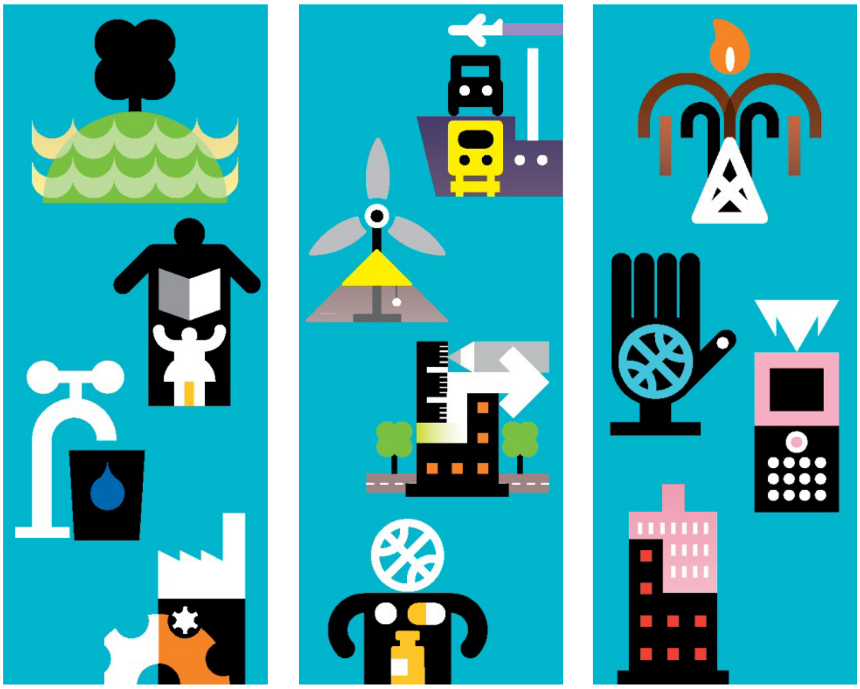

River Almond - Structural Examination and Silt Surveys

Level 3 Flood Risk Assessment - Cramond Weirs

August 2014

Rivers and Fisheries Trusts of Scotland

RIVERS & FISHERIES TRUSTS OF SCOTLAND
Safeguarding Scotland's Rivers & Lochs

Mott MacDonald

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Issue and revision record

Revision	Date	Originator	Checker	Approver	Description	Standard
A	August 2014	A Low	A Badcock	K Keast	First Issue	

Contents

1 Introduction

The Rivers and Fisheries Trusts of Scotland (RAFTS), in partnership with the Scottish Environmental Protection Agency (SEPA), are financing a project to assess the feasibility of the removal or modification of 7 weirs on the River Almond in order to enhance the environment within the River Almond basin. Mott MacDonald Limited (MML) have been commissioned by RAFTS to investigate the key risks associated with weir removal/modification. The key risks include risk of sediment mobilisation, unknown structural condition of the weirs and impact on flood risk. This document presents a detailed flood risk assessment (FRA) to determine how the removal of Dowies weir and Peggies weir may potentially impact flood risk in their vicinity.

As per the invitation to tender (ITT) document for the Structural Examination and Silt Surveys for the River Almond (RAFTS, December 2012), a Level 3 FRA, with requirements as prescribed in CIRIA C624, Development and flood risk – guidance for the construction industry (CIRIA, 2004), has been undertaken to assess the impacts on flood risk from the removal of Dowies or Peggies weirs. CIRIA C624, Table 5.2 (CIRIA, 2004) states the requirements of Level 1, Level 2 and Level 3 FRAs, which are reproduced in Table 1.1, below.

Table 1.1: Levels of flood risk assessment

FRA Level	Description
1	Screening study to identify whether there are any flooding issues related to a development site which may warrant further consideration.
2	Scoping study to be undertaken if the Level 1 study indicates that the site may lie within an area which is at risk of flooding or that the site may increase flood risk due to increased runoff, to confirm the possible sources of flooding which may affect the site. The study should include the following objectives: ▪ assess the availability and adequacy of existing information ▪ qualitative assessment of flood risk to the site, and the impact of the site on flood risk elsewhere ▪ assessment of the possible scope for appropriate development design and to scope additional work required.
3	Detailed study to be undertaken if the Level 2 study concludes that quantitative analysis is required to assess flood risk issues related to the development site. The study should include: ▪ quantitative assessment of the potential flood risk to the development ▪ quantitative assessment of the potential impact of the development on flood risk elsewhere ▪ quantitative demonstration of the effectiveness of any proposed mitigation measures.

Source: CIRIA C624, Development and flood risk – guidance for the construction industry, Table 5.2

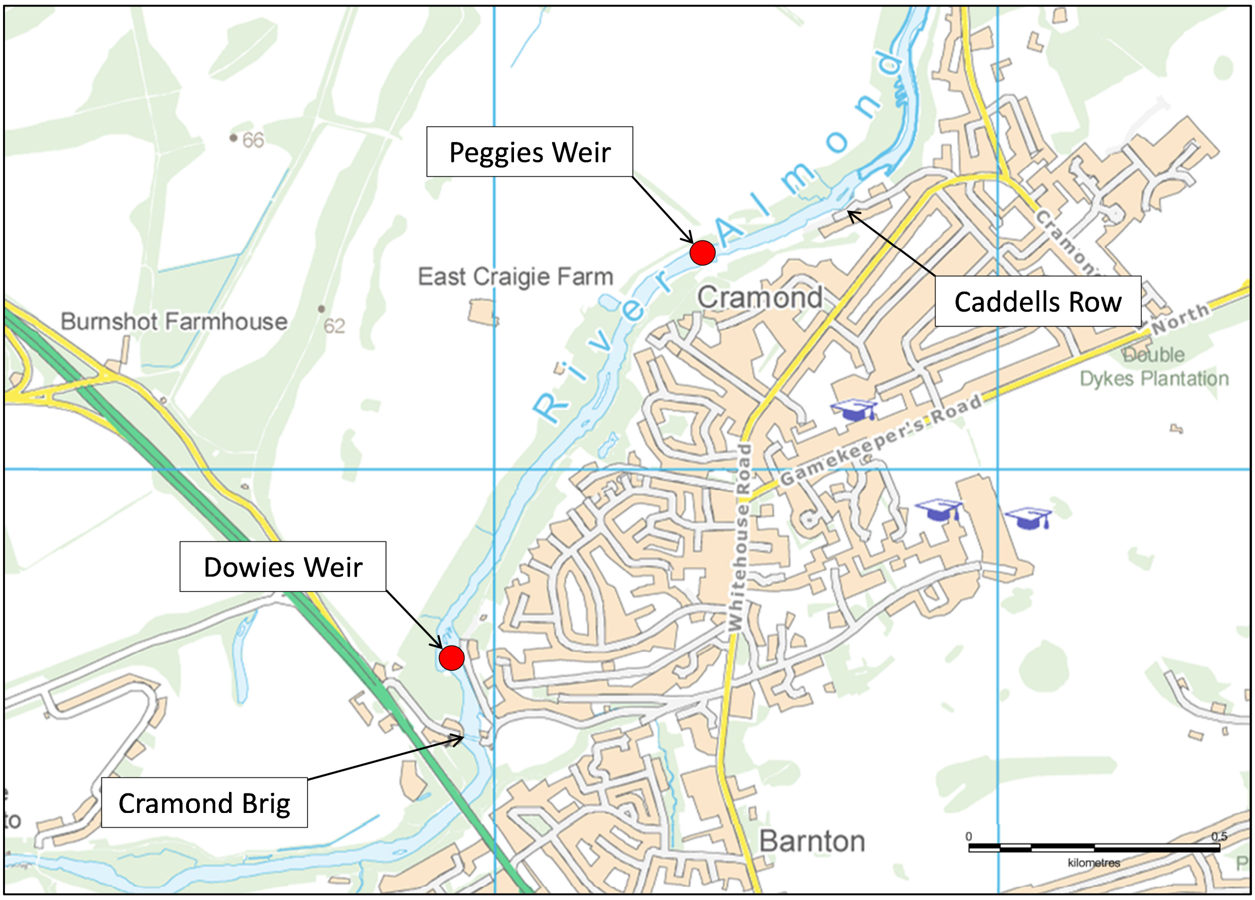
This document presents the findings from a hydrological study of the River Almond catchment and a modelling study to understand flood risk due to the removal of Dowies weir and Peggies weir. It is noted that there is not a specified 'development' as alluded to in the CIRIA flood risk guidance (CIRIA, 2004) so the impact of weir removal on modelled flood levels and flood extents along the River Almond are considered in lieu of a development site. The study has included the construction of a hydrodynamically linked 1D 2D ISIS TUFLOW model of the lower reaches of the River Almond.

2 Background

2.1 Study Area Overview

Dowies weir and Peggies weir are located on the lower reaches of the River Almond at Cramond, between Cramond Brig and Caddells Row. The weir locations are presented in Figure 2.1.

Figure 2.1: Overview of Study Area



Source: Contains Ordnance Survey data © Crown Copyright and database right 2014

The catchment area of the River Almond to Cramond Brig is 387 km². The area to the west of the watercourse is dominated by agricultural land with the residential area of Cramond to the east. The riparian areas of the watercourse are heavily wooded for the entirety of the study area.

The watercourse is contained within a steep sided valley, where cliff walls rise to approximately 40m above channel banks in places. The approximate gradient of the channel for the study area is 0.0072 (m per m). The channel is generally of regular cross section, ranging between 40m and 60m wide, depending on location, with bed material consisting of silt, cobbles and boulders.

Upstream of Dowies weir the channel is approximately 40m wide increasing to 60m immediately downstream of the weir. The Dowies weir crest is 70m long and is a curved construction orientated oblique to the main direction of the channel. The weir structure is damaged in places, where concrete slabs are undercut and disintegrating, with rubble present in the channel. A small fish pass / bypass channel is located at the right bank of the structure. The drop across the structure is approximately 1m, with a steep channel gradient immediately downstream. The original weir structure was destroyed 20 years ago and subsequently replaced to protect the foundations of Cramond Brig upstream (Atkins, 2011). The construction included placing large boulders in the channel downstream of the weir (Atkins, 2011), presumably to dissipate high energy and high velocity flows and offer protection to the downstream channel.

Figure 2.2: Dowies weir crest

Source: Mott MacDonald, 2014

Figure 2.3: Dowies weir – downstream damage

Source: Mott MacDonald, 2014

Upstream of Peggies Weir the river channel is uniform, with a shallow gradient and is contained within a steep sided river valley consisting of bedrock cliff walls. The weir crest is approximately 40m long and is in generally good condition, despite a minimal length of crest masonry being dislodged (Atkins, 2011). The structure is built into a derelict, masonry mill building located on the right bank of river, with a fish pass located on the left bank of the channel. There is a vertical drop of approximately 3m across the weir, returning to a shallow channel bed gradient on the downstream side.

Figure 2.4: Peggies weir with mill ruins

Source: Mott MacDonald, 2014

Figure 2.5: Peggies weir fish pass

Source: Mott MacDonald, 2014

In addition to Dowies weir and Peggies weir, two additional structures are located upstream of Dowies weir, with a third weir 250m downstream of Peggies weir. The A90 road bridge (Queensferry Road Bridge) is a steel and concrete modern structure with steel raking columns founded on the channel banks. Cramond Brig, also upstream of Dowies weir, is a three span masonry arch structure which incorporates solid sandstone piers and abutments. Cramond Brig also contains wing walls which will channel the flow through the three spans during flood events. A third weir is located approximately 250m downstream of Peggies weir.

2.2 History of Flooding

Consultation has been undertaken with SEPA and the local authority (West Lothian Council) regarding flooding history on the River Almond.

SEPA reported that no incidents of fluvial flooding from the River Almond have been recorded in the area, with any localised flooding being attributed to a surcharged sewer network.

Information regarding flooding was requested from the local authority though no studies were available.

2.3 Sources, Pathways and Receptors

This study considers fluvial flood risk from the River Almond due to the removal of Dowies weir and Peggies weir. The study does not consider risk of flooding from pluvial or tidal sources, though the downstream boundary is based on an extreme tidal level due to the boundary being located in a tidal reach of the River Almond (see Chapter 4.4.4).

Assessments of pluvial, groundwater and tidal flooding have been omitted from the study after considering SEPA flood maps[1] of the area and the fact that weir removal will not impact tidal, groundwater or pluvial design flood levels in the area.

The Level 3 FRA will consider any changes to the flood envelope of the River Almond due to weir removal as derived in this study.

2.4 Model Approach and Justification

To meet the requirements of a Level 3 FRA (CIRIA, 2004) a hydrodynamically linked 1D-2D ISIS TUFLOW model has been constructed to represent the reach of the River Almond which contains Dowies weir and Peggies weir. ISIS and TUFLOW modelling packages are industry standard software and allow a fully quantitative assessment of flood risk. Details of the modelling methodology are presented in Chapter 4.

A hydrological analysis of the River Almond catchment has been undertaken to derive inflows to the hydraulic model at prescribed annual exceedance probability (AEP) flood events using industry standard

[1] SEPA flood maps can be viewed at http://www.sepa.org.uk/flooding/flood_maps.aspx

methodologies as stated in the Flood Estimation Handbook (FEH) (Institute of Hydrology, 1999). Details of the hydrological analysis are presented in Chapter 3.

3 Technical Method - Hydrological Analysis

3.1 Introduction

Hydrological analysis of the River Almond has been undertaken with the aim of generating flood flows to input into the hydraulic model. The full hydrological analysis is presented within the component reports for this project, with the following title, River Almond – Structural Examination and Silt Surveys, Level 3 Flood Risk Assessment – Hydrological Analysis. The hydrology report should be consulted for complete information on the hydrological analysis but this section provides a summary of the key elements of the approach and the results obtained.

Flows have been derived at Peggies weir and applied to the upstream end of the model. This ensures a slightly conservative approach to the hydrology due to the larger upstream catchment area at Peggies weir compared with the upstream boundary. There are no major inflows to the River Almond in the short reach between Dowies weir and Peggies weir and therefore it is not anticipated that there will be a notable difference in the peak design flows between the two locations.

The Flood Estimation Handbook (WINFAP FEH) (Institute of Hydrology, 1999) has been used to ensure an appropriate methodology has been applied to derive inflows to the model. A data review was undertaken to identify any local hydrometric gauges which could be incorporated into the analysis. Due to the size and characteristics of the catchment, the statistical method was judged to be the most suitable approach for calculating peak flows in the catchment, particularly for higher return period events.

The statistical method includes using a set of pooled gauges to derive growth curves to which an estimate of the median flood flow (QMED) of the catchment is applied. The QMED flow is used as an index flood which is combined with derived growth curves to provide a flood frequency curve for rarer flood events. A flood hydrograph shape calculated from the FEH rainfall-runoff method was scaled to the peak flow from the statistical analysis for each of the design events considered. These hydrographs were used as the upstream inflows to the hydraulic model.

3.2 Pooling Group

An initial pooling group was generated for the FEH Statistical Method using the WINFAP software. The pooling group did not identify any initial discordancy in the selected gauging stations, however all stations were compared for discrepancies against the key catchment characteristics including AREA, SAAR and BFIHOST. A number of the stations in the group were identified as having high BFIHOST values that were inconsistent with the target catchment. These were removed from the pooling group and were substituted with alternative HiFlows gauges which were more hydrologically similar to the Almond catchment.

3.3 Derivation of QMED

The QMED value was automatically generated by WINFAP based on the catchment descriptors of the target catchment. Applying this method the QMED value is 86.9m^3/s. A gauging station exists just upstream of the site (SEPA gauging station reference 19001), which has a catchment area only 2%

smaller than the target site. Flow data, annual maxima series and rating curve data was obtained from SEPA for this gauging station to make best use of local hydrological data in the vicinity of the target weirs.

In this instance it was thought that due to the proximity of the gauging station to the subject site, a data transfer could be applied to the QMED value.

It is noted that the FEH guidance does not recommend a QMED adjustment is made for urban catchments. However the potential donor gauging station is on the same watercourse as the target weirs and is located only 3km upstream of Peggies Mill. In this particular instance it was judged reasonable to make best use of the available data and apply a QMED adjustment. Consequently no urban adjustment has been made to the growth curve to avoid double-counting the impact of catchment urbanisation within the catchment in the flow calculation. The observed QMED at the upstream gauging station is 124.7m^3/s. The adjusted QMED value for the subject site was 125.2m^3/s, an increase of 0.5m^3/s on the upstream gauged site.

3.4 Calculation of flows

Catchment flows have been calculated using three different methods:

- Statistical pooled FEH approach using QMED calculated using catchment descriptors
- Statistical pooled FEH approach using adjusted QMED as described above
- Statistical single site FEH analysis at gauge 19001, upstream of the target site

The results of the analysis show that the statistical approach using the adjusted QMED gives the most conservative inflows. These have been taken forward for use in the hydraulic modelling.

Table 3.1: Model Inflows

Event AEP	Peak Flow (m^3/s)
50%	125.2
20%	168.6
10%	198.6
4%	240.0
2%	274.2
1%	311.7
0.5%	353.1
0.5% + CC	423.7

Source: Mott MacDonald, 2014

4 Technical Method - Hydraulic Modelling

4.1 Objectives

The aim of the modelling study is to understand how removal of Dowies weir and Peggies weir from the watercourse will impact flood risk in the chosen study area. Historically, weir structures have been used to attenuate flow, with water being re-routed for use to drive mills of various types (Peggies Weir); or to reduce flow velocities upstream and hence scour, thereby protecting in-channel structures (Dowies weir). It is generally perceived that removing a weir from a watercourse will allow peak velocities to increase in that vicinity, which has the potential to impact flood risk. Therefore hydraulic modelling and a FRA are required to be undertaken to understand the impact of removing this type of structure.

4.2 Approach and Justification

4.2.1 Modelling Approach

No existing hydraulic models of the River Almond were made available to inform this study and therefore a new model of the watercourse was constructed. A hydrodynamically linked 1D-2D ISIS TUFLOW model was selected as being the most appropriate type of model for simulating flood water levels in the River Almond channel and on the adjoining floodplain areas. Using an ISIS TUFLOW model enables the linkage of a 1D representation of the watercourse, including any in channel structures, with a 2D representation of floodplain areas from LiDAR Digital Terrain Model (DTM) data. This allows a detailed simulation of the behaviour of channel flow at structures and the interaction of this flow with flooding and attenuation on the floodplain. ISIS and TUFLOW are industry standard software packages which allow a fully quantitative assessment of flood risk. The model was built and run using ISIS version 3.6.0.156 and TUFLOW version 2012-05-AE-iDP-w64

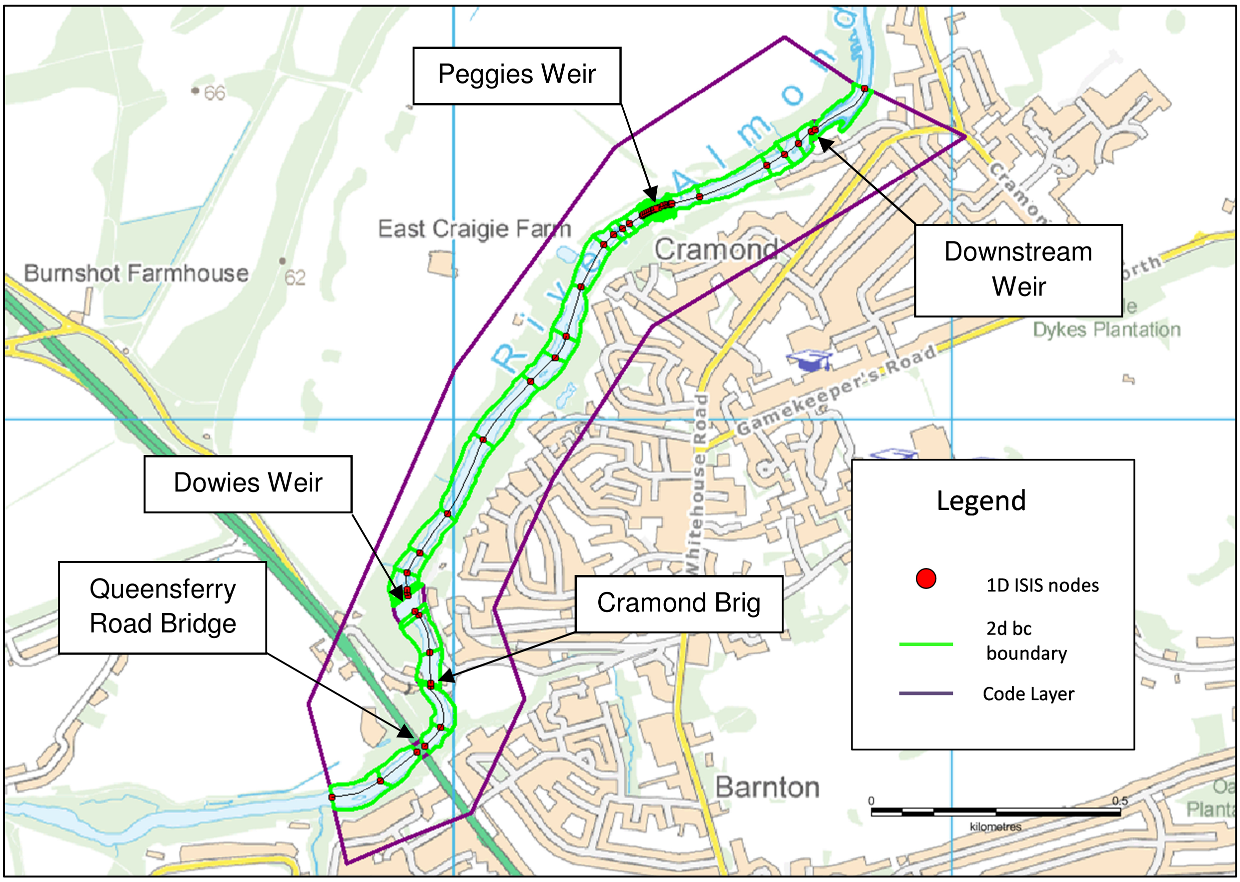
Full model build details are presented in Chapter 4.4.

4.3 Input Data

4.3.1 Model Extent

The map presented in Figure 4.1 shows the extent of the model domain including delineation of the 1D and 2D components. The River Almond flows from south to north through Cramond and Barnton, with the upstream extent of the model located just upstream of Queensferry Road Bridge and the downstream extent located approximately 600m downstream of Peggies weir. The area within the green boundary along the banks of the River Almond presented in Figure 4.1 is the 1D model domain (noted as the 2d bc layer on the Figure). The area between the green and purple boundaries is the 2D model domain which is represented using LiDAR DTM data. Water spills between the two domains at the green boundary and spreads over the DTM showing the principal flow paths and the propagation of the flood extent. All structures within the River Almond are represented in the 1D domain using data from ground-based topographical surveys.

Figure 4.1: River Almond Model Overview



Source: Contains Ordnance Survey data © Crown Copyright and database right 2014

4.3.2 Hydrological Data

Hydrological inputs to the model are as presented in Table 3.1, Chapter 3. The inflows are applied to the model via the ISIS model at node DW_01_0000.

4.3.3 Topographic Data

As discussed above the model uses two sources of topographic data, namely LiDAR DTM data to represent floodplain areas, and topographic ground survey data to define channel geometry.

The LiDAR DTM data has been purchased for the study area from the internet data source, Emapsite. The ground survey was commissioned and managed by Mott MacDonald on behalf of RAFTS and was undertaken by Greenhatch Group between March and April 2014. The survey includes 47 cross sections of the channel with details of two bridge structures and three weirs. In addition to cross sections and structure survey, gridded elevation survey points have been gathered on a 1m grid upstream and downstream at Dowies weir and Peggies weir. The gridded survey area also includes the floodplain in the same area.

Verification of the LiDAR DTM data using the ground survey data shows a reasonable match between the datasets across a broad sample of data points. This reduces uncertainty in the exchange of flows between the 1D ISIS and 2D TUFLOW model domains which therefore increases confidence in modelled outputs.

4.4 Technical Method and Implementation

4.4.1 Site Specific Modelling

Table 4.1 outlines key model components and their application to the model.

Table 4.1: Model Build Details

Item No.	Model Component	Detail	Reason
1	1D Model Extent	Model extends 2005m from cross section DW_01_0000 (540m upstream of Dowies weir) to PW_24_2005 (500m downstream of Peggies weir)	The model extent allows the impact of weir removal to be assessed a significant distance u/s of Dowies weir and d/s of Peggies weir. A reasonable distance of modelled channel upstream of the target site has been included to ensure flow conditions are not impacted by the chosen upstream extent.
2	1D Channel Geometry	Channel geometry represented using surveyed cross sections.	Topographical survey of the channel ensures a detailed representation of the channel geometry to ensure accurate model outputs.
3	1D Structures	Queensferry Road Bridge, Cramond Brig, Dowies weir, Peggies weir and downstream weir represented using survey data.	Topographical survey of the structures ensures a detailed representation of the geometry to ensure accurate model outputs.
4	1D Roughness	Manning's n roughness values are as stipulated in Chapter 4.4.5	Roughness values have been chosen based on observations from site visits cross referenced against standard values (Chow, 1959)
5	1D Downstream Boundary	Downstream boundary based on the 0.5% AEP tidal level taken from the EA / DEFRA Coastal flood boundary conditions for UK mainland and islands dataset.	The SEPA coastal flood map shows the downstream reaches of the River Almond are impacted by tidal flood levels. The 0.5% AEP level was chosen to ensure a conservative representation of water levels at the downstream boundary.
6	2D Model Extent	Model extends from cross section DW_01_0000 (540m u/s of Dowies weir) to PW_24_2005 (500m d/s of Peggies weir) and also approximately 100m from each channel bank.	The model extent was chosen to ensure all relevant areas of the floodplain are included and to prevent 'glass walling' of water at the extent boundary.
7	2D Cell Size	3m cell size	The cell size chosen is suitable for the FRA as major flow routes are adequately represented in

Item No.	Model Component	Detail	Reason
			the model; therefore, smaller grid size is unlikely to improve the model results.
8	2D Floodplain Geometry	Floodplain areas are represented using 2m resolution LiDAR DTM data.	LiDAR DTM data is of sufficient quality to ensure floodplain geometry is represented in high enough detail to ensure accurate modelled outputs.
9	2D Roughness	Manning's n roughness values are as stipulated in Chapter 4.4.5	Roughness values have been chosen based on observations from site visits cross referenced against standard values (Chow, 1959).
10	2D Downstream Boundary	Shallow gradient applied via HQ boundary to represent floodplain flow.	A shallow gradient has been applied to replicate ground levels at the downstream boundary. There is little flow over the floodplain at the downstream boundary in the design model runs and therefore this assumption will have little impact on the model.
11	2D Building Representation	Buildings raised to threshold level of 150mm Building/structure Manning's n set as 0.5	Buildings and structures on the floodplain are an obstacle to flood flow routes, either slowing or preventing flood propagation. The representation of buildings in the hydraulic model has been adjusted to show an increase in surface roughness and attenuation of flow. The ground levels for the average building threshold levels were raised by 150mm. As the building thresholds were raised, the Manning's n value for buildings in the 2D model domain was set at 0.5 (not 1.0) so that blockage of flow is not double counted. The Manning's n values for other land use types are outlined in Chapter 4.4.5.

4.4.2 Calibration and Verification

The model has not been calibrated due to lack of gauged data within the modelled reach. The closest gauging station is located upstream at Craigiehall, approximately 1.25km from the model boundary. No hydraulic data has been identified from within the extent of the model domain which could be used for calibration.

However, a sensitivity analysis has been carried out to gain a better understanding of the model uncertainties (see Chapter 4.6).

4.4.3 Model Scenarios

The aim of the modelling is to understand how removal of Dowies weir and Peggies weir impact flood risk in the vicinity of the River Almond. In order to do this, the hydraulic model has been adapted to represent four scenarios:

- *Baseline* – The baseline scenario model is the 'as is' scenario where both Dowies weir and Peggies weir are represented in the model in their current state (model reference DP_001).

- *Dowies Removal* – Removal of Dowies weir is simulated through removal of its representation in the 1D ISIS channel component of the model. The weir structure was deleted from the model. Model node DW_08_0508 was connected to node DS_20_0648 across the current location of the weir structure to represent the channel gradient if the weir was removed and a significant period of time has passed to allow the channel bed profile to smooth out (model reference DP_002).
- *Peggies Removal* – Removal of Peggies weir is simulated through removal of its representation in the 1D ISIS model. The weir structure was deleted from the model. Model node PW_02_1448 was connected to node PW_19_1541 across the current location of the weir structure to represent the channel gradient if the weir was removed and a significant period of time has passed to allow the channel bed profile to smooth out (model reference DP_003).
- *Dowies and Peggies Removal* – Both weirs are removed from the hydraulic model as described above (model reference DP_006).

All model scenarios are run for a range of AEP flood events including 50% AEP, 20% AEP, 10% AEP, 4% AEP, 2% AEP, 1% AEP, 0.5% AEP and 0.5% AEP plus allowance for climate change events.

4.4.4 Boundary Conditions

An extreme tidal level has been chosen as the downstream boundary of the model as the SEPA indicative flood map shows the lower reaches of the River Almond are controlled by tidal levels in the Firth of Forth. The 0.5% AEP tidal level from the Firth of Forth (3.98mAOD), in close proximity to the River Almond estuary has been taken forward as the downstream boundary for modelling. The likelihood of the 0.5% AEP fluvial event occurring coincidently with 0.5% AEP peak tidal level is small, though in the absence of a detailed joint probability assessment the modelled scenario will ensure conservative estimates of water levels are produced by the hydraulic model.

4.4.5 Manning's n Roughness Coefficients

Manning's n roughness coefficients were estimated as follows:

- *1D domain:* Roughness values have been chosen based on observations from site visits, cross-referenced against standard values (Chow, 1959).
- *2D domain:* estimated based on floodplain land-use coverage and cross-referenced against standard values (Chow, 1959).

The Manning's n roughness coefficients applied in the 1D model domain are set to 0.05 due to the large boulders and cobbles in the majority of the watercourse. This ensures conservative flood levels are computed by the model.

Manning's n roughness coefficients are applied in the 2D domain via manually digitised polygons informed by Ordnance Survey mapping and aerial photography. A summary of the applied coefficients is presented in Table 4.2.

Table 4.2: 2D Domain Manning's n Roughness Values

Land Cover	2D Floodplain Manning's n Roughness Coefficient
Natural Surface (default value)	0.045
Roads/Tracks	0.025
Buildings	0.500
Trees	0.100

Source: Mott MacDonald, 2014

5 Hydraulic Model Analysis and Results

5.1 Results Overview

A selection of outputs from the flood model have been produced to identify areas at fluvial flood risk; illustrate the different weir removal scenarios and quantify the impact they have on flood extents and flood water depths and levels. Flow velocities have been considered in the accompanying document; Dowies Weir, Structural Examination and Silt Survey Report, Mott MacDonald, Aug 2014 (Ref 319034/102), where an assessment of fluvial morphology has been undertaken to understand whether weir removal will impact on scour risk in the channel and around bridge structures.

The results are presented as follows:

- Section 5.2: Baseline results for the 0.5% AEP plus climate change and for the 20% AEP events (the 200-year plus climate change and the 5-year return period events) for comparison;
- Section 5.3: Dowies weir removal for the 0.5% AEP plus climate change;
- Section 5.4: Peggies Weir removal for the 0.5% AEP plus climate change;
- Section 5.5: Both weirs removed for the 0.5% AEP plus climate change.

Results from each of the additional design event probabilities considered in the modelling have been checked and show a similar trend to the selected results presented below. This is mainly due to the watercourse geometry in this reach of the River Almond, where almost all flows are contained within the channel and there is a relatively low impact from floodplain attenuation on flow peaks and maximum water levels.

A summary of the model performance is presented in Chapter 5.10.

5.2 Baseline Results

Figure 5.1 shows the flood extent for the 0.5% AEP plus climate change model run and Figure 5.2 shows the flood extent for the 20% AEP model run. The results show that for the majority of the modelled reach, flows are contained within the steep sided River Almond channel for both events.

For the 0.5% AEP plus climate change event, at the upstream extent of the model, water levels in the channel are controlled by Dowies weir and the two bridges upstream of the weir. The combined impact of these structures results in high water levels and the inundation on two properties on the left bank of the watercourse and part of Brae Park Road on the right bank.

In the mid-section of the modelled reach, upstream of Peggies weir, there are small areas of out of bank flow. There is no impact on any properties in the residential area of Cramond to the east with peak water levels well below the building elevations.

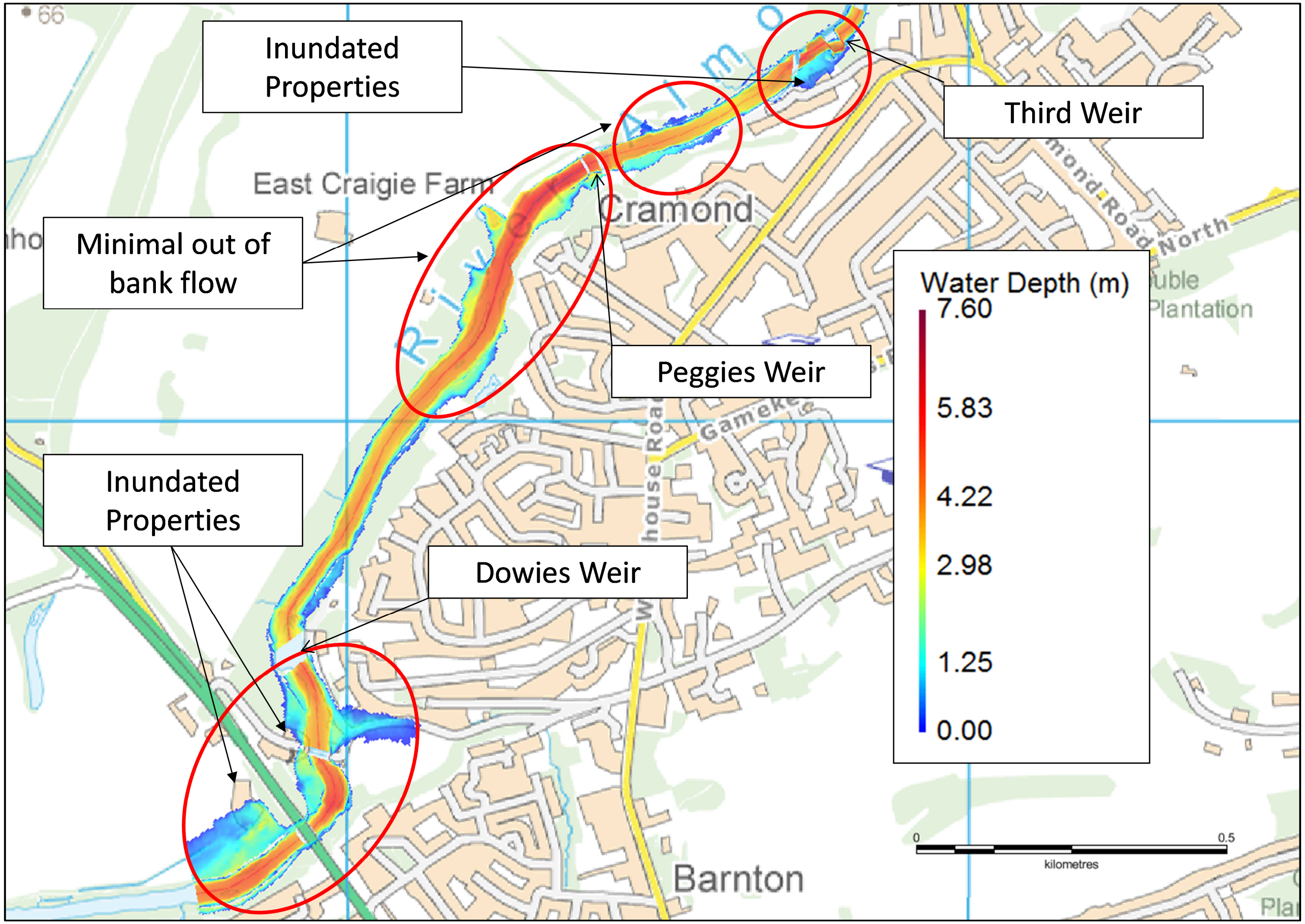
At the downstream end of the modelled extent, the third weir in the channel is controlling water levels upstream, which causes out of bank flow on the right hand bank and the inundation of a group of properties located in close proximity to the channel.

The results for the lower magnitude, 20% AEP event show minimal out of bank flow, with the majority of flows contained within the River Almond channel.

The 0.5% AEP plus climate change results have been compared with the SEPA flood map in the Cramond area. The comparison is favourable with the SEPA flood map corresponding well with the areas of out of bank flow shown in the model. The SEPA flood map shows the majority of flows are contained within the River Almond channel[2].

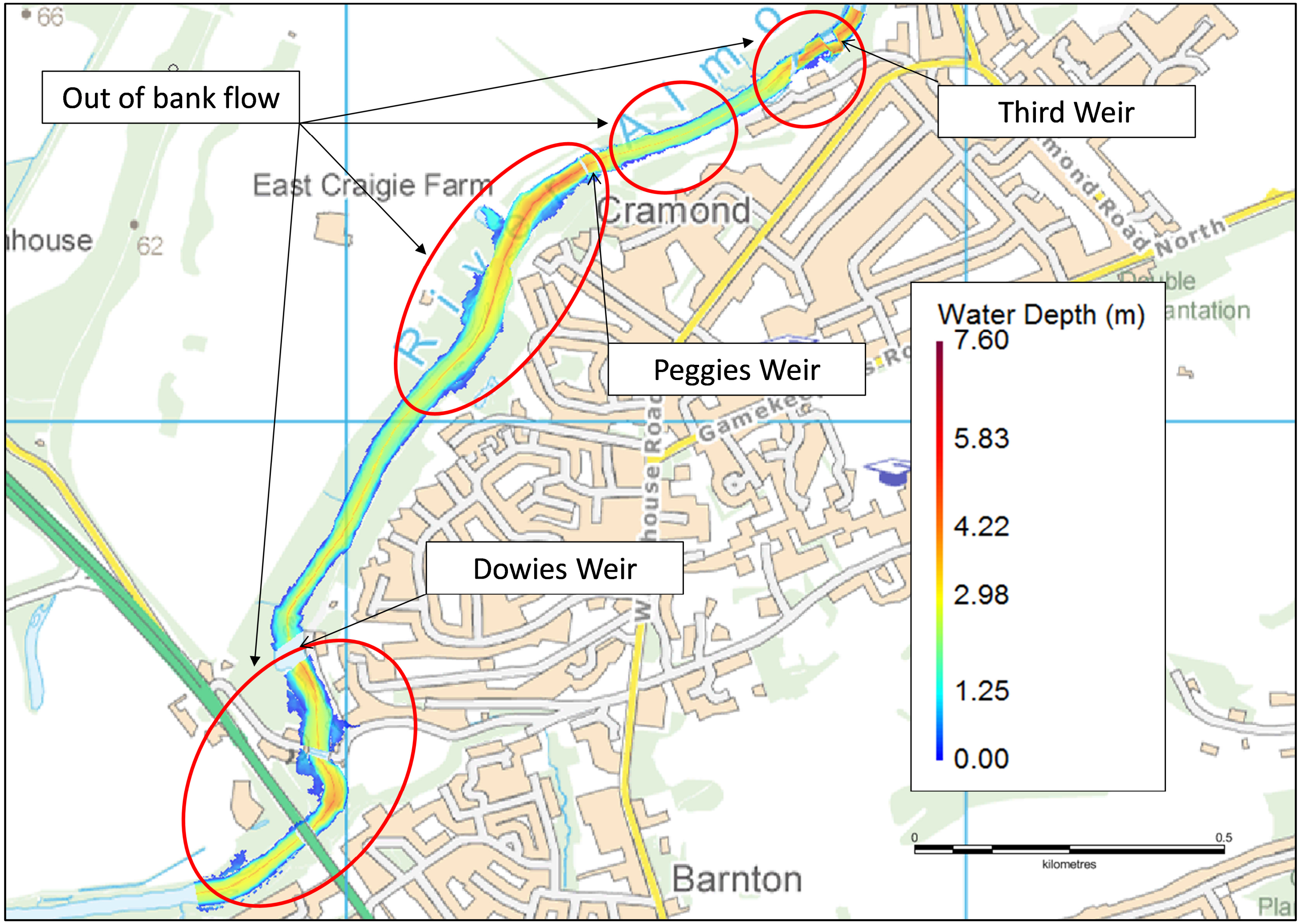
[2] Outputs from the SEPA flood map have not been reproduced in this document due to licencing restrictions. The SEPA flood map can be viewed at http://www.sepa.org.uk/flooding/flood_maps.aspx

Figure 5.1: 0.5% AEP plus Climate Change Event – Baseline inundated area and flood depths



Source: Contains Ordnance Survey data © Crown Copyright and database right 2014

Figure 5.2: 20% AEP Event – Baseline inundated area and flood depths



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5.3 Dowies Weir Removal

Figure 5.3 shows a comparison of the modelled flood extent for the 0.5% AEP plus climate change event between the baseline scenario and the scenario with the removal of Dowies weir from the model.

Figure 5.4 shows the comparison of bed levels and water levels in the River Almond for the same scenarios in a long section plot. Corresponding colour schemes have been used for the two model runs between the flood extent plot and the long-section graph.

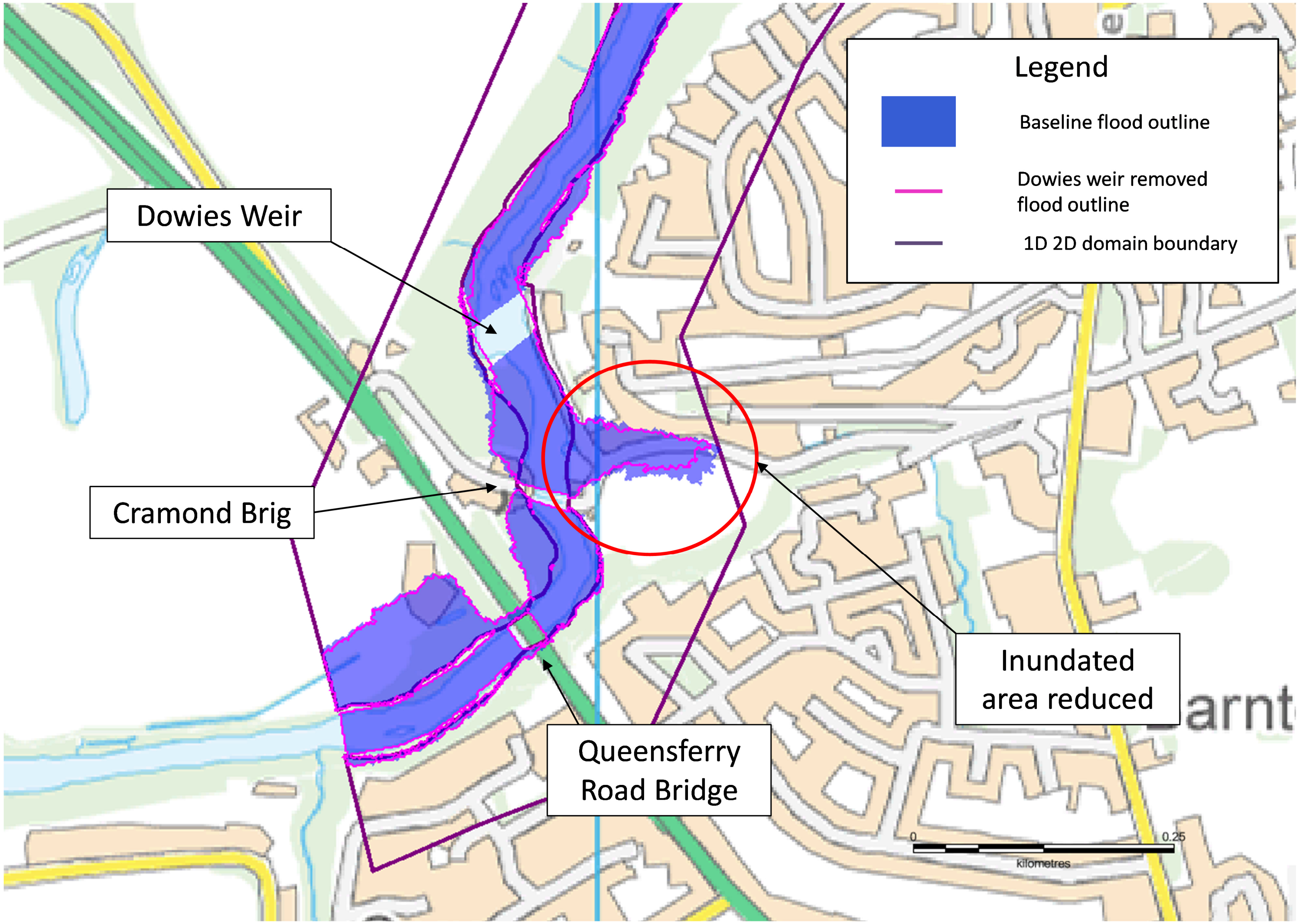
It is clear that the size of the flooded area at Brae Park Road has reduced when Dowies weir is removed (blue area versus pink outline in the Figure 5.3). This shows that under the existing channel and structure configuration, water levels at this location are partially controlled by the weir crest. The deletion of the weir in the model removes the backwater influence of the structure, lowering the peak water levels upstream significantly and providing a slight reduction in the peak levels downstream. The long section plot presenting peak water levels in the channel between these two scenarios also shows this pattern.

Upstream of Queensferry Road Bridge and Cramond Brig there is little difference in the inundated area and there are only small reductions in modelled flood levels in the channel. This suggests that peak flood levels in this reach are at least partially controlled by the Cramond Brig bridge structure rather than Dowies weir. This would appear to be a reasonable conclusion considering that the geometry of the Cramond Brig causes a significant reduction in convective area compared to the open channel at this point.

The building inside the flood extent under the baseline scenario in this area remains inundated for the scenario with Dowies weir removed.

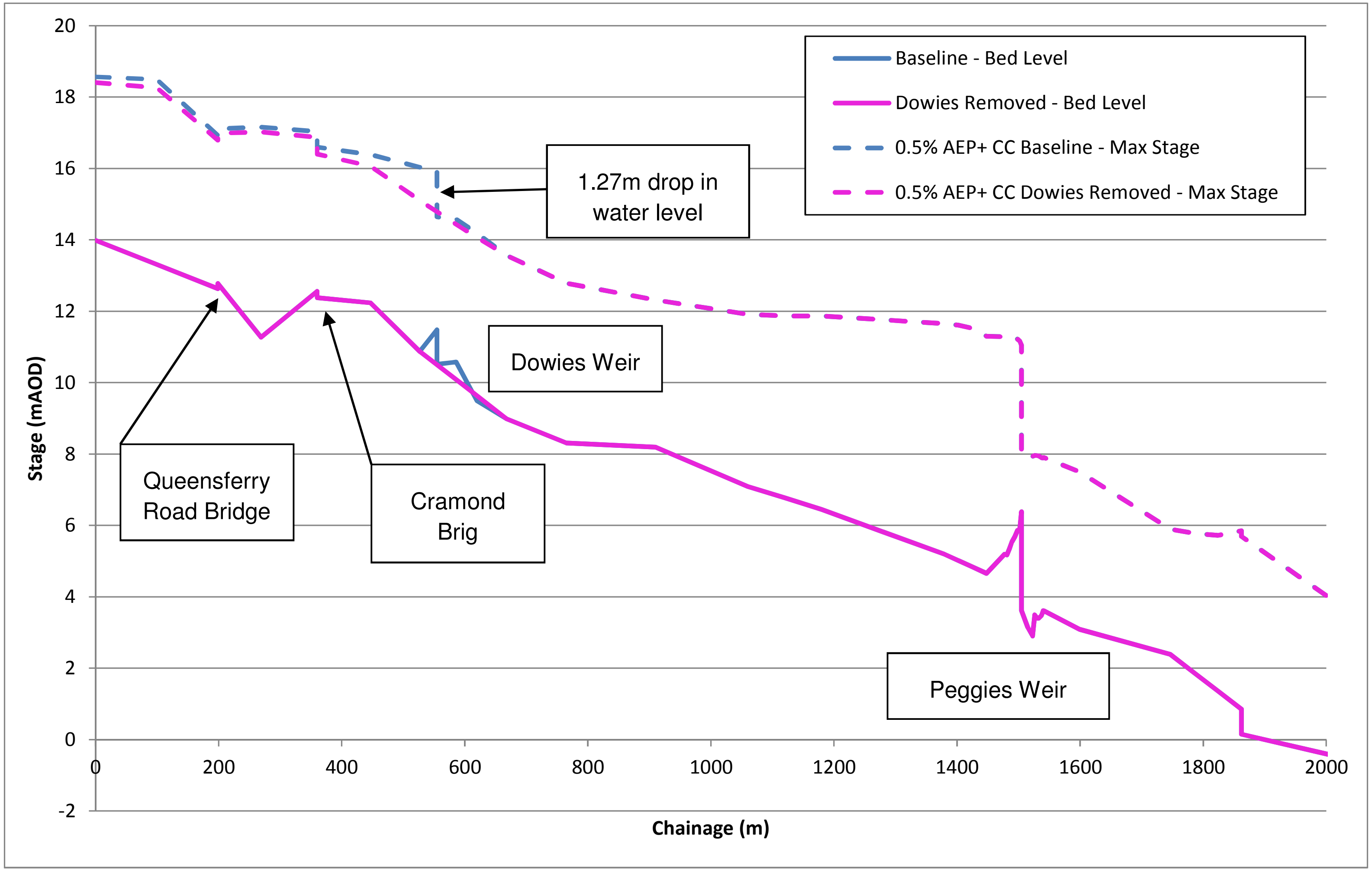
Downstream of Dowies weir there is minimal impact on water levels for a reach length of approximately 50m from the weir and there is no discernable impact further downstream.

Figure 5.3: Dowies Weir Removal – 0.5% AEP plus Climate Change Event, Maximum Flood Extent Comparison



Source: Contains Ordnance Survey data © Crown Copyright and database right 2014

Figure 5.4: Dowies Weir Removal – 0.5% AEP plus Climate Change Event, Peak Flood Level Comparison



5.4 Peggies Weir Removal

Figure 5.5 shows a comparison of the modelled flood extent of the 0.5% AEP plus climate change event for the baseline scenario and the scenario with removal of Peggies weir from the model. Figure 5.6 shows the comparison of bed levels and water levels in the River Almond for the same scenarios in a long section plot. Corresponding colour schemes have been used for the two model runs between the flood extent plot and the long-section graph.

The reduction in inundated area upstream of Peggies weir (blue area versus green outline) is relatively small given the significant reduction in modelled flood levels for this reach as shown in the long-section graph. This is due to the topography of the River Almond in its downstream reach, where the steep sided river valley means the flood extent is insensitive to water level.

The long section plot shows that Peggies weir controls water levels almost to the toe of Dowies weir. Significant reductions in the peak water level occur in the vicinity of the weir from the removal of the structure, up to a maximum reduction of 3.4m just upstream of the existing weir crest. The graph shows that the channel length impacted upstream of the weir is approximately 700m.

Downstream of Peggies weir there is minimal impact on water levels from the weir removal due to the backwater impact of the third weir and the downstream boundary conditions.

Figure 5.5: Peggies Weir Removal – 0.5% AEP plus Climate Change Event, Flood Extent Comparison

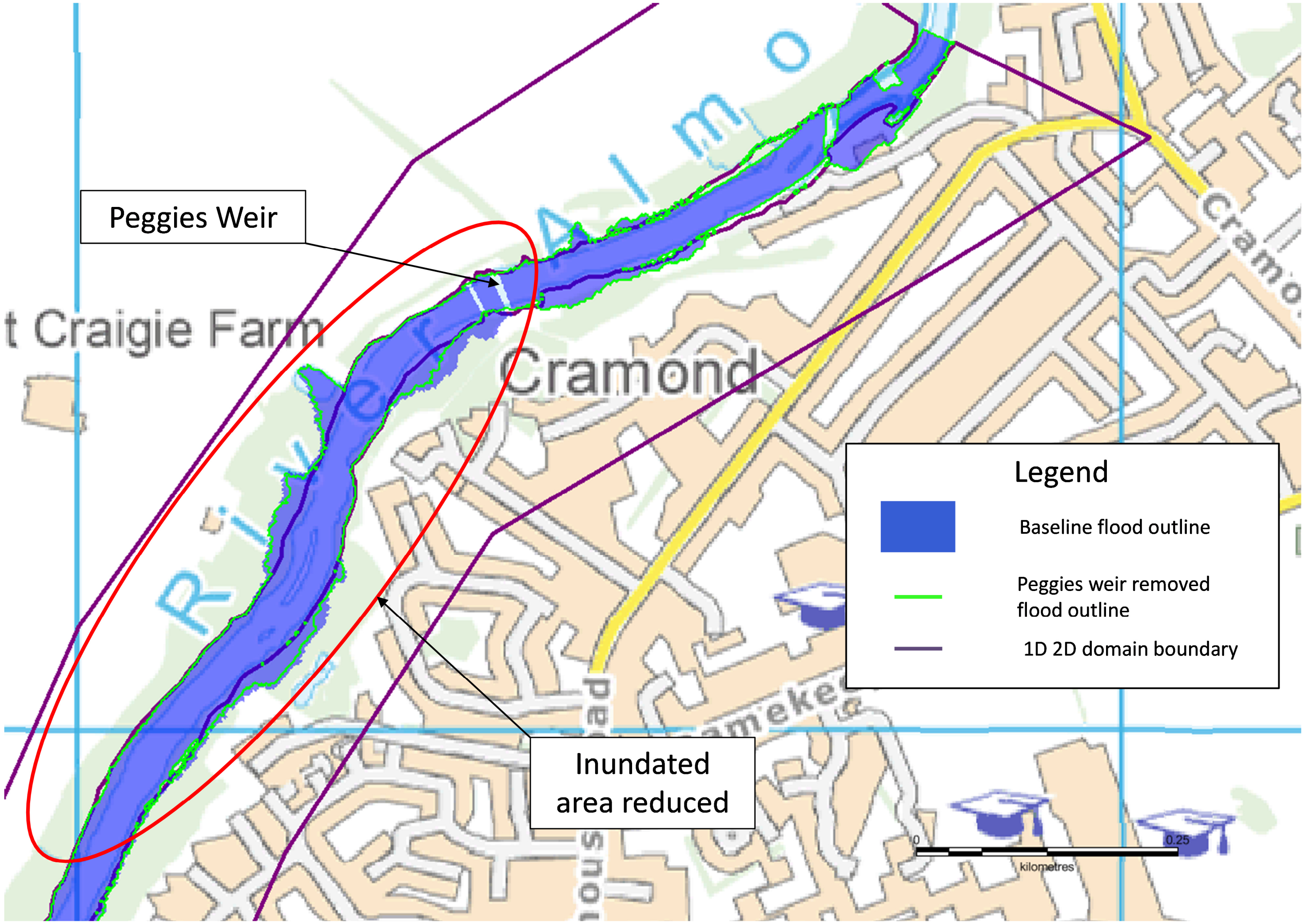


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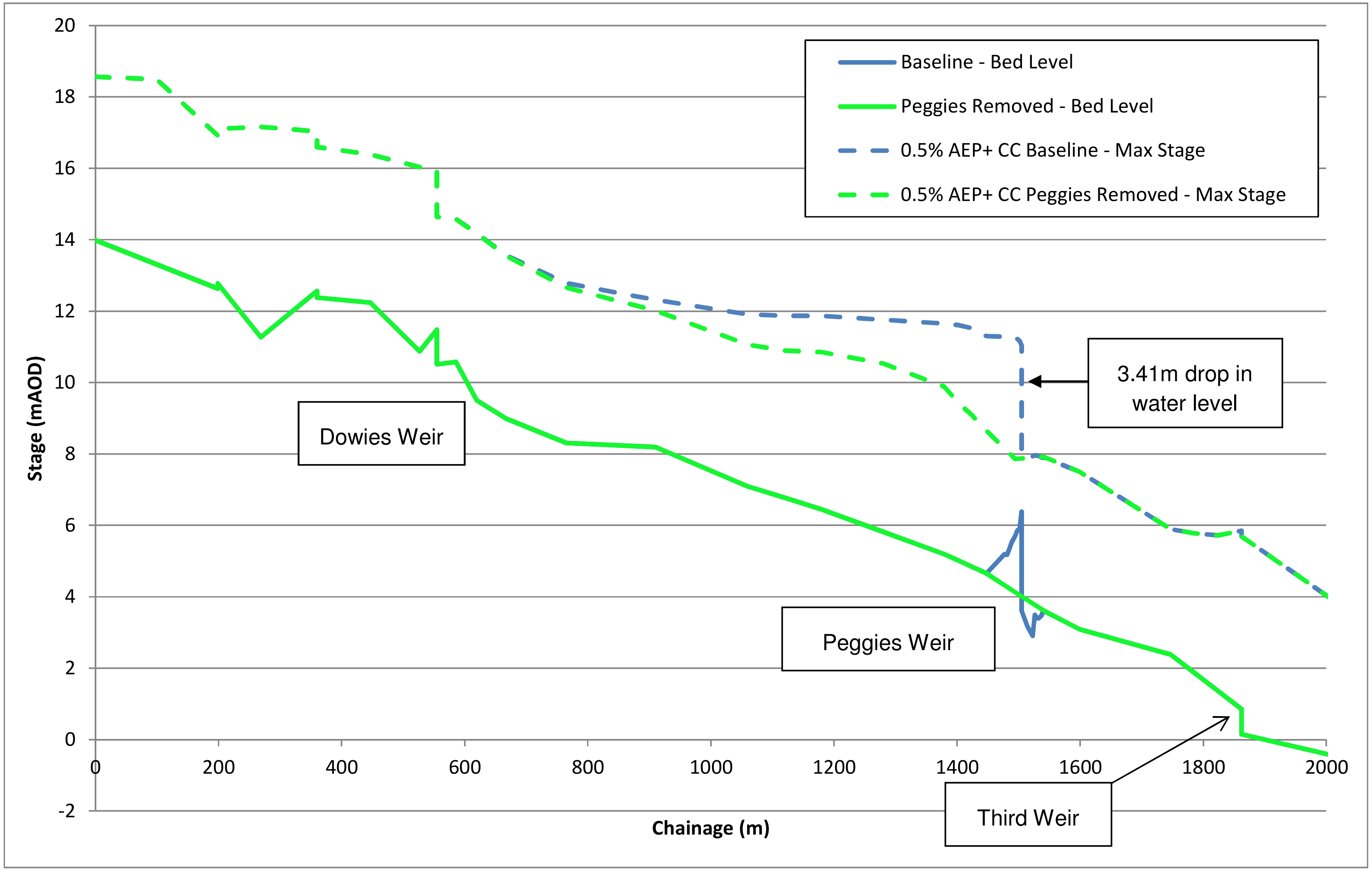
Figure 5.6: Peggies Weir Removal – 0.5% AEP plus Climate Change Event, Flood Level Comparison



5.5 Dowies Weir and Peggies Weir Removal

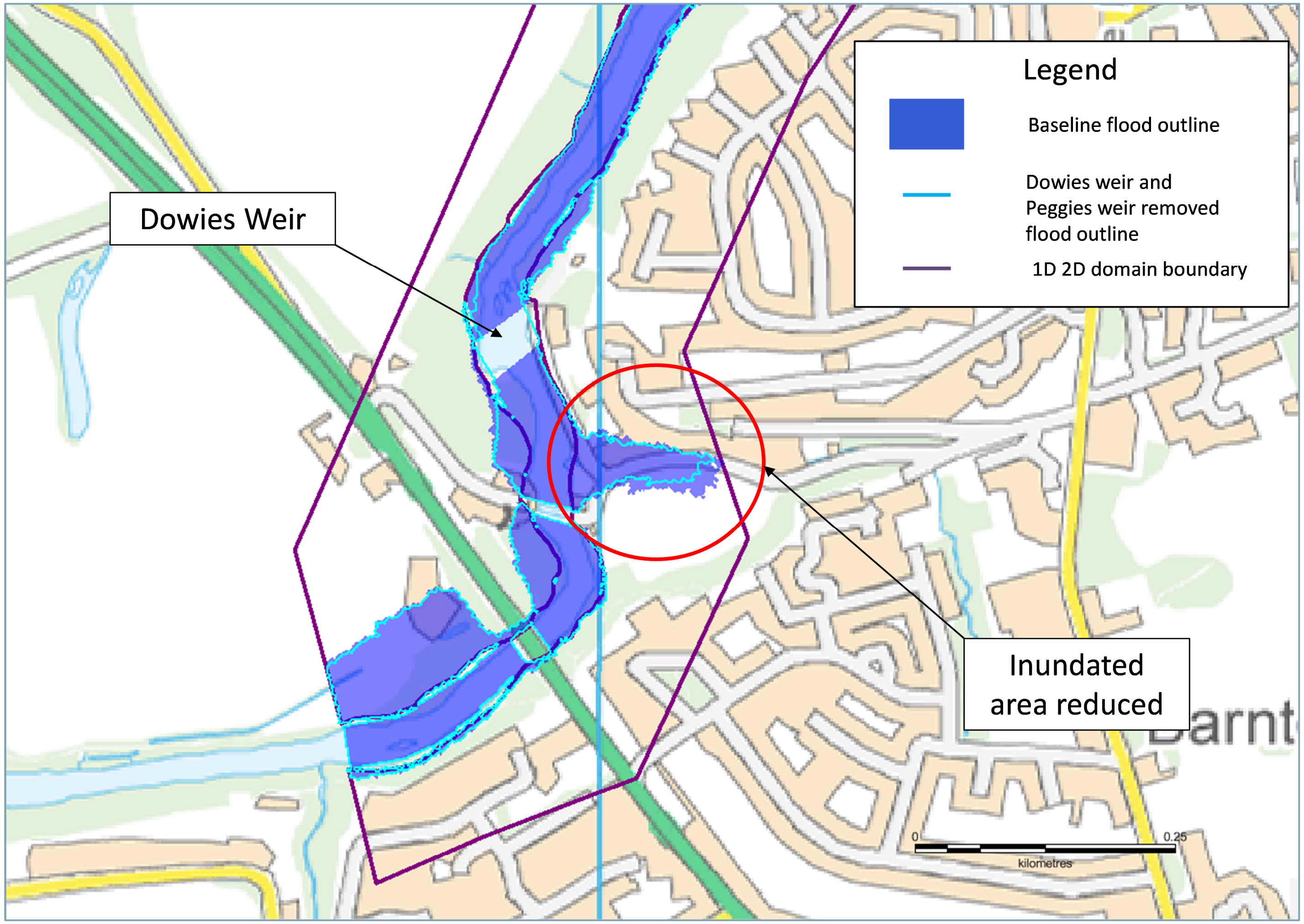
Model runs have been undertaken for the scenario where both Dowies and Peggies weirs have been removed from the model, to assess if there is a combined effect on flood risk from removing both structures.

Figure 5.7 and Figure 5.8 show a comparison of the modelled flood extent for the 0.5% AEP plus climate change event between the baseline scenario and the scenario with both weirs removed. Figure 5.9 shows the comparison of bed levels and peak water levels in the River Almond for these scenarios in a long section plot.

The reduction in inundated area after removal of both weirs is very similar to the combined impact of removing each of the weirs individually as shown in the scenarios presented in Section 5.3 and 5.4 above. This is also shown in the water level results presented in the long section plot and the tabulated water level results in Table 5.1 in Section 5.7.

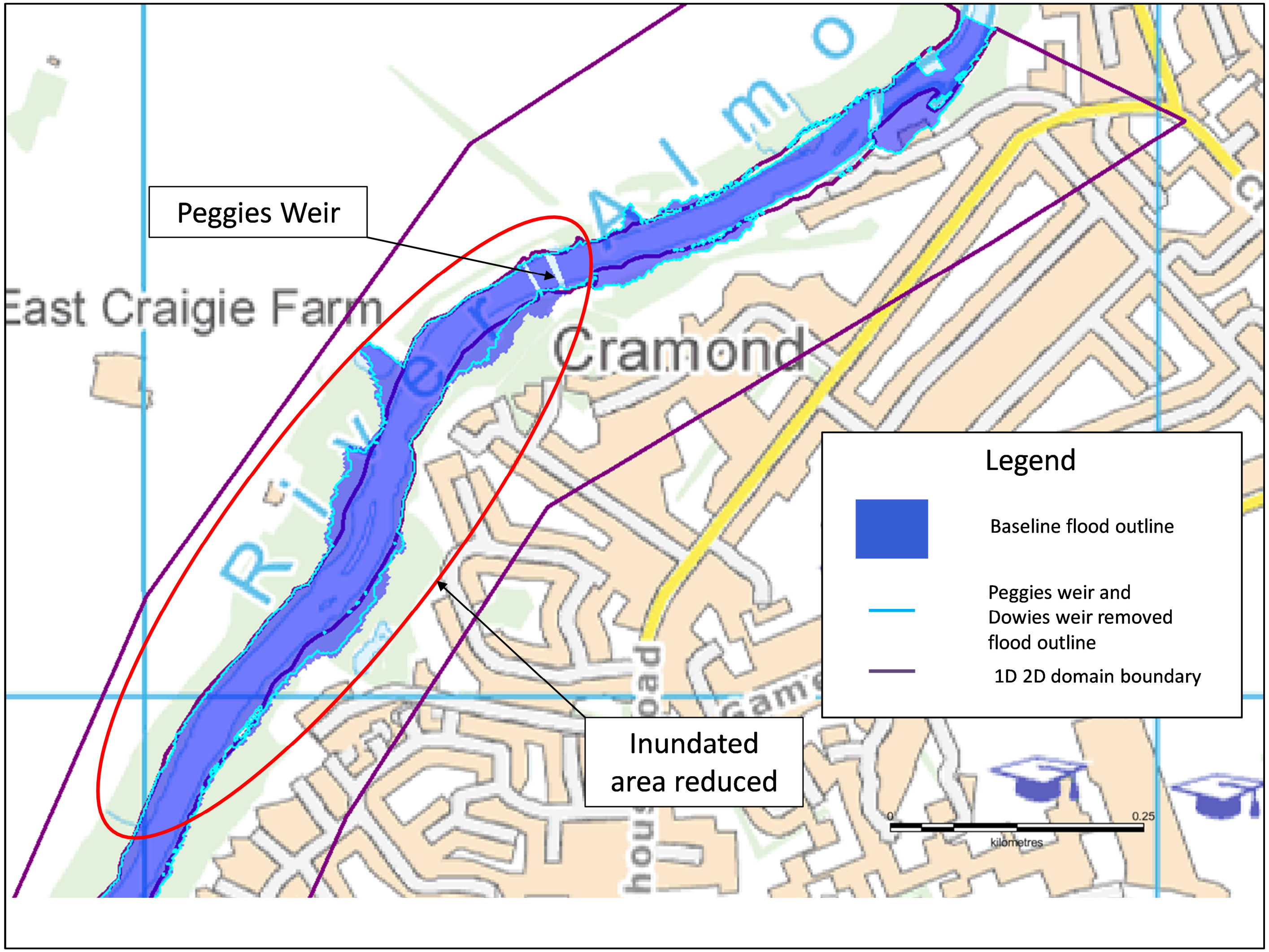
The map figure and the graph show that the weirs are acting independently to influence water levels in the River Almond and therefore a combination weir removal scenario is not perceived to offer any additional benefits in any reduction in localised flood risk.

Figure 5.7: Dowies Weir and Peggies Weir Removal, upstream – 0.5% AEP plus Climate Change Event, Flood Extent Comparison



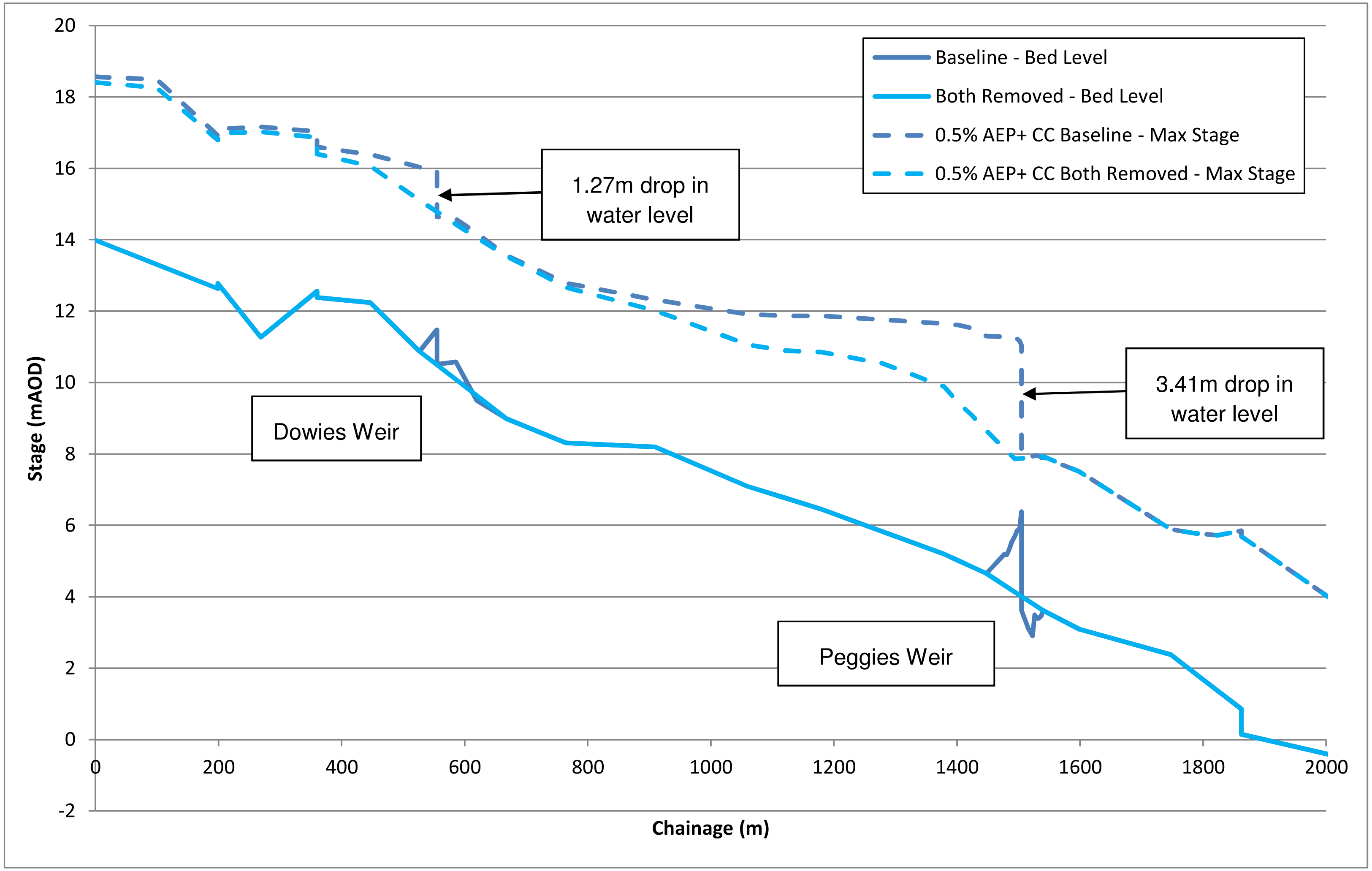
Source: Contains Ordnance Survey data © Crown Copyright and database right 2014

Figure 5.8: Dowies Weir and Peggies Weir Removal, downstream – 0.5% AEP + Climate Change – Flood extent comparison



Source: Contains Ordnance Survey data © Crown Copyright and database right 2014

Figure 5.9: Dowies Weir and Peggies Weir Removal – 0.5% AEP plus Climate Change Event, Flood Level Comparison



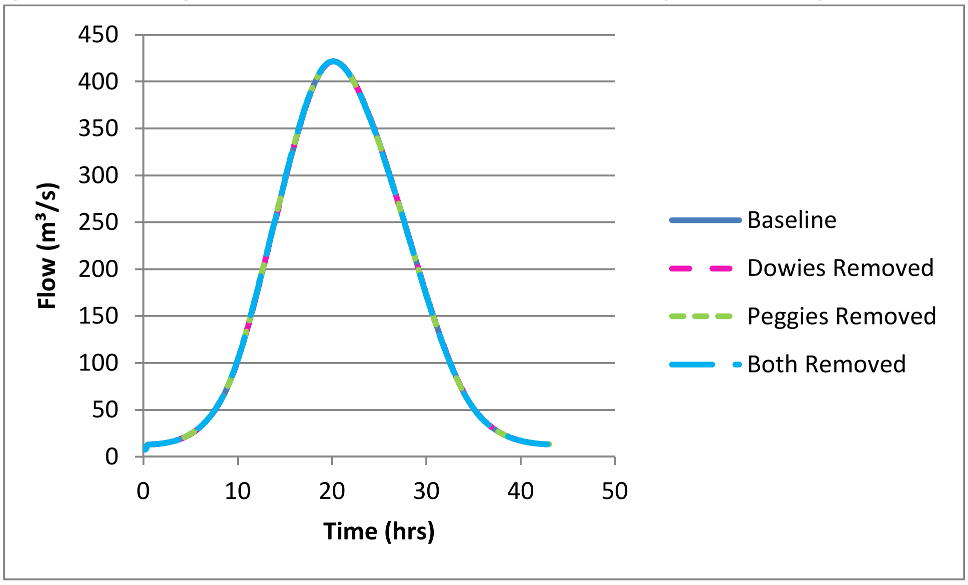
5.6 Downstream Impacts of Weir Removal

The flood extent and longitudinal water level plots in Sections 5.3-5.5 show little evidence of increased water levels downstream of the weirs under the weir removal scenarios and hence no increase in flood risk. To confirm this, flows at the downstream boundary have been compared for each scenario and are presented in Figure 5.10 and Figure 5.11 for comparison.

The first plot shows the full outflow hydrograph at the downstream boundary. The second plot presents the peak only to show the small differences in the hydrograph due to the different weir removal scenarios. Although the differences in the hydrographs are small, the trend is as expected from removing these weirs i.e. the peak flow is higher and reaches the downstream boundary marginally quicker due to the reduced attenuation upstream.

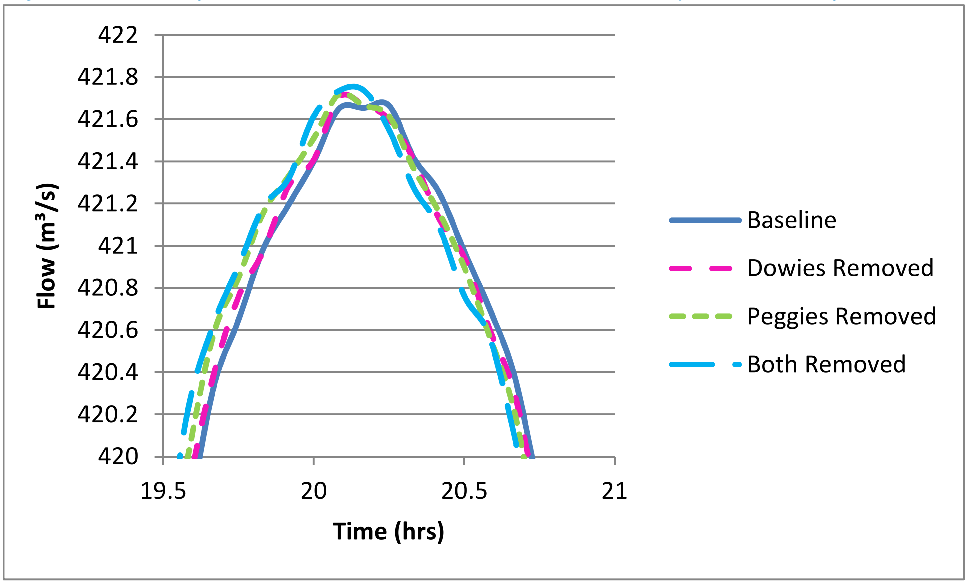
The differences in the peak outflows between these graphs are less that 0.02% when compared to the baseline, which is within the modelling error and is therefore considered negligible, confirming that weir removal has a negligible downstream impact on flood risk.

Figure 5.10: Comparison of Flows at the Downstream Boundary – 0.5% AEP plus Climate Change Event



Source: Mott MacDonald, 2014

Figure 5.11: Comparison of Flows at the Downstream Boundary – 0.5% AEP plus Climate Change Event



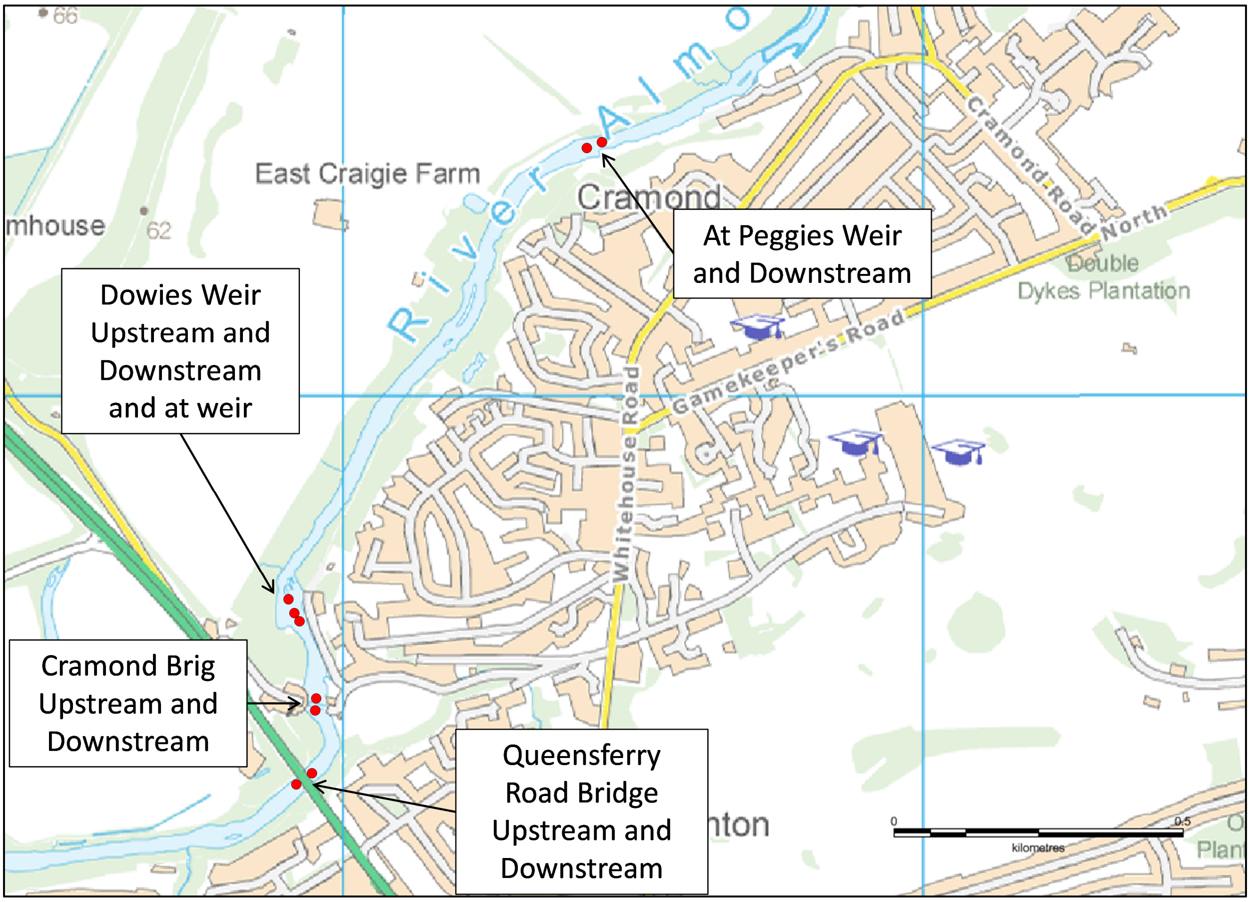
Source: Mott MacDonald, 2014

In general the modelled results produced show water levels in the River Almond acting as would be expected from weir removal, with depths decreasing upstream of the weirs and flow velocities increasing through river reaches where the weirs have been removed. Inundated areas are shown to reduce with weir removal indicating a reduction in flood risk. The results show there is minimal impact on the water levels downstream of the weirs, meaning removal of the weirs will not increase fluvial flood risk downstream.

5.7 Tabulated Water Level Results

Modelled flood water levels have are presented in Table 5.1 at pertinent locations along the modelled extent of the River Almond. Figure 5.12 shows the locations where results have been extracted from the model.

Figure 5.12: Locations where modelled results are presented



Source: Contains Ordnance Survey data © Crown Copyright and database right 2014

Table 5.1: 0.5% AEP plus Climate Change Event- Tabulated Results

Location	Baseline	Dowies weir removed		Peggies weir removed		Both weirs removed	
	Peak Level (mAOD)	Peak Level (mAOD)	Difference (m)	Peak Level (mAOD)	Difference (m)	Peak Level (mAOD)	Difference (m)
Upstream of Queensferry Road Bridge	**16.92**	16.79	**-0.13**	16.92	**0.00**	16.79	**-0.13**
Downstream of Queensferry Road Bridge	**17.11**	16.99	**-0.12**	17.11	**0.00**	16.99	**-0.12**
Upstream of Cramond Brig	**17.03**	16.87	**-0.16**	17.03	**0.00**	16.87	**-0.16**
Downstream of Cramond Brig	**16.60**	16.40	**-0.19**	16.60	**0.00**	16.40	**-0.20**
Upstream of Dowies Weir	**16.04**	15.11	**-0.93**	16.04	**0.00**	15.11	**-0.93**
At Dowies Weir	**15.92**	14.65	**-1.27**	15.92	**0.00**	14.65	**-1.27**
Downstream of Dowies Weir	**14.56**	14.30	**-0.26**	14.56	**0.00**	14.30	**-0.26**
At Peggies Weir	**11.28**	11.28	**0.00**	7.87	**-3.41**	7.87	**-3.41**
Downstream of Peggies Weir	**7.90**	7.90	**0.00**	7.92	**0.02**	7.92	**0.02**

Source: Mott MacDonald 2014

5.8 Level of Uncertainty

Several sources of uncertainty in the model have been identified which may impact the results of the modelling.

The underlying DTM for the 2D domain is based on LiDAR DTM data of 2m resolution, which has a quoted vertical accuracy of between 0.15m and 0.25m. In urban areas, areas of steep gradient and areas of dense vegetation cover the accuracy is reduced due to the high degree of filtering that is required to provide ground levels required for modelling. Aerial photography was examined to check areas of LiDAR DTM have been filtered correctly and ensure no artificial barriers to flow are present due to the remnants of vegetation or buildings, which can remain following the use of automated filtering algorithms.

It is noted that areas surrounding the River Almond channel are both steep and are covered with dense vegetation which could impact the accuracy of the LiDAR DTM data and therefore increase uncertainty in exchange of flows between the 1D ISIS and 2D TUFLOW model domains. To reduce the uncertainty, data gathered during the topographic survey has been used to 'ground truth' the LiDAR DTM by reviewing floodplain and bank crest levels. The vertical accuracy of the topographic survey data used to represent in channel geometry is ±10mm and is not impacted by vegetation cover.

The weir removal scenarios have been schematised based on an assumption of the channel cross section geometry and channel gradient after weir removal. The assumption is made that the channel would revert to a constant gradient between the cross sections upstream and downstream of the weir. Embedded in this assumption is the consideration that the weirs are restricting the movement of mobile bed material at their upstream face which will be washed out after their removal. The aim of the assumed channel gradient is to replicate channel conditions a significant period after weir removal, where legacy impacts of the weir have been fully removed from the channel, with channel flows and processes returned to a natural state. No detailed modelling of sediment transport and channel bed erosion and therefore its impact on channel gradient has been undertaken and therefore there is some uncertainty in the assumptions made above. The assumptions should not alter the conclusions taken from the model as changes to peak water levels are as expected from removing a controlling structure from the watercourse.

Model calibration has not been undertaken and therefore there is residual uncertainty in the model, particularly for the highest flow design events considered. However, the scale of the uncertainty in the hydrology was reduced with the use of local gauged data from the River Almond watercourse. To further reduce uncertainty in the modelled flood levels, a series of sensitivity analyses has been undertaken with the approach and results from these model runs presented in Section 5.9.

5.9 Sensitivity Analysis

In lieu of any appropriate data to undertake a model calibration exercise, sensitivity analyses have been undertaken to give an indication of the level of confidence that can be placed in the modelled results. The analysis considers the effects on water level estimates obtained from the computational hydraulic model, when specific model parameters are altered.

Adjustments were made to the following model parameters for the 0.5% AEP plus climate change allowance fluvial event.

- Inflows increased by 20% for the 0.5% AEP plus climate change scenario;
- Manning's 'n' roughness coefficients increased by 20%;
- Downstream extreme tidal boundary level increased to the 0.1% AEP level.

Figure 5.13 shows the impact on extent when compared to the baseline scenario. Table 5.2 shows the impact on water levels at pertinent locations when compared to the baseline scenario.

Model inflows have been derived using standard methodologies stated in the FEH (Institute of Hydrology, 1999) using local data where appropriate. It is recognised that there is some uncertainty in the modelled inflows and therefore the model has been rerun using 0.5% AEP plus climate change flows increased by 20%. The modelled results show an increase in water levels for the whole modelled reach, between 0.33m and 0.63m depending on location.

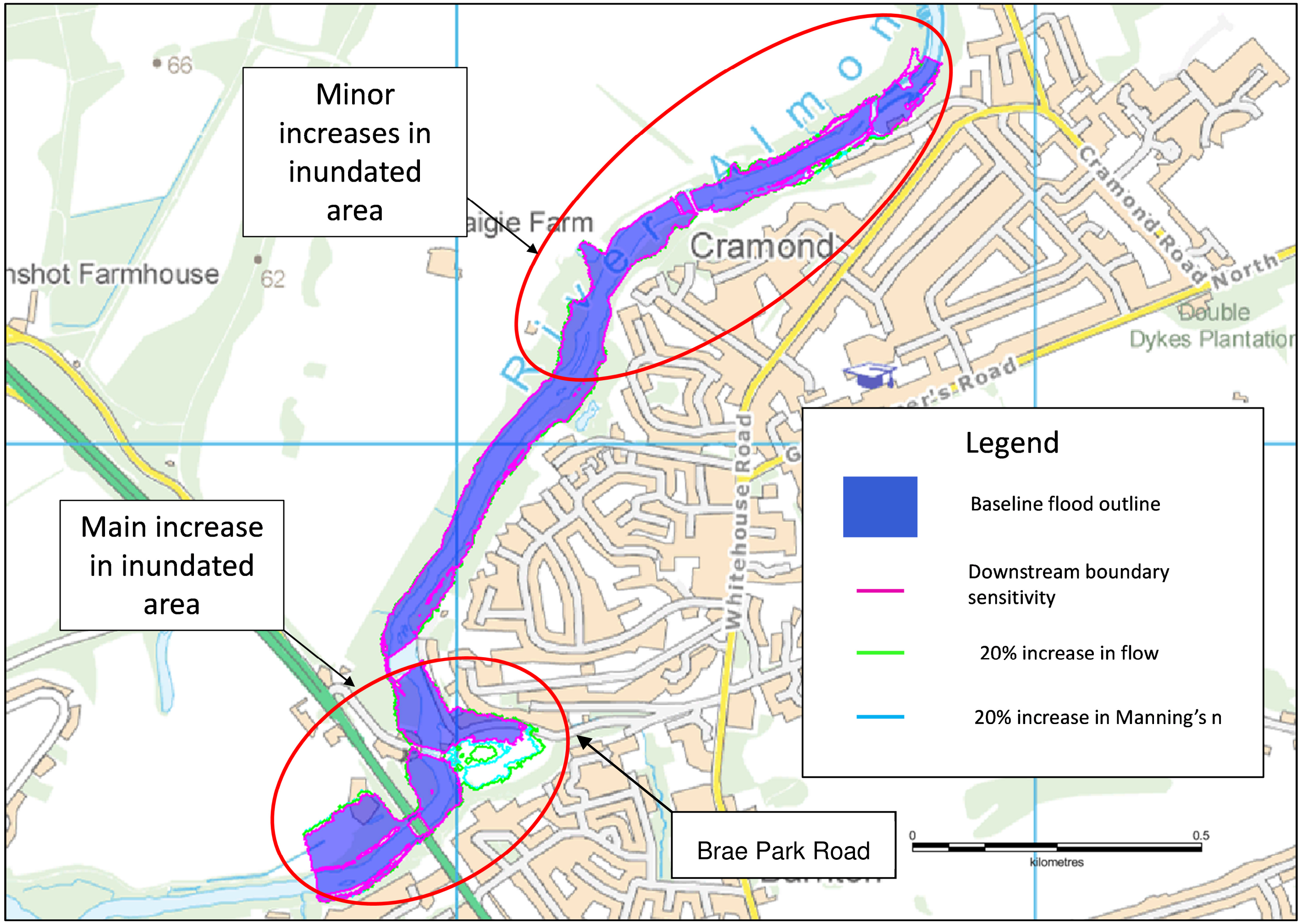
In order to assess the sensitivity of the model to the chosen roughness values, the model has been rerun using 0.5% AEP plus climate change flows with all Manning's 'n' coefficients in both the 1D and 2D model domains increased by 20%. The modelled results show an increase in water levels for the majority of the modelled reach to a maximum of 0.59m depending on location.

To assess the sensitivity of the model to changes at the downstream boundary, the extreme tidal level has been increased from the 0.5% AEP event (3.98mAOD) to the 0.1% AEP event (4.20mAOD). The modelled results show an increase in water level of 0.22m at the boundary, with the increase diminishing to zero approximately 250m upstream.

The changes in water levels from the Manning's 'n' and model inflow increase sensitivity runs are relatively large, but are expected due to the geometry of the River Almond channel in the modelled reach. The lack of floodplain areas and the fact that the watercourse is contained in a deep valley means that increased flows and reduced flow velocities from the increased channel roughness directly impact the modelled flood levels. As presented in Figure 5.13, the large increases in modelled flood levels do not translate into major increases in flood extent, with only the inundated area at Brae Park Road increasing.

The sensitivity runs are considered to show extreme circumstances. The relative insensitivity of the flood extents for extreme conditions increases confidence in the baseline model where the majority of flows are contained within the River Almond valley. As the removal of the two weirs has been shown to generate reductions in peak water levels in the river, there is no impact from the sensitivity runs on flood risk for this reach of the watercourse.

Figure 5.13: Sensitivity Run Flood Extent Comparison



Source: Mott MacDonald, 2014. Contains Ordnance Survey data © Crown Copyright and database right 2014

Table 5.2: Comparison of sensitivity run water levels

Node Location	Baseline	Downstream Boundary Sensitivity		Inflow increased by 20%		Manning's n increased by 20%	
	Peak Level (mAOD)	Peak Level (mAOD)	Difference (m)	Peak Level (mAOD)	Difference (m)	Peak Level (mAOD)	Difference (m)
Upstream of Queensferry Road Bridge	16.92	16.92	0.00	17.25	0.33	17.33	0.41
Downstream of Queensferry Road Bridge	17.11	17.11	0.00	17.48	0.38	17.49	0.38
Upstream of Cramond Brig	17.03	17.03	0.00	17.59	0.56	17.22	0.19
Downstream of Cramond Brig	16.60	16.60	0.00	16.96	0.37	16.80	0.20
Upstream of Dowies Weir	16.04	16.04	0.00	16.40	0.36	16.09	0.05
At Dowies Weir	15.92	15.92	0.00	16.27	0.35	15.92	0.00
Downstream of Dowies Weir	14.58	14.58	0.00	15.03	0.45	14.86	0.28
At Peggies Weir	11.20	11.20	0.00	11.71	0.50	11.23	0.03
Downstream of Peggies Weir	7.91	7.89	-0.02	8.28	0.37	8.22	0.31

Source: Mott MacDonald, 2014

5.10 Model Proving

5.10.1 Run Performance

The performance of a model run has been assessed based on the 1D model domain convergence in ISIS and the cumulative mass balance error from the 2D model domain in TUFLOW. Model convergence and mass balance error values enable a judgement to be made on the stability of the model and hence its ability to deliver an accurate estimate of water levels. A summary of the run performance for the models is provided in Table 5.3.

Table 5.3: Run Performance

Model Build	AEP	1D Model Convergence	2D Cumulative Mass Balance Error (%)
Baseline	50%	Fully Convergent	0.03
	20%	Fully Convergent	-0.02
	10%	Fully Convergent	-0.01
	4%	Fully Convergent	-0.09
	2%	Fully Convergent	-0.16
	1%	Fully Convergent	-0.16
	0.5%	Fully Convergent	-0.15
	0.5%+CC	Fully Convergent	-0.14
Dowies Removal	50%	Fully Convergent	-0.01
	20%	Fully Convergent	-0.02
	10%	Fully Convergent	0.01
	4%	Fully Convergent	-0.05
	2%	Fully Convergent	-0.18
	1%	Fully Convergent	-0.18
	0.5%	Fully Convergent	-0.16
	0.5%+CC	Fully Convergent	-0.15
Peggies Removal	50%	Fully Convergent	0.10
	20%	Fully Convergent	-0.04
	10%	Fully Convergent	0.00
	4%	Fully Convergent	-0.11
	2%	Fully Convergent	-0.21
	1%	Fully Convergent	-0.21
	0.5%	Fully Convergent	-0.19
	0.5%+CC	Fully Convergent	-0.17

Model Build	AEP	1D Model Convergence	2D Cumulative Mass Balance Error (%)
Peggies and Dowies Removal	50%	Fully Convergent	-0.14
	20%	Fully Convergent	-0.08
	10%	Fully Convergent	0.04
	4%	Fully Convergent	-0.07
	2%	Fully Convergent	-0.26
	1%	Fully Convergent	-0.24
	0.5%	Fully Convergent	-0.20
	0.5%+CC	Fully Convergent	-0.18
Inflow increased by 20%	0.5%+CC	Fully Convergent	-0.13
Manning's n coefficients increased by 20%	0.5%+CC	Fully Convergent	-0.11
0.1% AEP tidal boundary applied	0.5%+CC	Fully Convergent	-0.14

No model runs show problems with model convergence or mass balance, which increases confidence in the modelled results. None of the runs shows a cumulative mass balance error greater than +/-0.25%, showing the model is stable through the run length for all of the scenarios considered.

6 Conclusions and Recommendations

The modelled results show that removal of either Dowies weir or Peggies weir, or the combined removal of both structures will result in a reduction in fluvial flood levels upstream of the weir locations, thereby reducing flood risk from the River Almond to the surrounding area. There is negligible impact on water levels downstream of the weirs if the structures are removed. Despite significant reductions in modelled flood levels, there is only a marginal impact on flood extent. The topography of the River Almond channel valley along this reach, with steep valley walls ensures flows are generally contained, with little in the way of floodplain inundation.

The 0.5% AEP plus climate change allowance results show three properties at risk of fluvial flooding. For the weir removal scenarios the marginal reduction in inundation extent means that these properties remain at risk of flooding.

Weir removal has a positive impact on modelled flood levels upstream of the weirs, though only marginal impact on flood extents, and a neutral impact downstream of the weirs. Model outflows have been compared between the baseline, as-now conditions and weir removal scenarios with little impact on the outflow hydrograph from the model supporting the fact that there is a neutral downstream impact on flood risk.

The model has been constructed to produce conservative modelled flood levels through selection of inflows, downstream boundary and Manning's roughness coefficients. Results of the sensitivity analysis show that modelled water levels are sensitive to increasing inflows and increases in Manning's 'n' roughness coefficients, though the flood extent is insensitive for the majority of the modelled reach. This is due to the geometry of the River Almond channel and its location in a steep sided valley.

It is noted that the model has been constructed based on conservative estimates of inflows, channel and floodplain roughness and boundary conditions and the sensitivity runs include modelling parameters which are considered to be extreme. Confidence can therefore be held in the fact that the modelled outputs are conservative.

Modelled results show weir removal will have a positive impact on flood risk, but removal should only be considered after detailed consideration of, amongst other key issues, the potential bank erosion and structural damage upstream of the weirs where flood flow velocities will increase.

It is recommended that further model runs are undertaken when there is a full understanding of how the channel geometry will change after weir removal. It may also be worthwhile undertaking further model runs to understand flood risk at different stages of erosion and deposition after the weir removal to ensure there is not a period during which flood risk is increased.

7 Bibliography

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