Scottish Environment Protection Agency
Buidheann Dìon Àrainneachd na h-Alba

For the future of our environment

River Flooding Summary: Methodology and Mapping

25 February 2025

1. Introduction

The Flood Risk Management (Scotland) Act 2009 (FRM Act) introduced a co-ordinated and partnership approach to how we sustainably tackle flood risk in Scotland. To fulfil this, we are considering all sources of flooding and whole river catchments when making flood risk management decisions.

A key outcome of the FRM Act is the production of flood hazard and flood risk maps for Scotland. The published maps provide the most comprehensive national source of data on flood hazard and risk and include information on different likelihoods of flooding:

Time horizon	Likelihood of flooding	Return period
Present Day	High	10 year
Present Day	Medium	200 year
Present Day	Low	1000 year
Climate Change 2080s-High emissions	Medium	200 year

To produce a flood hazard map for each source of flooding SEPA has developed datasets and methodologies for river, coastal and surface water flooding.

This summary provides information on how we developed our river (fluvial) flood map and how to interpret this data. Previous knowledge of flood modelling and mapping is beneficial when using this summary.

2. Development and review

The mapping of flooding is a dynamic process and the flood maps will be subject to review and change as we develop our input data, methodologies and techniques. SEPA will continue to work with responsible authorities and partner organisations to improve our confidence in representing river flood hazard across Scotland.

Ongoing developments that SEPA is working towards include:

- Improving input data. For example, the use of Light Detection And Ranging (LiDAR) data that extends our coverage of higher resolution ground models.
- Investigating how to effectively apply the most appropriate hydrological and hydraulic modelling methods.
- Incorporation of outputs from detailed local studies where appropriate.
- Continuing to develop SEPA's Observed Flood Event database of historical flood records to support model calibration and validation.

3. Methodology and data

3.1 Approach

The flood maps provide an indication of the flood hazard across the country. A nationally consistent methodology has been used to produce the river flood map for Scotland. The application of a consistent national methodology provides a baseline which is supplemented by more detailed, local assessments where they are available and can be taken into consideration. The map provides indicative flood hazard information and identifies communities at risk from river flooding.

There is an inherent uncertainty in flood modelling as a result of assumptions and simplifications that are required to enable complex natural processes to be reflected through hydraulic modelling software. Please refer to Section 5 for guidance on interpretation.

3.2 Data

The data used to produce the river flood map is listed in Table 1 (Appendix), alongside a description of the data, how it was used and the quality review process.

3.3 Methodology

The development of the river flood map is based on a two-dimensional (2D) flood modelling method applied across Scotland to all catchments greater than $3km^2$. This method of flood modelling has the capability to estimate flood depths, velocities, extents and in turn a hazard score to estimate impacts on people, properties and the environment.

19 different scenarios have been simulated through each model across Scotland (listed in Table 2, Appendix).

3.3.1. Model domains

The country was split into around 3500 domains that were used to define each of the areas that hydraulic models would be run for. (Figure 1 shows examples of model domains).

Each model domain was then attached to domains upstream and downstream so that the entire reach of the river was modelled.

The grid resolution applied to each domain was assigned based on the ground model (Digital Terrain Model (DTM)) available and the remoteness of the area. The adopted grid resolution is shown in Figure 2 (below) with a summary of the assigned grid resolutions available in Table 3 (Appendix).

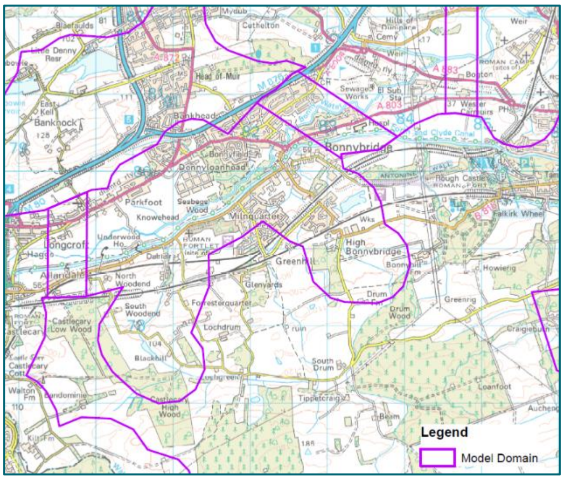

Figure 1: Map showing examples of model domains.

3.3.2. Ground model

The underlying ground model is made up of a composite DTM consisting of LiDAR and NEXTMap data. The DTM, along with the domains and the grid resolution, (the underlying data sources) determined the flow routes of the applied inflows.

3.3.3. Flow

The UK Centre of Ecology & Hydrology (UKCEH) flow grid is a national dataset giving an estimate of design flows at 50m intervals on all watercourses with a catchment area greater than 0.5km^2. Local data has been used to inform changes to the original flow grid. An assessment was made of the flow grid where flow grid points were found to be +/-25% relative to estimates based on local recorded data in that region available in 2011-12. Utilising advice from SEPA regional experts the flow grid was then updated using this data.

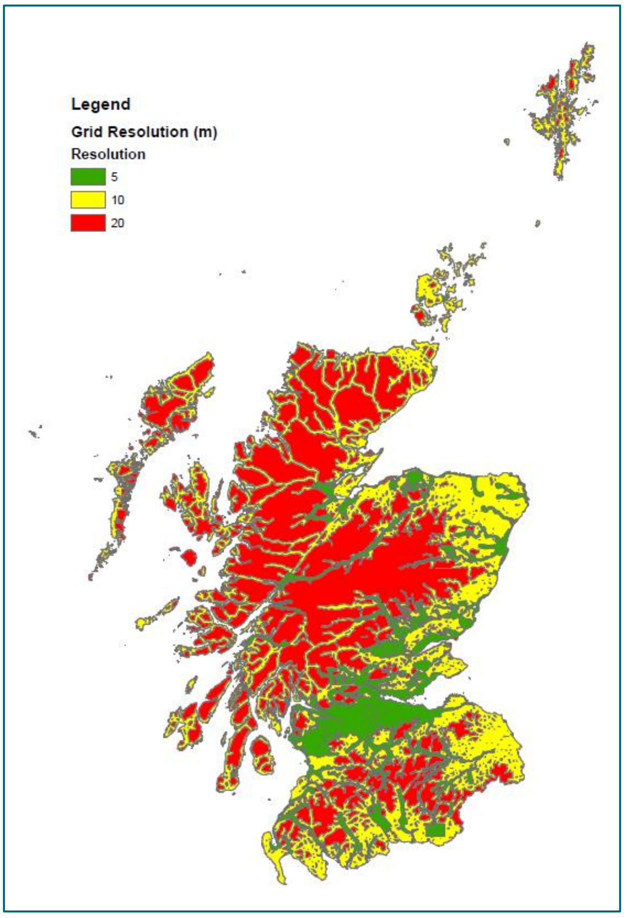

Figure 2: Map showing the hydraulic grid resolution applied across Scotland.

Values from the revised and updated UKCEH flow grid[1] were extracted and used for the upstream inflows. The downstream boundary was assumed as a non-varying level boundary. In the case of the coastal boundary, the Mean High Water Springs level was used. To reflect additional flows from small and un-modelled watercourses entering the system along the

[1] Table 1 of the Appendix provides more information on the UKCEH flow grid.

watercourse, additional point flows were entered at specific and calculated points along the channel.

3.3.4. Structures and defences

The river flood map represents hydraulic structures and defences such as bridges, culverts and flood storage areas where appropriate and possible to do so.

Short culverts, less than 50m in length, were modelled as open channels by manually adjusting the underlying DTM to allow flow to pass through the culvert location. The same methodology was adopted for the representation of bridges. If the culvert was greater than 50m in length it was represented as a full blockage. There were several circumstances where this methodology for culvert representation was unsuitable and, in consultation with local authorities in priority areas, the following alternative options were put into place as appropriate:

- Surface water outlines available at the time of river flood map development (2011-2013) were adopted from SEPA's surface water flooding projects.
- Sewage surcharge values ran in a rapid flood spreading model to route flows across the underlying DTM.
- Outputs from studies which use more sophisticated culvert representation (supplied by local authorities and consultants).

Some structures have been implicitly represented in the models through the DTM. Where data was available formal defences have been explicitly included. Data on the positioning and level of direct defences, namely flood walls and flood embankments, was supplied via the Scottish Flood Defence Asset Database (SFDAD)[2]. As SFDAD is an incomplete dataset and some of the data is not in an appropriate format to be included in national flood mapping, in a number of

[2] Scottish Flood Defence Asset Database Final Report, JBA Consulting for the Scottish Executive, 2007. This is the best national source of formal defence information for Scotland. However, it is an incomplete data set and not always in an appropriate format to be included in the maps.

instances this data was supplemented or superseded using additional data supplied by local authorities or directly by SEPA.

In the defended flood scenarios, this defence data was applied to reflect the presence of defences and level of protection they offered. Where the defences were a raised structure, the DTM was adjusted manually to represent the top of the defence height.

Nine specific flood storage areas (FSAs) were incorporated into the national modelling process (Table 4, Appendix).

Due to the national scale of the project, a simplified approach to representing flood storage areas has been adopted. To account for FSAs, inflows into the model have been adjusted based on a comparison between the hydrograph volume, flood storage volume and the designed throttle flow. Using this method for the inclusion of FSAs, the inflows are reduced to reflect the volume of water being held in the FSA.

3.3.5. Climate Change

Two climate change scenarios were modelled: the 30 year return period and the 200 year period (both with defences). The estimates of future flood flows are based on an assessment of the vulnerability of Scotland's river catchments and coasts to the impacts of climate change (CEH, 2011). The 2080s high emissions scenario, 67th percentile was selected.

This CEH study reported that there is an anticipated spatial variation in the effect of climate change on flows with catchments in areas exposed to Atlantic weather systems likely to experience the largest increase in flood flows. Subsequently a regional approach was adopted for the uplift factors using main river basin areas. A summary of the percentage uplift factors used within each hydrometric area is contained in Table 5 (Appendix).

An assumption on channel capacity was made in that it would remain equal to the pre-climate change median annual flow (QMED). Tidal boundaries within the river flood models used the Mean High Water Springs levels and were not adjusted to account for climate change.

Further information on climate change can be found within the published Future Flood Maps and the accompanying Future Flood Summary guidance document

4. Validation and quality review

A robust validation and review process was undertaken for the river flood map data:

- **Peer contribution** - The Scottish Advisory and Implementation Forum for Flooding (SAIFF) Modelling Appraisal Strategy Group provided peer contribution in developing the approach for river flood mapping. This group includes industry representatives, academia, representation from the Society of Chief Officers of Transportation in Scotland (SCOTS), Scottish Water and Scottish Government.

- **Internal review -** Internal review included:
  - The representation of each domain was reviewed against draft results for the 1 in 10 year and 1 in 1000 year return periods (high and low likelihood events).
  - Measures of model performance have been used to identify where models failed to meet key performance targets, supporting further assessment and improvement of those models, where practical.
  - A high level review of the results at the river basin scale, focussing on the 1 in 10 year and 1 in 200 year return period results.

- **Local authority review** - Local authorities reviewed flood extents for high, medium and low likelihood scenarios. SEPA hosted workshops and drop-in sessions to review the maps in partnership with local authorities and has acted on comments and feedback where there is data available to do so. Local authorities further supported map development by supplying data. This was used by SEPA where the data was in a format consistent with criteria set out to enable integration with the national dataset.

- A comparison was made with the Indicative River and Coastal Flood Map (Scotland) to highlight areas which were considered significantly different. These areas were given further consideration to attempt to understand why there may be differences between them.

- Local studies that had previously been submitted to SEPA.

- High level sense-checks were undertaken to ensure there were no obvious inconsistencies between return periods.

5. Interpretation

The river flood map has been developed using a nationally consistent methodology. It is a tool to help raise public awareness and understanding of flood risk and support flood risk management and land use planning decisions.

The map is of a strategic nature to support flood risk management planning at a community level. It is not appropriate for property level assessment. This is due to the necessary assumptions and inherent uncertainty from using a nationally consistent methodology to provide Scotland-wide flood mapping.

As the national source of flood hazard information in Scotland, the flood map forms a key basis for flood risk management planning and supports the development of the National Flood Risk Assessment and the National and Local Flood Risk Management Plans.

5.1 Assumptions

The methodology was implemented based on a number of key assumptions:

5.1.1. Hydrology

- The updated UKCEH Flow Grid is broadly representative of river flows across Scotland.
- There is no allowance for artificial modifications to flow due to reservoir operation, flow path blockage or dam breaks.

5.1.2. Hydraulics

- The channel capacity for all watercourses approximates to the Median Annual Maximum Flow (QMED).
- Coastal sea level is equal to Mean High Water Springs for all flood events.
- For national scale assessment, in channel hydraulics and channel morphology are not a key factor.

5.1.3. Digital Terrain Model and hydraulic structures

- The Digital Terrain Model (DTM) is a true representation of the ground surface.
- There are no geomorphological changes to the mapped river network or ground surface during flood events or over an extended period.
- Simplified representation of structures is appropriate.

5.2 Confidence

Flood hazard mapping and the assessment of the sources and impacts of flooding is a complex process. Due to assumptions that are necessary to allow us to reflect complex natural processes, there are uncertainties associated with developing any assessment or modelling methodology.

Assumptions may be applied at each stage of the process and from a range of sources. For example, sources of uncertainty in flood hazard mapping include:

- The data going into the assessment such as hydrological inputs.
- The resolution of topographical information.
- The method or model used.
- Future changes e.g. climate change and land use changes.

The consideration of model/map confidence enables us to make informed decisions by providing understanding of the confidence in the data and the final mapped outputs. It also identifies where resources can be focused for further development.

5.2.1. Confidence mapping method

To measure the confidence in the model and its outputs assumptions were recorded from:

- Hydrology (quality of the flow data, i.e. distance from gauged data).
- Topography (LiDAR or NEXTMap and degraded resolution in conjunction with river/floodplain extent).
- Method (including stability of modelling and model assumptions).

Model confidence has been considered in a relatively simple way at the model domain scale which has allowed appropriate confidence classes to be defined for each domain. The approach was developed based on the following evidence:

- Statistical analysis of channel capacity and floodplain flow calculation.
- Analysis of sensitivity in model outputs to uncertainty in key input parameters.
- Comparison of model depth grid outputs with benchmark models for two locations.
- Comparison of flood extent outputs with benchmark models for seven locations.
- Comparison of flood extent outputs with public records.

5.2.2. Presentation of velocities

The presentation of velocity information shows the speed of flood water and the direction in which it is travelling.

The 2D quasi-steady state approach used for the national hazard mapping means that for most areas the fluvial velocity shown is depth averaged velocity at maximum depth rather than maximum velocity. In areas where flood water ponds the velocity may be zero (standing water) and the maps may not show the velocity of water flowing into an area, e.g. over a flood bank. In addition, there may be areas with high velocity but very shallow flow.

Within the post-processed modelled outputs, there are instances where there is high uncertainty in speed data, and ‘data not available’ code values of either 777ms^{-1} or 9999ms^{-1} have been used to flag these locations. Where the flood map has significant misalignments from the mapped watercourse, this has been flagged by setting the speed data to 777ms^{-1} along the watercourse as shown in the OS MasterMap Waterbody layer. Floodplain velocities cannot be obtained from 1D models therefore in areas where the maps have been updated using 1D modelling, a value of 9999ms^{-1} has been used to flag unavailable velocity data. Post processing of the hazard maps for publication involved filling dry islands with an area < 200m^{2}, and in these areas a value of 0.1ms^{-1} was assigned to the velocity. Within the published Flood Maps, locations where data is not available are displayed as grey within the web viewer.

In all the above cases the velocity direction has a ‘no data’ value of -9999 and these areas are not included within the direction dataset.

Within the published maps, the directional component of the river velocity dataset is sampled at a 150m cell resolution and therefore cannot be used to identify detailed flow pathways. The velocity shown within the fluvial hazard maps shows the general speed and direction of flood water over a set distance at the scale limitations set by the published flood maps.

Over time as SEPA makes ongoing developments to the flood maps, velocity information may be added for locations it is not currently displayed.

5.3 Limitations

The river flood map has been produced at the national scale using national datasets and a consistent methodology. This map is a strategic product intended for use at a community scale and should not be used at the individual property level.

Due to the strategic nature of the output and the methodology used, there are limitations associated with the river flood map. Such modelling at the national scale and limitations of the methodology leads to difficulties representing:

- Urban areas where there is a complex surface drainage system such as heavily culverted areas.
- Very steep and upland catchments.
- Areas with low resolution DTM such as NEXTMap.
- Small or narrow river channels where even high resolution models cannot accurately identify the channel.
- Hydraulic structures and flood defence assets.

Every effort has been made to create a river flood map that reflects the knowledge and information available. Where this included information for a specific return period this was merged with our modelled flood outline. As we develop and improve our data, methodologies and techniques the maps will be reviewed and updated. SEPA will continue to work with responsible authorities and partner organisations to improve our knowledge, understanding and the representation of flooding across Scotland.

5.4 Caveats

- The river flood map does not show flooding from very small watercourses i.e. where the area draining to the river is less than $3km^2$.
- The flood maps are indicative and of a strategic nature. It is inappropriate for these flood maps to be used to assess flood risk to an individual property.

5.5 Small watercourses

The river flood map shows flooding from rivers with catchment areas greater than $3km^2$. Whilst the surface water and small watercourses flood map (referred to hereafter as the surface water flood map), provides indicative flood hazard information from both surface water flooding and from small watercourses which have a catchment area smaller than $10km^2$. Therefore, watercourses with catchment areas between $3\text{-}10km^2$ will be represented in both the river and surface water flood maps. Different modelling approaches and input datasets were used to develop each flood map which means there may be differences in the outputs. Consequently, it is recommended that users consult both the river and surface water flood maps to understand flood risk from small watercourses. Further information on the surface water flood map can be found in the Surface Water and Small Watercourses Summary.

6. Data availability

The published flood hazard maps as shown on the SEPA website are available for third party use under Open Government Licence. The datasets and supporting documentation are available for download on our Data Publication page. Please note that the availability of these datasets under Open Government Licence, does not provide access to the data or models underpinning the SEPA Flood Maps.

Appendix

Table 1: Data used as an input to the river flood map.

Data	Description	How the data was used	Quality check
UK Centre for Ecology and Hydrology (UKCEH) Flow Grid	A national dataset giving an estimated design flows at 50m intervals on all watercourses with a catchment area >0.5km^2. It is produced via simplified automation based on industry standard methodology.	• As a licensed product of UKCEH to inform the model inflow for all model return periods. • It has been updated in some areas where observed data could be applied to update the flows.	
HiFlows UK/National Peak Flow Archive	The HiFlows-UK is a flood peak database for river flow gauging stations across the UK. It contains around 1000 river flow gauging stations with supporting information to allow hydrologists to make informed judgments on the use of the data. Data can be used with the statistical flood estimation methods set out in the Flood Estimation Handbook (FEH), which is the basis for most current flood estimation in the United Kingdom. https://nrfa.ceh.ac.uk/peak-flow-data	• Derived statistical peak flows were used to revise UKCEH flow grid where necessary.	• Screened to provide suitable AMAX (Annual Maxima) data for flow frequency analysis at individual sites. • Catchments where single site analysis was undertaken are deemed to have higher confidence in flow estimates than the UKCEH flow grid.

Data	Description	How the data was used	Quality check
Gauged data	The systematic, quality controlled time series of water level measurements and calculated flow data at a river gauging station. Gauging stations are normally maintained by the relevant hydrometric authority (SEPA in Scotland).	• To update the UKCEH flow grid. • Used to either replace the HiFlows data as it was considered more accurate or to fill in missing years of data from the HiFlows dataset.	
Coastal boundaries	Mean High Water Springs (MHWS) for all ports around Scotland extracted from Admiralty Tide Tables 2012. Volume 1. United Kingdom and Ireland (including European Channel Ports).	• Used as tidal boundaries for the hydraulic model.	
Digital Terrain Model (DTM)	A composite DTM comprising LiDAR and Intermap's NEXTMap DTM with a horizontal resolution of 5m.	• Used as the ground model basis for the river flood models.	• A mask layer was provided by SEPA to indicate the LiDAR data coverage within the composite DTM. • LiDAR data was classified as having higher confidence than NEXTMap DTM.
Hydraulic structures	Bridge data supplied through SEPA's Morphology Pressures Database (MPD) and from local authorities. Culvert data supplied	• To inform the representation of the structure in the hydraulic model where the water flow	

Data	Description	How the data was used	Quality check
	through MPD and local authorities and a separate dataset for the Glasgow area.	path has been blocked in the ground model by bridge decks. • Dimension of culverts used to estimate the culvert capacity. • Standard of protection (SoP) provides the complementary information on the area of protection.	
Scottish Flood Defence Asset Database (SFDAD)	SFDAD identifies formal raised defences in coastal areas and along tidal rivers. It supplies information on the defence heights or the standard of protection (SOP) offered by the defences.	• To check levels of defences in the DTM and remove flooding behind defences from those extents with a return period lower than the standard of protection of the structure.	
Indicative River and Coastal Flood Map (Scotland)	Until the publication of the flood hazard map, this is the national source of flood risk information (2006-2013). The Flood Map shows the possible extent of river and coastal flooding. It was an important strategic tool for managing flood risk, primarily focusing on the 200-year flood event (an	• Used as a comparator for model outputs.	

Data	Description	How the data was used	Quality check
	event with a 0.5% chance of occurring in any given year) in line with Scottish Planning Policy (SPP).		
Historical flood records	Historical flood records held by SEPA.	• The modelled present-day events were compared against the historical records of pluvial flooding during model validation.	
Ordnance Survey MasterMap Topography layer	This is a nationally maintained dataset that provides details of addressing, height and imagery, backdrop, detailed networks and addresses and locations. Within the scope of this project, OS MasterMap was used for various reasons including identifying locations of airports and runways.	• To inform the land use. • Land use type has been used to assign roughness values (Manning's) to be applied in the hydraulic models. • The water theme within OS MasterMap Topography Layer has been extracted to inform the water bodies in the model area.	• Water features within the model domain were aggregated into the final model flood extent, ensuring consistency with background mapping.
Centre for Ecology and Hydrology 2011 study on peak river flows and	The CEH 2011 study produced probabilistic estimates for change in peak river flows for river basins across Scotland for high, medium and low emissions scenarios for	• Provided climate projection information for the 2080s, high emissions scenario 67th percentile	• No further validation of the climate change information from UKCP09 was undertaken as this is a previously

Data	Description	How the data was used	Quality check
climate change.	2020s, 2050s and 2080s time horizons. This uses the land projections for precipitation and temperature from the UK Climate projections 2009 (UKCP09) projections. https://webarchive.nationalarchives.gov.uk/20181204111018/http://ukclimateprojections-ukcp09.metoffice.gov.uk/ CEH 2011 study reference. Kay, A., Crooks, S., Davies, H., & Reynard, N. (2011). An assessment of the vulnerability of Scotland's river catchments and coasts to the impacts of climate change. Wallingford: Centre for Ecology and Hydrology.	probability 50-yr return period.	published dataset.

Table 2: List of return periods and descriptions.

Scenario no.	Description
1	1 in 5 year-defended
2	1 in 10 year-defended
3	1 in 30 year-defended
4	1 in 30 year-defended: climate change 2080H
5	1 in 50 year-defended
6	1 in 100 year-defended
7	1 in 200 year-defended
8	1 in 200 year-defended: climate change 2080H
9	1 in 1000 year-undefended
10	1 in 30 year-undefended
11	1 in 100 year-undefended
12	1 in 200 year-undefended
13	sensitivity-10yr-defended+20%flow
14	sensitivity-200yr-defended+20%flow
15	sensitivity-1000yr-undefended+20%flow
16	sensitivity-10yr-defended +40% roughness
17	sensitivity-200yr-defended+40% roughness
18	sensitivity-10yr-defended-high n blockages
19	sensitivity-1000yr-undefended-high n blockages

Table 3: Extent of grid coverage.

5m grid	10m grid	20m grid
All areas within 1000m of a public road in areas that are covered by LiDAR and are below 350mAOD	All areas within 1000m of a public road which are not covered by LiDAR and are below 350mAOD	All other areas
10,085 km^2	**30,852km^2**	**39,036km^2**

Table 4: Flood Storage Areas (FSAs) incorporated into the river model.

Flood Storage Area Name	Watercourse	Description	FSA Volume (m^3)	Throttle Flow (m^{3}s^{-1})
Blackhouse	Earn Water	FSA to the south of Glasgow outskirts at Blackhouse	810,000	8
Broxden Burn	Broxden Burn	FSA in Broxden attenuating flow as it conveys through Perth towards the River Tay	29,600	0.87
Cairneyhill FPS 1982	Torry Burn	FSA to the west of Cairneyhill	24,537	1.96
Chapelton Storage area	Burn of Mosset	FSA in Chapelton to the south of the town of Forres	3,500,000	8.5
Gadloch	Park Burn	FSA in High Gallowhill to the east of Glasgow and at the west of Kirkintilloch *(Note: long culvert represented as FSA).*	1E+14	1.46
Kirkland	White Cart Water	FSA upstream of Glasgow outskirts to the east of Eaglesham	1,080,000	33

Flood Storage Area Name	Watercourse	Description	FSA Volume (m^3)	Throttle Flow (m^3s^{-1})
Kittoch	White Cart Water	FSA present at Carnbooth, east of Clarkston in Glasgow	670,000	8
Lhanbryde Flood Alleviation Scheme 2004	Longhill Burn	FSA just north of Lhanbryde	140,000	2.4
Linlithgow FPS	Mains Burn	FSA to the south of Linlithgow	6,060	1.45

Table 5: Summary of the percentage uplifts used to estimate the potential effect of climate change on peak flood flows within the river flood hazard map climate change scenarios. High emissions scenario for the 2080s from the CEH 2011 study (Kay et al. 2011) study.

River basin region	Hydrometric Area	% change in flood peak flow (2080s High emissions 67% percentile used for all event probabilities)
North Highland	1, 2, 3, 4, 5, 6, 7, 8[3]	37
North East	9, 10, 11, 12, 13 (northern)	24
Tay	13 (southern),14,15,16	35
Forth	17,18,19,20,21 (coastal)	40
Tweed	21	33
Orkney and Shetland	107, 108	41
West Highland	93, 94, 95, 105, 106	56
Argyll	87, 88, 89, 90, 91, 92, 104 (Kintyre),105	56
Clyde	82, 83, 84, 85, 86, 104 (Arran)	44
Solway	77, 78, 79, 80, 81	44

[3] HA008 was incorrectly identified as being in the North Highland river basin region rather than the North East region for application of the climate change uplifts during the modelling process. A 37% uplift has been applied within the river flood hazard map climate change scenarios but the uplift for North East Scotland from the CEH study (Kay et al. 2011) for the 2080s High Emissions 67th percentile is 24%. Analysis indicated that this made a limited difference to the number of properties likely at risk.

For information on accessing this document in an alternative format or language, please contact SEPA by emailing equalities@sepa.org.uk

If you are a user of British Sign Language (BSL), the Contact Scotland BSL service gives you access to an online interpreter, enabling you to communicate with us using sign language: contactscotland-bsl.org/