Aberdeen City Council

Maidencraig Flood Alleviation Scheme

Hydrology and Hydraulics - Method Statement

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Table of Contents

List of Figures

List of Tables

Background

Aberdeen City Council have undertaken hydrological and hydraulic modelling work to inform the design and demonstrate the effectiveness of a Flood Alleviation Scheme at Maidencraig, Aberdeen (approximate NGR 389100 869500). This scheme is intended to alleviate flooding downstream of the Den of Maidencraig, and in particular to reduce flood volumes arriving at the existing Flood Alleviation Scheme at Stronsay Park, and subsequently the Merchants Quarter.

A secondary requirement of the scheme is to utilise the planned Safe Route to School Bund as part of the Maidencraig FAS, and to compliment the wetland that currently exists at the site.

A third requirement of the work was to model the diversion of a small watercourse, which previously ran closer to a new development neighbouring the Den of Maidencraig, and which suffered from severe erosion problems. The channel diversion was intended to move the channel away from this development, and to reduce flow velocities within the watercourse such that the problems with erosion are not simply moved elsewhere.

The fourth requirement was to ensure that withheld flood waters do not exceed 10,000 m^3 in volume, which mean that the scheme was treated as a Reservoir under the Reservoirs (Scotland) Act 2011, and would be subject to the normal regulations and inspection regimes as other reservoirs in Scotland.

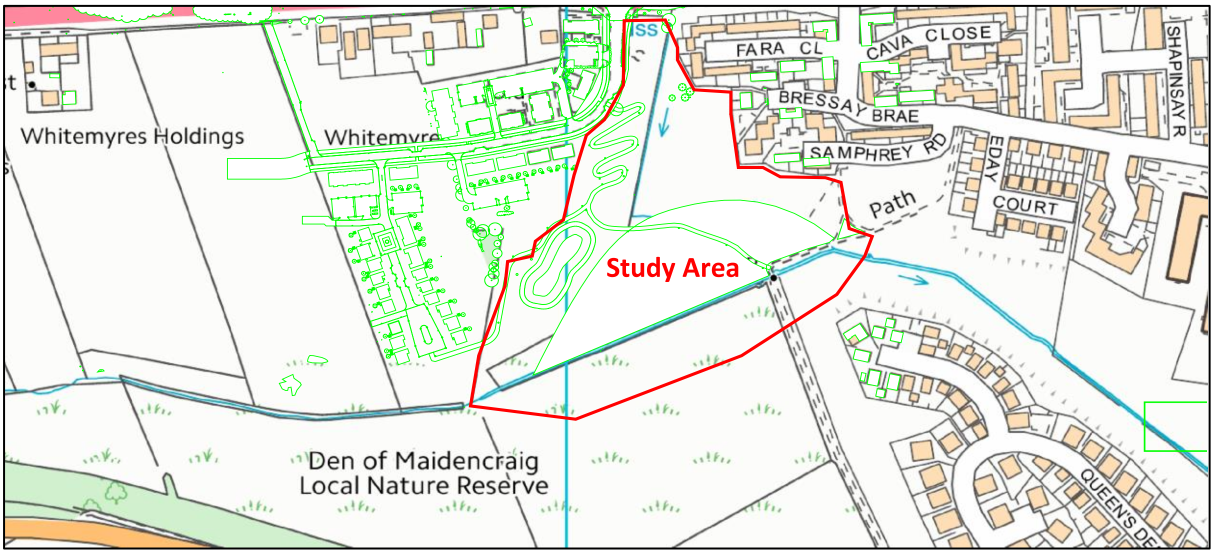


Figure 1: *Den of Maidencraig*

Previous Work

Ramsay and Chalmers have previously undertaken a Drainage Impact Assessment for the site immediately to the west of the Den of Maidencraig (Drainage Impact Assessment, Revision 'B', 16/09/2013).

ACC have also undertaken work in 2016 which related to this development and subsequent development phasings.

Method

This report describes work that was undertaken in four main areas, as follows:

- Hydrology – Den Burn, unnamed watercourse and SUDS/drainage inputs.
- Ground Modelling
- Hydraulic Modelling
- Results analysis

These are now described in turn.

Hydrology

There are four inflows to the site, these being the Den Burn, the unnamed watercourse, SuDS ponds, and highway drainage from the Lang Stracht, which runs from east to west at the northern boundary of the site. Return periods used in the analysis were as follows:

- 1: 200 years
- 1:100 years
- 1:30 years
- 1:10 years
- 1:5 years
- 1:2 years

A wide range of flows were modelled in order to assess the performance of the scheme at extreme events, to quantify the effect of the FAS in terms of return periods, and to assess the effect of the FAS at lower (more frequent) return periods to inform of likely flood extents that might influence the wetland.

Den Burn

The Den Burn forms the main component of flow to the site. The FEH Rainfall/Runoff (RR) method was chosen to estimate flows principally because it was considered to offer a conservative approach to flood estimation at the site, and other methods of flow estimation were thought of as unsuitable.

FEH 13 parameters used within this model were taken from the FEH online service (https://fehweb.ceh.ac.uk/) provided by CEH, and are shown in Table 1 below:

Catchment Descriptor	Value
AREA (km^2)	4.575
ALTBAR	147
ASPBAR	90
ASPVAR	0.34
BFIHOST	0.601
DPLBAR	2.16
DPSBAR	61.4
FARL	1
FPEXT	0.0224
FPDBAR	0.121
FPLOC	1.023
LDP	4.2
PROPWET	0.42
RMED-1H	8.3
RMED-1D	34.4
RMED-2D	47.8
SAAR (m)	839
SAAR4170	921
SPRHOST	29.06
URBCONC1990	0.444
URBEXT1990	0.0117
URBLOC1990	0.972
URBCONC2000	0.712
URBEXT2000	0.0344
URBLOC2000	1.177
C	-0.0106
D1	0.46507
D2	0.43218
D3	0.25472
E	0.2277
F	2.24151
C(1 km)	-0.01
D1(1 km)	0.465
D2(1 km)	0.428
D3(1 km)	0.25
E(1 km)	0.227
F(1 km)	2.234

Table 1: *Maidencraig FEH 13 Catchment Descriptors*

Previous work had used FEH 1999 parameters and investigated the use of ReFH2 as the modelling approach, which although previously accepted by SEPA for use in Scotland following a moratorium period, has been called into question for the calculation of flows in the North-East of Scotland as there is a belief that it may be under-estimating flows. The Statistical Method was not used as the catchments were ungauged and the unnamed watercourse catchment was considered too small to reliably use the pooling group approach as part of the statistical method. The Rainfall Runoff method was therefore the method of choice for both the Den Burn and the diversion channel.

As is normal with flow calculations using the rainfall-runoff approach, there was a requirement to calculate the times to peak and storm durations. The time to peak was estimated as **2.52 hrs** using the equation:

$$Tp\ (0) = 4.270 * DPSBAR^{-0.35}\ PROPWET^{-0.80}\ DPLBAR^{0.54}\ (1+URBEXT)^{-5.77}$$

From this, the duration was calculated as **5.25 hrs** using the equation:

$$D = \left(1 + \frac{SAAR}{1000}\right) T_p$$

These were entered into Infoworks RS software in order to generate hydrographs for the various return periods, using the unit hydrograph approach. The derived hydrographs are shown below, along with a table showing the peak flow for each return period.

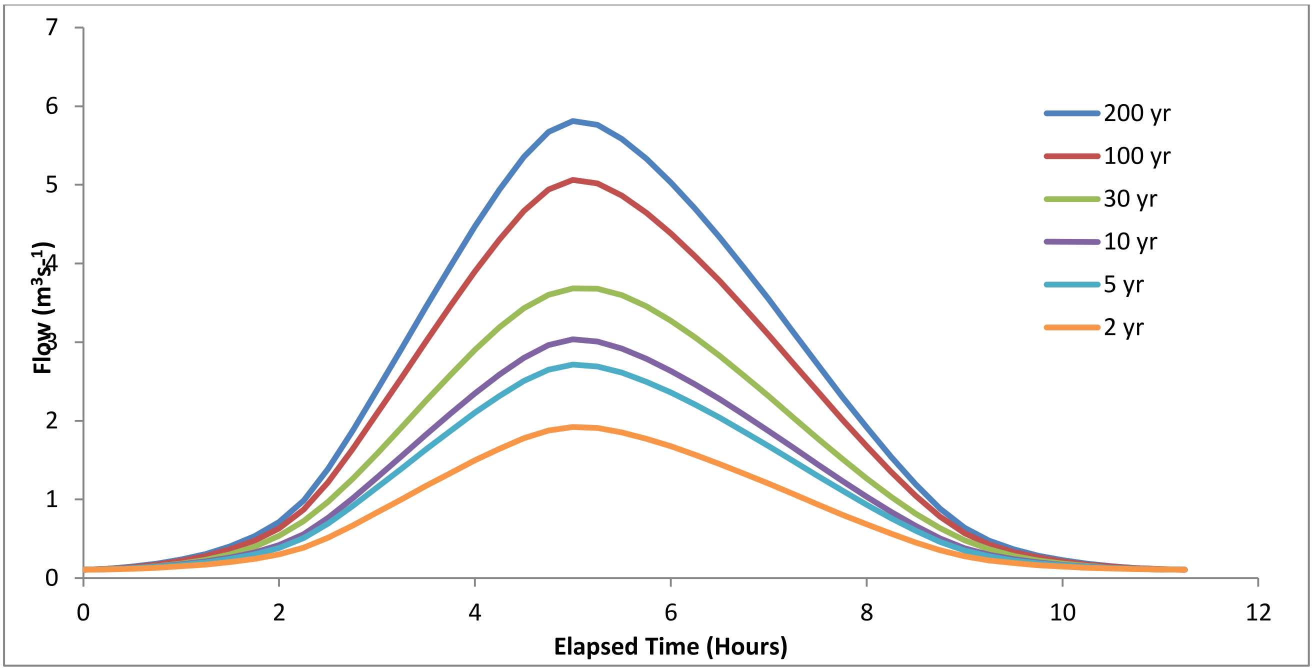


Figure 2: *Flow hydrographs for the Den Burn using the FEH-RR method*

Return Period	Flow (m^3s^{-1})
200 yr	5.812
100 yr	5.061
30 yr	3.685
10 yr	3.035
5 yr	2.715
2 yr	1.923

Table 2: *Peak flows in the Den Burn using the FEH RR method*

Diversion Channel

The catchment of the unnamed watercourse was estimated using tools within ARC GIS, and was found to have an area of 26.5 Ha, or 0.265 km^2. This is too small to feature on the FEH online services.

The FEH RR approach was also adopted for estimation of design flows from this watercourse. The time to peak was calculated as 1.91 hrs, from which the duration was determined as 3.62 hrs. As expected, the durations and times to peak of this catchment are considerably less than those for the Den Burn, and this is reflected in the modelling.

This information was used along with FEH catchment characteristics taken from the FEH online service for the Den Burn so that more general attributes such as SAAR can be estimated, but other site-specific factors such as DPLBAR and catchment size were modified so that they remained true to the diversion channel catchment. DPLBAR was adjusted from 2.2 to 1.0 km, and the catchment area was adjusted from 4.6 km^2 to 0.266 km^2. Figure 3 below shows the calculated hydrographs from the diversion channel using this methodology.

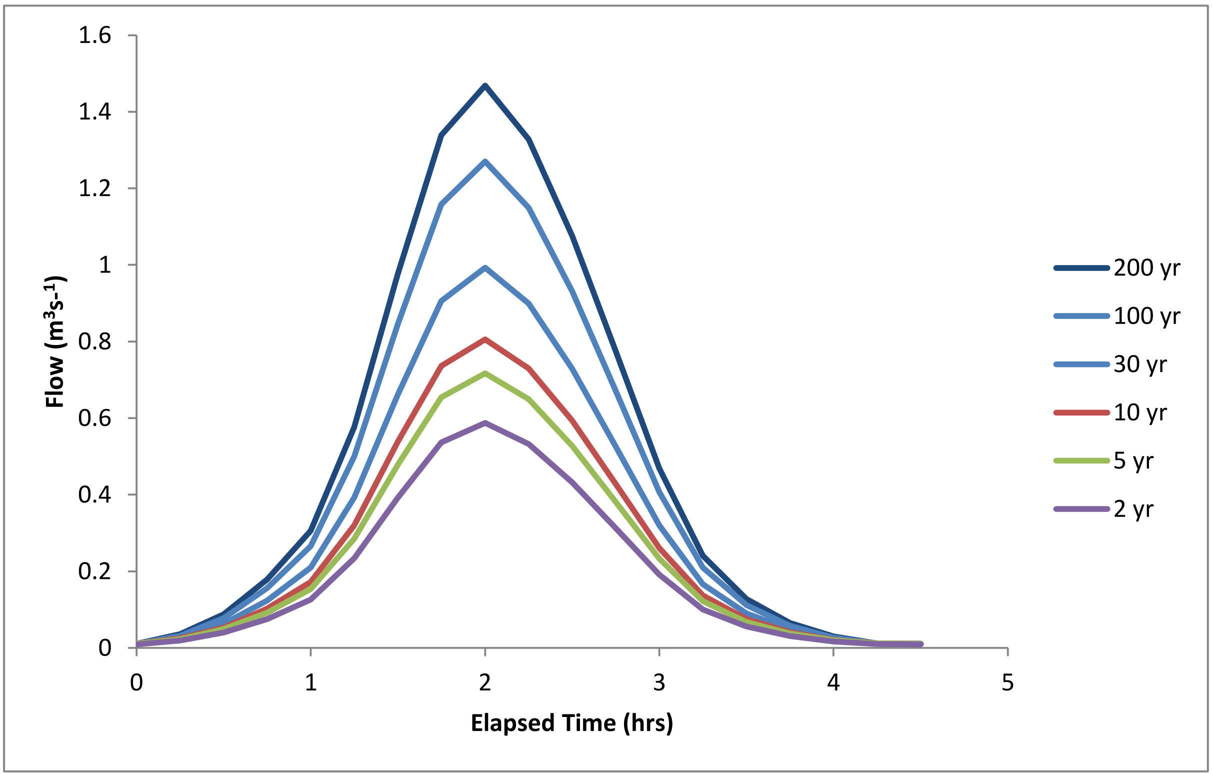


Figure 3: *Flow hydrographs for the diversion channel using the FEH RR method*

Return Period	Flow (m^3s^{-1})
200 yr	1.468
100 yr	1.27
30 yr	0.993
10 yr	0.806
5 yr	0.717
2 yr	0.588

Table 3: *Peak flows in the diversion channel using the FEH RR method*

Figure 4 shows hydrographs for the same range of return periods for the Den Burn and diversion channel combined. The shorter time to peak and hence duration of the diversion channel hydrographs result in the kink that is evident in the rising limb of the combined hydrographs.

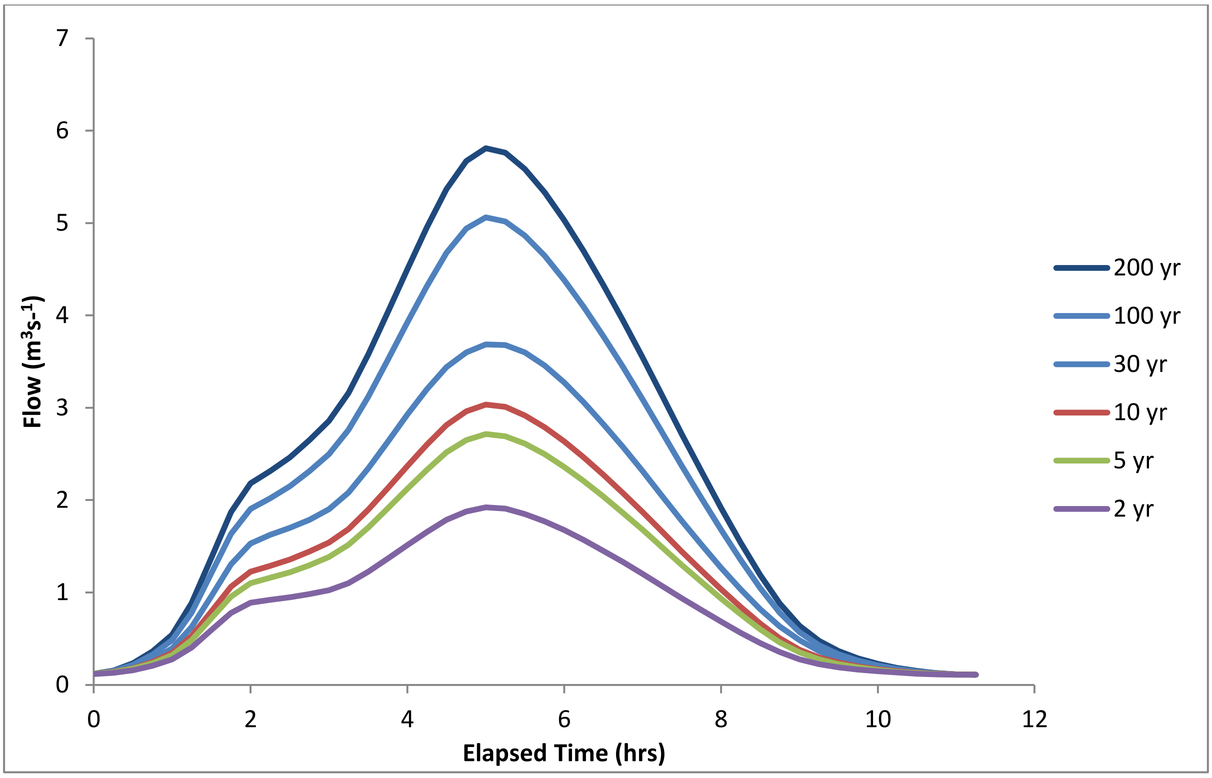


Figure 4: *Combined hydrographs for the Den Burn and diversion channel*

Lang Stracht

The Lang Stracht is a main route through Aberdeen, and a significant section of it drains into the diversion channel, which feeds into the Den Burn. As is normal for highway drainage, the Wallingford Procedure was used to calculate design flows from the Lang Stracht, at the same return periods as used for the other hydrological inputs.

The catchment contributing flow to the subject site was estimated as 2.269 km^2 from the 2014 LiDAR. Figure 5 shows the highway drainage catchment contributing to the subject site, Figure 6 shows the design hydrographs, and Table 4 summarises the peak flows from this source.

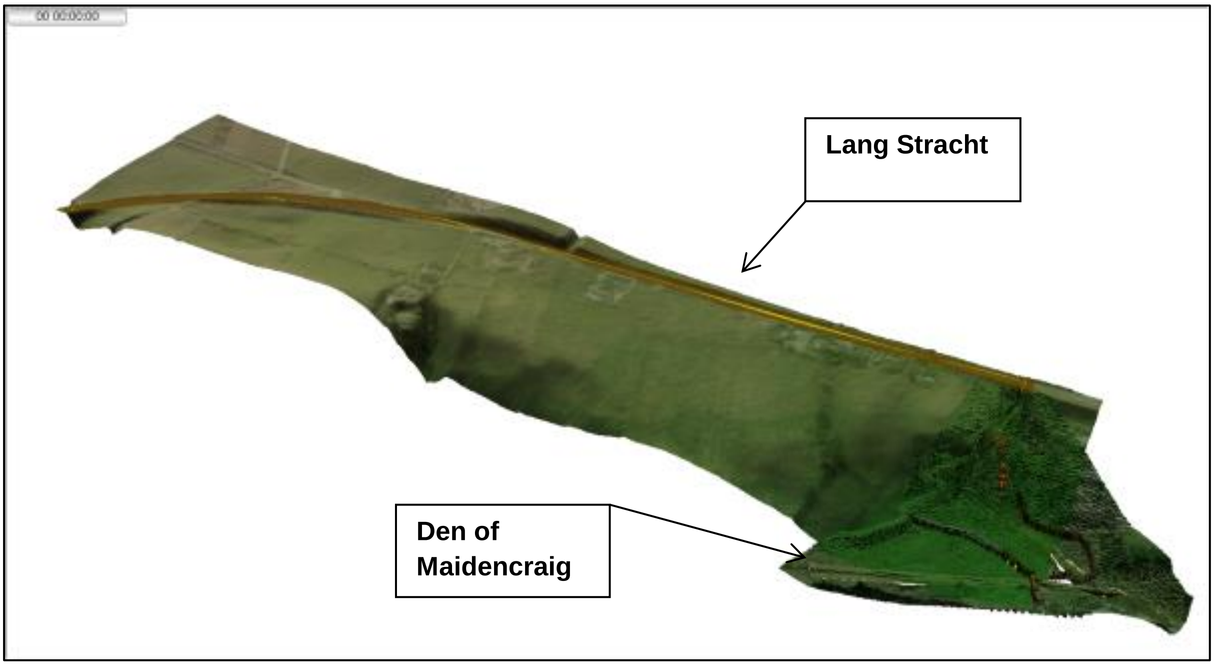
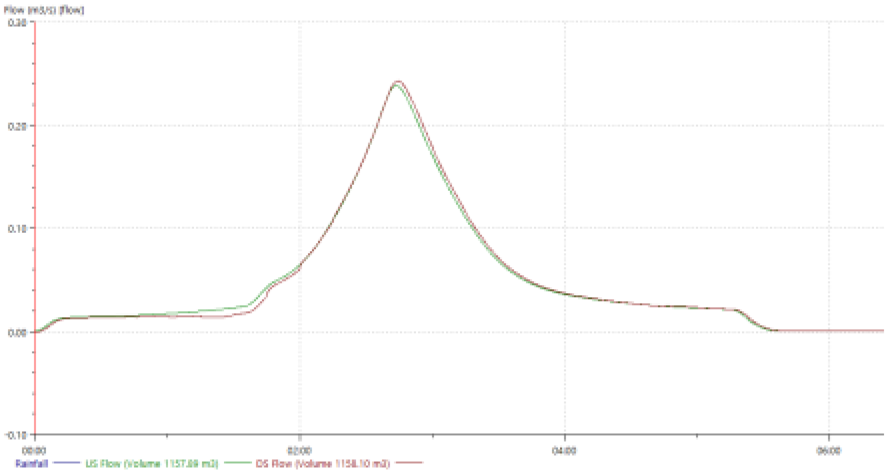
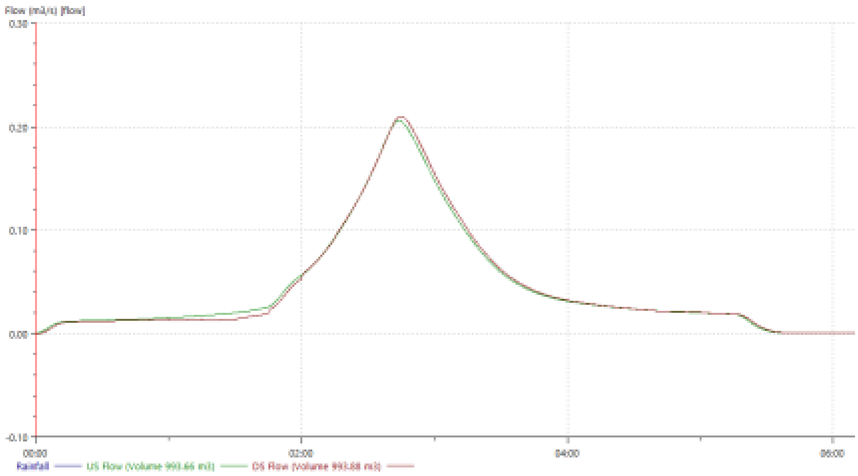


Figure 5: *Derivation of surface water contribution from Lang Stracht*

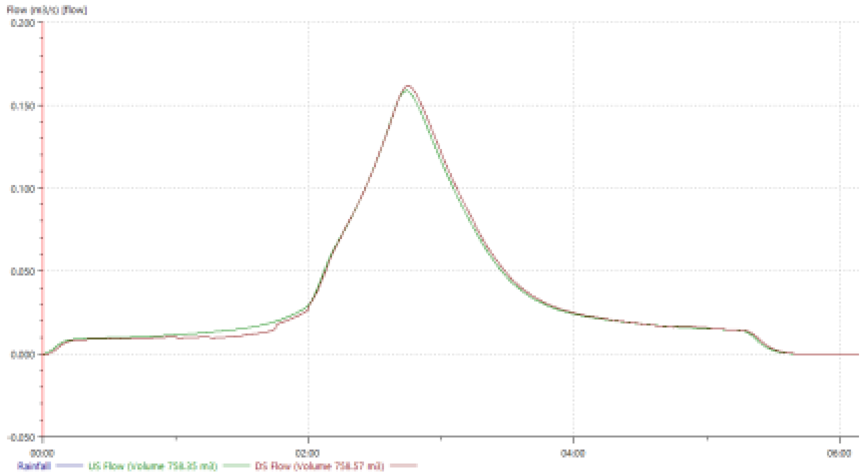
200 year



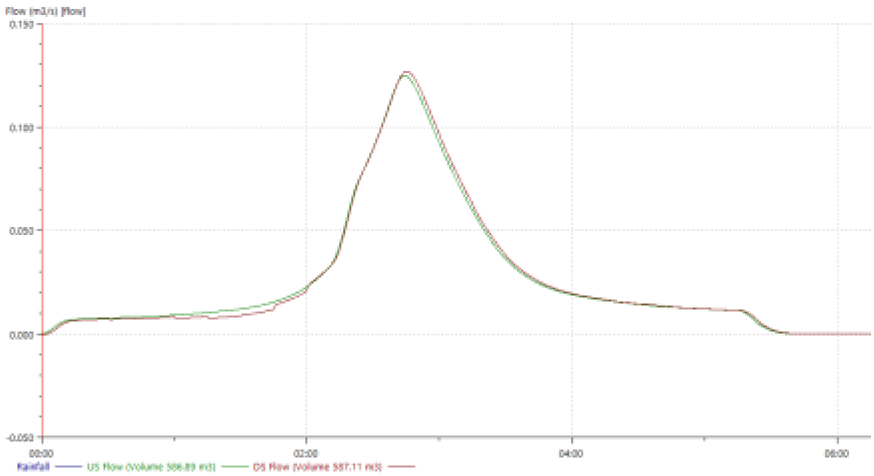
100 Year



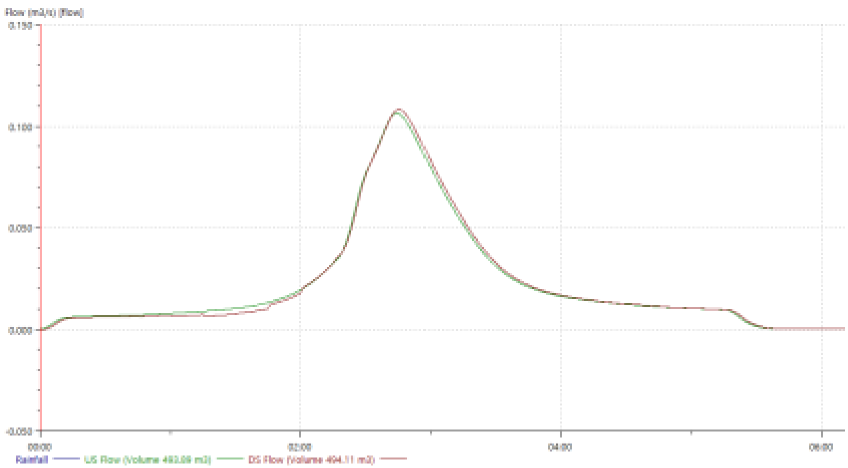
30 Year



10 Year



5 Year



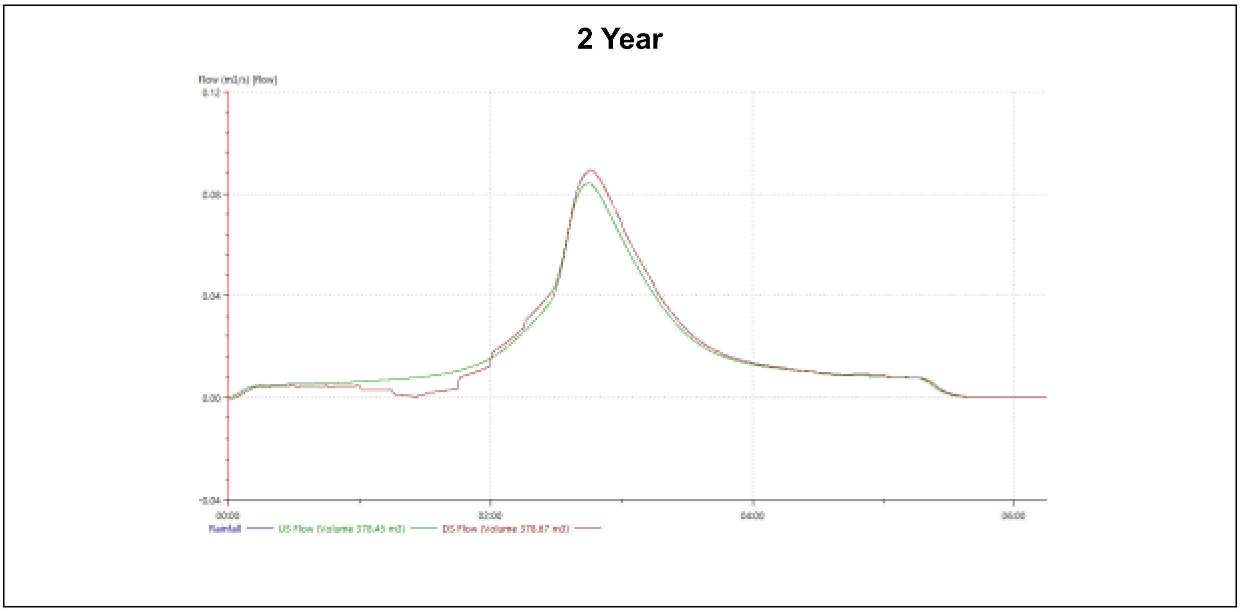


Figure 6: Design hydrographs for the Lang Stracht

Return Period	Flows (m^3s^{-1})
200 year	0.24
100 year	0.21
30 year	0.16
10 year	0.24
5 year	0.11
2 year	0.09

Table 4: Lang Stracht return period flows

SUDS pond

Flows from the SUDS pond at the north of the study area were restricted to 0.036 m^3/s^{-1}. This was included as a constant flow within the model, thereby adopting a conservative approach.

Ground Modelling

The initial investigation used LiDAR supplied by SEPA under the Flood Risk Management (Scotland) Act 2009. This was suitable for the investigative work that was carried out at the time, but more detailed LiDAR was required for the detailed design.

JBA Consulting were commissioned in 2017 to undertake a ground-based laser scan survey, which provided LiDAR to a greater accuracy and resolution for the detailed aspect of the work. Figure 7 below shows the LiDAR provided by JBA. This was provided in a TIN format and was subsequently converted to grid format using tools within Arc GIS.

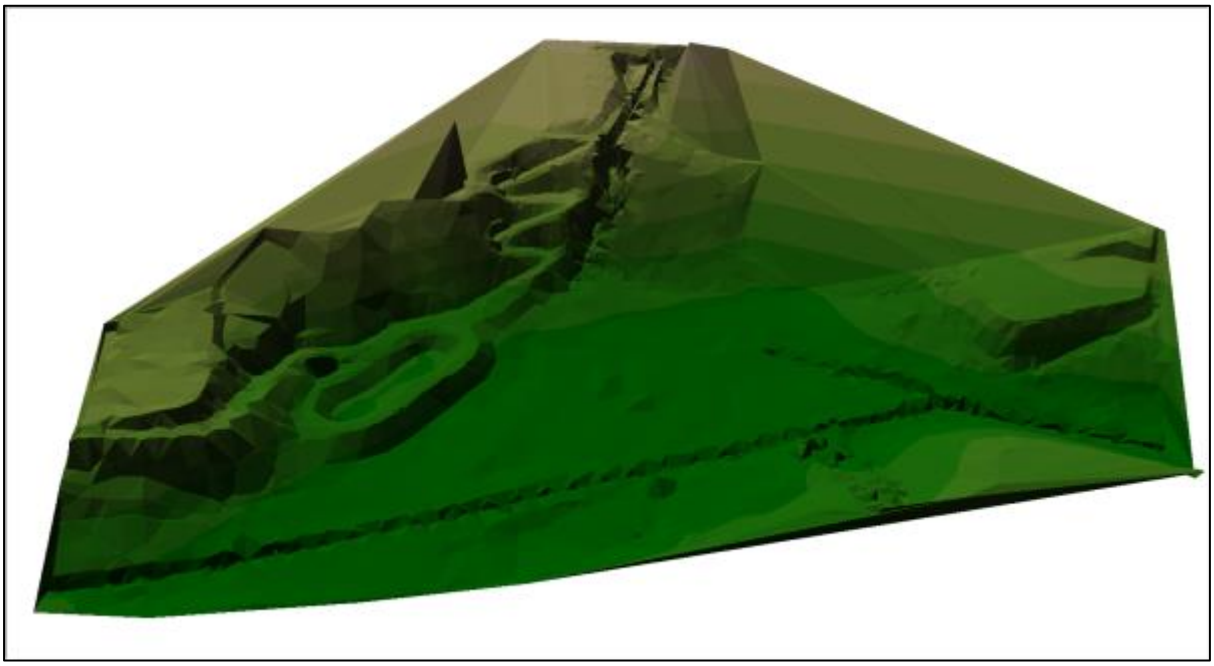


Figure 7: *Ground Laser Scan LiDAR*

Initial modelling results showed that the 2D zone required to be extended so that no flow was lost from its boundaries, which would have a deleterious effect on the model in that downstream flows would be significantly underestimated. This was achieved using tools within Arc. The format was changed from TIN to grid during this process also. Figure 8 below shows the extended LiDAR, with aerial photography from 2014 also draped over the DTM.

Figure 8: *Extended LiDAR with aerial photograph*

Hydraulic Model

The hydraulic model used in this work was created in InfoWorks ICM. This is an industry standard software, which allows for the interaction of above and below ground wet infrastructure, and has powerful GIS interface capabilities.

The base model was constructed first, with additional scenarios being modelled for different flood alleviation options.

Surveyed cross sections were obtained from JBA Consulting, which were used to build the river reaches within the Den Burn. LiDAR from the ground-based laser scan also provided by JBA were used to create cross sections for the diversion channel. This is further elaborated upon in the Flood Alleviation Scheme section.

The hydraulic model was built as an interaction of 1D (river channel) and 2D (floodplain) zones.

The Den of Maidencraig is heavily vegetated, with a dense shrub and hedgerow covering, as well as long grass, and trees at certain locations around the perimeter. Manning's "n" values of 0.05 were applied to the 2D zone, and values of 0.03 and 0.05 were used for the river bed and banks respectively.

Given the steep nature of the catchment, the timestep used in the modelling was set as 1 s. This was in order to reduce instabilities caused by the occurrence of supercritical flow at the diversion channel, and flow reversals caused by the effects of the bunds that were introduced as part of the flood alleviation scheme.

A discharge coefficient of 1 was selected for the interaction of the banks with the 2D zone, and the modular limit was set at a relatively low 0.7 to account for the expected dynamic interaction between the 1D and 2D zones at the river bank boundary.

Diversion Channel

There was a requirement to divert the original channel away from the housing development to the east of the site, because of severe erosion problems due to high flow velocities being generated as a result of the steepness of the reach. As part of the design of the diversion channel, it was considered important to protect against such erosion occurring in the future, therefore the channel was diverted to the east where it could follow a more shallow gradient, and a weir cascade was suggested to reduce flow velocities and hence the erosivity of the watercourse.

Modelling of the diversion channel presented its own particular challenges, essentially because the reach was so steep, with a gradient of approximately 0.3. With such a steep gradient, the flow can be described as supercritical, as gravitational forces dominate over inertial forces. Modelling such a reach can result in significant instabilities, therefore interpolated cross sections were placed at a short intervals (~1m) throughout the steep part of the reach. The locations of the weirs is shown in Figure 9 below.

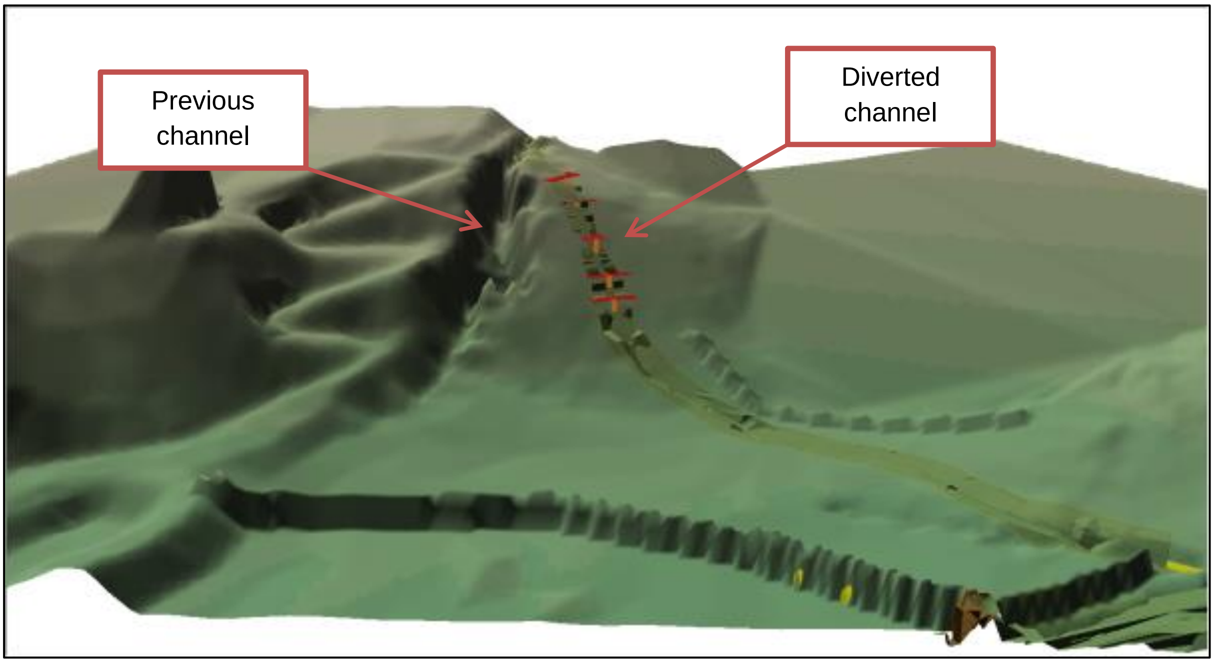


Figure 9: *Diversion channel showing weir cascade*

The channel was also designed such that the right bank (looking downstream) was lower than the left bank, which would encourage flood water to flow towards the storage area.

Weir Cascade

A cascade comprising five weirs was introduced to the diversion channel in order to remove energy from the flow, thereby decreasing velocities and hence the erosivity of the channel. The weirs are expected to be broad crested and made of concrete.

Bunds

The Safe Route to School (SRTS) bund will also be used to contain flood waters, and split the flood storage area into two main areas. These will be connected by two culverts, so that interflow will occur between both areas. The north area is expected to fill quicker than the south area, as the north catchment area is smaller and is more urbanised. The SRTS bund will also be extended to the east in order to control the flows reaching the Den Burn, and a smaller bund will protect the properties at Samphrey Road from any flooding from the diverted channel.

Overpass

The temporary bridge that currently traverses the channel will be removed, and replaced with an overpass with a 0.9m culvert to allow flow from the Den Burn. This will have the additional effect of controlling the flow, and allowing flood water to attenuate within the storage area.

Analysis of Results

Flood Extents

Figure 10 below shows the flood extents at the 200 year event with the FAS in place. A further requirement of the scheme was that the flood extents do not significantly change from the existing situation. Appendix B shows the extent of flooding in comparison with SEPA's indicative flood map at the 200 year event, and Appendix A shows the extents of flooding at the range of return periods studied.

It is considered that the flood extents do not significantly differ from those predicted by SEPA at the 200 year event.

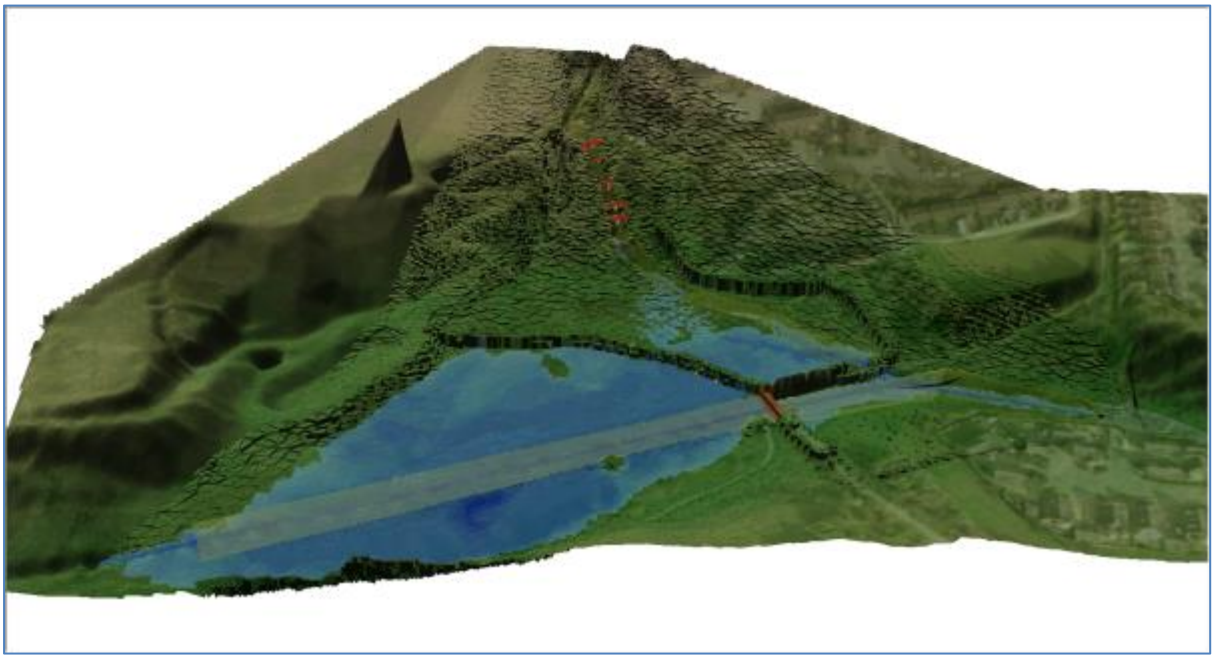


Figure 10: Flood extents at the 200 year event

Flows

As anticipated, flows downstream of the underpass are considerably reduced as a result of the FAS. Figure 11-13 below show the hydrographs for the reach upstream of the overpass, downstream of the overpass, and after the confluence with the diversion channel.

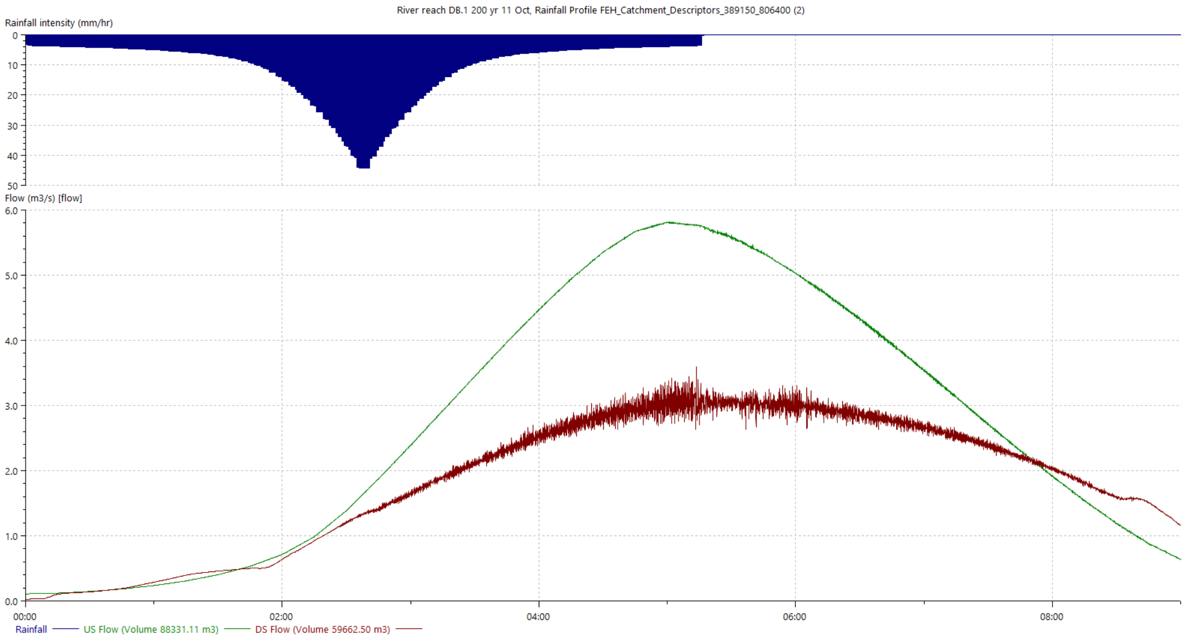


Figure 11: Flows upstream of the overpass

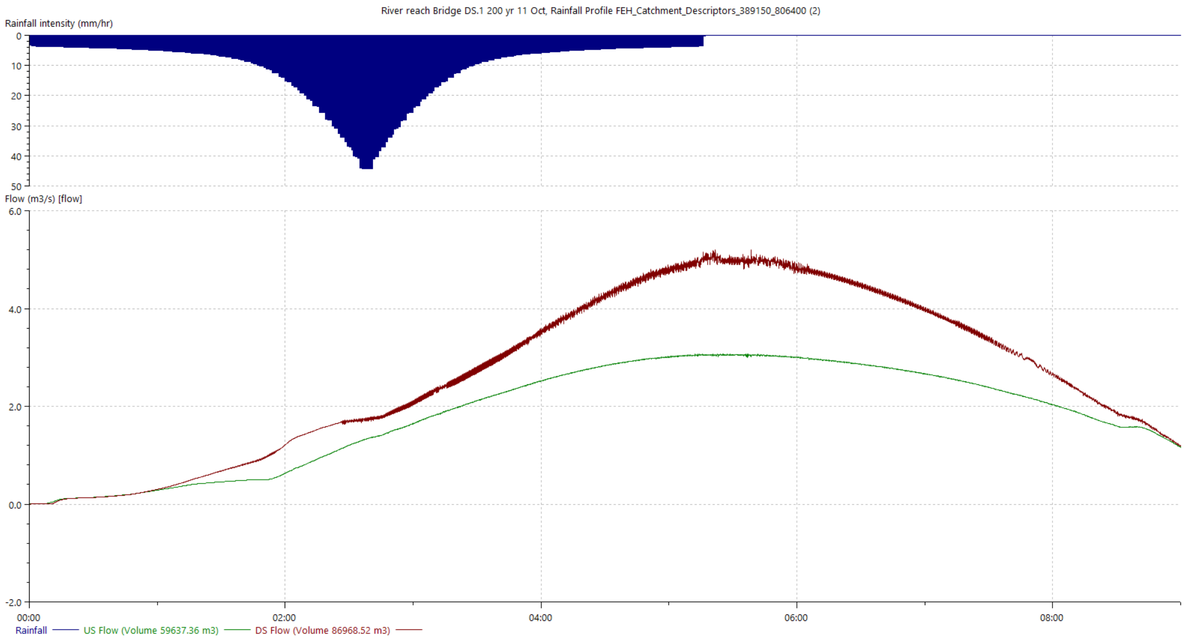


Figure 12: Flows downstream of the overpass

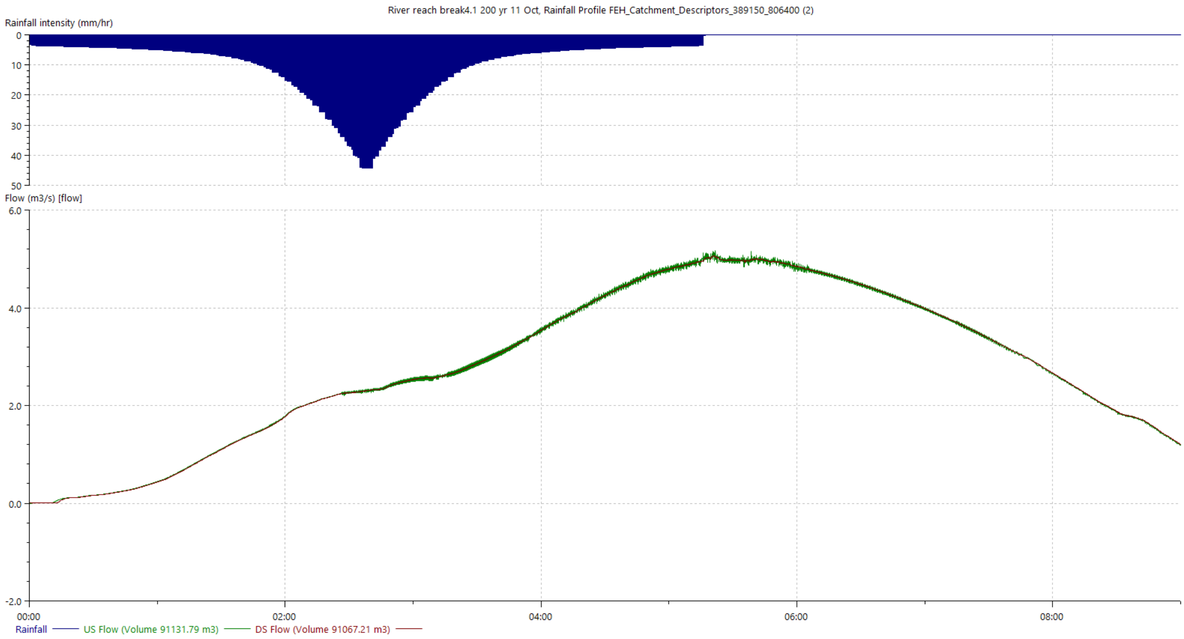


Figure 13: Flows downstream of the confluence with the diversion channel

The above charts show that the FAS has the effect of attenuating peak flow at the 200 year event of 7.5 m^3s^{-1} to around 5.9 m^3s^{-1} downstream of the overpass, which corresponds with the 50 year return period event when including all inflows, i.e. the Den Burn, the diversion channel, the SuDS pond, and the Lang Stracht. The return period to which the flows were attenuated was estimated by interpolation, using a regression analysis of the estimated flows with return periods, as is shown in Figure 13 below. It was considered that the R^2 value of 0.984 was acceptable.

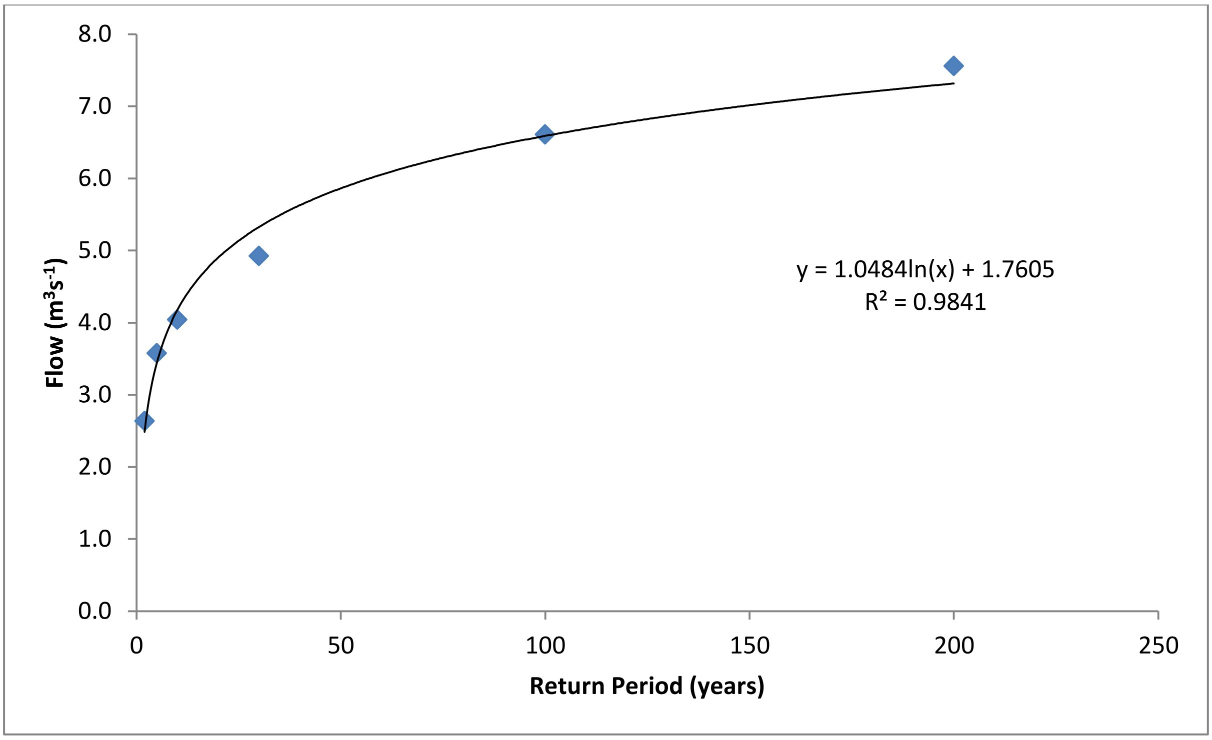


Figure 14: Estimated flows against return period

Volumes

Figure 14 below shows volume hydrographs for each storage area at the 200 year event. The south area has a peak volume of 6,000 m^3 and the north area peaks at 690 m^3, giving a combined storage area of 6,690 m^3, which is considerably below the benchmark of 10,000 m^3 at which point it would be subject to the requirements of the Reservoirs (Scotland) Act 2011.

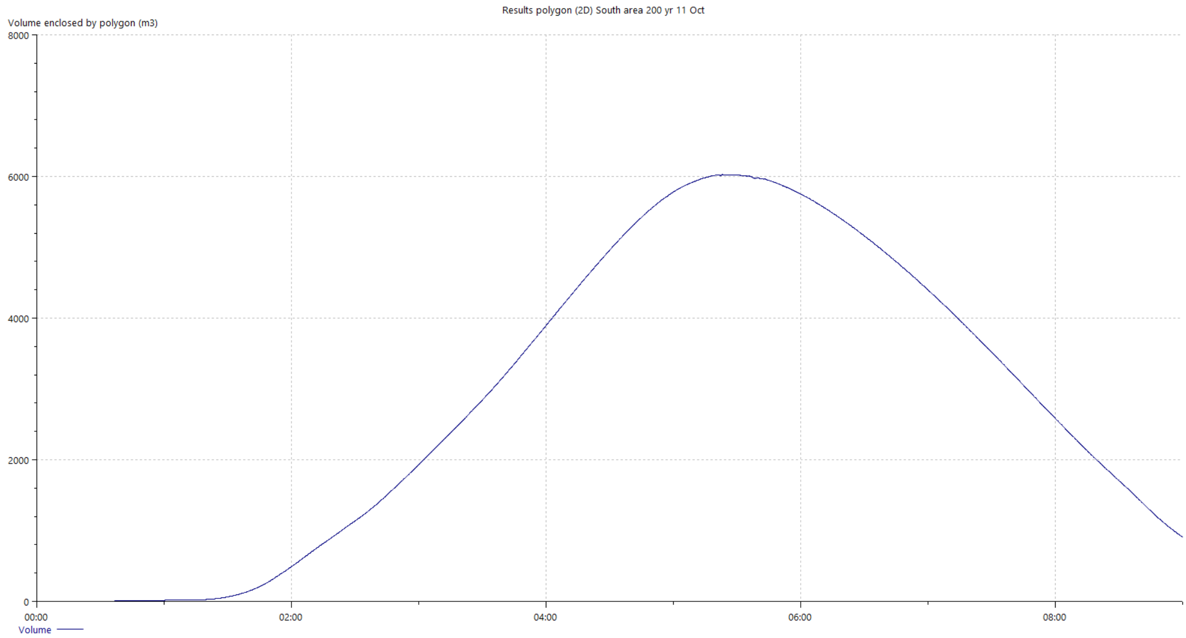


Figure 15: North area storage

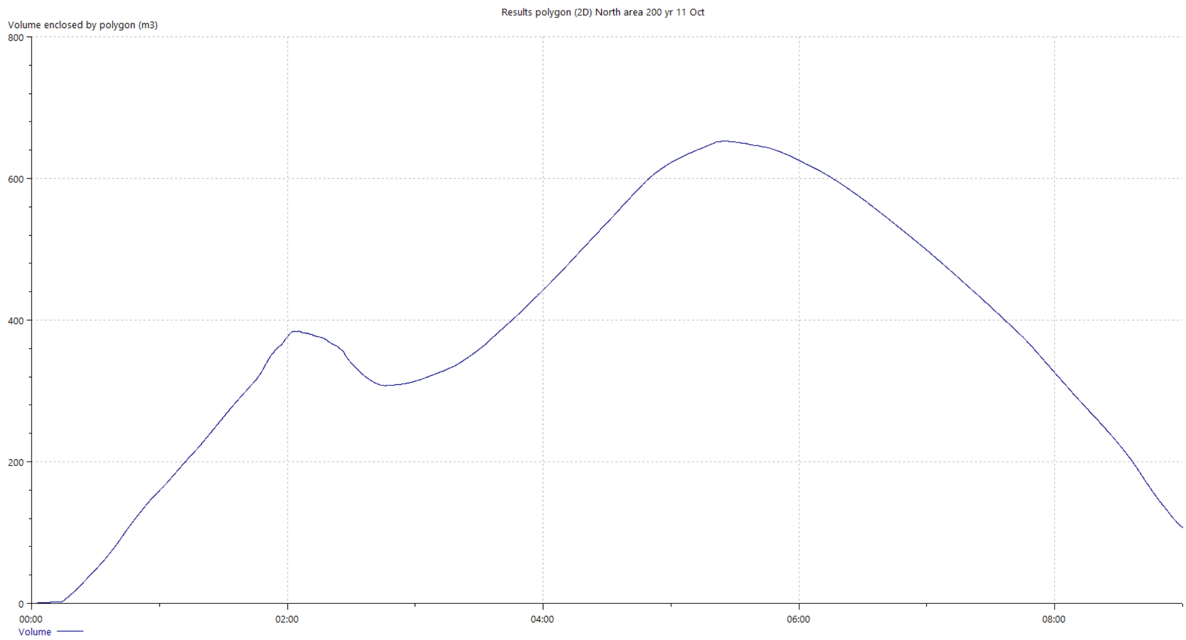


Figure 16: South area storage

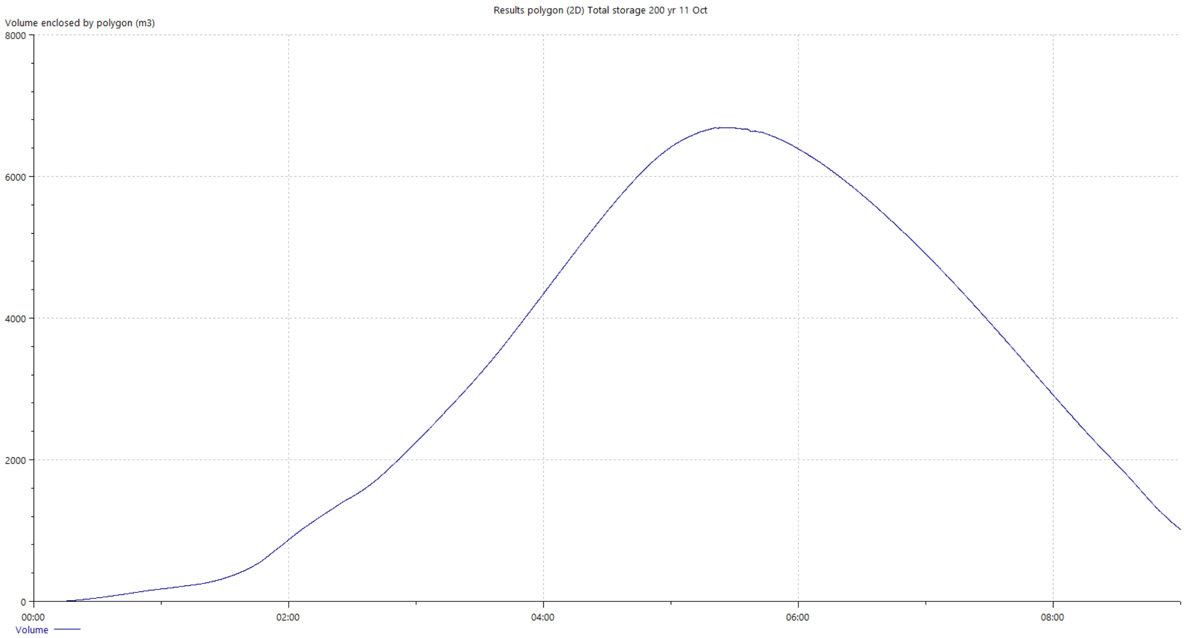


Figure 17: Total storage

Conclusions

Modelling work has shown that the design of the Flood Alleviation Scheme for the Den of Maidencraig will be effective in attenuating flows from the 200 year to approximately the 50 year return period. This document has detailed all hydrological and hydraulic methodologies involved, and given reasons as to why they were chosen.

The total volume stored at the site at the 200 year event is 6,690 m^3, which is considerably less than the 10,000 m^3 benchmark set for the Reservoirs Act (Scotland) 2011.

The diversion channel will not cause flooding to nearby properties, however it is recommended that a low bund is placed between the diversion channel and the properties at Samphrey Road.

The culvert through the overpass has an opening of 0.9m^3. This controls the flow in such a way that downstream flood peaks are reduced, but the amount of storage upstream of this point does not reach 10,000 m^3.

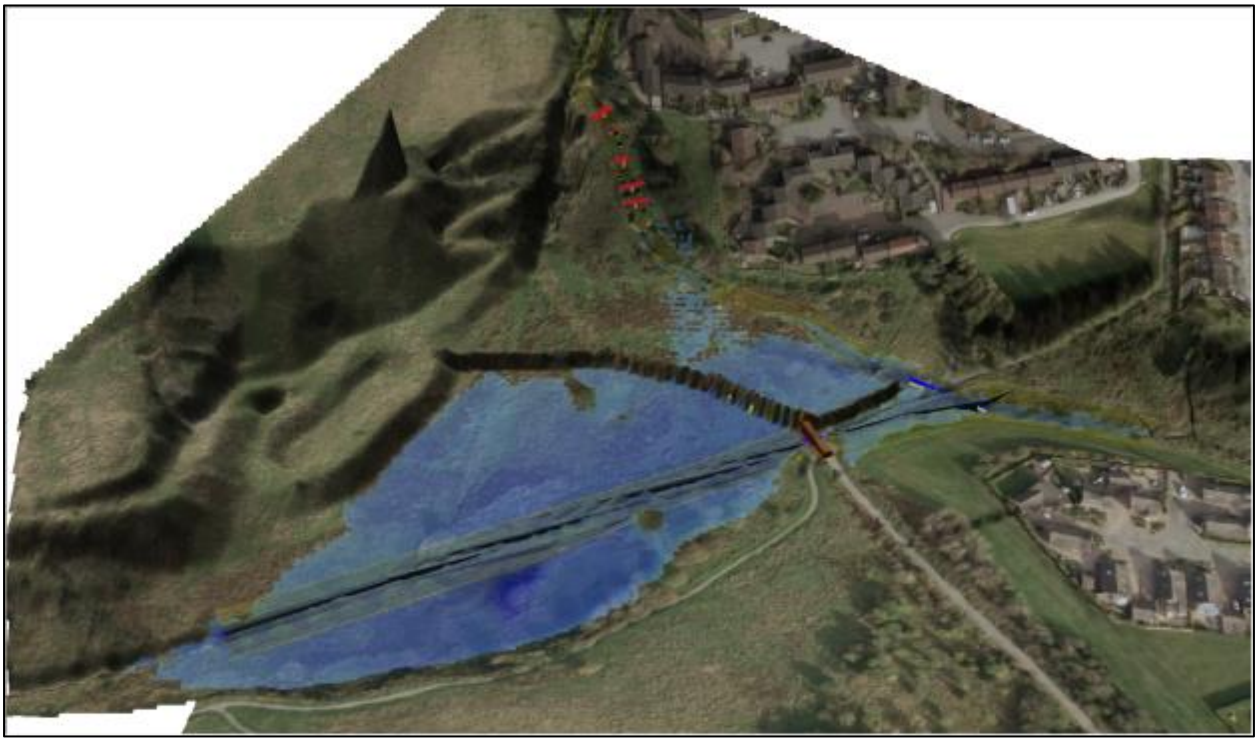
Flood extents derived from this investigation have been compared with SEPA's Indicative flood map, and it is considered that the extents developed as part of this work do not deviate significantly from those predicted by SEPA.

It is recommended that further work is undertaken to assess the potential storage of the Den of Maidencraig, following which adjustments to the heights of the bunds may be required.

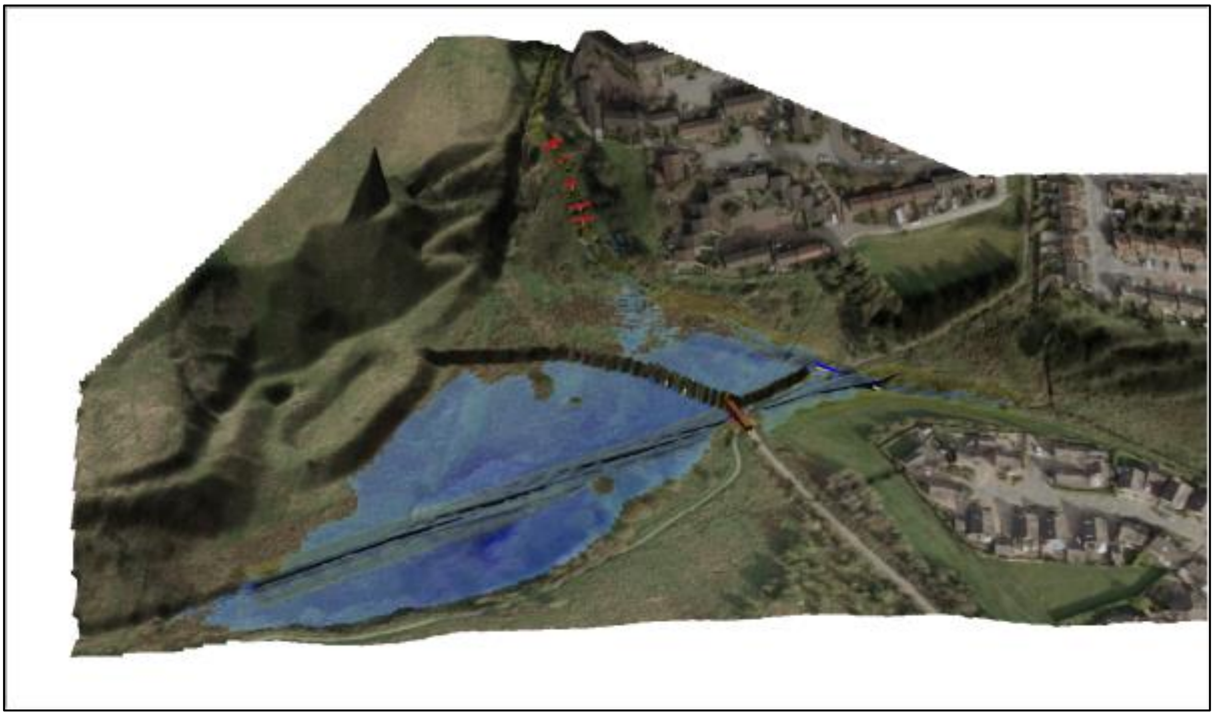
Appendices

Appendix A – Flood Alleviation Scheme - 3D Flood Extents

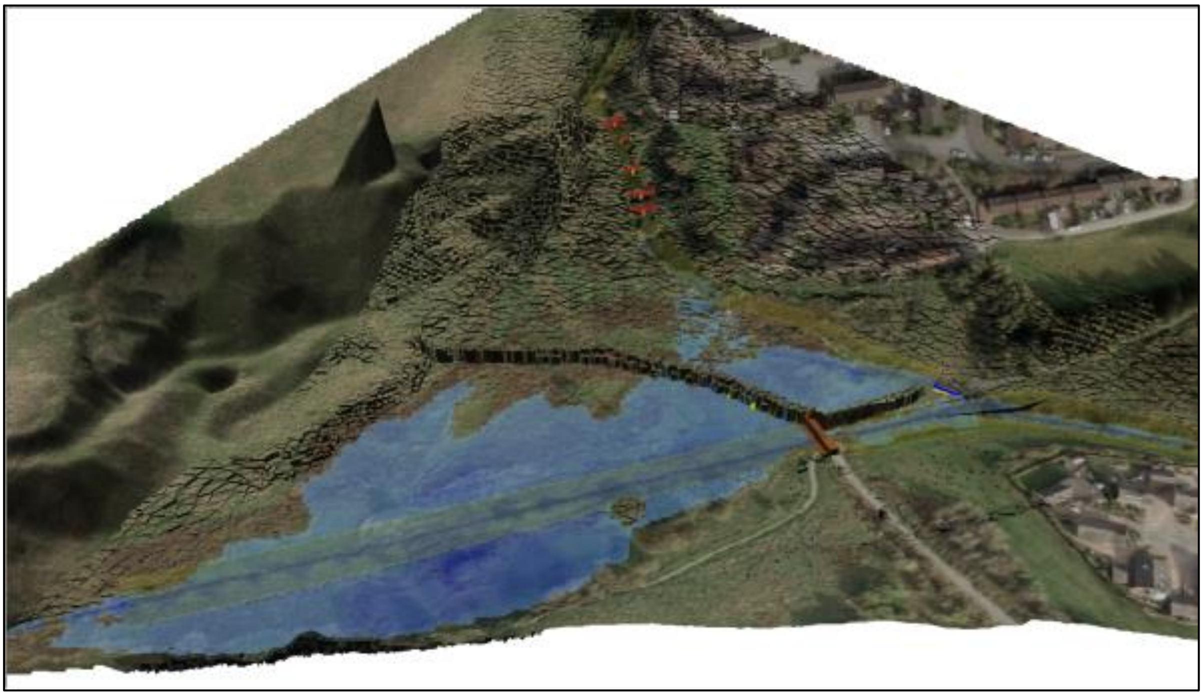
200 year



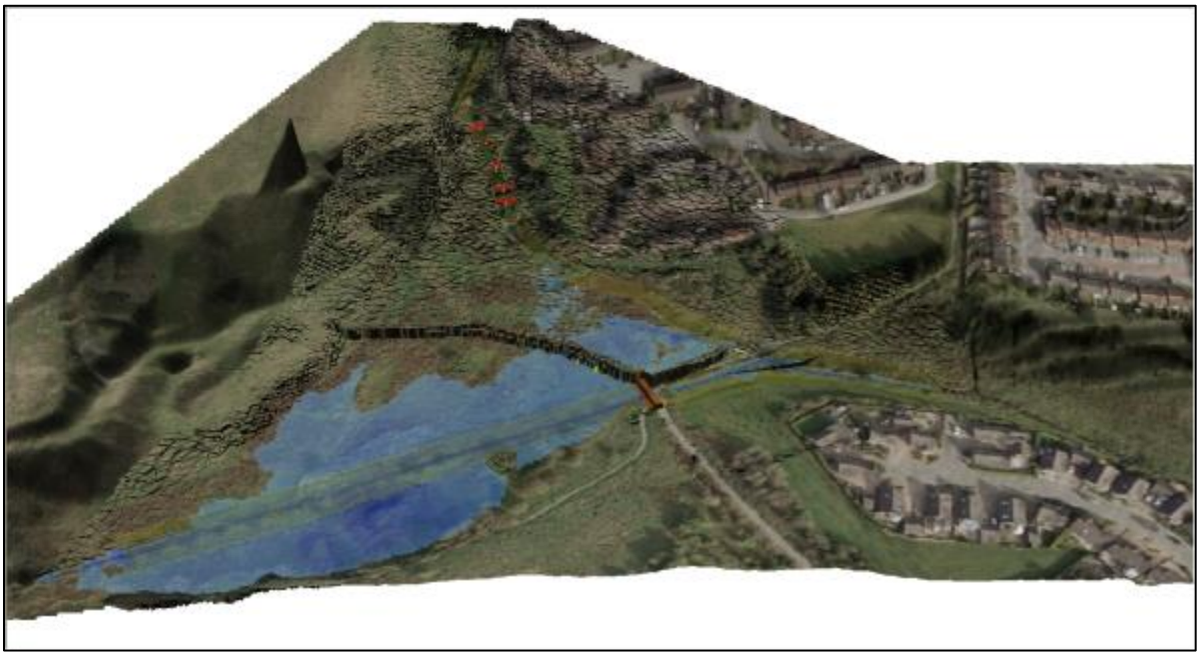
100 Year



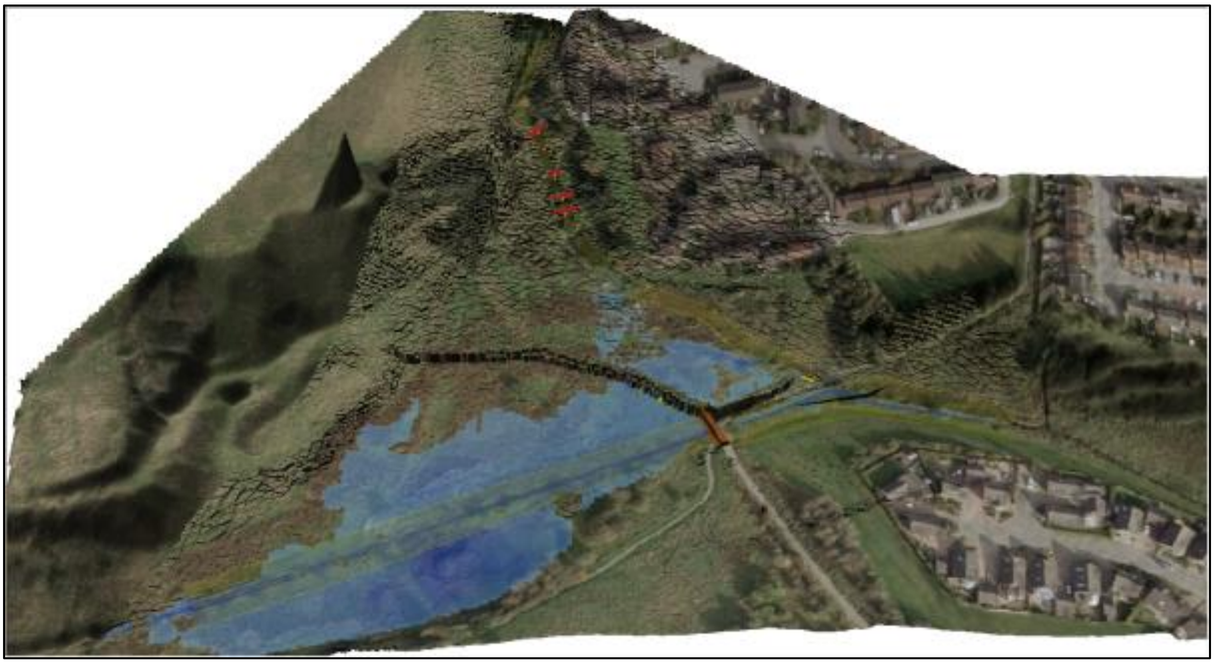
30 Year



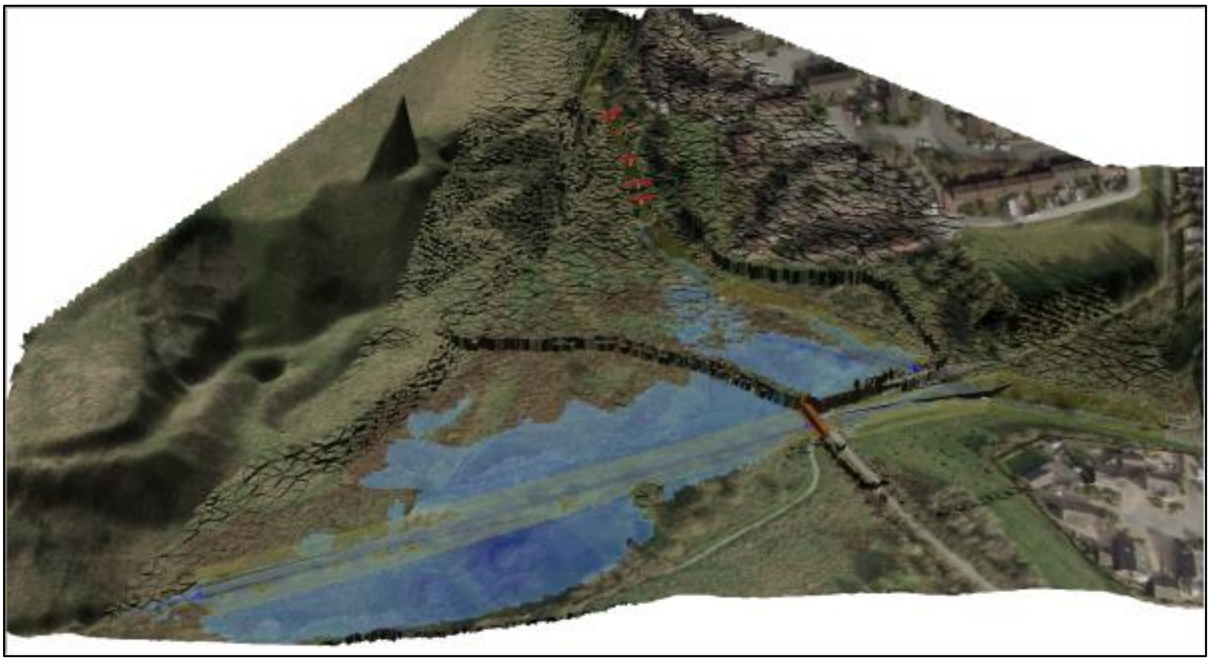
10 Year



5 Year



2 Year



Appendix B – ACC 200 year flood extent comparison with SEPA's Indicative Floodmap

Maidencraig Flood Alleviation Scheme

Legend

- SEPA 200 Year Flood Extent
- ACC 200 Year Flood Extent

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