Scottish Environment Protection Agency
Buidheann Dìon Àrainneachd na h-Alba

For the future of our environment

Coastal Flooding Summary: Methodology and mapping

8 November 2023

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. These 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 for the year 2080 or 2100- high emissions[1]	Medium	200 year

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

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

[1] For most of Scotland the climate change scenario uses relative sea level rise projections for the year 2080. For the Outer Hebrides, these projections are for the year 2100. Further details are provided in Section 5.

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 coastal flood hazard across Scotland.

Ongoing developments that SEPA is working towards include:

- Improved input data. For example, the use of Light Detection And Ranging (LiDAR) information that extends our coverage of higher resolution ground models.
- Investigating how to effectively apply the most appropriate hydraulic modelling methods.
- Considering where and how wave impact studies might improve confidence in outputs.
- Improvements to the Coastal Flood Boundary dataset with other UK environment agencies
- Sourcing additional coastal observational data, including wave data and archived historic data such as tidal gauge records.

3. Methodology and data

3.1 Approach

A suite of national and regional methodologies has been used to produce the coastal flood map for Scotland. The map is indicative providing 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 coastal flooding. The map provides indicative flood hazard information and identifies communities at risk from coastal flooding.

3.2 Data

The data used to produce the coastal flood map is listed in Table 2 (Appendix), alongside a description of the data, how it was used and the quality review process.

3.3 Methodology

The coastal flood map incorporates data from three separate SEPA studies as well as incorporating the data from detailed local studies where appropriate:

- National coastal study developed to meet the requirements of the FRM Act (2013).
- Regional coastal flood study for Northeast Scotland and the Orkney Islands (2018)
- Regional coastal study for the Outer Hebrides (2021)

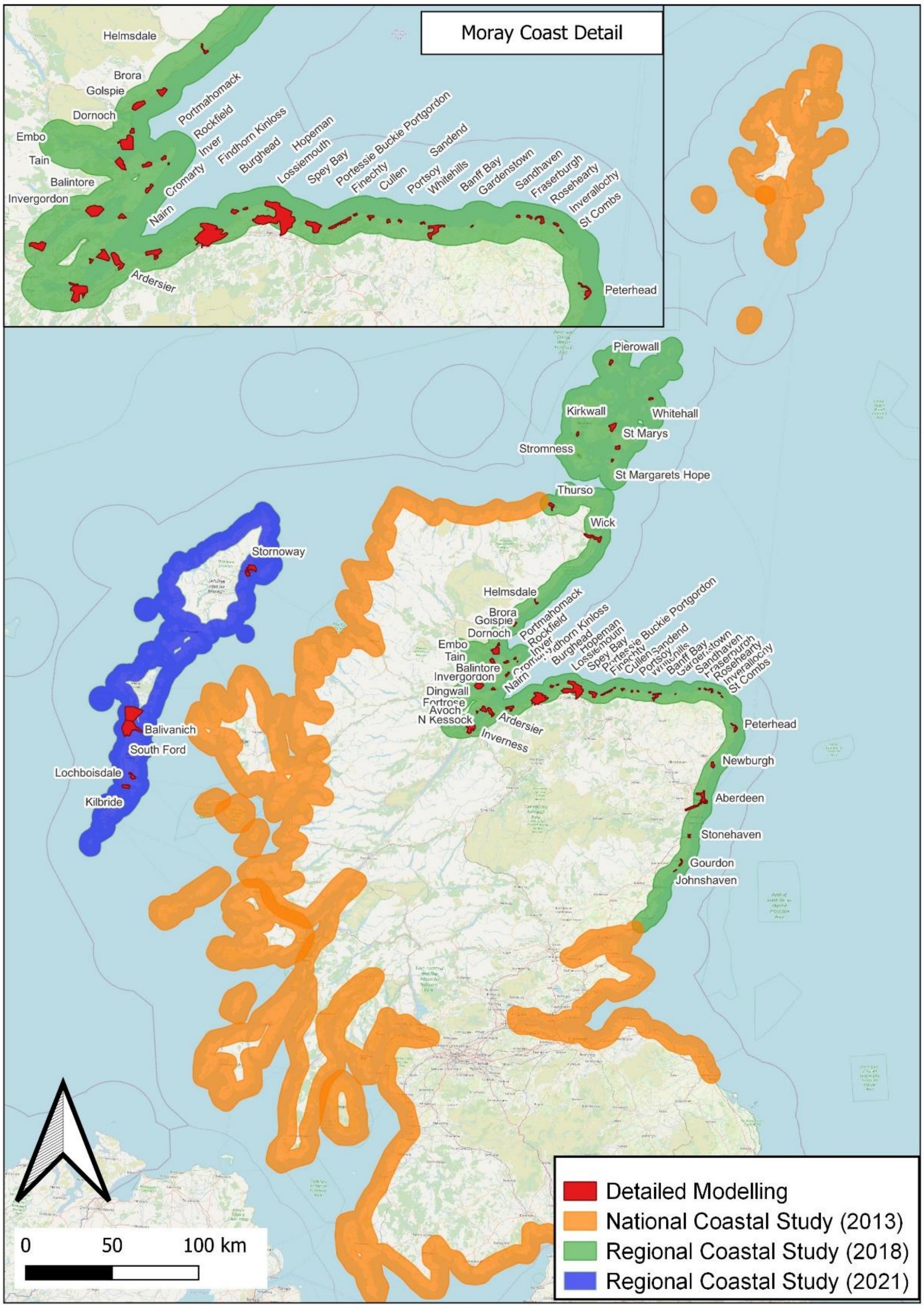
Figure 1 shows the areas covered by each study. Detailed modelling areas from the regional studies are also highlighted on the map.

The coastal flood map provides:

- Flood extents and depth grids for 8 scenarios including one climate change scenario for the entire country.

Table ***3*** (Appendix) shows the return periods for which coastal sea level points, flood extents, sea level grids and depth grids were derived.

Figure 1: Location of the SEPA coastal studies that have been used to develop the coastal flood map.



3.3.1 National Coastal Study

The national study (2013) took an existing Coastal Flood Boundary (CFB) dataset (2011)[2] as the basis for developing a coastal flood map for the Scottish mainland and islands. Whilst CFB 2011 design sea levels did not cover sea lochs, estuaries and firths, SEPA developed design sea level coverage for the whole of the Scottish mainland and islands. Figure *3* (Appendix) shows the gauge data locations with CFB 2011 sea level points and those additional sea level points derived for the national coastal study.

For this study, the following dataset were developed:

- Sea levels for 16 return periods and sea level uplifts for projected climate change which can be applied to any return period.
- Flood extents, sea level grids and depth grids for 8 return periods.
- Sea level confidence dataset.
- Flood extent confidence dataset.
- Dataset of areas benefitting from coastal defences.

[2] *Coastal Flood Boundary conditions in the UK mainland and islands*, Environment Agency/Defra Flood and Coastal Risk Research and Development Programme. N.B. Superseded by an updated dataset in 2018.

Table ***3*** (Appendix) shows the return periods for which coastal sea level points, flood extents, sea level grids and depth grids were derived.

Velocity data is not available from the national study due to the methodology used.

Sea Level Derivation

The CFB 2011 dataset provides estimates of design sea levels every 2km around the UK coast excluding estuaries, sea lochs and firths. To derive design sea levels outside the coverage of the CFB 2011 data points for Scotland, one of three methods was applied depending on the available supporting data:

Method 1: Analysis of observed data

Sea levels were derived using an estuary relationship between the nearest CFB data point and the upstream gauge data from SEPA, local authorities or the Class A tide gauge network[3]. This relationship was expressed as a gradient using the difference between the upstream and downstream points. The data, at the upstream gauges, was manually checked to ensure the sea levels were not unduly influenced by river flows.

Method 2: Use of data from existing studies

Design sea levels were taken directly from existing studies supplied by local authorities where the data was of a quality, scale and approach equivalent to the purpose of the flood hazard maps[4]. The studies used were:

- Glasgow City Council River Clyde Flood Management Strategy (Fairhurst Halcrow JV, 2005).
- Highland Council Extreme Sea Level and Modelling Report for the Firth of Lorne/Loch Linnhe System (JBA Consulting, 2009).

[3] More information on the dataset is available in Table 2 (Appendix)

[4] SEPA provided criteria to local authorities for the data to be applicable in the development of flood hazard maps. A copy is available on request from SEPA.

- Shetland extreme sea levels estimates from Indicative River and Coastal Flood Map (Scotland) (JBA / Royal Haskoning,.2005).
- Falkirk Council: Wave Hindcast and Joint Probability Analysis for Grangemouth (Halcrow. 2012).
- Stirling Council: River Forth Flood Mapping Stage 4 (Halcrow, 2009).

Method 3: Donor data from method 1

For the majority of the areas for which design sea levels were to be derived there was no data or existing study to provide information on sea level changes within the estuary, so this was the primary method used. In these areas, data developed through method 1 was donated by selecting a relationship from a similar estuary or assuming a flat gradient. Criteria were established to ensure that the data was suitable for another area which included aspect, width of estuary opening, alignment of estuary and constrictions at the estuary mouth.

Method 4: Indicative River and Coastal Flood Map (Scotland)

With agreement from Shetland Islands Council, sea levels from the Indicative River and Coastal Flood Map (Scotland) were used to support the derivation of sea levels in the Shetland Isles due to only one CFB 2011 data point being available at Lerwick in the Shetland Isles. More information is available from SEPA on request.

Flood extent derivation

Flood extents have been defined using a horizontal projection method. This approach identifies all land at a lower elevation than the calculated sea levels for each return period as being at risk of flooding. Limitations of this approach are included in Section 7.1.2.

Sea level grids, depth grids and flood extents were produced for eight scenarios (10, 25, 50, 100, 200, 200 plus climate change, 1000, and 10,000 year return periods). Unlike outputs created with hydraulic models, false restrictions are not an issue with the projection method as any low-lying ground beneath the level of the extreme sea level is shown as flooded.

3.3.2 Regional Coastal Studies

For North East Scotland and the Orkney Islands (2018), and the Outer Hebrides (2021), SEPA has undertaken regional scale modelling to further develop our understanding of the coastal flood hazard affecting these parts of Scotland. These studies comprise areas which benefit from more detailed flood modelling and locations where a simplified modelling methodology has been applied.

A key area of improved understanding compared to the national study is the consideration of waves and wave overtopping as a coastal flooding mechanism.

These regional study areas have been modelled using a combination of hydraulic modelling and horizontal projection modelling with the inclusion of wave run (where appropriate)

Sea Level Derivation

The Coastal Flood Boundary (CFB) 2018 dataset was used as the basis for design sea levels for the regional studies and comprises additional observations and tidal analyses since the publication of the CFB 2011 dataset used in the national study. This dataset builds on previous work and now fully extents to cover sea lochs, estuaries and firths. This dataset has also previously been used for flood mapping in Grangemouth and Loch Etive.

Waves

Wave action is a complex process controlled by several factors that determine the magnitude of any wave induced flood impacts. Waves are generated in deep water offshore and then move towards the land. As they do so, they enter shallower waters where wave transformation processes occur, including shoaling, diffraction, refraction, depth limitation and breaking.

The consequence of these transformation processes is that the properties of the waves when they reach the base of coastal defences are quite different to those in deep water. In terms of wave overtopping, it is the nearshore waves that are of the greatest importance, as it is these that interact with beaches and defences and lead to wave overtopping and inundation. Wave overtopping itself is a complex process controlled by the state of the sea (water depth, wave properties) and the geometry of the nearshore and local flood defences.

The impact of all the above drivers during a particular storm is also heavily dependent upon the location and orientation of the community with respect to the sea. This means that while one community may be flooded during a storm event, while another, just a short distance away, may have lesser impacts because of a different orientation with respect to the dominant wind/wave direction. This complexity requires a range of models to calculate final depths and extents of flooding from the major components.

Modelling Approaches

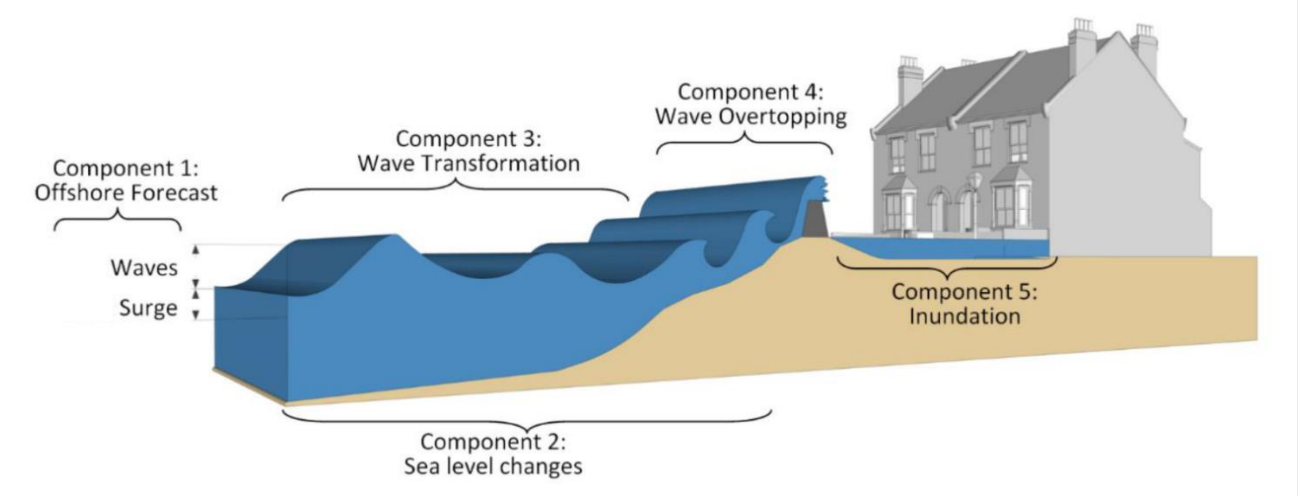
Hydrodynamic Modelling

Coastal hydrodynamic models simulate the interaction between wind, waves, tides, and other factors that influence water levels along the coast. The hydrodynamic models used for the updated areas provided levels and wave heights near shore for calculation of either wave runup in projection modelling locations or the input to wave overtopping calculations where appropriate in detailed model locations.

Detailed Inundation modelling:

For each detailed mapping location shown in Figure 1 a two-dimensional (2D) inundation model was developed. These models were driven by both still water levels derived from the CFB 2018 dataset, and wave overtopping data. The models provide maximum depths and extents of coastal flooding for each location. Although velocities are calculated, they are limited to the velocity of inundation water and do not include the velocity or momentum of overtopping waves. Velocity data is not shown in the published flood maps.

Figure 2: Components of sea level variation that lead to coastal flooding



Source: Coastal Flood Mapping Scotland – Phase 1 (JBA Consulting, June 2021)

Horizontal Projection Modelling with wave runup

The horizontal projection method, sometimes also referred to as the *'bathtub'* method, involves the horizontal spreading of flood levels to areas of lower elevation. For most of the coast, it is an appropriate method of modelling inundation, but it does not account for the finite flood volumes, hydraulic roughness, the duration of flood events or fully integrate the complexities of coastal flow paths and constrictions. However, the simplicity of computation allows the mapping of large areas relatively quickly.

The method involves the comparison of water levels with an underlying Digital Terrain Model. The resulting outputs then require post processing to remove anomalies, for example, to remove areas of low-lying topography that do not have connectivity to the coast.

Still water levels used within the projection modelling areas were taken from the CFB 2018 dataset, with wave action accounted for, where appropriate, using wave runup levels.

4. Flood defences

Horizontal projection modelling cannot specifically account for flood defences as it floods all land below the specified sea level, irrespective of whether or not it is behind a flood defence, effectively providing an undefended output. Please note that this is not the case for the river flood map.

Formal flood defence information was taken from the Scottish Flood Defence Asset Database (SFDAD)[5] and any flooded areas behind defences were identified as areas benefitting from defences, however these areas were not removed from the flood extent. A dataset of areas benefiting from defences was created.

For those detailed modelling locations contained within the regional coastal studies (Figure 1) topographic surveys of coastal defences were carried out to allow calculation of overtopping rates and subsequent extents and depths of coastal flooding.

5. Climate change

Climate change and sea-level rise scenarios are considered to assess long-term coastal flood risk. These scenarios help policymakers plan for future resilience and adaptation. Sea levels with consideration of climate change were derived for the 200 year return period using a climate change uplift applicable to any return period.

For the future coastal flood maps, the UK Climate Projections 2009 (UKCP09) relative mean sea level rise projections[6] were used to account for predicted sea level rise to 2080 for most of Scotland. The scenario used to produce the coastal flood map was the High emissions, 95th percentile for the year 2080.

[5] More information on this dataset available in Table 2 (Appendix)

[6] More information on this dataset available in Table 2 (Appendix)

For the Outer Hebrides UK Climate Projections 2018 (UKCP18) projections of relative mean sea level rise were used to account for predicted sea level rise to 2100. The scenario used for this location was the Representative Concentration Pathway (RCP8.5) 95th percentile for the year 2100.

The future flood maps have been produced using projected changes in mean sea levels only; for most of Scotland they do not reflect potential changes in wave overtopping. In areas covered by the regional coastal studies for the North East Scotland and the Orkney Islands, and the Outer Hebrides, changes in wave overtopping and wave runup with increased still water levels is taken into account.

Wave heights at the coast are often limited by water depth, so sea level rise will increase wave height and overtopping rates at the coast so that the impact of climate change on coastal flood hazard will likely be greater than that shown in areas of the future coastal flood map derived from the national coastal study which only considers projected changes in sea level.

Further information on climate change can be found within the published Future Flood Maps and accompanying guidance, the Future Flood Maps summary.

6. Validation and quality review

A robust validation and review process was undertaken for the coastal 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 coastal 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** - Data input checks and quality review are included in Table 1 (Appendix). Checks on the coastal flood map outputs were carried out on design sea level points, sea level and depth grids and extents.

- **Sea level Points**: A manual review was undertaken to ensure that newly derived design sea levels corresponded to the adjacent CFB point, that there were no unrealistic values and that all areas had been covered.
- **Sea level and depth grids**: Automated checks were carried out to ensure that water levels equalled the sum of the DTM height and water depth, and that water levels and depths increased with return period. Manual checks were undertaken to check for extreme depths and to ensure that values in the sea level grids tied up with corresponding sea level point values.
- **Flood extents**: Checks were carried out to ensure that extents increased with return period, i.e., the extent for the 200 year return period (medium likelihood) is larger than the 10 year return period (high likelihood). Sense checks were also undertaken for issues such as extents engulfing small islands. As further validation the flood extents from the national coastal study for the 200 year return period were compared against those in the Indicative River and Coastal Flood Map (Scotland). A review of public records was also carried out as a sense check to capture locations with a history of coastal flooding. Of the 500 recorded flood events in the records only four are in areas not covered by the flood extents.
- **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.

7. Interpretation

The coastal flood map has been developed using a suite of national and regional methodologies. It is a tool to help raise public awareness and understanding of flood risk, 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 application of national and regional methodologies being applied to provide Scotland wide mapping and with these approaches there are assumptions and inherent uncertainty.

As the national source of flood hazard information in Scotland, the flood map forms a key basis for Flood Risk Management Planning and to support the development of the National Flood Risk Assessment, National and Local Flood Risk Management Plans.

7.1. 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 quality and completeness of the data going into the assessment, e.g. nearshore wave heights, sea level data
- The resolution of topographical information, e.g. nearshore bathymetry, terrestrial digital terrain model
- The method or model used
- Future changes e.g. sea levels associated with climate change and land use changes (erosion and/or development)

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

7.1.1. Confidence in sea level data

The CFB datasets have been implemented as the primary source of information and confidence information from that dataset has been considered. At a national level and alongside the considerations set out in Section 7, the coastal flood map is fit for its published purpose.

However, within the national coverage there are varying degrees of confidence in the data. A sea level confidence figure has been derived for each sea level point. Generally, as the distance from a Class A tide gauge increases our confidence in the data decreases. Where available and appropriate to do so, some local applications of confidence have been applied. Design sea levels are accurate to ±0.1m near to the Class A tide gauges, but additional uncertainties are possible between gauge locations particularly within channels, estuaries and inland extensions of the CFB dataset.

7.1.2. Confidence in flood extents

National Study

The relative confidence in the flood extents was determined based on the accuracy of the underlying datasets. The confidence assessment took into account the confidence intervals from the sea levels, the source of the underlying DTM, and the degree of exposure to open sea waves and the nature of the floodplain. Components in the analysis of confidence include:

- **Sea level confidence estimate**: Where the sea levels have been determined through detailed local studies, a high confidence was assigned, given the more detailed scope of this work. These areas include:
    - the Firth of Clyde/Tidal River Clyde
    - the Firth of Forth
    - Loch Linnhe

- **Digital Terrain Model (DTM) confidence**: A DTM confidence score was determined based on whether the underlying data source was LiDAR (higher confidence) or NEXTMap (lower confidence).

- **Suitability of projection method approach**: An assessment was made as to whether the projection method approach used was appropriate for an area or whether the local characteristics would ideally merit more sophisticated hydrodynamic modelling.

Regional Studies

An estimation of confidence in the inputs to both the detailed and projection modelling was undertaken in order to determine a total score for each model or mapping area. Confidence for the different detailed and projection modelling locations were determined and totally separately, based on the factors shown in Table 1.

The detailed modelling is generally considered more accurate than projection modelling, and therefore the total scores were weighted appropriately. The present scoring approach, although not encompassing every metric, is considered to adequately capture the relative confidence between models and modelling methods. All projection modelling areas score lower than the detailed models, reflecting the lower overall confidence in this modelling method.

Table 1: Factors used to determine confidence in regional coastal studies.

Confidence Factor	Detailed Modelling	Projection Modelling
Terrain data quality	✓	✓
Defence survey availability	✓	
Overtopping defence type	✓	
Calibration Data	✓	
Wave Data	✓	

Confidence Factor	Detailed Modelling	Projection Modelling
Model Forcing		✓
Wave Runup Accuracy		✓
Type of beach and evidence of beach type		✓

Terrain data

Models that had complete LiDAR coverage (1m resolution) were given a score of 10. Models that were covered by either 2m resolution terrain data, or a combination of LiDAR and lower resolution terrain data were given a score of 5. A score of 1 was given to models only covered by 5m resolution datasets (GetMapping or NEXTMap).

Defence survey

If survey data was included in a model, it was given a score of 10. A score of 1 was given to models that did not include survey data.

Overtopping defences

If the overtopping in the model was calculated for hard defences, e.g. concrete revetments, walls, or rock armour, a score of 10 was assigned. If the defence type in the model was a combination of both hard and natural defences, it was given a score of 5. For models where overtopping was calculated for natural defences, e.g. dunes, a score of 1 was assigned.

Calibration Data

If georeferenced observed flood events were available for calibration, the model was given a score of 10. If anecdotal evidence or photographs were available in the modelling review process, the model was given a score of 5. The remaining models with no calibration data were given a score of 1.

Model Forcing

If the projection model area was forced by still water levels only, a score of 25 was assigned. Still water levels are considered to be the most accurate forcing for projection modelling, compared to wave runup which can be conservative. For areas where sections of wave runup was included along with areas of still water levels, a score of 5 was assigned. If the entire projection model area was covered by wave runup, a score of 1 was given.

Wave Runup Accuracy

For locations where wave runup was included, a further two variables were considered and scored against. The runup formulas used are most appropriate for uniform beaches. For uniform beaches, a score of 10 was assigned; for composite beaches a score of 5 was assigned, and for rocky shorelines a score of 1 was assigned. The evidence available for determining the type of beach was also given a score. Runup areas where photographs were available were given a score of 10. Areas where street level imagery was available were given a score of 5. Areas where only aerial imagery was available were given a score of 1.

7.2. Limitations

The coastal flood map has been produced at a national and regional 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 the individual property level without further guidance.

7.2.1. Method limitations

Horizontal projection method

This is used in flood depth and extent derivation (Sections 3.3.1 and 3.3.2). It represents a simplification of the flooding mechanisms at work during a storm event. Specifically, this method cannot:

- Account for the impacts of wave overtopping.

- Directly account for the influence of flood defences, however a dataset of areas benefitting from defences was created as part of the national study (see section 4).

This method does not take any account of the volume of water able to inundate an area over a tidal cycle and can therefore lead to flood extents being overestimated in locations with wide and flat floodplains. The generally steep nature of the Scottish coastline means such places are few and far between. Examples of locations with wide floodplains are North Uist, South Uist and Benbecula in the Outer Hebrides, land surrounding the Dornoch Firth and Cromarty Firth, low ground between Lossiemouth and Elgin and floodplains on the Firth of Forth. Note that where appropriate and, data are available, detailed modelling has been carried out in those areas of North East Scotland and the Outer Hebrides. However, despite these uncertainties, experience has shown that the flood extents from detailed 2D modelling, and the simplified projection modelling approach are generally very similar in areas affected by still water. Conversely, as design water levels do not account for wave overtopping, in areas exposed to the action of waves, the flood extents may be underestimated.

Detailed Modelling Method

Depths and extents are calculated with inundation models for each detailed area. These models were driven by both still water levels, from the CFB dataset, and wave overtopping data.

Whilst the method includes waves as a source of flooding, and also the time varying nature of tide levels, it does not account for momentum of the overtopped waves. There are examples where overtopped waves flow back to the sea and do not contribute to the maximum depth of flooding or the extent even though they would pose a hazard to a community. This also has implications for calculating the cost of flooding since the current methods use depth of flooding to calculate damages.

Joint Probability

Note that in some cases, coastal flooding may also result from heavy rainfall or river overflow, usually in combination with high tide. Joint probability of four variables (river flow, high tide and surge, and extreme waves) were not considered for this national scale assessment but could be appropriate to smaller scale local assessments. Therefore, the coastal flood maps do not include contributions from coincident fluvial events.

7.2.2. Resolution

Due to the resolution of the 5m DTM, smaller features such as bridges shown as flooding, may not be identified. This is particularly an issue in areas where the DTM is based on NEXTMap.

7.3. Caveats

- Design sea-level values include the effects of storm surge but do not account for any local increase in sea level that may be induced by onshore wave action.
- For locations covered by the national coastal study, evaluating the effects of wave overtopping was out with the scope of this study due to the national scale of this project.
- 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.

8. 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 2: Data used as an input to the coastal flood map.

Data	Description	How the data was used	Quality check
Coastal Flood Boundary (CFB) dataset (2011)	The *"Coastal flood boundary conditions for the UK mainland and islands"* was developed undertaken as part of the joint Environment Agency/Defra Flood and Coastal Risk Research and Development Programme. The dataset provides design sea levels at a 2km spacing around the UK for 16 return periods. This dataset does not cover estuaries, sea lochs or firths.	To provide design sea levels for the majority of the Scottish coastline. To determine where additional sea level points were required. To infer confidence levels for new sea level points.	No additional quality checks of the CFB 2011 dataset were undertaken as this was a published dataset.
Coastal Flood Boundary (CFB) dataset (2018)	The *"Coastal flood boundary conditions for the UK: update 2018"* was undertaken by the Environment Agency to update the previous 2011 dataset. The 2018 dataset provides updated design sea levels at a 2km spacing around the UK for 16 return periods. This dataset also includes coverage for estuaries, sea lochs or firths.	To provide design sea levels for: Grangemouth, Loch Etive, North East Scotland, Orkney Islands, Outer Hebrides	No additional quality checks of the CFB 2018 dataset were undertaken as this was a published dataset.
Tide gauge data	Observed sea level data was taken from three sources: • SEPA gauges, • Local authority gauges,	To derive sea levels in those areas not covered by the CFB 2011 dataset.	Gauge data was inspected for: Missing data;

Data	Description	How the data was used	Quality check
	• Class A tide gauge network[7].		Erroneous high data 'spikes' Datum shifts and drifts, Data for each year was assigned a quality class.
Wave data	Observed wave data at Bilia Croo and Scapa Flow	To provide calibration data for coastal modelling	No additional checks carried out on these data
Wind and Wave Hindcast Data	Historic offshore wave and wind conditions modelled over a wide area	To provide calibration data for coastal modelling	No additional checks carried out on these data.
Multivariate Joint Probability data	National joint probability dataset of offshore conditions of levels and waves combined and provided at a range of return periods.	Inputs into the wave transformation models used to bring offshore conditions to the nearshore.	This dataset was previously created for SEPA, no additional checks carried out on these data.
Local authority modelling studies	Detailed local assessments of flood risk providing numerical models to cover specific areas	To derive sea levels and flood extents in areas not covered by CFB 2011	A review of these studies was undertaken.

[7] Obtained from the British Oceanographic Data Centre website (http://www.bodc.ac.uk/): The British Oceanographic Data Centre is responsible for remote monitoring and retrieval of sea level data from the UK National Tide Gauge Network on behalf of the National Tidal and Sea Level Facility (NTSLF).

Data	Description	How the data was used	Quality check
National Digital Terrain Model (DTM)	A composite DTM comprising LiDAR and Intermap's NEXTMap (IfSAR) DTM with a horizontal resolution of 5m	To develop the national coastal flood model	Manual quality checks to ensure blockages were removed from river channels, such as bridges and vegetation. Checks were also undertaken at the dataset boundaries ensure there were no jumps in ground level
Regional DTM	A composite DTM comprising LiDAR, NEXTMap (IfSAR), GetMapping (Photogrammetry, Oceanwise Bathymetry	To develop the regional coastal flood models	
Topographic Survey	Beach and defence survey data for North East Scotland and the Outer Hebrides. Local authority survey data were also used where available	To schematise flood defences for wave overtopping calculations and define beach slopes for wave runup calculations	Check on beach profiles and defence schematisation were undertaken
Bathymetric Data	Underwater topography from Oceanwise	These data are used for both wave transformation modelling for calculation of near shore waves and for inundation modelling to extend the model domains seaward.	Sensitivity tests to bathymetry were carried out in some locations

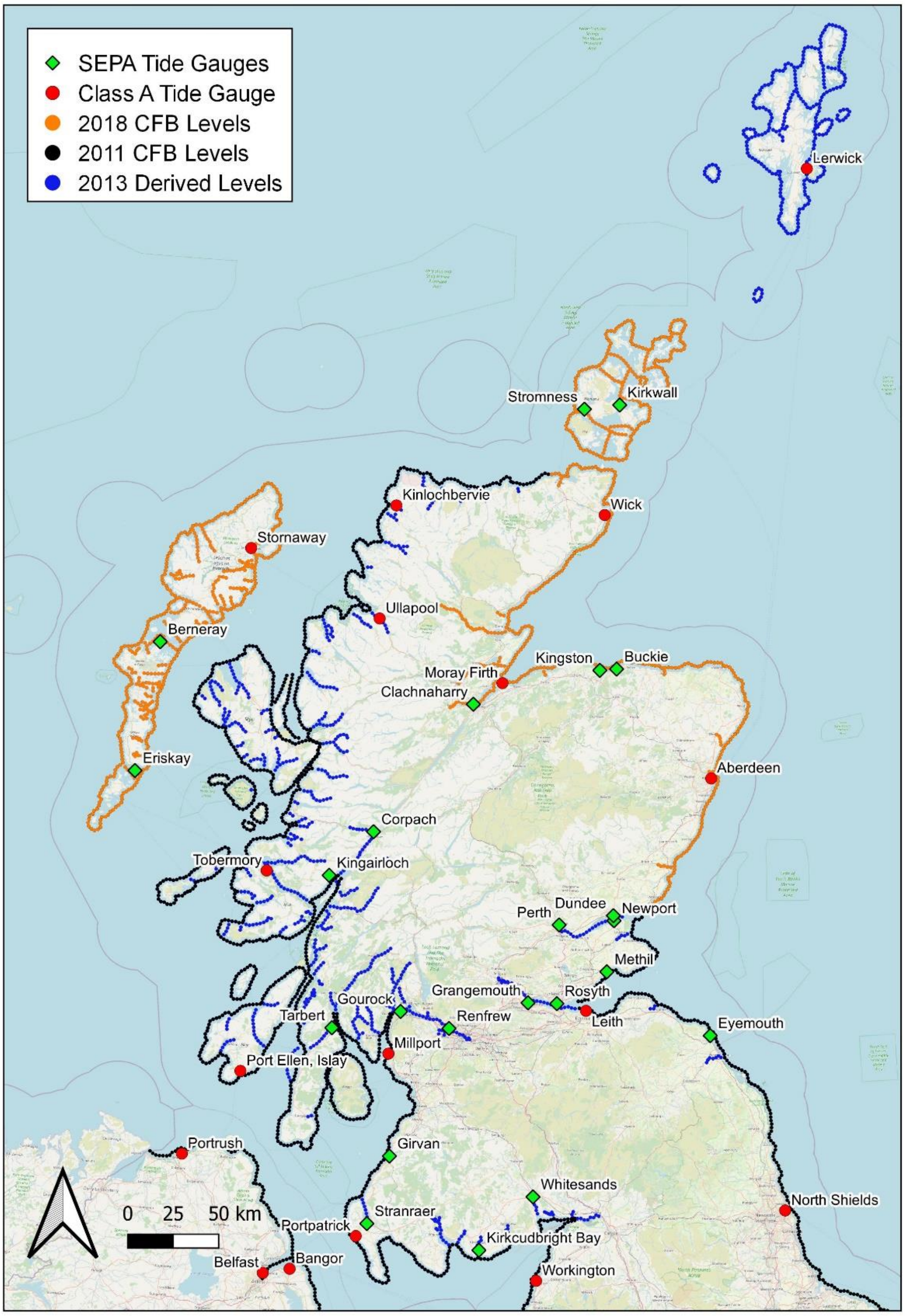
Data	Description	How the data was used	Quality check
Indicative River and Coastal Flood Map (Scotland)	Until the publication of flood hazard map, this was the national source of flood hazard information (2006 - 2013). The Flood Map showed the possible extent of river and coastal flooding. It was an important strategic tool for managing flood risk, primarily focusing on the 200-year flood event in line with Scottish Planning Policy.	Design sea levels used to develop water level trends around the Shetland Isles due to limited CFB 2011 data.	No further validation was undertaken as this is a previously published dataset.
Scottish Flood Defence Asset Database (SFDAD)	Detailed information on flood protection schemes and associated assets.	To check levels of defences in the DTM	Data from SFDAD has come from local authorities and it is therefore assumed that information has been reviewed prior to inclusion in the database.
Local authority structures and defences information	Local authorities provided SEPA with information on hydraulic structures and defences in their areas where available, for example as built drawings or flood defence scheme reports	To check flow conduits	No further quality checks required by SEPA in addition to the information supplied by local authorities

Data	Description	How the data was used	Quality check
Climate change information (UKCP09)	Projections of sea level rise on a 25km grid around the Scottish coastline taken from the UK Climate Projections 2009 website. (UKCP09) https://webarchive.nationalarchives.gov.uk/20181204111018/http://ukclimateprojections-ukcp09.metoffice.gov.uk/	To obtain sea level rise projections for the majority of the Scottish coastline. Applied to the 200 year return period sea levels.	No further validation of undertaken as this is a previously published dataset.
Climate change information (UKCP18)	Projections of sea level rise around the coastline from the UK Climate Projections 2018 dataset. Met Office Hadley Centre (2018): UKCP18 21st Century Time-mean Sea Level Projections around the UK for 2007-2100. Centre for Environmental Data Analysis. https://catalogue.ceda.ac.uk/uuid/0f8d27b1192f41088cd6983e98faa46e	To obtain sea level rise projections for the Outer Hebrides	No further validation undertaken as this is a published dataset.

Table 3: Return Periods for which coastal sea levels, extents, sea level and depth grids were derived.

Return Period	Sea Level	Flood Extent	Sea Level Grid	Depth Grid
1	✓			
2	✓			
5	✓			
10	✓	✓	✓	✓
20	✓			
25	✓	✓	✓	✓
50	✓	✓	✓	✓
75	✓			
100	✓	✓	✓	✓
150	✓			
200	✓	✓	✓	✓
200 + climate change	✓	✓	✓	✓
250	✓			
300	✓			
500	✓			
1000	✓	✓	✓	✓
10,000	✓	✓	✓	✓

Figure 3: Gauge data locations with Coastal Flood Boundary 2011 and 2018 sea level points, and sea level points derived for the national coastal study



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