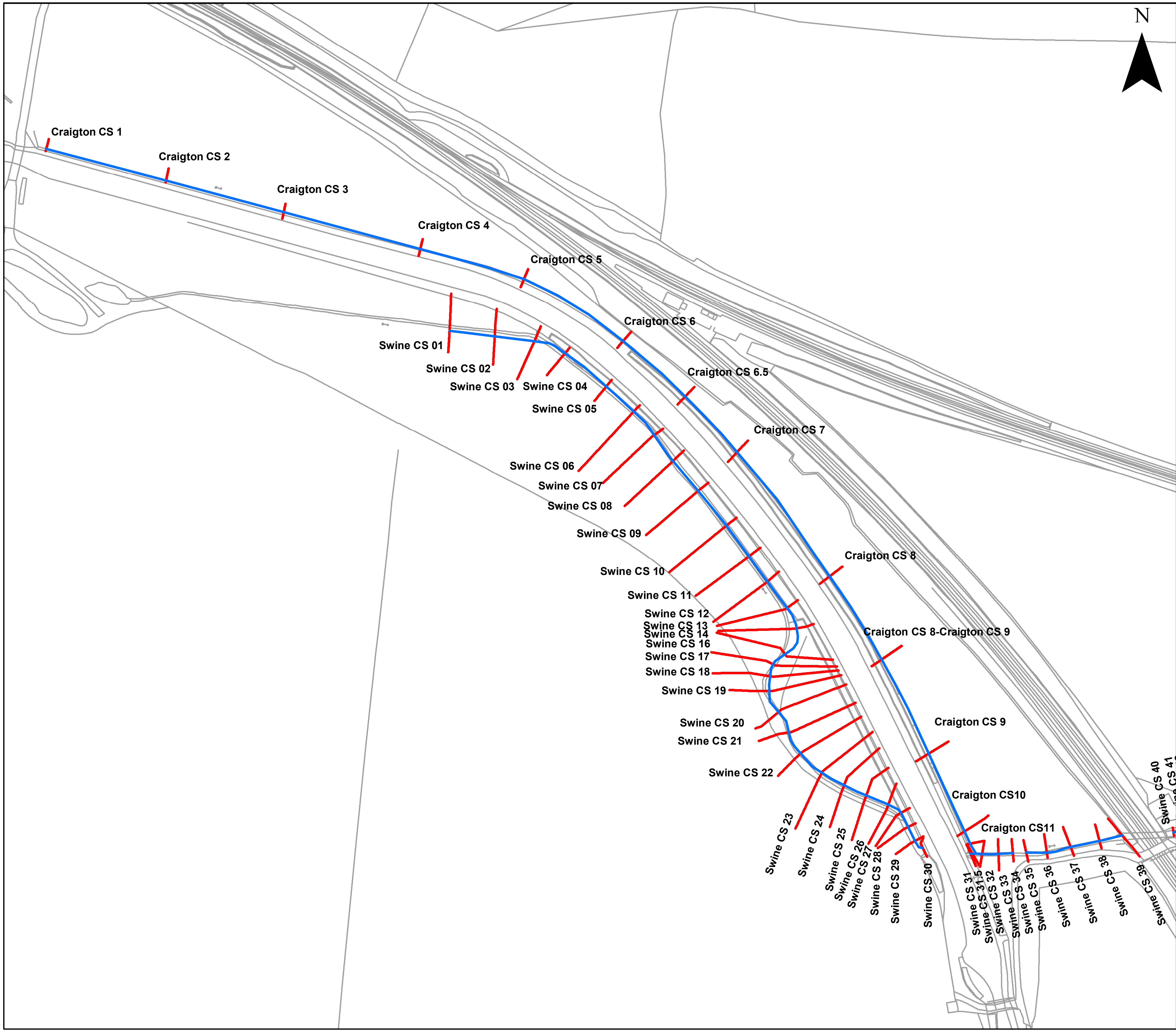
SWECO

Winchburgh Developments Ltd

Winchburgh M9 Junction

Cross-section Locations

Scale @ A3	1:2,000	DO NOT SCALE
Project No.	761068	



Legend

- River reach
- River reach Section Lines

0 30 60 120 Meters

Rev.	Rev. Date	Drawing Status	Drawn	Appr'd
0	V1	First Issue	JJW	JPF

Sweco,
2nd Floor Quay 2
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Tel: +44 (0) 131 550 6300
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SWECO

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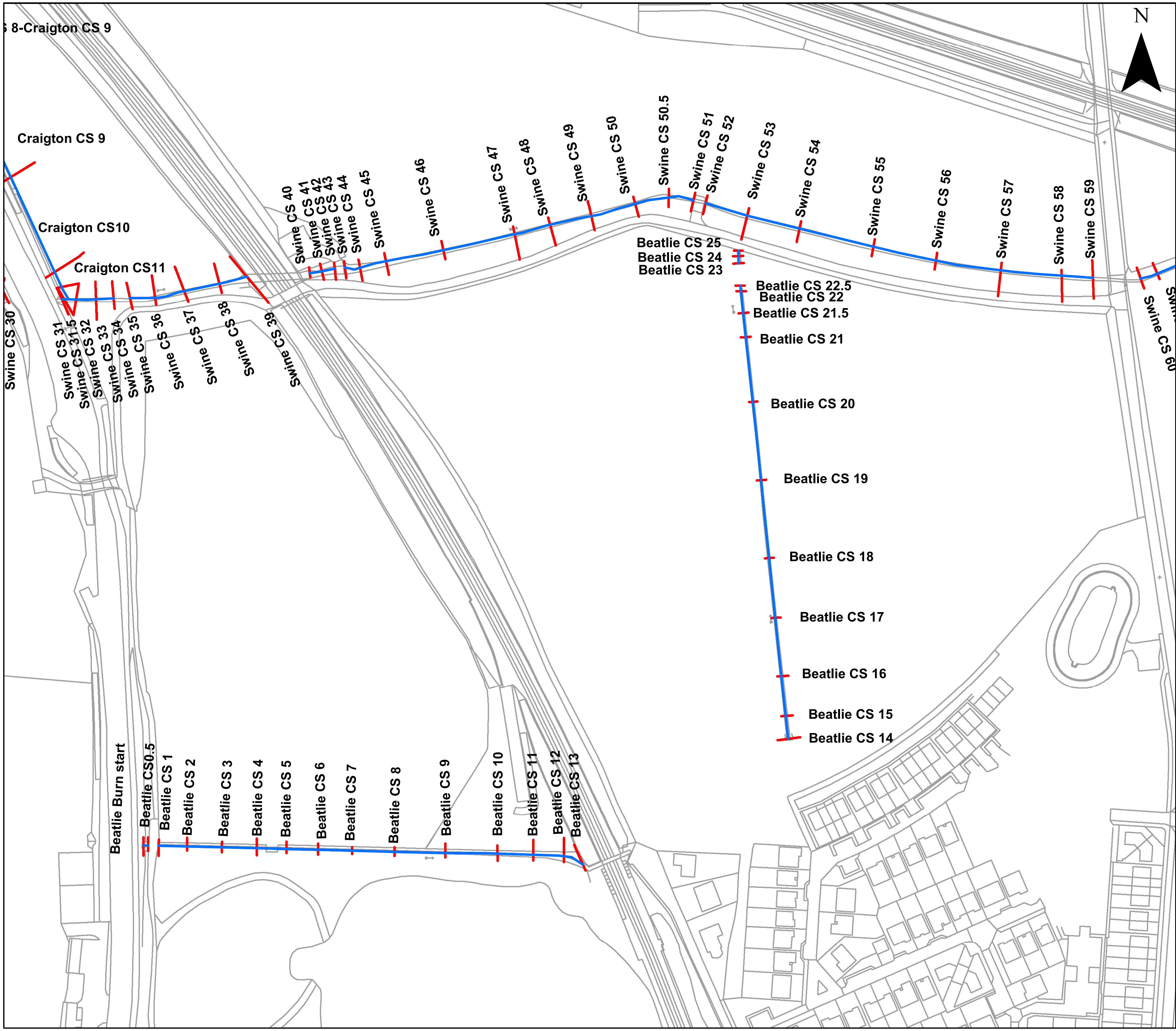
Winchburgh M9 Junction

Cross-section Locations

Scale @ A3: 1:2,200 DO NOT SCALE

Project No. 761068



Legend

- River reach
- River reach Section Lines

0 25 50 100 Meters

Rev.	Rev. Date	Drawing Status	Drawn	Appr'd
0	V1	First Issue	JJW	JPF

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Winchburgh M9 Junction

Cross-section Locations

Scale @ A3: 1:1,800 DO NOT SCALE

Project No. 761068

Appendix C2 - Topographic survey and LiDAR data coverage

NOTES

1. NOTES

AIRDS TOPO AREAS

Rev.	Date	Amendment Details	Drw'n	Chk'd	App'd
0	#				

Sweco
2nd Floor, Quay 2
139 Fountainbridge
Edinburgh
EH3 9QG
Tel: +44 (0)131 550 6300
Web: www.sweco.co.uk

SWECO

Client

Winchburgh Developments Ltd

Drawing Status

DRAFT

Project Title

WINCHBURGH
WEST LOTHIAN

MASTERPLAN

Drawing Title

AIRDS SURVEY AREAS

Scale	Designed	Drawn	Checked	Approved
1:5000	#	TJH	#	#
Original Size	Date	Date	Date	Date
A1	#	MAR 19	#	#

Drawing Number	Revision
761068/01/AIRDS	0

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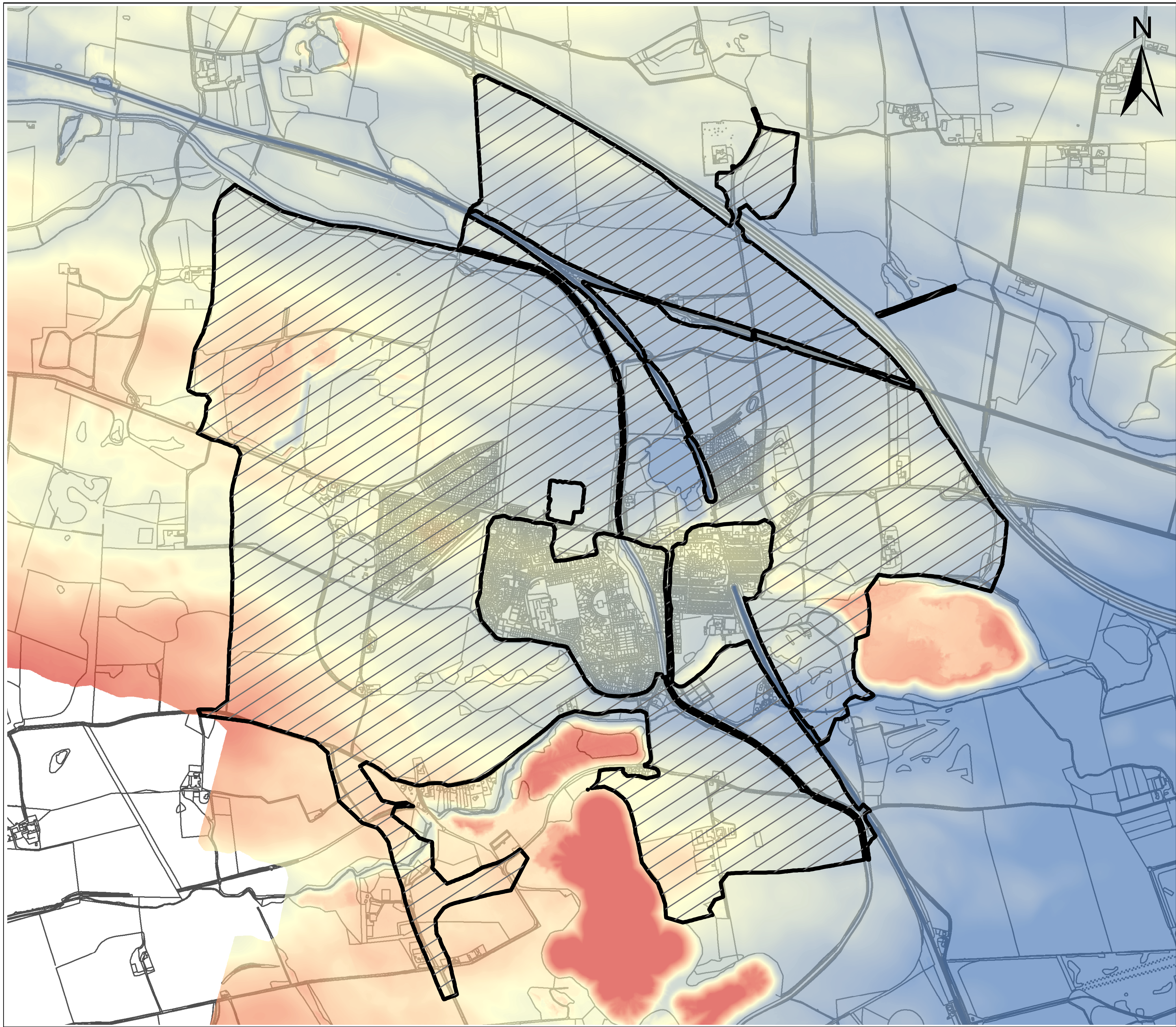

Legend

Legend

Topographic Survey Extent

High : 120

Low : 60

0 200 400 800 Meters

0	V1	First Issue	JJW	JPF
Rev.	Rev. Date	Drawing Status	Drawn	Appr'd

Sweco,
2nd Floor Quay 2
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Edinburgh, EH3 9QG,
Tel: +44 (0) 131 550 6300
Web: www.sweco.co.uk

SWECO

Client

Winchburgh Developments Ltd

Project

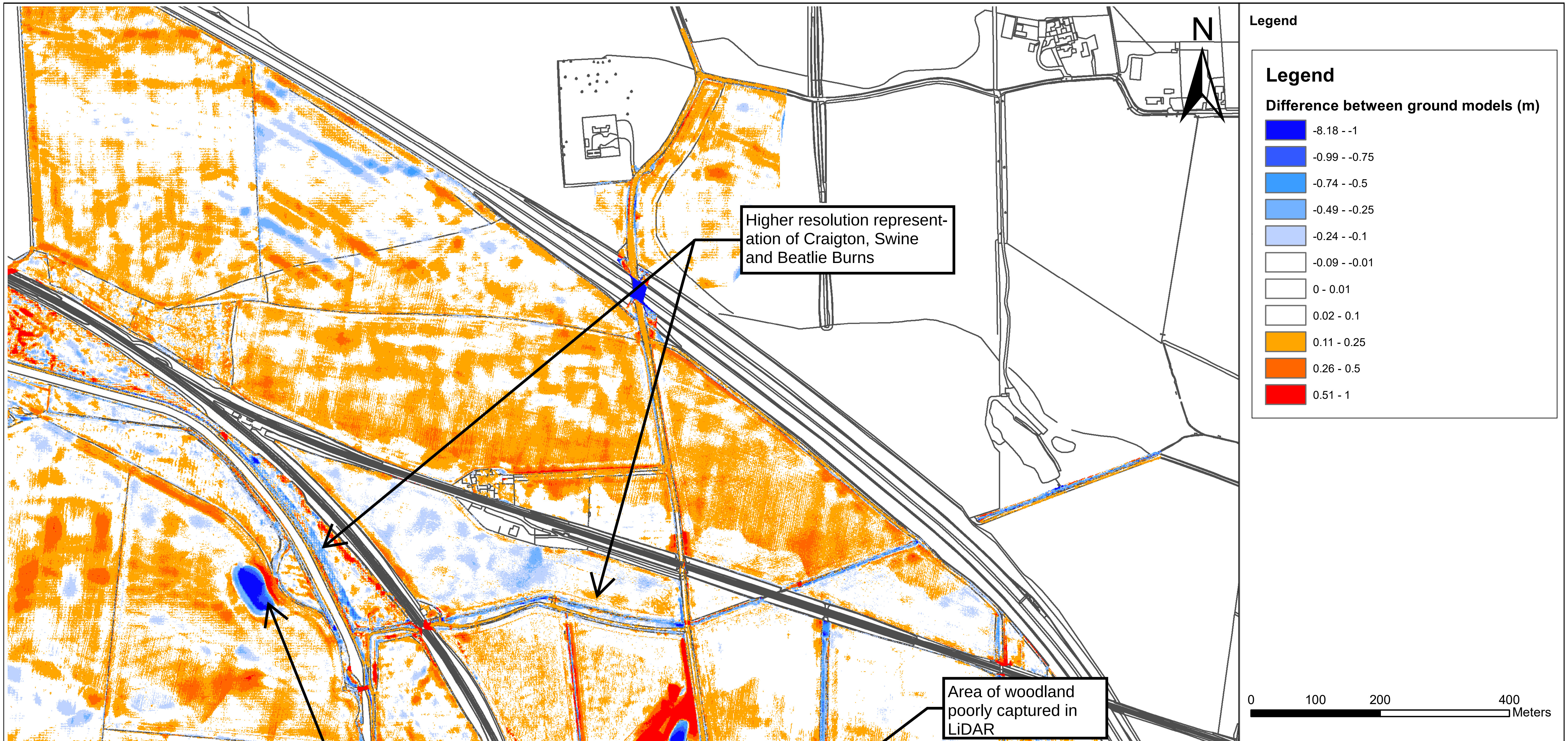
Winchburgh M9 Junction

Drawing Title

Overview of topographic data

Scale @ A3	1:13,500	DO NOT SCALE
Project No.	761068	

Appendix C3 - Map of elevation differences between the topographic data and LiDAR



Rev.	Rev. Date	Drawing Status	Drawn	Appr'd
0	V1	First Issue	JJW	JPF

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Web: www.sweco.co.uk

SWECO

Client

Winchburgh Developments Ltd

Project

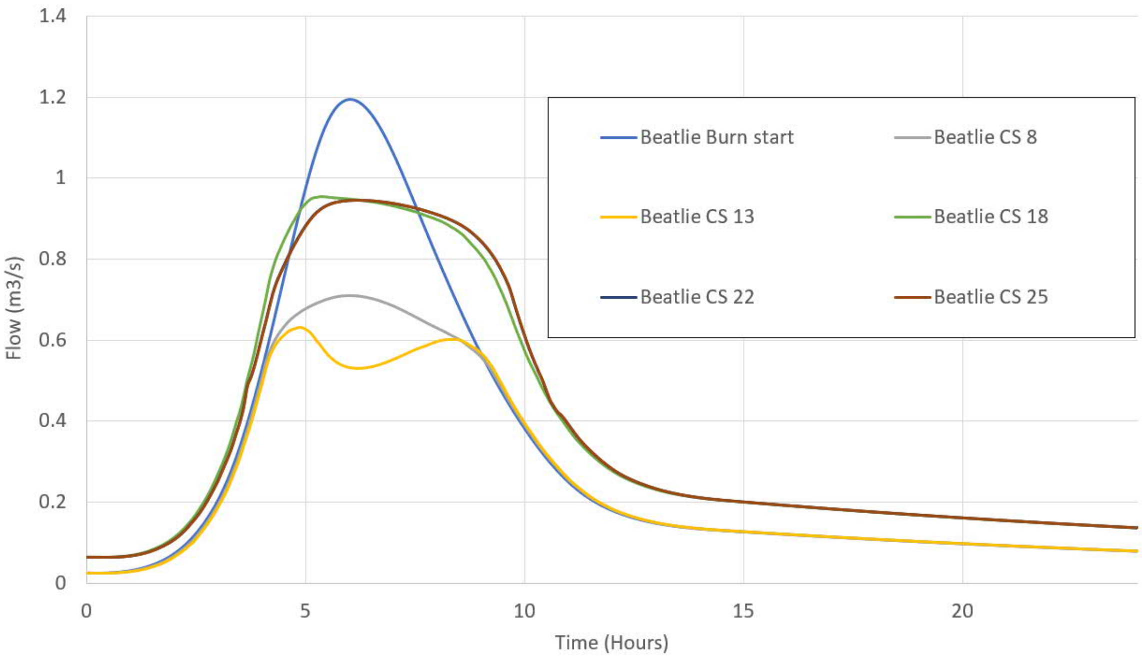
Winchburgh M9 Junction

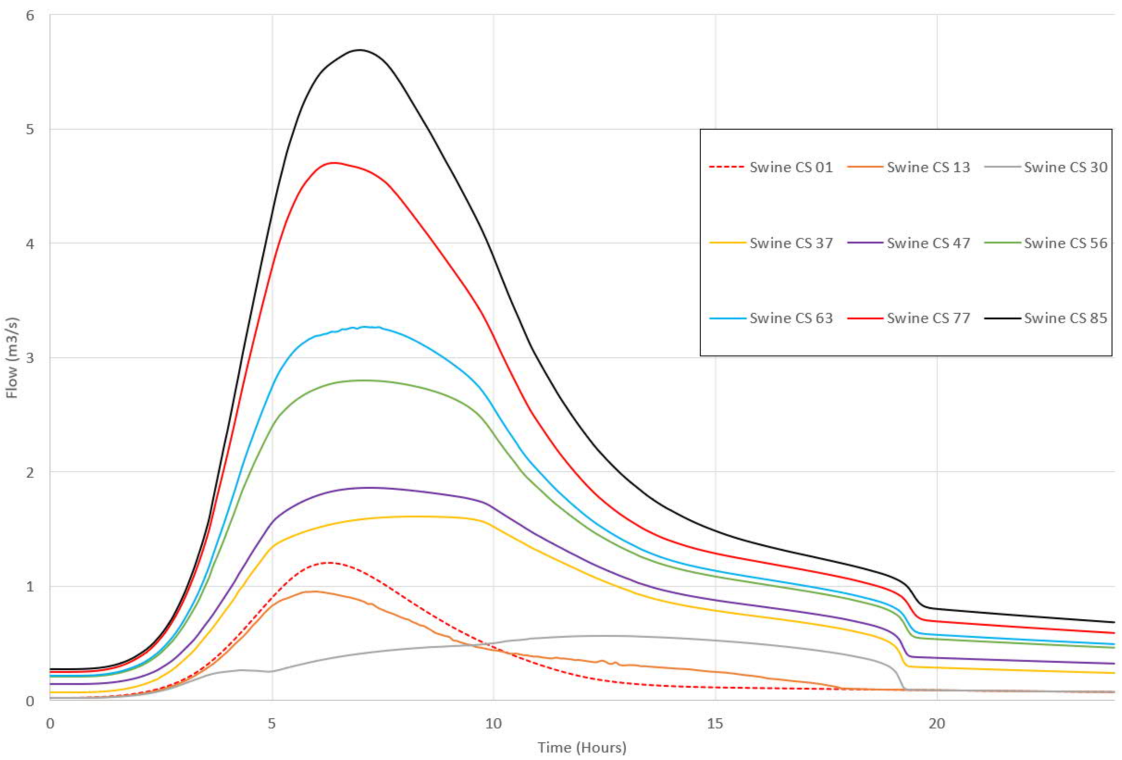
Drawing Title

Comparison of Topographic groundmodel and LiDAR

Scale @ A3	1:5,969	DO NOT SCALE
Project No.	761068	

Appendix C4 - Flow Hydrographs for the 1: 200-year (35% climate change) scenario along the Beatlie and Swine Burn





Appendix C5 - Sensitivity Analysis Results

Section ID	Baseline		+20% Roughness				-20% Roughness			
	Level (m AOD)	Depth (m)	Level (m AOD)	Difference (m)	Depth (m)	% Difference	Level (m AOD)	Difference (m)	Depth (m)	% Difference
Swine CS 68	68.304	1.124	68.349	0.045	1.169	4.0%	68.240	-0.064	1.060	-5.7%
Swine CS 69	68.289	0.875	68.337	0.047	0.923	5.4%	68.221	-0.068	0.807	-7.8%
Swine CS 70	68.291	0.891	68.335	0.045	0.935	5.0%	68.226	-0.064	0.827	-7.2%
Swine CS 71	68.301	1.355	68.342	0.041	1.396	3.0%	68.243	-0.058	1.297	-4.3%
Swine CS 72	68.242	1.133	68.291	0.049	1.182	4.3%	68.176	-0.066	1.067	-5.8%
Swine CS 73	68.200	0.860	68.252	0.051	0.912	5.9%	68.131	-0.069	0.791	-8.0%
Swine CS 74	68.151	0.814	68.199	0.048	0.863	5.9%	68.087	-0.064	0.750	-7.9%
Swine CS 75	68.107	0.832	68.151	0.044	0.877	5.3%	68.048	-0.059	0.774	-7.0%
Swine CS 76	68.054	0.900	68.091	0.037	0.937	4.1%	68.007	-0.047	0.853	-5.2%
Swine CS 77	68.041	1.233	68.068	0.027	1.259	2.2%	68.008	-0.033	1.199	-2.7%
Swine CS 78	68.026	1.322	68.048	0.022	1.344	1.7%	67.999	-0.028	1.295	-2.1%
Swine CS 78.5	68.015	1.156	68.036	0.021	1.177	1.8%	67.988	-0.027	1.129	-2.3%
Swine CS 79	68.015	1.614	68.032	0.017	1.631	1.1%	67.993	-0.022	1.592	-1.4%
Swine CS 80	67.991	1.129	68.007	0.016	1.145	1.4%	67.971	-0.020	1.109	-1.8%
Swine CS 81	67.992	1.088	68.003	0.011	1.099	1.0%	67.976	-0.015	1.073	-1.4%
Swine CS 82	67.957	1.140	67.969	0.012	1.153	1.1%	67.940	-0.016	1.124	-1.4%
	Maximum			0.051		5.9%		-0.069		-8.0%
	Average			0.033		3.3%		-0.045		-4.5%

Section ID	Baseline		+20% Inflows				-20% Inflows			
	Level (m AOD)	Depth (m)	Level (m AOD)	Difference (m)	Depth (m)	% Difference	Level (m AOD)	Difference (m)	Depth (m)	% Difference
Swine CS 68	68.304	1.124	68.357	0.053	1.177	4.8%	68.235	-0.069	1.055	-6.1%
Swine CS 69	68.289	0.875	68.345	0.056	0.931	6.4%	68.217	-0.072	0.804	-8.2%
Swine CS 70	68.291	0.891	68.347	0.056	0.947	6.3%	68.218	-0.072	0.818	-8.1%
Swine CS 71	68.301	1.355	68.356	0.055	1.411	4.1%	68.229	-0.071	1.284	-5.3%
Swine CS 72	68.242	1.133	68.291	0.050	1.183	4.4%	68.178	-0.063	1.070	-5.6%
Swine CS 73	68.200	0.860	68.251	0.050	0.911	5.8%	68.136	-0.064	0.796	-7.4%
Swine CS 74	68.151	0.814	68.204	0.053	0.867	6.5%	68.084	-0.067	0.747	-8.2%
Swine CS 75	68.107	0.832	68.163	0.056	0.888	6.7%	68.036	-0.071	0.762	-8.5%
Swine CS 76	68.054	0.900	68.114	0.060	0.960	6.7%	67.978	-0.076	0.824	-8.4%
Swine CS 77	68.041	1.233	68.102	0.061	1.294	4.9%	67.965	-0.076	1.156	-6.2%
Swine CS 78	68.026	1.322	68.088	0.061	1.384	4.7%	67.950	-0.076	1.246	-5.8%
Swine CS 78.5	68.015	1.156	68.079	0.064	1.220	5.5%	67.936	-0.079	1.077	-6.8%
Swine CS 79	68.015	1.614	68.078	0.063	1.677	3.9%	67.938	-0.077	1.537	-4.8%
Swine CS 80	67.991	1.129	68.055	0.064	1.193	5.7%	67.912	-0.079	1.050	-7.0%
Swine CS 81	67.992	1.088	68.056	0.064	1.152	5.9%	67.912	-0.079	1.009	-7.3%
Swine CS 82	67.957	1.140	68.019	0.062	1.202	5.5%	67.880	-0.076	1.064	-6.7%
	Maximum			0.064		6.7%		-0.079		-8.5%
	Average			0.058		5.5%		-0.073		-6.9%

Section ID	Baseline		+20% conduit size				-20% conduit size			
	Level (m AOD)	Depth (m)	Level (m AOD)	Difference (m)	Depth (m)	% Difference	Level (m AOD)	Difference (m)	Depth (m)	% Difference
Swine CS 68	68.304	1.124	68.306	0.002	1.126	0.2%	68.350	0.046	1.170	4.1%
Swine CS 69	68.289	0.875	68.288	-0.001	0.874	-0.1%	68.342	0.053	0.928	6.0%
Swine CS 70	68.291	0.891	68.289	-0.001	0.889	-0.1%	68.343	0.052	0.943	5.9%
Swine CS 71	68.301	1.355	68.302	0.001	1.356	0.1%	68.349	0.049	1.404	3.6%
Swine CS 72	68.242	1.133	68.267	0.026	1.159	2.3%	68.212	-0.030	1.103	-2.6%
Swine CS 73	68.200	0.860	68.223	0.022	0.883	2.6%	68.176	-0.024	0.836	-2.8%
Swine CS 74	68.151	0.814	68.169	0.018	0.832	2.2%	68.135	-0.016	0.798	-2.0%
Swine CS 75	68.107	0.832	68.119	0.013	0.845	1.5%	68.099	-0.008	0.825	-0.9%
Swine CS 76	68.054	0.900	68.058	0.004	0.904	0.5%	68.059	0.005	0.905	0.5%
Swine CS 77	68.041	1.233	68.043	0.001	1.234	0.1%	68.050	0.009	1.242	0.7%
Swine CS 78	68.026	1.322	68.024	-0.002	1.320	-0.1%	68.039	0.013	1.335	1.0%
Swine CS 78.5	68.015	1.156	68.011	-0.004	1.152	-0.4%	68.031	0.016	1.172	1.4%
Swine CS 79	68.015	1.614	68.011	-0.004	1.610	-0.3%	68.031	0.016	1.630	1.0%
Swine CS 80	67.991	1.129	67.981	-0.010	1.119	-0.9%	68.014	0.023	1.152	2.0%
Swine CS 81	67.992	1.088	67.982	-0.010	1.078	-0.9%	68.015	0.023	1.111	2.1%
Swine CS 82	67.957	1.140	67.940	-0.017	1.124	-1.5%	67.988	0.032	1.172	2.8%
	Maximum			0.026		2.6%		0.053		6.0%
	Average			0.002		0.3%		0.016		1.4%

Section ID	Baseline		DS boundary				Sediment removed from Union Canal Culvert			
	Level (m AOD)	Depth (m)	Level (m AOD)	Difference (m)	Depth (m)	% Difference	Level (m AOD)	Difference (m)	Depth (m)	% Difference
Swine CS 68	68.304	1.124	68.354	0.050	1.174	4.5%	68.348	0.044	1.168	3.9%
Swine CS 69	68.289	0.875	68.343	0.054	0.929	6.2%	68.334	0.045	0.920	5.1%
Swine CS 70	68.291	0.891	68.345	0.054	0.945	6.1%	68.335	0.045	0.935	5.0%
Swine CS 71	68.301	1.355	68.353	0.052	1.408	3.9%	68.346	0.045	1.400	3.3%
Swine CS 72	68.242	1.133	68.294	0.053	1.186	4.7%	68.276	0.035	1.168	3.1%
Swine CS 73	68.200	0.860	68.262	0.061	0.922	7.1%	68.235	0.035	0.895	4.0%
Swine CS 74	68.151	0.814	68.227	0.076	0.890	9.3%	68.187	0.036	0.851	4.5%
Swine CS 75	68.107	0.832	68.198	0.092	0.924	11.0%	68.144	0.038	0.870	4.5%
Swine CS 76	68.054	0.900	68.165	0.111	1.011	12.4%	68.094	0.040	0.940	4.5%
Swine CS 77	68.041	1.233	68.160	0.119	1.351	9.6%	68.082	0.041	1.273	3.3%
Swine CS 78	68.026	1.322	68.151	0.125	1.447	9.4%	68.067	0.041	1.363	3.1%
Swine CS 78.5	68.015	1.156	68.147	0.132	1.288	11.4%	68.057	0.042	1.198	3.7%
Swine CS 79	68.015	1.614	68.145	0.130	1.744	8.1%	68.057	0.041	1.655	2.6%
Swine CS 80	67.991	1.129	68.130	0.139	1.268	12.3%	68.033	0.042	1.171	3.7%
Swine CS 81	67.992	1.088	68.131	0.140	1.228	12.8%	68.034	0.042	1.130	3.9%
Swine CS 82	67.957	1.140	68.104	0.148	1.288	12.9%	67.997	0.041	1.181	3.6%
	Maximum			0.148		12.9%		0.045		5.1%
	Average			0.096		8.9%		0.041		3.9%

Section ID	Baseline		Syphon 50% Blocked			
	Level (m AOD)	Depth (m)	Level (m AOD)	Difference (m)	Depth (m)	% Difference
Swine CS 68	68.304	1.124	68.282	-0.021	1.102	-1.9%
Swine CS 69	68.289	0.875	68.267	-0.022	0.854	-2.5%
Swine CS 70	68.291	0.891	68.269	-0.022	0.869	-2.4%
Swine CS 71	68.301	1.355	68.279	-0.022	1.333	-1.6%
Swine CS 72	68.242	1.133	68.224	-0.017	1.116	-1.5%
Swine CS 73	68.200	0.860	68.183	-0.017	0.843	-2.0%
Swine CS 74	68.151	0.814	68.133	-0.018	0.796	-2.2%
Swine CS 75	68.107	0.832	68.088	-0.019	0.814	-2.2%
Swine CS 76	68.054	0.900	68.035	-0.020	0.881	-2.2%
Swine CS 77	68.041	1.233	68.022	-0.020	1.213	-1.6%
Swine CS 78	68.026	1.322	68.007	-0.020	1.303	-1.5%
Swine CS 78.5	68.015	1.156	67.995	-0.020	1.136	-1.7%
Swine CS 79	68.015	1.614	67.995	-0.020	1.594	-1.2%
Swine CS 80	67.991	1.129	67.971	-0.020	1.109	-1.8%
Swine CS 81	67.992	1.088	67.971	-0.020	1.068	-1.9%
Swine CS 82	67.957	1.140	67.937	-0.019	1.121	-1.7%
	Maximum			-0.022		-2.5%
	Average			-0.020		-1.9%

Appendix D – Post Development Modelling Overview

Post Development Analysis

Project Name: M9 Winchburgh Junction	Author: James Walker		
Project Reference: 65200072	Date: 16/08/2019		
Project Manager: Allan Mason	Document Reference: 99165423/WFR/WPDA		Revision: 3

Rev.	Date	Reason for issue	Prepared		Reviewed		Approved	
[1]	16.08.19	First Issue	JJW	15.08.19	JP	15.08.19	JPF	16.08.19
[2]	20.12.19	Second Issue	JJW	17.08.19	JP	18.12.19	JPF	19.12.19
[3]	06.03.20	Final Issue	JJW	05.03.20	AB	06.03.20	JPF	06.03.20

1 Introduction

This briefing note has been prepared to provide a summary of the post development hydraulic modelling undertaken to support the development of a new motorway junction and access roads along the M9 at the B8020, Winchburgh, West Lothian. This memo should be read in conjunction with Appendix B, Hydrological Analysis and Appendix C, Baseline Modelling Overview of the M9 Winchburgh Junction – Flood Risk Assessment (FRA).

1.1 Development Proposal

The proposed development is situated in West Lothian, to the north east of Winchburgh (grid reference NT 09575 75878). The development comprises a proposed upgrade to the existing M9 including a junction with Beatlie Road, slip roads, as well a new access road. The only impact to the existing M9 will be localised at the 4 tie-in locations, where the proposed slip roads meet the existing motorway carriageway and hard shoulder. An overview of the scheme can be seen in Figure 1-1.

The new access road crosses the Swine Burn and will therefore require the installation of a new box culvert 12 m in length, 2.4 m high and 5 m wide. The culvert also includes 300 mm sediment depth to provide a more natural channel bed following SEPA guidance[1].

[1] https://www.sepa.org.uk/media/151036/wat-sg-25.pdf

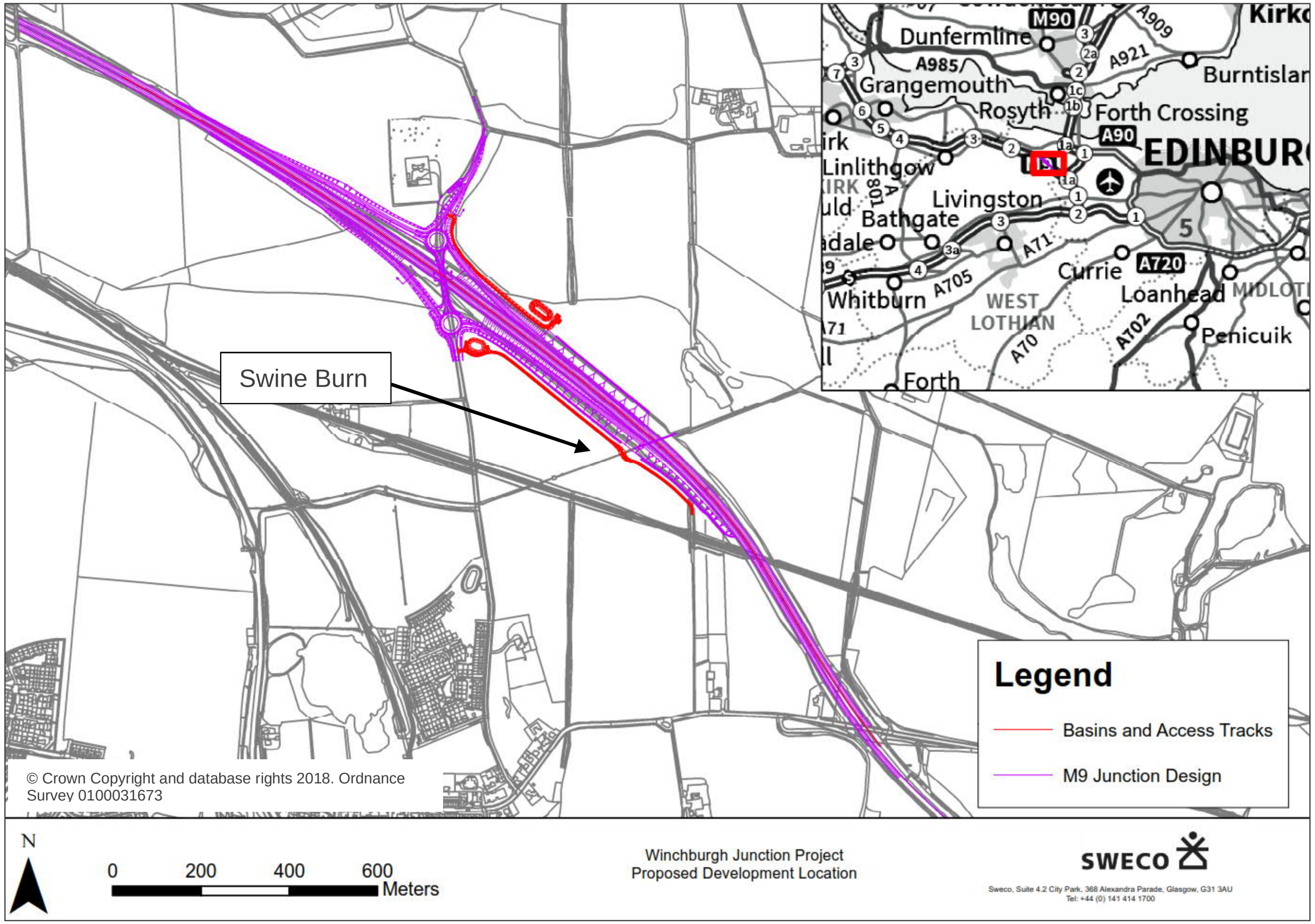


Figure 1-1 Site location and overview of the proposed development.

1.2 Modelling Approach

For the post development scenario, the baseline model outlined in the Baseline Hydraulic Modelling Summary (see Appendix C of the FRA) was amended. The river reach upstream of the M9 was split into three sections with cross-section inferred immediately upstream and downstream of the proposed crossing. The reach between the two new cross-sections was removed and replaced with a culvert link. The culvert was defined as rectangular, 2.4 m high and 5 m wide. The upstream and downstream invert levels were set to 66.563 and 66.525 mAOD, and a 300 mm sediment layer was added to the conduit.

The bed levels of the upstream and downstream cross-sections were smoothed to match the level of the top of the 300 mm sediment layer proposed within the culvert.

The access road was represented within the mesh as a mesh level zone, with the depth above ground level set to an arbitrary value of 3 m to provide a physical barrier to flows. Figure 1-2 and Figure 1-3 show an overview of the new culvert and access road as represented in the model.

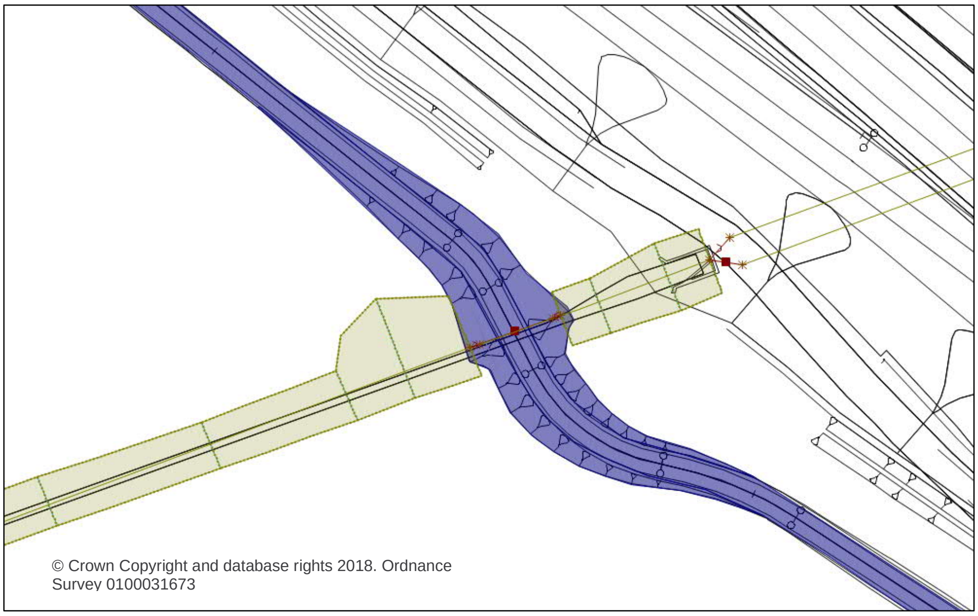


Figure 1-2 Overview of the proposed new access road and culvert along the Swine Burn.

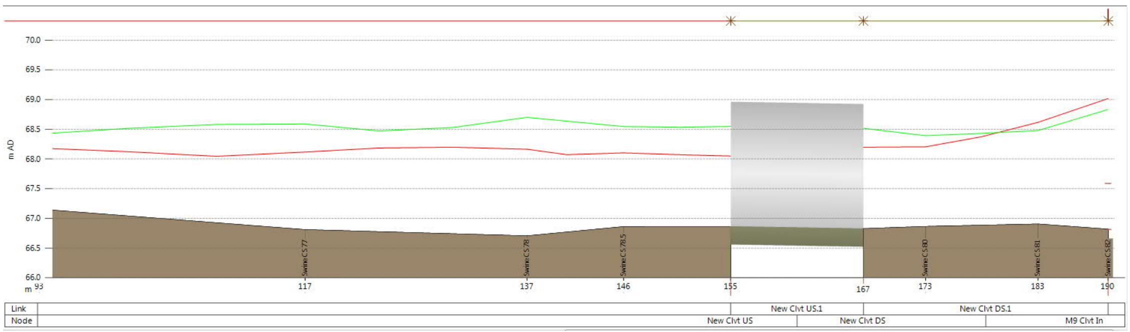


Figure 1-3 New culvert along the Swine Burn and alteration of bed level upstream and downstream.

The mesh parameters, cross-sectional geometry for the remaining river sections, and the hydrological input into the model remained the same as the baseline scenario (without the existing SuDS scenario).

1.3 Post Development Flood Impact

The 1: 200-year flood extent (without an allowance for climate change) is predicted to remain within the channel along the section of the Swine Burn which the access road crosses. The new culvert was predicted to result in a negligible increase in velocities upstream which in turn leads to a reduction in peak water levels (see Table 1-1). The reduction in levels was less than 5 mm and is therefore within model tolerance. The proposal will therefore not impinge on the functional floodplain and compensatory storage will not be required.

Table 1-1 Comparison of pre and post development water levels and velocities for the 1: 200- year flood scenario without an allowance for climate change

Object ID	Baseline Level (m AOD)	Post Dev Level (m AOD)	Difference (m)	Baseline Velocity (m/s)	Post Dev Velocity (m/s)	Difference (m/s)
Swine CS 68	68.304	68.303	-0.001	0.728	0.728	0.001
Swine CS 69	68.289	68.288	-0.001	0.874	0.875	0.001
Swine CS 70	68.291	68.289	-0.001	0.751	0.752	0.001
Swine CS 71	68.301	68.300	-0.001	0.491	0.492	0.001
Swine CS 72	68.242	68.241	-0.001	0.724	0.725	0.001
Swine CS 73	68.200	68.199	-0.001	0.963	0.965	0.002
Swine CS 74	68.151	68.149	-0.002	1.010	1.013	0.003
Swine CS 75	68.107	68.104	-0.002	1.052	1.055	0.004
Swine CS 76	68.054	68.051	-0.003	1.057	1.061	0.004
Swine CS 77	68.041	68.038	-0.003	0.821	0.824	0.003
Swine CS 78	68.026	68.023	-0.003	0.790	0.793	0.003
Swine CS 78.5	68.015	68.011	-0.004	0.841	0.845	0.004
wine CS 79	68.015	-	-	0.704	-	-
Swine CS 80	67.991	67.991	0.000	0.877	0.877	0.000
Swine CS 81	67.992	67.992	0.000	0.730	0.730	0.000
Swine CS 82	67.957	67.957	0.000	1.081	1.081	0.000
Swine CS 83	67.679	67.679	0.000	1.092	1.092	0.000
Swine CS 84	67.534	67.534	0.000	1.780	1.780	0.000
Swine CS 85	67.266	67.266	0.000	2.376	2.376	0.000

The post development modelling predicted that the culvert would be appropriately sized, with a freeboard of 0.82 m retained above the 200-year (including 35% climate change allowance) water level (see Figure 1-4).

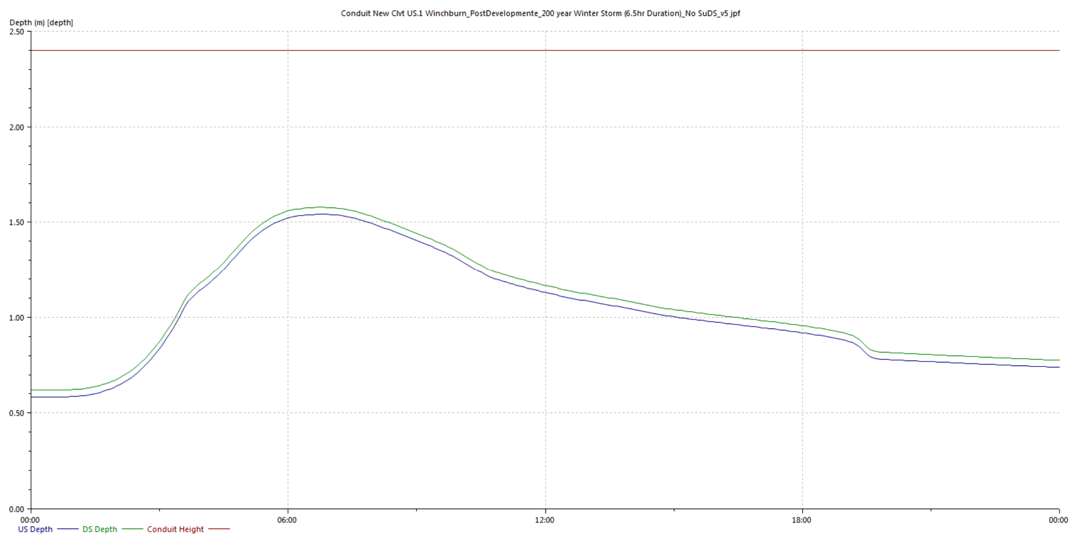


Figure 1-4 Predicted depth within the proposed culvert for the 1:200 year (+35% climate change)

The modelling also indicates that the design would result in a reduction in the 200 year (including 35% climate change allowance) flood extent and volume between the second railway culvert and the M9 (shown in Figure 1-5, Figure 1-6 and Table 1-2). This reduction relates to the position of the culvert along a section of the reach where there is a drop in the northern bank, therefore slightly more water is retained within the channel.

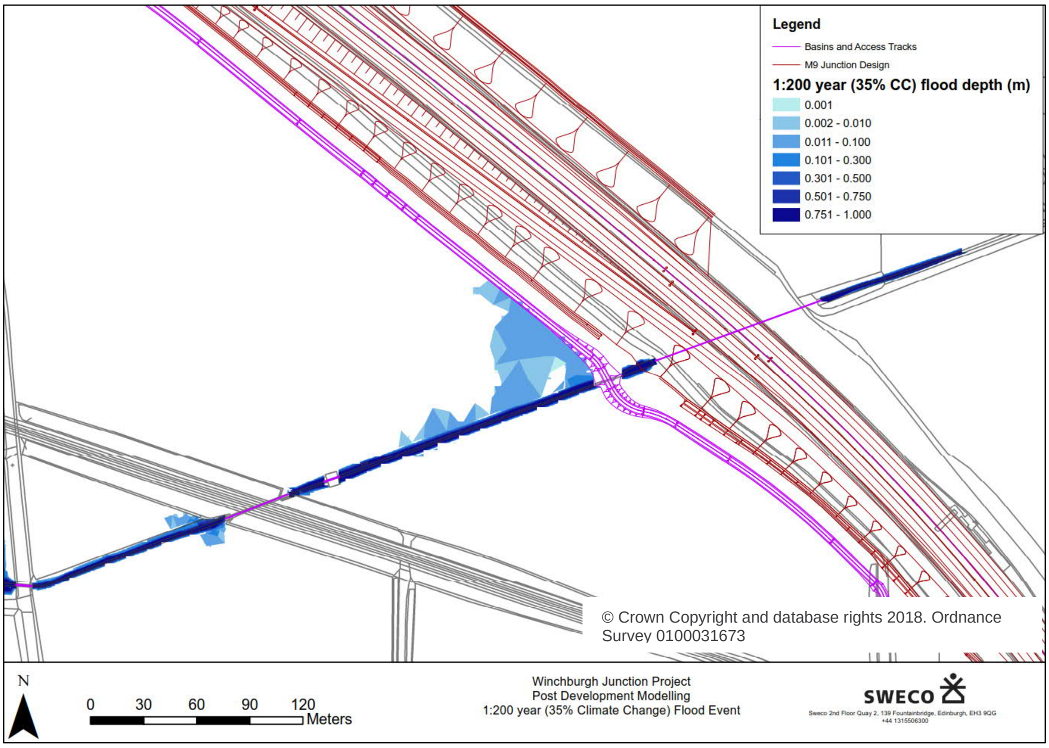


Figure 1-5 Post development flood patterns for the 1:200-year storm with a 35% climate change allowance.

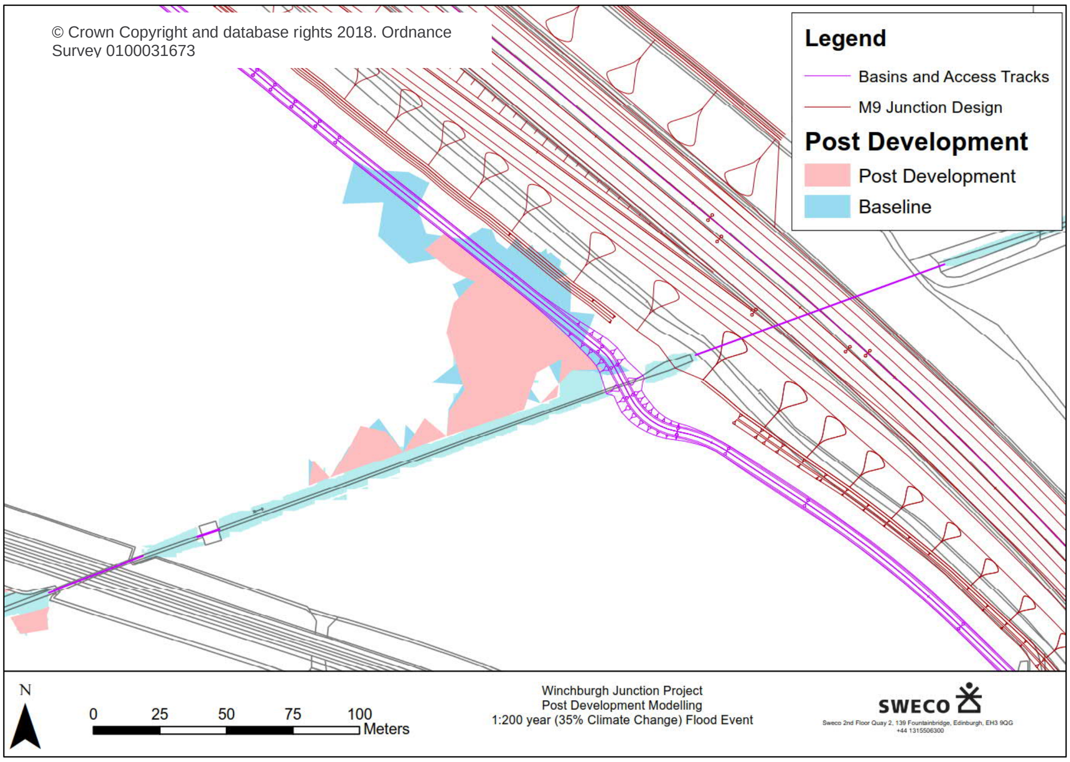


Figure 1-6 Comparison of baseline and post development flood extents for the 1:200-year storm with a 35% climate change allowance

Table 1-2 Comparison of flood volume between railway and M9

Baseline: Peak Volume (m^3)	Post Development: Peak Volume (m^3)
131	72

There was predicted to be a negligible change in water levels and velocities upstream and downstream of the proposals (see Appendix D1), with the differences well within model tolerance (<5% change). As a volume of ~160,000 m^3 is predicted over the duration of the baseline simulation the change in volume of 60 m^3 has no significant impact.

2 Summary

This briefing note has been prepared to provide a summary of the post development hydraulic modelling undertaken to support the development of a junction and access infrastructure along the M9 at Winchburgh. The model was adapted from the initial Winchburgh baseline model (see Appendix C of the FRA) and updated to incorporate the proposed new culvert along the Swine Burn.

The 1: 200-year flood extent (without an allowance for climate change) is predicted to remain within the channel along the section of the Swine Burn which the access road crosses. Similarly, the new culvert was predicted to have a negligible impact on water levels (<5 mm). The proposal will not impinge on the functional floodplain or peak water levels and compensatory storage will not be required.

For the 1: 200-year flood event with a 35% allowance for climate change, the new culvert was predicted to results in a reduction in the flood extent and volume within the area between the second railway and the M9. The impact in terms of flood levels and velocities downstream was however negligible and is well within model tolerance.

Appendix D1 - Comparison of water levels, depths and velocities for the baseline and post development scenarios (1: 100 year with 35% climate change allowance)

Object ID	Peak Water Level (m AOD)			Peak Water Depth (m AOD)			Peak Velocity (m/s)		
	Baseline	Post Development	Difference (m)	Baseline	Post Development	% Difference	Baseline	Post Development	Difference (m)
Craigton Burn									
Craigton CS 1	73.839	73.839	0.000	0.856	0.856	0.0%	0.711	0.711	0.000
Craigton CS 2	73.561	73.561	0.000	0.790	0.790	0.0%	0.936	0.936	0.000
Craigton CS 3	73.275	73.275	0.000	0.702	0.702	0.0%	1.079	1.079	0.000
Craigton CS 4	72.884	72.884	0.000	0.679	0.679	0.0%	1.121	1.121	0.000
Craigton CS 5	72.422	72.422	0.000	0.584	0.584	0.0%	1.521	1.521	0.000
Craigton CS 6	71.613	71.613	0.000	0.591	0.591	0.0%	1.423	1.423	0.000
Craigton CS 6.5	71.288	71.288	0.000	0.677	0.677	0.0%	0.763	0.763	0.000
Craigton CS 7	71.177	71.177	0.000	0.721	0.721	0.0%	0.820	0.820	0.000
Craigton CS 8	70.975	70.975	0.000	0.779	0.779	0.0%	0.762	0.762	0.000
Craigton CS 8-Craigton CS 9	70.825	70.825	0.000	0.650	0.650	0.0%	0.956	0.956	0.000
Craigton CS 9	70.690	70.690	0.000	0.715	0.715	0.0%	1.151	1.151	0.000
Craigton CS10	70.687	70.687	0.000	1.306	1.306	0.0%	0.459	0.459	0.000
Craigton CS11	70.684	70.684	0.000	1.316	1.316	0.0%	0.425	0.425	0.000
Beatlie Drain									
Beatlie Burn start	70.987	70.987	0.000	0.674	0.674	0.0%	0.705	0.705	0.000
Beatlie CS0.5	70.986	70.986	0.000	0.972	0.972	0.0%	0.664	0.664	0.000
Beatlie CS 1	70.911	70.911	0.000	0.650	0.650	0.0%	1.200	1.200	0.000
Beatlie CS 2	70.855	70.855	0.000	0.610	0.610	0.0%	0.842	0.842	0.000
Beatlie CS 3	70.697	70.697	0.000	0.525	0.525	0.0%	1.304	1.304	0.000
Beatlie CS 4	70.676	70.676	0.000	0.574	0.574	0.0%	0.506	0.506	0.000
Beatlie CS 5	70.624	70.623	0.000	0.516	0.516	0.0%	0.832	0.832	0.000
Beatlie CS 6	70.556	70.556	0.000	0.580	0.580	0.0%	0.713	0.713	0.001
Beatlie CS 7	70.482	70.482	0.000	0.610	0.610	0.0%	0.795	0.795	-0.001
Beatlie CS 8	70.423	70.423	0.000	0.553	0.552	0.0%	0.617	0.616	0.000
Beatlie CS 8	70.423	70.423	0.000	0.553	0.552	0.0%	0.617	0.616	0.000
Beatlie CS 9	70.370	70.370	0.000	0.575	0.575	0.0%	0.520	0.520	0.000
Beatlie CS 10	70.338	70.338	0.000	0.654	0.654	0.0%	0.601	0.601	0.000
Beatlie CS 11	70.314	70.314	0.000	0.639	0.639	0.0%	0.804	0.804	0.000
Beatlie CS 12	70.303	70.303	0.000	0.665	0.665	0.0%	1.085	1.085	0.000
Beatlie CS 13	70.305	70.305	0.000	0.790	0.790	0.0%	0.421	0.421	0.000
Beatlie CS 14	70.203	70.203	0.000	1.227	1.226	0.0%	0.329	0.329	0.000
Beatlie CS 15	70.197	70.197	0.000	1.104	1.104	0.0%	0.716	0.716	0.000
Beatlie CS 16	70.188	70.188	0.000	1.208	1.208	0.0%	0.921	0.921	0.000
Beatlie CS 17	70.181	70.181	0.000	1.446	1.446	0.0%	0.688	0.688	0.000
Beatlie CS 18	70.176	70.176	0.000	1.573	1.573	0.0%	0.581	0.581	0.000
Beatlie CS 19	70.171	70.171	0.000	1.531	1.531	0.0%	0.613	0.613	0.000
Beatlie CS 20	70.166	70.166	0.000	1.628	1.628	0.0%	0.535	0.535	0.000
Beatlie CS 21	70.164	70.164	0.000	1.813	1.813	0.0%	0.384	0.384	0.000
Beatlie CS 21.5	70.163	70.163	0.000	1.844	1.844	0.0%	0.388	0.388	0.000
Beatlie CS 22	70.162	70.162	0.000	1.802	1.802	0.0%	0.476	0.476	0.000
Beatlie CS 22.5	70.161	70.161	0.000	1.705	1.705	0.0%	0.580	0.580	0.000
Beatlie CS 23	68.998	68.998	0.000	0.785	0.785	0.0%	0.711	0.711	0.000
Beatlie CS 24	68.999	68.999	0.000	0.939	0.939	0.0%	0.603	0.603	0.000
Beatlie CS 25	68.981	68.981	0.000	0.864	0.864	0.0%	0.856	0.856	0.000
Swine Burn									
Swine CS 01	71.647	71.647	0.000	0.624	0.624	0.0%	0.806	0.806	0.000
Swine CS 02	71.600	71.600	0.000	0.591	0.591	0.0%	0.732	0.732	0.000
Swine CS 03	71.571	71.571	0.000	0.601	0.601	0.0%	0.588	0.588	0.000
Swine CS 04	71.505	71.505	0.000	0.605	0.605	0.0%	1.152	1.152	0.000
Swine CS 05	71.422	71.422	0.000	0.749	0.749	0.0%	1.279	1.279	0.000
Swine CS 06	71.425	71.425	0.000	0.866	0.866	0.0%	1.072	1.072	0.000
Swine CS 07	71.425	71.425	0.000	0.868	0.868	0.0%	0.828	0.828	0.000
Swine CS 08	71.425	71.425	0.000	0.924	0.924	0.0%	0.642	0.642	0.000
Swine CS 09	71.425	71.425	0.000	0.950	0.951	0.0%	0.632	0.632	0.000
Swine CS 10	71.425	71.425	0.000	0.996	0.997	0.0%	0.629	0.629	0.000
Swine CS 11	71.425	71.425	0.000	1.031	1.031	0.0%	0.512	0.512	0.000
Swine CS 12	71.425	71.426	0.000	1.065	1.065	0.0%	0.743	0.743	0.000
Swine CS 13	71.425	71.425	0.000	1.126	1.126	0.0%	0.726	0.726	0.000
Swine CS 14	71.425	71.425	0.000	1.191	1.191	0.0%	0.855	0.855	0.000
Swine CS 16	71.426	71.426	0.000	1.285	1.285	0.0%	0.777	0.777	0.000
Swine CS 17	71.426	71.426	0.000	1.365	1.365	0.0%	0.567	0.567	0.000
Swine CS 18	71.425	71.425	0.000	1.403	1.403	0.0%	0.305	0.305	0.000
Swine CS 19	71.425	71.425	0.000	1.401	1.401	0.0%	0.478	0.478	0.000
Swine CS 20	71.425	71.425	0.000	1.410	1.410	0.0%	0.575	0.575	0.000
Swine CS 21	71.425	71.425	0.000	1.445	1.445	0.0%	0.349	0.349	0.000
Swine CS 22	71.425	71.425	0.000	1.467	1.467	0.0%	0.383	0.383	0.000
Swine CS 23	71.425	71.425	0.000	1.495	1.495	0.0%	0.449	0.449	0.000
Swine CS 24	71.425	71.425	0.000	1.528	1.528	0.0%	0.482	0.482	0.000
Swine CS 25	71.425	71.425	0.000	1.564	1.564	0.0%	0.489	0.489	0.000
Swine CS 26	71.426	71.426	0.000	1.603	1.603	0.0%	0.422	0.422	0.000
Swine CS 27	71.427	71.427	0.000	1.656	1.656	0.0%	0.598	0.598	0.000
Swine CS 28	71.428	71.428	-0.001	1.882	1.881	0.0%	0.207	0.207	0.000
Swine CS 29	71.429	71.428	-0.001	1.983	1.982	0.0%	0.172	0.172	0.000
Swine CS 30	71.429	71.429	-0.001	1.929	1.929	0.0%	0.105	0.105	0.000
Union Canal Culvert									
Swine CS 31	70.684	70.684	0.000	1.449	1.449	0.0%	0.194	0.194	0.000
Swine CS 31.5	70.684	70.684	0.000	1.323	1.323	0.0%	0.158	0.158	0.000
Swine CS 32	70.684	70.684	0.000	1.198	1.198	0.0%	0.504	0.504	0.000
Swine CS 33	70.686	70.686	0.000	1.273	1.273	0.0%	0.354	0.354	0.000
Swine CS 34	70.683	70.683	0.000	1.311	1.311	0.0%	0.421	0.421	0.000
Swine CS 35	69.990	69.990	0.000	0.846	0.846	0.0%	0.903	0.903	0.000
Swine CS 36	69.933	69.933	0.000	0.640	0.640	0.0%	1.181	1.181	0.000
Swine CS 37	69.845	69.845	0.000	0.611	0.611	0.0%	1.167	1.167	0.000
Swine CS 38	69.695	69.695	0.000	0.670	0.670	0.0%	1.886	1.886	0.000
Swine CS 39	69.710	69.710	0.000	0.718	0.718	0.0%	0.465	0.465	0.000
Railway Syphon									
Swine CS 40	69.158	69.158	0.000	0.408	0.408	0.0%	1.306	1.306	0.000
Swine CS 41	69.087	69.087	0.000	0.543	0.543	0.0%	1.637	1.637	0.000
Swine CS 42	69.103	69.102	0.000	0.740	0.740	0.0%	0.665	0.665	0.000
Swine CS 43	69.001	69.001	0.000	0.674	0.674	0.0%	0.778	0.778	0.000
Swine CS 44	68.974	68.974	0.000	0.744	0.744	0.0%	0.935	0.935	0.000
Swine CS 45	68.969	68.969	0.000	0.748	0.748	0.0%	0.713	0.713	0.000
Swine CS 46	68.928	68.928	0.000	0.764	0.764	0.0%	0.779	0.779	0.000
Swine CS 47	68.834	68.834	0.000	0.540	0.540	0.0%	1.261	1.261	0.000
Swine CS 48	68.827	68.827	0.000	0.771	0.771	0.0%	0.716	0.716	0.000

Swine CS 49	68.824	68.823	0.000	1.029	1.028	0.0%	0.499	0.499	0.000
Swine CS 50	68.812	68.812	0.000	1.005	1.004	0.0%	0.550	0.550	0.000
Swine CS 50.5	68.807	68.807	0.000	1.100	1.100	0.0%	0.501	0.501	0.000
Swine CS 51	68.805	68.804	0.000	0.944	0.943	0.0%	0.466	0.466	0.000
Swine CS 52	68.763	68.763	0.000	0.961	0.961	0.0%	0.608	0.608	0.000
Swine CS 53	68.759	68.759	0.000	0.907	0.907	0.0%	0.665	0.666	0.000
Swine CS 54	68.734	68.733	0.000	1.111	1.110	0.0%	0.728	0.728	0.000
Swine CS 55	68.677	68.677	-0.001	0.818	0.818	-0.1%	0.943	0.943	0.000
Swine CS 56	68.637	68.637	-0.001	1.103	1.102	-0.1%	0.851	0.852	0.000
Swine CS 57	68.613	68.613	-0.001	1.301	1.300	-0.1%	0.711	0.712	0.000
Swine CS 58	68.601	68.601	-0.001	1.225	1.224	-0.1%	0.605	0.606	0.000
Swine CS 59	68.610	68.610	-0.001	1.450	1.449	0.0%	0.311	0.311	0.000
Beatlie Road Bridge Culvert									
Swine CS 60	68.522	68.521	-0.001	1.240	1.239	-0.1%	1.017	1.018	0.001
Swine CS 61	68.515	68.514	-0.001	1.290	1.289	-0.1%	0.938	0.939	0.001
Swine CS 62	68.492	68.491	-0.001	1.349	1.348	-0.1%	0.859	0.860	0.001
Swine CS 63	68.466	68.464	-0.001	1.371	1.369	-0.1%	0.954	0.955	0.001
Swine CS 64	68.457	68.455	-0.001	1.357	1.355	-0.1%	0.838	0.838	0.001
Swine CS 65	68.443	68.442	-0.001	1.263	1.262	-0.1%	0.868	0.869	0.001
Swine CS 66	68.433	68.433	-0.001	1.255	1.254	0.0%	0.798	0.799	0.001
Swine CS 67	68.401	68.401	-0.001	1.015	1.015	-0.1%	1.176	1.178	0.002
Second Railway Culvert									
Swine CS 68	68.388	68.387	-0.001	1.208	1.207	-0.1%	0.738	0.739	0.001
Swine CS 69	68.377	68.377	-0.001	0.964	0.963	-0.1%	0.881	0.883	0.001
Swine CS 70	68.379	68.378	-0.001	0.979	0.978	-0.1%	0.757	0.758	0.001
Swine CS 71	68.388	68.387	-0.001	1.442	1.442	-0.1%	0.497	0.497	0.001
Swine CS 72	68.320	68.319	-0.001	1.211	1.211	-0.1%	0.755	0.756	0.001
Swine CS 73	68.279	68.278	-0.001	0.939	0.938	-0.1%	0.993	0.994	0.001
Swine CS 74	68.234	68.233	-0.001	0.897	0.896	-0.1%	1.028	1.030	0.002
Swine CS 75	68.196	68.193	-0.002	0.921	0.919	-0.2%	1.064	1.067	0.003
Swine CS 76	68.148	68.146	-0.003	0.995	0.992	-0.3%	1.069	1.073	0.004
Swine CS 77	68.138	68.135	-0.003	1.330	1.327	-0.2%	0.849	0.851	0.001
Swine CS 78	68.124	68.121	-0.003	1.420	1.417	-0.2%	0.821	0.822	0.001
Swine CS 78.5	68.117	68.114	-0.003	1.258	1.255	-0.2%	0.844	0.848	0.004
Swine CS 79	68.115	-	-	1.714	-	-	0.714	-	-
Proposed Culvert Access Culvert US	-	68.105	-	-	1.242	-	-	0.833	-
Proposed Culvert Access Culvert DS	-	68.103	-	-	1.278	-	-	0.820	-
Swine CS 80	68.093	68.094	0.001	1.23075	1.232	0.1%	0.881	0.881	0.000
Swine CS 81	68.094	68.095	0.001	1.19041	1.192	0.1%	0.742	0.743	0.000
Swine CS 82	68.056	68.057	0.001	1.23921	1.240	0.1%	1.130	1.131	0.002
M9 Culvert									
Swine CS 83	67.768	67.769	0.000	1.246	1.247	0.0%	1.176	1.176	0.000
Swine CS 84	67.616	67.617	0.000	1.155	1.155	0.0%	1.862	1.863	0.000
Swine CS 84.5	67.503	67.503	0.000	1.013	1.013	0.0%	1.628	1.628	0.000
Swine CS 85	67.342	67.343	0.000	0.914	0.915	0.0%	2.465	2.466	0.000