Clachan Flood Study

Phase 2 Report
Baseline Conditions

Argyll and Bute Council

December 2019

Quality information

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Revision History

Revision	Revision date	Details	Authorized	Name	Position
0	29.12.18	First draft for client review	SH	Sally Homoncik	Senior Geomorphologist
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2	13.12.19	Final	DHS	Debbie Hay Smith	Principal Hydrologist

Distribution List

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Table of Contents

Glossary/Abbreviations

ABC	Argyll & Bute Council
AEP	Annual Exceedance Probability – the probability that a value is exceeded in any year
AMAX	Annual Maximum series – a data record of the highest flow in each water year (Oct – Sept)
DTM	Digital Terrain Model
FC	Forestry Commission
FEH	Flood Estimation Handbook. Published 1999, contains standard recommended hydrological estimation methods
NFM	Natural Flood Management
NGR	National Grid Reference
OS	Ordnance Survey
PVA	Potentially Vulnerable Area – areas identified to be vulnerable to flooding as defined by Flood Risk Management (Scotland) Act 2009
QMED	Median annual flood – the median of the AMAX series, having a return period of 1 in 2 years or an AEP of 50%
ReFH2	Revitalised Flood Hydrograph method version 2
SEPA	Scottish Environment Protection Agency
SMD	Soil Moisture Deficit – the amount of rainfall the soil can absorb before becoming saturated

1. Introduction

AECOM have been commissioned by Argyll and Bute Council (ABC) to undertake a Flood Study for the town of Clachan to assess the fluvial risk to the village. The project is being undertaken using a phased approach, and includes the following main tasks:

- Phase 1 – Data review and gap analysis
- Phase 2 – Baseline existing conditions
- Phase 3 – Long list to short list screening
- Phase 4 – Option development and modelling

Phase 1 was completed in July 2018, and this report outlines the work undertaken for Phase 2.

2. Background to the Project

The study area is outlined in Figure 2-1 below and encompasses the town of Clachan and the A83 to the east. The main fluvial flood risk to the town is from the Clachan Burn, which flows east to west through the town, joined by its tributary, the Allt Mor, downstream of the weir at the western end of the town at national grid reference (NGR) NR 76315 56075. A number of small natural lochs are present in the catchment areas of both watercourses, and a large raised reservoir, Loch Ciaran is located to the south of Clachan on the Allt Mor. Both catchments also include large areas of managed forestry, and a further commercial forestry plantation is planned within the Allt Mor catchment at Talatoll. The wider catchment areas of both watercourses are also considered in the study.

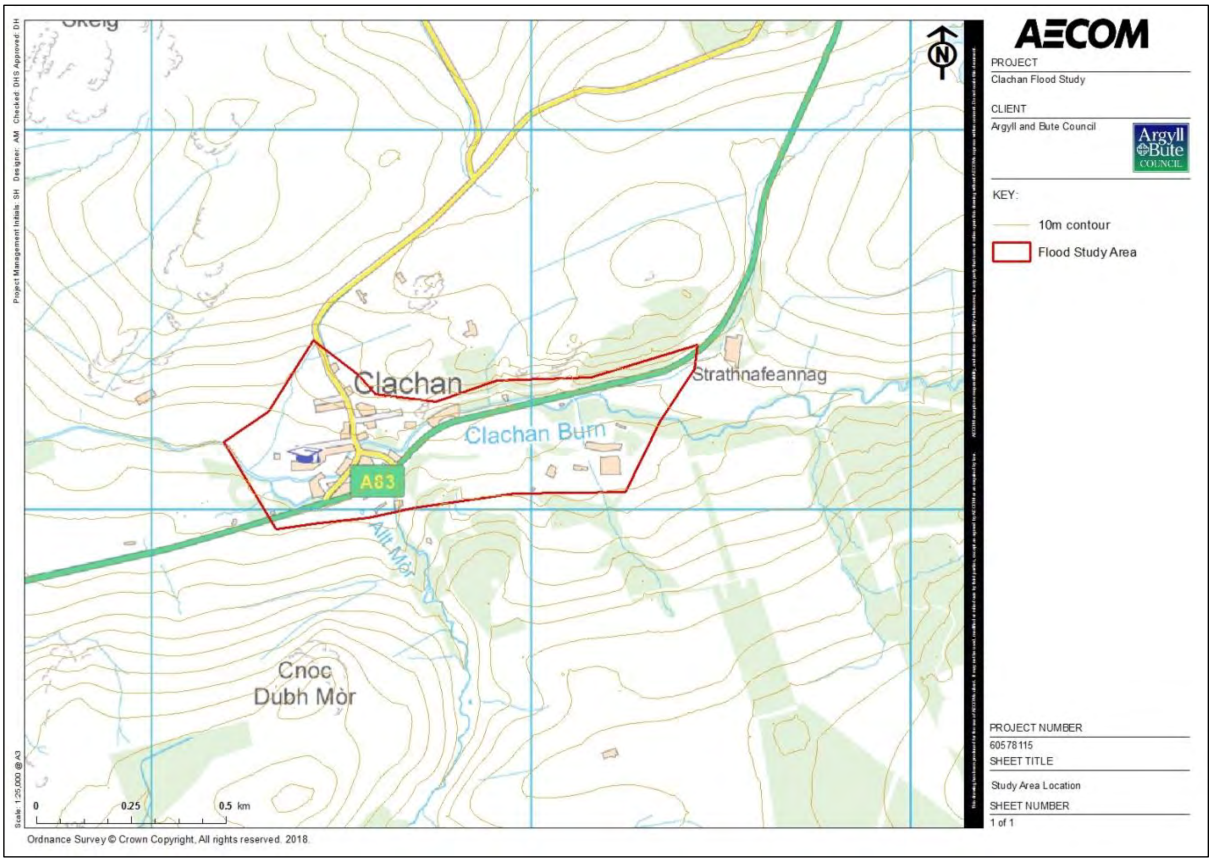

Figure 2-1 Map of Study Area

2.1 Potentially Vulnerable Area

The Highland and Argyll Flood Risk Management Strategy[1] (the Strategy) drawn up under the Flood Risk Management (Scotland) Act 2009, identified Potentially Vulnerable Areas (PVAs) around Lochgilphead and Tarbert. PVAs are defined as catchment units identified to be significantly impacted by flooding either now, or in the future as a result of climate change. Following identification of these areas the Strategy set out a long term vision to reduce overall flood risk in each PVA via a summary of objectives and measures. The Strategy was used as the basis of the Highland and Argyll Local Flood Risk Management Plan (LFRMP) developed by Local Authorities to identify how actions would be implemented. This Flood Study forms one of ABC's statutory obligations to deliver under the LFRMP.

Clachan is not currently covered by a PVA due to the small number of affected properties, but this study has been commissioned as a result of the recent flood history and with a view to developing Natural Flood Management (NFM) options for the catchments. The area is included in the 2018 revision of the PVAs[2]. Flooding in Clachan is predominantly fluvial, with two main watercourses in the study area; the Clachan Burn and the Allt Mor.

2.2 Flooding issues

Fluvial flooding is predicted by the SEPA online Flood Risk Management Maps[3] (FRM maps), from the Clachan Burn and Allt Mor, encroaching on the A83 and properties within Clachan. These maps are backed up with the historic flood reports, where flooding has been noted at properties, community facilities, utilities, agricultural land and transport networks.

3. Data Collation

3.1 Hydrometric data

Hydrometric data to use for model calibration/verification is limited. There are no historic flow or level gauges on either the Clachan Burn or the Allt Mor. However, level gauges were installed on both watercourses, along with a raingauge in each of the two catchment areas in 2018. This data can be used to calibrate the model if further flood events occur during the study period as well as being of use for the future. There is also no sub-daily rainfall data available (apart from the new raingauges). Daily rainfall totals are available at Portachoillan for 1989 – 2006 (excluding 2004). The gauge was then moved to Ronachan and daily data is available for 2007 onwards. The location of these gauges is shown in Figure 3-1 below and it can be seen that they are both nearer the coast and subsequently at lower altitudes than the majority of the watercourse catchments. The rainfall data cannot therefore be said to be representative of the catchment rainfall.

[1] Highland and Argyll Flood Risk Management Strategy, SEPA, December 2015
[2] https://sepaweb.maps.arcgis.com/apps/Cascade/index.html?appid=323aefe6abcf4f859acabca202c30f9b – accessed 19.12.2018
[3] http://map.sepa.org.uk/floodmap/map.htm

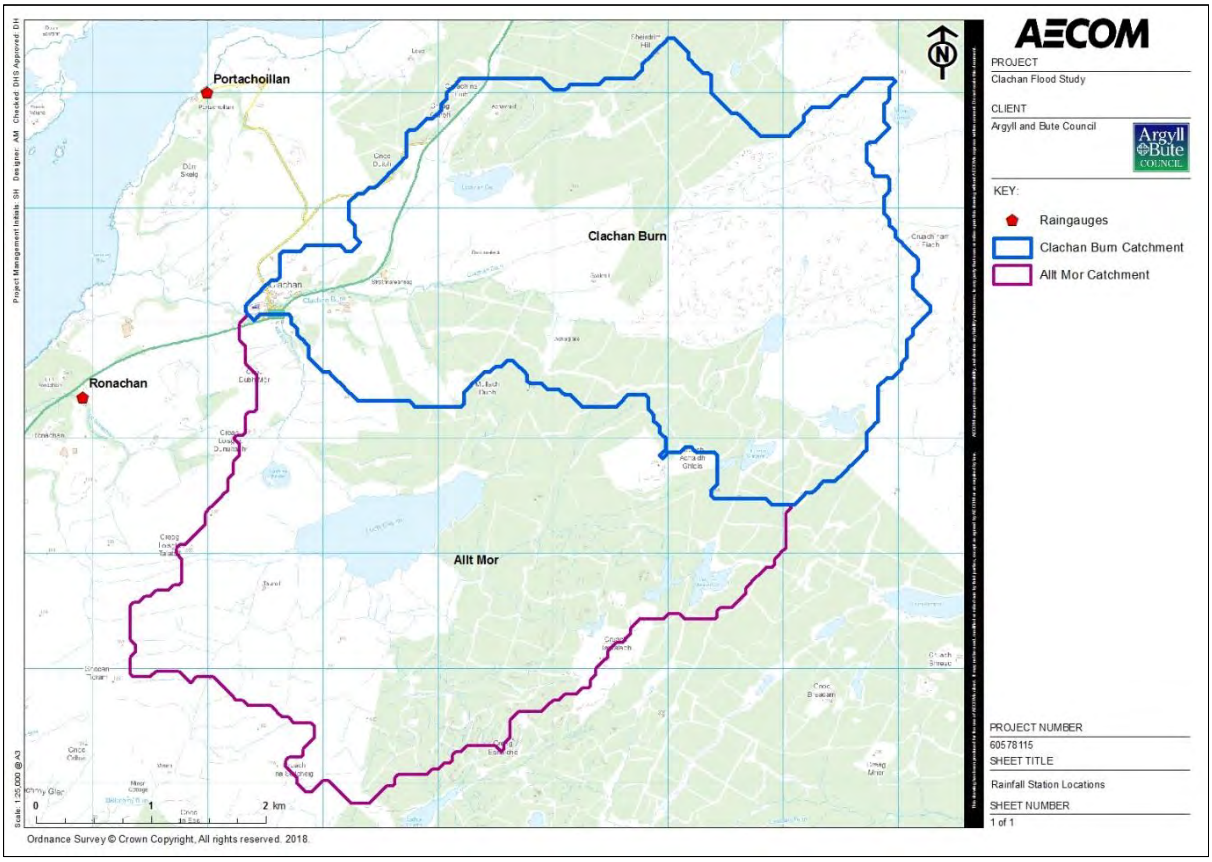

Figure 3-1 Location of rain gauges in relation to catchment areas

The lack of sub daily rainfall and flow or level data means that full model calibration will not be possible. The daily rainfall is also not wholly representative of the catchment rainfall, limiting even high level verification. However we have used this daily rainfall to investigate any trends that could feed into the assessment of catchment changes and the recent flood events (see **Error! Reference source not found.**).

ABC has sourced alternative sub daily rainfall data and radar data for some of the more recent flood events. We have also collated photographs and anecdotal evidence from the Clachan community for these flood events, which have been used for high level verification of the model.

3.2 Spatial data

Spatial data was gathered from a range of sources during Phase 1 of the study. This was used to better understand the catchment characteristics and to develop our modelling approach. This included:

- NEXTMap to use as a base for the Digital Terrain Models.
- Soils type location and NFI Forestry GIS datasets were provided by Forestry Commission (FC) to feed into the catchment model.
- Scottish Wetland Inventory.
- BGS superficial and bedrock geology.
- Landuse – roads, buildings, waterbodies etc. derived from OS Vector Map to refine land uses and roughness values.
- River survey obtained in August 2018 to represent the channels.

4. Catchment Characteristics

4.1 Historic maps

Online historic maps from National Library of Scotland were used to review the changes in the study areas that have occurred over time and that may have had an influence on flooding.

Some expansion of Clachan has occurred since the early OS maps, with a number of newer properties constructed, although the road layout and watercourse crossings are broadly unchanged. Much of the Allt Mor and Clachan Burn catchments have remained similar to today, with the lochs, planform and location of the confluence shown on first edition OS mapping (1873). However, commercial forestry was introduced in the catchments in the 1960s, which will have had some impact on the hydrology of the watercourses. The A83 crossings over the Clachan Burn and Allt Mor were constructed in 1965. The A83 runs close to the Clachan Burn for approximately 600m, and is likely to have had an impact on the morphology and hydrology of the burn in this reach.

Figure 4-1 Historic Mapping of Clachan 1873 (Reproduced with the permission of the National Library of Scotland)

Assessment of the watercourse catchments indicates that there have been historic changes that are likely to have affected their response to rainfall events. This includes the intensification of drainage networks in some areas for grazing land. Figure 4-2 and Figure 4-3 highlight this point, where current drainage ditches are extensive in a boggy area of land to the east of Loch nan Gad.

Figure 4-2 Historical mapping of part of the Clachan Burn catchment 1873 (Reproduced with the permission of the National Library of Scotland)

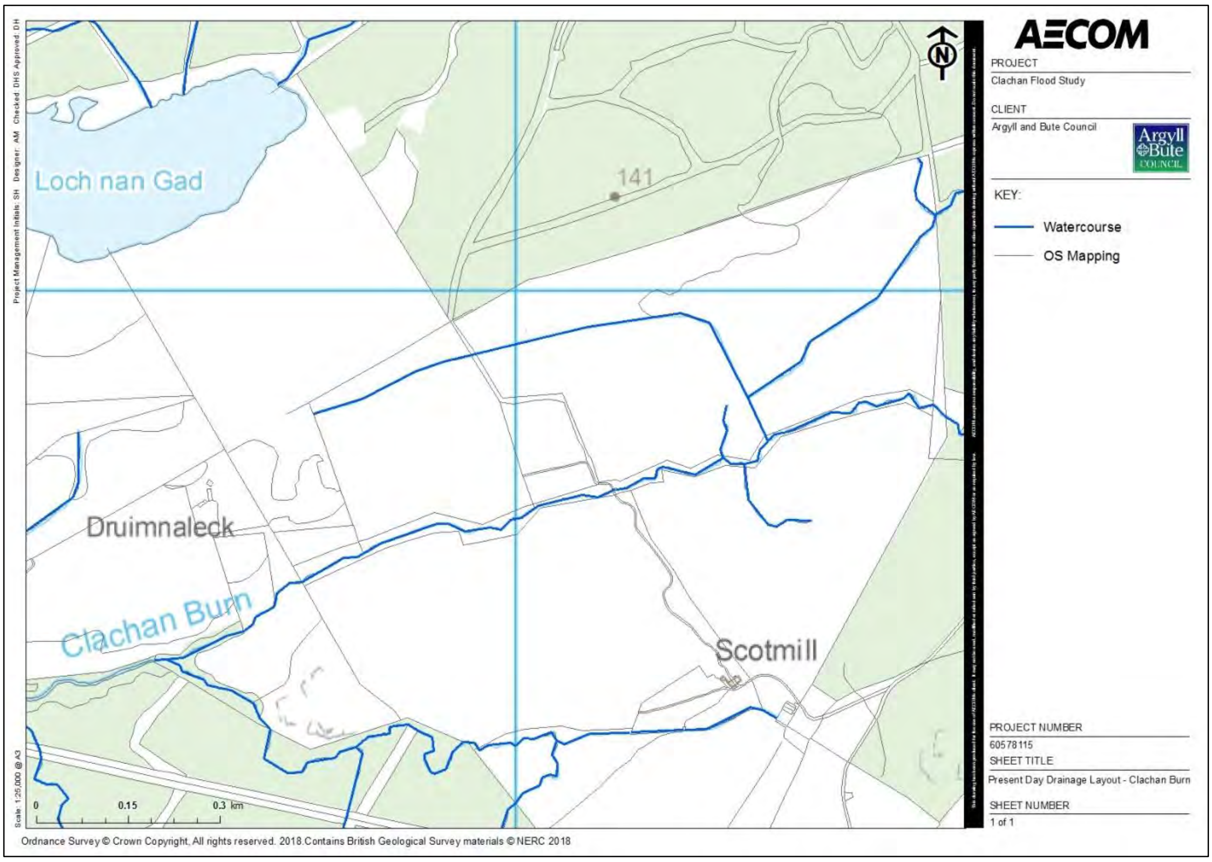

Figure 4-3 Present day mapping of area of Clachan Burn catchment shown in Figure 4-2 (OS map)

A similar pattern is seen within the Allt Mor catchment, downstream of Loch Ciaran as indicated by Figure 4-4 and Figure 4-5.

Figure 4-4 Historical mapping of part of the Allt Mor catchment 1873 (Reproduced with the permission of the National Library of Scotland)

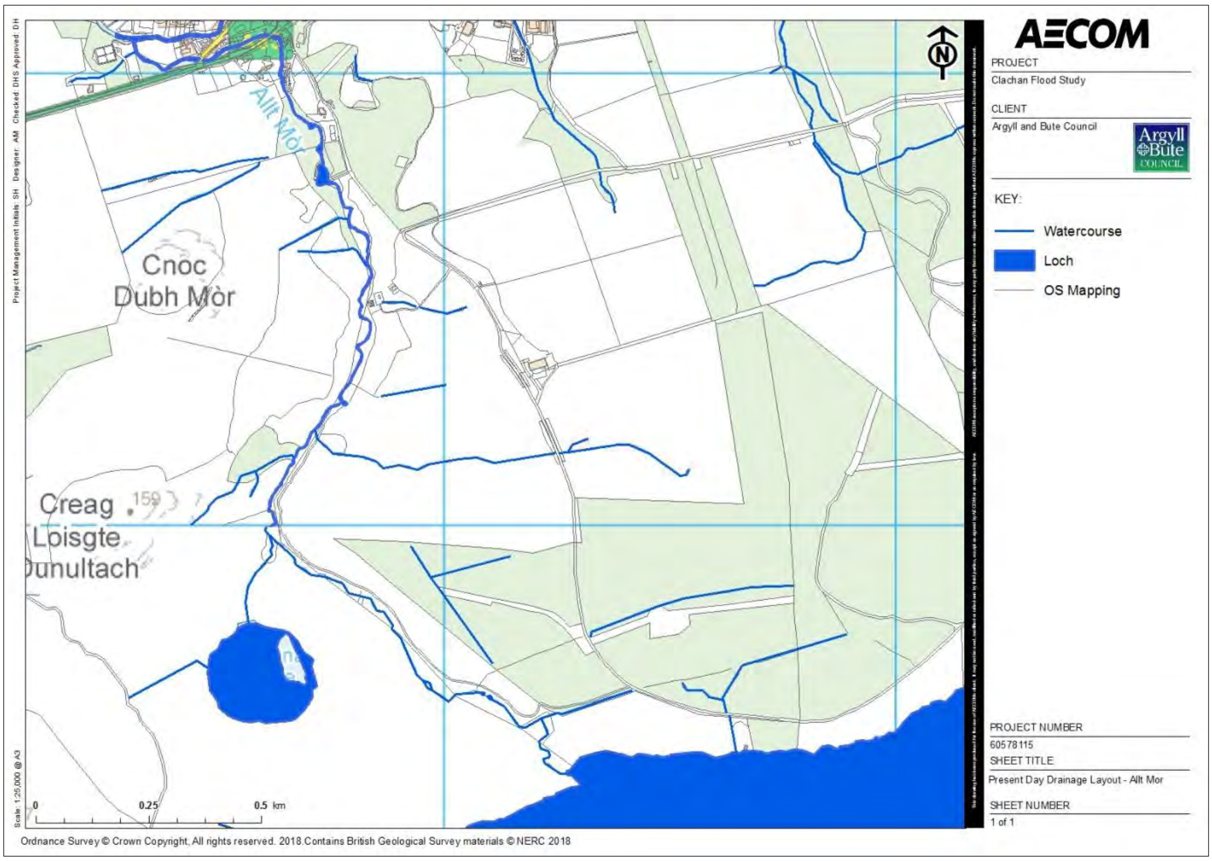

Figure 4-5 Present day mapping of area of Allt Mor catchment shown on Figure 4-4

4.2 Land use management

30% of Clachan Burn catchment is currently planted with commercial forestry, and 33% of the Allt Mor catchment. A further plantation is planned at Talatoll, of which around 199 hectares (ha) lies within the Allt Mor catchment equating to a further 15% of the catchment (forested areas only included, Figure 4-6).

It is understood the FC have analysed the management of the commercial forestry and consider it is generally in line with good practice which is intended to ensure that there is no detrimental impact on drainage or soil erosion. However, forest management is a concern for residents and there has anecdotally been less good forestry practice in some areas and there is a perception in the community that felling has exacerbated flooding.

In the upland areas of the catchment, those areas that are not forested are generally moorland, some areas of which are used for rough grazing (Figure 4-7). Closer to the town, landuse within the catchment consists of pasture fields that rise steeply from the valley floor (Figure 4-8).

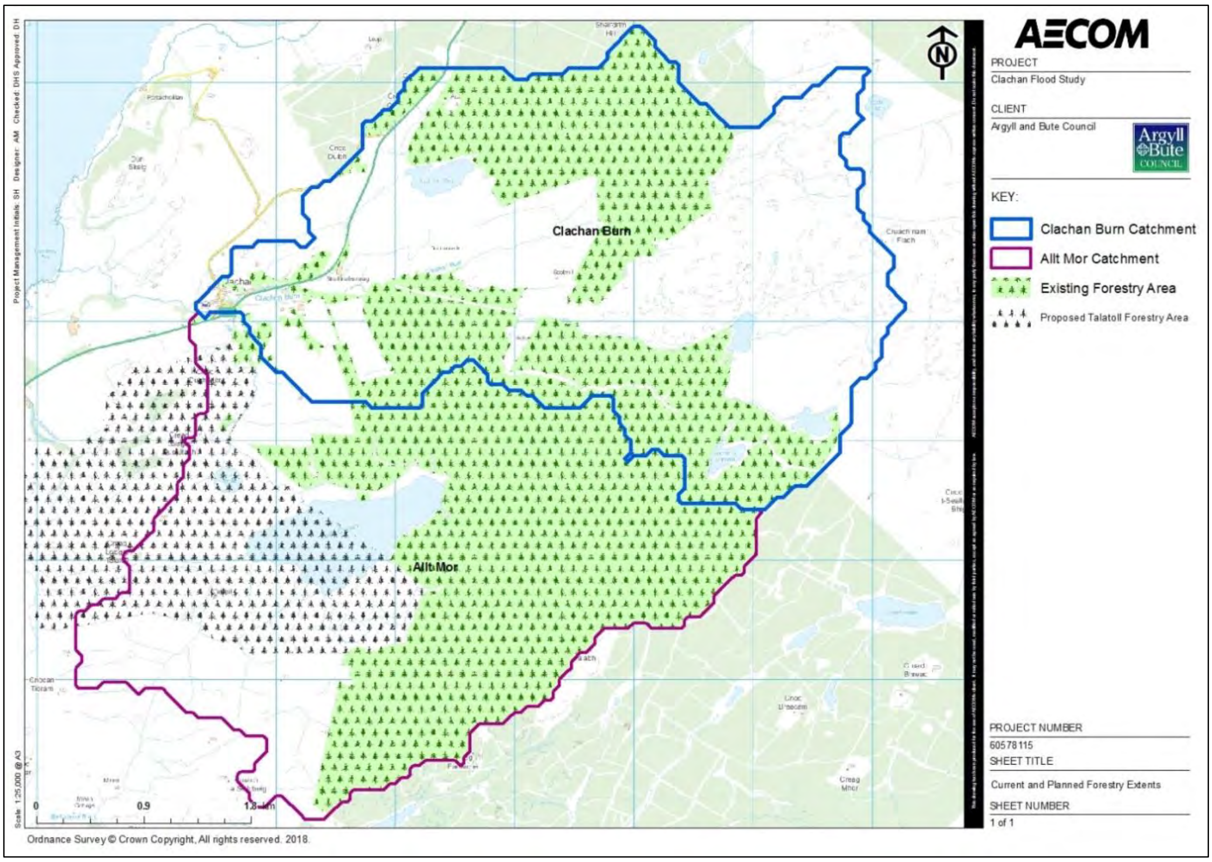

Figure 4-6 Current and planned forested areas within Clachan Burn and Allt Mor catchment areas

It is important to note that the nature of forestry management is cyclical; with felling and replanting being undertaken in different areas on a year by year basis. For example, significant felling was carried out in 2005 and 2006 (103.3ha) which was then restocked in 2008 and 2009. By contrast, small scale felling occurred in 2009 and restocked in 2010. Higher proportions were then felled and restocked from 2012 – 2016 at around 50ha per year. Therefore, the work undertaken to represent the baseline case will be a snapshot in time.

Land use of the area will be significantly changed by the proposed Talatoll Estate New Woodland Creation Scheme. The proposed scheme will be over an area of approximately 528 ha; the prime objective will be to produce a commercial crop of Sitka spruce, whilst creating a planting design which complies with the UK Forestry Standard (UKFS). This will cover approximately 15% of the Allt Mor catchment, so has potential to impact run off, interception and soil losses in the catchment. Given the scale of the proposal it will be included in this assessment as a future land use scenario.

The upper 85% of the Allt Mor catchment area drains to Loch Ciaran, about 60% of which is currently forested. The Talatoll plantation will increase this to nearly 75%. Downstream of Loch Ciaran, the catchment is mainly uncultivated rough grazing/moorland (Figure 4-9).

4.3 Clachan Burn catchment general description

The Clachan Burn generally flows east to west, draining a total catchment area of 14.1km^2 to its confluence with the Allt Mor, downstream of Clachan village. 30% of this area is currently planted with commercial forestry. Altitudes fall from a maximum of around 266 mAOD in the headwaters, to 18 mAOD at Clachan village.

The headwaters of the watercourse in the east arise from mainly peaty moorland, with extensive wetland vegetation and forestry (at various stages, Figure 4-7). The land is used for grazing and some cultivation in less wet areas, and there is riparian woodland from Clachan upstream to around the boundary wall crossing the burn at Druimnaleck (NS 78648 56521).

From the watershed boundary, the watercourse gradient is a relatively flat 1%. This steepens in the middle section to around 3% and is joined by another small tributary from the south. The final section upstream of the forestry road is very steep at 7%. The gradient then flattens and another tributary joins from the felled catchment area to the north. The watercourse then travels through peat bog (with drainage channels) and wet heathland at a gradient of approximately 2.5%. The lower reach of the watercourse runs along the valley at a fairly regular gradient of around 2.3% before reaching the village. A large tributary draining the catchment area from the south east totalling 4.5 km^2, much of which is forested, drains through Loch Chorra-riabhaich and joins the Clachan Burn approximately 2km upstream of the village.

Figure 4-7 Upland moorland, Clachan Burn catchment

In the lower catchment, hillslopes become steeper and the land is more intensively managed (Figure 4-8). A number of small tributaries join the burn draining the pasture fields to the north and south, and about 700m upstream of the village, where the burn flows adjacent to the A83 road, a large tributary joins from the north. This drains a largely forested catchment area of around 2.3 km^2 through Loch nan Gad, and a further 0.5 km^2 of steep moorland/rough grazing. From Loch nan Gad, the watercourse flows south west towards the A83 at a steady gradient of around 2.5%. On reaching the A83 the watercourse flows parallel to the road down a steep gradient of around 6.5% before reaching its confluence with the Allt Mor.

Figure 4-8 Steep pasture, lower catchment area of Clachan Burn

4.4 Allt Mor catchment general description

The total catchment area of the Allt Mor to its confluence with the Clachan Burn is 13.2km^2. The watercourse generally flows south to north, joining the Clachan Burn immediately downstream of the weir at the west end of the village. Altitudes fall from a maximum of around 270 mAOD in the headwaters, to 110 mAOD at Loch Ciaran, and to 18 mAOD at Clachan village

Flows in the Allt Mor are largely dominated by the attenuating effect of Loch Ciaran, with the upper 85% of the catchment draining through the loch. 60% of the catchment area draining to Loch Ciaran is currently given to commercial forestry. Downstream of Loch Ciaran, the Allt Mor meanders northwards at a relatively gentle gradient through a broad valley, bounded by moorland, falling approximately 15m over the first 1km (Figure 4-9).

Figure 4-9 Allt Mor catchment area downstream of Loch Ciaran

Approximately 1km downstream of the dam, the gradient increases for a short section, falling by around 10m over a distance of 100m. The next 700m falls at a shallower gradient of around 2.5% before a very steep section just upstream of the A83, where the watercourse drops 15m over 100m distance. Downstream of the A83, the watercourse turns sharp westwards and flows at a shallower 1% gradient past properties in Clachan on the north bank before reaching the confluence with the Clachan Burn, downstream of the weir. Landuse in this downstream catchment is mainly moorland given to rough grazing with small areas of forestry to the south east and pasture fields close to the A83. Forested areas will increase significantly with the proposed Talatoll plantation (Figure 4-6).

4.5 Soil types

Information on soil types for the catchment was provided by the FC and soil types are shown in Figure 4-10. 85% of the catchment is covered by peaty gley soil. Gleys are highly common in Scotland and develop as a result of intermittent or permanent waterlogging. As such they tend to have low infiltration rates. They also occur where the soil is dense and water is prevented from moving through the soil. The downstream end of the Clachan catchment is dominated by Noncalcareous gleys which are similar and also poorly drained.

A small proportion of the Allt Mor catchment is dominated by blanket bog. Peat can be have highly variable properties depending on the near surface or deeper layers. However this soil type accounts for only 3% of the combined catchment so the uncertainty over its influence is not a significant consideration.

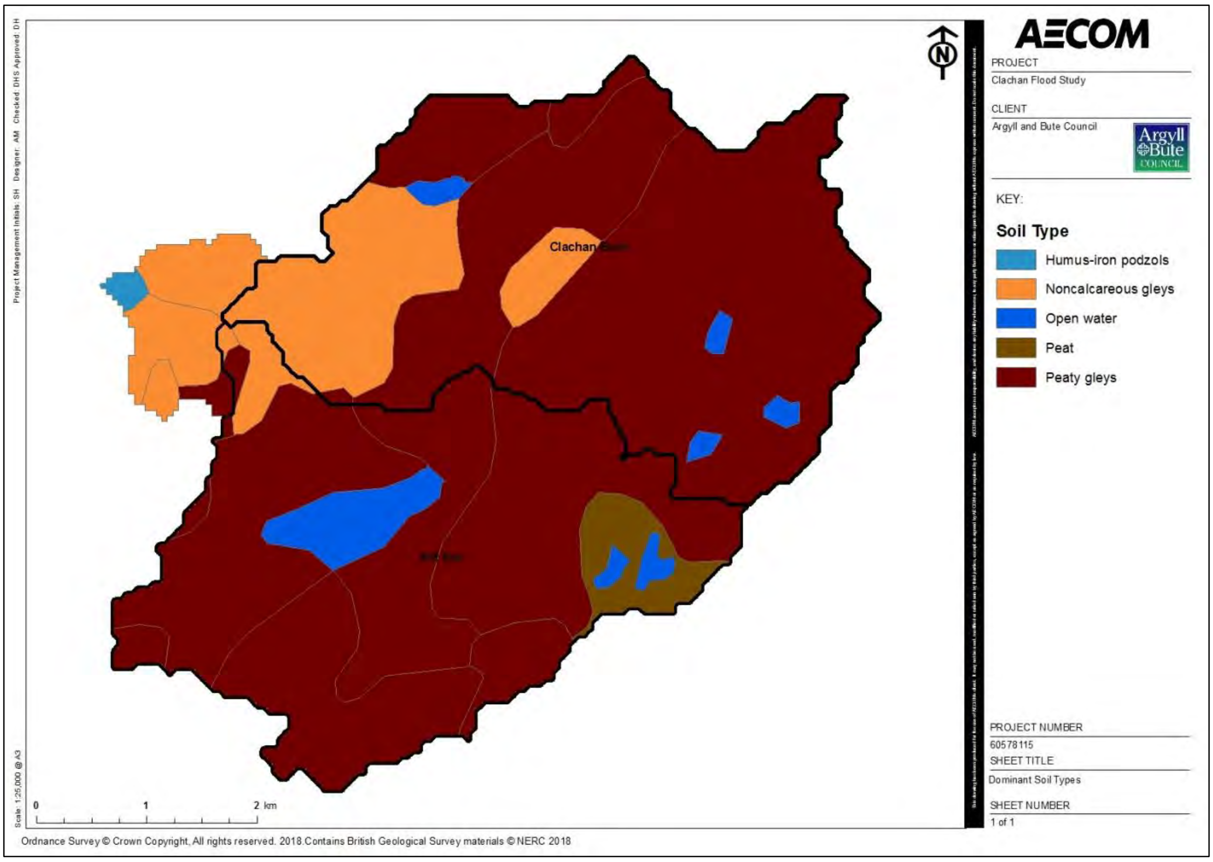

Figure 4-10 Dominant soil types across the two catchments

4.6 Bedrock and superficial geology

Bedrock geology is dominated by metamorphosed mainly Dalradian sedimentary rocks including psammite, pelite and metalimestone along with metamorphosed deep sea rocks aligned in a roughly North-South direction. Metamorphosed intrusions of basic volcanic rocks are seen trending North-South and a much younger suite of igneous dykes are seen through the catchment. Part of the Clachan Burn catchment (approx. 35%) is overlain with superficial deposits, comprising glacial till along part of the Clachan Burn valley. Much of the Allt Mor catchment downstream of Loch Ciaran is covered by glacial till (approx. 45%), and alluvium is deposited along the valley around Clachan and further downstream (see Figure 4-11 and Figure 4-12).

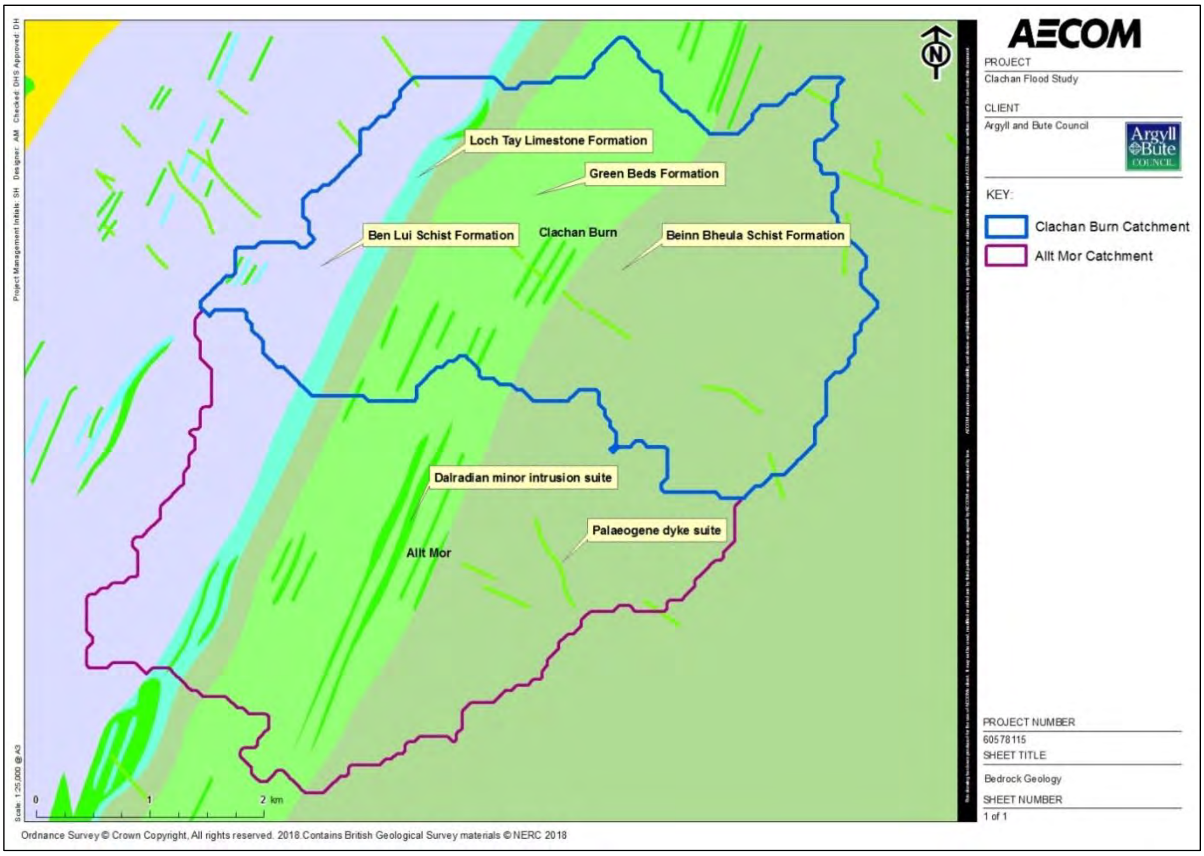

Figure 4-11 Bedrock Geology

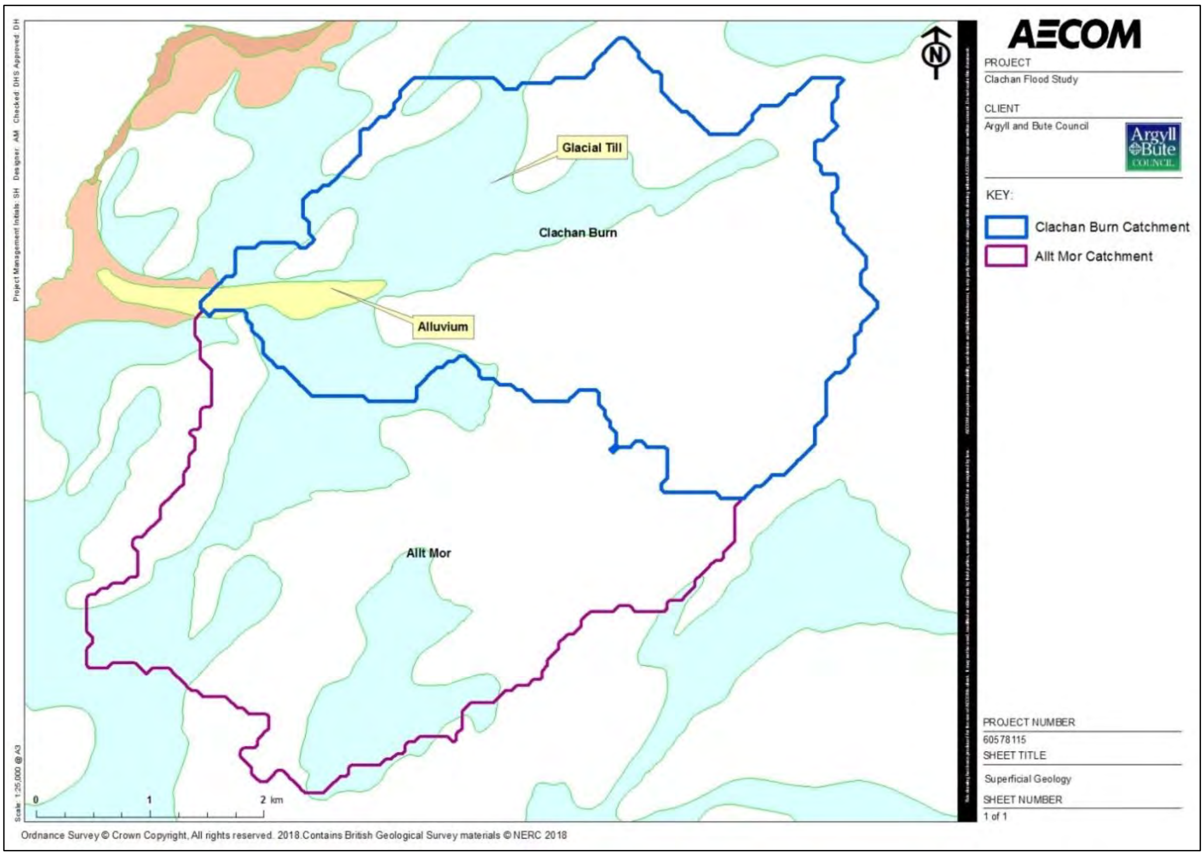

Figure 4-12 Superficial Geology

4.7 Slopes

A slope analysis was undertaken in Arc GIS using the NEXTMap DTM data to assess the likely locations of rapid runoff across the catchments. The steepest slopes in the Clachan Burn catchment (>18°) occur close to the village of Clachan, particularly on the north side of the valley (Figure 4-13). Also to the east of Balinakill House, the valley side is very steep. The shallowest slopes are seen in the middle catchment, around the confluence of tributaries close to Scotmill and to the north east of this area. The north east corner of the catchment and the area to the north of Loch Fraoich are also very flat (<2°).

In the Allt Mor catchment, the steepest slopes are along the burn downstream of Loch Ciaran, close to Clachan (Figure 4-14). Several tributaries flowing into Loch Ciaran are relatively steep (>12 °). however, the majority of the Allt Mor catchment outwith these areas has very little slope.

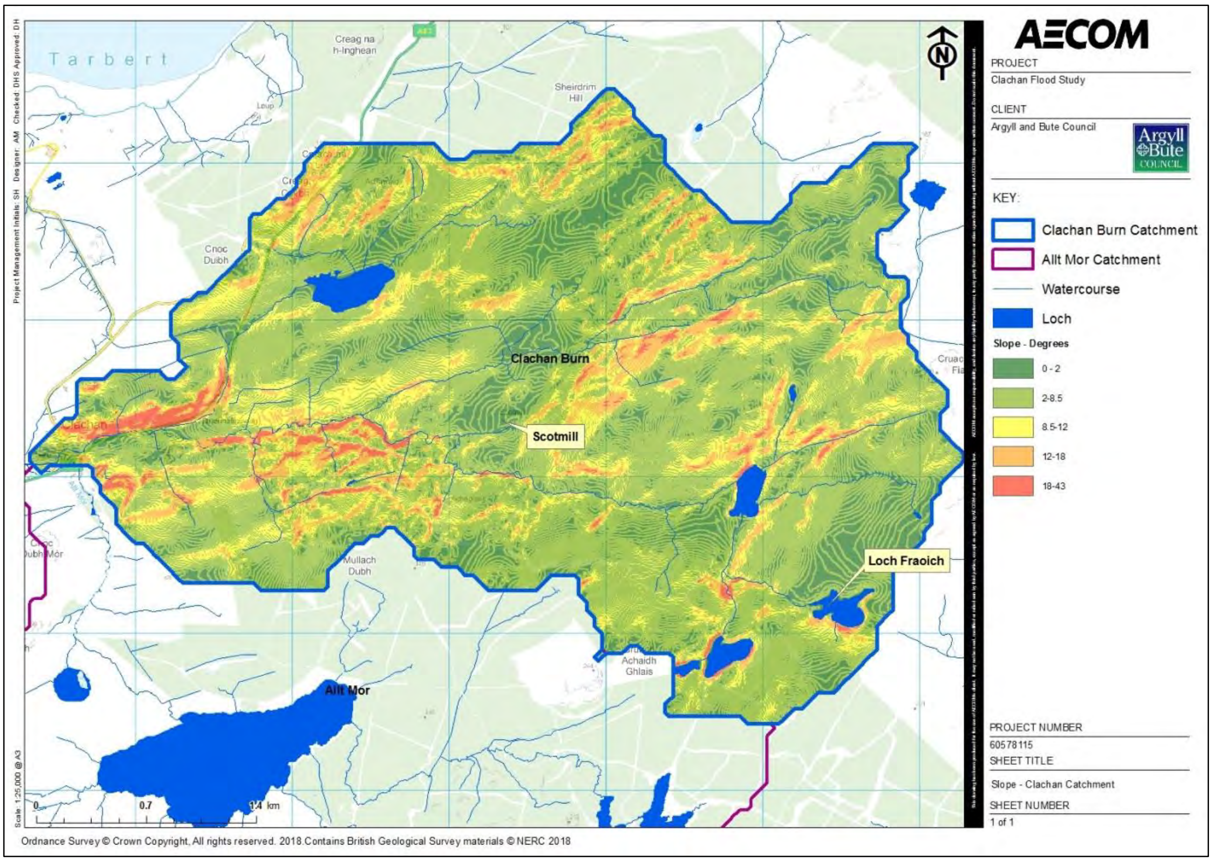

Figure 4-13 Slope steepness in Clachan Burn catchment

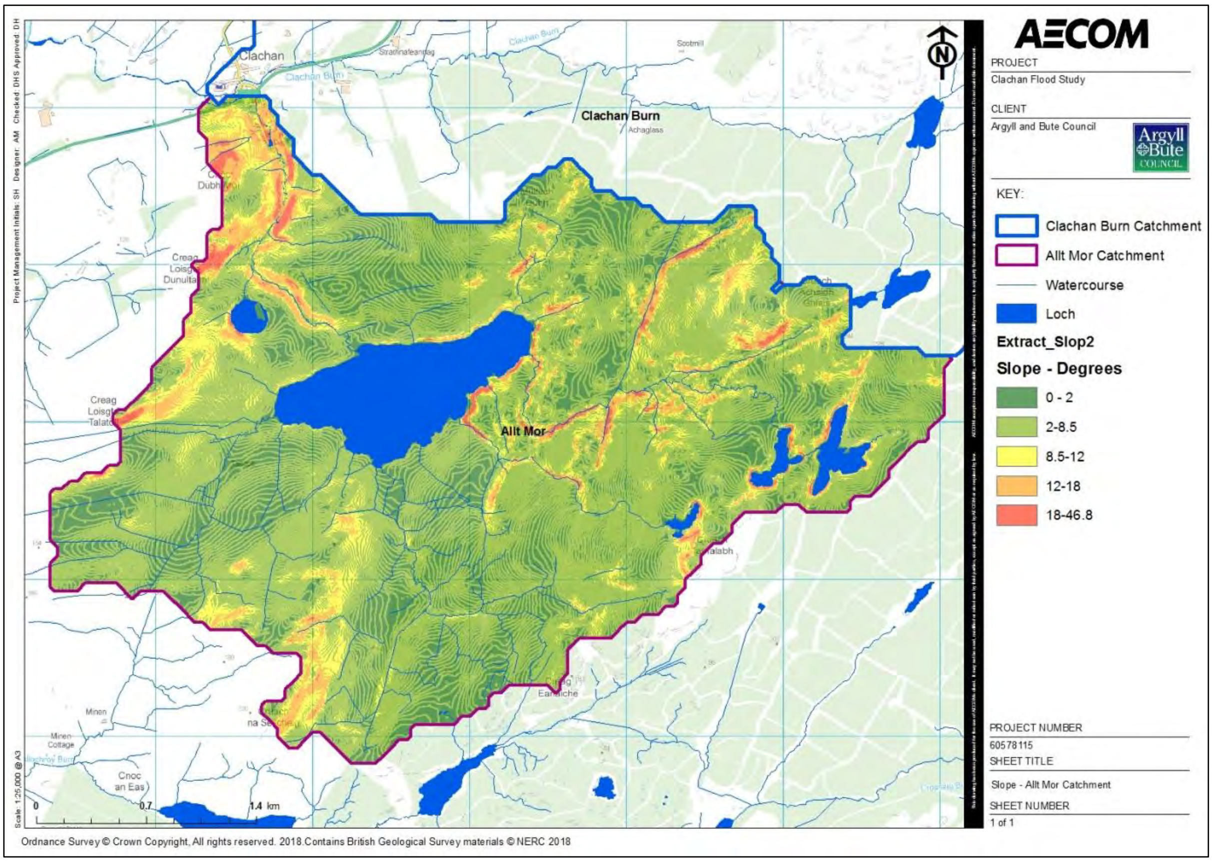

Figure 4-14 Slope steepness in Allt Mor catchment

4.8 Standing water bodies and wetlands

4.8.1 Standing water bodies

A number of lochs exist within each catchment; both natural and man-made (Figure 4-15).

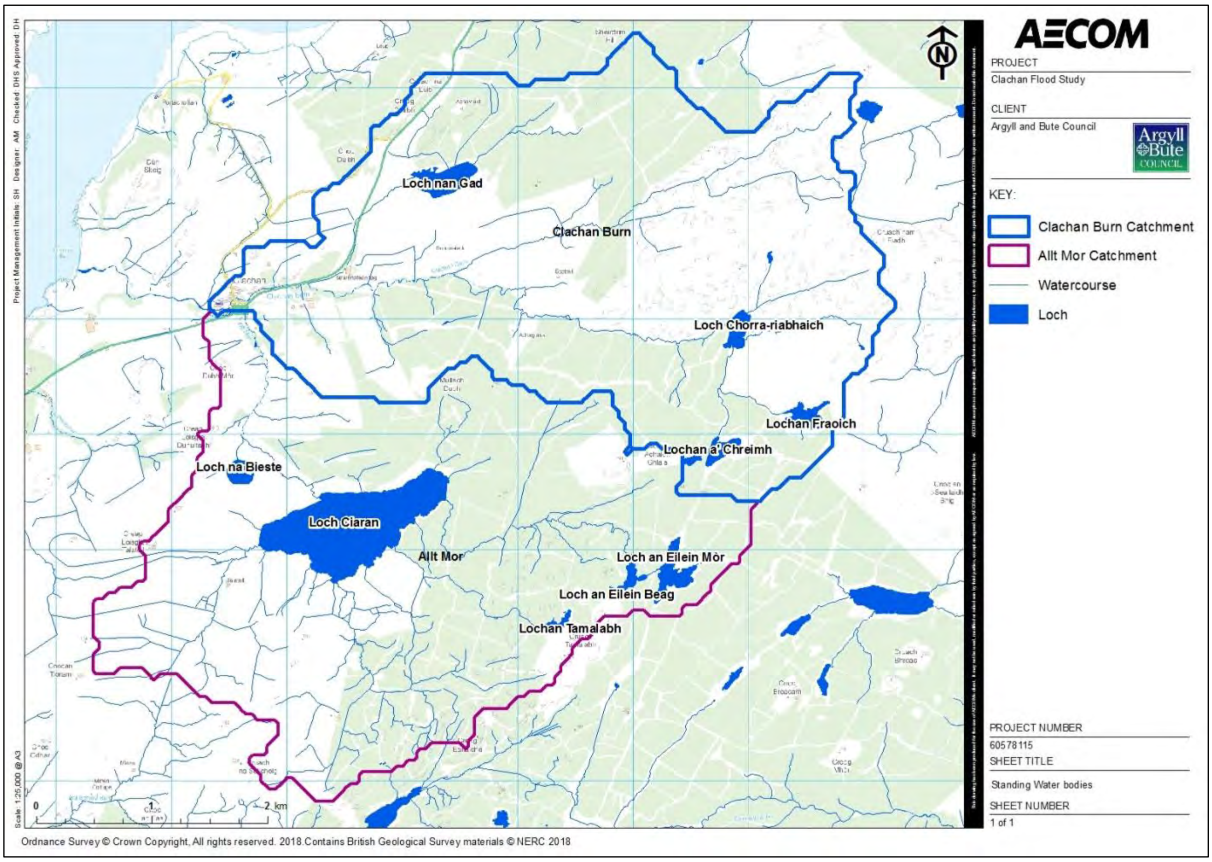

Figure 4-15 Location of standing waterbodies within the Clachan Burn and Allt Mor catchments

As stated above, flows in the Allt Mor are largely dominated by the attenuating effect of Loch Ciaran, with the upper 85% of the catchment draining through the loch. It is a large natural loch, with a surface area of over 770,000m^2 that has been raised by a 1.5m high concrete and masonry weir (Figure 4-16). Outflow from the loch is used by the fish hatchery downstream at Clachan and is regulated by a SEPA CAR licence.

Figure 4-16 Loch Ciaran dam

The loch is a large raised reservoir as defined by the Reservoirs (Scotland) Act 2011, which sets out required supervision and inspection regimes to ensure reservoir safety. The last inspection of the reservoir was undertaken by Inspecting Engineer John Cowie in 2009. The inspection report states that the loch is a Category B reservoir: that is one where a breach could endanger lives not in a community or could result in extensive damage. The report further states that the overflow arrangements are not adequate in their present form, and requires a scheme to be prepared to increase the overflow capacity to safely accommodate the design 1,000 year flood. The scheme should be implemented by the end of 2012, and the recommendation is made in the interests of safety, meaning it has the force of law. No such works have been implemented to date, so it would appear that this recommendation is outstanding.

In addition to Loch Ciaran, there are three smaller natural lochs in the east of the Allt Mor catchment, all of which lie upstream of Loch Ciaran. Loch na Bieste is a natural loch of approximately 40,250m^2 in surface area located downstream of Loch Ciaran. The loch has been modified historically and now includes a dam with piped outflows and an overflow[4].

Within the Clachan Burn catchment, the majority of natural water bodies are clustered in the south east area of the catchment (Figure 4-17), all of which discharge into Loch Chorra-riabhaich. The total catchment draining through this loch amounts to approximately 2.7km^2 (19%).

Located in the north west of the catchment, Loch nan Gad is a substantial size, with a surface area of over 100,000km^2, and drains a catchment area of 2.3km^2. In total, about 35% of the Clachan Burn catchment drains through a natural waterbody.

[4] http://gateway.snh.gov.uk/pls/apex_cagdb2/f?p=111:3 - Accessed 20.12.2018

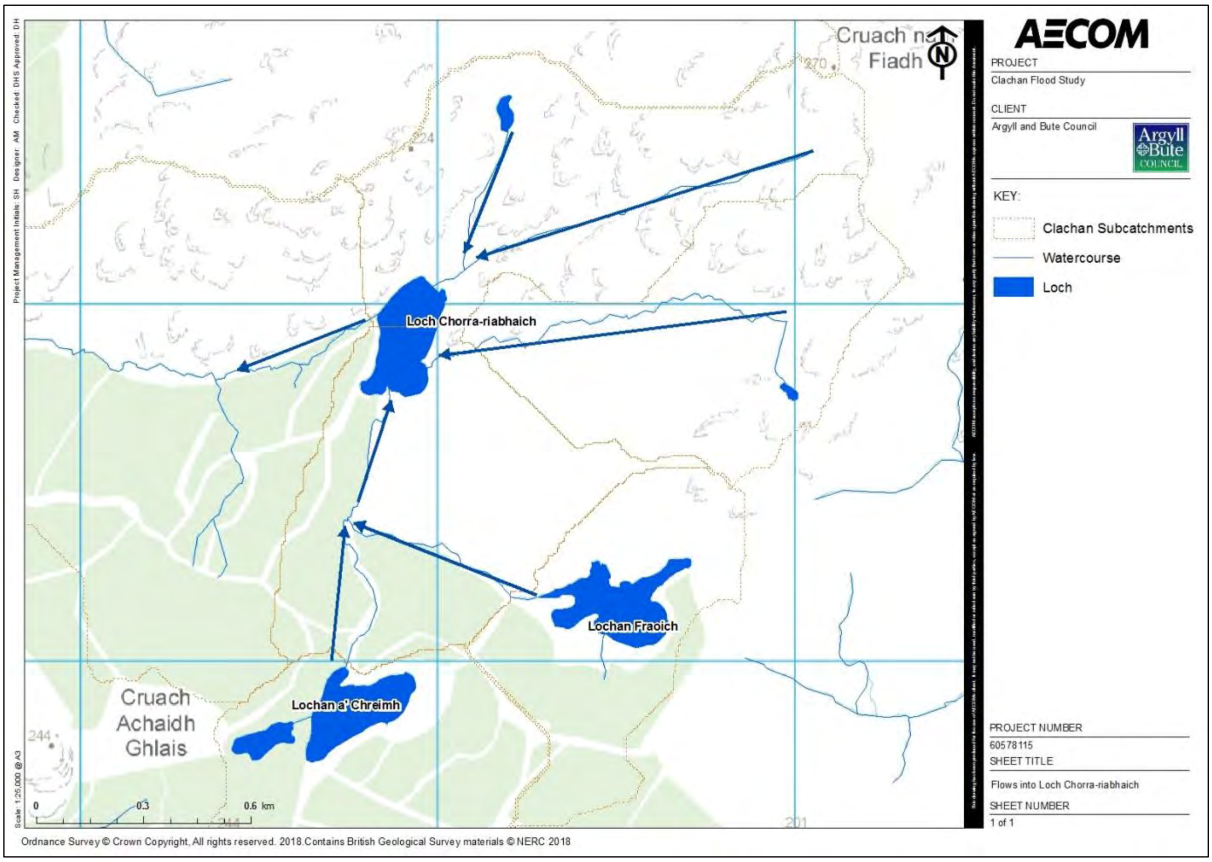

Figure 4-17 Flows into Loch Chorra-riabhaich

4.8.2 Wetlands

The Scottish Wetland Inventory dataset[5] was used to identify areas of mapped wetland vegetation across the catchment which can be a guide to identify low lying areas with potential for NFM measures to be located. Areas of wetland vegetation are mapped from survey data; however this may not provide a complete picture of the wetland vegetation across the catchment, only those which have been surveyed. The dataset does provide a useful starting point for the assessment of NFM options and was used for targeting during field survey. The mapped wetland areas in the catchment are shown in Figure 4-18.

[5] https://www.sepa.org.uk/media/163268/development-of-a-scottish-wetland-inventory.pdf - accessed 21.12.2018

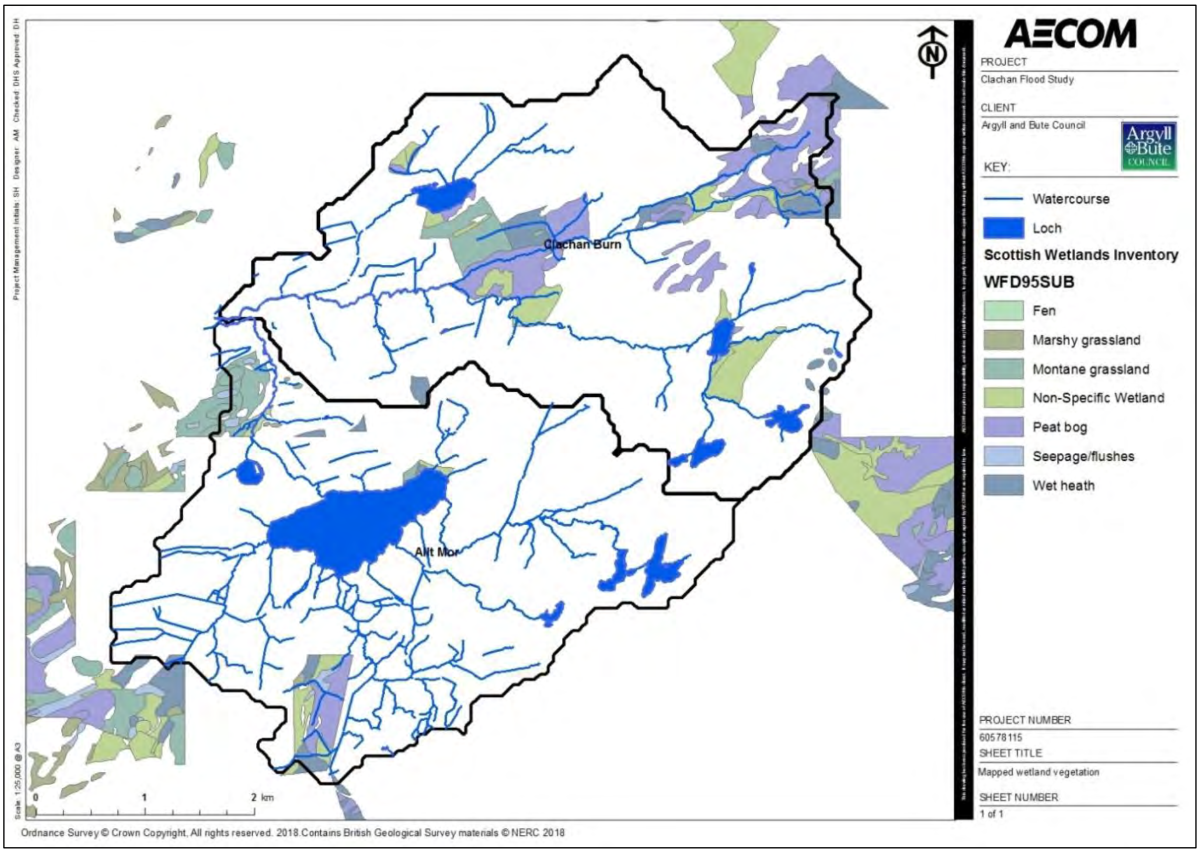

Figure 4-18 Scottish Wetland Inventory Data

The dataset shows that there is extensive wetland vegetation mapped in the Clachan Burn in the upper and middle catchment. Walkover survey of some of these areas confirmed the presence of boggy, wet ground which has been modified by drainage and could be improved as part of a catchment project or NFM scheme (Figure 4-19). Some wetland is mapped in the Allt Mor catchment, however this is less extensive and there are likely to be far less opportunities to utilise or enhance this for flood management.

Figure 4-19 Typical low gradient wetland area in the Clachan middle catchment

4.9 Subcatchment analysis

A watershed analysis using the NEXTMap DTM has been carried out on both catchment areas in order to identify the major subcatchments (Figure 4-20). Peak flow and hydrograph timings from the 2D modelling for each subcatchment have been reviewed. This analysis has helped to identify which subcatchments contribute most significantly to flooding in Clachan and therefore which tributaries have hydrograph synchronisation with the main watercourses and should be targeted. Mapping this information alongside current land use management information helps to focus on developing the most effective options in Phase 3 of the project.

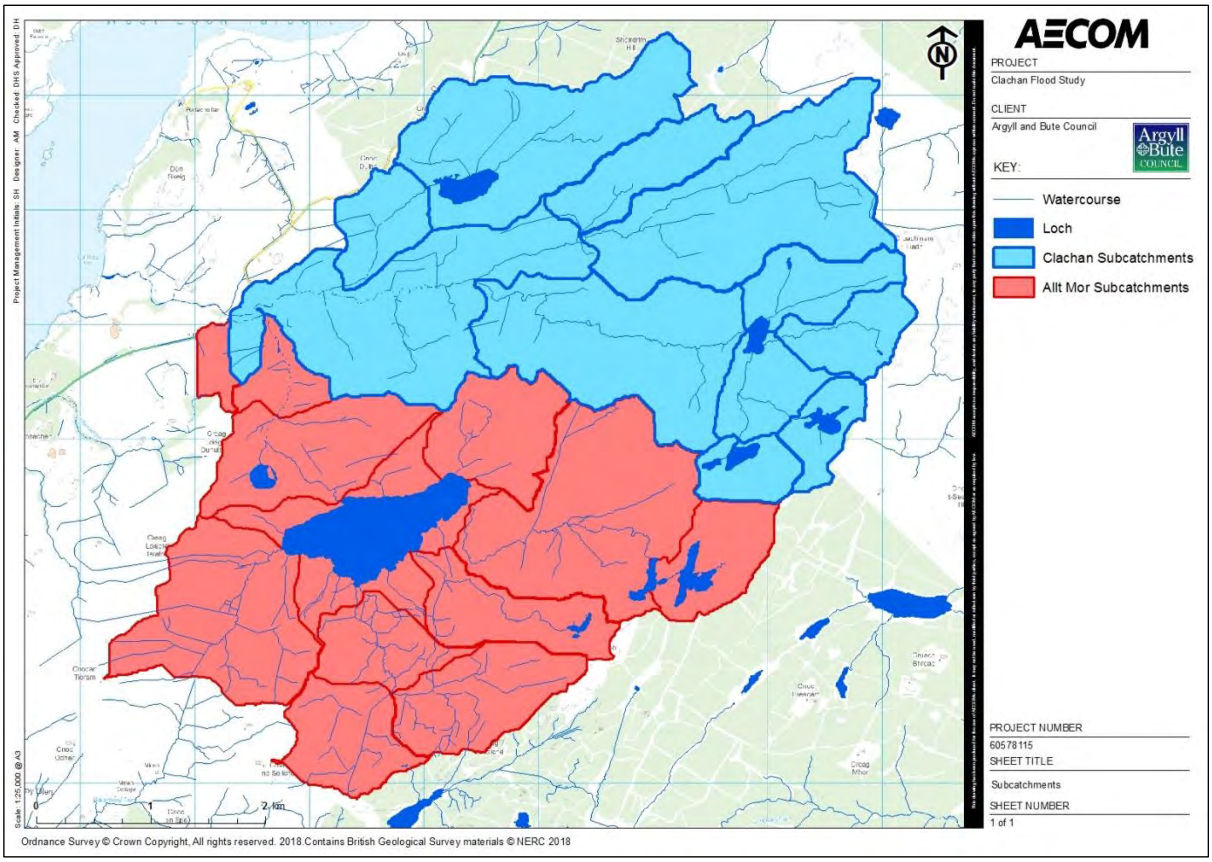

Figure 4-20 Allt Mor and Clachan Burn main subcatchments

5. Understanding Flooding Issues/Mechanisms

5.1 Local flood history

A number of sources of information were used to compile historic flood events. These included:

- Clachan residents
- ABC Biennial reports
- ABC Flooding team
- SEPA flooding team

Table 5-1 outlines the historic flood events for which there are records.

Table 5-1 - Recorded Historic Flood Events

Date	Reference	Conditions	Flooding Extent in Study Area
Nov 2001- Nov 2003	ABC Biennial Flood Report	NA	Flooding of roads and petrol station
2006/07	Clachan, Peninver and Stewarton, Kintyre		Flooding in areas during heavy rain
29th August 2012	Online reports	'Flash flooding' from Clachan burn	Properties flooded and roads damaged.
6th November 2014	Traffic Scotland website		Flooding of A83 at Clachan
15th November 2015	Community photos, ABC documents, online reports	'Flash flooding' from Clachan burn, container lodged in Clachan Burn which was removed.	
16th February 2016	Email from Linda Howden (Ciaran Cottage)	Heavy rain led to elevated river levels. 'drains not fit for purpose'	Properties threatened and road flooded. Burnside Cottage threatened with internal flooding

We have also collated photographs and anecdotal evidence from the Clachan community for three recent flood events.

5.1.1 29th August 2012

Online reports describe this as flash flooding from the Clachan Burn, resulting in properties flooding and roads damaged. Daily rainfall totals recorded at Ronachan were modest at 8.8mm (26th), 7.3mm (27th), 4.9mm (28th) and 2.8mm (29th). Given the time of year and the fact that very little rainfall was recorded at Ronachan, this was likely a small convective storm cell, limited spatially, that did not pass over the raingauge.

Information from residents and analysis of photographs suggest three locations were affected, by different mechanisms (Figure 5-1).

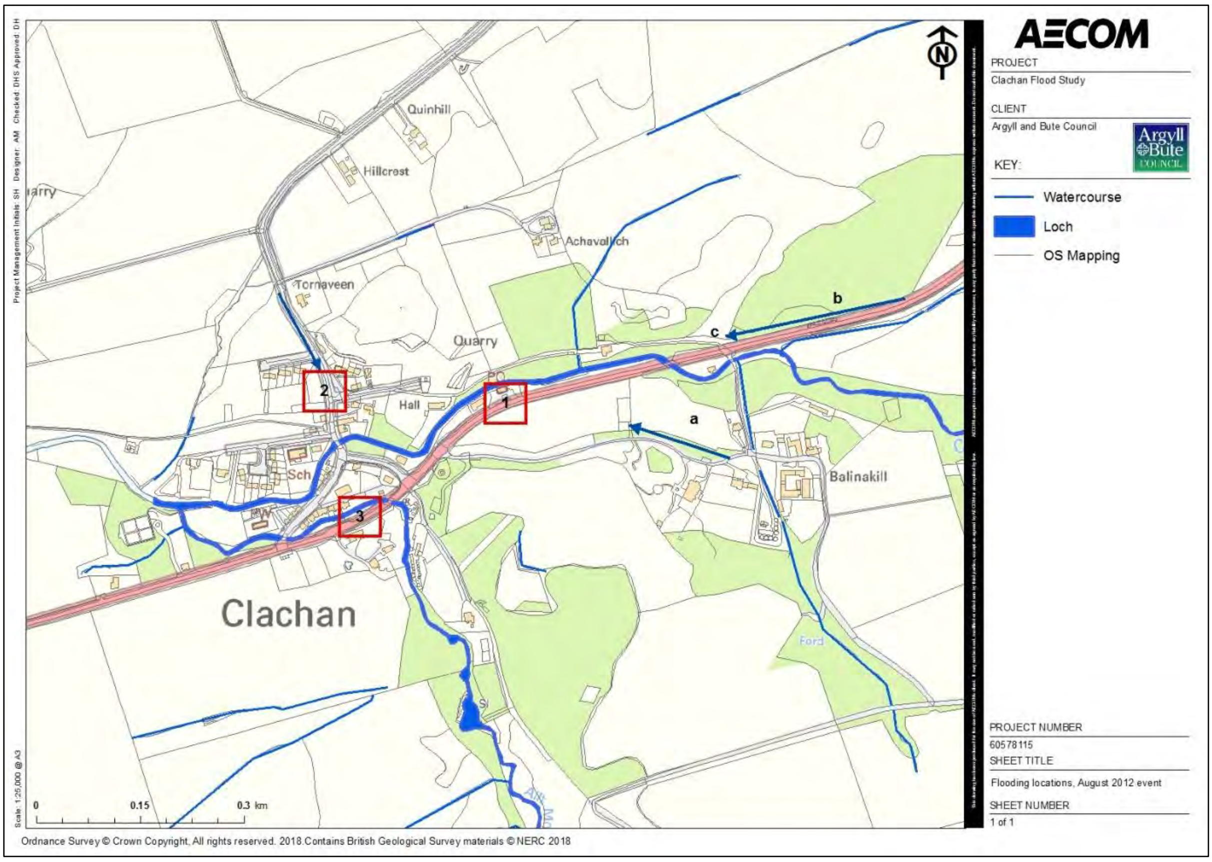

Figure 5-1 Flooding locations, August 2012 event

The A83 road was badly flooded around the petrol station (labelled 1 in Figure 5-1, also see Figure 5-2), which is located at a low point in the road. Flood depths here were significant, causing road closure which is a significant event for the community as there are no alternative routes in or out of the village, and for the wider Kintyre community as this is the main road to south Kintyre.

Analysis of photographs suggests this was the result of two overland flow routes (labelled a and b in Figure 5-1).

Figure 5-2 A83 flooding, August 2012 event

The first (a), appears to flow from near Balinakill House, and is likely the result of culvert blockage of the small watercourse flowing south to north through the grounds of the estate house (Figure 5-3). Floodwater made its way through the fields towards the road, and from there flowed down the road to the low point near the petrol station.

Figure 5-3 Cause of A83 flooding, August 2012 - overland flow path a)

The second overland flow path (b) appears to be the result of water shedding off the steep slope on the north side of the road into a small overgrown ditch (Figure 5-4). It can be assumed there is a culvert taking flow beneath a driveway crossing at C, and that either this was blocked or had insufficient capacity, resulting in floodwater spilling onto the road. This joined the flow from Balinakill House and travelled down the road to the low point near the petrol station.

Figure 5-4 Cause of A83 flooding, August 2012 - overland flow path b)

The second location of flooding and damage (labelled 2 in Figure 5-1) was to the steep section of Portachoillan Road between Tornaveen farm and the bridge over the Clachan burn in the village. High velocity floodwater is photographed flowing down the west side of the road, causing significant damage to the road surface (Figure 5-5), and surface water flooding of the road and gardens along the school road.

The cause of this flooding (2) is likely to have been blocked culverts preventing the watercourse near Tornaveen from crossing under the road to then discharge into the Clachan Burn to the west of the village, with the result that flow was redirected down the road (Figure 5-6).

Figure 5-5 Cause of A83 flooding, August 2012 - overland flow path c)

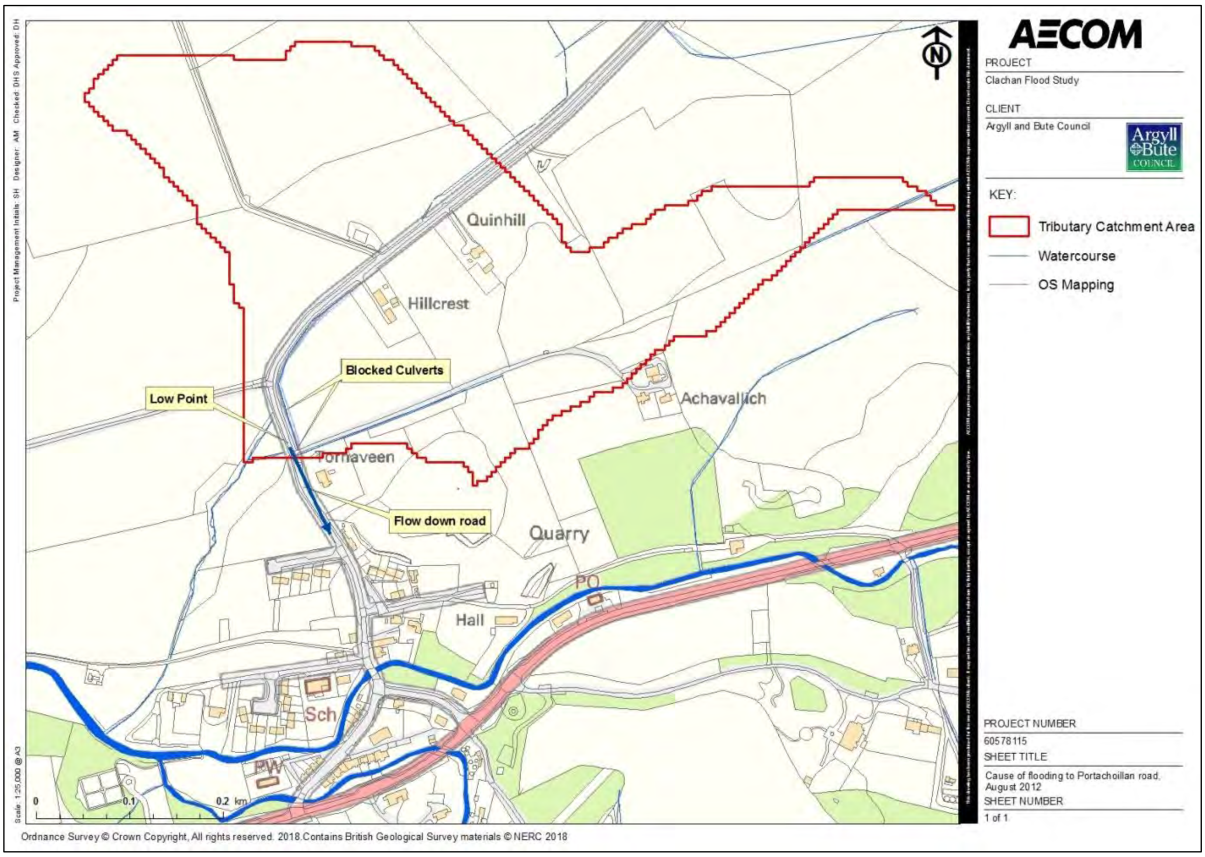

Figure 5-6 Cause of flooding to Portachoillan road, August 2012

Residents also reported that flooding from the Allt Mor occurred during the 2012 event (3), to properties in the village located on the north bank of the Allt Mor (Figure 5-7).

Figure 5-7 Out of bank flow, Allt Mor, August 2012

It can be surmised that the August 2012 event was a high intensity event that was limited spatially. It affected the steep flashy catchment area of the Allt Mor downstream of Loch Ciarian, resulting in high flows in the Allt Mor through the village causing out of bank flows, flooding gardens and properties. Several small watercourses/ditches to the north and south of the village were also affected. Blockages to culverts resulted in overland flow that ponded on the A83, and severe damage to Portachoillan Road in the village.

5.1.2 15th November 2015

This event is again described as flash flooding from the Clachan Burn. Daily rainfall recorded at Ronachan indicated 79.5mm fell in the 9 days between 5th and 13th November, with 67mm then recorded on 14th November. These rainfall totals do suggest a significant event, occurring on a saturated catchment.

SEPA provided ABC with sub-daily rainfall data for a gauge at Amod Farm in South Kintyre. This was the nearest gauge for which SEPA could provide rainfall data, however it is over 45km to the south of Clachan. Nevertheless, similarly significant daily rainfall totals were experienced with 51mm recorded on 14-15th November, and 62mm recorded in the 9 days prior

ABC also requested radar rainfall data from the Met Office for this event. This has been provided at 5 minute and hourly intervals for 14th and 15th November for Balinakill near Clachan. The daily rainfall total on the 14th matches that recorded at Ronachan. The Met Office gave the following detail on the severity of the event:

- 32.0mm in 5 hours from 0000GMT/15th = Return Period 8.7 years
- 35.9mm in 6 hours from 0000GMT/15th = Return Period 10 years

- 40.6mm in 8 hours from 2200GMT/14th = Return Period 10 years
- 67.0mm in 1 day (0900-0900GMT)/14th = Return Period 35 years

The rainfall data suggests a long duration frontal event, translating to high river levels rather than surface water flooding and this is confirmed by the photographs provided by the community (Figure 5-8.

Figure 5-8 Photos taken during the November 2015 flood event

Flooding of properties from both the Clachan Burn and the Allt Mor occurred during this event (Figure 5-9)

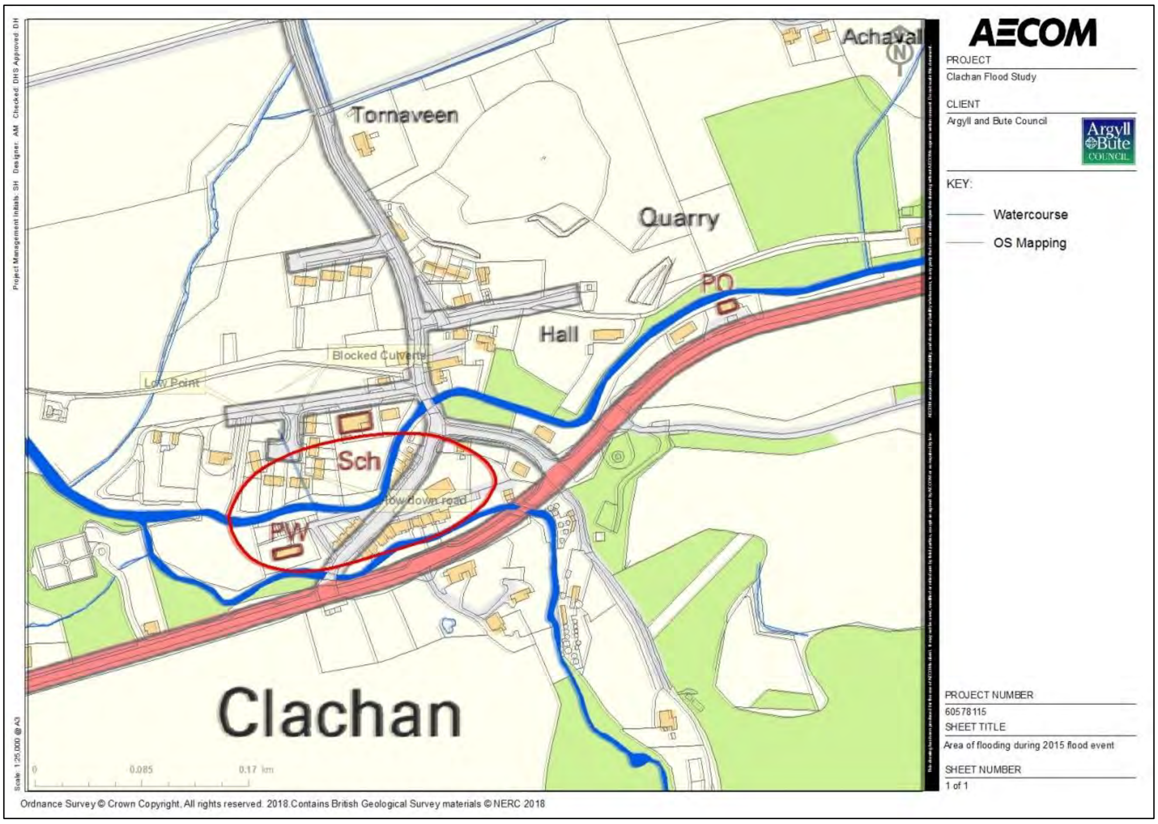

Figure 5-9 Area of flooding during 2015 flood event

5.1.3 16th February 2016

A total of 31.5mm of rainfall was recorded at the Ronachan gauge on 16th February. Although no rainfall was recorded in the 5 days prior to the event, January and the first part of February were very wet so the catchments were likely to have low or negligible soil moisture deficits (SMD), leading to high runoff.

No additional rainfall data is available. Heavy rainfall was reported to have led to elevated river levels (although the Clachan Burn did not overtop), and drains were overwhelmed. There are fewer photographs of this event, but those that exist suggest high river levels but not necessarily out of bank flow, coupled with surface water overland flow and ponding.

Figure 5-10 Photos taken during the February 2016 flood event

5.2 Flooding mechanisms

There appear to be two different flooding mechanisms occurring in Clachan – both pluvial and fluvial. The burns are reported to be flashy and rise very quickly, and such events are likely to be heavily influenced by antecedent catchment saturation levels. Such events are likely to be caused by winter frontal rainfall events on a saturated catchment.

Pluvial flooding seems to be caused by intense rainfall on the steep pastured fields close to the town. The steep slopes and high rainfall intensity means that there will be little infiltration, and the community describe sheets of water flowing down the slopes and ponding in the flatter areas near the A83 and the village.

6. Baseline Catchment Model

6.1 Introduction

The purpose of the hydrological assessment is to estimate runoff generated over the catchment areas of each watercourse, which will then be used as input to the hydraulic model of the Clachan Burn through the town, described in Section 7.

Normal practice when undertaking hydraulic modelling of a watercourse to establish flood risk is to use recommended hydrological methods such as FEH to generate peak flow estimates or full inflow hydrographs. Such methods use rainfall and catchment characteristics to estimate design flood hydrographs of a specified probability, that are then input to the hydraulic model to allow flood levels to be modelled.

Part of this study will investigate the potential for NFM techniques to mitigate flood risk. In addition, it is reported that some Clachan residents have a perception that recent deforestation of areas of the managed forestry is exacerbating flooding in the village. The study will therefore need to consider the impact of changing landuse and various types of NFM measures. FEH techniques are somewhat limited in how they can be manipulated to represent landuse and NFM measures. The following section describes the potential methodologies considered to model catchment runoff that would allow both baseline conditions and mitigation measures to be assessed.

6.2 Methodology selection

We consulted with hydrologists from FC (Tom Nisbet & Huw Thomas) on possible hydrological modelling techniques to represent the impact of forestry. One possibility is to use Hec-HMS software, a hydrological modelling package developed by the US Army Corps of Engineers. This software was used by Huw Thomas to quantify the effect of woodland planting on flooding in Pickering[6].

HEC-HMS incorporates several methods to represent losses from a rainfall input and how this is transformed to runoff. The Pickering study used the Soil Conservation Service's Curve Number method which assigns a Curve Number to a given land use/soil type and this is used to represent how much rainfall is transformed to runoff. A 50m x 50m grid of the catchment was created and appropriate Curve Numbers assigned to each grid cell. Then a weighted average Curve Number was calculated for each sub-basin defined in the model. This method is a good way to study and assess the impact of land use change, but one drawback is that the representation of NFM features in the channel network (e.g. debris dams) is more limited as it isn't a hydraulic model.

Another alternative would be to use a fully gridded 2D model such as Tuflow, which would allow in channel hydraulic features to be included as 1D elements. This method was used by JBA in a study of flood management and woodland creation in Southwell for FC[7]. The approach taken was to construct a 1D-2D ISIS Tuflow direct rainfall model, calibrated to an observed flood event. The model represented interception, infiltration and physical representation of the tree stand from different tree types (eg broadleaf or conifer). Infiltration and interception were represented by applying appropriate infiltration and interception rates to each 2D cell depending on land use and tree type. The hydraulic impact on surface flows of the physical tree stand was represented by applying a flow restriction through each grid cell, which was considered to produce a more realistic hydraulic response over modification of Manning "n" roughness values. Calibration involved altering the initial soil wetness and scaled interception/infiltration rates to match observed flows in the watercourse.

For this study, we consider the use of a 2D direct rainfall Tuflow model to provide the best approach with the fewest limitations to model the impact of land use change and other NFM measures. The main input to the model is rainfall using the FEH 2013 DDF model for design events, and local rainfall data for historic events for calibration/validation. Elevation data, soil infiltration, interception and transpiration from vegetation, and flow conveyance depending on land use will also form inputs to the model. The outlet control structure at Loch Ciaran will also be represented as this may have a significant impact on the flows in Allt Mor, and must be included in the catchment model. Model runs will then provide runoff hydrographs from the catchment areas in response to rainfall, which will then form inputs to the hydraulic model.

The proposed methodology was communicated to SEPA in technical notes dated 8th August and 1st November. SEPA responded with letters dated 15th October and 3rd December 2108. These communications are contained in Appendix B: Review of Rainfall Data for Clachan

[6] *Slowing the Flow in Pickering: Quantifying the effect of catchment woodland planting on flooding using the Soil Conservation Service curve number method*, Huws et al, Int. J. of Safety and Security Eng., Col 6, No 3, 2016
[7] *Flood management and woodland creation – Southwell Case Study, Hydraulic Modelling and Economic Appraisal Report*, JBA, 2017

Liaison with SEPA. SEPA agreed in principle with the modelling approach and provided some advisory points which have been taken on board.

6.3 Detailed methodology

After promising results from preliminary model runs, the decision was made to progress with the option to use a fully gridded 2D model using Tuflow software, which we considered to provide the best approach with the fewest limitations to model the impact of landuse change and other NFM measures.

The model represents direct rainfall, interception, infiltration, soil porosity, initial soil moisture content and physical representation of the tree stand from different tree types (eg broadleaf or conifer). For non-forested areas, interception is set to zero, whilst infiltration and soil porosity are based on underlying geology with best estimates set in consultation with our in-house hydrogeologist. Representative summer and winter season initial soil moisture content are modelled as depth to groundwater, and reflect increased SMD reported below tree stands, but set to zero for all areas for winter events (representing saturated conditions). For forested areas, infiltration and interception are represented by applying appropriate infiltration and interception rates to each 2D cell depending on tree type, again based on values found in literature. These parameters have been drawn from values reported in literature and agreed with FC.

Realistic sensitivity envelopes for each parameter have been estimated in consultation with our hydrogeologist and FC to form part of the sensitivity tests (Section 6.10). The hydraulic impact on surface flows of the physical tree stand is represented by applying a flow restriction through each grid cell, based on average tree spacing and trunk width.

The 2D model domain covers the entire catchment area of both the Clachan Burn, and the Allt Mor, totaling 27.5 km^2. Figures C1 and C2 (Hydrological Model Schematics) show the model schematics. A preliminary grid size of 10m has been selected, as a compromise between accuracy and model run time. The impact of grid size was assessed within the sensitivity runs. At this resolution, many of the small tributaries and other small preferential flow paths are not well represented in the ground model, and this was overcome by reinforcing breaklines along the watercourses (Figure 6-1). Drains were delineated using mastermap and site walkovers. The ground model was lowered by 200mm in these locations to represent this preferential flow path in a simplistic manner given the level of information available.

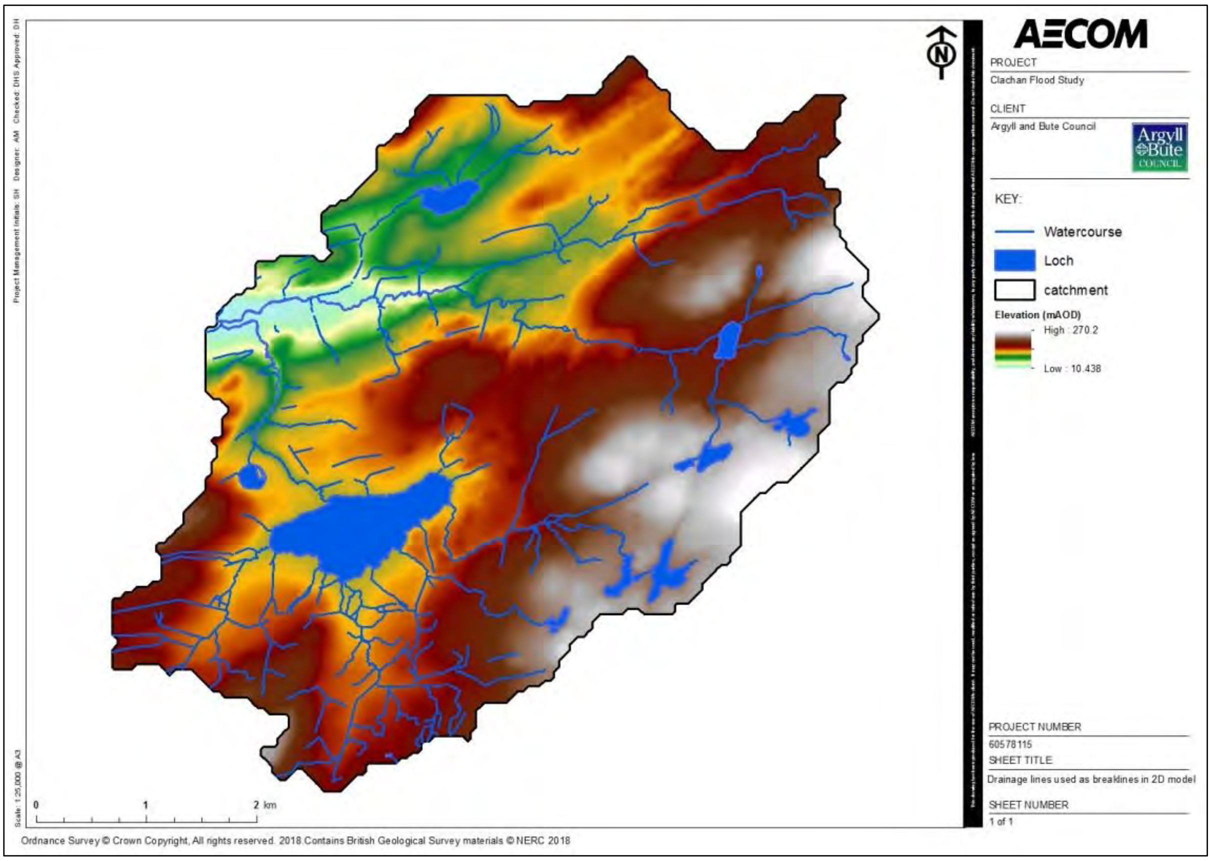

Figure 6-1 Drainage lines used as breaklines in 2D model

The main input to the model is rainfall – FEH 2013 DDF model for design events, and local rainfall data of historic events for verification.

The attenuating capacity of existing water bodies can be accommodated fairly easily within Tuflow as 1D elements representing the loch outlets embedded within the 2D domain. The outlet of Loch Ciaran which has been surveyed has been included as a 1D element.

6.4 Forestry baseline

As stated previously, the nature of forestry management means land cover is constantly changing due to felling and restocking. This has an impact on the hydrological processes in the catchment as the maturity of trees will impact on interception and soil losses. Given the area is dominated by conifer planting it was assumed that the areas marked as felled in the forestry records were likely conifer. An assumption was made that anything that had been replanted pre 2013 would have been at least 5 years old at the time of the 2015 fluvial flood event and considered likely to have an impact given conifers are deemed fast growing tree and was modelled using conifer parameters for these areas of land use. Anything replanted after this year was still considered felled.

This assumption was tested by running the 2015 rainfall event through the 2D model. Hydrographs were extracted at relevant locations and input to the 1D-2D fluvial model. The model outputs indicated underrepresentation of flooding with no overtopping occurring from the Allt Mor and limited overtopping of the Burn in the village itself which contradicts photos and local reports.

Conversely, keeping the pre-2013 restocks in as felled areas better represented the reports of flooding. The result suggests that restocking was not established enough to have an impact. This is likely because the oldest restocked tree stand was at most seven years old during this event so its impact on water use was not yet fully established. Research by FC suggests water use in conifer trees following felling will recover at the stage of canopy closure which is typically 10 – 20 years[8].

[8] The role of woodland in flood control: a landscape perspective, Proceedings of the 14th annual IALE(UK) 2006 conference on Water and the Landscape, T.R. Nisbet and H. Thomas, 2006

6.5 Model parameters

Tuflow has the capability of modelling infiltration in a number of ways, including; Green & Ampt, Horton, and initial loss, continuing loss (ILCL). The ILCL method was chosen as its simplicity aligns with the level accuracy of input parameters available, all of which are based on literature rather than specific site measurements. The ILCL method infiltrates water based on an initial amount then at a constant rate. Porosity is equivalent to the saturated moisture content and depends on the type of soil. The initial moisture fraction specifies the initial level of saturation within the soil, and is considered along with the porosity to calculate the soil capacity. Once the infiltrated volume reaches the value of soil capacity, the soil is considered saturated and no further infiltration will occur, with all excess rainfall assumed to contribute to surface runoff. The initial soil moisture must be specified as a fraction, however available literature tends to quote initial soil moisture in terms of SMD in mm; so converting such values to a fraction requires knowledge of the depth of soil. An alternative method is to define the depth to groundwater. If the groundwater level rises to the ground surface, no additional infiltration will occur. This option was applied, using quoted SMD as depth to groundwater, and assigning zero initial moisture. Although the parameter values would vary during an event, averages from literature have been applied in order to simplify this representation.

The model parameters have been taken from a range of academic studies, particularly Calder, 1986[9] which contains data related to Crinan, the closest research site to Clachan. It should be noted that SMD values remain the same for broadleaf and conifer coverage as there was no data available for broadleaf in this study. FC hydrologists indicated SMD for broadleaf coverage would be marginally lower than the conifer value and suggested it would be reasonable to use the same value for both species. This has been adopted as a conservative assumption. The model parameters used are outlined in Table 6-1 and Table 6-2 and the model schematization is given in Figure C1 and C2 of Appendix C for the forested and non-forested scenarios.

[9] The influence of land use on water yield in upland areas of the U.K., Ian R.Calder, Journal of Hydrology Volume 88, Issues 3–4, 30 November 1986, Pages 201-211

Table 6-1- Model parameters

Physical description	Tuflow parameter	Rural (no woodland)		Conifer		Broadleaf	
		Winter	Summer	Winter	Summer	Winter	Summer
Interception (mm)	Initial loss	0	0	6.91[10]	6.91[9]	1.2[11]	2.6[10]
SMD (mm)	Depth to groundwater	0	85[12]	0	110[11]	0	110[11]
Infiltration (mm/hr)	Continuing loss	Based on soil type	Based on soil type	Based on soil type	Based on soil type	Based on soil type	Based on soil type
	Initial moisture* (fraction)	0	0	0	0	0	0
Porosity (fraction)	Porosity (fraction)	Based on soil type	Based on soil type	Based on soil type	Based on soil type	Based on soil type	Based on soil type
Tree stand	Flow constriction (fraction)	0	0	0.4	0.4	0.4	0.4

*taken as zero – initial moisture represented by depth to groundwater

Table 6-2- Infiltration parameters

Description	Infiltration mm/hr (saturated soil conductivity)	Porosity (fraction)
Peaty gleys	3.6[13]	0.486[14]
Non calerous gleys	0.36[13]	0.385[14]
Humic gleys	0.5	0.423
Peat	252[15]	0.71 (winter), 0.95 (summer)[15]
Forested – conifer	1239[16]	As for underlying soil
Forested - broadleaf	379[16]	As for underlying soil

[10] The role of woodland in flood control: a landscape perspective, T.R. Nisbet and H. Thomas, Proceedings of the 14th annual IALE(UK) 2006 conference on Water and the Landscape
[11] Medium range value chosen in consultation with FC Impact of lowland forests in England on water resources: Application of the Hydrological Land Use Change (HYLUC), Calder et al., 2003 and Hydrological impacts of broadleaf woodlands: implications for water use and water quality, Harding et al., 1992,
[12] The influence of land use on water yield in upland areas of the U.K., Ian R.Calder, Journal of Hydrology Volume 88, Issues 3–4, 30 November 1986, Pages 201-211
[13] Dynamics of Fluids in Porous Media, Bear, J (1972)
[14] Tuflow manual, 2017, Table 6-**Error! Main Document Only.** - USDA Soil types
[15] Structure of peak soils and implications for water storage, flow and solute transport: a review update for geochemists, Rezanezhad et al, Chemical Geology, Vol 429, 2016
[16] Influence of tree species and forest land use on soil hydraulic conductivity and implications for surface runoff generation, Chandler et al, Geoderma 310 (2018) 120-127

6.6 Model runs

Model runs will provide runoff hydrographs from the catchment areas in response to rainfall, which will then form inputs to the hydraulic model. Modelled scenarios are as follows:

- Non-forested baseline, winter event
- Current baseline (including existing forested areas), summer and winter events
- Predicted baseline (including proposed foresting for the Talatoll scheme. No account of future felling is included as this information is not available), summer and winter events
- Sensitivity runs (see section 6.10)
- In Phase 3 of the project, a number of option scenarios (including proposed interventions) will be modelled

A full range of return periods events will be analysed from 50% - 0.5% AEP (2 – 200 year return periods). The runs were carried out for the critical storm duration of 5.25hrs.

6.7 Climate change

It was originally proposed to use UKCP18 data in order to uplift rainfall figures to factor in climate change to the assessment. This data was released at end of November 2018; however there have been issues in accessing the information via the online user interface. As such current SEPA modelling guidance[17] based on UKCP09 relating to pluvial modelling has been followed in order to uplift rainfall depths in the catchment model.

SEPA recommends the use of UKWIR study for sewer design as giving the most representative uplift for climate change scenarios. This study compared present rainfall data with a “climate analogue” at a similar climate location to the projected climate location. Results for Glasgow and Newcastle have been advised for use in the west and east of Scotland respectively. A high resolution climate model simulation was used in this study which is more applicable to rainfall patterns that tend to be more localised. Table 10.3 in the SEPA modelling guidance summaries the percentage change in rainfall depth for different locations and different epochs recommended by the study.

The 2080 central projection scenario for the West of Scotland has been used to represent climate change and indicates 20% uplift to rainfall based on 6 hour duration, critical to this catchment. A high projection scenario has also been assessed for sensitivity for the same time period and indicates 36% uplift in rainfall should be used.

For Argyll catchments, SEPA modelling guidance for fluvial uplifts recommends an uplift in peak flows of between 37 – 45% for a medium emissions scenario with medium probabilities of 50% and 67% respectively.

Using the UKIWR data with a central emission scenario results in 39% uplift in peak flows in the combined catchment at the 1 in 200 year winter event. This lies within the fluvial modelling recommendations for peak flow giving confidence in the application of climate change to rainfall uplifts for use in a fluvial flood study.

The central emission scenario (20% rainfall uplift) has been used for the purpose of this flood study. This is deemed a balanced estimation of climate change progression. Given the SEPA Strategic mapping utilizes the 67% medium scenario use of a method which comes close to the 50% medium emissions scenario fluvial uplifts is deemed reasonable for a catchment specific study.

A sensitivity test using the high projection rainfall uplift and its impact on the flows in the watercourses and flooding mechanisms modelled on site has been carried out and is discussed in Section 7.4.5.

[17] Flood Modelling Guidance for Responsible Authorities, SEPA 2015

6.8 FEH flow estimates

As discussed above, there are no past flow or level measurements recorded on the Clachan Burn or Allt Mor so full calibration to historic events cannot be achieved. High level verification of the model will be based on observed rainfall and anecdotal evidence (eg photos) of flood events. This increases the uncertainty in the hydrographs generated, and as such, a full suite of sensitivity tests will be undertaken to understand which model parameters have the largest impact on modelled flows (Section 6.10). Comparison to FEH design storms may also prove useful and the FEH statistical and ReFH2 methods have been used to derive design peak flows for the Clachan Burn and Allt Mor.

ReFH2 has been used to derive flood hydrographs for the Allt Mor and Clachan Burn to their confluence at Clachan, as well as the total combined catchment. An FEH statistical analysis has also been carried out on the total combined catchment.

The hydrological analysis commenced by identifying the study catchments on the FEH Web Service and extracting both their catchment boundaries and catchment descriptors. OS Mapping was used to confirm catchment boundaries where appropriate.

A technical note detailing the hydrological analysis was issued to SEPA for review and their comments have been addressed. A revision of the technical note was then issued and comments received. For details, please refer to Appendix A.

6.8.1 FEH Statistical Method

The FEH statistical method is based on performing statistical analysis on a pooled group of hydrologically similar gauged sites to the subject site. It is generally considered to be the most robust and reliable flow estimation method as it is based on measured flow data. However it only provides an estimate of peak flow for any given annual exceedance probability (AEP) or return period, not a full flow hydrograph.

The method involves estimating QMED, defined as the median annual flood, i.e. the flood event with an annual exceedance probability (AEP) of 50% (1 in 2 year return period). A growth curve is then derived by pooling data from hydrologically similar gauged sites, and the two are multiplied together to produce a flood frequency curve for the subject site.

The method is generally preferred for larger subject catchments. Theoretically it can be applied to any catchment area greater than 0.5 km^2; however the number of small gauged catchments is low and generating a representative pooling group can be problematic. For this reason, the method was used to derive a flood frequency curve for the combined Clachan Burn and Allt Mor catchment, with a total area of 27.5km^2.

QMED estimation was defined by catchment descriptors as there is no gauge located on the watercourse to provide observed data. Donor adjustment was carried out within the WIN-FAP v4 software, using the single gauging station method and the multiple gauging station method. The resultant QMED estimations are shown in Table 6-3. There was only marginal difference between donor transfer using one site and using multiple sites. As the QMED estimate using one site was slightly higher, this was adopted

Table 6-3-QMED Estimation

Location	QMED CD	QMED DT one site	QMED DT multiple sites
Total Clachan Catchment	18.07	17.77	17.64

After deriving QMED, the second step of the statistical method involves generating a pooling group of gauged catchments which are hydrologically similar to the subject site and deriving the pooled growth curve. The growth curve is then multiplied by the QMED estimate to provide a flood frequency curve for the subject site.

WINFAP-FEH v4 software was used, together with version 6 of the database of gauging station data, to derive a suitable pooling group. The database contains the annual maximum (AMAX) series data for each station in the database giving AMAX series up to and including the 2015 water year for the majority of UK gauges. For Scottish sites, WINFAP only covers up to 2005, so requests were made for such sites included in the pooling group to update the AMAX series.

The WINFAP software derives a default pooling group of hydrologically similar gauging stations that are deemed suitable for pooling. Similarity is judged using a distance measure derived from the difference in floodplain extent (FPEXT), rainfall (SAAR) and catchment area (AREA) between the subject site and the gauging station sites. The total data record from the resulting group should amount to around 500 years of data as recommended in Science Report SC050050.

The resulting default pooling group was then reviewed, and several adjustments made. Sites were removed that had unsuitable SPRHOST and periods of record. The next most hydrologically similar sites were added to maintain a total data record of 500 years. The full process is included in Appendix D.

For the Clachan catchment, the best fitting statistical distribution was the GL (Generalized Logistic) and the heterogeneity measure H2 was 0.63. This indicated the pooling group is acceptably homogenous and further review of the pooling group was not required. Table 6-4 shows the growth and flood frequency outputs for the total Clachan catchment.

Table 6-4 - Pooling Group Growth Curve and Flood Frequency Curve for Clachan Catchment

AEP/ Return Period	Growth Curve	Flood Frequency Curve
50% / 2 year	1.000	17.8
20% / 5 year	1.334	23.7
10% / 10 year	1.579	28.1
5% / 20 year	1.845	32.8
4% /25 year	1.936	34.4
3.33% / 30 year	2.014	35.8
2% / 50 year	2.246	39.9
1.33% / 75 year	2.446	43.5
1% / 100 year	2.598	46.2
0.5% / 200 year	3.003	53.7
0.1% / 1000 year	4.195	74.6

6.8.2 ReFH2 Method

The ReFH2[18] method is a design event rainfall-runoff method. It is based on design rainfall hyetographs (FEH 2013 DDF model), and applying a loss model, routing model and baseflow model to provide a total runoff flow hydrograph. This method has been applied to generate peak flows and flow hydrographs for the Allt Mor, Clachan Burn and total combined catchments.

ReFH2 automatically calculates the critical duration and time step based on FEH equations. The critical duration calculated by ReFH2 is shown in Table 6-5 and the peak flows are given in Table 6-6.

Table 6-5 ReFH2 Default Parameters

Parameter	Clachan Burn	Allt Mor	Clachan Catchment (Both)
Critical Duration	04:45:00	05:30:00	05:15:00
Timestep	00:15:00	00:30:00	00:15:00

[18] The Revitalised Flood Hydrograph Model, REFH2.2: Technical Guidance, CEH, 2016

Table 6-6 ReFH2 Peak Flow Estimates

AEP/ Return Period	Clachan Burn	Allt Mor	Clachan Catchment (Both)
50% / 2 year	17.90	16.96	34.77
20% / 5 year	23.90	22.40	46.12
10% / 10 year	28.15	26.27	54.11
5% / 20 year	32.45	30.20	62.28
4% /25 year	33.89	31.53	64.98
3.33% / 30 year	35.09	32.65	67.24
2% / 50 year	38.68	35.88	73.94
1.33% / 75 year	41.76	38.68	79.73
1% / 100 year	44.12	40.83	84.17
0.5% / 200 year	50.73	46.82	96.54
0.1% / 1000 year	75.14	68.65	142.14

6.9 Preliminary model runs

Initial 2D model runs have been completed, firstly using direct rainfall only, with no forestry or soil losses, secondly assuming no forestry with our best estimate of soil losses for winter conditions (soil moisture deficit is zero, best estimate of soil infiltration and porosity based on soil type), and lastly with current forest cover, with soil losses for winter conditions, interception losses and hydraulic constriction in forested areas. These preliminary results are compared against FEH derived peak flows for the Clachan Burn and Allt Mor at Clachan in the table below.

Table 6-7 Comparison of preliminary model runs with FEH flow estimates for a 1 in 200 year event.

Hydrological method	200 year peak flow		
	Allt Mor	**Clachan Burn**	**Total catchment ds of confluence**
FEH statistical	-	-	53.4
ReFH2	46.8	50.7	96.5
2D model direct rainfall	14.0	43.3	57.0
2D model direct rainfall + soil losses (non-forested baseline)	14.0	43.3	57.0
2D model direct rainfall + soil losses + interception losses + constriction losses (forested baseline)	13.0	41.0	54.0

As seen from the table above, routing impacts from natural lochs in catchments are being picked up in the 2D model. The peak 1 in 200 year flow in the Clachan Burn is 15% lower than the calculated REFH2 flow. This is to be expected when considering the 6 smaller natural lochs located in the upstream catchment. The flows from the direct rainfall model are closer to those calculated by the statistical method which takes FARL into account when calculating QMED, further evidencing that the 2D modelling approach is taking account of reservoir routing impacts. It should be noted there is a difference in timings of peaks between REFH2 and the modelling. REFH2 calculations indicate the peak flow would occur at 5 hours in the combined catchment where the modelling indicates this would occur at 3.3 hours. This is to be expected as the catchment wide model replicates flows paths towards river as rainfall is applied across the grid which includes estimated key drainage paths.

When looking at the different catchments with soil losses applied there is no difference in peak flow compared to the 2D direct rainfall model with no losses. This is considered to be realistic given this is based on a winter season where soil is considered saturated. The winter soil moisture as 0 and conservatively assumes no infiltration is possible deficit is modelled as 0 and conservatively assumes no infiltration is possible.

When looking at the initial representation of forest interception and constriction losses, the hydrograph is also not fundamentally changed compared to the soil and direct rainfall models. At the Clachan Burn there is a 4% reduction is peak flow compared to the soil loss model and minor attenuation affect seen in the hydrograph shape.

This is considered reasonable given the small percentage of the catchment which is forested once the current felled landuse is considered partnered with the lack of infiltration in the winter soil profile. Larger differences are expected for the summer season model runs, when soil moisture deficits are positive, and also for lower return periods where soil losses and interception form a larger proportion of the rainfall input

The Allt Mor Burn is more heavily influenced by reservoir routing effects. Initial model runs indicate a 70% lower peak flow than the calculated REFH2 hydrograph. A check on this mechanism was carried out through construction of a 1D reservoir routing model in Flood Modeller. The inflow to the reservoir unit represented the upstream catchment draining to Loch Ciaran (10.1km^2). Survey information for the outlet for Loch Ciaran was obtained to accurately model this control. At a 1 in 200 year event, 10m^3/s was found to discharge from the Loch in the 1D model. In the 2D model with no losses this was in the same order at 12.5m^3/s, which indicates the reservoir has a substantial attenuation impact on flows in the catchment. A further check comparing the rural REFH2 hydrograph and the 2D model hydrograph indicates that for this to be the realistic discharge flow the equivalent rise in water level in the reservoir would equate to 200,000m^3 of water which is more than available within the 800,000m^3 impounding capacity of the reservoir.

The impact of soil loss modelling on the Allt Mor catchment is less pronounced given the attenuation impacts of Loch Ciaran dominate the response in the catchment. A further 2% reduction in peak flow can be seen with almost no change to hydrograph shape as seen in Figure 6-4.

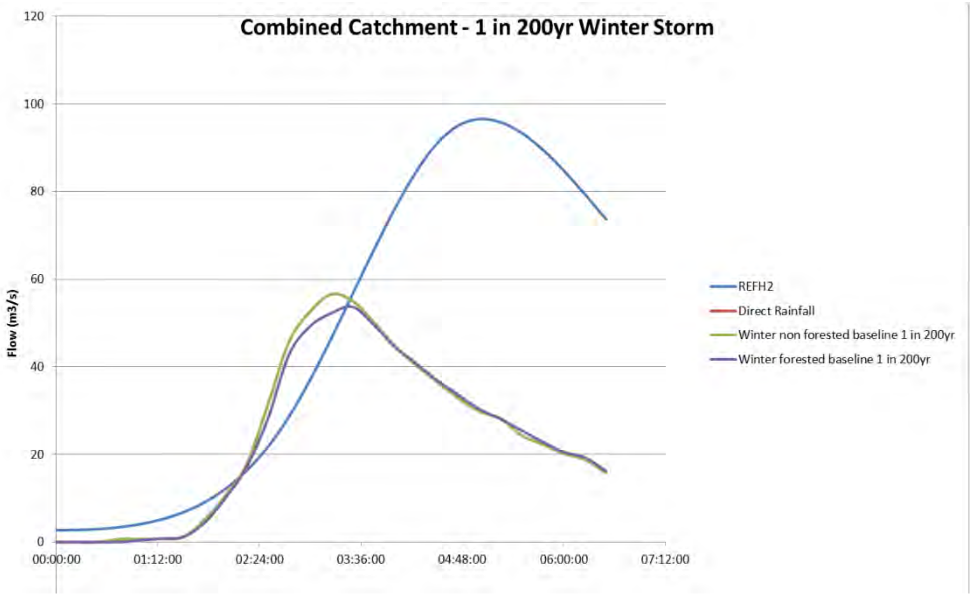

Figure 6-2 Combined catchment hydrograph comparison

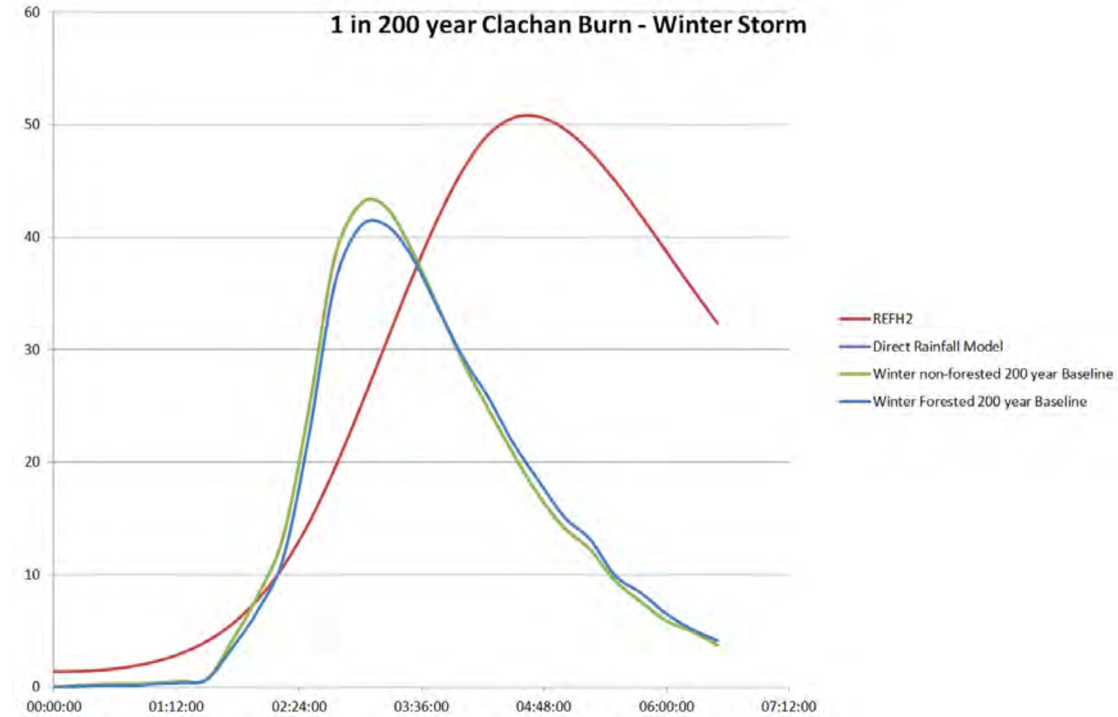

Figure 6-3 Combined catchment hydrograph comparison

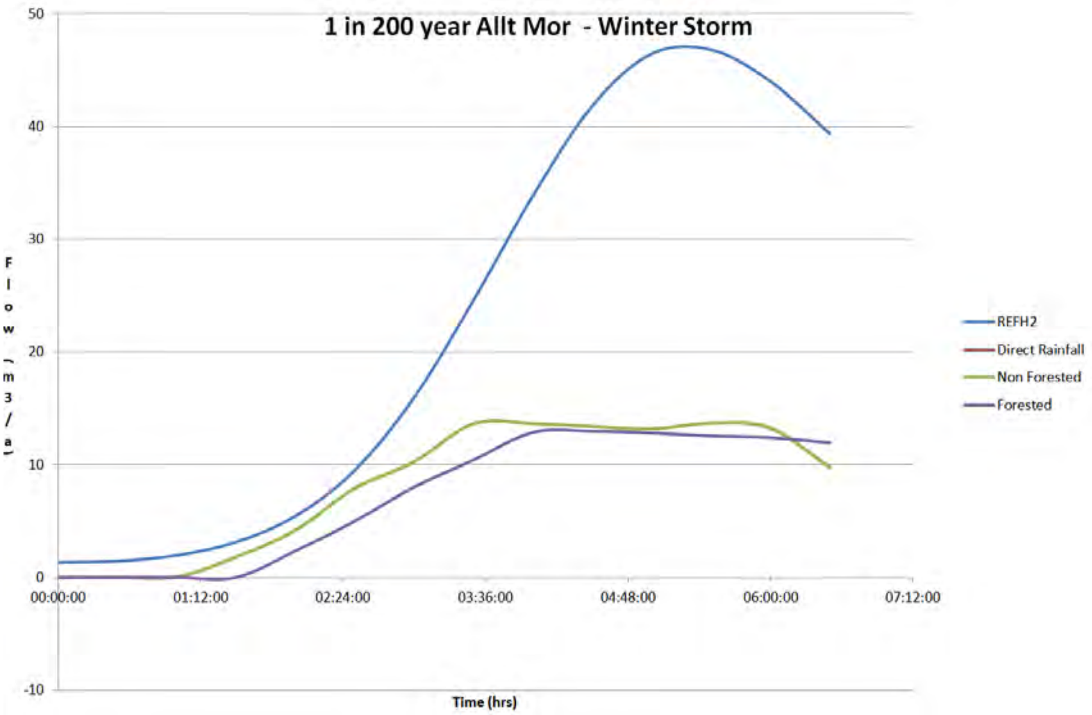

Figure 6-4 Allt Mor hydrograph comparison

A similar exercise has been carried out looking at a summer storm profile. The same 2D modelling scenarios were run with the key difference being the input rainfall profile and the soil moisture deficient which is determined based on land cover and ranges from 85 – 110mm. These preliminary results are compared against FEH derived peak flows for the Clachan Burn and Allt Mor at Clachan in Table 6-8 below for the summer profile.

Table 6-8 Comparison of preliminary model runs with FEH flow estimates – Summer Profile

Hydrological method	200 year peak flow		
	Allt Mor	Clachan Burn	Total catchment ds of confluence
ReFH2	46.8	56.6	104.6
2D model direct rainfall	14.5	54.9	67.5
2D model direct rainfall + soil losses (non-forested baseline)	12.5	43.2	51.7
2D model direct rainfall + soil losses + interception losses + constriction losses (forested baseline)	12.0	40.5	47.8

Initial results indicate a 23% reduction in peak flow in the overall catchment when considering soil losses. This increases to 30% with the inclusion of interception and blockage losses due to forested areas. This is representative of the increased potential for infiltration and soil storage to be utilised in summer events.

On the Clachan Burn catchment representation of soil losses results in a 20% reduction in peak flow compared to direct rainfall alone. There is a further 6% reduction in peak flow compared to the soil loss model when forested losses are considered. This is considered reasonable given the small percentage of the catchment which is forested once the current felled land use is considered (approx. 15% of area)

The hydrograph shown in Figure 6-5 is not fundamentally changed but is shown to have further attenuation effect compared to the no loss model to a reasonable degree when considering the infiltration capacity of the underlying gley soil types and there is a small percentage of the catchment which is forested once current felled landuse is considered.

The impact of soil losses on the Allt Mor catchment is also more marked in the forested scenario with a 13% reduction in peak flow. Although the impact of forestry which covers a large area of the catchment is still limited to the same degree as the winter storm, likely due to attenuating effect of Loch Ciaran dominating flows which can be seen in the hydrograph shape (Figure 6-6).

These initial results give us confidence in the approach showing that reservoir routing effects are being accounted for in the 2D modelling approach. The modelling as indicates that soil and interception losses can be reasonably represented in 2D and show impact on rural conditions which would be expected in a winter storm. This will allow us to reasonably determine how felling in the catchment has influenced flood risk in recent years. This will also give us the mechanism to determine and quantify if attenuation effects of forestry can be enhanced to improve flood risk. However, sensitivity testing of the parameters adopted and understanding these limitations will be a key part of the process.

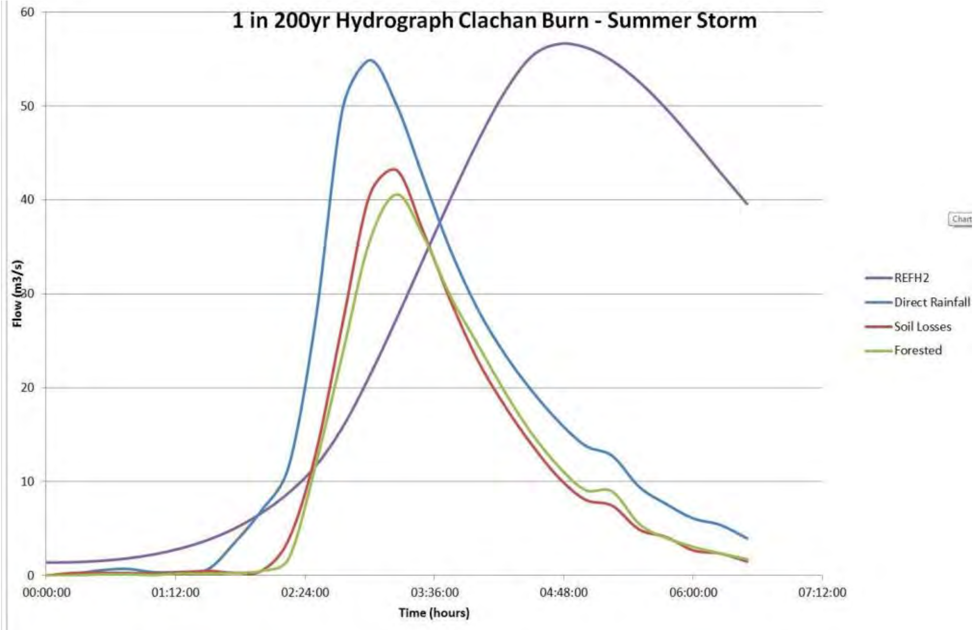

Figure 6-5 Summer storm 1 in 200 year Clachan Burn hydrograph comparison

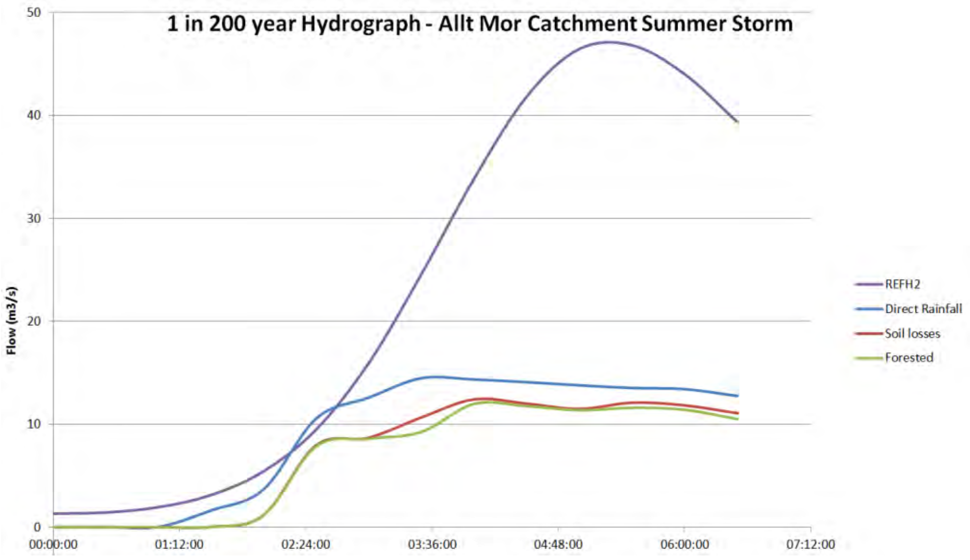

Figure 6-6 Summer storm 1 in 200 year Allt Mor hydrograph comparison

6.10 Sensitivity analysis of catchment model

The lack of data available for calibration increases the uncertainty in the hydrographs generated, and as such, a full suite of sensitivity tests have been undertaken to understand which model parameters have the largest impact on modelled flows. Table 6-9 details the sensitivity tests carried out and the impact on peak flows and time to peak at hydrographs. The 20% sensitivity envelope for interception loss, soil infiltration rate, soil porosity and SMD values were selected based on consultation with Forestry Commission hydrologist with extensive knowledge in this field.

Table 6-9 Sensitivity testing scenarios for catchment model

		Clachan Burn		Allt Mor		Combined	
Return period	**Scenario**	**Peak flow (m^3/s)**	**Time to peak (hrs)**	**Peak flow (m3/s)**	**Time to peak (hrs)**	**Peak flow (m3/s)**	**Time to peak (hrs)**
25 year Winter	**Winter forested baseline**	**28.1**	**3.25**	**10.0**	**5.0**	**33.8**	**3.33**
25 year Winter	Winter forested baseline + summer SMD	13.3	3.75	3.3	2.8	15.2	3.9
25 year Winter	Winter forested baseline +20%* flow constriction	27.7	3.33	9.6	5.9	33.4	3.33
25 year Winter	Winter forested baseline -20%* flow constriction	28.4	3.25	10.1	5.0	34.2	3.25
25 year Summer	**Summer forested baseline**	**16.6**	**3.67**	**5.0**	**2.75**	**19.5**	**3.17**
25 year Summer	Summer Forested +20% SMD	16.4	3.58	5.0	2.75	19.3	3.17
25 year Summer	Summer Forested -20% SMD	16.8	3.58	5.0	2.75	19.8	3.17
25 year Summer	Summer Forested +20% soil infiltration	13.1	3.75	4.4	2.75	14.5	3.33
25 year Summer	Summer Forested -20% soil infiltration	18.6	3.5	5.3	2.75	21.3	3.67
25 year Summer	Summer Forested +20% soil porosity	16.4	3.58	5.0	2.75	19.3	3.17
25 year Summer	Summer Forested -20% soil porosity	16.8	3.58	5.0	2.75	19.8	3.17
25 year Summer	Summer Forested + 20% interception	16.5	3.67	5.0	2.75	19.5	3.16
25 year Summer	Summer Forested - 20% interception	16.6	3.67	5.0	2.75	19.6	3.16

200 year Winter	Winter non-forested base 10m grid	43.3	3.08	14.0	3.25	57.0	3.33
200 year Winter	25m grid Winter non-forested base	43.3	3.33	5.8	2.83	42.0	3.42
200 year Winter	5m grid Winter non-forested base	45.2	3.08	8.3	2.75	56.0	3.0
200 year Winter	1.25hr duration non-forested base	33.4	1.33	7.7	2.0	40.7	1.0
200 year Winter	12.25hr duration non-forested base	38.6	2.25	11.12	3.75	45.6	2.25

As illustrated in the table above, the influence of losses due to forestry are more pronounced at the 1 in 25 year compared to the 1 in 200 year previously reported in Section 6.9. This is in keeping with the body of research into the influence of forestry impacts on hydrology available in the UK. It is generally accepted forestry impacts will be negligible at return periods of magnitudes higher than 1 in 25 year.

The choice of flow constriction factor is shown to have little impact on the model with peak flows changed by around +/-2% in all catchments with a +/- 20% increase in the percentage blockage applied. The hydrograph shape is unchanged with slight increase in time to peak.

The winter scenario is shown to be sensitive to the assumption that soil conditions are considered saturated during these kind of storms. When applying a summer scenario soil moisture deficit condition of 85mm for rural land use and 110mm for forested coverage to the winter scenario, the peak flow is significantly reduced (50%) and time to peak noticeably increased in the hydrograph shape (Figure 6-7). This is to be expected as previously no soil infiltration was occurring as conditions are considered saturated in winter. Although the model is shown to be sensitive to this assumption, it is a realistic assumption particularly given the nature of poorly drained gley soils in the catchment.

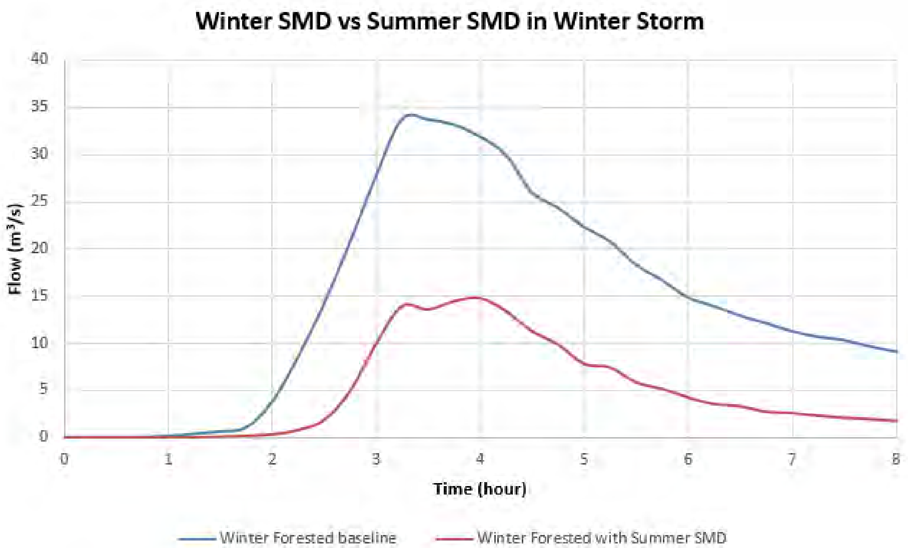

Figure 6-7 Sensitivity to assumption that soil conditions are saturated in Winter storm

Looking at the summer forested scenario, SMD is shown to be less sensitive when capacity is available in the soil profile. A +/-20% change in SMD was shown to have an almost negligible difference in hydrograph shape and peak flows in all catchments. A change of +/-20 porosity is shown to have the same impact. Given this defines how much of the SMD is available for storage this is again to be expected. This indicates the model is not sensitive to these parameters.

Similarly the model is not very sensitive to interception values applied with only minor difference in the summer 25 year forested event travel time and peak flow with +/-20% interception rates applied. The hydrographs of these sensitivity results are unchanged from Summer forested baseline. This is likely because this factor is modelled as an initial loss therefore has less impact over the entire storm profile compared to soil infiltration losses which are continual until the SMD is full.

Sensitivity was also carried out on the storm duration applied to the model. This looked at short (1.25hr), event and long duration event (12.25hr). The catchment model response was more sensitive to the 1.25 hour event where the rising limb of the hydrograph begins 20min into the storm. As expected during a high intensity event, the magnitude of flow generated is much smaller with a 23% reduction in peak flow generated. Response times are much faster with time to peak reduced by half in the Clachan catchment. The hydrograph shape for the Allt Mor illustrates a steep rising limb and more flashy response with a much reduced peak flow generated (45%). This is due to the impact of Loch Ciaran where the storage and control structure moderates any flashy response of a flashy storm from the upper catchment and results in attenutated flow being released from the reservoir.

The 12.25 hour storm results indicate only a 10% reduction in peak flows compared to critical duration in the Clachan catchment. The hydrograph shape is similar to the critical duration hydrograph with the rising limb beginning 15mins prior and time to peak reduced by an hour compared to chosen storm. This is likely due to the longer duration of this event which would result in available storage in the catchment becoming full and causing surface flows to run off to the main watercourse faster. Again the hydrograph shape in the Allt Mor is dominated by Loch Ciaran. The longer duration event allows the reservoir to fill slower and allow a more gradual release of flow. This results in a reduced peak in the Allt Mor by 20% and increase time to peak by half an hour compared to critical case. These sensitivity tests indicate the critical duration (5.25 hours) is an appropriate representation of worst case flood response in the combined catchments.

As the 2D model covers a large area (24km^2), it was important to choose a grid size which was a balance between run times and realistic representation of the DTM. Sensitivity testing on the chosen grid size of 10m has been carried out and indicated it is suitable. The 25m grid was shown to be too coarse in the Allt Mor catchment to pick up all channels with flow getting trapped higher in the catchment reducing the peak flow by 26% and increasing the time to peak. A more detailed 5m grid offered similar hydrograph shape to the 10m grid particularly when looking at the combined catchment and Clachan Burn catchment outputs whilst significantly reducing run time. The Allt Mor catchment is shown to be most sensitive to grid size adopted although the use of an ESTRY unit to control outflow from the dominating Loch Ciaran reduces the impact of this sensitivity on the overall model.

The model is most impacted by soil infiltration values adopted. The Clachan Burn shows reduction of 12% in peak flow with a 20% increase in soil infiltration rates and increased attenuation with time to peak increasing by 15 mins. For the Clachan catchment the hydrograph maintains it’s dominant shape (8), however the slowing impacts of an increasing soil infiltration rates can be seen at the extended peaks of the hydrograph. Sharper peaks are also shown with a reduction in soil infiltration rates to a lesser extent. The Allt Mor catchment shows less impact despite being more heavily forested with flows changing by around 6% due to this change in soil infiltration rates. The hydrograph shape remains unchanged, except for small flow magnitude changes, compared to the forested baseline indicating small level of soil losses have no attenuation impact in this catchment. This lesser impact is to be expected given the dominating impact of the Loch Ciaran reservoir on flow response in the Allt Mor catchment.

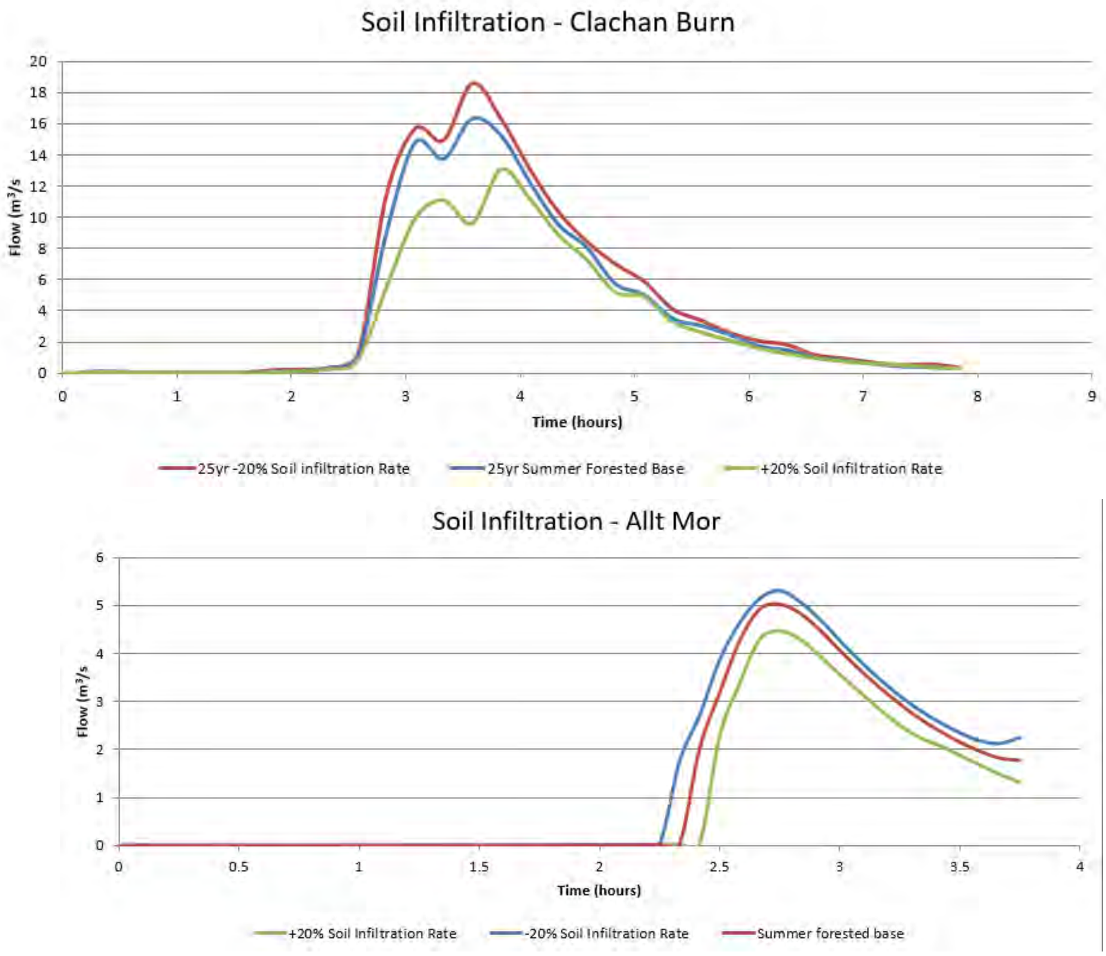

Figure 6-8 Soil Infiltration Sensitivity Hydrographs

6.11 Adopted flows

Following sensitivity testing and refinement of the method, the 2D catchment model was run for a range of return period events. Hydrographs were then generated from PO lines for input to the 1D-2D models. The adopted peak flows derived from the assessment are summarised in Table 6-10 below. In general, the impacts of soil and forestry losses were shown to reduce peaks by around 5% at different return periods in a Winter storm scenario compared to non-forested baseline.

Table 6-10 Adopted peak flows (Winter Forested Baseline)

AEP/ Return Period	Clachan Burn	Allt Mor
50% / 2 year	12.1	4.6
20% / 5 year	18.4	6.6
10% / 10 year	22.7	8.3
4% /25 year	28.1	10.0
2% / 50 year	31.8	11.2
1% / 100 year	36.0	12.6
0.5% / 200 year	41.4	14.4
0.5% / 200 year + CC	57.8	18.6

7. Baseline Hydraulic Model

7.1 Methodology

As discussed previously, the catchment model is needed to understand impacts of forestry on the wider catchment beyond traditional FEH handbook estimates. However given the catchment model covers a large area it is necessary to use a coarser grid size to balance run times and accuracy of outputs. It is therefore not appropriate to use the model to accurately model overland flow paths and fully understand flooding impacts in the village of Clachan. A more detailed linked 1D-2D model of the Clachan and Allt Mor Burns have been constructed to achieve this.

7.2 Model description

A one dimensional (1D) Flood Modeller model was constructed of the Clachan Burn with the modelled reach extending 1km upstream of the village to 0.2km downstream of the weir at the west end of the village. The Allt Mor has also been modelled 0.5km upstream of its confluence with the Clachan Burn.

The 1D channel consists of 48 surveyed cross sections including 7 bridges and 1 weir. Survey was obtained in August 2018 so is representative of the current state of the channel. Several minor footbridges were omitted from the modelling exercise as they would have minimal impact on flow mechanisms. Interpolated sections were added for stability where the distance between sections was greater than 100 m. Cross section locations can be seen in Figures C4 and C5 in Appendix C.

The model inflows were applied to the upstream end of each river and are represented as Flow-Time boundaries using hydrographs extracted from relevant locations from the 2D catchment model. A normal depth based on bed slope was applied at the downstream boundary as it was sufficiently far downstream to not cause any backwater effects.

Channel Manning's 'n' roughness values vary throughout the channel. In the very upper reaches of the Clachan Burn the channel is winding with boulders in channel so 0.07 has been adopted. Similarly the bank roughness has been set to 0.07- 0.1 to account for the densely vegetated nature of banks or when they are bounded by tree cover. The channel becomes straighter and cleaner for the majority of the reach so roughness reduces to 0.04, whilst the banks are lightly vegetated though to a much lesser degree so roughness is again reduced to 0.035. Similar values have been adopted on the Allt Mor channel as it follows a similar pattern with boulders and tree cover along banks further upstream.

The model was run unsteady, i.e. time varying flow, for the return periods discussed in Section 6.6. Model parameters were unchanged from default.

7.2.1 Model parameters

A linked 1D/2D model was constructed of the river channel and wider floodplain to gain a better understanding of the flood mechanisms and flow routes in the area. A schematisation of the model can be seen in Figure C3 in Appendix C. The Tuflow 2D model, linked to the 1D model discussed above, contained the following elements:

- 2D grid built using NEXTMap DTM, 5m resolution;
- 1D/2D links to allow free flow between models, based on top-of-bank survey;
- Roughness layer depicting different surfaces taken from OS mapping including;
  - Buildings 0.5
  - Roads 0.02
  - Water 0.03
  - Grassland 0.04
- Downstream boundary - Automatic HQ (head/flow) boundaries applied to allow water to escape from the active area and not create areas of artificial ponding.

Structures noted to impact flow mechanism were represented, this included 7 bridges and 1 weir. Survey parameters are summarised in Table 7-1 based on survey obtained in 2018. Where the downstream section of the bridge was not surveyed, a copy of the upstream face was used. During the model runs, all structures were assumed to be clear of obstruction. Given the rural nature of the site and quality of the ground model data, a 5m DTM resolution was deemed to be sufficient to accurately model the depth and direction of flow.

Table 7-1 Summary of structures in 1D model

Label	Type	Opening Width (m)	Opening height/height above bed level (m)
CB9	Bridge	9.9	1.64
CB12	Bridge	9.2	1.83
CB20	Arch Bridge	7.8	2.3
CB25	Bridge	4.11	1.98
CB27	Weir (spill)	7.12	0.4
AM8	Bridge	5.47	3.09
AM11	Arch Bridge	3.69	2.55
AM15	Bridge	4.05	1.77

7.2.2 Digital elevation data

A review of the Scottish Remote Sensing Portal[19] indicated no LiDAR data was available; therefore the use of NEXTMap data was required. This data is less accurate than LiDAR as it is at 5m resolution with vertical accuracy of 1m compared to preferred LiDAR data which is 1m resolution and typically within 0.15m. Given the rural nature of the study area it was assessed that this would provide reasonable level of detail for the purpose of this assessment. This data was supplemented by obtaining spot levels at a 10m grid in the core reported flood cell within the village of Clachan. This was assessed to be worthwhile to supplement the poor quality of the available data and would help to map flow routes in the built-up area where more localised variation in topographic was likely. This data has been stamped onto the DTM.

7.3 Model verification

As discussed above, there are no historic flow or level measurements recorded on the Clachan Burn or Allt Mor so full calibration to historic events cannot be achieved. High level verification of the model will be based on observed rainfall and anecdotal evidence (e.g. photos) of flood events. The photographs provided generally provide a snapshot of flood mechanisms at discrete locations.The photographs were not necessarily taken at the peak of the events.

The 15th November event was deemed to offer the best opportunity against which to verify the model. The Met office provided 5 minute and hourly rainfall data for 14th and 15th November for Balinakill near Clachan. The residents of Clachan have also provided anecdotal accounts and photos of the flooding that occurred during this event, which were used to check the model outputs.

A winter storm scenario was adopted in the catchment model and direct rainfall from the met data applied to the catchment. Given the time of year and preceding 9 days of rainfall, it was decided that a winter saturated scenario was likely to replicate the antecedent condition of the catchment. Hydrographs were then extracted and input to the 1D-2D linked model. Analysis of radar rainfall recorded of the event from the Clachan catchment indicates this event was equivalent to a 1 in 10 year rainfall event. An initial review of the flood mechanisms and extents resulting from this scenario indicated flood mechanisms were reasonably represented along the Allt Mor channel and at the upstream and downstream extents of the village. However, only minor overtopping from the Clachan Burn was shown downstream of the old road bridge which did not tie up with reports, photographs and videos of the event.

[19] https://remotesensingdata.gov.scot/ - accessed 28.12.18

Discussion from public consultation events as well as and information provided by residents indicates debris blockage had a unique and significant impact during the 2015 event. Landowners upstream felt this was a result of poor maintenance of treelines in the upper catchment, causing trees to fall into the Clachan Burn causing issues downstream. The old road bridge was blocked with tree trunks significantly reducing its capacity to convey flows. This can be seen from post event photos (**Error! Reference source not found.**) which illustrate heavy lifting machinery required to clear the Burn when flood water receded. Based on this significant blockage scenario, an 80% blockage was modelled at the A83 bridge. The outputs from this scenario were shown to tie up well with the 2015 event shown as Location 1 in Figure 7-2. No other changes were made to the model.

Figure 7-1 Photos of clean up following November 2015 flood event indicating blockage

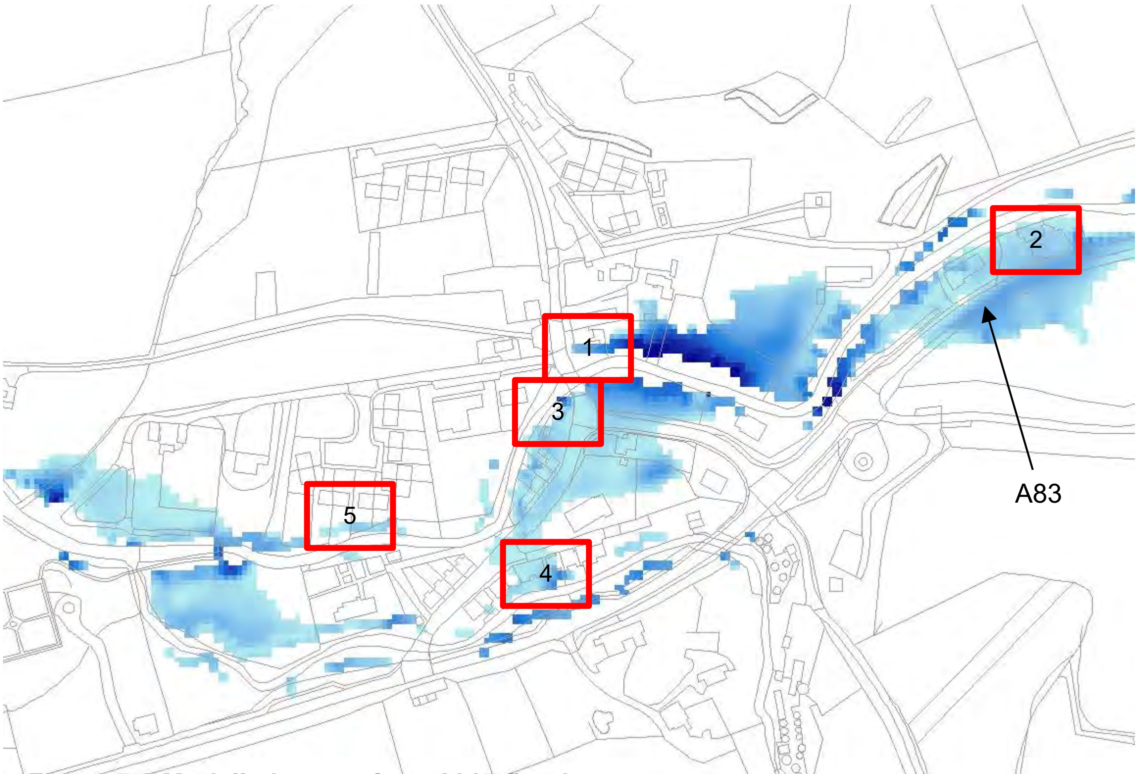

Figure 7-2 Modelled extent from 2015 flood event

Overtopping during this event is first shown to occur at the north end of Clachan at the A83 and Clachan Filling Station (Location 2). Anecdotal reports submitted of SEPA's consultation on PVAs for the second round of Flood Risk Strategies suggest water was up to knee height at this location. This is replicated in the model with flood depths of around 300mm predicted at the Filling Station and up to 400mm at on the road. The flood extent is shown along the A83 carriageway which has been reported to flood frequently. Although there are no photographs of water levels in this location available, Figure 7-3 below illustrates the storage container from Clachan Filling Station being washed downstream during the event, indicating significant out of bank flows at this location during the storm.

Figure 7-3 Storage container washed away from Clachan Filling Station

Overtopping from the Clachan Burn is predicted at properties directly downstream of the road bridge within the village, shown as Location 3 above. (Figure 7-4) is believed to be near peak of the storm. Photos here indicate flooding of an outbuilding to about three quarters of door height and flood level reaching up to 50mm in garden. This is replicated in the modelling with flood level of 200mm shown to inundate the outbuilding whilst flood levels of around 100mm are around the main property and garden.

Figure 7-4 Overtopping at Clachan Burn downstream of road bridge

In the 2015 event, significant overtopping from the Allt Mor was also reported, affecting several cottages immediately downstream of the A83 road bridge shown as Location 4. From photographs flow entered many gardens along the right bank of the Allt Mor and travelled overland towards the Clachan Burn moving around properties. The model replicates this flow path and indicates flood depths up to 150mm around properties which ties up with the photographs (Figure 7-5).

Figure 7-5 Photos during the November 2015 flood event at Allt Mor

Flooding was also been reported at Mansecroft, on the north bank of Clachan Burn (Figure 7-6). Flooding can be seen to come close to properties and build to significant depth in gardens due to the burn overtopping. This is replicated in the model with overtopping from the burn building in gardens up to 150mm.

Figure 7-6 Photos during the November 2015 flood event at Mansecroft

The model has been shown to replicate conditions of the 2015 November event reasonably well. It must be stated that the extent of overtopping in the Allt Mor has been slightly under predicted compared to reports with properties where gardens were impacted upstream of the Allt Mor road bridge are not shown to be affected by the verification run. This could be a result of the nature of the rainfall event as we have no information regarding the spatial distribution of the event. Further to this during the 2015 event blockage was reported on the Allt Mor channel which likely had an impact on overtopping.

As with any form of hydraulic modelling there are inherent uncertainties as calculations are based on layered assumptions and the quality of data available. For Clachan there is a high level of uncertainty in the verification exercise due to several uncertainties. These include; the lack of local hydrometric data, limited observed flood data, the generalized parameters used in the catchment model and their simplification to an initial loss continuing loss model as well as the coarse nature of ground model available. However, this exercise allows some confidence that a suitable approach has been adopted in light of the limited data available.

7.4 Sensitivity checks

Sensitivity checks are carried out on the hydraulic model parameters where these are estimated or are inherently uncertain in order to explore the effect of these model inputs, and the influence the selection of these parameters may have on the results from the model.

The aim is to understand broadly the range of model results that could be obtained within typical variability of these parameters. The intention is not to evaluate an accuracy range or otherwise quantify uncertainty; but to give an indication of the influence certain parameters have and identify if there are significant or disproportionate influences.

Model parameters tested are

- Flow,
- Manning's roughness,
- Structure blockages
- Downstream boundary
- Climate change scenario

Model results showing a water level comparison from the sensitivity modelling are presented in Appendix E.

7.4.1 Flow

Model sensitivity to flow was tested with a 20% increase and decrease in flow for the 1 in 200 year baseline event. In general flood depths on the 2D grid are altered by an average of 150mm. 1D river levels are shown to alter by an average of 140 – 200mm.

The most notable increase to river level is 650m upstream of Clachan village at a footbridge bridge. With an increase flow of around 20% the flood level increases by 200mm compared to baseline which is a reasonable variation. However, when a 20% reduction in flow is applied the water level is reduced by 1m. This is because the reduced flow is within the capacity available under the deck of the bridge and able to be passed by this bridge without surcharging. Under baseline conditions, 200 year would back up here due to this restriction causing water level to rise significantly.   This is an outlier compared to rest of the model which is within the 200mm envelope.

When reducing flow, flood extents are generally reduced as more flow can be retained in channel. The same issue occurs at bridge CB12 located 500m upstream of Clachan. Here an increase in flow results in the bridge being surcharged and a back-up of flow occurring at this point in the channel resulting in increased flood levels.

Although these two areas have been shown to be highly sensitive to flow entering the model, these are not areas which have been reported to flood. Further to this, the area of interest with receptors downstream at greatest risk of flooding has been shown to experience minor impact with this variation of flows; with slight variation in flood extents, channel levels and floodplain depths.

This gives confidence in the flows adopted in the model in the context of the study, Furthermore, the flows used in the baseline model are deemed to be appropriate as they are based on best practice methodologies and results are well matched to observed flood data. It is recommended that the general uncertainty be built into any freeboard allowance.

7.4.2 Downstream boundary

Model sensitivity to the downstream boundary was tested with a 20% increase and decrease in the normal depth selected for downstream boundary condition. The model showed a maximum variation of 50mm in 1D river levels with a generally negligible difference in levels in both the 1D and 2D domains. This indicates the downstream boundary has been sited appropriately to not influence results significantly.

7.4.3 Manning's roughness

Manning's 'n' roughness was increased and decreased by 40% in both the 1D channel and 2D floodplain 1 in 200 year events.

In general the watercourse is shown to be sensitive to the roughness value applied with a general change in flood depth of 200 mm with the 40% uplift in roughness value. The Clachan Burn is particularly sensitive to manning's at the area immediately upstream of the road bridge with 600mm increase in flood level predicted compared to baseline. This results in increased spill upstream of the road bridge with a new area of spill predicted between the burn and the A83 reaching flood depths of 300mm. It should be noted this an area of green space with no vulnerable receptors. Additional spill is also noted downstream of the road bridge though this is minor with in flood depth of 40mm predicted. Further downstream the model is shown to be moderately sensitive at the church grounds with flood level increased by around 400mm at the bend in the watercourse. Generally, in the 2D domain the flood extent is slightly larger at Mansecroft, Longrigg and around Clachan Filling Station with flood depths in these areas increased by around 200mm. Spill from the Allt Mor is also increased impacting 3 properties not previously flooded along the right bank. However these flood depths are minor at less than 100mm.

This is similar to the impact shown when roughness is decreased by 40%, where water levels in both Burns are generally reduced by around 300mm. The model is particularly sensitive to this change around bridge CB9, 600m upstream of the village. This reduction allows flow to be within capacity of the structure preventing flow from backing up to significant level upstream resulting in a reduction in flood level of 1m. This results in spill no longer occurring in this location. Although significant, this sensitivity is not deemed to be a concern as only farmland is impacted and it does not have a subsequent effect downstream at the core area of interest. In the 2D domain the flood extent is reduced slightly, on the right bank of the Clachan Burn at Mansecroft and immediately downstream of the Old Road Bridge. Flood depths are shown to be reduced by around 200mm. Flood extent is also reduced on the Alt Mor with less overtopping impacting properties and flood depths reduced by around 170mm.

Generally, the model can be considered sensitive to selection of manning’s n. This is to be expected when this is a core parameter for the hydraulic calculations carried out in the model and the uplift applied is significant. Although some areas have been shown to have significant increase in water levels these impact less critical areas and open spaces and do not fundamentally change flood risk to the key receptors. Further to this the roughness values used in the baseline model are deemed to be appropriate based on channel type and geometry; and the model has been sense-checked against a past flood events. It is recommended that an appropriate uncertainty be built into freeboard allowance where required.

7.4.4 Blockages

Blockage scenarios were tested for the 1 in 200 year events to assess the impacts on flooding should a structure become partially blocked during a flood event. Two key structures were identified as “at risk”; downstream of areas that may have high debris levels or that have historically been prone to blockage, and where blockage would either increase existing flooding or cause new flooding to properties or roads. These locations area is shown in Figure 7-7 below.

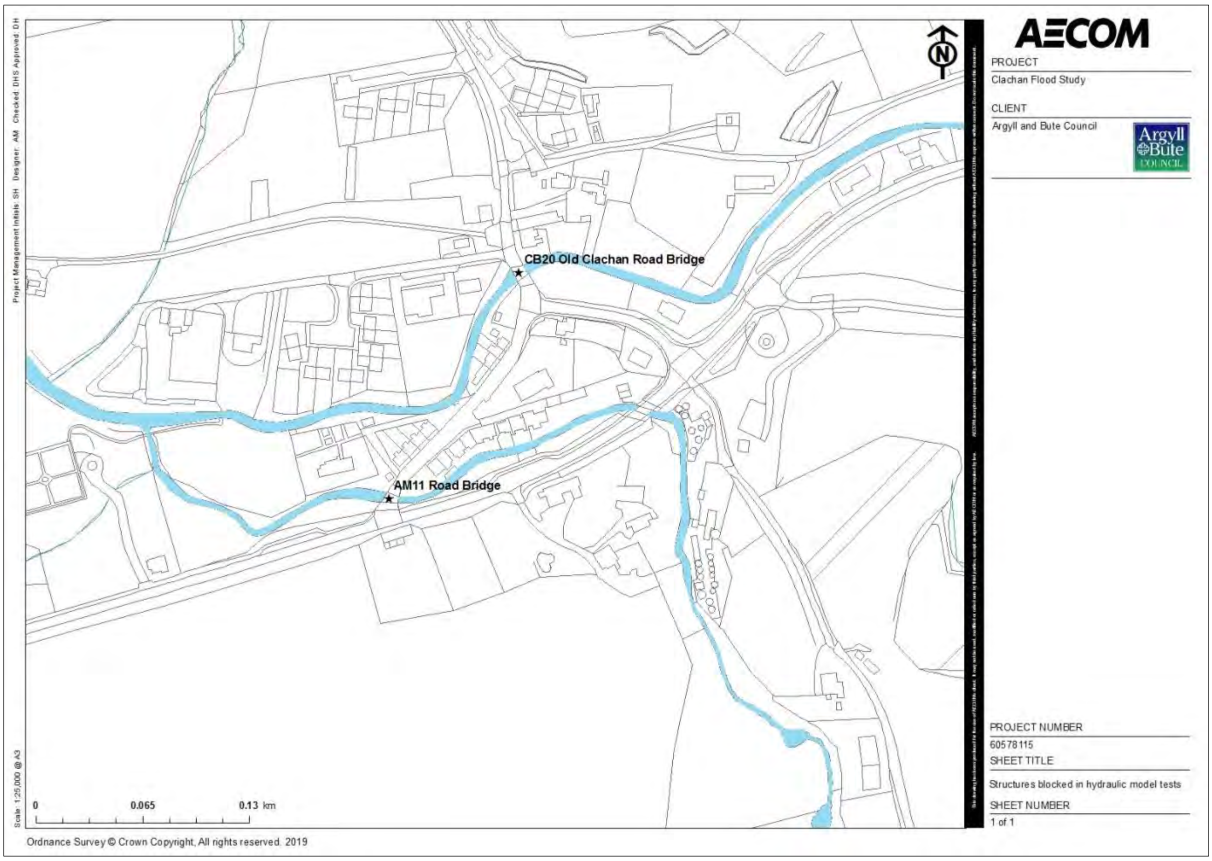

Figure 7-7 Location of structures where blockages have been applied

Structures were modelled as partially blocked to 50% of the flow area by reducing the cross sectional area accordingly.

Blockage has been recorded at this bridge in past events, with indications it contributed to flooding during the November 2015 event. In the 1 in 200 year event, 50% blockage at the CB20 road bridge across the Clachan Burn has a distinct impact on flood depths within the village of up to 150mm. The blockage of this bridge has a significant impact on flow upstream causing a backup of flow at the bridge result in a significant increase in flood level of up to 1m. This changes the flood mechanism within the village, where flow would have spilled downstream of the bridge and affected cottages on the left bank, this constraint at the bridge then forces water to spill out upstream of the road bridge also. The extent of flooding is significantly increased as flow travels overland to the south and towards the Allt Mor Burn. This out of bank flow results in flooding of the A83 approach road which reaches up to 300mm in flood depth which in the baseline is not shown to flood.

Blockage at the AM11 bridge was also tested as flooding has been reported at properties immediately upstream of the bridge. The AM11 bridge which crosses the Allt Mor east of the cemetery is shown to be less sensitive to blockage. Although this scenario indicated localised sensitivity to blockage with an increase in water level of up to 600mm immediately upstream of the bridge, the impact on the floodplain is less pronounced. A 50% blockage was shown to increase the extent of flooding affecting an additional four properties located on the left bank of the Clachan Burn, however flood depths are shown to be very small between 50mm, given the area available for flood water to travel overland and the fact some flow re-enters the Clachan Burn. This impact on the floodplain can be considered a minor impact for this kind of extreme event.

Identifying the structures that are at increased blockage risk and where blockage may result in increased flooding, is useful for identifying structures that would benefit from either extra maintenance or additions such as trash screens. Given the forested nature of the catchments, the potential for blockage is high, therefore these structures should be monitored and blockage scenarios considered going forward.

7.4.5 Climate change

Climate change predictions are inherently uncertain and therefore sensitivity in results is expected. As discussed previously the central projection for rainfall uplift has been used for climate change scenario in this study in line with SEPA guidance. This results in 20% uplift to rainfall depths which equates to a 39% uplift in peak flows. As a sensitivity analysis the high projection scenario recommended in SEPA modelling guidance has also been tested.

Looking at the high projection scenario for West Scotland, 36% uplift was applied to rainfall and run through the 2D catchment model. This indicated 60% uplift in peak flow in the resultant hydrograph for the combined catchment. This is consistent with recommendations in SEPA modelling guidance regarding percentage uplifts for 2080 scenario for different emissions scenarios for peak fluvial flows. In this case, the use of the high projection rainfall UKIWR uplift correlates to a high emissions scenario which is very unlikely to be exceeded up to 2080 for the Argyll area. This has been agreed with Argyll and Bute Council.

Comparing the 36% climate change scenario with the chosen 20% climate change scenario shows slightly increased flood extent along the Clachan Burn and increased flood depths between 150 – 320mm, particularly at the downstream reach, on the right bank adjacent to the weir. The Allt Mor is shown to be less sensitive with floodplain depths increasing by 80mm on average in the high scenario.

This sensitivity is not expected to influence the outcomes of this study greatly as the current SEPA guidance has been used to make an educated assessment on the most suitable climate change scenario. Best practice has been used to ensure climate change is considered in the baseline assessment and will carry through to optioneering with an understanding of the inherent uncertainty surround this variable.

7.5 Baseline model results

Full flood level results are provided in Table F1 in Appendix F and flood maps are provided in Appendix G. A brief summary or the results is given here.

Flooding is indicated to occur first at the upstream end of the village of Clachan, The banks of the burn are predicted to overtop from a 1 in 2 year event causing flow to travel overland over the A83 carriageway. During this event, a stretch of 80m of the A83 is flooded to a depth of approximately 300mm.This flow travels towards the Filling Station and reenters the burn here. Additional overtopping of the burn is seen adjacent to the Filling Station from a 1 in 5 year event also causing increased flow to travel over the A83 and onto agricultural land.

From a 1 in 10 year event further overtopping is expected along the right bank of the Clachan Burn affecting scrub land here. This extends to a property at Long Rigg from a 1 in 50 year event. Within the village, out of bank spill is experienced along both banks from downstream of the road bridge at this return period. Cottages on the left bank are shown to be inundated from a 1 in 25 year event with flood depths of up to 150mm predicted. Further downstream, flooding from the burn is shown to spill on the right bank impacting gardens of properties at Mansecroft from a 1 in 10 year event with flood depths of up to 300m predicted.

Flooding is also shown from Allt Mor Burn at its confluence with the Clachan Burn from a 1 in 2 year event. This flow is constrained the overbank area of the Allt Mor. Overtopping covers a greater extent from the 1 in 5 year with out of bank flow shown downstream of the weir along the right bank of the Clachan Burn. No properties appear to be impacted at this return period. Flow appears to back up at the confluence and spread out over agricultural land adjacent to the church from a 1 in 10 year event. Lack of capacity in the channel appears to be the cause of flooding here but also a backwater effect from the weir located at the Allt Mor confluence which impacts river levels in the Clachan Burn up to the road bridge.

At a 1 in 50 year event, spill is shown along the right bank of the Allt Mor upstream of the road bridge, affecting cottages here. Overtopping is shown further upstream along this bank from a 1 in 10 year event. This out of bank flow is shown to travel overland towards the Clachan Burn impacting a number of properties and carriageway with flood depths of up to 150mm in a 1 in 10 year event.

During the 1 in 200 year event, out of bank spill occurs 1 hour before the peak on the left bank of the Clachan Burn approximately 360m upstream of the Clachan road bridge. Depths in this area reach up to 700m on the road and 500mm at the Filling Station. The flow continues overland and rejoins the channel. Out of bank spill is also observed on the right bank, downstream of the Filling Station with floodwaters reaching property at Long Rigg. Spill from the left and right bank of the Clachan Burn downstream of the road bridge is more extreme. Flood depths of up to 300mm are predicted at properties on the left bank and up to 500mm at Mansecroft. The flooding on the right bank covers a much larger extent extending towards the school. Flooding from the Allt Mor exacerbates this issue as out of bank flow is attempting to enter the Clachan Burn which is already overtopped. Flooding at agricultural land around the Allt Mor/Clachan Burn confluence is more significant covering a larger extent.

The 1 in 200 year plus climate change flow mechanism is consistent with the 1 in 200 year event, albeit with significantly greater flood extents and depths as these mechanisms are exacerbated. Increased overtopping is shown from the Allt Mor affecting cottages along the Clachan Burn and Allt Mor. In addition, overtopping of the left bank of the Clachan Burn upstream of the road bridge is now predicted with this flow travelling overland and joining overtopped flow from the Clachan and Allt Mor Burns to exacerbate flooding at properties along both river banks in the village. Flood depths around properties along the left bank of the Clachan Burn are shown to increase by an average of 300mm whilst further downstream flood depths are shown to increase by around 150mm. At properties along the Allt Mor flood depths are shown to increase by 150mm. The flood extent is also shown to affect more houses at Mansecroft up to the edge of the cul de sac carriageway. This increase in flooding is to be expected given the climate change uplift to rainfall results in 40% uplift in peak flows, particularly when the channel was shown to significantly overtop at this return period without climate change.

7.6 Impact of felling pre 2015 event

The residents of Clachan have reported that they perceived that recent felling in the upper forested catchments was a contributing factor in the 2015 flood event. In order to test this, the catchment model was run for the 2015 storm event with areas felled in the 2013 and 2014 cycle (93.5ha) reinstated as conifer areas.

The felling has been shown to have had no impact on the flooding mechanism which occurred during the 2015 event. The change in peak flows due to this forestry being in place was less than 1% on the Clachan Burn. The Allt Mor Burn response was slightly more noticeable with a 2% in peak flow experienced in the same event pre-felling and time to peak of the storm extended by 15mins. This change in response time in the hydrograph is not enough to have created synchronization of the peaks in both watercourses. Further to this analysis of the impact of the 1D-2D model with these hydrographs from the pre-felling scenario suggest no discernable difference in flood levels or flood extents. These impacts are so small it is unlikely that the 2013 and 2014 felling contributed to flood risk in the area from a purely hydrological standpoint. The model does not represent any instances of poor felling practice which may have contributed to the 2015 event.

7.7 Impact of Talatoll forestry creation scheme

As discussed in Section 4.2, a woodland creation scheme has been proposed for the Talatoll Estate. The proposed scheme will be over an area of approximately 528 ha. The area will largely be Sitka spruce and cover approximately 15% of the Allt Mor catchment (forested only areas included).

A scenario in the catchment model with the scheme in place has been used to determine if the woodland creation would have an impact on flood risk in the village of Clachan. Given the forestry is likely to have noticeably different impact in a summer and winter storm both scenarios have been analysed. The impact of forestry is also known to be more noticeable at smaller magnitude but more frequent events therefore; both scenarios have been run for the a 1 in 25 year storm event to give an initial indication of the impact of the scheme on frequent flood risk.

In a 1 in 25 year winter storm event, the proposed Talatoll forestry has been shown to have significant impact on the Allt Mor catchment. No overtopping is predicted upstream of the A83 road bridge. Properties at the left bank of the Allt Mor which were previously shown to flood at this return period are no longer within the flood extent. The peak flow in the Allt Mor is reduced by 70% whilst time to peak is increased by 2 hours, showing significant attenuation effect from the proposed forestry. As expected, the scheme has no effect on flooding from the Clachan Burn as the upstream catchment from which these flows are generated is unchanged. One property along the left bank of the Clachan Burn is removed from the flood extent as this is generated by out of bank spill from the Allt Mor.

In a 1 in 25 year summer storm event, the proposed Talatoll forestry flood risk impacts on the Allt Mor are more pronounced. Although much less overtopping is predicted at this event for the summer storm in the base condition, the scheme eliminates this along the east bank of the Burn. In both scenarios flooding still remains at the confluence of the Clachan Burn and Allt Mor at green space, though this is likely due to a backwater effect from the Clachan Burn which is at capacity rather than from the Allt Mor catchment alone.

Based on this, the proposed Talatoll scheme is likely to have a positive impact on flood risk from the Allt Mor at frequent flood events, but with no reduction in flood risk along the Clachan Burn.

8. Conclusions

This report details the work carried out in baselining conditions in the catchment for Phase 2 of the Clachan Flood Study. Extensive work has been carried out to understand the character of the catchments and different flood mechanisms impacting the village of Clachan.

Modelling techniques have been developed in consultation with FC to move beyond traditional modelling techniques to ensure the forested nature of the catchment can be better accounted for. Furthermore, this allows the testing of opportunities to implement natural flood solutions in a formal manner as part of the long list of options. Initial work has been carried out to target subcatchments which would likely benefit from these measures, which has been communicated to residents.

The assessment has indicated significant flood risk from the Clachan and Allt Mor Burns from fairly frequent events (1 in 10 year). This flooding affects key infrastructure such as the A83 and the Filling Station as well as a number of residences. Generally flood risk appears to be a result of a lack of capacity for larger storm events. The weir at the downstream end of Clachan is also shown to have a backwater effect on water levels. This impact extends upstream as far as the Clachan Filling Station and the reach of the Allt Mor immediately upstream of its confluence with the Clachan Burn, contributing to flood risk. Options around this mechanism will be explored as part of the long list of mitigation options to be recommended at the next stage of the study.

A review of anecdotal evidence and rainfall patterns has also indicated that significant pluvial flooding has affected the village. This occurs during intense summer storms such as the 2012 event. The steep nature of the catchment and surrounding roads causes significant and rapid overland flow to run off slopes as it attempts to enter the watercourses, impacting carriageways and properties. Although the study is focused on fluvial flooding, AECOM would recommend this mechanism is investigated further and options explored to capture significant contributions from overland flow.

Work has also been undertaken to understand the impact of recent and proposed forestry interventions on flood risk in the area. A review of the impact of areas of forestry felled in 2013 and 2014 would have had on the 2015 storm event has indicated there would have been no change in flood mechanism had these trees been in place. The size of the area felled in these years (0.9km^2) in the context of the entire contribution of the catchment (27.3km^2) is unlikely to have significantly altered local hydrological processes.

A review of the potential impact of the proposed Talatoll Estate woodland creation scheme has also been carried out. This indicates that foresting 15% of the Allt Mor catchment has potential to have significant flood risk benefit to properties affected by flooding from this watercourse. This needs to be considered in conjunction with other flood mitigation options and will require continued close working with FC and the forestry company.

Based on the analysis within this report, AECOM now have a clearer understanding of the catchment and its mechanisms. This will feed into the next stage of the project which involves developing a long list of options to reduce flood risk. These options will be assessed for their feasibility and consulted on with key stakeholders and the community to develop a short list of options. A key driver for this work will be to ensure a short list of solutions is developed which are appropriate to the scale of flooding in Clachan and are (potentially) deliverable.

Appendix A Review of Rainfall Data for Clachan

Review of Rainfall Data for Clachan

Introduction

This document sets out the analysis of daily rainfall data received as part of the Clachan Flood Study for Argyll and Bute Council (ABC) and should be read in conjunction with the Clachan Phase 2 Baseline Report (AECOM, December 2018).

Daily rainfall totals were received from Peter Simson, a local resident and Met Office rainfall recorder. The data is from two stations, operated at different times. The period 1989-2006 is captured by the Portachoillan station (see report for map locations) and from 2007 to present, the data is from the station at Ronachan. Both stations are located closer to the coast than the study catchments and provide only daily rainfall totals and therefore have only limited value to this project. However, a brief study of any long term trends has been undertaken and is outlined in the following sections.

Portachoillan data

The record from Portachoillan has a number of gaps including January to October 1989, January to May 2001 and all of 2004 (Figure 1).

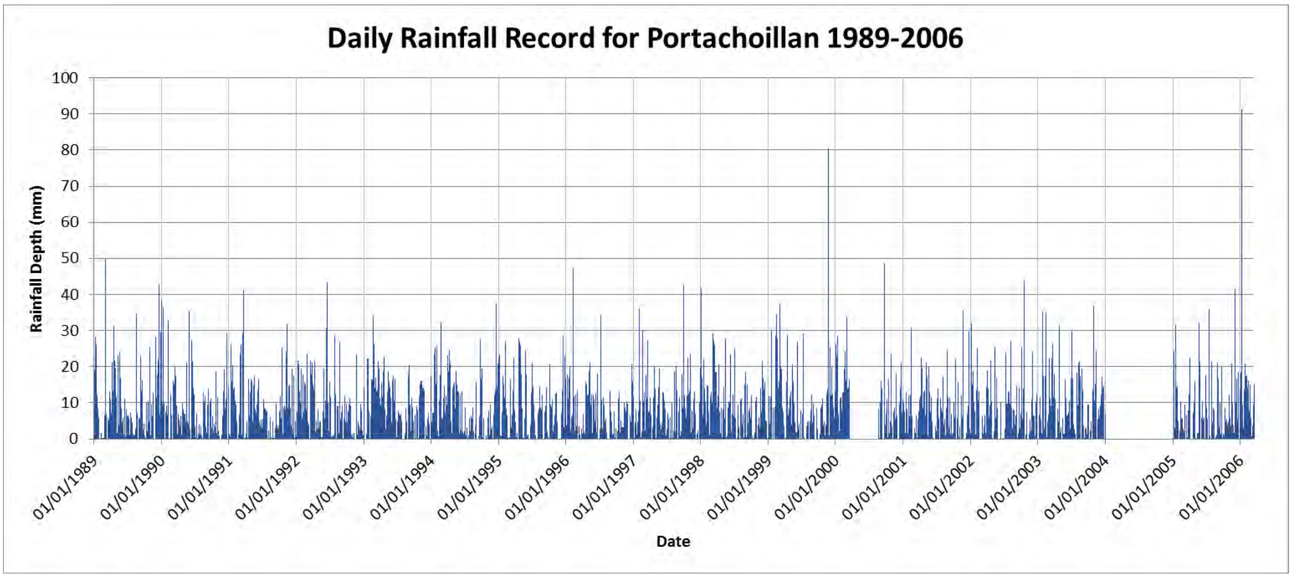

Figure 1 Portachoillan daily rainfall record

The maximum daily rainfall values from each year are shown in Figure 2 and show the highest values are from September 2000 (80.4mm) and October 2006 (91.4mm).

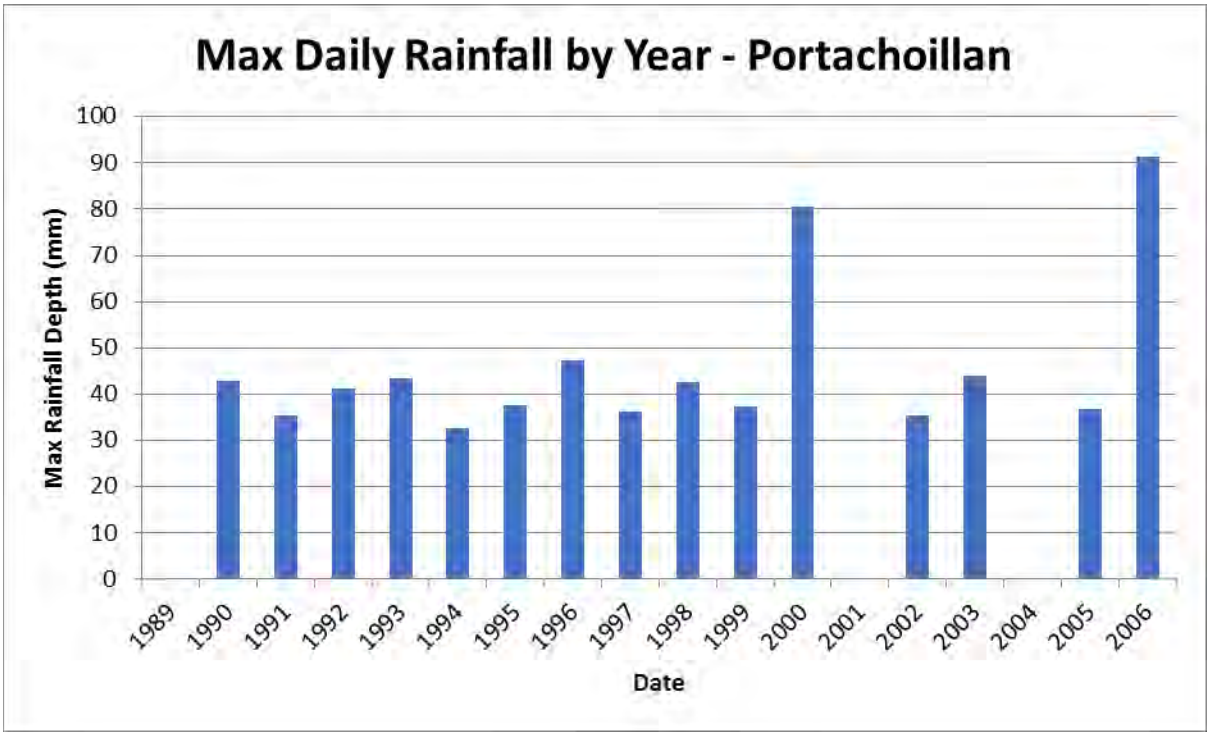

Figure 2 Maximum recorded daily rainfall by year at Portachoillan

Mean annual rainfall was calculated for Portachoillan to identify if any obvious long term trends could be detected (Figure 3). The graph shows that there is no obvious trend.

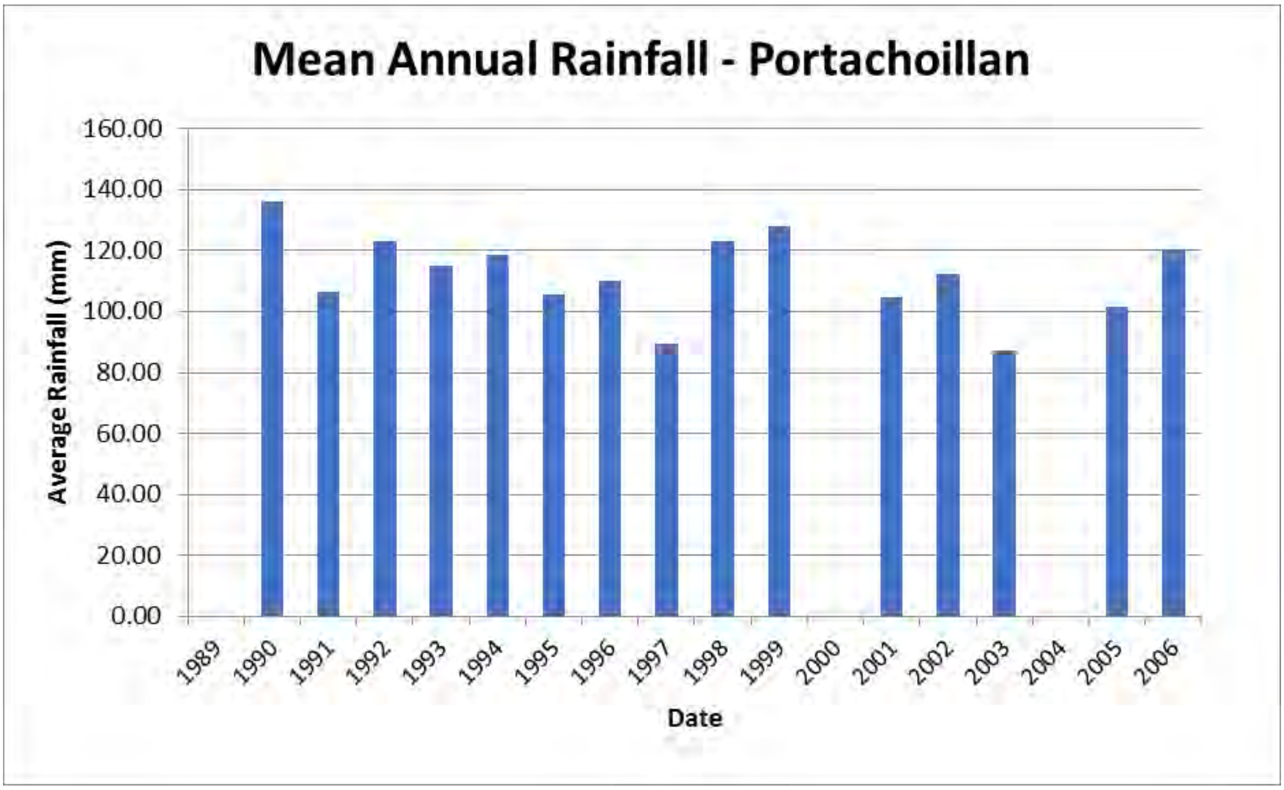

Figure 3 Yearly average rainfall for Ronachan

Ronachan data

The rainfall station was changed from Portachoillan to Ronacahn in 2006 and there have been no data gaps since that time (Figure 4).

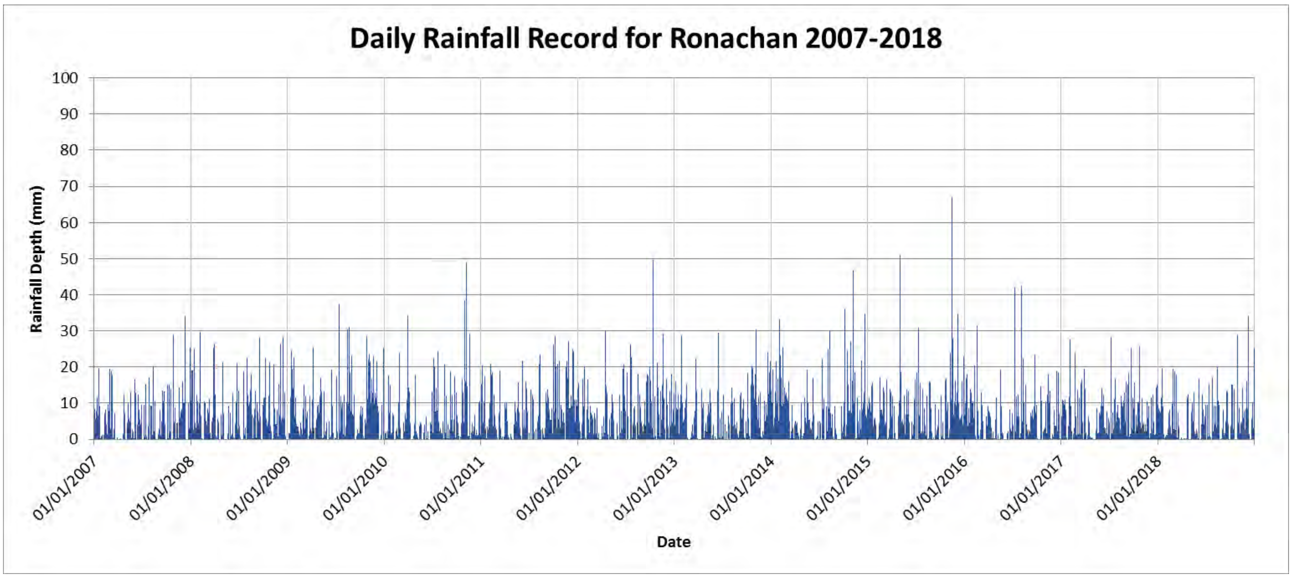

Figure 4 Ronachan dailyrainfall record

The maximum daily rainfall values from each year are shown in Figure 5 and show the highest value is from November 2015 (67mm).

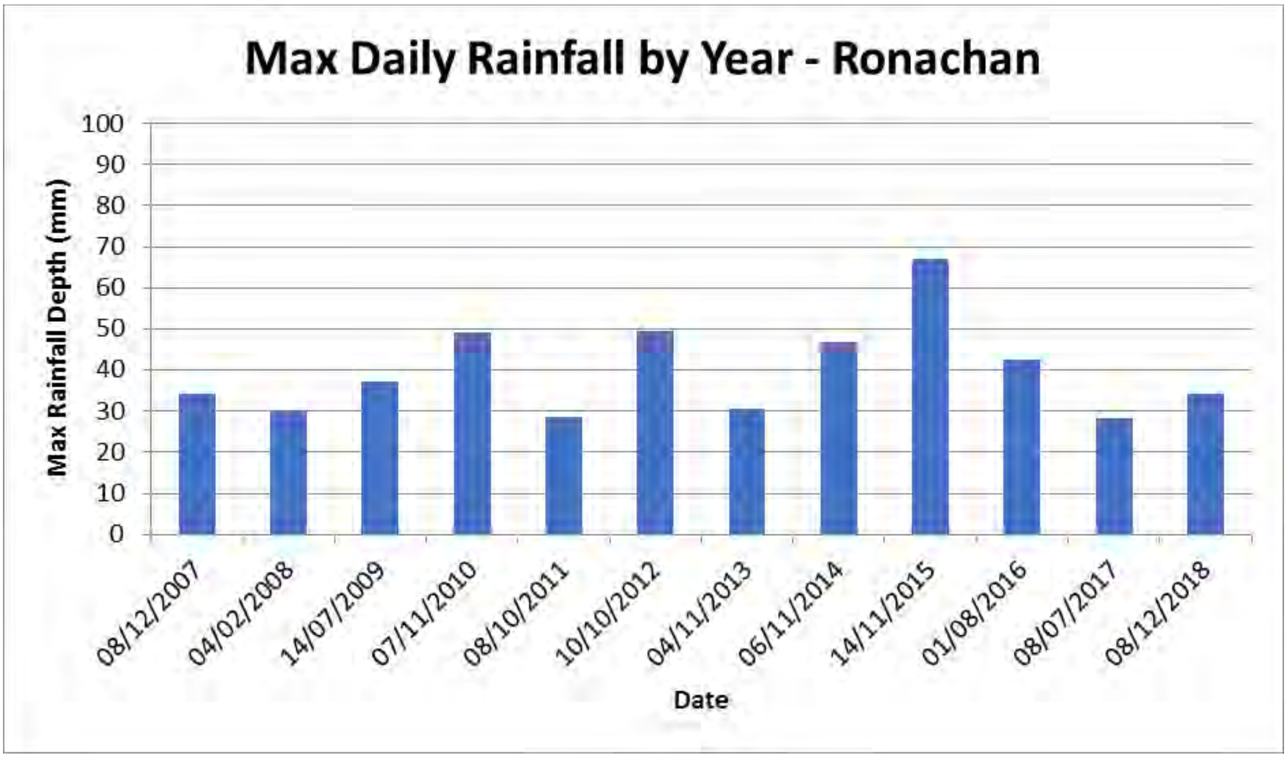

Figure 5 Maximum recorded daily rainfall by year at Ronachan

Mean annual rainfall was calculated for Ronachan to identify if any obvious long term trends could be detected (Figure 6). The graph shows that there is no obvious trend.

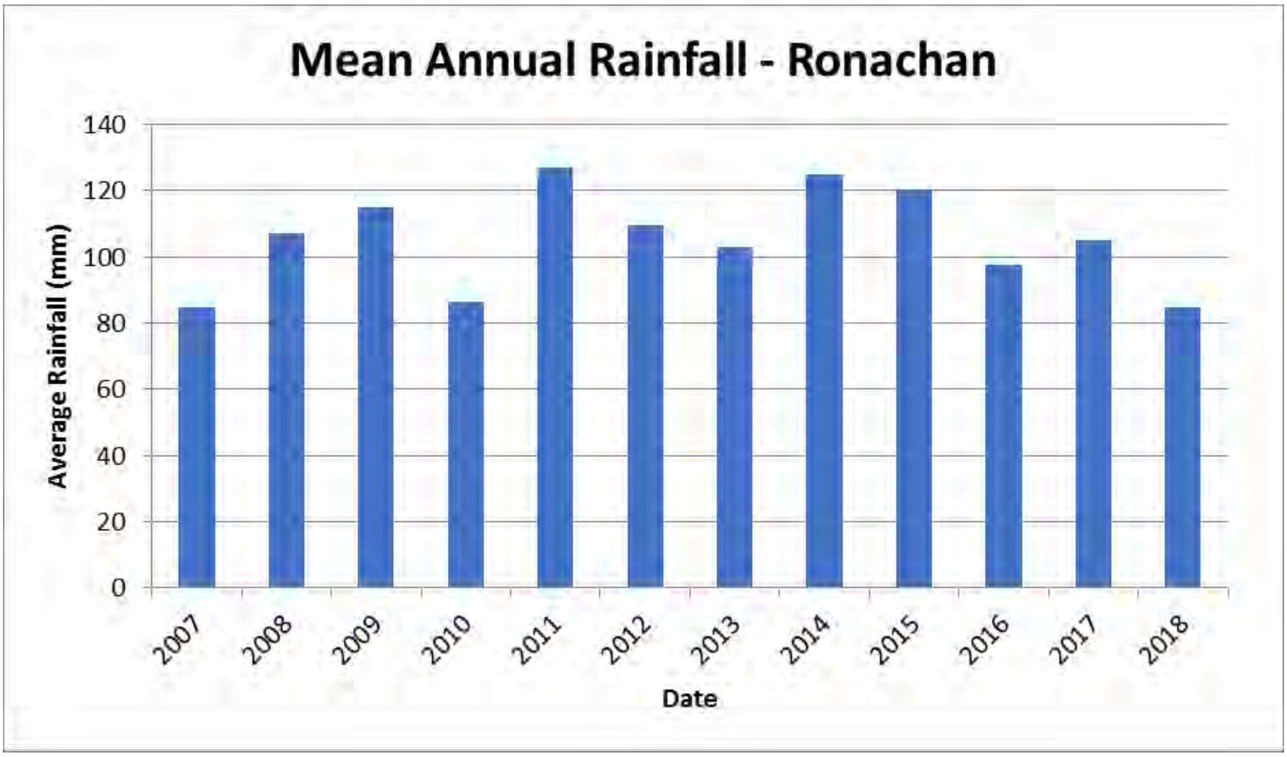

Figure 6 Yearly average rainfall for Ronachan

Assessment of whole record

The highest yearly rainfall total is 1632.4mm from 1990 (Portachoillan) and the lowest rainfall total is 1014.9mm from 2007 (Ronachan). The max daily rainfall record in each year is given in Figure 7 for the full record of data. The stations are located approx. 2.8km apart and therefore any difference between the records could be related to local variation rather than changes in rainfall over time across the region.

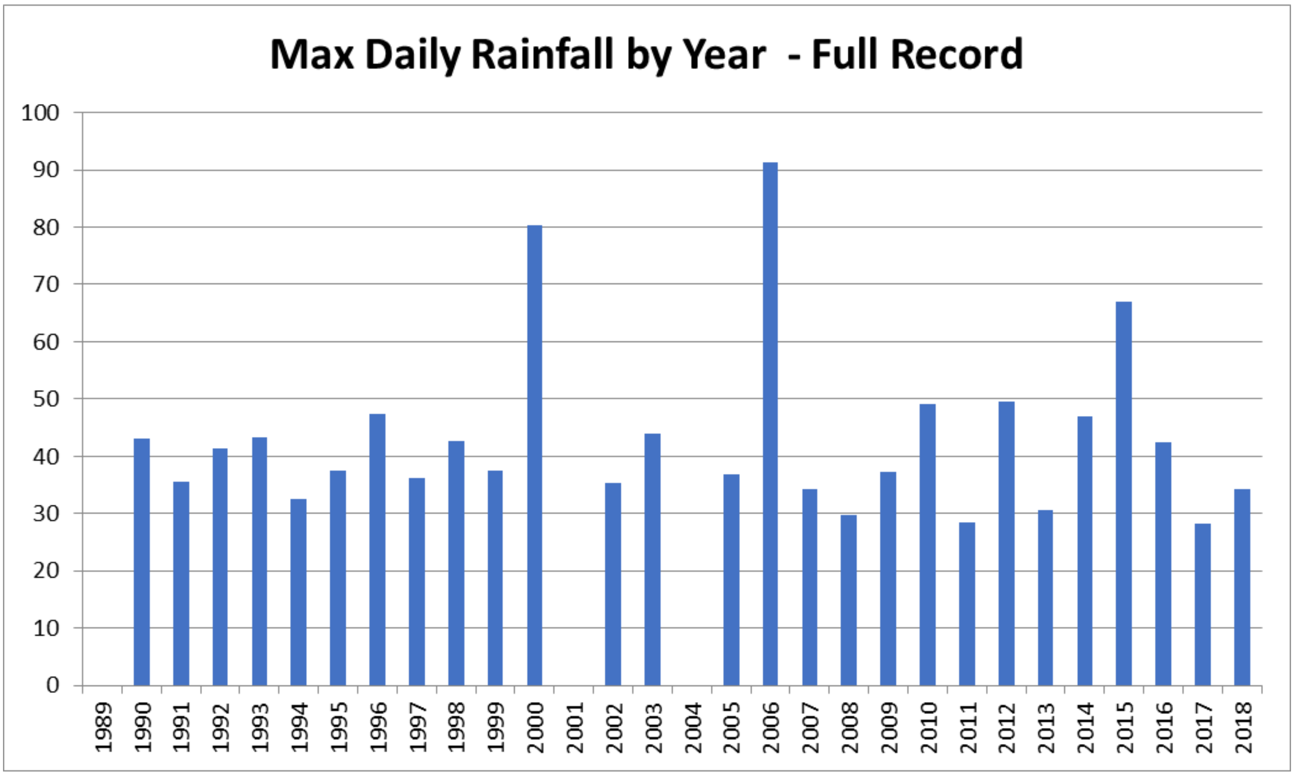

Figure 7 Maximum recorded daily rainfall by year for the full record

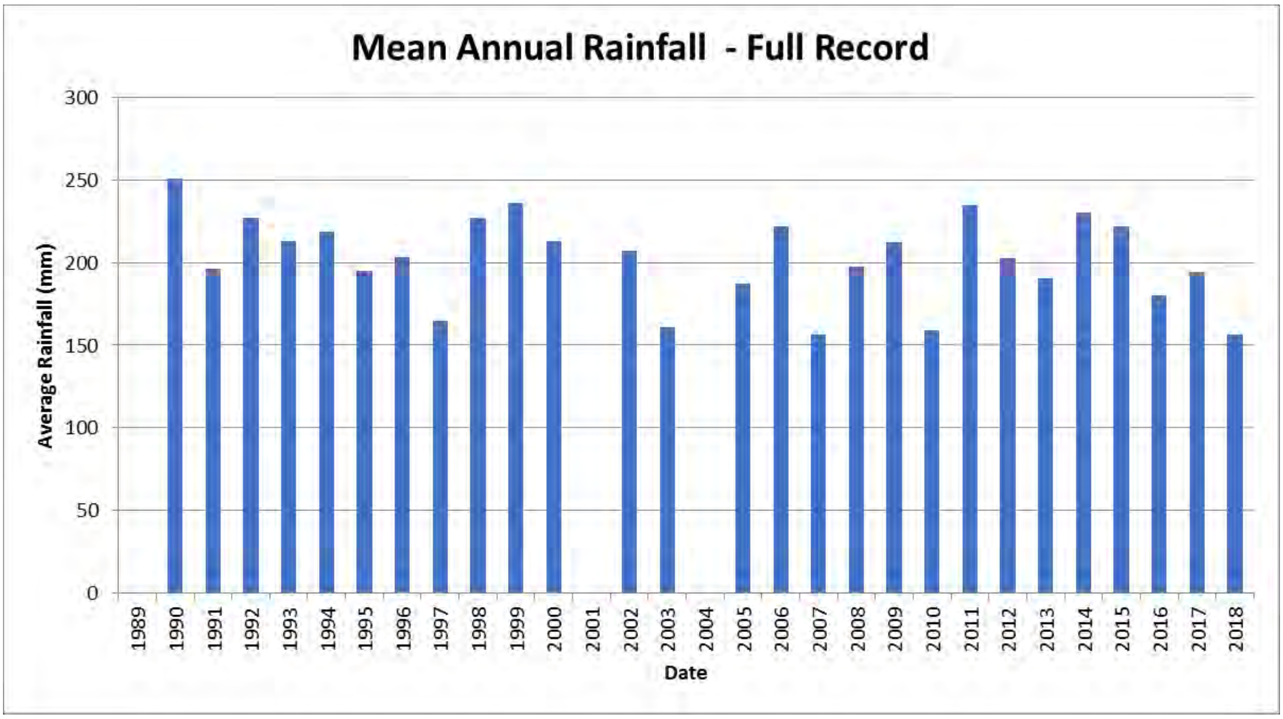

Figure 8 Full record of mean annual rainfall

Appendix B Liaison with SEPA

- AECOM technical note 8/8/18
- SEPA response letter 15/10/18
- AECOM technical note 1/11/18
- SEPA response letter 1/12/18
- SEPA response Letter 22/03/19

Technical Note

Project:	**Clachan Flood Risk Assessment**	Job No:	**60578115**
Subject:	**Hydrological assessment and hydraulic modelling approach**		
Prepared by:	**Debbie Hay-Smith**	Date:	**07/08/18**
Checked by:	**Morag Hutton**	Date:	**08/08/18**
Approved by:	**Hazel MacLeod**	Date:	**08/08/18**

Introduction

AECOM has been commissioned by Argyll and Bute Council to undertake a flood study for the settlement of Clachan in Kintyre. The main fluvial flood risk to the village is from the Clachan Burn, which flows east to west through the village, joined by its tributary, Allt Mor, downstream of the weir at the western end of the village at national grid reference NR 76315 56075. A number of small natural lochs are present in the catchment areas of both watercourses, and a large raised reservoir, Loch Ciaran is located south of Clachan on the Allt Mor. Both catchments also include large areas of managed forestry, and a further commercial forestry plantation is planned within the Allt Mor catchment at Talatoll.

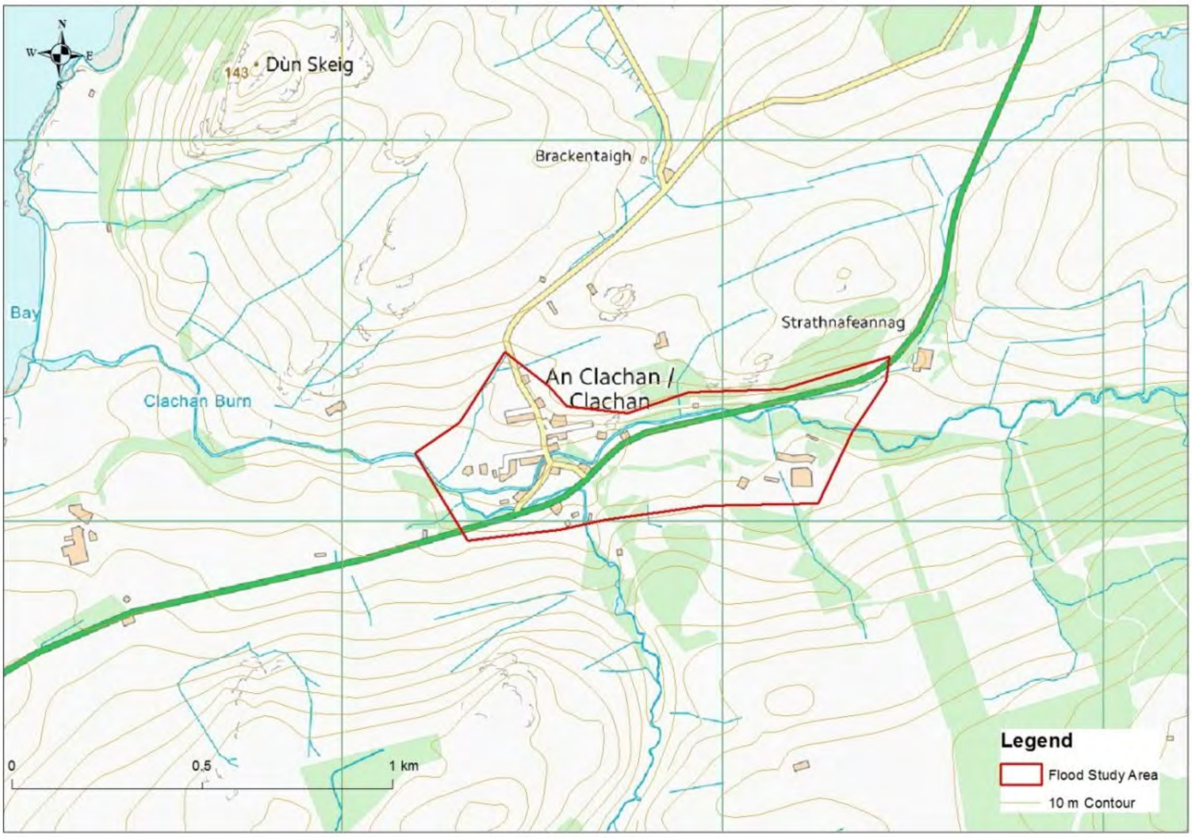

Figure 1 Map of Study Area

Phase 1 of the project included data review and gap analysis. The next phase will be to establish baseline conditions. This will require hydraulic modelling of the watercourses to establish current flood risk. Hydrological assessment will also be required to determine flood flows generated in the catchment areas. Later phases of the project will include option development and modelling. This technical note sets out our intended approach to the hydrological assessment and hydraulic modelling.

Hydrological assessment

Hydrological assessment will be undertaken to estimate runoff generated over the catchment areas of each watercourse. Normal practice when undertaking hydraulic modelling of a watercourse to establish flood risk is to use recommended hydrological methods such as FEH[1]. Such methods use rainfall and catchment characteristics to estimate design flood hydrographs of a specified probability, that are then input to the hydraulic model to allow flood levels to be modelled.

Part of this study will investigate the potential for natural flood management (NFM) techniques to mitigate flood risk. In addition, it is reported that some Clachan residents have a perception that recent deforestation of areas of the managed forestry is exacerbating flooding in the village. The study will therefore need to consider the impact of changing landuse and various types of NFM measures. FEH techniques are somewhat limited in how they can be manipulated to represent landuse and NFM measures. We have consulted with hydrologists from the Forestry Commission (Tom Nisbet, Huw Thomas) on possible modelling techniques to represent the impact of forestry. One possibility is to use Hec-HMS software, a hydrological modelling package developed by the US Army Corps of Engineers. This software was used by Huw Thomas to quantify the effect of woodland planting on flooding in Pickering[2].

HEC-HMS incorporates several methods to represent losses from a rainfall input and how this is transformed to runoff. The Pickering study used the Soil Conservation Service's Curve Number method which assigns a Curve Number to a given landuse/soil type and this is used to represent how much rainfall is transformed to runoff. A 50m x 50m grid of the catchment was created and appropriate Curve Numbers assigned to each grid cell. Then a weighted average Curve Number was calculated for each sub-basin defined in the model. This method is a good way to study and assess the impact of landuse change, but one drawback is that the representation of NFM features in the channel network (e.g. debris dams) is more limited as it isn't a hydraulic model.

Another alternative would be to use a fully gridded 2D model such as Tuflow, which would allow in channel hydraulic features to be included as 1D elements. This method was used by JBA in a study of flood management and woodland creation in Southwell for the Forestry Commission[3]. The approach taken was to construct a 1D-2D ISIS Tuflow direct rainfall model, calibrated to an observed flood event. The model represented interception, infiltration and physical representation of the tree stand from different tree types (eg broadleaf or conifer). Infiltration and interception were represented by applying appropriate infiltration and interception rates to each 2D cell depending on landuse and tree type. The hydraulic impact on surface flows of the physical tree stand was represented by applying a flow restriction through each grid cell, which was considered to produce a more realistic hydraulic response over modification of Manning "n" roughness values. Calibration involved altering the initial soil wetness and scaled interception/infiltration rates to match observed flows in the watercourse.

For this study, we consider the use of a direct rainfall Tuflow model to provide the best approach with the fewest limitations to model the impact of landuse change and other NFM measures. The main input to the model will be rainfall – using the FEH 2013 DDF model for design events, and local rainfall data for historic events for calibration/validation. Elevation data, soil infiltration, interception and transpiration from vegetation, and flow conveyance depending on land use will also form inputs to the model. The outlet control structure at Loch Ciaran will also be represented as this may have a significant impact on the flows in Allt Mor, and must be included in the catchment model. Model runs will then provide runoff hydrographs from the catchment areas in response to rainfall, which will then form inputs to the hydraulic model.

There are no flow measurements recorded on the Clachan Burn or Allt Mor so calibration to real events must be based on observed rainfall and anecdotal evidence (eg photos) of flood events. This data is

[1] Flood Estimation Handbook, Institute of Hydrology (now CEH), 1999

[2] Slowing the Flow in Pickering: Quantifying the effect of catchment woodland planting on flooding using the Soil Conservation Service curve number method, Huws et al, Int. J. of Safety and Security Eng., Col 6, No 3, 2016

[3] Flood management and woodland creation – Southwell Case Study, Hydraulic Modelling and Economic Appraisal Report, JBA, 2017

currently being gathered. Calibration to FEH design storms may also prove useful. This was undertaken for the Pickering study:

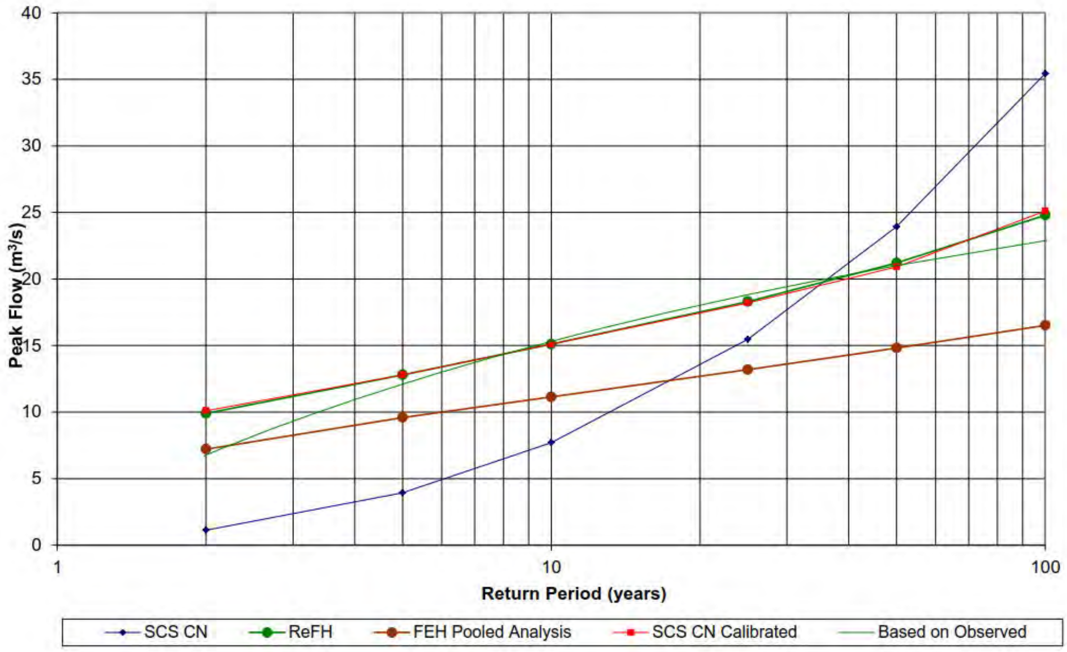

Figure 2 Calibration to design storms and real events (after Thomas et al, 2016)

As this will be a direct rainfall model, the impact of climate change will be assessed using rainfall uplift figures recommended in Table 10.3 of SEPA's flood model guidance[4]. Low and high projections will be assessed to define a likely envelope of impact.

It is proposed to use TUFLOW 2D software to model the catchment areas, which will provide the option of combining the catchment model with the hydraulic model of the watercourses, providing a single model of both the catchments and watercourses. An appropriate grid cells size in the catchment areas is likely to be larger than that appropriate for the floodplain areas in the town where more detail will be required. A multi-domain model will therefore be needed if combining the catchment and watercourse models.

Hydraulic modelling

Flows generated by the hydrological assessment will be used as input to a hydraulic model of the Clachan Burn and Allt Mor to determine peak water levels, floodplain extents and overland flow paths. A river cross section topographic survey has been commissioned, with spacing in accordance with best practice to allow construction of the model. The survey includes river cross sections along both the Clachan Burn and Allt Mor, together with bank levels at 10m intervals. As there is no lidar data available for this area, spot levels on a 10m grid and property threshold levels have also been specified as shown in Figure 3.

The survey will be used to construct a 1D-2D Floodmodeller-Tuflow model of the watercourses, relevant hydraulic structures and adjacent floodplains. The model will be run in hydrodynamic mode, modelling the full flood hydrograph as opposed to just peak flows. This will allow proper assessment of floodplain storage and overland flow paths. The normal flow, roughness, downstream boundary, structure coefficient and blockage sensitivity model runs will be carried out. This will form the baseline model to assess existing flood risk to the village.

[4] Flood Modelling Guidance for Responsible Authorities, version 1.1, SEPA

In later phases of the project, options modelling will be carried out, which may involve changes within the catchment areas, eg landuse change, woody debris dams, increased storage, or within the watercourses, eg changes to structures to remove hydraulic restrictions or inclusion of flood walls.

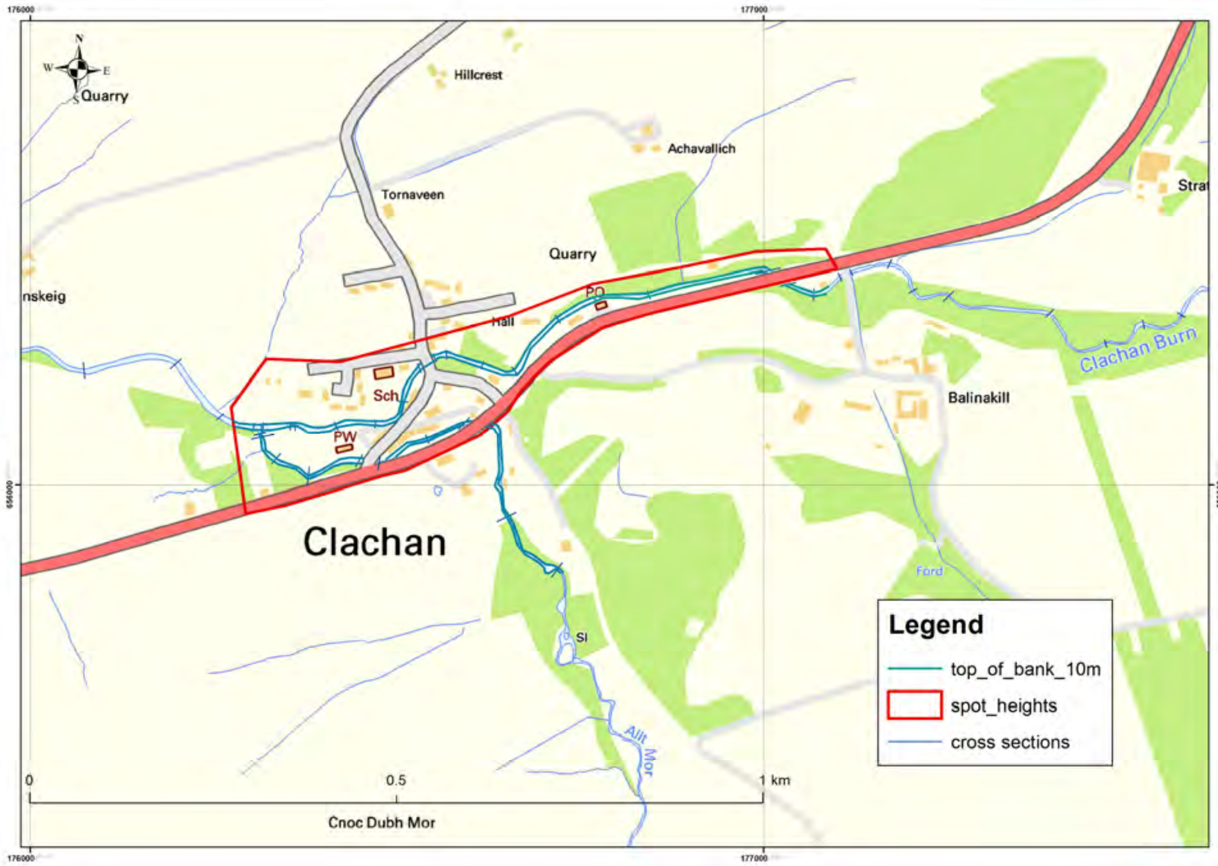

Figure 3 Topographic survey

SEPA
Scottish Environment Protection Agency
Buidheann Dìon Àrainneachd na h-Alba

Our ref: PCS/160688
Your ref:

Hazel Macleod
Aecom
1 Tanfield
Edinburgh
EH3 5DA

If telephoning ask for:
Nicki Dunn

15 October 2018

By email only to: hazel.macleod@aecom.com

Dear Madam

Mid Argyll and Kintyre Flood Protection Schemes
Clachan

We have been provided with a hydrological assessment and hydraulic modelling approach by AECOM with regard to a proposed flood risk assessment for the village of Clachan. We make the following comments on this submission.

1. Technical Report

1.1 In summary, we highlight the points below as being key components of our review of the technical note provided by AECOM:

- The information provided in the technical note is very high level and does not provide much detail on the proposals for hydrological and hydraulic modelling. Further information would be required for us to comment more fully on the appropriateness of the proposals;
- Given the ungauged nature of the catchment we must highlight there will be considerable inherent uncertainties in model outputs. Calibration is proposed, which we are clearly supportive of, although we note calibration data will be limited. Such limitations should be clearly documented in the modelling report;
- Sensitivity analysis will be a key component of the modelling exercise and is critical in determining the possible ranges of change to peak flows and hydrograph shape resulting from the implementation of NFM. We consider the consultant will require to go beyond the standard sensitivity scenarios outlined in our modelling guidance. Testing of the full range of plausible parameters in the hydrological and hydraulic model should be considered (noting these parameters should not be altered to outwith acceptable, justifiable limits).

1.2 A more comprehensive catchment hydrological and hydraulic model schematisation would be helpful. This should indicate available data, the size of the project and potential impacts and will help inform the choice of hydrological/hydraulic model.

1.3 It is unclear from the scoping document how it is proposed to model the attenuating capacity of the upstream lochs, particularly Loch Ciaran. It should be noted however that attenuating effects may be less important in some cases than others e.g. intense rainfall events where the centroid of the storm is downstream of the lochs.

1.4 The scoping document states that recommended hydrological methods such as Flood Estimation Handbook (FEH) will be employed. However, it is unclear which actual hydrological method (e.g. ungauged statistical or a form of rainfall-runoff deterministic approach) is proposed; therefore this section of the report should be expanded upon. This should include specifically the hydrological approach selected (and why), including reference to key parameters of the approach, e.g. the storm profile, duration etc.

1.5 FEH Rainfall Runoff (RR) and ReFH2, while amongst the most common hydrological models used, have limitations. Both methods are based on catchment average properties and calculate flows at the catchment outlet, so the models cannot be used where within a catchment Natural Flood Management (NFM) measures will have the greatest effect. However, despite these limitations these models can be used for sensitivity testing of NFM options. The limitations should be clearly acknowledged and documented and justification should be provided that a more complex approach is not required.

1.6 It will not be possible to fit either results from a TUFLOW model or a HEC-HMS model to either ReFH2 or FEH RR design hydrographs for the whole catchments, as these will not account for attenuation due to the lochs and reservoirs (which we note are present in both the Allt Mor and Clachan Burn catchments). To account for attenuation due to reservoirs or lochs using the FEH RR or ReFH2 methods, a routing model would be required. This may be required in any case if future options are likely to include optimising storage in the lochs.

1.7 An alternative initial approach may be to apply standard FEH methods to investigate flood risk to Clachan, including constructing reservoir routing models where appropriate. It would then be possible to compare the scale of changes to flood peaks, phasing or volumes to the range of changes in flood flows due to afforestation/deforestation identified by previous studies and the uncertainty in these. This may help identify whether further detailed modelling, such as the TUFLOW modelling proposed, is likely to be deliver results within the required level of confidence. For example if the uncertainty in the modelling approach is greater than the scale of change required to provide flooding betterment, then further more detailed modelling is unlikely to be justified.

1.8 Calibration of the hydrological model is discussed, which we are pleased to see, particularly given the catchments are ungauged and uncertainties are therefore significant. A critical aspect of this should be to provide an indication of how well the model is performing and in particular whether travel times in the model are realistic. We recommend the model be run for an event with observed rainfall and realistic antecedent conditions. Given the ungauged nature of the catchment the shape of the hydrograph and timings of the peaks will require particular consideration, with limitations acknowledged.

1.9 Use of a 2D model with appropriate infiltration, interception, transpiration and roughness allowances is in principal appropriate. However there are a number of uncertainties associated with this approach which will need to be assessed, in order to ensure that the results are not quoting effects from NFM which are smaller than the uncertainty in the modelling. In particular sensitivity testing should be undertaken for infiltration, interception, roughness parameterisation, antecedent conditions and to different duration storm events.

1.10 Recent studies have highlighted the importance of sensitivity testing, particularly in ungauged catchments where little or no calibration data is available. We therefore reiterate this sensitivity will be a crucial component of both the hydrological and hydraulic modelling exercises. Sensitivity testing should go beyond the standard scenarios described in the SEPA modelling guidance. Sensitivity analysis on the full range of plausible parameters in the hydrological and hydraulic model should be undertaken. If a similar approach to the JBA study is proposed then this will include testing of the porosity and initial wetness in the soil layer as well as the interception capability of the forestry.

1.11 A key task is to model the impacts from initial ploughing of furrows at the planting stage of a forest. Past evidence from the Institute of Hydrology experimental catchments showed that an increase in flood peaks of 20% to 40% can occur within the first 5 years. This may be modelled simply by increasing the rainfall input to a deterministic model by increments up to 40%, with no assumed losses. The installation of hydrometric instruments now will in future provide better evidence of both the short term and longer terms impacts of forestry upon the hydrological response of this catchment.

1.12 Model resolution may also have an impact, as if the entire catchment is modelled in TUFLOW it is unlikely that preferential flow paths such as drainage ditches will be picked up. Sensitivity analysis of this parameter will also be required.

1.13 Sensitivity analysis would also be required if the alternative approach of using HEC-HMS is adopted instead. There are questions about the robustness of this approach given that a return period dependent scaling factor had to be applied to force the model to fit results from standard FEH methods.

2. Caveat

2.1 Please note that we are reliant on the accuracy and completeness of any information supplied by the applicant in undertaking our review, and can take no responsibility for incorrect data or interpretation made by the authors.

If you have any queries relating to this letter, please contact me by telephone on 01698 839000 or e-mail at planning.sw@sepa.org.uk.

Yours faithfully

Nicki Dunn
Senior Planning Officer
Planning Service

Technical Note

Project:	**Clachan Flood Risk Assessment**	Job No:	**60578115**
Subject:	**Hydrological assessment and hydraulic modelling approach - update**		
Prepared by:	**Debbie Hay-Smith**	Date:	**23/10/18**
Checked by:	**Aisling Marlow**	Date:	**01/11/18**
Approved by:	**George Harley**	Date:	**14/11/18**

Introduction

AECOM has been commissioned by Argyll and Bute Council to undertake a flood study for the settlement of Clachan in Kintyre. The main fluvial flood risk to the village is from the Clachan Burn, which flows east to west through the village, joined by its tributary, Allt Mor, downstream of the weir at the western end of the village at national grid reference NR 76315 56075. A number of small natural lochs are present in the catchment areas of both watercourses, and a large raised reservoir, Loch Ciaran is located south of Clachan on the Allt Mor. Both catchments also include large areas of managed forestry, and a further commercial forestry plantation is planned within the Allt Mor catchment at Talatoll.

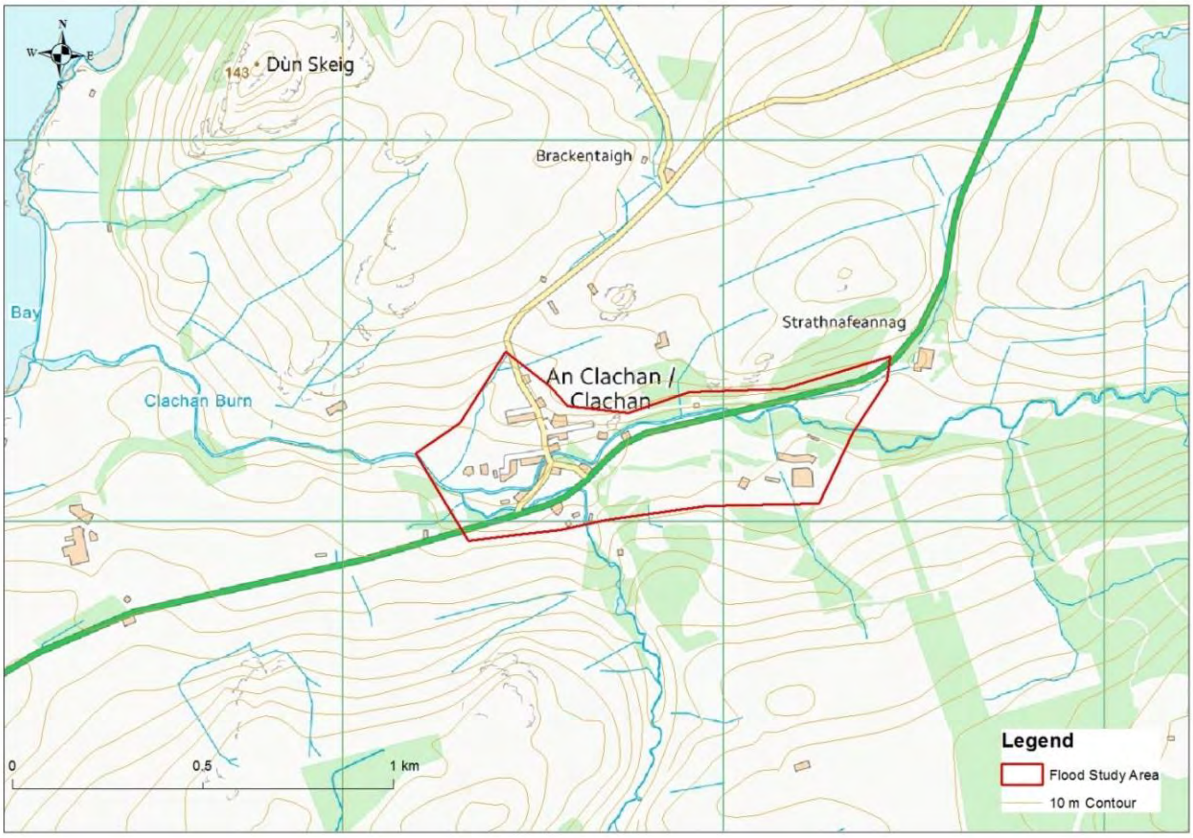

Figure 1 Map of Study Area

Phase 1 of the project included data review and gap analysis. Phase 2 is to establish baseline conditions. This requires hydraulic modelling of the watercourses to establish current flood risk. Hydrological assessment will also be required to determine flood flows generated in the catchment areas. This phase has currently underway. Later phases of the project will include option development and modelling.

Liaison with SEPA

In August 2018, AECOM provided a technical note to SEPA, setting out a proposed approach to the hydrological assessment and hydraulic modelling at a high level, as the project was at an early stage. The intention was to confirm with SEPA that they broadly agreed with the proposed methodology. Paras were received from SEPA on 15 October, and these are summarized below.

- The information provided in the technical note is very high level and does not provide much detail on the proposals for hydrological and hydraulic modelling. Further information would be required for us to para more fully on the appropriateness of the proposals;
- Given the ungauged nature of the catchment we must highlight there will be considerable inherent uncertainties in model outputs. Calibration is proposed, which we are clearly supportive of, although we note calibration data will be limited. Such limitations should be clearly documented in the modelling report;
- Sensitivity analysis will be a key component of the modelling exercise and is critical in determining the possible ranges of change to peak flows and hydrograph shape resulting from the implementation of NFM. We consider the consultant will require to go beyond the standard sensitivity scenarios outlined in our modelling guidance. Testing of the full range of plausible parameters in the hydrological and hydraulic model should be considered (noting these parameters should not be altered to outwith acceptable, justifiable limits).

This technical note forms an update to provide more detail information on the approach, now that the modelling is underway. In addition to the summary above, the following paragraphs are also addressed in the technical note. The remaining paragraphs form comments rather than queries to be addressed.

1.2 A more comprehensive catchment hydrological and hydraulic model schematisation would be helpful. This should indicate available data, the size of the project and potential impacts and will help inform the choice of hydrological/hydraulic model.

1.3 It is unclear from the scoping document how it is proposed to model the attenuating capacity of the upstream lochs, particularly Loch Ciaran. It should be noted however that attenuating effects may be less important in some cases than others e.g. intense rainfall events where the centroid of the storm is downstream of the lochs.

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1.12 Model resolution may also have an impact, as if the entire catchment is modelled in TUFLOW it is unlikely that preferential flow paths such as drainage ditches will be picked up. Sensitivity analysis of this parameter will also be required.

We have sought advice from FC Hydrologists on para 1.11. In their view, they do not agree that modelling the impacts of ploughing is necessary, nor do they agree with the proposed methodology for doing so. The reference to past evidence from IoH relates to the Coalburn study in North England and concerns an unusually intensive cultivation treatment trailed for a short time in the early 1970's, involving 90 cm deep ploughing at 4.5-5.0 m spacing, which extended across 90% of the catchment (with furrows discharging directly into watercourses). The quoted 20% to 40% increase was for smaller peak flows (half-hour unit hydrograph) and not flood flows; in fact there was no significant effect on the annual flood peak. Ground preparation practice has significantly changed over the years and ploughing operations now limited to shallow depths, with furrows disconnected from watercourses by a riparian buffer (as well as by frequent in-furrow breaks where ploughing is practiced on >5 degree slopes). It is understood that ploughing is likely to be scaled back at the proposed new plantation at Talatoll and combined with the nature of modern practice, is unlikely to significantly increase flood flows.

Verification events (SEPA para 1.8)

Hydrometric data

Hydrometric data to use for model calibration/verification is limited. There are no flow or level gauges on either the Clachan Burn or the Allt Mor. There is also no sub-daily rainfall data available. Daily rainfall totals are available at Portachoillan for 1989 – 2006 (excluding 2004). The gauge was then moved to Ronachan and daily data is available for 2007 onwards. The location of these gauges is shown in the figure below and it can be seen that they are both nearer the coast and subsequently at lower altitudes than the majority of the watercourse catchments. The rainfall data cannot therefore be said to be representative of the catchment rainfall.

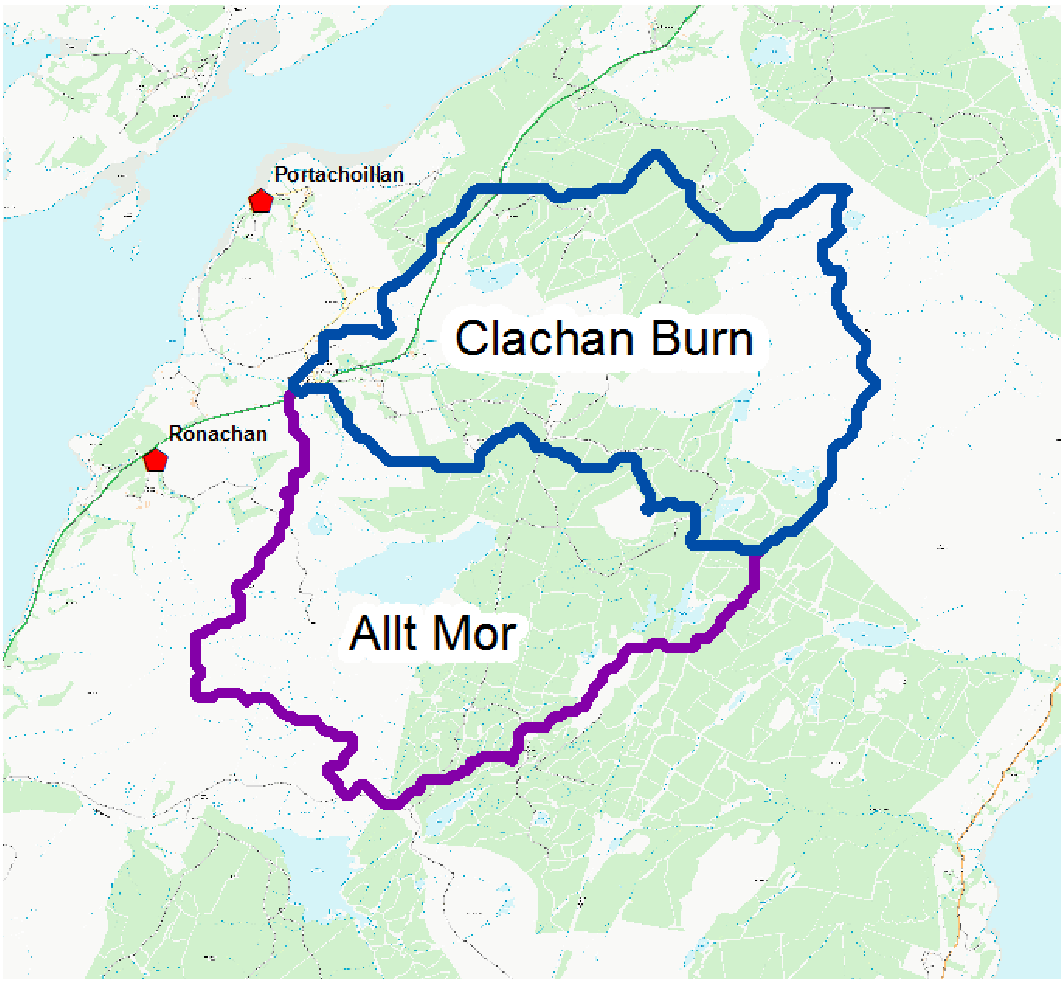


Figure 2 Location of rain gauges in relation to catchment areas

The lack of sub daily rainfall and flow or level data means that full model calibration will not be possible. The daily rainfall is also not wholly representative of the catchment rainfall, limiting even high level verification. However we can use this daily rainfall to investigate any trends that could feed into the investigation behind the community perception that flooding has increased in recent years.

Argyll and Bute Council (ABC) has sourced alternative subdaily rainfall data and radar data for some of the events described below. We have also collated photographs and anecdotal evidence from the Clachan community for 3 recent flood events. These can be used for high level verification of the model.

29th August 2012

Online reports describe this as flash flooding from the Clachan Burn, resulting in properties flooding and roads damaged. Photographs show extensive floodwaters that could be due to out-of-bank river flow and/or surface water.

Figure 3 Photos during the August 2012 flood event

Daily rainfall totals recorded at Ronachan were modest at 8.8mm (26th), 7.3mm (27th), 4.9mm (28th) and 2.8mm (29th). Given the time of year and the fact that very little rainfall was recorded at Ronachan, this was likely a small convective storm cell, limited spatially, that did not pass over the raingauge. Given the lack of rainfall information on this event, it is unlikely to be of value for model verification.

<u>15th November 2015</u>

Again described as flash flooding form the Clachan Burn. Daily rainfall recorded at Ronachan indicated 79.5mm fell in the 9 days between 5th and 13th November, with 67mm then recorded on 14th November. These rainfall totals do suggest a significant event, occurring on a saturated catchment.

SEPA provided Argyll and Bute Council (ABC) with sub-daily rainfall data for a gauge at Amod Farm in South Kintyre. This was the nearest gauge for which SEPA could provide rainfall data, however it is over 45km to the south of Clachan. Neverthless, similarly significant daily rainfall totals were experienced with 51mm recorded on 14-15th November, and 62mm recorded in the 9 days prior. The subdaily rainfall could be used to provide information on the shape of the storm profile and storm duration experienced at Clachan.

ABC also requested radar rainfall data from the Met Office for this event. This has been provided at 5 minute and hourly intervals for 14th and 15th November for Balinakill near Clachan. The daily rainfall total on the 14th matches that recorded at Ronachan. Again we cannot be certain that this rainfall is wholly representative of the rainfall on the whole catchment area, but it can be used to provide a storm profile for model verification. The Met Office gave the following detail by way of para on the severity of the event:

- 32.0mm in 5 hours from 0000GMT/15th = Return Period 8.7 years
- 35.9mm in 6 hours from 0000GMT/15th = Return Period 10 years
- 40.6mm in 8 hours from 2200GMT/14th = Return Period 10 years
- 67.0mm in 1 day (0900-0900GMT)/14th = Return Period 35 years

We have a number of photographs provided to aid model verification. The rainfall data suggests a long duration frontal event, translating to high river levels rather than surface water flooding and this is confirmed by the photographs provided:

Figure 4 Photos during the November 2015 flood event

16th February 2016

A total of 31.5mm of rainfall was recorded at the Ronachan gauge on 16th February. Although no rainfall was recorded in the 5 days prior to the event, January and the first part of February were very wet so the catchments were likely to have low or negligible soil moisture deficits, leading to high runoff.

No additional rainfall data is available. Heavy rainfall was reported to have led to elevated river levels, and drains were overwhelmed. There are fewer photographs of this event, but those that exist suggest high river levels but not necessarily out of bank flow, coupled with surface water overland flow and ponding.

Figure 5 Photos during the February 2016 flood event

Summary

Given the additional subdaily rainfall data available for the November 2015 event, this event provides the best opportunity for model verification.

Hydrological assessment

Introduction

The purpose of the hydrological assessment is to estimate runoff generated over the catchment areas of each watercourse, which will then be used as input to the hydraulic model of the Clachan Burn through the town. Normal practice when undertaking hydraulic modelling of a watercourse to establish flood risk is to use recommended hydrological methods such as FEH[1]. Such methods use rainfall and catchment characteristics to estimate design flood hydrographs of a specified probability, that are then input to the hydraulic model to allow flood levels to be modelled.

Part of this study will investigate the potential for natural flood management (NFM) techniques to mitigate flood risk. In addition, it is reported that some Clachan residents have a perception that recent deforestation of areas of the managed forestry is exacerbating flooding in the village. The study will therefore need to consider the impact of changing landuse and various types of NFM measures. FEH techniques are somewhat limited in how they can be manipulated to represent landuse and NFM measures. We consulted with hydrologists from the Forestry Commission (Tom Nisbet, Huw Thomas) on possible modelling techniques to represent the impact of forestry, and these options were presented in the previous technical note.

Methodology

We have decided to progress with the option to use a fully gridded 2D model using Tuflow software, which we consider to provide the best approach with the fewest limitations to model the impact of landuse change and other NFM measures. We understand from SEPA's response (para 1.9) that this approach is considered appropriate in principle.

The model represents direct rainfall, interception, infiltration, soil porosity, initial soil moisture content, roughness based on landuse (represented by Manning's "n" for each grid cell) and physical representation of the tree stand from different tree types (eg broadleaf or conifer). For non-forested areas, interception is set to zero, whilst infiltration and soil porosity are based on underlying geology with best estimates set in consultation with our in-house hydrogeologist. Representative summer and winter season initial soil moisture content will be modelled and are based on literature. For forested areas, infiltration and interception are represented by applying appropriate infiltration and interception rates to each 2D cell depending on tree type. Summer and winter initial soil moisture contents will be modelled to reflect increased soil moisture deficits below tree stands. These parameters have been drawn from literature and agreed with FC.

Realistic sensitivity envelopes for each parameter will also be estimated in consultation with our hydrogeologist and FC to form part of the sensitivity tests (SEPA para 1.9 & 1.10). The underlying soil types are mainly peaty or non calerous gleys, with only a very small proportion of peat. Infiltration and porosity of gleys is less variable than peat, so sensitivity tests will consider ±20% on soil parameters. We are awaiting confirmation from FC for appropriate sensitivity envelopes for forested parameters.

The hydraulic impact on surface flows of the physical tree stand is represented by applying a flow restriction through each grid cell, based on average tree spacing and trunk width. Best estimates of soil and forested parameters to be used in the model are shown in the table below.

[1] *Flood Estimation Handbook*, Institute of Hydrology (now CEH), 1999

Table 1: Soil and forested model parameters

	Rural (no woodland)		Conifer		Broadleaf	
	Winter	Summer	Winter	Summer	Winter	Summer
Initial loss mm (interception) mm	0	0	6.91 mm	6.91 mm	1.2mm	2.6 mm
Infiltration mm/hr	Peaty gleys – 3.6 Non calerous gleys 0.36 Peat – 0.252 Humic gley – 0.5					
Porosity fraction	Peaty gleys – 0.486 Non calerous gleys 0.385 Peat – 0.71 Humic gley – 0.423					
Soil moisture deficit mm (model as depth to groundwater)	0	85	0	110	0	110
Flow constriction (fraction)	0	0	0.4	0.4	0.4	0.4

The 2D model domain covers the entire catchment area of both the Clachan Burn, and the Allt Mor, totalling 27.5 km^2. Figures A1 and A2 show the model schematics (SEPA para 1.2). A preliminary grid size of 10m has been selected, as a compromise between accuracy and model run time. Depending on the results of the preliminary model runs, this may require to be amended. At this resolution, many of the small tributaries and other small preferential flow paths are not well represented in the ground model, and this was overcome by reinforcing breaklines along the watercourses (SEPA para 1.12, Figure 6).

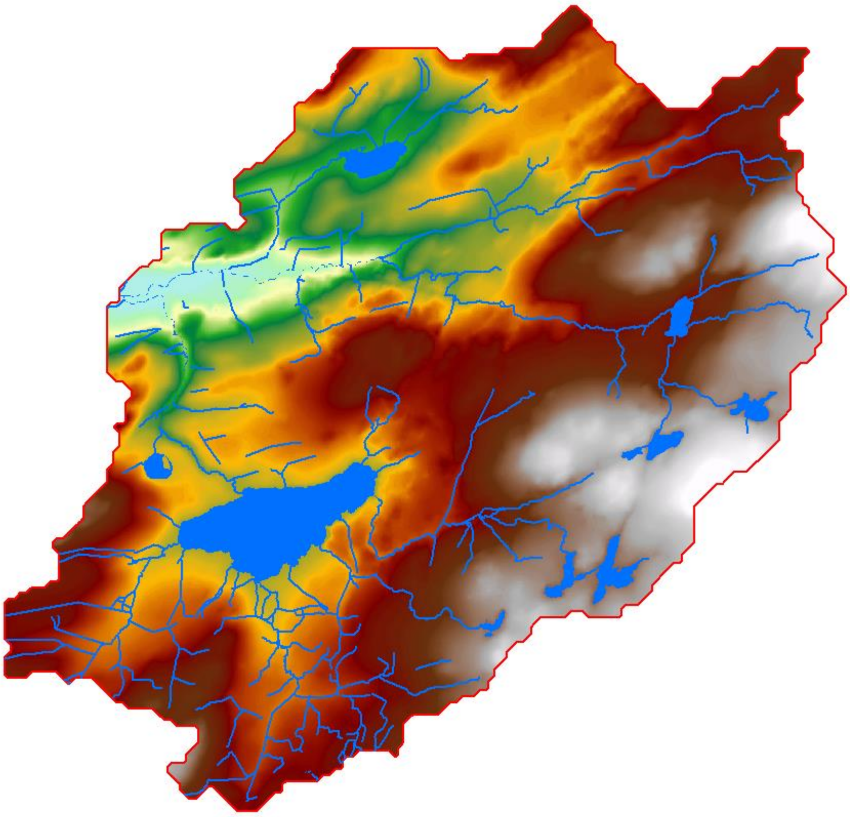


Figure 6 Drainage lines used as breaklines in 2D model

The main input to the model is rainfall – FEH 2013 DDF model for design events, and local rainfall data of historic events for verification.

The attenuating capacity of the lochs (SEPA para 1.3) can be accommodated fairly easily within Tuflow as 1D elements representing the loch outlets embedded within the 2D domain – we are currently incorporating the weir at the outlet of Loch Ciaran which has been surveyed. For the natural lochs, part of our sensitivity analysis will be to test the impact of more accurate 1D representation of the natural outlets on the flow reaching Clachan (SEPA para 1.10). These haven't been included in the topographic survey so will have to be determined from the Nextmap DTM. It's also quite likely that potential mitigation measures might be located at the loch outlets to increase attenuation which would require to be modelled using embedded 1D elements, so to get an accurate picture of the impact, the baseline would have to be modelled the same way.

Model runs will then provide runoff hydrographs from the catchment areas in response to rainfall, which will then form inputs to the hydraulic model. Modelled scenarios will be as follows:

- Non-forested baseline (summer and winter)
- Current baseline (including existing forested areas, summer and winter)
- Predicted baseline (including proposed forested areas, summer and winter)
- A number of option scenarios (including proposed interventions, summer and winter)

A full range of return periods events will be analysed from 50% - 0.5% AEP (2– 200 year return periods) As this will be a direct rainfall model, the impact of climate change will be assessed using rainfall uplift figures recommended in Table 10.3 of SEPA's flood model guidance. Low and high projections will be assessed to define a likely envelope of impact.

As discussed above, there are no flow or level measurements recorded on the Clachan Burn or Allt Mor so full calibration to historic events cannot be achieved. High level verification of the model will be based on observed rainfall and anecdotal evidence (eg photos) of flood events. This increases the uncertainty in the hydrographs generated, and as such, a full suite of sensitivity tests will be undertaken to understand which model parameters have the largest impact on modelled flows (SEPA para 1.9 & 1.10). The following sensitivity tests are proposed:

Table 2: Proposed sensitivity tests

Return period	Scenario
200 year	Winter non-forested baseline 25m grid
200 year	Winter non-forested baseline 5m grid
200 year	Summer non-forested baseline ±20% soil porosity
200 year	Summer non-forested baseline ±20% soil infiltration
200 year	Summer forested baseline ±20%* soil moisture deficit
200 year	Summer forested baseline ±20%* interception
200 year	Summer forested baseline ±20%* flow constriction

*tbc in consultation with FC hydrologists

Comparison to FEH design storms may also prove useful and the FEH statistical and ReFH2 methods have been used to derive design peak flows for the Clachan Burn and Allt Mor.

ReFH2 has been used to derive flood hydrographs for the Allt Mor and Clachan Burn to their confluence at Clachan, as well as the total combined catchment. An FEH statistical analysis has also been carried out on the total combined catchment. The results of this analysis will be fully reported in the final report (SEPA para 1.4).

Preliminary model runs

Initial 2D model runs have been completed, firstly using direct rainfall only, with no forestry or soil losses, secondly assuming no forestry with our best estimate of soil losses for winter conditions (soil moisture deficit is zero, best estimate of soil infiltration and porosity based on soil type), and lastly with current forest cover, with soil losses for winter conditions, interception losses and hydraulic constriction in forested areas. These preliminary results are compared against FEH derived peak flows for the Clachan Burn and Allt Mor at Clachan in the table below.

Table 3: Comparison of preliminary model runs with FEH flow estimates – Winter Profile

Hydrological method	200 year peak flow		
	Allt Mor	Clachan Burn	Total catchment ds of confluence
FEH statistical	-	-	53.4
ReFH2	46.8	50.7	96.5
2D model direct rainfall	14.0	43.3	57.0
2D model direct rainfall + soil losses (non-forested baseline)	14.0	43.3	57.0
2D model direct rainfall + soil losses + interception losses + constriction losses (forested baseline)	13.0	41.0	54.0

As seen from the table above, routing impacts from natural lochs in catchments are being picked up in the 2D model. The peak 1 in 200 year flow for the direct rainfall only model in the Clachan Burn is 15% lower than the calculated REFH2 flow. This is to be expected when considering the 6 smaller natural lochs located in the upstream catchment. The flows from the direct rainfall model are closer to those calculated by the statistical method which takes FARL into account when calculating QMED, further evidencing that the 2D modelling approach is taking account of reservoir routing impacts.

When looking at the different catchments with soil losses applied there is no difference in peak flow compared to the 2D direct rainfall model with no losses (Figure 7). This is considered to be realistic given this is based on a winter season where soil is considered saturated. The winter soil moisture deficit is modelled as 0 and conservatively assumes no infiltration is possible. When looking at the initial representation of forest interception and constriction losses, the hydrograph is also not fundamentally changed compared to the soil and direct rainfall models. At the Clachan Burn there is a 4% reduction is peak flow compared to the soil loss model and minor attenuation affect seen in the hydrograph shape. This is considered reasonable given the small percentage of the catchment which is forested once the current felled landuse is considered partnered with the lack of infiltration in the winter soil profile. Larger differences are expected for the summer season model runs, when soil moisture deficits are positive, and also for lower return periods where soil losses and interception form a larger proportion of the rainfall input.

The Allt Mor Burn is more heavily influenced by reservoir routing effects. Initial model runs indicate a 70% lower peak flow than the calculated REFH2 hydrograph. A check on this mechanism was carried out through construction of a 1D reservoir routing model in Flood Modeller. The inflow to the reservoir unit represented the upstream catchment draining to Loch Ciaran (10.1km^2). Survey information for the outlet for Loch Ciaran was obtained to accurately model this control. At a 1 in 200 year event, 10m^3/s was found to discharge from the Loch in the 1D model. In the 2D model with no losses this was in the same order at 12.5m^3/s. This indicates the reservoir has a substantial attenuation impact on flows in the Allt Mor catchment. A further check comparing the rural REFH2 hydrograph and the 2D model hydrograph indicates that for this to be the realistic discharge flow the equivalent rise in water level in the reservoir would equate to 200,000m^3 of water which is more than available within the 800,000m^3 impounding capacity of the reservoir.

The impact of interception and soil loss modelling on the Allt Mor catchment is less pronounced given the attenuation impacts of Loch Ciaran dominate the response in the catchment. A further 2% reduction in peak flow can be seen the forested baseline with almost no change to hydrograph shape (Figure 9)

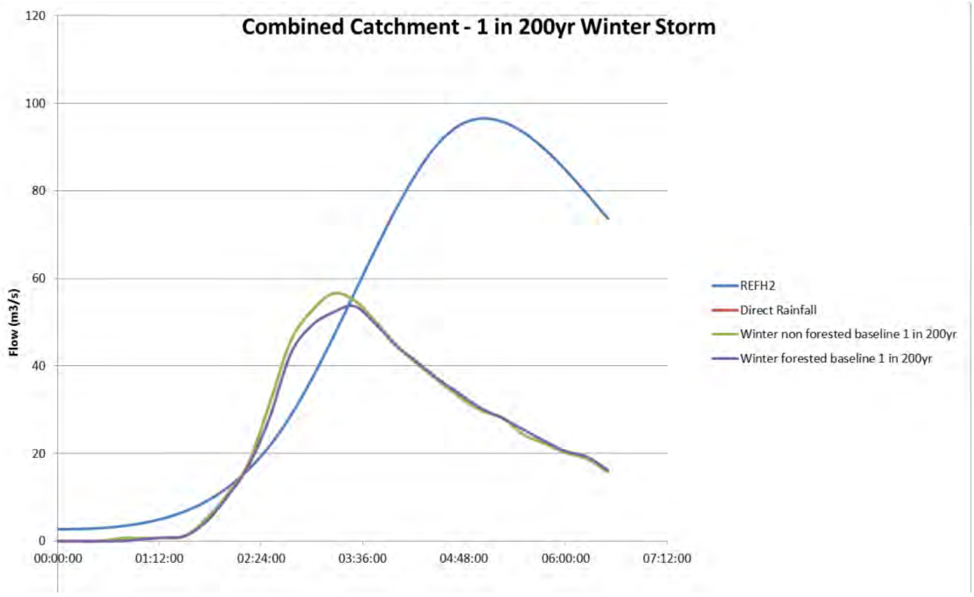


Figure 7 Winter storm 1 in 200 year combined catchment hydrograph comparison

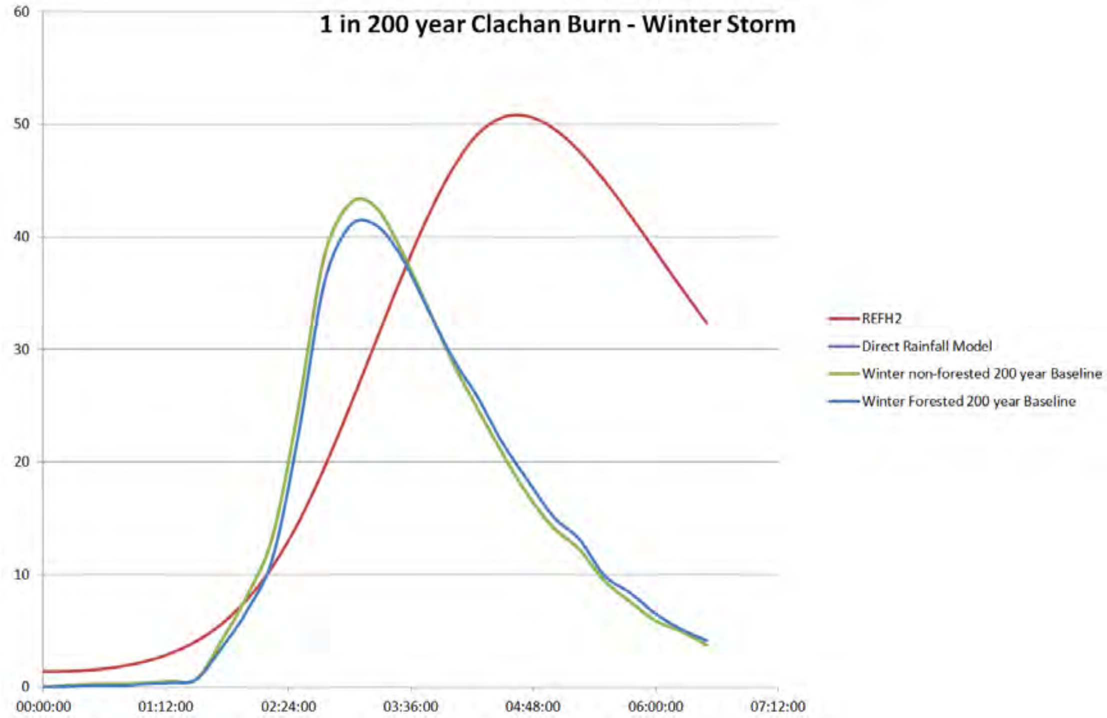


Figure 8 Winter storm 1 in 200 year Clachan hydrograph comparison

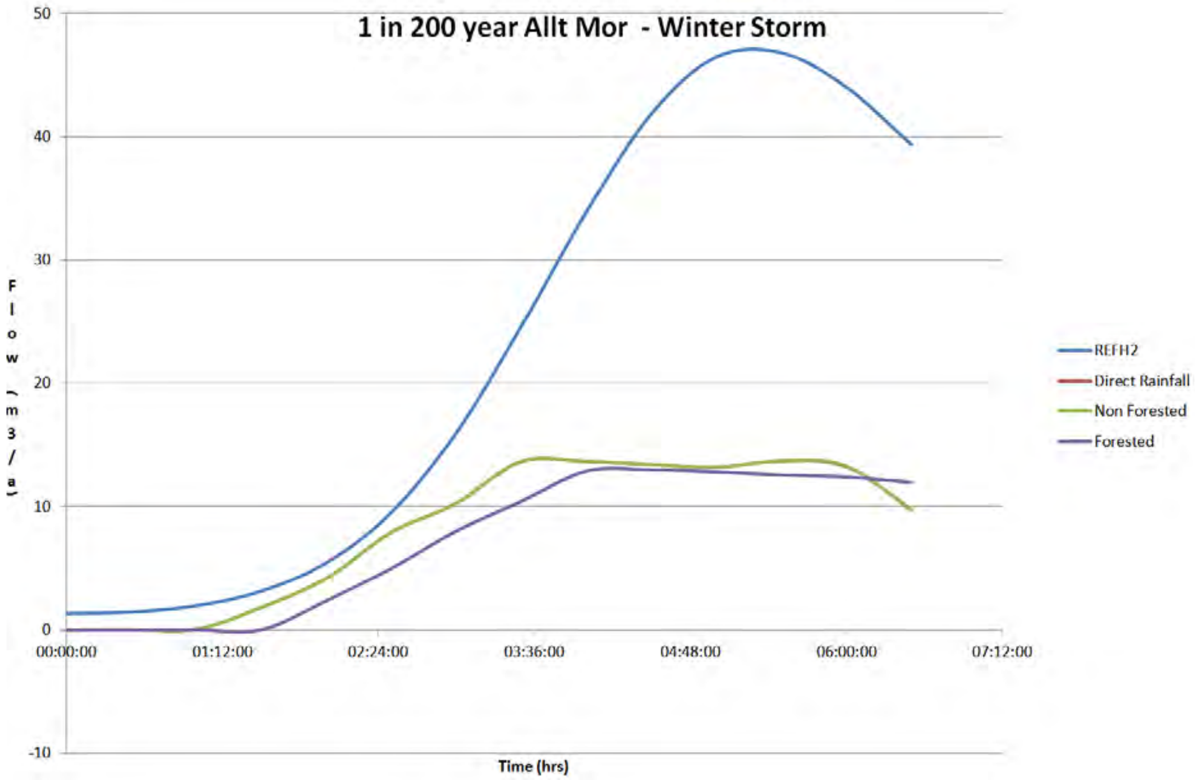


Figure 9 Winter storm 1 in 200 year Allt Mor hydrograph comparison

A similar exercise has been carried out looking at a summer storm profile. The same 2D modelling scenarios were looked at with the key difference being the input rainfall profile and the soil moisture deficient which is determined based on land cover and ranging from 85 – 110mm.

Table 2: Comparison of preliminary model runs with FEH flow estimates – Summer Profile

Hydrological method	200 year peak flow		
	Allt Mor	Clachan Burn	Total catchment ds of confluence
ReFH2	46.8	56.6	104.6
2D model direct rainfall	14.5	54.9	67.5
2D model direct rainfall + soil losses (non-forested baseline)	12.5	43.2	51.7
2D model direct rainfall + soil losses + interception losses + constriction losses (forested baseline)	12.0	40.5	47.8

Initial results indicate a 23% reduction in peak flow in the overall catchment when considering soil losses (**Figure 10**). This increases to 30% with the inclusion of interception and blockage losses due to forested areas. This is representative of the increased potential for infiltration and soil storage to be utilized in summer events.

On the Clachan Burn catchment representation of soil losses results in a 20% reduction in peak flow compared to direct rainfall alone. There is a further 6% reduction in peak flow compared to the soil loss model when forested losses are considered. This is considered reasonable given the small percentage of the catchment which is forested once the current felled land use is considered (approx. 15% of area)

The hydrograph shown (**Figure 11**) in is not fundamentally changed but is shown to have further attenuation effect compared to the no loss model to a reasonable degree when considering the infiltration capacity of the underlying gley soil types is constrained and there is a small percentage of the catchment which is forested once current felled landuse is considered.

The impact of soil losses on the Allt Mor catchment is also more marked in the forested scenario with a 13% reduction in peak flow. Although, the impact of forestry which covers a large area of the catchment is still limited to the same degree as the winter storm, likely due to attenuating effect of Loch Ciaran dominating flows which can be seen in the hydrograph shape (**Figure 12**).

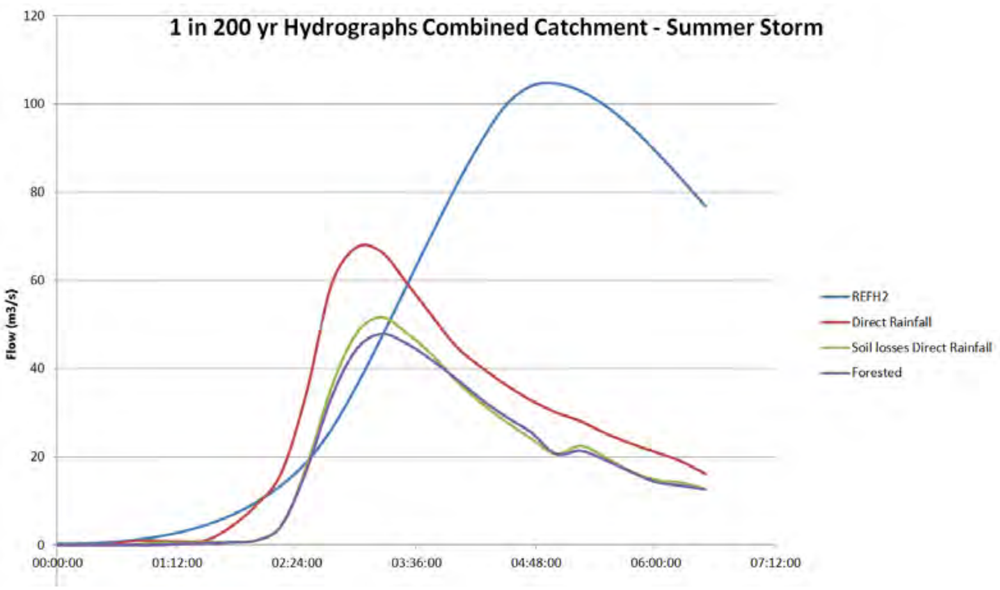


Figure 10 Summer storm 1 in 200 year combined hydrograph comparison

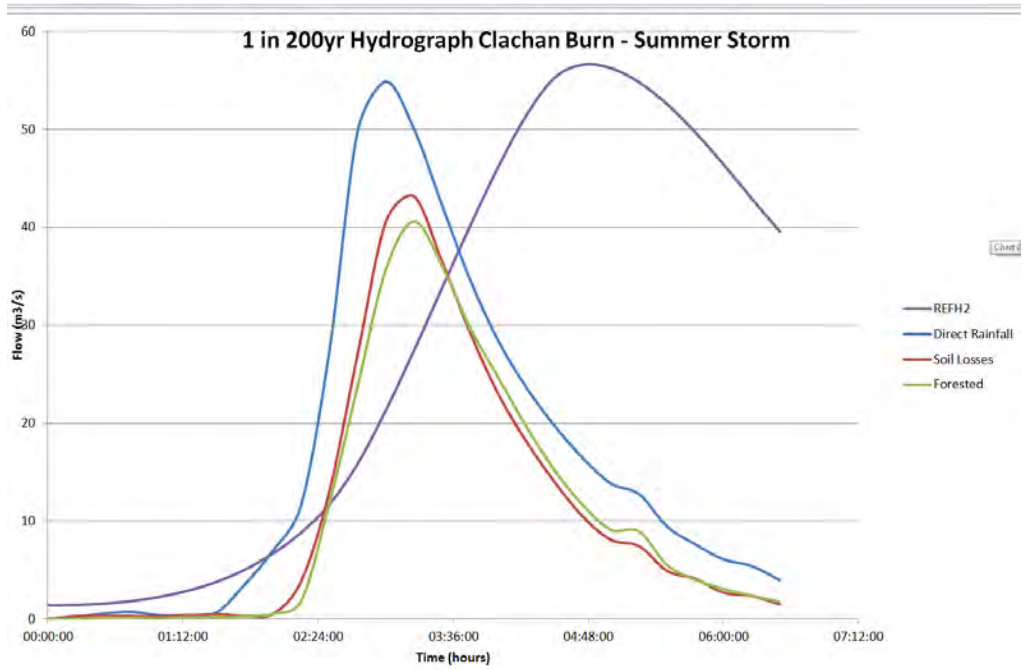


Figure 11 Summer storm 1 in 200 year Clachan Burn hydrograph comparison

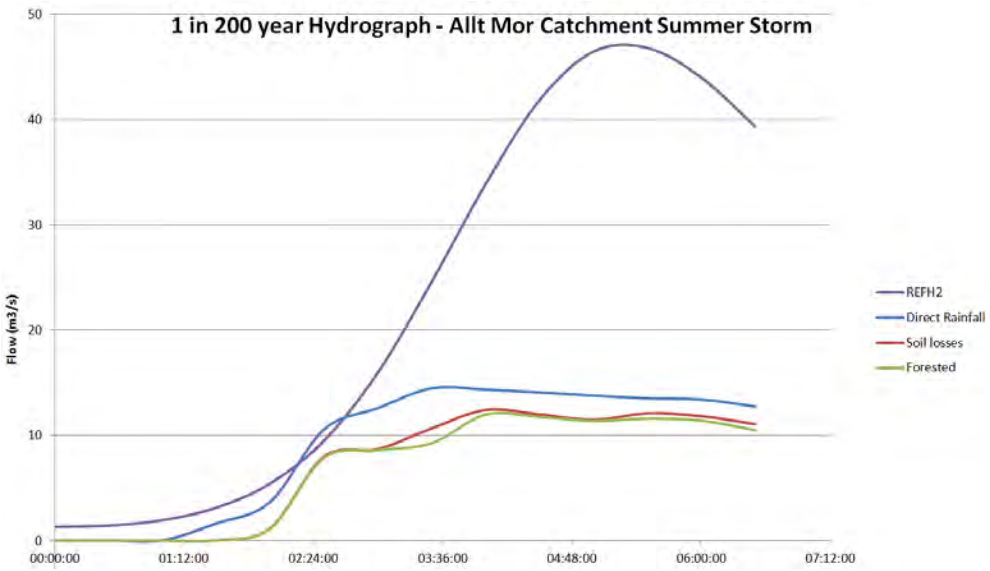


Figure 12 Summer storm 1 in 200 year Allt Mor hydrograph comparison

These initial results give us confidence in the approach showing that reservoir routing effects are being accounted for in the 2D modelling approach. The modelling also indicates that soil and interception losses can be reasonably represented in 2D and show impact on rural conditions for different storm profiles. This will allow us to determine how felling in the catchment has influenced flood risk in recent years. This will also give us the mechanism to determine and quantify if attenuation effects of forestry can be enhanced to improve flood risk. However, sensitivity testing of the parameters adopted and understanding these limitations will be a key part of the process.

Further analysis

A watershed analysis using the Nextmap DTM has been carried out on both catchment areas in order to identify the major subcatchments (**Figure 13**). Peak flow and hydrograph timings from the 2D modelling for each subcatchment will be reviewed and may be compared to ReFH2 hydrographs generated for that purpose. This analysis will help us identify which subcatchments contribute most significantly to flooding in Clachan. Mapping these against potential mitigation opportunities will allow us to focus on developing the most effective options.

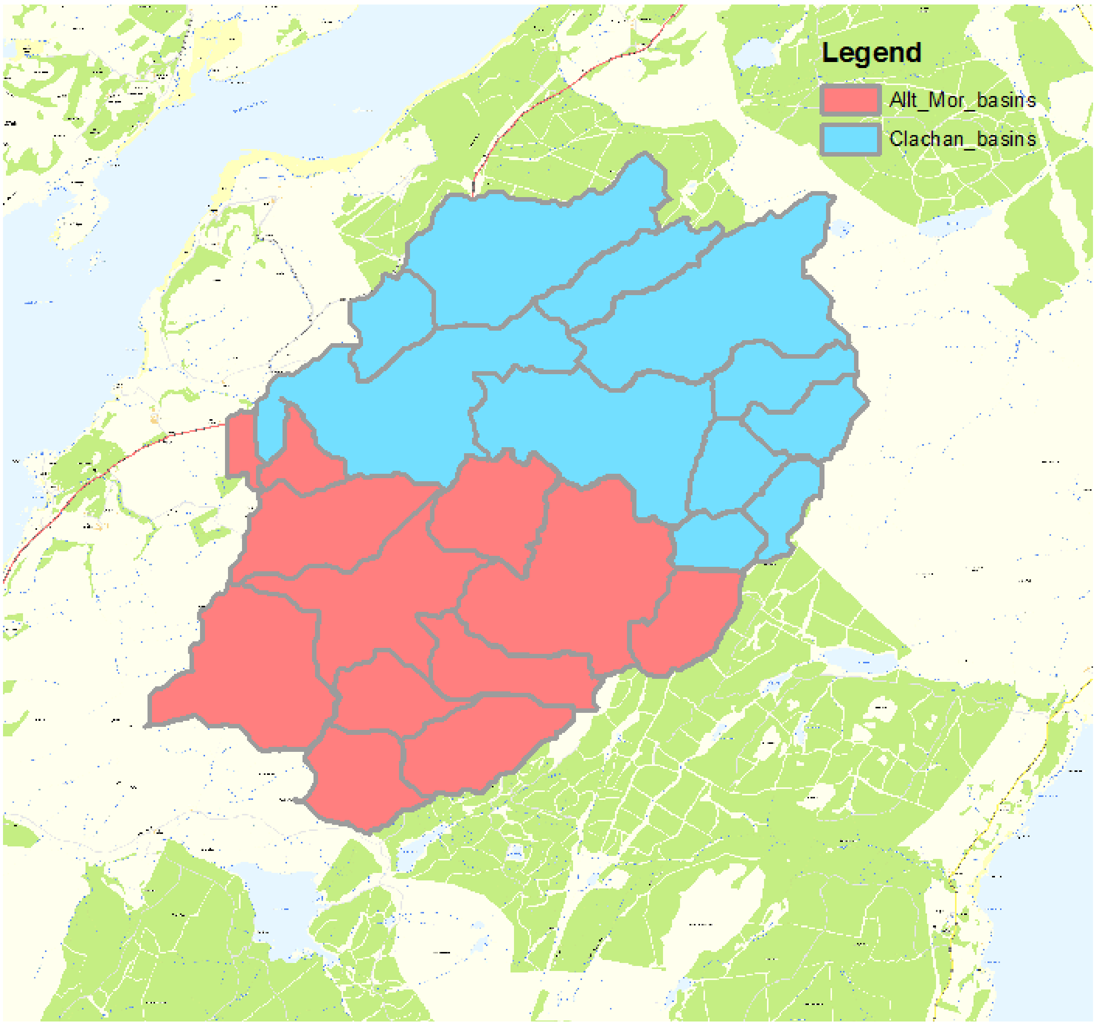


Figure 13 Allt Mor and Clachan Burn main subcatchments

Hydraulic modelling

Flows generated by the 2D hydrological model will be used as input to a hydraulic model of the Clachan Burn and Allt Mor to determine peak water levels, floodplain extents and overland flow paths within the town.

A river cross section topographic survey has been completed, with spacing in accordance with best practice to allow construction of the model. The survey includes river cross sections along both the Clachan Burn and Allt Mor, together with bank levels at 10m intervals. As there is no lidar data available for this area, spot levels on a 10m grid and property threshold levels have also been specified as shown in Figure 14.

The survey is being used to construct a 1D-2D Floodmodeller-Tuflow model of the watercourses, relevant hydraulic structures and adjacent floodplains – see Figure A3 for the model schematic (SEPA para 1.2). Using this software provides the option to combine the model with the 2D only hydrological model.

The model will be run in hydrodynamic mode, modelling the full flood hydrograph as opposed to just peak flows. This will allow proper assessment of floodplain storage and overland flow paths. The normal flow, roughness, downstream boundary, structure coefficient and blockage sensitivity model runs will be carried out. This will form the baseline model to assess existing flood risk to the village.

In later phases of the project, options modelling will be carried out, which may involve changes within the catchment areas, eg landuse change, woody debris dams, increased storage modelled within the 2D hydrological model, or within the watercourses, eg changes to structures to remove hydraulic restrictions or inclusion of flood walls.

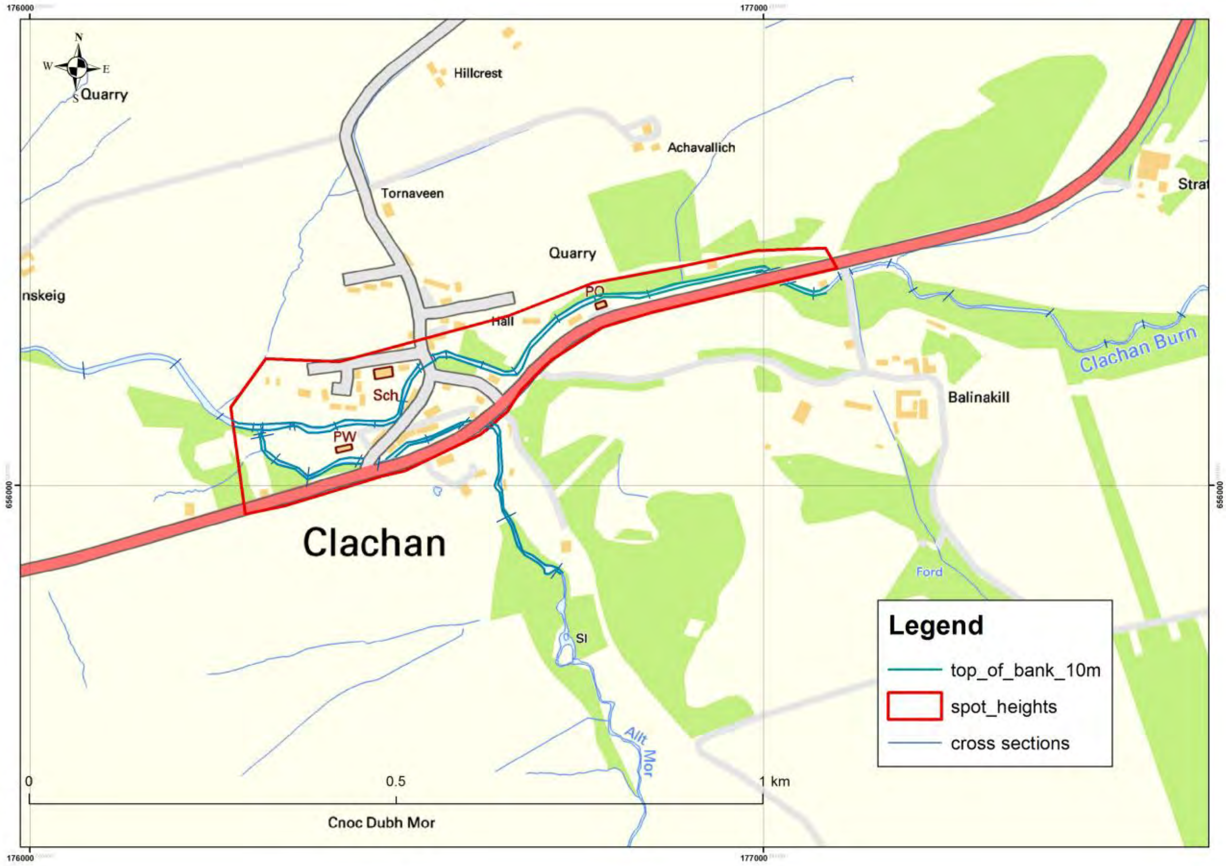


Figure 14 Topographic survey

SEPA
Scottish Environment Protection Agency
Buidheann Dìon Àrainneachd na h-Alba

Job No. 26 MAR 2019

Our ref: PCS/164053

Aisling Marlow
AECOM Limited
1 Tanfield
Edinburgh
EH3 5DA

If telephoning ask for:
Judith Montford

22 March 2019

Dear Ms Marlow

Clachan Flood Study - Phase 2 Report Baseline Conditions & Options Longlist Clachan

We received information (AECOM Draft Baseline Clachan Flood Study (Phase 2, Baseline Conditions, 19 February 2019) on 22 February 2019, from AECOM Limited regarding the above flood study.

This information is in response to queries raised in our previous responses/letters of 3 December 2018, PCS/162340 and 15 October 2018, PCS/160688. We thank you for this information and would make the following comments.

1. Technical Report

1.1 We previously reviewed the updated AECOM Hydrological Assessment and Hydraulic Modelling approach and in summary we recommended that the following points are addressed or included in any subsequent analysis. Points have been omitted that are no longer required:

- Clear statement of the modelling limitations and the lack of observational data is acknowledged
- References to literature from which forestry model parameters have been derived
- Confirmation of the time period from which the soil/forestry parameters have been taken.
- Justification as to why SMD values are the same for Broadleaf and Conifer
- Undertaking survey of all key structures
- Confirmation of the storm durations
- Justification for 20% parameter tolerances in sensitivity analysis
- Inclusion of storm duration and manning's n roughness in sensitivity analysis
- Further consideration as to whether differences in peak flow can be attributed to soil/forestry losses alone or whether this can be attributed to modelling uncertainty
- Appropriate assessment of hydrograph shape and timing
- Confirmation as to whether ReFH2 has been calculated using catchment descriptors and application of a donor catchment where appropriate
- Further development of the catchment delineation exercise to consider the impact of spatially varying the rainfall on these catchments and looking at travel time and durations

1.2 Based on the updated technical note, we highlighted that we were satisfied if AECOM could either address our points raised in the letter, or alternatively provide a robust argument where methodologies vary from the recommendations provided, the hydrological analysis and hydraulic modelling approach should form a reasonable basis for the Clachan Flood Study. We re-iterated that the document appeared to focus solely on peak flows and would benefit from considering spatial variability of rainfall, sub catchment travel times and the impact of hydrograph shape and storm duration which alongside peak flows are key when trying to assess any potential changes resulting from Natural Flood Management (NFM).

1.3 We have now been consulted on of the AECOM Draft Baseline Clachan Flood Study (Phase 2, Baseline Conditions, 19th February 2019) and we would make the following comments.

Response to points raised through Technical Note correspondence

1.4 We note that AECOM have acknowledged that existing hydrometric data to use for model calibration is limited, therefore level and rainfall gauges have been installed on the Allt Mor and Clachan Burn catchments in 2018. We are in agreement that the rainfall data from the Portachoillan (1989-2006, excluding 2004) and Ronachan gauge are not representative given their lateral and vertical separation from the catchment. The only flood event for which verification has been undertaken is the 'flash flooding' event which occurred on 15th November 2015, whereby radar rainfall data from the Met Office has been acquired. Section 7.3 of the baseline report discusses model verification and highlights that full calibration to historic events cannot be achieved, instead the model verification is based on available anecdotal evidence (photographs) and rainfall data.

1.5 We acknowledge the lack of data available for calibration, therefore we consider it pertinent to communicate the high level of inherent uncertainty in the modelling. This message does not appear to have been conveyed by AECOM as follows, "the degree of verification however is acceptable to give confidence to both the catchment model technique and the 1D-2D linked model itself".

1.6 Given the lack of observation data from which to calibrate the model, SEPA previously highlighted the importance of sensitivity testing. AECOM have assessed a wide range of parameters and the impact changes would make to peak flows and time to peak in the catchment model. We previously asked for the sensitivity to look at changes in peak flow, sub catchment travel times and the impact on hydrograph shape. No commentary has provided on the hydrograph shape and we would ask that this be included. We note that the sensitivity analysis has not considered varying storm durations and the impact of spatially varying the rainfall on the Allt Mor and Clachan Burn catchments. An explanation should be provided as to the reasoning not to sensitivity test these aspects of the modelling.

1.7 We note that no justification for the blanket 20% forestry parameter tolerances have been provided. We would ask for further justification that a 20% change is considered reasonable.

1.8 In relation to our request for references to literature, we note that forestry infiltration parameter references have been cited (Table 6-2), however no literature references have been provided for Table 6-1 (Model Parameters) and would ask that these be provided.

1.9 We note that the AECOM report has not provided justification as to why SMD values are the same for Broadleaf and Conifer, though we are aware they are referenced as depth to groundwater. For Table 6.1 we would look for references to be provided similar to Table 6.2.

1.10 In prior correspondence we had requested at which time step the parameters presented in Table 6.1 and 6.2 have been taken from,i,e average, from the start of an event, as these would be expected to change over time. The report has not addressed this point.

1.11 We highly recommended that key structures were surveyed, and we are pleased to see the outlet of Loch Ciaran has been surveyed, in addition to 48 surveyed sections which includes 7 bridges and 1 weir (Section 7.2, AECOM draft baseline report). We are in agreement with the omission of minor footbridges from the modelling exercise based on the minimal impact on flow mechanisms.

1.12 In Section 6.6 (Model Runs), we note that a range of return period events have been analysed (2 – 200 year return periods) and the runs were carried out for a critical storm duration of 5.25 hours which we understand to be based on the default values calculated from the ReFH2 method. We would have expected further sensitivity analysis of the storm duration to determine the critical duration and that duration be part of the suite of sensitivity tests. Further details should be provided as to why this is not required. In relation to SEPA's Strategic Modelling Guidance, we also highlight that a 40% increase in Manning's roughness is recommended for the purposes of sensitivity analysis in a 1 in 200 (0.5% AEP) year event. The 20% increase in Manning's n therefore falls below the recommended range for sensitivity analysis.

1.13 We previously queried the initial model runs, whereby the changes to flow estimates due to forestry losses are minimal. We re-iterate that the changes to forestry losses such as interception and constriction losses are minimal and within the bounds of modelling uncertainty.

1.14 To address our query regarding whether ReFH2 has been calculated using catchment descriptors and the application of a donor catchment where appropriate, we refer to section 6.8.1 of the AECOM draft baseline report.

Baseline Hydrology and Hydraulic Model Review

1.15 The flood history clearly indicates that are two different flood sources in Clachan, these being surface water and river flooding. It should be noted that the flood study only focuses on the flood risk from fluvial flooding and the surface water flooding identified in the flood history has not been considered further in this study. The 2015 flood event has been used to validate the model, we would ask that further details on the flood mechanisms for this event be presented in the flood history. The study has used direct FEH13 rainfall (with critical duration derived from ReFH2.2 model), a comparison has been made to the peak flows derived using FEH Statistical and ReFH2 methods. It is important to note that the purpose of the verification is not for the direct rainfall model to match the FEH estimates.

1.16 The FEH statistical method, Qmed (median annual flood) has been derived from catchment descriptors. Donor adjustment has been carried out using the single gauging station and multiple gauging station methods. We have reviewed the pooling group development which has been outlined in Appendix C and our flow estimates are in line with those reported. We would note that the FARL value for all stations in the FEH Pooling group are higher than the subject site and very few have an attenuating response. A check on ReFH2.2 has been undertaken which suggests this method gives a comparatively much greater estimate of flows which can be attributed to the attenuating effect of the upstream lochs on these catchments rendering ReFH2.2 as an unsuitable flood estimation method in this instance.

1.17 Section 6.11 reports a 20% reduction of flow peaks from soil and forestry losses compared to the ReFH2 calculations. This is misleading to the reader as it implies a greater effect, when we are aware the lumped ReFH2 would not be considered acceptable due to the attenuation in the upper catchment.

1.18 We would note that SEPA use the high emissions scenario 67% flow uplift for our fluvial hazard maps. We would draw the consultant's attention to the current UKWIR guidance Rainfall intensity for sewer design – Stage 2, Guidance for water companies, 2017.

1.19 The research undertaken by UKWIR in 2017 provides the most recent analysis of predicted increase in rainfall intensities due to climate change. We are about to provide updated guidance on climate change that incorporates this science. We recommend that contact is made with Argyll and Bute Council regarding requirements based on the latest climate change data.

1.20 A 1D/2D unsteady state mathematical model of the watercourses in the area have been constructed over a 1.7km model reach using FloodModeller Pro software which is suitable for such a study. We are in agreement with the modelling approach adopted. We would also seek confirmation as to whether model parameters have been altered from model defaults such as allowable tolerances and number of iterations.

1.21 The 2D model grid is based upon Nextmap DTM 5m resolution data which is less accurate than LiDAR data. We are pleased that a 'ground-truthing' exercise has been undertaken whereby the Nextmap data has been supplemented by obtaining spot levels at a 10m grid within the village of Clachan which has been stamped onto the DTM. We also note that our previous comment referring to the representation of drainage ditches in the NEXTMAP has been considered and break lines have been used to reinforce the flow paths. However we would note that this is very subjective. Information should be provided on the source for delineation.

1.22 Mannings of 0.07 is reported in the Chow Table as the maximum value for a mountain stream comprising cobbles with large boulders. Photographs have not been provided so we cannot confirm if this is correct.

1.23 The number and location of modelled cross-sections (Figures C4 and C5, Appendix C) appear reasonable.

1.24 Hydrographs derived from the catchment model have been extracted at PO lines for input to the 1D-2D model, these have been compared against FEH derived peak flows for the Clachan Burn and Allt Mor watercourses. We are in agreement that the flows from the direct rainfall model are closer to those calculated by the FEH statistical method and that the REFH2.2 results are an outlier given this method is not appropriate based on the low FARL values, however we would note that the aim of the study is to not match the direct rainfall to the FEH flows. The downstream model boundary is based upon normal depth from bed slope and has been sited sufficiently downstream to not influence results significantly.

1.25 Existing hydraulic structures have been included in the model, particularly CB12 (A83 upper road bridge), CB9 (footbridge), AM8 (A83 road bridge), CB20 (A83 road bridge), AM11 (road bridge), CB25 (Mansecroft footbridge), CB26 (weir) and AM15 (footbridge). The modelling assumptions/structure coefficients used in relation to these structures have not been supplied for review, this is particularly pertinent given the percentage blockage that has been required to emulate an observed flood mechanism from anecdotal evidence, see below.

1.26 Anecdotal evidence from the 15th November 2015 event has been used to sense check the model. Radar rainfall from the Met Office has been applied alongside soil/forest parameter values derived from literature representing a winter storm scenario. We note the importance of incorporating a significant bridge blockage scenario (80% blockage) to replicate the flow pathways that correspond to the observed flooding. We would ask that all parameter values used in the 2015 calibration be presented and that any assumptions required to replicate the observed history be clearly stated.

1.27 To support the calibration modelled extents should be presented alongside the text and the photos mentioned in the report. We would ask whether the photos give maximum flood extents or whether these provide a snapshot at discrete locations, if the latter we would ask that this be reported. We would also ask that the approximate annual exceedance probability be stated for the 2015 event to allow a comparison to the design flood extents.

1.28 We would recommend that the high level of uncertainty be acknowledged in the verification section and as a result advice against stating that there is a high degree of confidence in the modelling. Limitations should be clearly documented including the lack of hydrometric data, limited observed flood event data, the use of generalised parameter values, the limitations associated with the Initial Loss Continuing Loss (ILCL) method, short comings in the NEXTMAP and the requirement to include an 80% blockage to enable verification.

1.29 The water level data (Appendix F) appears appropriate, however no velocity information has been submitted and we would recommend this information is included in subsequent reporting.

1.30 Sensitivity analysis (Section 7.4) of the hydraulic model has been undertaken on flow, Manning's roughness, structure blockages, downstream boundary and climate change. The model is notably sensitive to a 20% increase in flow upstream of a small footbridge in Clachan and causes some of the bridge structures to surcharge. The model is also sensitive to changes in Manning's roughness. Blockages, particularly 50% blockage of the CB20 road bridge across the Clachan Burn has been shown to have a significant impact on flows upstream of the bridge and increases flood level up to 1m. In turn, we note that an additional flood mechanism is introduced through this scenario which introduces a new area at risk of flooding when compared to the baseline model. We note that 50% blockage applied to the AM11 also results in some out of bank flow. With regards to climate change sensitivity, compared to the 20% increase in flows the flood extents are shown to increase particularly adjacent to the weir on the right bank.

1.31 Flow sensitivity appears to have greatest affect at structures we would query whether as a result of the flow sensitivity analysis a review of the structure modelling was conducted to ensure headloss values reported across the structures are considered sensible. If not, we would ask this be acknowledged. It is reported in Section 7.4.1 that for a 20% increase in flow result in a 200mm drop in level, we would ask for further explanation, was this reported downstream of a structure? The report indicates that the model is highly sensitive to blockage and we would ask that the consultant in discussion with the Local Authority take this into consideration when determining the baseline scenarios.

1.32 Sensitivity of the catchment model has been modelled for the 4% AEP and 0.5% AEP, justification should be provided for the use of the 4% AEP. We previously queried whether a blanket 20% was appropriate for the catchment model parameters and we asked for some commentary on this query. The model shows a degree of uncertainty to infiltration, SMD and grid resolution. The most notable changes are reported in the Clachan catchment, where applying a summer SMD to the winter scenario results in a significant reduction in peak and a notable increase in the time to peak, a 26% reduction in peak flow is noted when a 20% increase in soil infiltration rate is applied and a 5% increase in peak flow is noted when a 5m grid resolution is adopted. These changes appear to be greater than the peak flow changes due to forestry reported in Tables 6.7 and 6.8 and we ask that further commentary be provided to ensure that the results are not quoting effects from Natural Flood Management (NFM) which are smaller than the uncertainty in the modelling.

1.33 Table 6.10 should state that the winter forested baseline profile has been used for the baseline.

1.34 For all 1D sensitivity it is standard practice to provide the extents and long sections.

1.35 The baseline report indicates that flooding occurs for all return periods including the most frequent events from the Clachan Burn and the Allt Mor.

Long list of options

1.36 We would draw attention to the report *'Do trees in UK-relevant river catchments influence fluvial flood peaks?', Centre for Ecology and Hydrology, 7th August 2017* and ask that the this be considered when drawing conclusions for the Clachan Study . The report is a literature review of the peer-reviewed studies focussing on the impact of trees on flooding. The key points are summarised as follows, *"Considering all statements together, distinguishing only on the basis of increasing or decreasing cover, there is broad support for the conclusion that trees influence flood peaks. ...However, if a distinction is made between studies based on observations and those based on model output the conclusion is less clear. The majority of statements supporting both the relationship between increasing tree cover and decreasing peak flows, and decreasing tree cover and increasing peak flows are based on model outputs." "(If) the observation-based statements are considered in isolation, the results of analysis are more mixed. There remains a majority of statements showing increasing cover to decrease flood peaks but notable numbers supporting the opposite effect or no influence, resulting in no overall significant difference. No clear difference was found between the number of observation-based statements indicating an increase in flood peak due to decreasing cover and those reporting no influence on flood peak, although none reported a decrease. Distinguishing further on the basis of flood magnitude, all statements that distinguish between small and large flood events (defined qualitatively) indicate that the peak flows of small flood events are reduced by increasing tree cover. However the majority of statements from observed case studies report that the peak flows of large flood events are not influenced by the presence or absence of trees in* *the catchment. It is worth noting that in both cases the number of statements involved is small."*

1.37 We have previously highlighted that on the basis good forestry practices are adhered to at the proposed Talatoll forestry creation scheme, flood risk should not be exacerbated to Clachan. We note that an additional 15% of the Allt Mor catchment is proposed to be planted as part of this scheme. Whilst NFM has many benefits, we do not consider the modelling results validate the report conclusion that there would be a "significant flood risk benefit to properties affected by flooding from this watercourse" on the basis that the forestry related reduction in flows are also within the bounds of modelling uncertainties and the lack of observational data. Given the observed flood records show that woody debris has exacerbated flood risk when causing blockage to structures in Clachan, there remains a risk that the existing forested catchment may continue to contribute a woody debris supply in subsequent flood events. No afforestation has been proposed on the Clachan Burn catchment as part of the Talatoll scheme, therefore we agree that this scheme will not have any reduction on flood risk from the Clachan Burn. Is it possible for a commercial forestry proposal to go beyond compliance with Forestry Standards to help flood management? Also would any change in forestry practices in existing forestry help reduce flood risk? But it is acknowledged that for existing forestry access is really only available during felling.

1.38 The NFM measures could be viable but would in isolation not manage the significant flooding issues within the catchment. We would look for further consideration on options to prevent or at least further reduce woody debris getting to the village such as debris screening posts for example. We would query how much additional flood storage would be provided by wetland enhancement? Riparian woodland benefits would also need to be assessed further and consideration of the potential for increased woody debris and structure blockage. Enhancing the capacity of existing lochs is also a viable measure.

1.39 We would be supportive of maintenance of the un-named watercourse and potentially re-direction of overland flow to this watercourse as long as this would not increase flood risk elsewhere.

1.40 Property Level Protection ('PLP') is a viable option where appropriate.

1.41 We would note that no formal flood warning scheme is proposed for Clachan. However, SEPA do operate for regional flood alert for the Argyll & Bute area.

1.42 No mention of sediment management has been included within the long list and we would wish to see this option at least being considered.

1.43 Improved flow conveyance by removing the weir is also viable but further assessment of the benefits and implications would need to be undertaken. A83 culvert upsizing is also viable but would need further assessment.

1.44 Construction of an upstream flood storage area would also be viable but could have implications under the Reservoirs Act 2011. Improvement works to existing lochs/reservoirs could also be viable this could include works to Loch Ciaran for example which already requires improvement works to ensure compliance.

1.45 Direct defence could also be a viable option and should be subject to further assessment.

1.46 The high flow diversion channel based on the available information would seem to be a very challenging measure. It would also not resolve the flooding issues on the Allt Mor watercourse.

1.47 We note that pluvial / surface water flooding is known to impact Clachan and has attributed to the A83 road damage from the August 2012 event and to a lesser extent the February 2016 event (Section 5, Understanding flood issues/mechanisms, AECOM draft baseline report). We note that no direct assessment of pluvial flooding has been undertaken in the AECOM study and therefore further consideration will be required in the optioneering stage to protect property and road flooding associated with this flooding mechanism.

1.48 Please note that we are reliant on the accuracy and completeness of any information supplied by the applicant in undertaking our review, and can take no responsibility for incorrect data or interpretation made by the authors.

If you have any queries relating to this letter, please contact me by telephone on 01224 266604 or e-mail at planning.sw@sepa.org.uk

Yours sincerely

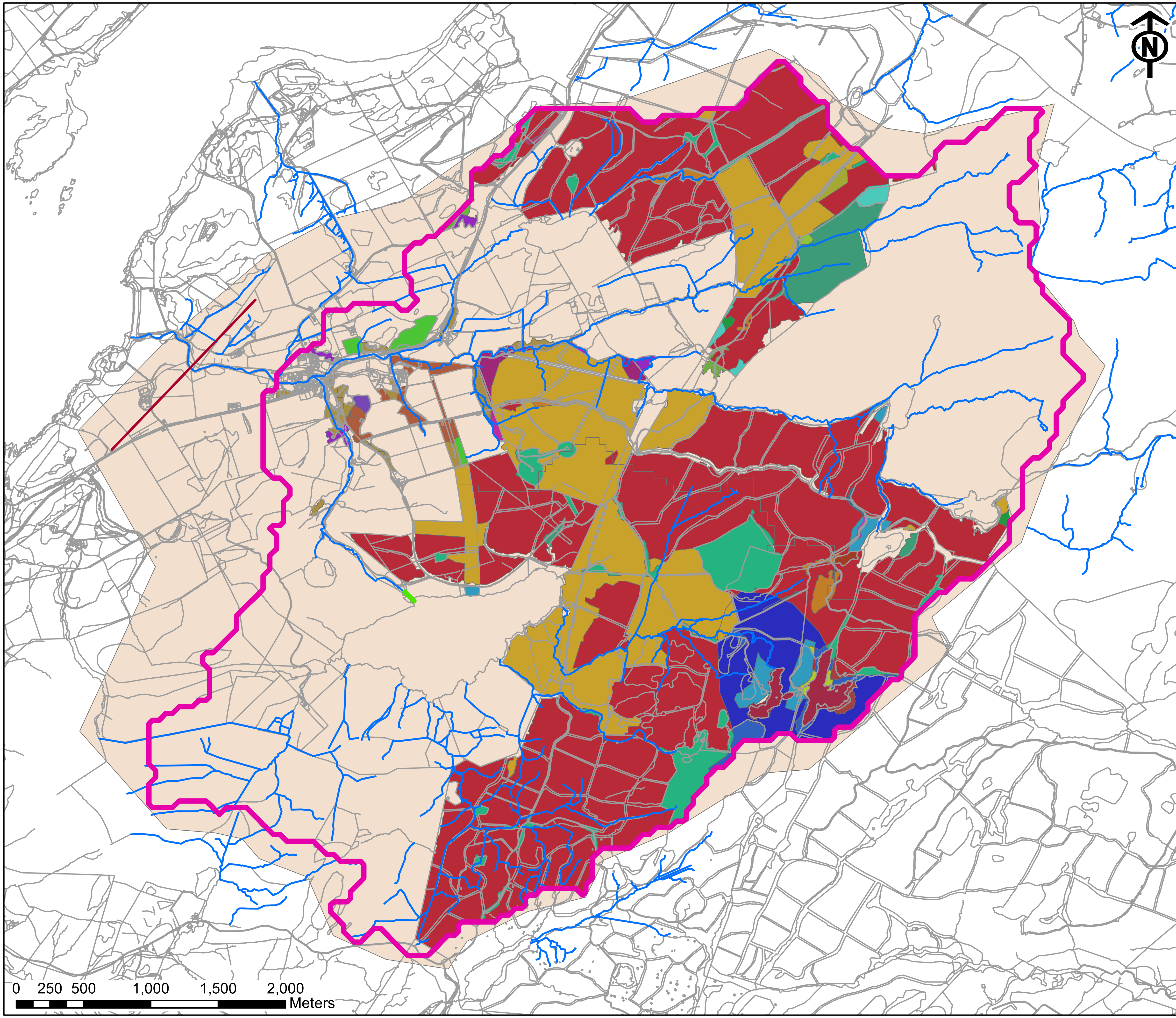
Judith Montford
Senior Planning Officer
Planning Service

Disclaimer
This advice is given without prejudice to any decision made on elements of the proposal regulated by us, as such a decision may take into account factors not considered at this time. We prefer all the technical information required for any SEPA consents to be submitted at the same time as the planning or similar application. However, we consider it to be at the applicant's commercial risk if any significant changes required during the regulatory stage necessitate a further planning application or similar application and/or neighbour notification or advertising. We have relied on the accuracy and completeness of the information supplied to us in providing the above advice and can take no responsibility for incorrect data or interpretation, or omissions, in such information. If we have not referred to a particular issue in our response, it should not be assumed that there is no impact associated with that issue. For planning applications, if you did not specifically request advice on flood risk, then advice will not have been provided on this issue. Further information on our consultation arrangements generally can be found on our website planning pages.

Appendix C Hydrological Model Schematics

- Figure C1 Catchment Hydraulic Model Schematisation: Non-forested Baseline
- Figure C2 Catchment Hydraulic Model Schematisation: Baseline Forested Areas
- Figure C3 1D-2D Hydraulic Model Schematisation
- Figure C4 Crossection Locations 1
- Figure C5 Crossection Locations 2

Project Management Initials GH Designer: AM Checked: DHS Approved: DH



AECOM

PROJECT

Clachan Flood Study

CLIENT

Argyll & Bute COUNCIL

Legend

- 2d_rf layer to apply direct rainfall from REFH2
- ESTRY Unit represent weir at Loch Ciaran using 2018 survey
- HT boundary to allow flow to leave 2D domain based on slope
- Z shape lowering grid -0.1m to stamp out channels
- Extent of grid built from NextMap

Soil parameters applied based on landcover and soil type

SoilID*

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*Specific values for soil infiltration loss, porosity and soil moisture deficit have been applied based on underlying geology at each Soil ID location. Representative summer and winter soil moisture deficits will be modelled

These are set in the tsoil file and applied to relevant GIS attribute.

The parameters selected have been considered in consultation with Forestry Commission and in-house Hydrogeologist.

PROJECT NUMBER

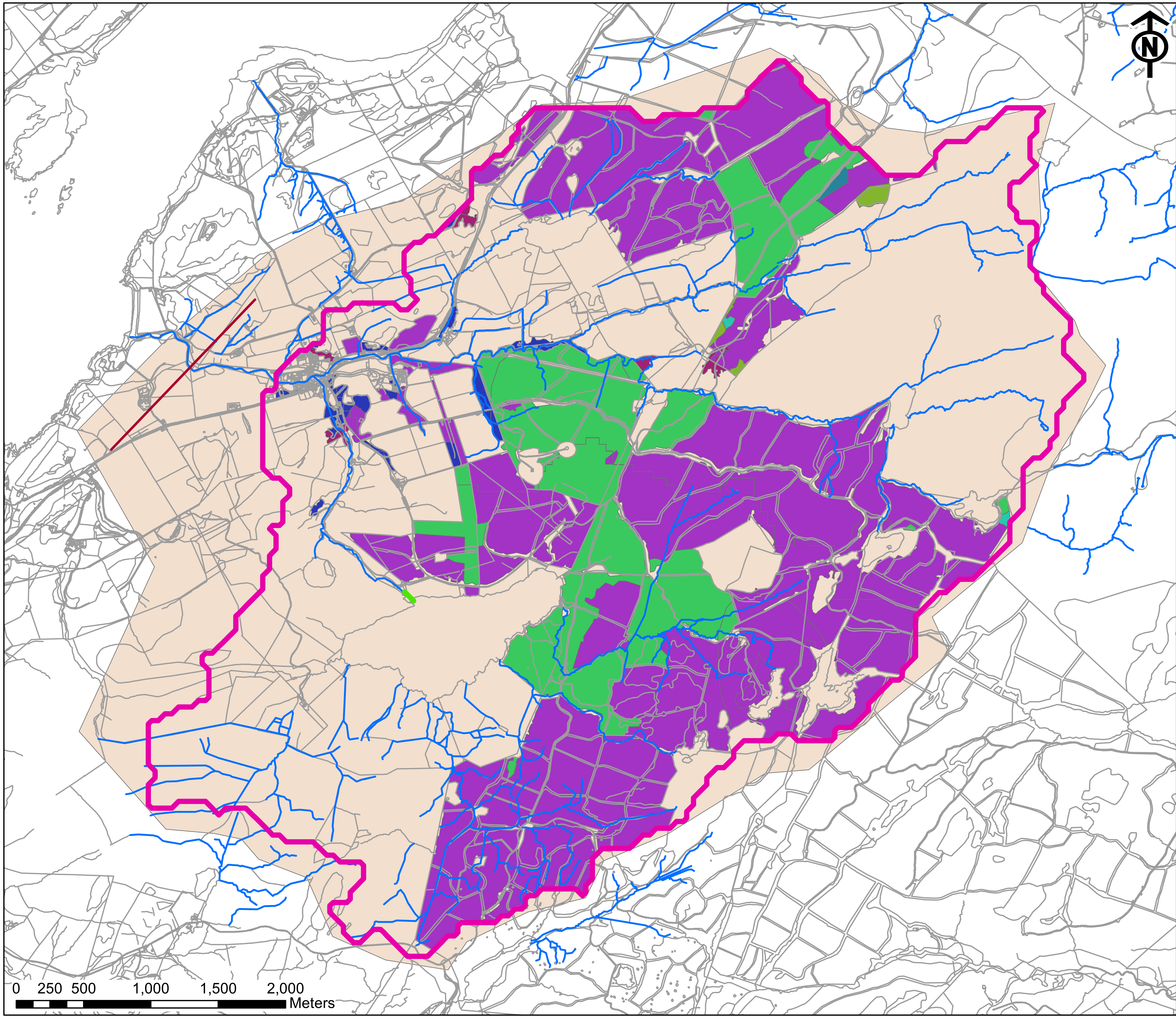
60578115

SHEET TITLE

Figure C1: Catchment Hydraulic Model Schematisation: Non-forested Baseline

-

Project Management Initials GH Designer: AM Checked: DHS Approved: DH



AECOM

PROJECT

Clachan Flood Study

CLIENT

Argyll & Bute Council

Legend

- 2d_rf layer to apply direct rainfall from REFH2
- ESTRY Unit represent weir at Loch Ciaran using 2018 survey
- HT boundary to allow flow to leave 2D domain based on slope
- Z shape lowering grid -0.1m to stamp out channels

Forested Areas*

- broadleaf
- conifer
- felled
- shrub
- windblow
- woodland
- young trees
- Extent of grid built from NextMap

*Soil parameters applied will match those for the non-forested baseline. In forested areas, summer soil moisture deficits will be increased to reflect the impact of trees. Interception losses based on the overlying tree stock will also be applied.

Flow constriction is also applied at these locations through flow construction files based on tree spacing figures from Forestry Commission based on particular tree stocks.

The parameters selected have been considered in consultation with our in-house hydrogeologist and Forestry Commission hydrologists.

PROJECT NUMBER

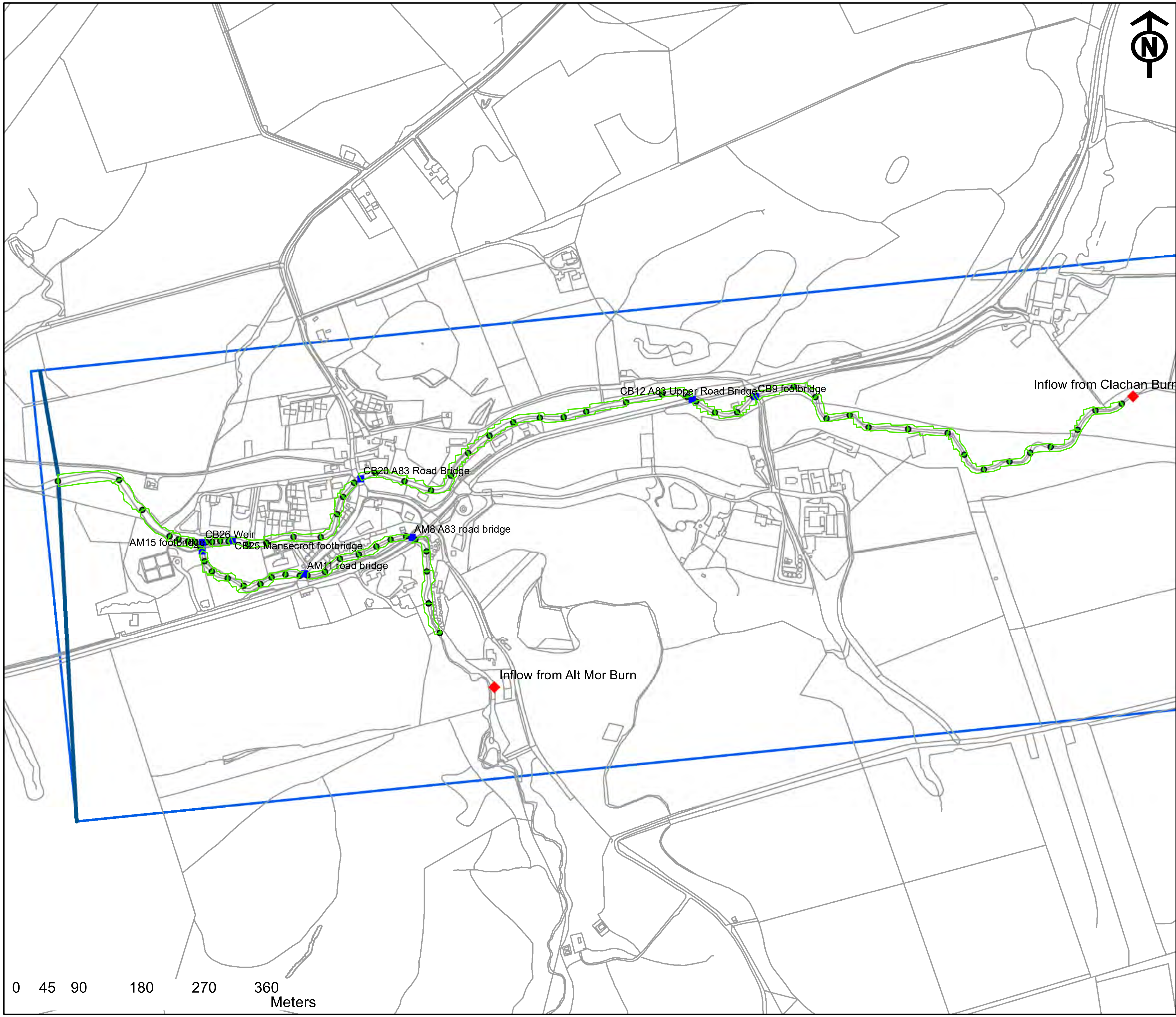
60578115

SHEET TITLE

Figure C2: Catchment Hydraulic Model Schematisation Baseline Forested Areas

-

Project Management Initials GH   Designer: AM   Checked: DHS Approved: DH



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PROJECT

Clachan Flood Study

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Legend

- Link lines
- Modelled structures
- Crosssection locations
- Inflow from Alt Mor Burn
- Inflow from Clachan Burn
- HQ boundary to allow flow to leave 2D domain
- 2D Domain - grid built from Next Map and survey

Normal depth related to channel slope used as 1D downstream boundary

PROJECT NUMBER

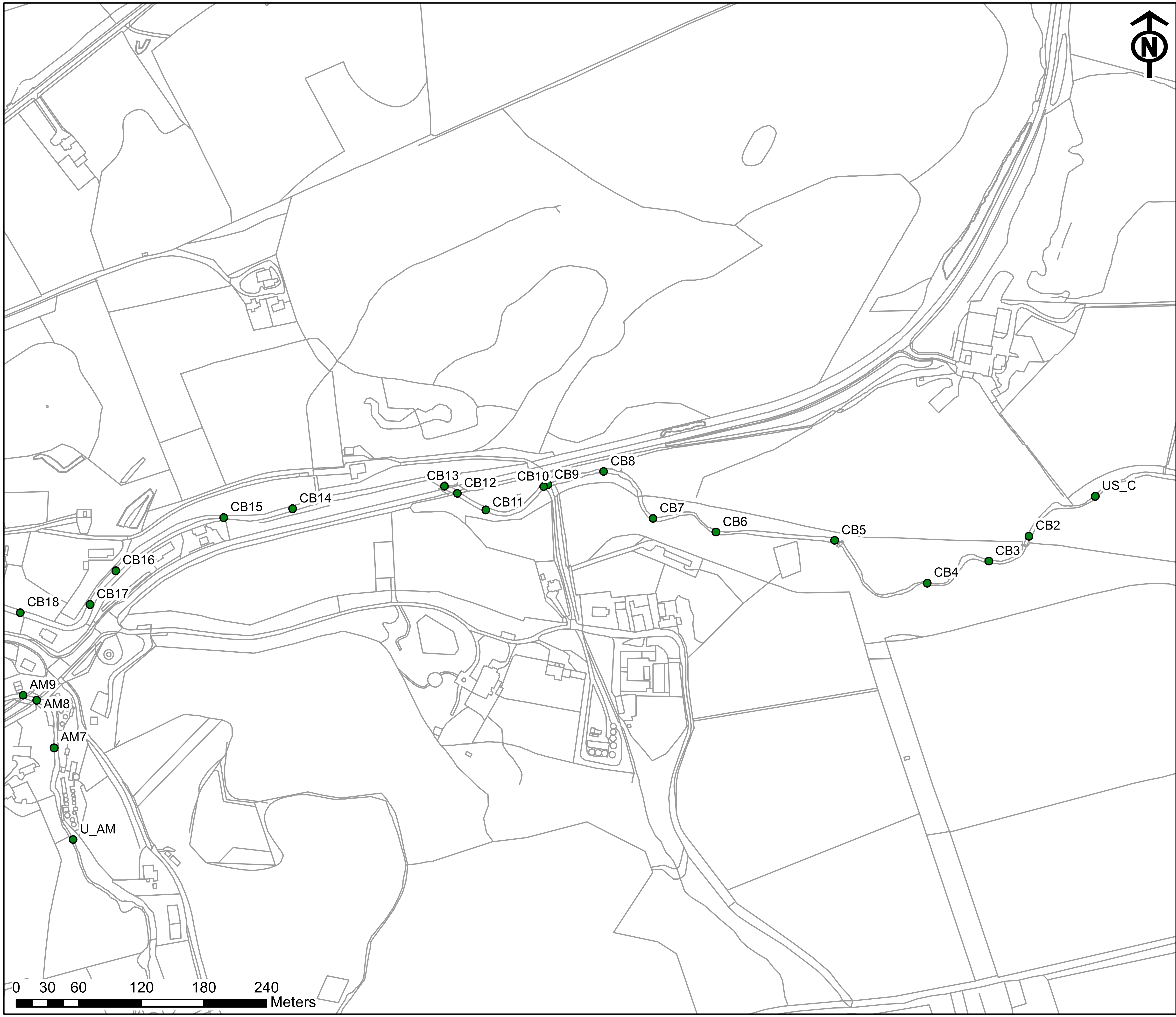
60578115

SHEET TITLE

Figure C3: Catchment 1D-2D Hydraulic Model Schematisation

-

Project Management Initials GH Designer: AM Checked: DHS Approved: DH



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Legend

- crosssection locations

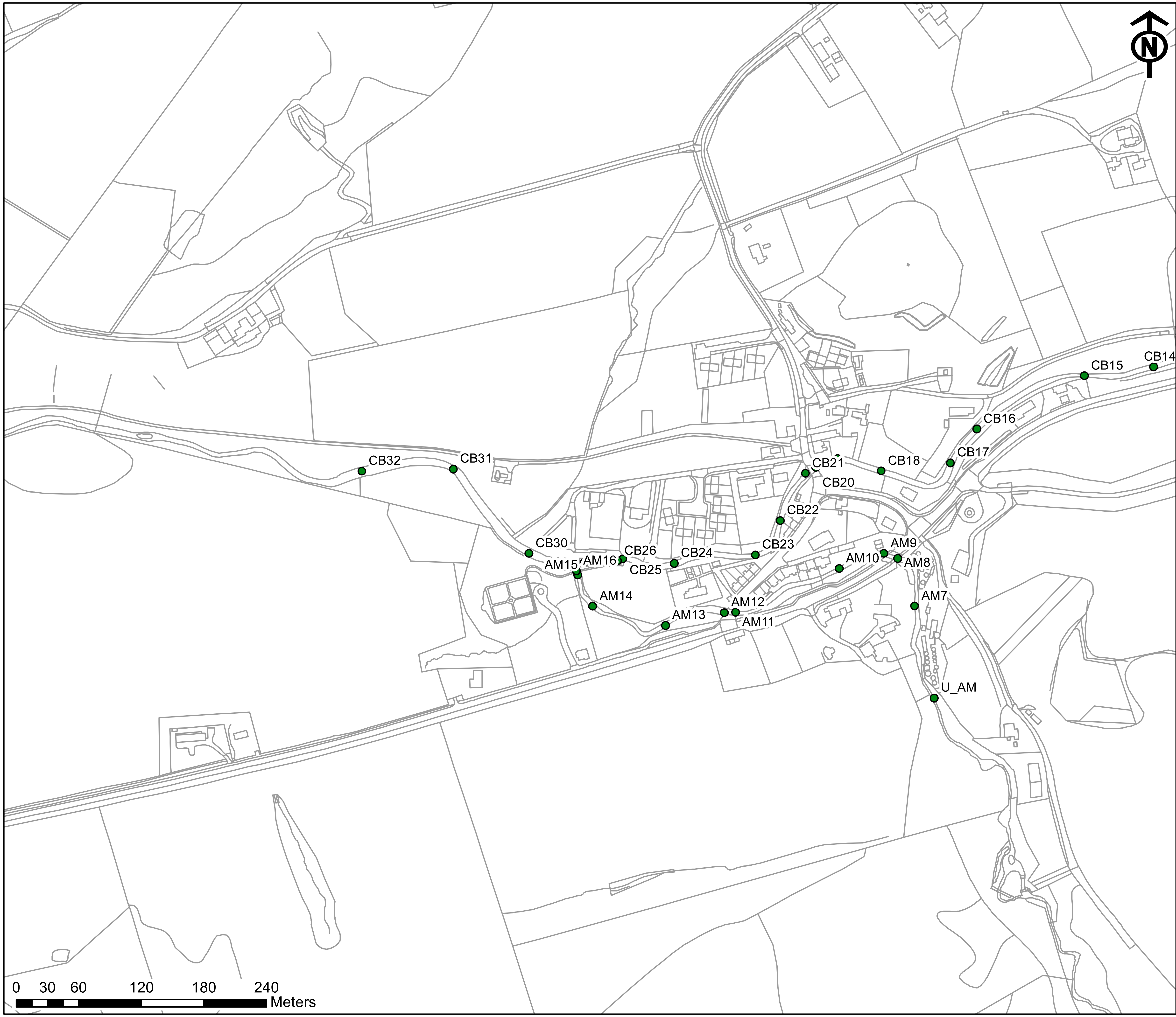
PROJECT NUMBER

60578115

SHEET TITLE

Figure C4: Crossection Locations 1

Project Management Initials GH Designer: AM Checked: DHS Approved: DH



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Legend

● crosssection locations

PROJECT NUMBER

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Figure C5: Crossection Locations 2

Photograph 1: Clachan Burn Upper Reach Strathnafanig

Photograph 2: Clachan Burn Upper Reach upstream A83

Photograph 3: Clachan Burn Upper Reach downstream of Old Road Bridge

Photograph 4: Clachan Burn in village

Photograph 5: Clachan weir

Photograph 6: Downstream extent of Clachan Burn

Photograph 7: Loch Ciaran Outlet

Photograph 8: Allt Mor upper reaches


Photograph 9: Allt Mor lower reaches

Photograph 10: Allt Mor/Clachan Burn confluence

Appendix D Flow estimates using FEH Statistical Method

		Years of data			L-SKEW	
25012 (Harwood Beck @ Harwood)						
47023 (Tamar @ Tamarstone Bridge)						
72007 (Brock @ Upstream of a6)						
21017 (Ettrick Water @ Brockhoperig)						
46005 (East Dart @ Bellever)					0.059	1.99
					0.196	0.451
Total		511				

Legend

Sites Not OK for Pooling	
Sites Not OK for Pooling or Qmed	
Discordant Sites	
Short Record	

Revised Pooling Group Great Somerford

	Pooling Group ID			Pool1		
	Site Code			Gt Somerford		
Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
48001 (Fowey @ Trekeivesteps)	0.841	47	17.615	0.222	0.269	0.25
48004 (Warleggan @ Trengoffe)	1.013	47	9.983	0.261	0.263	1.08
48009 (st Neot @ Craigshill Wood)	1.051	12	8.469	0.245	0.373	1.618
25012 (Harwood Beck @ Harwood)	1.139	47	33.265	0.188	0.24	0.601
27032 (Hebden Beck @ Hebden)	1.172	50	3.923	0.207	0.253	0.682
72007 (Brock @ Upstream of a6)	1.208	38	29.438	0.195	0.231	0.701
49003 (de Lank @ de Lank)	1.208	50	13.985	0.225	0.217	0.401
47021 (Kensey @ Launceston Newport)	1.239	14	13.778	0.257	0.103	2.874
21017 (Ettrick Water @ Brockhoperig)	1.244	52	69.804	0.197	0.208	0.069

46005 (East Dart @ Bellever)	1.259	52	38.967	0.159	0.059	1.647
73009 (Sprint @ Sprint Mill)	1.259	47	42.35	0.182	0.196	0.32
76811 (Dacre Beck @ Dacre Bridge)	1.261	16	35	0.196	0.262	1.699
73015 (Keer @ High Keer Weir)	1.263	25	12.239	0.174	0.191	0.6
72014 (Conder @ Galgate)	1.269	49	16.646	0.212	0.082	1.458
Total		546				
Weighted means				0.208	0.207	

Sites Removed from Initial Group

Criteria for Review	Comment	Action
Pre-Review	Initial pooling group generated by WINFAP-FEH	
	The pooling group is acceptabley homoogeneous and a review of the pooling group is not required	No Change
Station Location	Any sites lying upstream or downstream of the subject site, are likely to be hydrologically similar and give good reason for promotion to a higher ranking in the pooling group.	
	No sites are on the same watercourse	No Change
Period of Record	Check for any stations with less than 8 years of annual maxima, the minimum for inclusion in a pooling group, or any with less than 13 years of annual maxima, which can result in inconsistencies in the calculation of L-moments.	1 site removed- 47023 (Tamar @ Tamarstone Bridge)
	1 site has 7 years of data	1 site added - 27032 (Hebden Beck @ Hebden)
AREA	503	
	No stations are less than 0.5 km2.	No Change
URBEXT	Pooling groups are selected only from essentially rural catchments (URBEXT2000<0.030), regardless of the subject's URBEXT, so this cannot be used as a criterion.	
	The subject is rural	No Change
FARL	FARL is an indicator of the attenuation of flood flow as a result of reservoirs and lakes. A FARL value between 1 and 0.98 shows a trivial effect, less than 0.90 indicates a significant effect (FEH vol 3 p123, 172, 193.).	Maybe justification for adding more with lower FARL- not that many available and far further

	The subject's FARL is 0.823, indicating a significant effect. Stations have a range of FARL between 0.867 and 1, therefore indicating a spread of effect. FARL is one of the parameters used to select the pooling group so only remove if they have other unsuitable descriptors as well.	down the list therefore the current spread was deemed suitable
PROPWET	Consider removing sites with notably higher or lower PROPWET values than the rest of the PG or subject, indicating much wetter or drier catchments.	
	The subject is at the middle of the pooling group and spread deemed to be ok	No Change
SPRHOST	With the Kjeldsen method, permeability is no longer a criteria for pooling group selection, however it is reasonable to expect that highly permeable catchments would exhibit different hydrological behaviour to lower permeability catchments. Note that permeable stations (threshold defined as SPRHOST below 20%) require adjustment of their FFCs to account for any non-flood years.	1 site removed- 48007 (Kennal @ Ponsanooth) 3 sites added -76811 (Dacre Beck @ Dacre Beck) -73015 (Keer @ High Keer Weir) - 72014 (Conder @ Galgate)
	The subject has an SPRHOST o f 54.29% which is above the permeable threshold indicating it is a low permeability catchment. Catchments within a region of 8.63and 41.66. 1 site is permeable	
BFIHOST	The subject has a BFIHOST host of 0.267. Ideally similar catchments would range between 0.087 and 0.447.	47021 (Kensey @ Launceston Newport) could be removed at 0.584 however not too high
	The subject site has a low BFIHOST, therefore it is unlikely viable to achieve the ideal range, therefore only high BFIHOST sites will be removed.	
Flood seasonality	The gauging stations should have similar seasonality of flood peaks	
	The flood seasonality is reasonably well grouped from December to January.	No Change
Stations on same watercourse	Stations near to each other on the same river with overlapping time periods would bias the pooling group towards that record.	
	No stations are on the same watercourse	No Change
L Moments	Note outlier status may be due to flood history, e.g. a particularly large event which is not grounds for removal. Where potential outliers are identified, the site catchment descriptors and notes should be viewed to determine whether the site appears hydrologically different and hence there are grounds for removal.	No Change

	Generally the L-moments are quite spread.	
Site Comments	All sites have had comments examined to assess the quality of flow data:	
	Comments reviewed for all sites, 1 site found to be unacceptable	
Excess years	WINFAP 3 requires 500 years of station data	
	Already minimum number of stations.	No Change
Discordant Sites	There are 14 stations in the pooling group and hence the critical value to indicate possible discordancy is 2.971EH vol 3 p 160).	No Change

Appendix E Sensitivity results

Table E1: 1D Variation in 1 in 200yr river level compared to baseline (mAOD). Table should be read with figures C4 and C5 which indicate cross-section locations

Label	+20% DS boundary	-20% DS boundary	+40% manning	-40% manning	+20% flow	- 20% flow	50% blockage at CB20	50% blockage at AM11
US_C	0.03	0.00	0.00	-0.34	0.33	-0.44	0.00	0.00
CB2	0.03	0.01	0.08	-0.28	0.02	-0.18	0.00	0.00
CB3	0.02	0.01	0.13	-0.29	0.06	-0.18	0.00	0.00
CB4	0.02	0.01	0.12	-0.37	0.05	-0.21	0.00	0.00
CB5	0.00	0.00	0.22	-0.48	0.05	-0.28	0.00	0.00
CB6	0.00	0.00	0.14	-0.42	0.03	-0.27	0.00	0.00
CB7	0.00	0.00	0.29	-0.64	0.08	-0.32	0.00	0.00
CB8	0.00	0.00	0.24	-1.16	0.13	-0.40	0.00	0.00
CB9_BR_US	0.00	0.00	0.15	-1.28	0.25	-1.04	0.00	0.00
CB9_BR_DS	0.00	0.00	0.33	-0.45	0.17	-0.22	0.00	0.00
CB10	0.00	0.00	0.32	-0.45	0.17	-0.22	0.00	0.00
CB11	0.00	0.00	0.30	-0.18	0.23	-0.18	0.00	0.00
CB12_BR_US	0.00	0.00	0.44	-0.15	0.58	-0.20	0.00	0.00
CB12_BR_DS	0.00	0.00	0.23	-0.09	0.12	-0.16	0.00	0.00
CB13	0.00	0.00	0.30	-0.09	0.12	-0.17	0.00	0.00
CB14	0.00	0.00	0.11	-0.13	0.12	-0.13	0.00	0.00
CB15	0.00	0.00	0.13	-0.13	0.10	-0.11	0.00	0.00
CB16	0.00	0.00	0.19	-0.14	0.07	-0.06	0.05	0.00
CB17	0.00	0.00	0.11	-0.14	0.03	-0.12	0.12	0.00
CB18	0.00	0.00	0.63	-0.60	0.32	-0.37	0.76	0.00
CB19	0.00	0.00	0.88	-0.48	0.16	-0.23	1.14	0.00
CB20	0.00	0.00	0.68	-0.46	0.15	-0.24	1.50	0.00
CB20_BR_US	0.00	0.00	0.68	-0.31	0.15	-0.24	1.50	0.00
CB21	0.00	0.00	0.23	-0.32	0.07	-0.15	0.11	0.00
CB22	0.00	0.00	0.14	-0.44	0.03	-0.17	0.11	0.00
CB23	0.00	0.00	0.45	-0.49	0.35	-0.26	0.01	0.01
CB24	0.00	0.00	0.01	-0.20	0.10	-0.20	-0.03	0.00
CB25	0.00	0.00	0.01	-0.03	0.09	-0.12	-0.02	0.00
CB25_BR_US	0.00	0.00	0.01	-0.11	0.09	-0.12	-0.02	0.00
CB26	0.00	0.00	0.08	-0.11	0.06	-0.08	-0.01	0.00
CB27_W_US	0.00	0.00	0.23	-0.05	0.07	-0.09	-0.01	0.00
CB28	0.00	0.00	0.22	-0.36	0.13	-0.19	-0.02	-0.01
CB29	0.00	0.00	0.22	-0.36	0.13	-0.19	-0.02	-0.01
CB30	0.00	0.00	0.21	-0.37	0.18	-0.26	-0.03	-0.01
CB31	-0.01	0.03	0.22	-0.33	0.08	-0.09	-0.01	0.00
CB32	0.05	-0.06	0.18	-0.35	0.10	-0.13	-0.01	-0.01
U_AM	0.00	0.00	0.21	-0.28	0.11	-0.12	0.00	0.00
AM7	0.00	0.00	0.18	-0.23	0.09	-0.09	0.00	0.00
AM8	0.00	0.00	0.17	-0.09	0.16	-0.17	0.00	0.00
AM8_BR_US	0.00	0.00	0.17	-0.09	0.16	-0.17	0.00	0.00

AM9	0.00	0.00	0.22	-0.15	0.11	-0.13	0.00	0.01
AM10	0.00	0.00	0.23	-0.32	0.13	-0.15	0.00	0.03
AM11	0.00	0.00	0.39	-0.25	0.49	-0.18	0.00	0.62
AM11_BR_US	0.00	0.00	0.39	-0.25	0.49	-0.18	0.00	0.62
AM12	0.00	0.00	0.21	-0.27	0.17	-0.11	0.00	0.13
AM13	0.00	0.00	0.05	-0.08	0.02	-0.03	0.00	0.00
AM14	0.00	0.00	0.04	-0.17	0.11	-0.15	-0.01	-0.01

Appendix F Flood Levels and Velocities

Table F1: 1D Baseline flood levels (mAOD). Table should be read with figures C4 and C5 which indicate cross-section locations

Label	2YR BASE	5YR BASE	10YR BASE	25YR BASE	50yr BASE	100yr BASE	200yr BASE	200yrCC BASE
US_C	33.88	34.08	34.21	34.41	34.71	34.74	35.06	35.73
CB2	32.71	32.84	32.91	33.00	33.15	33.11	33.25	33.36
CB3	31.42	31.60	31.70	31.80	32.02	31.94	32.07	32.24
CB4	29.85	30.04	30.16	30.29	30.54	30.44	30.60	30.76
CB5	27.48	27.72	27.86	28.02	28.28	28.23	28.44	28.59
CB6	26.16	26.33	26.43	26.54	26.76	26.70	26.91	27.07
CB7	24.91	25.13	25.26	25.42	25.74	25.63	25.88	26.13
CB8	24.04	24.34	24.51	24.70	25.10	24.96	25.26	25.58
CB9	23.01	23.25	23.40	23.57	23.94	23.80	24.76	25.21
CB9_BR_US	23.01	23.25	23.40	23.57	23.94	23.80	24.76	25.21
CB10	22.91	23.15	23.29	23.45	23.82	23.68	23.82	24.12
CB11	21.29	21.54	21.70	21.85	22.17	22.05	22.16	22.51
CB12	20.92	21.18	21.32	21.48	21.80	21.67	21.80	22.59
CB12_BR_US	20.92	21.18	21.32	21.48	21.80	21.67	21.80	22.59
CB13	20.72	20.95	21.08	21.21	21.47	21.36	21.47	21.73
CB14	19.62	19.82	19.94	20.06	20.29	20.21	20.29	20.48
CB15	18.95	19.24	19.39	19.54	19.74	19.68	19.75	19.93
CB16	17.79	18.07	18.24	18.33	18.41	18.34	18.40	18.61
CB17	17.25	17.51	17.65	17.82	18.21	18.14	18.21	18.40
CB18	16.25	16.55	16.73	16.92	17.46	17.22	17.46	18.26
CB19	16.08	16.35	16.49	16.66	17.05	16.91	17.05	18.18
CB20	15.70	15.94	16.09	16.25	16.64	16.50	16.64	17.97
CB20_BR_US	15.70	15.94	16.09	16.25	16.64	16.50	16.64	17.97
CB21	15.57	15.81	15.95	16.08	16.34	16.25	16.34	16.65
CB22	14.90	15.24	15.42	15.62	15.97	15.88	15.97	16.19
CB23	14.37	14.73	14.92	15.14	15.57	15.40	15.57	16.21
CB24	13.78	14.07	14.17	14.33	14.70	14.65	14.77	14.97
CB25_BR_US	13.50	13.90	14.06	14.16	14.18	14.28	14.36	14.55
CB25	13.50	13.90	14.06	14.16	14.18	14.28	14.36	14.55
CB26	13.45	13.68	13.87	13.93	14.03	14.01	14.06	14.18
CB27	13.42	13.59	13.65	13.71	13.96	13.84	13.90	14.04
CB27_W_US	13.42	13.59	13.65	13.71	13.96	13.84	13.90	14.04
CB28	12.39	12.64	12.79	12.97	13.37	13.20	13.34	13.56
CB28	12.37	12.63	12.78	12.97	13.36	13.20	13.34	13.55
CB29	12.37	12.63	12.78	12.97	13.36	13.20	13.34	13.55
CB30	11.71	12.01	12.16	12.38	12.93	12.75	12.94	13.25
CB31	10.66	10.93	11.06	11.21	11.46	11.39	11.45	11.62
CB32	10.24	10.51	10.62	10.76	11.05	10.95	11.04	11.24
U_AM	26.50	26.62	26.71	26.79	26.99	26.92	26.99	27.15
AM7	21.28	21.39	21.47	21.53	21.68	21.63	21.68	21.81
AM8	17.30	17.49	17.66	17.84	18.11	18.01	18.11	18.33

AM8_BR_US	17.30	17.49	17.66	17.84	18.11	18.01	18.11	18.33
AM9	17.11	17.29	17.43	17.60	17.81	17.73	17.81	17.95
AM10	16.40	16.60	16.73	16.85	17.08	17.00	17.08	17.26
AM11	15.13	15.33	15.46	15.59	15.88	15.76	15.88	16.43
AM11_BR_US	15.13	15.33	15.46	15.59	15.88	15.76	15.88	16.43
AM12	14.99	15.15	15.24	15.33	15.52	15.46	15.52	15.74
AM13	14.25	14.30	14.38	14.41	14.46	14.44	14.46	14.49
AM14	13.11	13.19	13.33	13.63	13.99	13.96	14.07	14.27
AM15	12.39	12.70	12.89	13.10	13.59	13.70	13.82	14.03
AM15_BR_US	12.39	12.70	12.89	13.10	13.59	13.70	13.82	14.03
AM16	12.37	12.63	12.78	12.97	13.36	13.20	13.34	13.55

Table F2:1D Baseline velocities (m/s). Table should be read with figures C4 and C5 which indicate cross-section locations

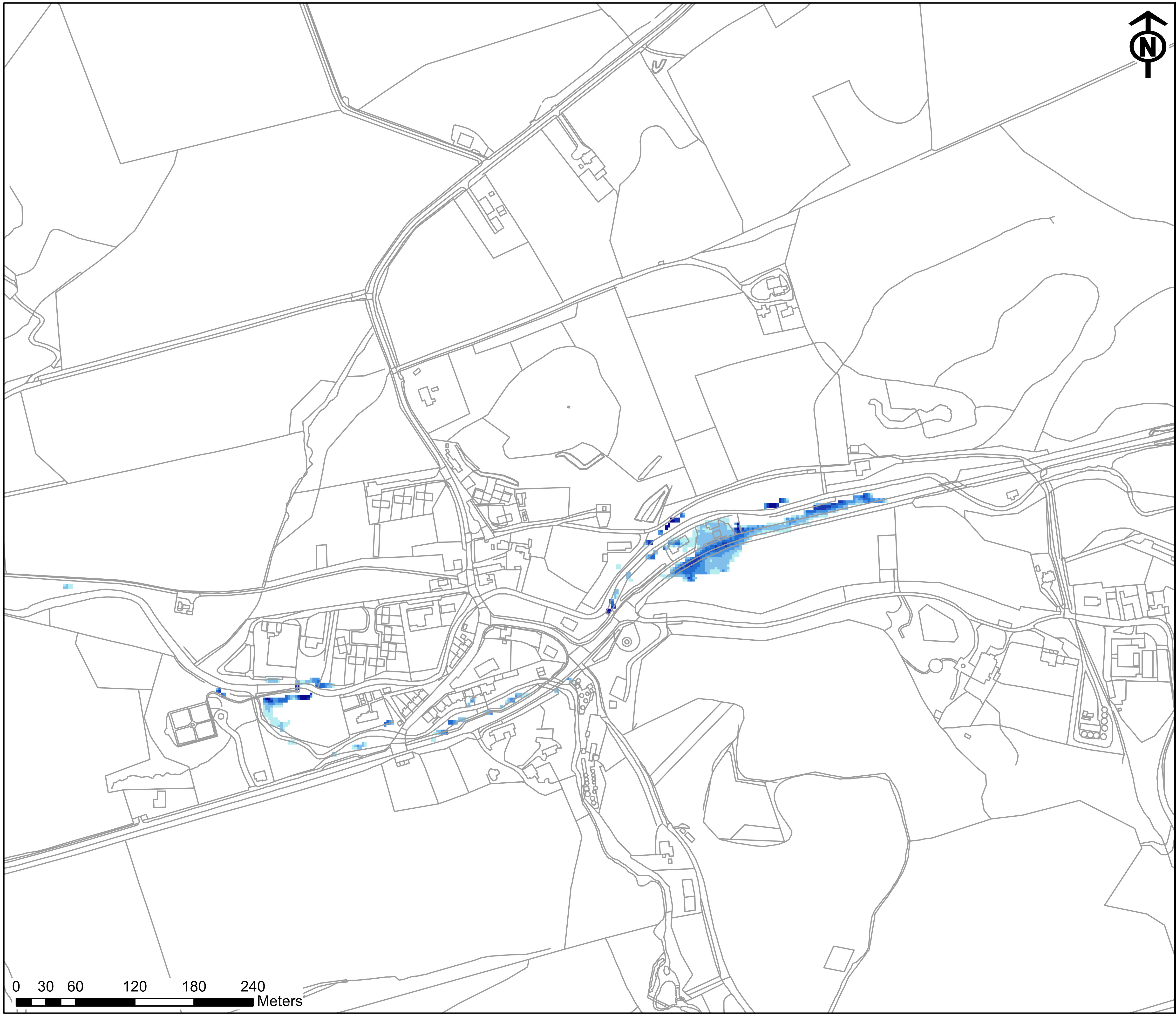
Label	2YR BASE	5YR BASE	10YR BASE	25YR BASE	50yr BASE	100yr BASE	200yr BASE	200yrCC BASE
US_C	2.14	2.39	2.50	2.54	2.55	2.56	2.73	2.71
CB2	2.79	3.11	3.27	3.42	3.53	3.64	4.02	4.17
CB3	1.53	1.70	1.81	1.92	2.00	2.08	2.42	2.47
CB4	1.62	1.81	1.92	2.05	2.13	2.23	2.63	2.69
CB5	1.76	2.04	2.21	2.39	2.50	2.62	3.02	3.30
CB6	2.12	2.45	2.64	2.84	2.95	3.08	3.68	4.16
CB7	2.11	2.28	2.38	2.48	2.55	2.63	3.30	3.77
CB8	1.43	1.60	1.71	1.82	1.89	1.98	3.16	3.15
CB9	2.89	3.29	3.52	3.75	3.90	4.06	4.45	4.47
CB10	2.81	3.23	3.45	3.68	3.82	3.98	4.36	4.51
CB11	1.75	2.00	2.14	2.30	2.42	2.55	2.73	2.94
CB12	1.74	2.01	2.16	2.29	2.40	2.51	2.62	2.68
CB13	1.72	1.96	2.06	2.22	2.34	2.47	2.61	2.75
CB14	1.61	1.72	1.72	1.73	1.73	1.73	1.74	2.05
CB15	2.00	2.05	2.10	2.12	2.13	2.14	2.14	2.26
CB16	1.69	2.07	2.11	2.37	2.76	3.03	3.27	3.86
CB17	2.04	2.31	2.42	2.48	2.49	2.49	2.49	2.62
CB18	2.13	2.48	2.59	2.66	2.73	2.75	2.77	2.78
CB19	1.54	1.89	2.10	2.31	2.43	2.59	2.69	4.28
CB20	2.30	2.77	2.92	3.09	3.22	3.38	3.51	3.93
CB21	2.68	2.98	3.12	3.27	3.38	3.44	3.50	3.83
CB22	2.67	2.94	2.98	3.00	3.02	3.08	3.26	3.86
CB23	2.30	2.73	2.95	3.16	3.29	3.48	3.52	3.82
CB24	1.71	2.11	2.39	2.52	2.52	2.52	2.52	2.52
CB25	1.80	1.91	1.81	1.80	1.80	1.80	1.80	1.80
CB26	1.66	1.81	1.66	1.66	1.66	1.66	1.66	1.66
CB27	1.01	1.11	1.14	1.17	1.20	1.24	1.27	1.34

CB28	1.11	1.20	1.18	1.14	1.13	1.13	1.13	1.13
CB28	2.03	2.32	2.49	2.62	2.69	2.69	2.70	2.72
CB29	2.32	2.64	2.77	2.89	2.94	2.99	3.03	3.09
CB30	2.18	2.62	2.89	3.23	3.44	3.69	4.00	4.36
CB31	1.73	1.93	2.01	2.12	2.19	2.29	2.36	2.53
CB32	1.88	2.17	2.34	2.52	2.63	2.75	2.88	3.16
U_AM	1.69	1.97	2.15	2.34	2.46	2.59	2.73	3.08
AM7	1.48	1.62	1.62	1.62	1.62	1.62	1.62	1.62
AM8	1.49	1.64	1.73	1.74	1.74	1.76	1.82	2.05
AM9	1.95	2.20	2.34	2.47	2.54	2.62	2.69	2.88
AM10	1.31	1.57	1.71	1.82	1.85	1.90	1.90	1.90
AM11	1.35	1.59	1.71	1.83	1.90	1.96	2.03	2.02
AM12	1.89	1.81	2.37	2.61	2.80	3.06	3.33	3.78
AM13	1.89	2.16	2.27	2.31	2.31	2.32	2.28	2.25
AM14	1.89	2.35	2.49	2.67	2.82	2.91	2.90	3.19
AM15	2.56	3.03	3.28	3.45	3.58	3.69	3.38	3.88
AM16	2.56	3.03	3.28	3.45	3.58	3.69	3.38	3.88

Appendix G Flood Maps

- Figure G1 2 year baseline flood map
- Figure G2 10 year baseline flood map
- Figure G3 25 year baseline flood map
- Figure G4 200 year baseline flood map
- Figure G5 200 year CC baseline flood map

Project Management Initials GH Designer: AM Checked: SH Approved: SH



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2yr flood depth (m)

- 0 - 0.05
- 0.05 - 0.15
- 0.15 - 0.25
- 0.25 - 0.35
- 0.35 - 0.45
- 0.45 - 0.7

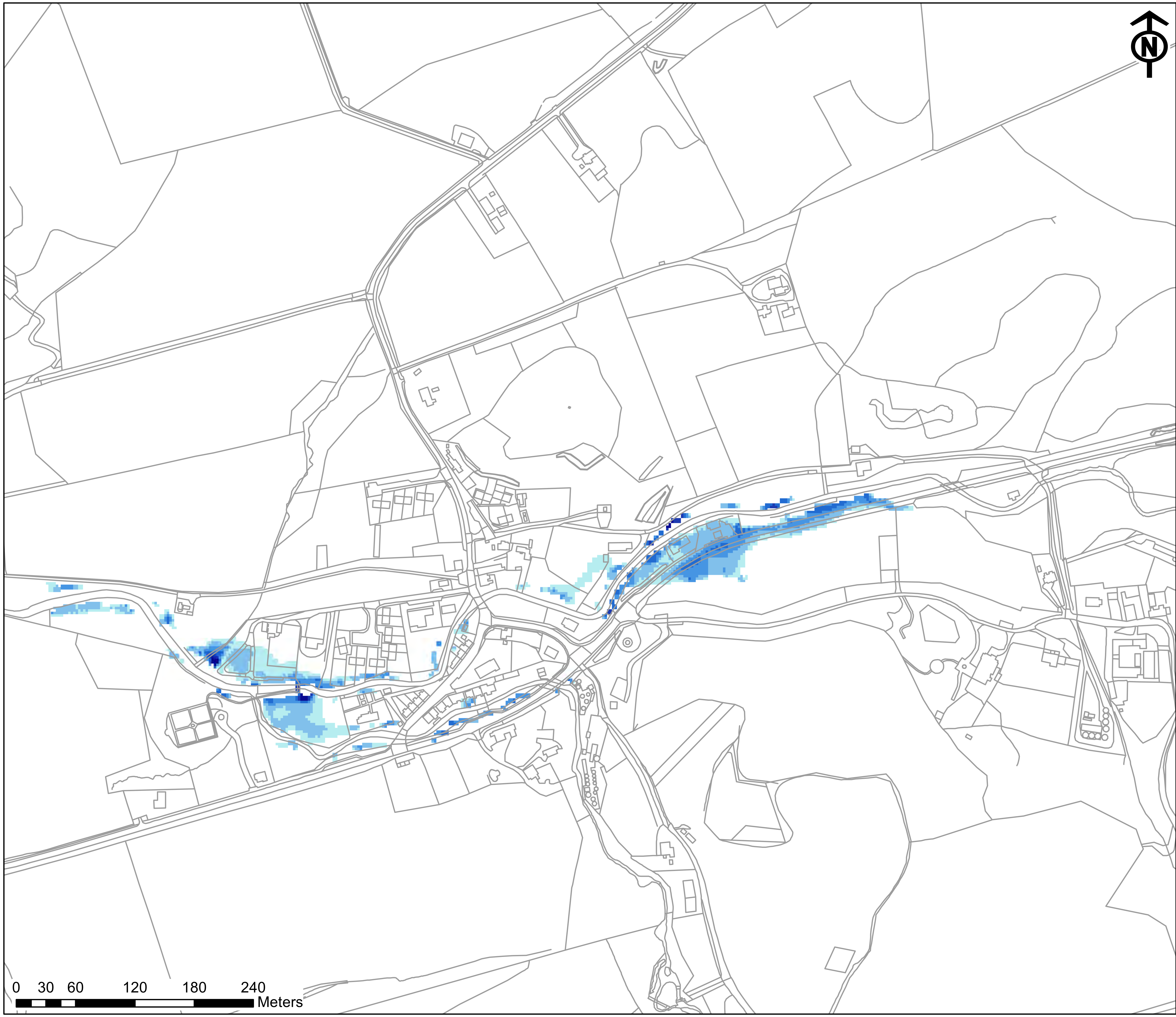
PROJECT NUMBER

60578115

SHEET TITLE

Figure G1: 1 in 2 year basline flood map

Project Management Initials GH Designer: AM Checked: SH Approved: SH



AECOM

PROJECT

Clachan Flood Study

CLIENT

Argyll Bute Council

Legend

10yr flood depth (m)

- 0 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.8
- 0.8 - 1
- 1.0 - 1.3

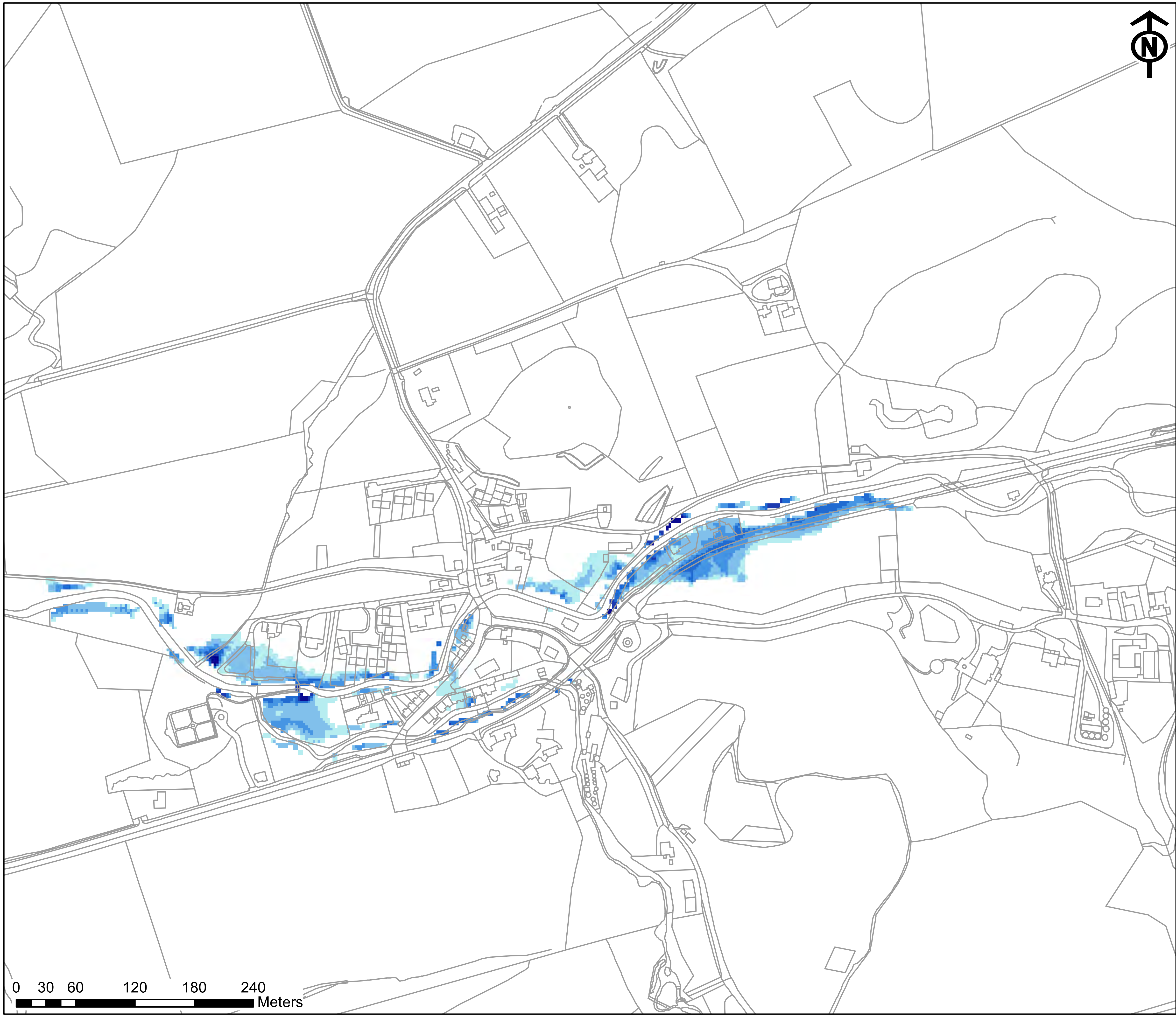
PROJECT NUMBER

60578115

SHEET TITLE

Figure G2: 1 in 10 year basline flood map

Project Management Initials GH Designer: AM Checked: SH Approved: SH



AECOM

PROJECT

Clachan Flood Study

CLIENT

Argyll Bute COUNCIL

Legend

25yr flood depth (m)

- 0 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.8
- 0.8 - 1
- 1.0 - 1.4

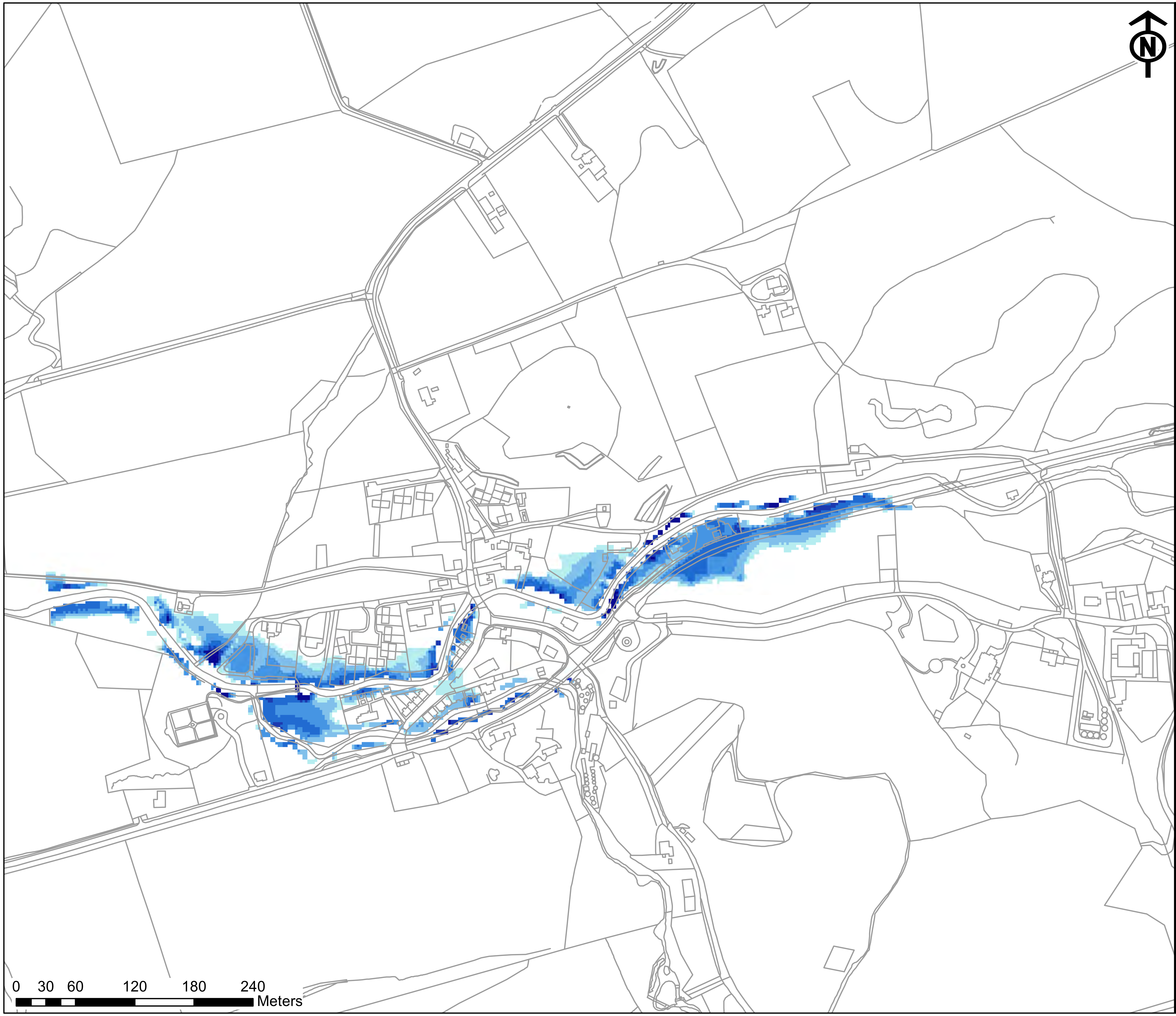
PROJECT NUMBER

60578115

SHEET TITLE

Figure G3: 1 in 25 year basline flood map

Project Management Initials GH Designer: AM Checked: SH Approved: SH



AECOM

PROJECT

Clachan Flood Study

CLIENT

Argyll Bute COUNCIL

Legend

200yr flood depth (m)

- 0 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.8
- 0.8 - 1.0
- 1.0 - 1.9

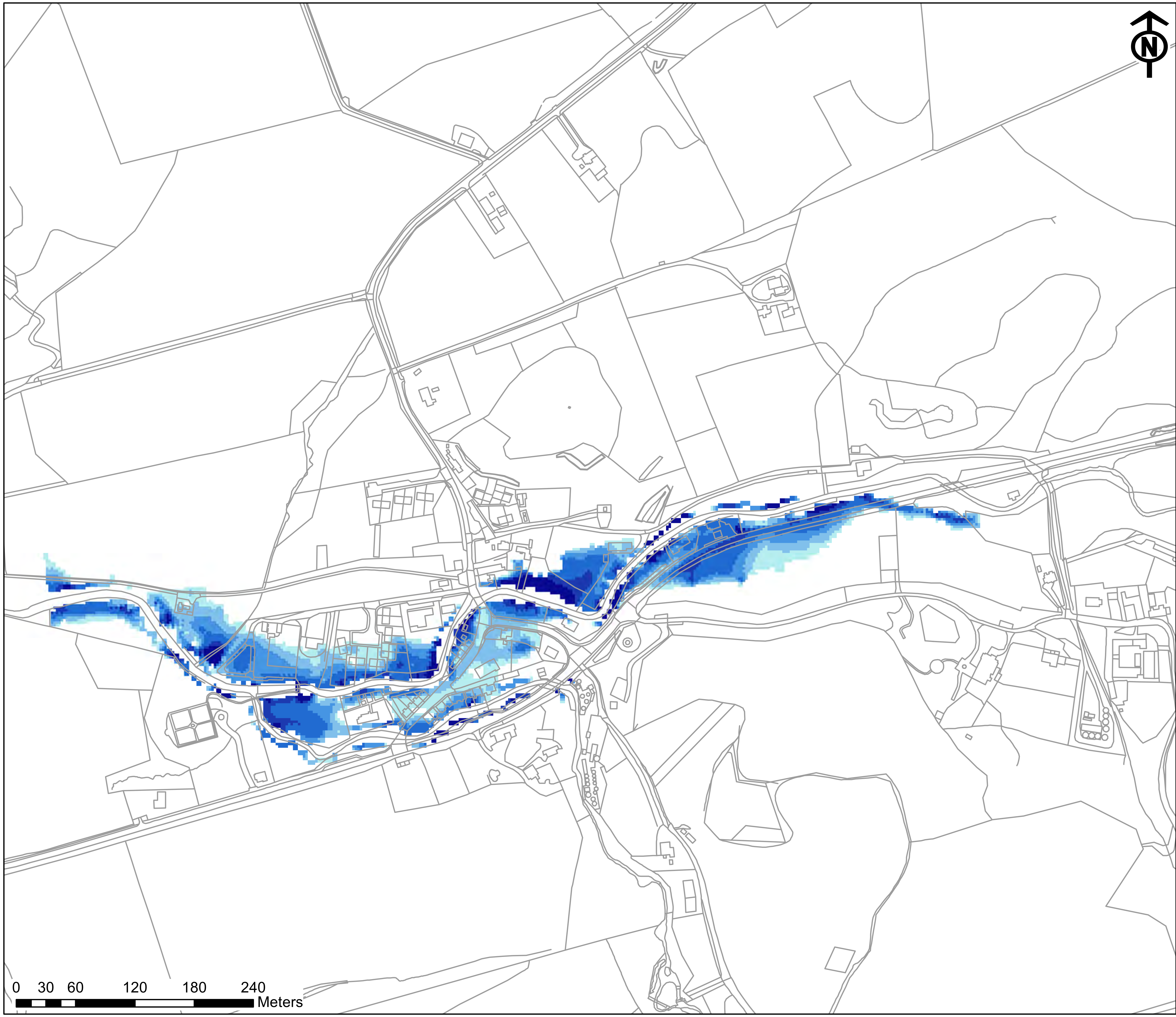
PROJECT NUMBER

60578115

SHEET TITLE

Figure G4: 1 in 200 year basline flood map

Project Management Initials GH Designer: AM Checked: SH Approved: SH



AECOM

PROJECT

Clachan Flood Study

CLIENT

Argyll Bute Council

Legend

200+CCyr flood depth (m)

- 0 - 0.1
- 0.1 - 0.3
- 0.3 - 0.5
- 0.5 - 0.8
- 0.8 - 1
- 1.0 - 2.1

PROJECT NUMBER

60578115

SHEET TITLE

Figure G5: 1 in 200+CC year basline flood map aecom.com