Natural flood management summary: Methodology and mapping

1. Introduction

The Flood Risk Management (Scotland) Act (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.

As part of this approach SEPA is required to consider whether techniques that restore, enhance or alter natural features and characteristics can contribute to managing flood risk. These techniques are referred to as natural flood management (NFM).

The production of NFM maps, a requirement of section 20 in the FRM Act, presents the first national source of information on opportunity areas for NFM across Scotland. They are part of a suite of tools which will be used in the Flood Risk Management Planning Process to help us to produce Scotland's first set of national co-ordinated to manage flooding.

This document provides a summary of the approach and development of NFM maps and how this information should be interpreted. 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 how we are considering NFM as part of the FRM Planning process and the areas where there is an opportunity for these techniques to be implemented.

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. Future development

NFM Maps will be considered through the FRM Planning process and will be one of the inputs used to produce characterisation reports. Any NFM opportunities identified will also be included in the list of FRM actions SEPA will recommend in its FRM Strategies, published in 2015. There will be a circular flow of information throughout the FRM Planning process, which will enable the maps to be updated.

3. Methodology and data

3.1 Approach

SEPA undertook a national screening exercise to identify areas where there are opportunities for alteration or restoration of natural features to help manage flood risk. Five natural flood management maps have been produced:

- Run off reduction
- Floodplain storage
- Sediment management
- Estuarine surge attenuation
- Wave energy dissipation

Each map identifies opportunity areas for a different set of NFM techniques, as detailed in table 1 (page 13). They provide a high level assessment of those areas within catchments and along coastlines where the implementation of the specified NFM techniques could be most effective and merit further investigation.

3.2 Data

The data used to produce the natural flood management opportunity maps is listed in table 2 (page 14), alongside a description of the data, how it was used and the quality review process.

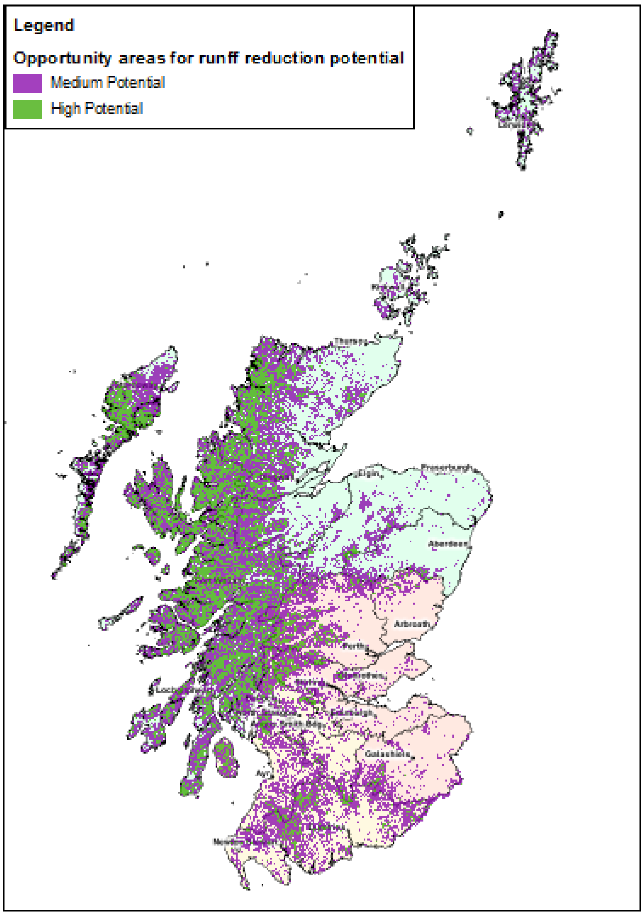

Diagram 1, Output for Opportunity areas for Runoff Reduction

3.3 Methodologies

The maps have been produced using nationally-applied methodologies. This is with the exception of the map showing opportunities for sediment management which focuses on the catchments containing a PVA only. The outputs used to create the maps (table 3, page) were classified from very low NFM potential to high NFM potential. moderate and high outputs only have been used to create the final maps.

3.3.1 Runoff reduction

This map identifies which areas, within a catchment, contribute most to the generation of river and surface water flows so that runoff reducing measures, such as woodland planting, can be targeted to areas where they would be most effective.

The approach is based on the Environment Agency's method for the identification of catchments sensitive to land use change[1]. In this method, land cover, soil type, slope and long term average rainfall are combined to create a 'combined sensitivity' score for 250m^2 grid cells (Equation 1, below).

[1] Environment Agency 2008. Delivery of Making Space for Water: Identification of catchments sensitive to land use change NA788.
http://archive.defra.gov.uk/environment/flooding/documents/manage/catchments.pdf

$$\text{Combined sensitivity} = \frac{\text{land cover class} + \text{soil class} + \text{slope class} + \text{rainfall class}}{4}$$

Equation 1: Summarises how the land cover, soil, slope and rainfall classes are combined to generate a combined sensitivity score.

3.3.2 Floodplain storage

This map identifies areas within floodplains of the 200 year return period where there is the greatest potential to increase floodplain storage. The production of this data involved two stages of assessment the 250m gridded outputs of which are then combined. For each 250m grid, the highest category of the two outputs is selected and those areas with moderate to high floodplain storage potential shown in the final published output, see diagram 2 below.

Diagram 2, Output for opportunity areas for floodplain storage

3.3.2.1 Floodplain Storage based on slope alone

The first stage of the assessment identifies the potential for floodplain storage based on the slope of the water surface; the rationale being that there is greater capacity to hold water on more gently sloping reaches. Water surface slope was determined from water levels taken from the fluvial flood map for the 200 year return period. The output of this assessment shows areas of very low to low slope (moderate to high potential) on a 250m grid. This approach identifies lochs as having floodplain storage potential as the water surface here is flat. However, such waterbodies are not be considered for floodplain storage.

3.3.2.2 Floodplain Storage based on slope and roughness

The second stage of the assessment identifies the potential for increased floodplain storage through floodplain roughening (such as planting). This assessment considers the maximum possible increase in land roughness as well as water surface slope, and identifies areas of low slope with the greatest potential to increase vegetation roughness as having the greatest potential for floodplain storage. The land cover map 2007 is used to derive current roughness values whilst maximum potential roughness is based on the land capability map for forestry (LCF). The maximum potential increase in roughness (n max – n existing) was then divided by the water surface slope (S) (Equation 2).

$$ISP \approx \frac{\left(n_{\max} - n_{existing}\right)^2}{S}$$

Equation 2. Equation for generating a measure of indicative increased storage potential through floodplain roughening.

3.3.3 Sediment management

This map classifies reaches of a river based on whether they are a source of sediment, transporting sediment or depositing in-stream coarse sediment. The purpose of the map is to identify measures to manage morphology-driven flood mechanisms, such as the management of channel instability. It can also be used to inform the selection of some of the NFM techniques which fall under the runoff and floodplain storage maps as shown in table 1, Appendix A.

The 'Sediment Transport: Reach Equilibrium Assessment Method' (ST:REAM), developed at the University of Nottingham [2] was applied to Scottish catchments to produce this map.

This map shows river reaches as high deposition, moderate deposition, balance, moderate erosion, or high erosion.

The output has been created using a rivers dataset which covers rivers with a catchment of more than $10km^2$. The tool has been run for catchments which have a baseline river in a Potentially Vulnerable Area (PVA). Therefore some parts of the country do not have an output.

[2] Parker, C. 2010. Quantifying catchment-scale coarse sediment dynamics in British rivers. Ph.D.Dissertation Thesis, University of Nottingham, Nottingham.

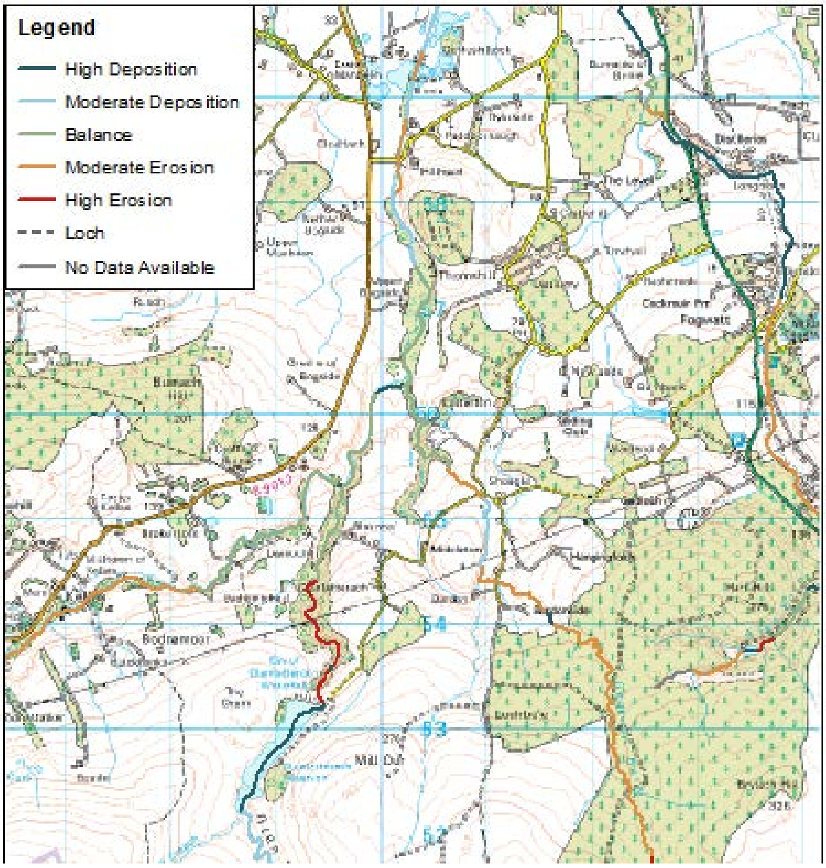

Diagram 3, Output for opportunity areas for sediment management

3.3.4 Estuarine surge attenuation

This map helps to identify areas within estuaries where techniques such as regulated tidal exchange or coastal realignment could be used to reduce estuarine surge and thereby contribute to reducing flood risk.

This screening method uses water depth data from the coastal flood map for the 200 year return period. Data is classified from 1 (very low potential) to 4 (high potential) with larger depths equating to higher potential as the benefit offered is assumed to be directly proportional to the depth of water. Data is only shown for areas classified as estuaries under the Water Framework Directive.

Diagram 4, Output for opportunity areas for estuarine Surge attenuation

3.3.5 Wave energy dissipation

The purpose of this map is to help identify areas where salt marshes or other techniques, such as artificial reefs or sand dune restoration, could be used to reduce wave energy arriving at the shore. Such techniques could be used to reduce the flood risk associated with wave action, or supplement existing direct defences to either extend their lifespan or to increase the standard of protection they provide. The approach relates the space available for dissipation of wave energy with a proxy for wave energy (Equation 3).

Wave energy dissipation potential = Wave power / Space for Attenuation

Equation 3. Equation used to determine wave energy attenuation potential

For this screening, fetch (the distance over which wind can blow to create waves) has been used as an approximation for wave power as no national wave power dataset currently exists at a resolution suitable for this screening. Space for attenuation is the distance between mean high water spring and mean low water spring, for example where a cliff exists the space for attenuation will be zero. Both these datasets were split into 5 classes from 1 (low) to 5 (high) before being combined to produce the final output as shown in equation 3. The output is based on the rationale that there is greater potential to dissipate wave energy where the space available is comparatively greater than the wave energy i.e. areas were assumed to be of greater potential if the space for attenuation class was higher than the wave energy class.

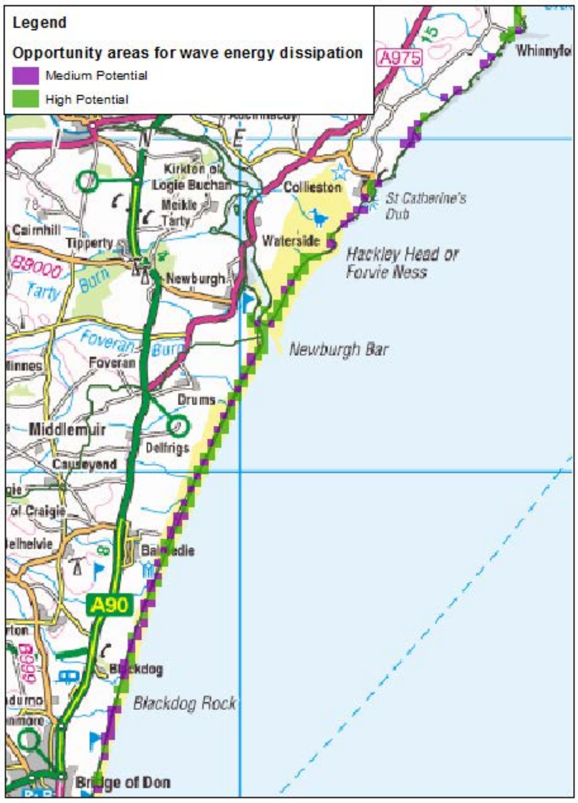

Diagram 5; Output for opportunity areas for wave energy dissipation

4. Validation and quality review

- **Peer contribution/review –** The methodology for the NFM maps was reviewed by a technical advisory group with membership from SEPA, Forestry Commission Scotland and Forest Research. The Scottish Advisory and Implementation Forum for Flooding (SAIFF) NFM group also reviewed and provided advice on the approach. This methodology was also peer reviewed by the Centre of Expertise for Waters (CREW). These reviews provided an opportunity for input into the development of the methodology.

- **Internal review-** NFM is a developing research area and our evidence base of where NFM measures might be effective is still evolving. There is currently limited field data available which inhibits the extent of validation that can be undertaken outputs.
    - For run off reduction, floodplain storage, estuarine surge attenuation and wave energy dissipation an internal review of the outputs and underlying datasets was undertaken in GIS:
        - Manual checks were undertaken on datasets which had been re-sampled from one resolution to another to ensure that values in the re-sampled output seemed reasonable, that there were no

extreme values and that the datasets still aligned with the originals.
  - Manual check of classifications applied to datasets was carried out to ensure that values of slope for example, fell within the correct category between 1 and 4.
  - Automated checks were also undertaken in a sample of areas to ensure that datasets which had been created by automated processes had worked correctly, for example hydraulic slope was checked by re-running the slope tool in some hydrometric areas.
  - A manual sense check of final outputs was undertaken in GIS to ensure that areas identified as being of high/medium potential seemed logical; for example checking that areas classified as high potential for wave attenuation potential weren't showing areas of cliffs, or that areas of medium floodplain storage potential weren't showing steeply sloping reaches of river

- **Local authority and stakeholder review** - Map outputs were reviewed at FRM local advisory group (LAG) meetings, and if requested, datasets sent out to local authorities and stakeholder organisations for a more detailed review. This provided an opportunity to compare outputs against local knowledge.

5. Interpretation

NFM maps have been developed using a nationally applied methodology. They are tools to support FRM planning and the identification of appropriate actions to tackle flood risk. The maps will also help to raise awareness and understanding of NFM and how these techniques will help us to tackle flood risk. The farming community and other land owners/managers have shown a particular interest in the maps and their use and are therefore a key audience to be considered.

The maps do not directly recommend which specific measure should be implemented where, nor do they facilitate the quantification of the flood risk management benefit, or wider benefits of undertaking a specific natural flood management activity.

The maps are of a strategic nature and support FRM Planning decisions at the catchment level. The zoom on the maps hosted on the SEPA website, has been set to support the use of information at a community scale.

With any methodology being applied nationally there are assumptions and inherent uncertainty. The maps should be viewed as the first step in identifying areas for NFM techniques to be implemented prior to site specific assessment.

The maps are not licensed for commercial use and all users must agree to terms and conditions before viewing the map.

5.1 Assumptions

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

5.1.1 Resolution and classification

The outputs and the underlying datasets have been produced at either 100m, 200m or 250m grid resolution, or are shown as river reaches based on a 50m dataset. It is assumed that any loss in detail at this resolution is acceptable for a strategic, national output.

Similarly datasets have been classified from 1 (low potential) to 4 (high potential) and it is assumed that any loss in detail due to this is acceptable for a strategic, national output.

5.1.2 Fluvial and coastal flood map datasets

200 year return period (medium likelihood) water levels from the fluvial flood map and 200 year return period (medium likelihood) water depths from the coastal flood map were used in the production of the NFM maps. Assumptions which applied to the production of these datasets are also relevant for the NFM maps.

5.1.3 Current and maximum land cover roughness

The LCM2007 dataset is used to derive current roughness values and therefore it is assumed that LCM2007 is an accurate representation of current land cover on a national scale.

Maximum land cover roughness is derived from the current roughness dataset and also from the LCF map. The LCF dataset was chosen as field evidence suggests that a substantial amount of floodplain roughening is required to have an effect in a flood event and forestry generally represents maximum possible roughness. Areas classed as having limited to no potential for forestry were discounted from the screening for similar reasons. It is assumed that the LCF dataset is a fair representation of the maximum potential increase in roughness in the 200 year return period (medium likelihood) fluvial floodplain.

5.2 Limitations

NFM maps have been produced at the national scale using national datasets and nationally consistent methodologies. The maps are strategic and should be viewed at the community level. They are not suitable for street level or property assessment.

Due to the strategic nature of the output and the methodology used there are limitations associated with the NFM maps**:**

- Only data available at a national scale could be used in the derivation of the maps as the tools used were run nationally.
- Due to the lack of a suitable national wave power dataset a fetch dataset has been used a proxy for wave power. Fetch data has been used to determine wave exposure indices in Scotland in published research[3] however a wave power dataset would have been preferable.
- A national surge dataset does not exist for all estuaries and therefore still water sea levels from the coastal flood hazard map have been used as a proxy for a national surge dataset. The sea levels from the coastal flood map do not take wave set up due to bathymetry in estuaries into account and therefore do not fully represent surge in these areas.

[3] Wave exposure indices from digital coastline and the prediction of rocky shore community structure, M. T. Burrows, R Harvey & L Robb, Marine Ecologyy Progress Series Vol. 353, 2008

Appendix A

Table 1: NFM techniques related to each screening

Screening output	Measures
Runoff reduction	Woodland planting (conifer, native, broadleaf)
	Land Management, including; soil and bare earth improvements, changing agricultural field drainage.
	Creation of cross slope tree shelter belts
	Creation / restoration of non-floodplain wetlands
	Upland drain blocking
	Gully woodland planting
Floodplain storage	Floodplain reconnection
	Afforestation of floodplains
	Creation of riparian woodland
	Placed large woody debris and boulders
	Reach restoration (planform restoration)
	Creation of washlands
Sediment management	Reach restoration (planform restoration)
	Managing channel instabilities
	Sediment traps
	Bank restoration (e.g. riparian planting, green bank restoration)
Estuarine surge attenuation	Creation/ restoration of intertidal area including mudflats and saltmarsh, and regulated tidal exchange
Wave energy dissipation	Beach management (beach recharge schemes and shingle management)
	Artificial/ biogenic reefs and detached breakwaters
	Sand dune restoration (e.g. dune fencing and thatching, marram grass planting)
	Creation/ restoration of intertidal area including mudflats and saltmarsh

Table 2: Data as an input to the fluvial flood map

Data	Description	How the data was used	Quality check
Land cover Map 2007 (lcm2007)	LCM2007 has been derived from satellite images and digital cartography and gives land cover information for the entire UK on a 25m grid. Land cover classes are based on UK Biodiversity Action Plan Broad Habitats, for example coniferous forest or saltmarsh. LCM2007 is produced by the Centre for Ecology and Hydrology (CEH) (http://www.ceh.ac.uk/landcovermap2007.html).	LCM2007 was used in the runoff opportunity map to determine sensitivity to runoff. LCM2007 was degraded from 25m to 250m resolution. A sensitivity score was attributed to each land cover class in the dataset, in line with the classes applied by the EA in their study. LCM2007 was also used to determine mannings roughness values for the 200 year fluvial floodplain as explained below for the current roughness dataset.	Runoff sensitivity classes were the same as those applied in the EA study, which has been used in England and Wales. Manual checks were also carried out to ensure the resampled 250m^2 values were appropriate.
Base flow indicator of hydrologu of soil types (BFIHOST)	Soils in the UK have been classified according to their hydrological properties on a 1km grid in the Hydrology of Soil Types dataset. Base flow index is indicative of catchment responsiveness; lower figures represent less permeable soils and vice versa. BFI HOST values can be worked out for any soil in the HOST dataset, and therefore for any 1km grid square in the UK.	BFIHOST was used in the runoff opportunity map used to look at sensitivity to runoff. BFIHOST was calculated for the 1km^2 HOST dataset & resampled to 25m^2 grid. BFIHOST values were classed from 1 (low runoff) to 4 (high runoff) using a statistical classification method.	The calculation used to create BFI HOST values for 1km2 grids is published in the Flood Estimation Handbook, and is a widely used and accepted method. The BFIHOST values were checked by re-running the calculation manually. Manual checks were also carried out to ensure the resampled 250m^2 values were appropriate.
Standard - period Annual Average Runoff (SAAR) For 1961 - 1990	SAAR is a MET Office product which provides long term annual average rainfall totals for the UK on a 1km grid for the period 1961 to 1990.	SAAR was used in the runoff opportunity map used to look at sensitivity to runoff. SAAR was resampled from 1km^2 to 250m^2. Values were classed from 1 (low runoff) to 4 (high runoff) using the classes applied by the EA in their study.	SAAR is a dataset published by the MET Office and therefore no quality checks were carried out on this dataset. Manual checks were also carried out to ensure the resampled 250m^2

			values were appropriate.
Ground slope	Ground slope was derived on a $250m^2$ grid from the NEXT Map ground model.	Ground slope was used in the runoff opportunity map used to look at sensitivity to runoff. Slope was derived by using a GIS 'slope' tool on 5m Nextmap data and then resampled to $250m^2$. Values were classed from 1 (low runoff) to 4 (high runoff). Classes used are similar to those used by the EA, however slightly altered to account for steeper slopes in Scotland.	The slope dataset was sense checked for extreme values and some areas were re-run to ensure model outputs were consistent. Manual checks were also carried out to ensure the resampled $250m^2$ values were appropriate.
Current Roughness	Roughness values are an indication of resistance to flood flows, the higher the figure the higher the resistance i.e. water will flow more slowly. Current roughness dataset shows mannings roughness values attributed to LCM2007 classes on a 250m grid covering the entire country.	Current Roughness was used in the floodplain storage opportunity map to work out the possible change in roughness values on the 200 year fluvial floodplain. A roughness value was attributed to each vegetation class in the $25m^2$ LCM2007 dataset using published roughness information and guidance. The dataset was then resampled to $250m^2$.	Roughness values attributed to this dataset were checked by SEPA staff familiar with hydraulic modelling and against guidance on roughness values. Manual checks were undertaken in a GIS to ensure that the values had been attributed to the LCM2007 dataset correctly and that the resampled $250m^2$ values were appropriate.
Maximum Roughness	This dataset shows the maximum roughness values possible on the 200 year fluvial floodplain by altering vegetation cover. This dataset is a combination of current roughness values where there is no potential to increase vegetation roughness, and increased roughness values where the Land Capability Map for Forestry (LCF) suggests that there is good flexibility for supporting forestry	Maximum Roughness was used in the floodplain storage opportunity map to work out the possible increase in roughness values on the 200 year fluvial floodplain. This was derived by attributing mannings roughness values to the Land Capability for Forestry dataset, which classifies land from unsuitable to excellent based on its flexibility for supporting forestry. In	Roughness values attributed to this dataset were checked by SEPA staff familiar with hydraulic modelling and against guidance on roughness values. Manual checks were undertaken in a GIS to ensure that the agreed values had been

		areas classed as having limited to no potential current roughness values were retained whilst for other classes the LCF roughness value was adopted.	attributed to the LCM2007 and LCF datasets correctly and that the resampled $250m^2$ values were appropriate.
Hydraulic Slope	Hydraulic slope is the slope of the water surface for the 200 year fluvial flood event.	Hydraulic slope was used in the floodplain storage opportunity map to identify flat/low sloping areas. Water levels were taken from the fluvial flood hazard map and slope derived using the slope tool in a GIS. The dataset was then resampled from $5m^2$ to $250m^2$.	Manual checks were undertaken in a GIS to ensure that the resampled $250m^2$ values seemed sensible and some areas were re-run to ensure that the tool was producing consistent outputs.
200 year coastal flood depths	200 year coastal flood depths are water depths for the 200 year coastal flood event.	200 year coastal flood depths were used in the estaurine surge attenuation output to identify areas of greater depth and therefore greater potential. Depths were taken from the coastal flood hazard map and degreaded from $5m^2$ to $100m^2$ in a GIS.	Manual checks were undertaken in a GIS to ensure that the resampled $100m^2$ values seemed sensible
Space for Attenuation	Space for attenuation is the distance between the Mean high Water Springs line (MHWS) and the Mean Low Water Springs line (MLWS), This is the intertidal zone.	Space for attenuation was used in the wave attenuation potential output to identify areas with room to attenuate wave energy by implementing NFM measures. The dataset was derived by working out the distance between MHWS and MLWS in a GIS.	This dataset was manually sense checked against the MHWS and MLWS lines to ensure that values were appropriate.
Fetch Dataset	Fetch represents the distance over which wind can blow to create waves. A fetch index has been used to represent the distance to the nearest coastline.	The fetch dataset was used in the wave attenuation potential output and has been used as a proxy for a national wave power dataset.	This dataset was provided by Glasgow University and was therefore not quality checked
Sediment management output from the ST:REAM tool.	The ST:REAM tool classifies river reaches into sediment sources (i.e. erosion), sediment deposition or	The ST:REAM tool output was used to look at sediment management issues within a catchment. The tool considers	This tool was validated against field observations and photos of sediment for 4

	transport (i.e. balance in amount of sediment coming into and leaving a river).	topology, channel slope, channel width and annual median flow values for a reach of river and then calculates the annual mass of sediment predicted to enter a reach with the annual mass of sediment predicted to leave that reach.	pilot catchments in Scotland.