Scottish Environment Protection Agency
Buidheann Dìon Àrainneachd na h-Alba

For the future of our environment

Surface Water and Small Watercourses 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 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 2070 - high emissions	Medium	200 year

To produce the flood hazard maps SEPA has developed datasets and methodologies for river, coastal and surface water flooding.

This summary provides information on how we developed our surface water and small watercourses flood hazard map (referred to as the surface water flood map hereafter), 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 an evolving 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 surface water 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.
- 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 surface water flood map for Scotland. The map provides indicative flood hazard information and identifies communities at risk from surface water flooding and from small watercourses with a catchment area smaller than $10km^2$. For information on the representation of small watercourses in the flood maps see Section 5.1. The mapping does not show flood hazard associated with sewer flooding.

3.2 Data

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

3.3 Methodology

The surface water flood map was developed at a 2m spatial resolution using a two-dimensional (2D) flood modelling method applied nationally across Scotland.

The mapping provides flood depths, velocities, extents and in turn a hazard value to estimate impacts on people and properties for the nine present day scenarios and eight climate change scenarios modelled (listed in Table B and Table C, Appendix).

3.3.1. Model domains

To undertake hydraulic modelling nationally, the country was split into 1,153 catchment-based model domains. These domains were used to define each of the areas that models were run for. They were each then buffered by $1km^2$ to produce a set of overlapping model domains ensuring there were no gaps between models.

3.3.2. Ground model

The underlying ground model is made up of a national-scale composite Digital Terrain Model (DTM) consisting of Light Detection and Ranging (LiDAR) and photogrammetry data from 25 data sources. Data sources were prioritised using more detailed resolutions and more recent data, where possible. First the topographic data was resampled to a 2m spatial resolution. Then blending between data sources was undertaken to smooth potential changes in elevation at the boundaries between datasets. Identified holes or spikes in elevation in the DTM were addressed by several methods, including by raising or lowering the ground elevations within the hydraulic model to a specified height to better reflect the topography.

Figure 1 below shows where different types of topographic data were used within the modelling.

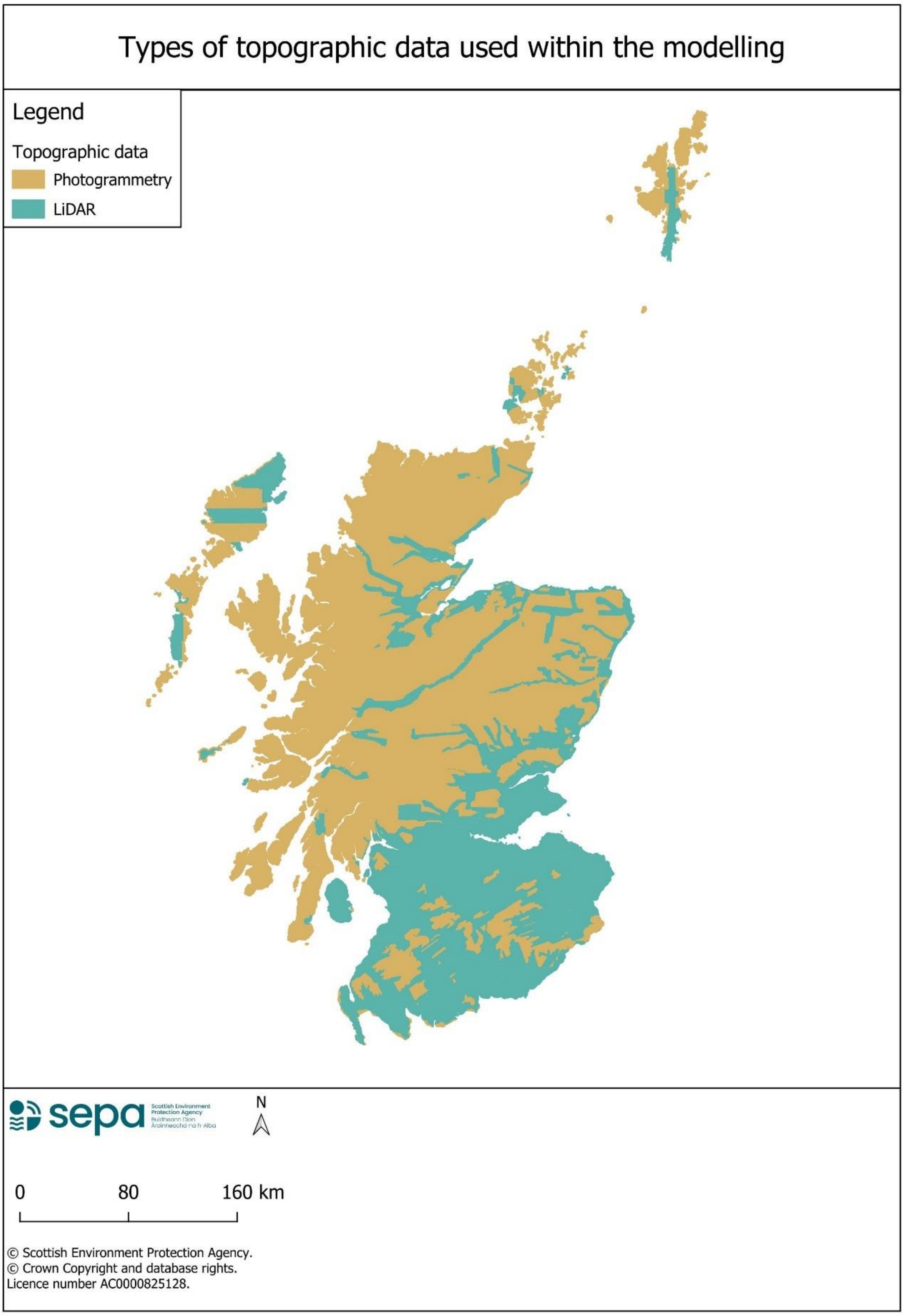

Figure 1: Types of topographic data used within the modelling.

3.3.3. Building topography representation

Buildings can have a significant influence on pathways for surface water flooding. Ground elevations in the DTM were flattened within the building footprints of defined buildings with an area of at least 2m^2 and then raised by 0.3m from the bare earth DTM to represent the level at which flooding of buildings could occur.

When ‘flattening’ the terrain, an algorithm was used to ensure that footprints were not cut into the ground level even on very steep slopes. This algorithm is informed by statistics calculated on the ground elevations in the DTM within the building footprint. Whilst a 0.3m upstand has always been added, on sloping ground these algorithms can mean that the resulting upstand level for the building can be greater than 0.3m relative to the original ground elevation values at downslope cells and less than 0.3m at upslope cells.

The resulting “flat building upstand” can deflect surface water flow and allows water to flow over the upstand when the depth of water exceeds the height of the upstand thereby simulating water entering buildings. Figure 2 shows example cross-sections through raised building upstands on flat and sloping ground.

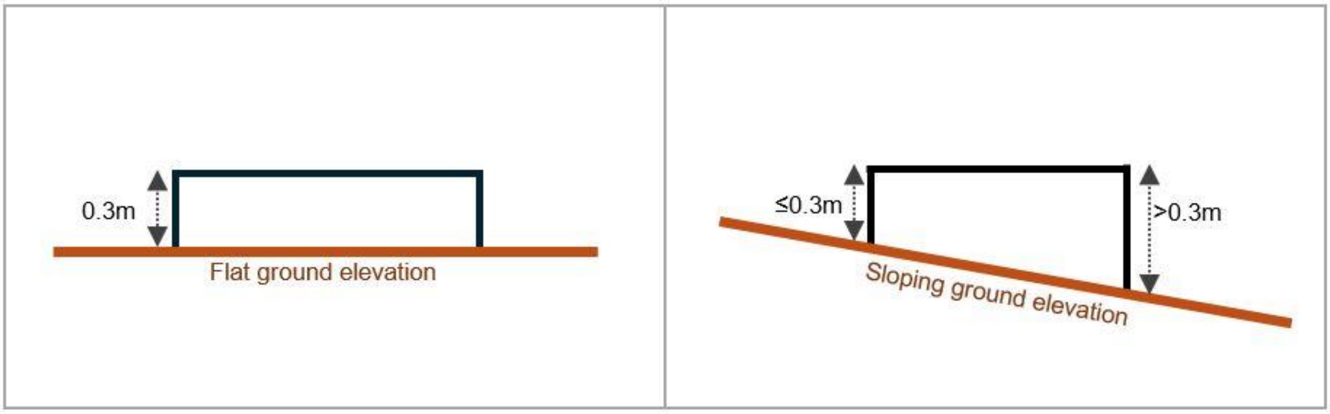

Figure 2: Cross-section profiles demonstrating how building upstands have been applied.

3.3.4. Rainfall

Rainfall depth estimates were provided by the UK Centre for Ecology and Hydrology (UKCEH) and were derived from the Flood Estimation Handbook (FEH) Depth-Duration-Frequency (DDF) model, FEH22. The rainfall depth estimates were supplied for the summer season on a 1km spatially varying grid for three storm durations (the 1-, 6- and 12-hour storm), and for all return periods modelled. See Section 3.3.8. Climate Change for details of how the impact of climate change on rainfall was considered.

3.3.5. Losses

The rainfall data was routed into the hydraulic model with adjustments made to account for losses to the drainage network in impervious areas and losses from infiltration in pervious areas.

Land was defined as pervious or impervious at a 2m spatial resolution based on Ordnance Survey MasterMap data. Where the centre of a grid square was designated with a manmade land use (including buildings, paved roads and other hardstanding areas), the square was classed as impervious. All other squares were classed as pervious.

Adjustments for losses in pervious areas

In pervious areas, the rural Revitalised Flood Hydrograph (ReFH) v2.3 loss model was adopted. The loss model translated the FEH22 design rainfall depths into net rainfall hyetographs, removing infiltration losses predicted based on the initial soil moisture content representative of the summer season and the catchment characteristics. The resulting net hyetographs were provided by Wallingford HydroSolutions on a 1km spatially varying grid and then used as an input to the hydraulic models with no further losses applied.

Adjustments for losses in impervious areas

In impervious areas, a modified version of the ReFH v2.3 urban loss model was used which assumed 100% runoff, i.e. that there were no rainfall losses due to infiltration. Then to account for losses to the surface water drainage network, within the hydraulic model a nationally consistent drainage rate of 15mm/hr was applied to all impervious model cells.

3.3.6. Drainage sump

The purpose of the flood map is to show predicted hazard from surface water and small watercourses. Therefore, to remove the fluvial influence, a drainage sump has been applied within the hydraulic model to drain water from major watercourses and large water bodies with an upstream catchment greater than $10km^2$.

Water was only drained from the model simulation once it reached the centreline of rivers meeting the drainage sump criteria so in wider watercourses, flooding outputs may be observed in channel (as seen in Figure 3). Then a 'data not available' value was stamped on all water bodies since they have not been explicitly modelled.

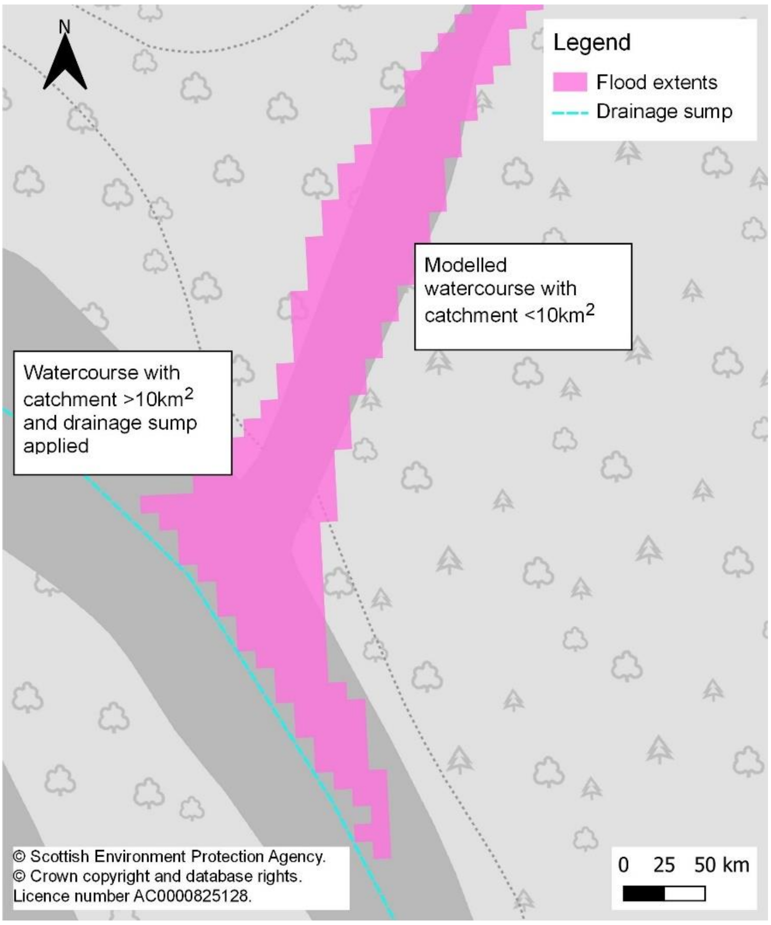

Figure 3: Example of the drainage sump applied on a watercourse.

3.3.7. Structures

Over 51,000 structures have been included nationally within the modelling process to remove false blockages and permit realistic flow pathways via culverts, tunnels and bridges, as supported by evidence from available asset databases. A list of contributing asset datasets is included in Table A (Appendix).

The structures incorporated were typically represented by either a one-dimensional (1D) culvert feature within the hydraulic modelling or by manually amending the underlying DTM to allow flow to pass through the structure. The approach selected for representing each feature was based on the structure's dimensions, its location and modeller judgement (Table 1).

Table 1: Criteria for selecting the method for representing structures.

Location	Criteria	Approach
Watercourse	Width of flow route <10m Or width >10m but length of structure >5x width Or if structure passes beneath buildings	Culvert
Watercourse	Width of flood route >10m	DTM cut
Non-watercourse	Length of flow route >8m Or if structure passes beneath buildings	Culvert
Non-watercourse	Length of flow route <8m	DTM cut
Watercourse/ non-watercourse	Significant flow path across the deck of a bridge	Bridge deck reinstated

Where there was evidence of a significant flow path across a bridge, the bridge deck was reinstated by raising the model cells within the DTM to maintain the flow path. Culverts were then added to permit flow at ground level beneath the structure's deck. Complex infrastructure flyovers were not reinstated.

Walls and embankments were also explicitly represented by raising the model cells in the DTM. This was only undertaken at 116 locations across the country where their influence on flow pathways was considered of critical importance. Whilst not explicitly represented in the flood map, other walls and embankments may have been captured in the underlying DTM.

Defences

Although some defences may have been captured in the DTM, flood defences have not generally been explicitly represented in the surface water flood map. However, following stakeholder and SEPA review, exceptions have been made to represent the following schemes:

- Stonehaven Flood Protection Scheme
- Smithton and Culloden Flood Alleviation Scheme
- Knowle Burn Flood Protection Scheme, Dumbarton

Whilst included, these schemes have not been represented in detail, reflecting the national scale of the flood mapping. Where the defences were a raised structure, the DTM was manually adjusted to represent the height of the structure in a simplified way. Whilst to represent flood storage areas, the DTM was manually adjusted to lower the ground level.

3.3.8. Climate Change

Eight climate change scenarios were modelled, four each for the 30 year return period and the 200 year return period. Table C (Appendix) outlines the scenarios modelled.

Rainfall intensity uplifts from the FUTURE-DRAINAGE project were used. The FUTURE-DRAINAGE project used analysis of the UK Climate Projections (UKCP18) high resolution (UKCP Local) projections for Representative Concentration Pathway 8.5 (RCP8.5)[1],[2].

[1] Fowler, H., *et al*., 2021. *FUTURE-DRAINAGE: Ensemble climate change rainfall estimates for sustainable drainage*. Newcastle University. Available at: https://www.ukclimateresilience.org/projects/future-drainage-ensemble-climate-change-rainfall-estimates-for-sustainable-drainage/.

[2] Dale, M., *et al*., 2021. *Guidance for water and sewerage companies and Flood Risk Management Authorities: Recommended uplifts for applying to design storms*. Available at: https://artefacts.ceda.ac.uk/badc_datadocs/future-drainage/FUTURE_DRAINAGE_Guidance_for_applying_rainfall_uplifts.pdf

Mean rainfall intensity uplift values within each UKCP18 river basin region were calculated for:

- each storm duration
- return period: 30 year and 100 year. (The 100 year uplift was used for the 200 year return period).
- time horizon: 2050 and 2070
- central and high estimates.

These were applied to present-day rainfall depth estimates. Uplift factors for Orkney were applied to Shetland, since uplifts from FUTURE-DRAINAGE are not available for Shetland. The percentage uplifts used can be seen in Table D - Table I (Appendix).

The future surface water flood map reflects the outputs for the 200 year 2070 central estimate scenario. For this scenario uplifts for the central estimate (50th percentile) for the 2070[3] time horizon and for the 100 year return period were applied to the 200 year present-day rainfall depths. See Table C, Appendix. Further information on climate change can be found within the published Future Flood Maps and the accompanying Future Flood Maps Summary.

3.3.9. Emulation

An emulation tool was developed that allows flood mapping outputs (depth, hazard, velocity) for unmodelled scenarios to be produced using linear interpolation based on rainfall depth, from the results of scenarios that were generated from hydraulic modelling.

Using an emulation approach generates outputs significantly faster than setting up and running large numbers of hydraulic models. This approach offers an efficient way to potentially generate additional scenarios in the future without the need for further hydraulic modelling.

Checks on how emulation performed for test areas using several measures of performance indicated that at a high level there were generally small differences in hazard metrics produced by emulation compared to those produced by hydraulic modelling.

[3] 2070 is the central year for the 2061-2080 time period, which is the latest period available in the UKCP Local projections used to develop the rainfall uplifts.

Emulation was applied to derive the surface water flood map for the 30 year and 200 year climate change scenarios for the 2050 time horizon.

3.3.10. Post-processing

Generation of the Storm Mosaic

For each scenario, three storm durations were independently modelled, reflecting the 1-, 6- and 12-hour storms. A “worst-case” storm mosaic was then generated by merging the outputs so that for each model cell, the outputs from the modelled storm duration with the maximum predicted hazard value was reflected in the resulting storm mosaic (as shown in Figure 4). The storm mosaic outputs are shown in the published surface water flood map.

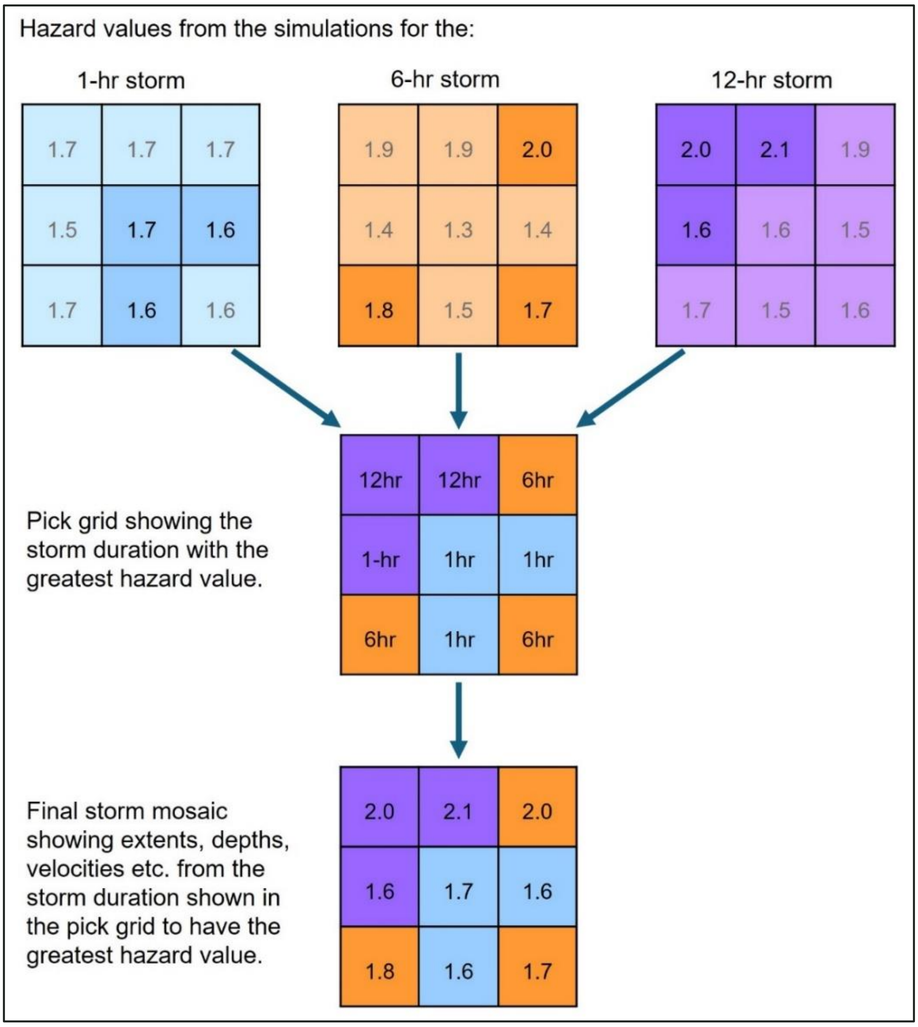

Figure 4: The "pick by hazard" method used to select outputs for each model cell from the three modelled storm durations to produce the storm mosaic.

Dataset post-processing

Based on common modelling post-processing practice we have processed the national model outputs as outlined below:

- Removed flooded areas with a very low hazard rating below 0.5625. For example, this is the equivalent of a time coincident depth of 0.1m with a velocity of over 0.1m/s, or a time coincident depth of 0.05m with a velocity of over 0.7m/s.
- Removed areas of flooding with a total area less than 48m^2.
- Non-modelled water bodies (lochs and small ponds) meeting set criteria have been included within the flood map via a national processing methodology applied after the modelling was undertaken. This process included these features in the output data and applied a ’data not available’ value of 777 to raster outputs.
- The mapping has been clipped to the Mean High Water Springs tidal limit at the coast.

Presentation of velocities

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

Flow direction at maximum velocity has been generated and aggregated to an 8m grid resolution. Each velocity direction point represents the resampled flow direction at maximum velocity within a 64m^2 area, rounded to their nearest cardinal or intercardinal direction (north, northeast, east, southeast, south, southwest, west and northwest).

Velocity direction vectors can extend beyond the relevant flood extent due to the coarser aggregation of the velocity vector points. The direction data should therefore only be used to understand flow direction, it cannot be used to identify spatial extent of hazard or detailed flow pathways.

4. Validation and quality review

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

- **Internal review** – The internal review included:
    - Manual reviews at locations identified by automated review tools as having extreme depth or velocity values, maximum depths occurring within 5% of the simulation end time, culverts with significant peak flows or which crossed model domains and locations where the default roughness coefficient was applied.
    - Manual sense checks of the mapping outputs to check for false blockages, DTM issues and any other issues or irregularities.
    - Manual reviews were also undertaken in locations of edits requested during the stakeholder and internal review. These checks assessed the impacts of the edits on the mapping outputs and identified any new issues arising from the updates.
    - An automated review to ensure flood depths generally increased with return period.
    - In order to assess the performance of the models during model validation, the flood extents were compared against the locations of historical surface water flooding recorded within flood event databases held by SEPA and Transport Scotland.

- **Stakeholder review:** A wide range of stakeholders including local authorities and national partner organisations reviewed the draft flood mapping on a dedicated online review portal (Figure 5). Stakeholders provided feedback directly in the review portal and during workshops hosted by SEPA. Stakeholder feedback was then reviewed and prioritised with changes applied to the final mapping where requested and feasible to incorporate.

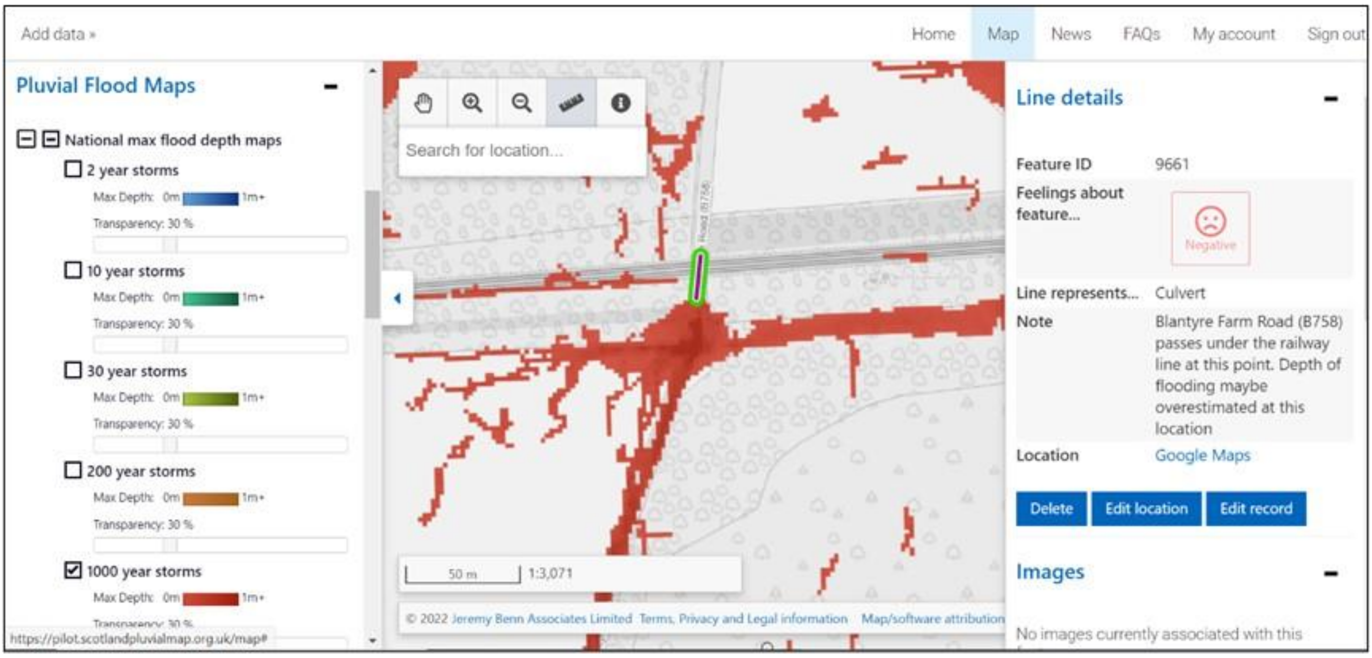

Figure 5: Online review portal used to collate feedback on the draft mapping.

5. Interpretation

The surface water 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 surface water 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 Small watercourses

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 $10km^2$. Whilst SEPA's river (fluvial) flood map shows flooding from rivers with catchment areas greater than $3km^2$. 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 river flood map can be found in the River Flooding Summary.

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, particularly at a national level.

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 input data going into the assessment, such as design rainfall;
- The resolution and accuracy 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.

Confidence mapping method

Confidence metrics were defined on a 1km grid spatial scale, taking into account:

- Rainfall depth uncertainty based on distance to rainfall gauge used in the creation of the FEH22 Depth Duration Frequency model.
- DTM data source, dataset age and any remaining quality issues.
- DTM slope.
- Number of hydraulic structures in the model.
- Validation and calibration performance, including comparison against recorded events.
- The level of detail of the modelling and mapping.

Each 1km grid cell has been assigned a scale of suitability classification based on the confidence in the modelling at that location considering the above components. The suitability class indicates what the data is suitable for and how likely it is to be reliable for a local area. Most of the data has been assessed as likely to be reliable for a local area. However, the suitability varies spatially mainly influenced by the input data. For example, generally there is higher confidence in areas that are close to FEH22 rainfall gauges, where recent LiDAR data without unresolved DTM issues was used, with few hydraulic structures present and where modelled predictions compare well with observed events. Whilst there is lower confidence in the mapping in areas with DTM issues or photogrammetry data and large distances from FEH22 rainfall gauges for example.

Other uncertainties are not considered within the confidence metric assessment, though some are described in Section 5.3.

5.3 Strengths and Limitations of the Flood Map

5.3.1. Strengths

The strengths of the surface water flood map include:

- A nationally consistent methodology used to develop the flood mapping at a 2m resolution.
- Use of the latest and highest resolution topographic data available at the time of development within the underlying ground model.
- Use of the latest rainfall data (FEH22) and climate change projections (UKCP18).
- Modelling for a wide range of return periods ranging from the 2 year to the 10,000 year as well as eight climate change scenarios.
- The independent modelling of three storm durations to create a worst-case storm mosaic.
- Use of the latest modelling techniques and tools (for example, emulation).
- The use of a drainage sump to remove the fluvial influence from large watercourses from the end mapping.
- The addition of >51,000 features to remove the influence of false blockages.
- Incorporation of feedback on the draft mapping from a wide range of stakeholders.

We regard the flood mapping as the best available source of national information on surface water flooding.

5.3.2. Limitations and assumptions

Whilst representing the best available information on surface water flooding at a national level, the flood map has been produced at a national scale using datasets and methodologies appropriate to this scale of flood modelling. This map is a strategic product intended for use at a community scale and should not be used at an individual property level.

The key limitations and assumptions of the strategic modelling approach taken for the surface water mapping are as follows:

- Rainfall inputs were based on three storm durations, reflecting the 1-, 6- and 12- hour storm. Whilst the storm durations were selected to minimise the risk of underestimating flood hazard, it is possible that greater flooding impacts could arise for storms of shorter or longer durations than those modelled.

- Rainfall losses to the surface water drainage system will vary locally based on the drainage rate, age and capacity of the drainage system. Applying a nationally consistent drainage rate to all impermeable model cells may therefore under or over-estimate rainfall losses occurring in reality. Whilst the mapping represents flooding caused by surface water exceeding drainage capacity, it does not account for water already within the drainage system nor show surcharging of manholes.

- The ground models used include the latest and highest quality topographic information available at the time the map was developed. Each topographic data source used however contains inherent limitations and developments, e.g. new housing since the topography was flown will not be reflected in the flood mapping.

- The national methodology assumed a consistent building threshold of 0.3m and does not account for variation in threshold heights of individual properties.

- Over 51,000 hydraulic structures were represented and prioritised for inclusion based on the potential impact of the false blockages on receptors. However, inevitably some false blockages in the mapping will remain. Furthermore, for structures not included in the available asset databases, dimensions were applied based on a best estimate from available imagery. Where dimensions could not be ascertained, nationally consistent default dimensions were applied.

- Joint probability of surface water flooding with other flood sources is not represented in the flood mapping. Consequently, a flood event comprising multiple flood sources (e.g. a heavy rain event coinciding with high tide and coastal surge), may experience more significant flood hazard than predicted solely in the surface water flood mapping.

5.4 Caveats

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.

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 A: Data used as an input to the surface water mapping.

Data	Description	How the data was used	Quality check
Rainfall Frequency Grids	Rainfall depth estimates derived from the Flood Estimation Handbook (FEH) 22 Depth-Duration-Frequency (DDF) model. Supplied on 1km resolution grids for each of the return periods and storm durations modelled.	Used to develop the national models. Used as design rainfall for impervious model cells and as an input to the loss model.	Rainfall values were provided by the UK Centre for Ecology and Hydrology (UKCEH). To ensure national coverage, checks were undertaken for gaps and where identified, donor data from adjacent grid cells were used as appropriate.
FUTURE-DRAINAGE climate change rainfall uplifts	Climate change rainfall depth uplift factors derived from analysis undertaken by Newcastle University of the UKCP18 high resolution projections for RCP8.5.	Mean uplift values were calculated by SEPA for each UKCP18 river basin region from the 5km grid FUTURE DRAINAGE data and used to model the climate change scenarios.	No additional quality checks carried out on these data.
ReFH2 Derived Losses Grids v2.3	Rural and urban ReFH2 v2.3 net rainfall grids supplied by Wallingford HydroSolutions on 1km resolution grids.	Used as the net rainfall input to the hydraulic model to define pervious losses and as the design rainfall input in impervious areas.	The loss grids were provided by Wallingford HydroSolutions. To ensure national coverage, checks were undertaken for gaps and where identified, donor data from adjacent grid cells

Data	Description	How the data was used	Quality check
			were used as appropriate.
Digital Terrain Model (DTM)	25 input data sources of topographic information including LiDAR and photogrammetry were used to develop the national-scale composite DTM with a horizontal resolution of 2m.	Used as the ground model for the surface water flood models.	During development of the national composite, DTM holes were identified and filled, and blending was undertaken at the boundaries of each DTM data source to reduce occurrence of jumps in ground level. Other DTM issues were also recorded either to be resolved where possible or reflected in the confidence metrics. Manual and automatic checks to ensure false blockages were removed from river channels, such as at bridge and culvert locations.
Ordnance Survey MasterMap Topography layer	This is a nationally maintained dataset that provides details of geographic features such as roads, properties and topography.	• For defining model cells as pervious or impervious based on land use for applying rainfall losses. • Land use type was also used to assign roughness values (Manning’s n) to be	This is a published dataset from Ordnance Survey and therefore checks on this dataset were not undertaken.

Data	Description	How the data was used	Quality check
		applied in the hydraulic models. • To identify rivers and water bodies to apply the drainage sump. • Used to identify buildings in order to raise DTM heights by 0.3m. • Used to identify possible false blockages in the DTM.	
Ordnance Survey MasterMap Water Network Layer	This is a nationally maintained dataset that provides a centre line and details of watercourses.	• Used to define the river network centreline and identify reaches with a catchment area >10km^2 on which to apply the drainage sump. • Used to identify possible false blockages in the DTM.	This is a published dataset from Ordnance Survey, therefore systematic additional checks were not undertaken. Where differences to local understanding of watercourse location were identified during the review process changes were made where appropriate.
Hydraulic structure databases	Information on structures supplied through SEPA's Morphology Pressures Database and asset databases from Local Authorities, Transport Scotland and Scottish Canals.	Used as reference data to inform the representation of structures such as bridges and culverts.	No further quality checks required by SEPA to the information supplied by local authorities.

Data	Description	How the data was used	Quality check
Topographic surveys	Topographic surveys commissioned by SEPA for the Brothie Burn, Tyndrum, Gargunnock and the Burn of Newton and Mill Lade, Wick.	Used as reference data to inform the representation of structures such as bridges and culverts.	Data quality checks undertaken at time of survey. No further checks carried out during the development of the flood map.
2Di Aberdeen model spatial outputs	Scottish Water's Aberdeen 2Di detailed surface water hydraulic model.	Used for validating the modelling in Aberdeen and for calibrating the nationally consistent drainage rate.	No additional checks carried out on these data.
Historical flood records	Historical flood records contained in Transport Scotland's IRIS database and SEPA's Observed Flood Event Database.	The modelled present-day events were compared against the historical records of pluvial flooding during model validation.	A 10m buffer was applied to each observed flood event location to manage uncertainties in the recorded location.

Table B: List of return periods for which surface water mapping outputs were derived.

	Return Period	Extents	Depth	Hazard	Velocity	Velocity Direction
Present day scenarios	2	✓	✓	✓	✓	✓
	5	✓	✓	✓	✓	✓
	10	✓	✓	✓	✓	✓
	30	✓	✓	✓	✓	✓
	50	✓	✓	✓	✓	✓
	100	✓	✓	✓	✓	✓
	200	✓	✓	✓	✓	✓
	1000	✓	✓	✓	✓	✓
	10,000	✓	✓	✓	✓	✓
Climate change scenarios[4]	30_2050C	✓	✓	✓	✓	✗
	30_2050H	✓	✓	✓	✓	✗
	30_2070C	✓	✓	✓	✓	✓
	30_2070H	✓	✓	✓	✓	✓
	200_2050C	✓	✓	✓	✓	✗
	200_2050H	✓	✓	✓	✓	✗
	200_2070C	✓	✓	✓	✓	✓
	200_2070H	✓	✓	✓	✓	✓

[4] See Table C of the Appendix for a further description of the climate change scenarios modelled.

Table C: Description of the climate change scenarios modelled.

Scenario	Emissions scenario	Return period	Time horizon	Percentile	Modelled / emulated
30_2050C	RCP 8.5	30	2050	Central (50th Percentile)	Emulated
30_2050H	RCP 8.5	30	2050	High (95th Percentile)	Emulated
30_2070C	RCP 8.5	30	2070	Central (50th Percentile)	Modelled
30_2070H	RCP 8.5	30	2070	High (95th Percentile)	Modelled
200_2050C	RCP 8.5	200	2050	Central (50th Percentile)	Emulated
200_2050H	RCP 8.5	200	2050	High (95th Percentile)	Emulated
200_2070C	RCP 8.5	200	2070	Central (50th Percentile)	Modelled
200_2070H	RCP 8.5	200	2070	High (95th Percentile)	Modelled

Summary of the percentage uplifts used to estimate the potential effect of climate change on rainfall

Table D to Table I include mean uplifts by river basin region and storm duration based on the uplifts from the FUTURE-DRAINAGE study[5]. The 100 year uplift was applied to the 200 year return period in the modelling. Central refers to the 50th percentile and High refers to the 95th percentile.

Figure A in this Appendix contains a map of the river basin regions.

Table D: Percentage uplifts used to estimate the potential effect of climate change on rainfall for the 1-hour storm duration, 2050 time horizon.

River basin region	30yr Central	30yr High	100yr Central	100yr High
Argyll	30	47	29	49
Clyde	30	42	26	44
Forth	28	41	26	42
North East Scotland	29	42	26	45
North Highland	30	46	29	48
Orkney and Shetland	30	50	30	50
Solway	27	40	25	42
Tay	29	42	27	45
Tweed	25	38	25	40
West Highland	30	49	30	51

[5] Chan, S.C.; Dale, M.; Fowler, H.J.; Kendon, E.J. (2021): Extreme precipitation return level changes at 1, 3, 6, 12, 24 hours for 2050 and 2070, derived from UKCP Local Projections on a 5km grid for the FUTURE-DRAINAGE Project. NERC EDS Centre for Environmental Data Analysis. https://dx.doi.org/10.5285/18f83caf9bdf4cb4803484d8dce19eef

Table E: Percentage uplifts used to estimate the potential effect of climate change on rainfall for the 1-hour storm duration, 2070 time horizon.

River basin region	30yr Central	30yr High	100yr Central	100yr High
Argyll	41	59	39	60
Clyde	38	51	35	53
Forth	37	49	34	50
North East Scotland	36	50	35	52
North Highland	40	56	38	57
Orkney and Shetland	40	59	40	60
Solway	35	47	33	48
Tay	37	51	35	52
Tweed	34	45	31	46
West Highland	43	62	40	63

Table F: Percentage uplifts used to estimate the potential effect of climate change on rainfall for the 6-hour storm duration, 2050 time horizon.

River basin region	30yr Central	30yr High	100yr Central	100yr High
Argyll	25	37	29	42
Clyde	24	34	26	39
Forth	22	34	25	39
North East Scotland	20	34	23	39
North Highland	22	38	25	43
Orkney and Shetland	22	40	25	45
Solway	22	32	25	36

River basin region	30yr Central	30yr High	100yr Central	100yr High
Tay	21	33	25	38
Tweed	20	32	24	36
West Highland	25	41	29	46

Table G: Percentage uplifts used to estimate the potential effect of climate change on rainfall for the 6-hour storm duration, 2070 time horizon.

River basin region	30yr Central	30yr High	100yr Central	100yr High
Argyll	37	52	41	58
Clyde	33	48	37	52
Forth	31	47	34	51
North East Scotland	27	46	31	51
North Highland	31	53	35	58
Orkney and Shetland	30	55	35	60
Solway	31	43	34	48
Tay	30	45	33	50
Tweed	27	43	30	47
West Highland	38	58	42	64

Table H: Percentage uplifts used to estimate the potential effect of climate change on rainfall for the 12-hour storm duration, 2050 time horizon.

River basin region	30yr Central	30yr High	100yr Central	100yr High
Argyll	21	35	23	40
Clyde	19	30	21	35
Forth	17	30	19	34
North East Scotland	15	31	16	35
North Highland	16	36	18	40
Orkney and Shetland	16	37	20	41
Solway	17	28	19	32
Tay	15	29	18	33
Tweed	15	27	15	31
West Highland	21	39	23	45

Table I: Percentage uplifts used to estimate the potential effect of climate change on rainfall for the 12-hour storm duration, 2070 time horizon.

River basin region	30yr Central	30yr High	100yr Central	100yr High
Argyll	31	48	33	54
Clyde	27	42	29	47
Forth	24	41	26	46
North East Scotland	20	41	21	46
North Highland	23	48	25	53
Orkney and Shetland	23	50	25	55
Solway	25	37	26	42

River basin region	30yr Central	30yr High	100yr Central	100yr High
Tay	22	40	25	45
Tweed	20	36	22	40
West Highland	31	54	33	60

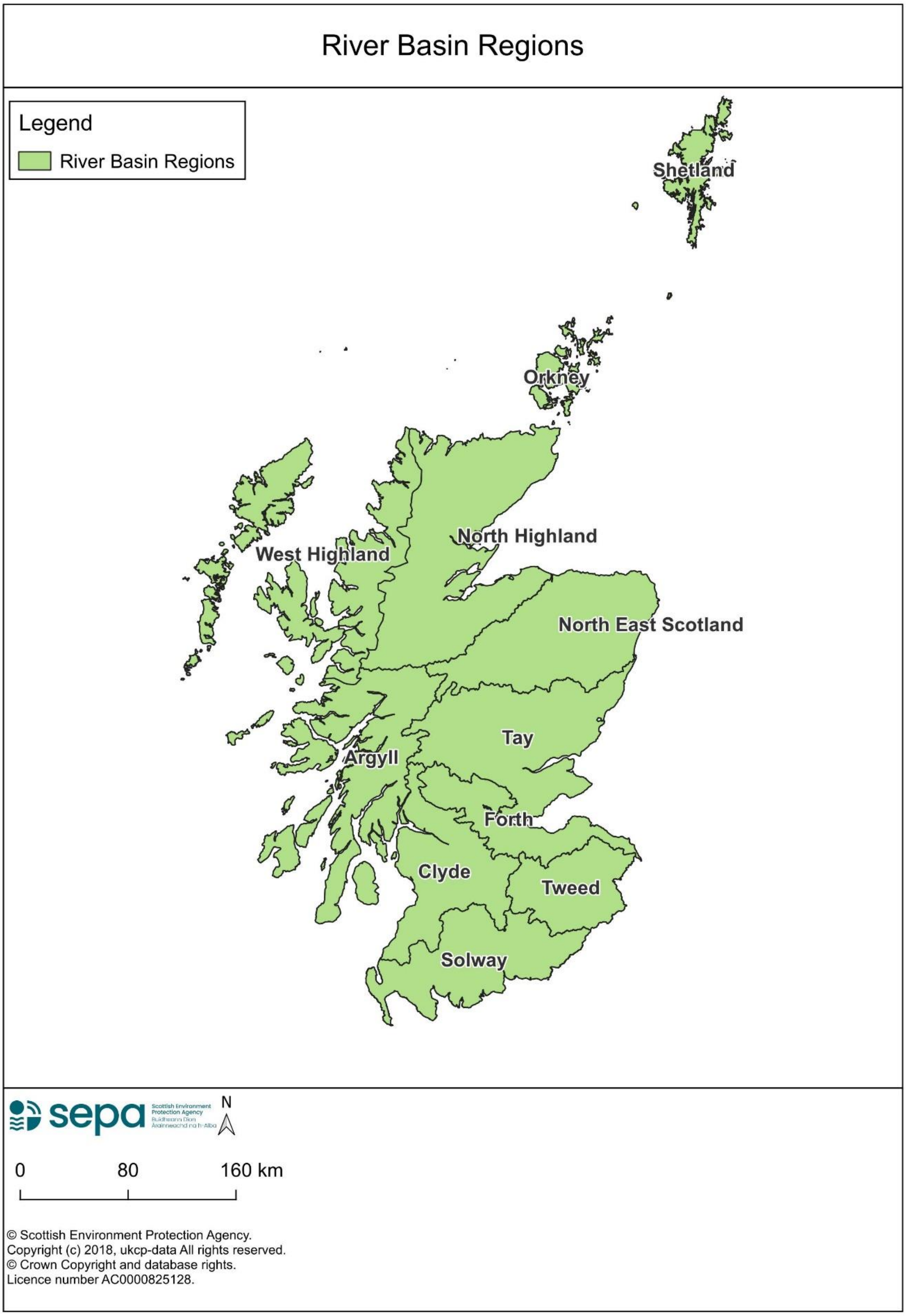

Figure A: River Basin Regions

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