Coastal flooding summary: Methodology and mapping

1. Introduction

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

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

Likelihood of flooding	Return period
High	10 year
Medium	200 year
Low	1000 year

To produce a flood hazard map for each source of flooding SEPA has developed new datasets and methodologies for coastal, river and surface water flooding. These create flood maps for Scotland and supersede the current Indicative River and Coastal Flood Map.

This summary provides information on how we developed our coastal flood map and how to interpret this data. The primary purpose of this summary is to support Scottish Government, local authorities and Scottish Water in their understanding of how the maps were developed and support internal/external briefings and enquiries. This in turn will help to increase public awareness and understanding of flood risk. This summary assumes previous knowledge of flood maps and their development.

This summary will also be shared with the Loch Lomond and Trossachs National Park, Cairngorms National Park Authority and the Forestry Commission Scotland as responsible authorities from 21 December.

2. Development and review

2.1 Improvements from the Indicative River and Coastal Flood Map (Scotland)

The production of this coastal flood map has improved our understanding of coastal flooding. In particular improvements relate to:

- Flood extents and depth outputs developed for a greater range of return periods

- Our national coastal flood map aligns with the most up to date method of design still water sea level estimation[1] by developing on an existing sea level dataset to provide national coverage.
- Increased the number of design sea level points around the Shetland Isles

2.2 Future review and development

The mapping of flooding is a dynamic process and the flood maps will be subject to review and change as we develop and our input data, methodologies and techniques. SEPA will 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:

- Improving input data. For example, use of new LiDAR information to extend our coverage of higher resolution ground models
- Investigating how to effectively apply hydraulic modelling methods
- Considering where and how wave impact studies might improve confidence in outputs.

The flood maps, publicly available from 15 January 2014, reflect the knowledge and data we have available at time of publication and were able to incorporate into our national methodologies.

3. Methodology and data

3.1 Approach

A nationally applied methodology has been used to produce the coastal flood map for Scotland. The map is indicative with a national methodology 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 approach took an existing Coastal Flood Boundary (CFB) dataset[2] as the basis for developing a coastal flood map for the Scottish mainland and islands.

3.2 Data

The data used to produce the coastal flood map is listed in table 1(Appendix A, page 10), alongside a description of the data, how it was used and the quality review process.

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[1] Still water sea levels include the effects of storm surge but do not account for local wave set-up (i.e. local sea level increase induced by on-shore wave action).

[2] *Coastal Flood Boundary conditions in the UK mainland and islands*, Environment Agency/Defra Flood and Coastal Risk Research and Development Programme.

3.3 Methodology

The coastal flood map builds on the CFB dataset for the Scottish mainland and islands. Whilst CFB design sea levels do not cover sea lochs, estuaries and firths, SEPA has developed design sea level coverage for the whole of the Scottish mainland and islands. Figure 1 (Appendix A, page 14) shows the gauge data locations with existing CFB sea level points and sea level points derived for the coastal flood map.

The coastal flood map provides:

- sea levels for 16 return periods and a climate change sea level increase 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

Table 2 (Appendix A, page 13) 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 for the coastal flood map due to the methodology used however it is available for river and surface water flooding.

3.3.1 Sea level derivation

The CFB dataset provides estimates of design sea levels every 2km around the coast out with estuaries, sea lochs and firths. To derive design sea levels out with the coverage of the CFB points 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 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 FRM flood hazard maps[4]. The studies used were:

[3] More information on the dataset in table 1

[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.

- Glasgow City Council River Clyde Flood Management Strategy
- Highland Council Extreme Sea Level and Modelling Report for the Firth of Lorne/Loch Linnhe System;
- Shetland extreme sea levels estimates from IRCFM(S) (2005);
- Orkney Islands Council tide gauge data for Stromness and Kirkwall;
- Scottish Water Model Data for Dornoch Firth and Cromarty Firth;
- Halcrow Wave Hindcast and Joint Probability Analysis for Grangemouth (2012);
- Stirling Council River Forth Flood Mapping Stage 4 (Falkirk Council) (Halcrow, 2009).

Design sea levels are still water levels. Based on local consultation and working in partnership with Falkirk Council return periods from the local authority study was adopted in the Grangemouth area. This dataset includes wave overtopping and therefore this area of the coastal flood map is not based on still water sea levels alone.

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.

Indicative River and Coastal Flood Map
In agreement with 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 point being available at Lerwick in the Shetland Isles. More information is available from SEPA on request.

Climate change
Sea levels with consideration of climate change were derived for the 200 year return period using the climate change uplift applicable to any return period.

A precautionary approach which considered the worst case scenario was adopted. UKCP09 projections[5] of sea level rise were used to account for sea level rise to 2080. The scenario used to produce the coastal flood map was high emissions, 95 percentile confidence limit and the year 2080.

[5] More information on this dataset is available in Table 1

3.3.2 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 model are included in 4.2.

Sea level grids, depth grids and flood extents were produced for eight scenarios (10, 25, 50, 100, 200, 200 plus climate change, 1,000 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**.**

3.3.3 Flood Defences

Horizontal projection modelling cannot specifically account for flood defences as it floods all land below the specified sea level, irrelevant 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 SFDAD[6] 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. An exception to this was made at Grangemouth where local authority information was used to alter flood extents and depths to account for defences around Grangemouth oil refinery.

4. 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 Modelling Appraisal Strategy Group provided peer contribution in developing the approach for coastal flood mapping. This group includes industry representatives, academia, representation from 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 A, page 10). Checks on the coastal flood map outputs were carried out on sea level points, sea level and depth grids and extents.

    - **Sea level Points**: A manual review was undertaken to ensure that newly derived sea levels corresponded to the adjacent CFB point, that there were no extreme values and that all areas had been covered.

[6] More information on this dataset available in Table 1

- **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**: An automated check was 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 (high likelihood). Sense checks were also undertaken for issues such as extents engulfing small islands. As further validation the flood extents for the 200 year return period were compared against those in the Indicative River and Coastal Flood Map. 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 new flood extents.

- **Local authority review** - Local authorities reviewed flood extents for low, medium and high likelihood events. SEPA hosted workshops and drop-in sessions to review the maps in partnership with local authorities and has acted on comments and feedback where data was available to do so.

5. Interpretation

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

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. As with any nationally consistent methodology there are necessary assumptions and inherent uncertainty in the application of the method to provide Scotland-wide coastal flood mapping. The zoom on the map, published on the SEPA website, is set to support the intended use of the maps at a community level. Similarly it is advised that when data is hosted on your internal servers that going beyond the recommended level of zoom will lead to increased uncertainty in the application of the map.

As the national source of flood hazard in Scotland, the map forms a key basis for FRM Planning and support decision making for FRM Strategies and Local FRM Plans.
The map is not licensed for commercial use and all users must agree to terms and conditions before viewing the map.

5.1 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 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 the confidence in the data and the final mapped outputs. It also identifies where resources can be focused for further development.

5.1.1 Confidence in sea level data

The CFB dataset has 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 5.2, 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. As a general rule, as the distance from the CFB point increases our confidence in the data decreases. Where available and appropriate to do, some local applications of confidence have been applied. Design sea levels are accurate to 0.1m

5.1.2 Confidence in flood extents

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
    - the Firth of Forth
    - the Cromarty Firth
    - the Dornoch Firth.
    - 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.

5.2 Limitations

The coastal flood map has been produced at the national scale using national datasets and a standard methodology. This map is a strategic product to support FRM Planning at a community level.

5.2.1 Method limitations

Horizontal projection method – This is used in flood extent derivation (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 has been created (see 3.3.3)

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 and 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 including Grangemouth. 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.

5.2.2 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 which is the case in Shetland.

5.2.3 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.

Due to the national scale coverage of this study, evaluating the effects of wave overtopping was out with the scope of this study and would need to be estimated separately.

Appendix A

Table 1: Data as an input to coastal flood map

Data	Description	How the data was used	Quality check
Coastal Flood Boundary (CFB) dataset	The "Coastal flood boundary conditions for the UK mainland and islands" (CFB project) was 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.	The CFB dataset is published and available for use. No additional quality checks were carried out on this dataset
Tide gauge data	Observed sea level data was taken from two sources; SEPA and local authority gauges, and the Class A tide gauge network[7].	• To derive sea levels in those areas not covered by the CFB dataset.	Gauge data was inspected for: • Missing data; • 'spikes', where the gauge is recording erroneously high levels; • datum shifts, where the datum suddenly moves from one level to another; • datum drift, where the datum shows an apparent general trend up and down through the year. • Data for each year was assigned a quality class.
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.	• A review of these studies was undertaken.
SEPA's Digital Terrain	The DTM comprises LiDAR and Intermap's NEXTMap DTM with a horizontal resolution of 5m.	• To develop the coastal flood model.	• Manual quality checks to ensure blockages were removed from

[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).

Model (DTM)			river channels, such as bridges and vegetation. • Checks were also undertaken at the boundary of Nextmap and LiDAR data to ensure there were no jumps in ground level.
Indicative River and Coastal Flood Map (Scotland)	Until the publication of flood hazard map, this is the national source of flood risk information. The Flood Map shows the possible extent of flooding from these sources and is an important strategic tool for managing flood risk, primarily focusing on the 200 year flood event (an event with a 0.5% chance of occurring any year) in line with Scottish Planning Policy (SPP).	• Sea levels used to work out sea level trends around the Shetland Isles due to limited CFB data.	No further validation of the indicative river and coastal flood map (Scotland) 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 use in the hazard maps.
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.
Climate change information	Projections of sea level rise on a 25km grid around the Scottish coastline taken from the UK climate projection 2009 website.	• To obtain climate change uplifts for the Scottish coastline. • Applied to the 200 year return period sea levels.	No further validation of the climate change information from UKCP09 was undertaken as this is a previously published dataset. (UKCP09, http://ukclimateprojections.defra.gov.uk/)

Table 2: Return periods for which coastal sea levels, extents, sea level grids 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	✓	✓	✓	✓
250	✓			
300	✓			
500	✓			
1,000	✓	✓	✓	✓
10,000	✓	✓	✓	✓

Figure 1: Gauge data locations with existing CFB sea level points and sea level points derived for the coastal flood map