Scotland's 4th National Planning Framework has recently been published. This document is therefore being reviewed and updated to reflect the new policies. You can still find useful and relevant information here but be aware that some parts may be out of date and our responses to planning applications may not match the information set out here.

SEPA
Scottish Environment Protection Agency
Buidheann Dìon Àrainneachd na h-Alba

Technical Flood Risk Guidance for Stakeholders

- SEPA requirements for undertaking a Flood Risk Assessment -

Version 13 June 2022

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1. Introduction

This document is designed to outline what information SEPA requires to be submitted as part of a Flood Risk Assessment (FRA) and to outline methodologies that may be appropriate for design flow estimation (hydrological modelling) and hydraulic modelling. The complexity of the FRA required will reflect the nature of the flooding problems, the mechanisms of flooding, and the characteristics of the site, rather than the complexity or scale of the proposed development. An FRA should be undertaken where any available information indicates there may be a risk of flooding to the site, or development of the site may increase risk elsewhere. The FRA must include sufficient information to provide a robust assessment of flood risk. The Planning Authority ultimately determines the requirement for an FRA to be undertaken.

SEPA is an independent advisor on flood risk within the context of National Planning Policy. This includes a statutory role to provide flood risk advice for certain consultations. Where SEPA receives an FRA in connection to a planning application that raises fluvial or coastal flooding issues, it will:

- Audit the FRA and advise on the soundness of the data used, methodology, conclusions, and recommendations proposed.
- Provide its own advice and comment on flood risk to the Planning Authority based on the audited FRA, and any other information held by or available to SEPA and reviewed in line with Scottish Planning Policy and the Flood Risk Management (Scotland) Act 2009.

The cornerstone of sustainable flood risk management is the avoidance of flood risk in the first instance. Flood Risk and Land Use Planning have a crucial role to play in ensuring that, wherever possible, a sustainable approach is taken towards flood risk management and the functional floodplain is protected. The clear presentation of data will enable an improved review and response time to Planning Authorities. SEPA therefore recommends that this document is reviewed and the guidance followed to ensure that appropriate techniques are applied, and sufficient information is supplied to avoid unnecessary delays in the planning process.

This document is intended to assist developers in carrying out site specific FRAs to inform land use planning. SEPA have provided other guidance that may be more appropriate depending on the requirements of the study in question:

- A Strategic Flood Risk Assessment (SFRA) is designed for the purposes of informing the development plan process (Local Development Plans). A SFRA involves the collection, analysis and presentation of all existing flood risk information for the area of interest. A SFRA would present a strategic overview of flood risk without necessarily meeting the reporting requirements of a detailed site-specific FRA. SEPA have prepared guidance on undertaking Strategic Flood Risk Assessments.

- SEPA have also prepared Flood Modelling Guidance for Responsible Authorities that is designed to support those key partners who are responsible for developing and commissioning flood studies in respect of flood risk management planning. It provides guidance on where uncertainty may arise in flood modelling and how it may be managed through the modelling process so that it can inform appropriate decisions. Responsible Authorities are encouraged to refer their contractors to that guidance to promote compliance with best practice.

2. SEPA Flood Maps

The SEPA Flood Maps are intended as a high-level tool to support decision making for flood risk management, and land use planning at a strategic level. The SEPA Flood Maps have been produced following a consistent, nationally applied methodology for catchment areas equal or greater than $3km^2$ using a Digital Terrain Model (DTM) to define river corridors and low-lying coastal land. Small watercourses with catchments less than $3km^2$ will not be identified by the fluvial extent of the SEPA Flood Maps. Small watercourses are poorly understood with respect to the severity of the flood hazard that can be generated on a catchment of this scale. Therefore, if a small watercourse has not been identified by the SEPA Flood Maps, this should not be interpreted as there being an absence of risk.

SEPA's Coastal Flood Maps are based on the astronomical tide level plus a surge factor, but do not include wave action or wave overtopping. In some areas in Scotland, the maps are based on more detailed modelling.

The flood extents shown by the SEPA Flood Maps are indicative in nature. The flood extents shown do not fully take account of structures such as culverts, bridges and that can influence local flooding. The SEPA Flood Maps do not account for fluvial and coastal flooding occurring simultaneously. Flood defences are generally not taken into account in the Flood Maps, but there are exceptions where more detailed modelling is available, and this has been incorporated into the Flood Maps. In such circumstances, users of the SEPA Flood Map are advised to also check any the extents of any areas of benefit.

The SEPA Flood Maps can be used, along with other sources of flood risk information, to provide an initial assessment of likely flood risk to a site. However, due to the indicative nature of the flood extents and necessary limitations of the methodology it does not make them suitable to explicitly quantify the potential flood risk at street or property level. Therefore, it is inappropriate for the SEPA Flood Maps to be used to assess flood risk to an individual property, or to be used to inform a detailed Flood Risk Assessment. The SEPA Flood maps cannot be used for commercial purposes, as outline in the Terms and Conditions of the maps, which all users must agree to before viewing the maps online.

Key caveats exist regarding the use of the Flood Maps that should be read, understood and adhered to. Further details are available on the SEPA website.

3. Requirements for Flood Risk Assessment (FRA)

3.1 Introduction

The functional floodplain is defined as land where there is a 0.5% or greater annual probability of flooding in any year. This probability is sometimes referred to as a 1 in 200-year flood. For development that falls under the 'Most Vulnerable Use' as defined by SEPA's Land Use Vulnerability Guidance, the 0.1% annual probability (1 in 1000-year flood) should be assessed and, in the case of civil infrastructure, avoided. In certain complex cases, an FRA may be required to assess pluvial flooding. Further information on surface water and pluvial flooding is outlined in Chapter 7.

An FRA for a specific site should investigate what the likelihood of flooding is, and should consider flood risk from all sources. It should demonstrate if the site is out with the required flood extent for the relevant probability, or if development of the site would be, appropriate, then what acceptable mitigation measures would be required. The complexity of the flooding mechanism(s) will inform the scope of the FRA required, and the information required can take a variety of forms.

Prior to investing in an FRA, applicants should consider the potential outcome of the assessment. We would caution that for some sites, providing additional information or a detailed flood risk assessment may only serve to confirm that this site is within the functional floodplain and therefore not suitable for development.

While SEPA will not provide recommendations for flood risk consultants, we offer the following advice when commissioning flood risk assessments:

- Contact more than one specialist or company to discuss your requirements and costs, ask for references and follow them up.
- Ask if they have experience in undertaking this type of assessment, taking into consideration the complexity if the flooding mechanisms at the site.
- Ask if their previous work has been accepted by SEPA in support of planning applications.
- Ensure they are familiar with and have used the guidance available on the SEPA website.
- Consider if they have a potential advantage by having local knowledge and experience.

3.2 Minimum Requirements for Flood Risk Assessment

There are a number of methods, of varying complexity, which can be used to assess the flood risk for a development and assess any impacts elsewhere. SEPA's advice will be based on the information available at the time of consultation. Therefore, in order to receive the most detailed advice, and avoid any unnecessary delays it is helpful to submit any supporting flood risk information at the application stage, although there may be cases where after review, further flood risk information is still required. SEPA welcome pre-application engagement with applicants and developers to discuss flood risk considerations and to identify the supporting information that is likely to be required.

As a minimum, we would require the following information to be submitted for any site that requires an FRA:

- Plans: a clearly geo-referenced location plan at an appropriate scale that includes geographical features and street names. The plan should identify all watercourses or other bodies of water in the vicinity of the application site that may have an influence. This should include drainage outfalls, overflows, and culverted watercourses. The site plan should show the location of the proposed development and include information on any existing development at the site that may be either retained or demolished.

- Photos: Photographs of the site should show the area of the proposed development relative to any watercourses or coastlines. Photos of the watercourse should show the channel, banks, floodplain, and any culverts or structures. Labelling should be provided to clearly identify what the photographs are showing (i.e., direction, location, flow direction etc.). Where possible a scale (metre staff) should be included within the photographs themselves. Photos should ideally be date stamped. If appropriate, other areas of importance should be identified and photographed such as areas of erosion, trash-lines from flood events, areas of woody debris accumulation etc.

- Topographic Information: As a minimum, a plan should be provided showing the existing ground levels at the site, and if applicable the proposed ground levels and finished floor levels. Any land raising should be clearly identified. Levels should be shown relative to Ordnance Datum Newlyn or to the local OS datum for Shetland (Lerwick) and the Western Isles (Stornoway).
- Cross Sections: Other topographic information could include site cross-sections. Sections should be of an appropriate length to include the application site, the channel bed levels, and bank levels of the opposite bank. Levels should be shown relative the metres above Ordnance Datum (Figure 1). Sections should always be taken perpendicular to the flow in the channel.

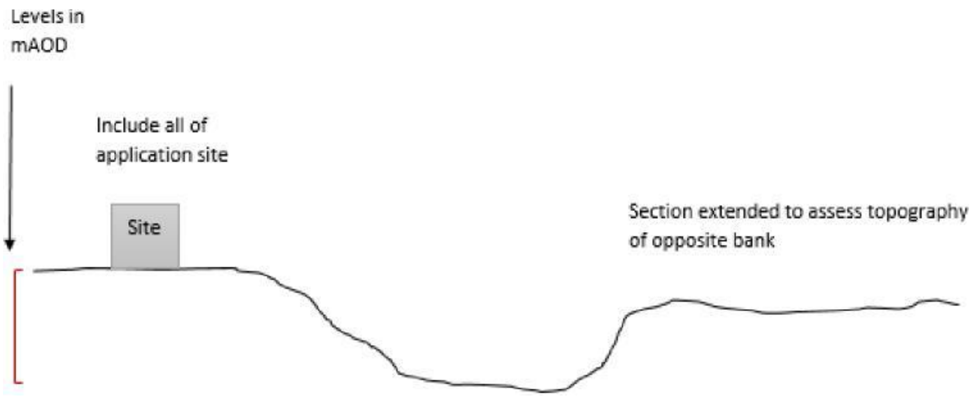

Figure 1. Example of appropriate site cross section.

As a minimum, sections would expected to be taken at points, upstream, downstream, and through the site. However, the appropriate spacing and number of cross-sections will depend on the physical characteristics of the channel e.g., taking into consideration the channel uniformity and slope. Additional sections would also be required at keys areas of interest including structures like bridges and culverts, significant changes in the channel or floodplain width, slope, or roughness, and if applicable, at gauging stations where information is available for calibration (Figure 2).

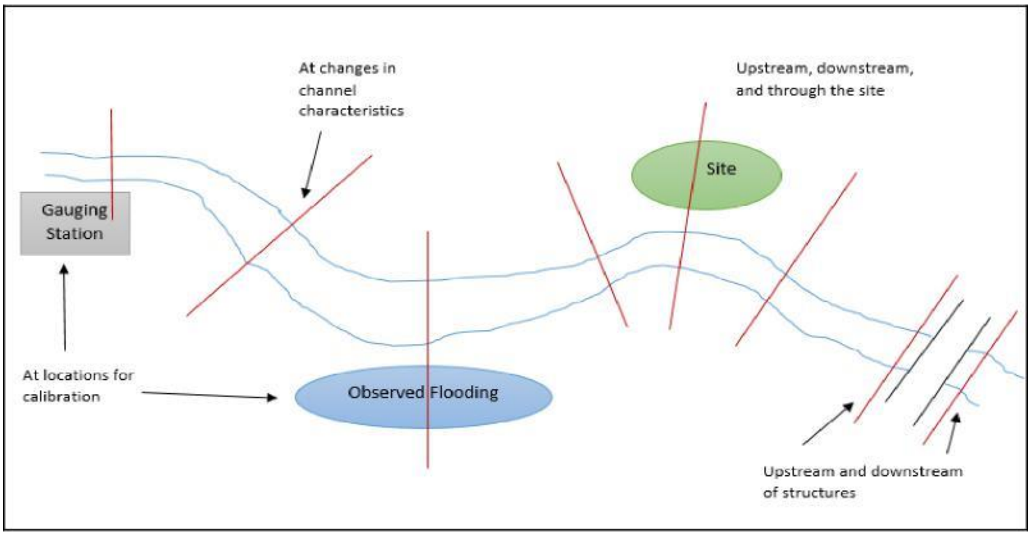

Figure 2. Example of suitable locations for cross sections. The number and spacing will depend on channel characteristics and the complexity of the FRA or hydraulic model.

- Structural Information: Details of any structures, such as culverts, bridges, weirs, and croys, which may influence water levels, should be provided. Further details on the conveyance capacity of such structures may also be required. Therefore, information on the dimensions of the structure including the opening shape, size, slope, length, invert and soffit level, material and condition, and flood relief level should be provided, alongside any initial assessment of the capacity of this structure.

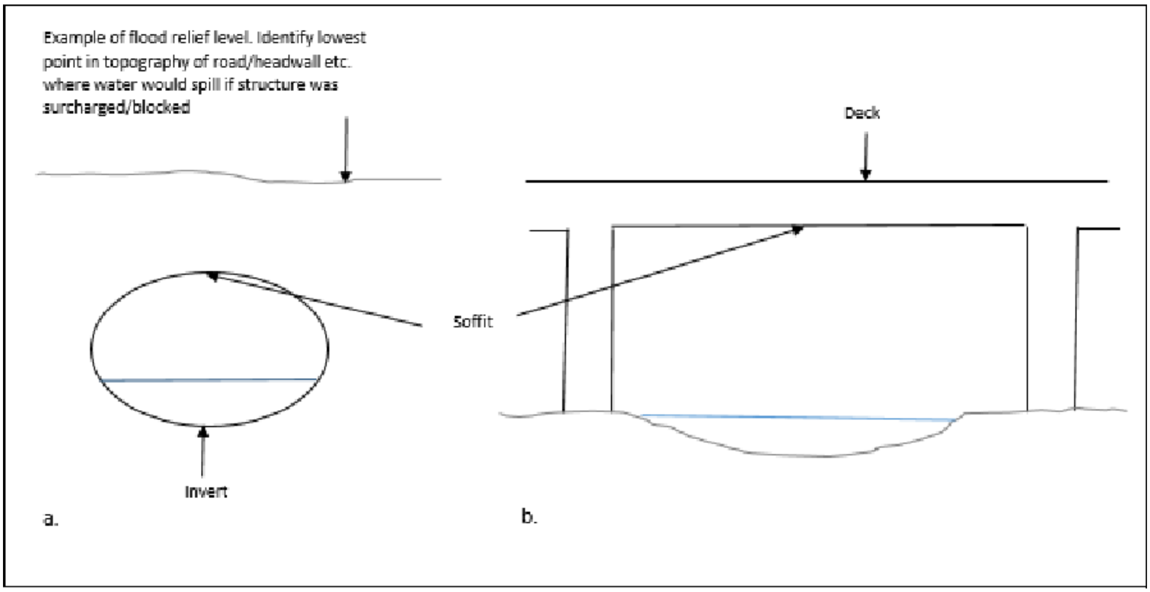

Figure 3. Examples of key structural information required a. culvert and b. bridge

- Other site-specific information: If applicable and available, details of any previous flooding at the site including the date and time of the event. This information could be anecdotal, and if possible, photos of flooding or trash lines should be provided to obtain an indication of the extent and depth of observed flooding. Although appropriate site photos should be provided, if not available then a description of the channel and floodplain should be included. If relevant, details of any existing flood alleviation measures should also be provided, along with the confirmed Standard of Protection.

For some sites, this information may be sufficient for us to verify the flood risk and no further information would be required. However, if this information were insufficient to provide a robust assessment of the risk of flooding to the development or elsewhere, then a detailed flood risk assessment would need to be provided and carried out by a suitably qualified professional.

3.3 Detailed Flood Risk Assessment

When a more detailed FRA is required, methods should be applied in accordance with available guidance, including the advice outlined in this document. Other literature and guidance could be used for reference, and up-to-date industry standards as appropriate for the site in question should be followed. All available local data and information of relevance should be utilised for any assessment. A precautionary approach should be applied, and particular attention paid to uncertainties and model sensitivity.

The FRA should identify the source of potential flooding i.e., fluvial, coastal, surface water (pluvial), or combinations of sources of flooding e.g., fluvial and coastal. The following chapters refer mainly to fluvial flood risk assessments that require hydraulic modelling. Other sources of flooding are discussed in later chapters. Fluvial flood risk assessments should identify the following elements:

- An assessment of appropriate design flows and flood levels at the site. This should provide sufficient information on the derivation of the design flows for auditing purposes. More detailed guidance on design flow estimation is presented in Chapter 4.

- An assessment for future climate change should be carried out, in order to take a precautionary and sustainable approach to flood risk assessment. Our recommendation is set out here albeit some local authorities may request a different standard be utilised by developers.

- Sensitivity analysis. Further guidance on sensitivity analysis is presented in Chapter 5.

- Details of any structures (including culverts, embankments, walls etc.) that may influence local hydraulics, and an assessment of how any structures may influence water levels at the site. Where culverts provide a significant flow restriction, levels and discharge rates at which flow would overtop the structure should be identified. An assessment of culvert blockage, and likely impacts should be carried out.

- The flood extent, depth, velocities, and flow pathways for appropriate return periods should be indicated on a site plan that shows the footprint of the proposed development. Any site sections should show the finished floor levels and any changes in ground level relative to the modelled flood level.

- An assessment should be made of the likely rate at which inundation may occur, or an identification of the order at which areas of the site may flood. Publicly accessible dry pedestrian access/egress routes to higher ground or refuge point should be clearly identified on a plan.

- Details of any mitigation measures proposed. In the case of any proposed land raising, estimates should be made of the expected volumes of water, which would be displaced from the site because of any land raising. For any land raising proposed, details of associated compensatory storage should be provided. Further guidance on land raising and compensatory storage is presented in Chapter 9.

- If appropriate, an assessment of the off-site flood risk as a result of the development should be made, identifying any changes in flows and levels upstream or downstream of the development. An assessment should be made of the likely impact of any displaced water on neighbouring locations by undertaking pre and post development modelling.

- The FRA should conclude with a summary of its findings.

4. Guidance for Fluvial Design Flow Estimation

4.1 Introduction

Estimation of the design flow can be a significant variable in determining flood risk at a site. No single method is considered as always being able to provide the 'right' answer, but correct application of the Flood Estimation Handbook (FEH) should preferentially be used to estimate design flows, and more than one method should be used for comparison.

The FRA should provide justification that the method used are the most appropriate for the specific site and catchment. While SEPA cannot always recommend one methodology over another, different factors need to be considered for different catchments and therefore we would have a preference for certain methods based on catchment specific circumstances. For each site the size and nature of the catchment needs to be considered, and if any gauged data and historic records of flooding are available.

The FEH web service (or CD-ROM) defines the catchment area, and catchment descriptors for catchments >0.5km^2. However, for small catchments, or catchments that are more 'unusual' for example those with a particularly flat topography or a number of artificial drainage channels we would require the catchment area to be verified against Ordnance Survey maps. If the catchment area is incorrectly defined then, this has implications for the catchment descriptors and flow estimation.

Design flow estimation in small catchments has more uncertainties as there is usually a lack of gauging stations. Generally, FEH methods are suitable for catchments down to 0.5km^2. The preferred method for estimating flow in catchments smaller than 0.5km^2 is to use a suitably sized donor catchment with similar catchment descriptors and to scale the FEH method by area.

While preference would be for FEH methods, other methods such as the Flood Studies Report or IH124 can be used in parallel where is they may be applied with justification. In these cases, the methods should be correctly labelled, and applied.

Design flow estimation should be carried out using the professional judgement and experience of the flood risk consultant. The review of design flow estimations submitted, as part of an FRA, will be carried out based on the professional judgement and experience of SEPA's flood risk hydrologists. However, this chapter provides advice that may assist in ensuring that best practice is followed, and the most up-to-date and appropriate methods be used in assessments to aid consensus on the best approach.

4.2 FEH Statistical Method

Hydrometric authorities hold flood data for many gauging stations not included in the FEH/National River Flows Archive (NRFA) UK database. Up to date station data should be included for all sites used in the analysis. Station data is available free of charge from the NRFA for all UK sites in Version 6 WINFAP-FEH dataset. For any stations with out of data, recent data should be requested. When using the statistical method, it should be considered if there are more appropriate gauging stations not included in the FEH/NRFA UK database, for use as donor sites and for inclusion in pooling groups. More recent data can be requested from SEPA here.

QMED is the median annual flood or the 1 in 2-year flood. QMED estimates should be improved using appropriate, hydrologically similar, local data, either from the catchment in question or nearby catchments, unless justification is provided for the use of catchment descriptors only. QMED should only be estimated from catchment descriptors as a last resort. The channel dimensions approach to estimate QMED may be acceptable as part of other methods for determining QMED as stated in the FEH.

Pooled analysis is usually required for large ungauged catchments. Revisions of FEH Pooling Groups should always be considered. Pooling groups should include sites based on catchment/hydrological 'similarity' rather than geographical location, and stations within the groups need to include up-to-date data. In some cases, single-site analysis may be more appropriate than using a pooling group, particularly when long high-quality gauged data is available, and the pooling group results do not reflect the flood history of observed data sufficiently.

The FEH Vol 3.17.3.2 advises, and studies have agreed that, on average the Generalised Logistic (GL) distribution is considered to perform better than the Generalised Extreme Value (GEV) for pooled growth curve derivation. The GEV distribution can be a better fit for flood data were a catchment generally has significant flood storage available upstream provided by large lochs, reservoirs or exceptional floodplain storage. The distribution that provides the "best fit" should usually be selected; however, we recommend that a justification should be provided where the recommended GL distribution is not applied.

A decision log or audit trail of the hydrological analysis undertaken should be provided to help ensure that all relevant information has been provided and justified. This should include justification for what stations were added and removed from pooling groups.

Up to date historical data should be incorporated into flood estimates where it is available. For example, given the severity of the flooding in Winter 2015/16 it is particularly important that data from those floods are included in any analysis. The latest version of WINFAP now has a function to use historical data, and in some cases, this may provide the most suitable approach to flood estimation.

The FEH Statistical Method is often not suited to small catchments as there is a lack of small gauged Scottish catchments in both the original FEH database and the updated NRFA UK database.

4.3 FEH Rainfall-Runoff Method

Rainfall-Runoff specifically relates to the re-statement of the FSR 'unit hydrograph' rainfall-runoff method, which is outlined in Chapter 4 of the Flood Estimation Handbook. Our experience is that this Rainfall Runoff method provides good estimates for small, ungauged catchments in Scotland and is still a valid approach particularly where uncertainties are high and there is a lack of local data for verification.

Rainfall-Runoff estimates can be made using the equations from FEH Volume 4, but there are also functions in some hydraulic modelling software to obtain rainfall-runoff estimates. If using modelling software for rainfall-runoff estimates, data from the FEH-99 Depth Duration Frequency Model (DDF) should be used, as this is the dataset for which the method was calibrated. This can be taken from either the FEH CD-ROM or from the FEH web service. There should be no difference in estimates regardless of where the catchment descriptors have been extracted from, as there has been no change to the parameters read by the software for the Rainfall-Runoff method.

The summer profile should only be selected if the catchment is small or heavily urbanised (URBEXT> 0.125).

Observed rainfall Records can be used for input into Rainfall-Runoff models, as well as improving the parameter estimation of the model e.g., LAG. SEPA operate a large rainfall-monitoring network and data is available on request.

The estimation of percentage runoff can be the most uncertain part of flood estimation and sometimes a proxy is used. A better estimate of one such proxy e.g., standard percentage runoff (SPR) is the most significant single improvement that can be made for any form of rainfall-runoff flood estimation. FEH Vol 4.2.3 recommends a number of alternative methods for estimating SPR, both theoretically and from observed data. Users of the Rainfall-Runoff method should take care in the selection of an appropriate SPR estimate for the catchment.

The Flood Studies Report 1975 (FSR) which set out the Unit Hydrograph (rainfall-runoff method), provided various methods to alter and enhance the approach given various circumstances. One particular advantage of the FSR approach to simulation was the ability to alter the convolution of the unit hydrograph with a dynamic SPR (standard percentage runoff) variable. This approach recognises that during longer duration rainstorm events, the SPR can increase as a catchment 'wets-up' and storage is lost. The method proved very effective in more accurately simulating past flood events.

Such FSR approaches should be retained within the suite of options available to the analyst, depending on the nature of the particular hydrological problem they are faced with. Albeit rare within the sphere of FRAs for land-use planning, for completeness, the FSR UH method is still the only UK standard option for estimation of Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF).

4.4 Revitalised Flood Hydrograph Method (ReFH)

The Revitalised Flood Hydrograph (ReFH) has been updated and calibrated for Scotland and launched as ReFH2 (v2.2). SEPA is pleased to have contributed to the development of ReFH2.2 and the improvements that have been made for Scotland. For ReFH2, only the FEH-13 DDF model should be used, and this is only available from the FEH Web Service. The default Critical Storm duration should be used for design peaks, and iteration used if looking for Critical Duration for a storage system.

While SEPA can recommend ReFH2 as contributing to the suite of methods available for design flow estimation in Scotland, the method will not adequately represent likely flood flows in all parts of Scotland as the calibration only uses a small number of Scottish gauges. We recognise that there is still scope for further improvements, particularly relating to small catchment data. Data collected during recent floods has highlighted the concerns SEPA still have with the robustness of flow estimates made using ReFH2 in Scotland. Therefore, a precautionary approach is required to estimating flood flows, although regardless of location, more than one appropriate flow estimation technique should be considered, as described above.

If ReFH2 is used in design flow estimation, we would recommend the adjustment of default parameter values, where relevant, for sites where superior local data exists or suitable donor data may be available. We would also caution against the use of ReFH2 for catchments where lochs and reservoirs exist, and the FARL value is less than 0.9, as the gauging stations selected to develop and test ReFH2 have FARL values greater than 0.9. For estimation of the Probable Maximum Flood (PMF) for reservoir design, the FSR method as re-stated in the Flood Estimation Handbook should still be adhered to. Please note that the ReFH2 presently does not allow the user to perform flood simulation of observed events, only design.

5. Guidance for Hydraulic Modelling

5.1 Introduction

A hydraulic model is an approximate and simplified mathematical representation of the real-world hydraulic processes that govern flooding mechanisms in a particular area (the modelled reach). Hydraulic modelling applications can range from simple Manning's calculations to complex hydraulic modelling solutions using a range of software packages. For flood modelling, a variety of modelling methods and combination of methods are available, although this chapter will focus on 1D, 2D and 1D/2D linked fluvial hydraulic modelling. Coastal modelling and 0D (spreading method) pluvial modelling is covered in chapters 6 and 7. Each modelling method has its own advantages and disadvantages. Therefore, a final decision about the choice of model will be subject to many considerations and should be appropriately justified.

Models should be provided to SEPA for review and audit, especially in the event of any discrepancy or misinterpretation of information presented in the FRA. SEPA also reserve the right to request the hydraulic model be provided and may do so for complicated sites and Flood Protection Schemes (FPS). Models may also be requested for smaller, less complicated sites as deemed appropriate. Where models are to be provided, we will also require the various files to run the model, including (but not limited to) inflow files, boundary files, geometry files, initial conditions and log files. For 1D-2D models evidence of mass balance checks should also be provided. The model log would also be particularly helpful in assisting our in-house specialists to interpret the model and associated files. Confirmation of the floodplain modelling approach used should be presented, particularly for 1D modelling.

5.2 Requirements for Hydraulic Modelling Studies

This section provides guidance on the parameters that should be presented as part of an FRA. The requirements outlined below can apply to 1D, 2D, and linked 1D/2D models; however, the parameters should be amended as appropriate depending on the complexity of the modelling and the application site.

- Statement of objective: This is required to demonstrate the modelling approach is fit for purpose. It should clearly explain the situation being modelled and the objectives of the modelling study, including details of the output required from the model.

- Justification of the model: This is to demonstrate that the model used is suitable for this study. It should include evidence of previous applications in similar circumstances and a demonstration of experience in the application of the model. This should indicate the particular modelling software used and its appropriateness for the situation.

- Data collection: All relevant data collection and measurement techniques should be quoted, including expected errors and relevant quality assurance. It is expected that appropriate input data is collected to support the objectives of the study. Surveyed cross-sections of the channel and floodplain should be comprehensive to avoid "glass walls" within the model. Locations of surveyed cross sections should be presented on a site plan and clearly referenced, with the geographical extent of the model shown. Cross sections extracted from LiDAR will not generally be accepted unless sufficient information is provided to indicate that this is an appropriate technique. Simply stating that it is conservative will not be considered sufficient. There is no substitute for real, surveyed topographic information, as this will form the basis upon which the study and model are completed. As a 'glass walled' model will be constraining the floodplain, and artificially increasing velocities, this means the model is not fully representative of the real-world hydraulic processes. It may be suitable to extend surveyed cross sections with LiDAR information to remove "glass walls" from 1D-model outputs.

- Roughness Coefficient: Manning's n should be presented for the different types of surfaces. Site photos representing the Manning's n values used may also be helpful to include. Panel markers and varying roughness on banks and in channel should be clearly identified. Land use cover maps could also be used to help derive appropriate Manning's roughness.

- Model Parameters: Where changes have been made to default model parameters and hydraulic units (e.g., bridge coefficients, modular limits etc.) details and an explanation should be provided for why such values have been amended. Information such as mesh size, underlying grid resolution, and details on how buildings have been represented in the 2D domain should also be provided.

- Simulation Parameters: Where changes have been made to default simulation parameters (e.g., max number of iterations, DFLOOD, alpha value) details and an explanation should be provided for why such values have been amended. Model time-step should also be provided as standard.

- Model calibration/boundaries: The model calibration coefficients and procedures used to optimise the calibration must be clearly stated. The choice of upstream and downstream model boundaries must be justified. 2D model boundaries should also be clearly identified. Consideration should also be given to backwater length calculations.

- Model Validation: Efforts should be made to validate the model against historic flood events, high flow events, or gauged data where available. If no such information is available, this should be clearly stated, and a more cautious approach followed.

- Sensitivity Analysis: This must be presented to demonstrate the effect on the key output parameters resulting from variation of input data and controlling assumptions. This is particularly important where limited data is available to validate the model, or where there are uncertainties. Parameters that should be tested for sensitivity analysis include the design flow estimate, roughness coefficient (including for 2D zones), mesh resolution if using a 2D model, and the boundary conditions. Climate Change sensitivity testing of +10 to 20% may be appropriate, irrespective of whether a CC allowance to the design flow is ultimately required or not (which of course may involve the use of higher regional CC values).

- Blockage Scenario: Culverts or other structures that may be prone to blockage during floods should also be assessed. The model should be run with full and/or partial blockage scenarios to better understand the impact of such processes. A comment on the likely level of blockage of the structure should also be provided where possible. Where there is a significant risk of blockage, the location and level of relief should be provided.

- Freeboard: This is often defined as the difference between the design flood level and the finished floor levels of a development, or soffit level of a bridge/culvert. It can also be defined as the difference between the design flood level and the flood defence level of a Flood Protection Scheme. Freeboard is both a SEPA requirement and a recommendation depending on the type of development, as laid out in our [flood risk background paper.](#) SEPA would expect a minimum 600mm freeboard, in line with CIRIA Guidance (CIRIA C624 Development and Flood Risk – Guidance for the Construction Industry 2004) unless a more detailed assessment of freeboard is made. The freeboard is to account for uncertainties involved in flood estimation, and other physical factors that vary between sites such as post-construction settlement or wave action. Therefore, in some cases, a freeboard in excess of 600mm may be necessary, and local authorities may have their own freeboard requirements. Any allowance for climate change should be independent of the freeboard allowance.

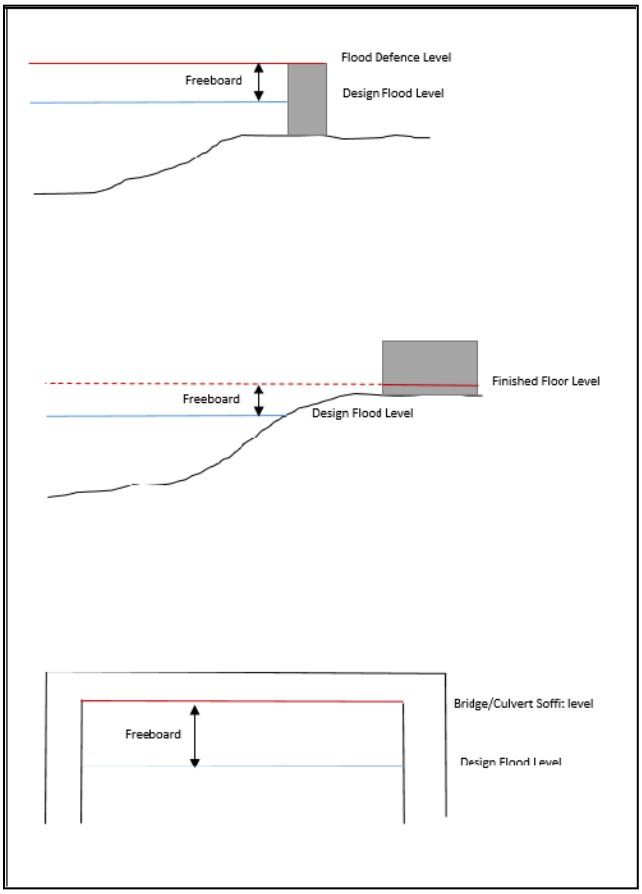

Figure 4. Examples of freeboard definitions

- Quality Assurance and Auditable: This is to demonstrate that the model has been subject to an evaluation procedure, and that there is a clear account of the modelling exercise.

- Reporting and Presentation of Model Outputs: This should be a clear description of the model including the underlying principles and assumptions. There should also be a clear summary of the numerical output, preferably in tabular format. This should include maximum depth, cross sectional area, velocity and Froude at every cross section. Model output should include mass balance errors and plots of model stability during the run. Rating curves in the area of interest should also be provided and hysteresis should be commented on if present. The relevant flood outline should be clearly marked on the site plan. The relevant flood outline could be either the 1 in 200 year (0.5% AP) or 1 in 1000 year (0.1% AP) depending on the vulnerability of the development. Hydraulic structures are subject to blockage and therefore, sensitivity analysis should include blockage scenarios. Our long-held position remains in that we consider the 1 in 200 year + blockage scenario to represent the functional floodplain for such locations. The model long section and each modelled cross section should also be provided, with the relevant flood levels clearly marked. A summary of the likely errors, bias, sensitivity, implications for the objectives of the study and conclusions should be presented.

5.3 1D Hydraulic Modelling

1D modelling is particularly suited for representing river or watercourse systems that have well defined channels near the application site. 1D modelling is most applicable to where in-channel processes dominate, whereas 2D modelling is better suited to where floodplain processes dominate, and a detailed understanding of floodplain hydraulics is required. 1D modelling may not be the most suitable approach where the site topography is relatively flat, or where there are other developments near the site, such as in complex or dense urban areas.

In some situations, it would be suitable to link a 1D model with a 2D model to produce an integrated 1D/2D model. This could be for better model representation or for cost effectiveness reasons. Where this is the case, values for weir coefficients or spill unit coefficients should be presented. 2D hydraulic modelling may be appropriate as an approach when flow direction and pathways are unknown or complex and where high-resolution topographic data is available. 1D models are simpler to construct (and hence often more cost effective) than a 2D or 1D/2D linked approach. However, this may not always be true especially if detailed topographic survey of the channel is undertaken, which is sometime preferred depending on the nature of the problem. Due to their assumptions, 1D models are conservative in nature and can provide a precautionary approach to the estimation of water levels. They have their place within FRA work especially where a simpler approach to the problem in hand will provide a sufficient representation of flooding.

5.4 2D Hydraulic Modelling

While the above information is relevant to 2D hydraulic models, additional factors need to be taken into consideration if carrying out a 2D or linked 1D/2D hydraulic model.

- Model Domain Boundaries: This should confirm the area represented by the model and should consider what to include in the model. The areas where the governing equations (such as the Shallow Water Equation) are invalid should be avoided, as the solution would not be appropriate. Water should not reach the domain boundary

- Boundary Conditions: The initial conditions e.g., waterlogged or saturated areas, inflow hydrographs, and downstream boundary conditions for the model domain should be specified. Explanation and justification for the boundary conditions and the initial condition values should be included. In coastal areas close to a watercourse, it may be necessary to perform a joint probability analysis of fluvial and coastal flooding to establish the design scenario. Further information on joint probability analysis can be found in Chapter 6.

- Topographic Information: The spatial extents of the data should be large enough to accommodate a given simulated flooding scenario. Topographic information for 2D hydraulic models is likely to be sourced from LiDAR. As there are limitations associated with the post-processing, LiDAR data may contain inaccuracies in the ground levels, for example in areas of dense vegetation, normally inundated areas, or where the data resolution is such that

hydraulically significant features are not captured. Therefore, LiDAR data should be supported with surveyed data to confirm ground levels and improve representation of structures. If structures are not adequately shown within the model grid, topographic modification should be undertaken to allow specific elevation data to be used. Where data from more than once source is used further processing may be required to obtain a common data set.

- **<u>Structures</u>: All hydraulically significant features and structures such as weirs, bridges, walls, natural bunds, hedges, ditches etc. falling within the model domain should be included to ensure that the model represents the real-world scenario as accurately as possible. If applicable all invert levels, soffit levels, springing heights etc. should be stated, and the type of unit modelled e.g., orifice, arch, culvert etc.**

- **<u>Roughness Coefficient</u>: The values used in the model should be justified and supported by a calibration and verification exercise.**

- **<u>Model grid size</u>: If using <u>structured grids</u>, the computational burden can be reduced by using nested grid models. The computational grids may be coarser for areas out with the floodplain or for areas where detailed information is not required. The grid size should be sufficiently fine to represent the flooding mechanism within the model domain. If using <u>unstructured grids</u>, particular care should be taken when creating the computational grid. If accurate channel bathymetry data is available, then the meshes for the river channel and floodplains should be discretised separately. This ensures that the variations in the channel bathymetry are captured better. The mesh should contain more elements near the meanders and bigger elements for straight reaches. More elements should be created along the river channel so that maximum information is passed onto the elements in located in the floodplain. In the floodplain, the mesh should contain more elements in urban areas, and fewer elements in rural or open areas. The mesh may also need more elements to capture structures. Elements should be equilateral to minimise mass balance errors. The mesh elements should have a smooth transition in sizes, and the selected mesh sizes should do justice to both the model representation and accuracy. The size of the main features to be represented, the level of detail required, and the run time are all relevant to such considerations.**

- **<u>Model Time Step</u>: Choosing an appropriate time step is vital for ensuring increased accuracy while reducing computational requirements. Generally, model time steps for 2D domains should be approximately half that of the grid cell size. A bigger time step can reduce computational time but may lead to model instability and increased mass balance errors Some software packages have a facility for specifying an adaptive time step which may be used to avoid modeller specific uncertainties.**

- **<u>Model Calibration and Validation</u>: If available historic flood information should be used for model calibration and validation, prior to simulating the design scenario. A sensitivity analysis should also be carried out to evaluate the uncertainties of model parameters. The mass balance error should also be presented. The modelling report should contain justification of the modelling method and software used and its limitations, any assumptions made for model simplification, and identify any other issues that may affect the accuracy of the flood output. Any post processing that has been undertaken should be stated and justified.**

- Linked 1D/2D hydraulic models: When linking 1D and 2D models it is important to establish the model domains of the individual models. If the 1D model domain is too wide, most of the floodwaters will be retained in the 1D model, whereas if the 1D model domain is too narrow then most of the floodwater will be passed to the 2D model. The distances between the cross-sections in the 1D model will also affect how a 1D model will interact with a 2D model. The most common method of connecting the models is by linking the 2D model laterally along the channel. The specific linking approach used should be confirmed. Appropriate geometry for the links needs to be established. The link geometry can be taken from 1D model cross-section data if the cross sections are a suitable distance, and there are no significant variations in the topography. Link geometry can also be extracted from the topography data; however, it needs to be ensured that the link geometry is as accurate as possible. LiDAR tends to be inaccurate for areas with dense vegetation and steep slopes, like riverbanks, so it is recommended that a survey should be taken along the finalised link alignment to identify any inaccuracies. Information on how the models have been linked should be presented and include how the best linking represents the flooding mechanism in the model domain.

- Presentation of Model Outputs: The design flood extents should be clearly marked on the site plan.

6. Guidance for Coastal Flood Risk Assessment

6.1 Introduction

Wider coastal processes should always be considered when assessing coastal flood risk, in particular thinking about how coastal flooding may be exacerbated in certain locations due to physical factors that can occur individually or in combination. The key physical components of coastal flooding are predicted astronomical tide, storm surge residual, wave/fetch effect, and local bathymetric effects. The astronomical tide combined with the storm surge is referred to as the 'still water' level.

Still water levels and waves are often treated as individual processes, however waves may increase still water levels at the coast due to wave setup, and still water levels can influence where waves break and the potential for overtopping and inundation. These processes will be discussed in more detail in Section 6.4.

Coastal erosion and coastal flooding are inextricably linked. This can be due to the force of wave action, which can include moving debris. Further information on coastal erosion can be found on the Dynamic Coast website. Wave overtopping or spray may present a risk to low lying coastal areas which under normal conditions appear to be protected.

SEPA can provide information on estimated coastal flood levels (still water level) that can provide a first indication of the risk to the application site. These can be compared to site and finished floor levels, and therefore it is imperative that good quality survey information related to Ordnance Datum Newlyn, or the local OS datum for sites in Shetland (Lerwick) and the Western Isles (Stornoway) is provided as a minimum in support of the application (see section 3.2). In some cases, depending on the elevation of the site, and other local physical characteristics, survey data may be sufficient to assess flood risk and no further information would be required.

6.2 Coastal Flood Levels

For the purposes of deriving design coastal flood levels in the UK, the application of the Coastal Flood Boundary (CFB) method is the current accepted standard. The CFB method supersedes the POL Report 112 (1997) which was the previous method for deriving extreme sea levels. The CFB method provides a consistent set of design sea levels, uncertainty data, and design surge curves around England, Wales and Scotland. It also provides a consistent set of design swell wave conditions around England, Wales and Scotland, and practical guidance on applying these datasets. This data will be updated in 2018.

The CFB method was derived from Class A tide gauges and is therefore most suitable to the open coast. Estimates of extreme sea levels and associated uncertainty data are available at 2km resolution around the coastline of Scotland, with the exception of Shetland and beyond the project defined estuarine limits. However, through work carried out by SEPA, extension of the CFB method does now provide values, with some uncertainty, for more complex coastlines, such as sea lochs and estuaries remote from Class A tide gauges. The CFB output for Lerwick was shown to have good correlation with existing SEPA data held for Lerwick, and therefore there is an acceptable level of confidence for coastal levels, but there is more uncertainty in areas of Shetland away from Lerwick.

In areas where there is more uncertainty in the CFB levels, good quality local data should be used to supplement the CFB method, if available. Observed data on past coastal flooding events also provides a valuable source of information for design purposes. Historic coastal data can be used to inform the choice of an appropriate design flood level at a particular site and assist in the calibration and validation of modelled estimates. Therefore, SEPA strongly recommend that any study should identify any historic flood information if available, especially for additional factors such as wave action. The SNIFFER FRM 10 project 'Coastal Flooding in Scotland: A Scoping Study' (2008) is a useful source from which to glean information on past coastal flood events.

6.3 Freeboard and Climate Change

Assuming good quality surveyed levels have been provided and accepted by SEPA, then a freeboard and climate change allowance should be factored into the design level for the site. Any additional separate allowances for freeboard and climate change should always be made over and above the coastal flood level.

SEPA would expect a minimum 600mm freeboard allowance, however, more may be necessary depending on local characteristics, such as evidence of wave action in the past and/or the recommendation of the local authority flood prevention teams. The freeboard allowance is to account for uncertainties associated with the design flood estimation and coastal processes including, wave action and spray, local bathymetric processes, and reduction of design level due to erosion.

Climate change allowances for sea level change should follow guidance from UKCP18, as laid out here.

In addition to freeboard, SEPA would recommend that water resilient materials and forms of construction are considered for development in coastal areas, particularly if the development may be exposed during storm conditions.

6.4 Coastal Flood Modelling

In some cases, surveyed levels may not be sufficient to provide a robust assessment of the risk of flooding to the development and a more detailed coastal flood risk assessment would need to be carried out. The following section represents good practice when undertaking coastal flood modelling.

- Boundary Conditions: As outlined in Section 6.2, the CFB method, or the extension of the CFB method, or local tide data should be used depending on the location of the site in question. The CFB method and extension includes the effect of storm surge but does not take into account wave or wind set up.

- Topographic Information: Coastal topography should consider land-based topography, the beach foreshore, and the seabed. If used LiDAR should be flown at low tide to ensure as much of the beach foreshore is collected at high resolution. Bathymetry data is used for the seabed and is merged with land-based topography to create a seamless topographic grid. However, bathymetric data often needs converting from local chart datum to Ordnance Datum. Other sources of topographic data include beach surveys, coastal defence crest and profile surveys, and tidal structure surveys.

- Wind Data: Wind data time series may be required to calibrate the model, and for generating wind wave boundary conditions. Wind data is primarily available from The Met Office but could also be obtained from local weather stations.

- Wave Data: The two different types of waves are wind waves and swell waves. Wind waves (or sea waves) are generated by local wind and have a shorter, irregular wave period. Swell waves are generated by more distant weather systems and have a more regular, longer wave period. Wave data is generally calculated from wave hind cast datasets, as there are limited long time series observations available. The Met Office Wave Watch 3 hind cast dataset is currently the most suitable from which to base an extreme value assessment.

- Joint Probability (Offshore Coastal Conditions): Coastal flooding is often a result of the simultaneous occurrence of multiple environmental variable such as sea level and wave height. Joint probability refers to the overall chance of these conditions occurring at the same time and needs to be carried out to determine these conditions of offshore variables. There are various approaches for joint probability analysis in the DEFRA Guidance (see below) and SEPA may be able to provide some joint probability data for some areas.

- Wave Transformation: As forecast points from the wave datasets are offshore, a wave transformation model is required to apply the conditions in shore. Wave conditions inshore cannot be used as a direct input into a hydraulic model. The offshore joint probability data is used as boundary conditions. Development of wave transformation models require good bathymetric and shore survey data. The transformation model should be calibrated and validated using observed wave buoy data where possible.

- Wave Overtopping: Overtopping models are required to determine the rate of flow over a defence, and is required to transform the inshore wave and water levels to overtopping discharges/rates. The most suitable model will depend on the defence type, and choice of model should be justified. There is usually very little measured data to calibrate the overtopping model; however, the uncertainty can be mitigated by carrying out sensitivity and validation of the overtopping model against simulation events. Sensitivity of the overtopping model parameters to overtopping rate should also be assessed.

6.5 Joint Probability Analysis

For coastal sites close to a watercourse, or for sites within an inner estuary, consideration of both coastal and fluvial events may be required to estimate the worst case combined 200-year event. Ideally, a range of various combinations should be presented, but the worst-case scenario would involve the concurrence of high tide, surge, and high fluvial flows.

Coastal/fluvial joint probability analysis typically involves running a model with different combinations of downstream tidal boundaries and fluvial inflow boundaries. Consideration should be given to the backwater influence of the tidal boundary on upstream water levels as this can have an effect further upstream than the tidal limit, and the probability will vary depending on fluvial peak duration.

In undertaking joint probability analysis, we would recommend that the DEFRA/ EA guidance be followed.

7. Surface Water

7.1 Introduction

Developers should consider the potential for flooding from all sources, and in some cases, for example where there is a pre-existing risk or surface water flooding issues are particularly complex, an FRA or drainage assessment may be required to assess surface water flood risk. SEPA will not comment on the suitability of drainage proposals, and solutions that involve on-site engineering design considerations for drainage will be matters for the local authority to consider in conjunction with Scottish Water.

7.2 Guidance for Surface Water Modelling

If a complex surface water issue has been identified, then the following generic guidance represents good practice for undertaking surface water modelling.

Surface water modelling can vary depending on the scale and complexity of the flooding scenario. Modelling approaches could include basic topographic GIS analysis to identify natural flow paths, direct rainfall models (0D rapid flood spreading techniques or 2D hydraulic models), and fully integrated approaches (1D model of the sewer network coupled with direct rainfall model of the above ground topography).

In some circumstances, there may be a need to combine an assessment of fluvial and pluvial flood risk, particularly where out of bank flows and overland surface water flows are likely to interact.

7.2.1 Hydrological Parameters

Surface water models need to be driven by rainfall volumes that are representative of events leading to surface water flooding and are one of the main sources of model uncertainty. It may be appropriate to use Depth Duration Frequency (DDF) models to construct a representative rainfall to apply over the model domain. The DDF parameters should be obtained from the FEH web service, which has the most recent (2013) rainfall model. Where available, observed rainfall data should be used to verify the model.

SEPA would recommend that climate change is considered and we would recommend use of the rainfall allowanced set out in the guidance here.

For surface water, modelling it is recommended that the 50% summer profile be applied across both urban and rural areas. The summer profile has a more pronounced peak to represent intense convective summer storms that can overwhelm drainage networks causing surface water flooding.

Due to the different nature of the catchments, storm durations in urban areas should be assessed differently to rural catchments. In rural areas with higher infiltration rates, relatively longer storm durations of 3 hours or more should be applied based on the critical storm duration approach in the FEH. In urban areas with a well-maintained drainage network, a shorter storm duration of approximately 1 hour should be applied to built-up regions. Alternatively, a range of modelled scenarios can be used to help indicate model sensitivity.

FEH guidance should be followed to identify the design rainfall; however, the primary rainfall event adopted should be either a 240 or 200-year return period based on the urban extent of the modelled catchment, or the particular deterministic method being used.

In urban catchments, it may be appropriate to incorporate a realistic drainage value to remove a proportion of the rainfall input based on any local information from drainage studies for that catchment. It is recommended that a figure similar to the 5-year rainfall event be used unless any site-specific data from Scottish Water suggests otherwise. No sewer allowance should be applied throughout rural environments.

Infiltration rates should vary between urban and rural areas to account for the effect of extensive impermeable surfaces in built-up regions. Any site-specific data should inform the infiltration rate but generally SEPA would recommend a percentage runoff of 70% in urban areas (after Akan & Houghtalen 2003 and Young & Black 2009), and 55% for rural areas (as used by SEPA for producing surface water hazard maps).

7.2.2 Digital Terrain Model

The topography of a site is a key controlling factor determining the overland flow pathways along which runoff will flow or accumulate. The most widely available Digital Terrain Model (DTM) is NEXT Map, but this has a low resolution and a limited vertical accuracy of +/- 0.7 to 1m and therefore is a large source of uncertainty with surface water models based on this underlying data. Therefore, LiDAR data should be used when possible.

Due to the influence that buildings and roads have on flow pathways, it may be appropriate to represent these features within the DTM, particularly for large-scale developments. In cases where this is deemed appropriate, buildings may be represented by either 'stamping' them onto the DTM or by using appropriate Manning's 'n' roughness values to represent buildings as part of the model grid.

Road heights should be lowered by 100mm when NEXT Map DTM is used but may not require any additional processing when LiDAR is used. Other building representation methods are also possible.

If a model uses a combination of DTM datasets it is anticipated that some interpolation and smoothing between the two DTM tiles has been carried out within a specified buffer zone. A step join between datasets can be used where appropriate, but this will be on a site-specific basis and influenced by the type of modelling approach proposed.

<u>7.2.3 Model Verification</u>

It is also expected that Quality Assurance work is carried out to check the accuracy of the DTM. The data should also be checked for any potential 'false blockages' which could create artificial barriers to flow paths.

Site investigations of site-specific factors, and property thresholds should be used to verify the model. Other appropriate verification methods would include anecdotal evidence and observed flows and depths where available.

8. Groundwater

It is considered that groundwater flooding in Scotland is likely to be a flooding mechanism that contributes or is linked to other sources of flooding, such as fluvial or surface water, on a local scale during heavy rainfall events as opposed to separate distinctive events. Groundwater has the potential to extend the duration or extent of flooding in low-lying areas.

Groundwater flooding is possibly under-represented in Scotland due to the difficulty of differentiating it from other types of flooding. There are several mechanisms of groundwater flooding which are described in more detail in Appendix 2. In parts of Scotland, the effects of mine workings can cause groundwater flooding, or contribute to fluvial or surface water flooding. In cases where this is an issue, dewatering would be required in perpetuity which could affect the sustainability of the site.

If there is a perceived risk of flooding, groundwater can be investigated as part of a flood risk assessment or drainage assessment, although SEPA only offer generic guidance on groundwater elements of flood risk assessments. These can be desk based or involve onsite ground investigations and groundwater level monitoring in conjunction with other hydrological data. Monitoring of groundwater, particularly through a flood event, is the ideal scenario to understand groundwater flooding mechanisms, although this data in Scotland is likely to be limited compared to other parts of the UK. For larger or strategic developments if groundwater flooding is perceived to be a risk, hydrometric monitoring equipment could be installed at an early stage to better inform the drainage assessment or flood risk assessment.

Groundwater assessments should be scaled to the complexity of the flooding risks under consideration. Consideration should also be given to how groundwater may interact with proposed mitigation of other sources of flooding.

Additional volumes of groundwater may also need to be accounted for in the design of drainage schemes on top of that required to mitigate against surface water flooding. Source control of rainfall is important for mitigating surface water flooding, and below ground storage elements such as detention basins and wetlands may need to be lined.

Mitigation of groundwater flooding can be difficult if not properly considered and therefore new development should be avoided in areas at risk. If flood mitigation measures are proposed, then it is important to identify groundwater flow paths and how they may be altered by a development, particularly those involving substantial ground engineering works. Installing physical barriers to alter groundwater flow may have detrimental environmental impacts outside flood events.

9. Land Raising and Compensatory Storage

9.1 Introduction

New development must not affect the ability of the functional floodplain to store and convey floodwater. Removal of the functional floodplain by land raising will displace floodwater and have an unacceptable impact unless it is linked to the provision of compensatory storage (Figure 5).

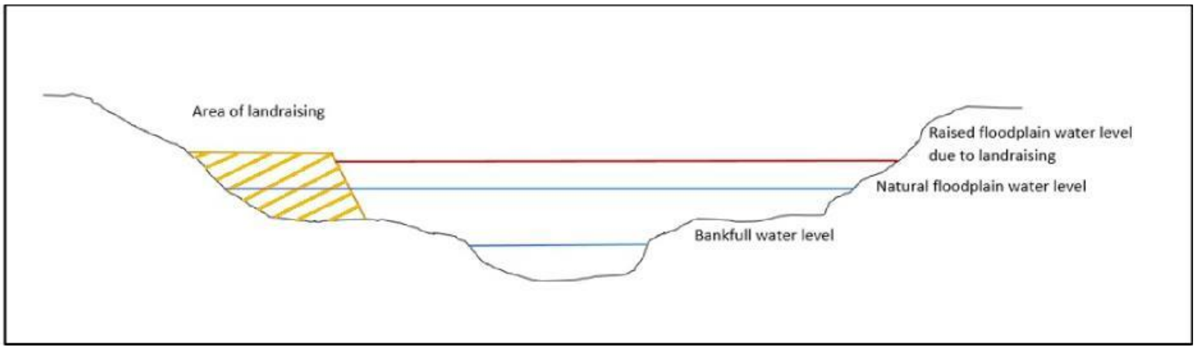

Figure 5. Example of how water levels can change across a floodplain due to land raising.

Generally, piecemeal reduction of the functional floodplain should be avoided given the cumulative effects of reducing storage capacity, and land raising should only be considered in exceptional circumstances where it is shown to have a neutral or better impact on flood risk outside the raised area. Land raising is unlikely to be acceptable within an area of natural or undeveloped floodplain.

In the exceptional circumstance where land raising is an appropriate approach, compensatory storage must be provided up to the 1 in 200-year design level. An exception may be made for sites on the open coast where the displaced water is unlikely to increase flood risk. In addition to ensuring there is no loss of floodplain storage, consideration should be given to floodplain conveyance and to ensure that flow paths are not altered because of any land raising.

Compensatory storage should be provided on a 'like for like' basis i.e., compensatory storage must become effective at the same point in a flood event, as the lost storage would have been. It should therefore provide the same volume and be at the same level, relative to the flood level, as the lost storage. This is to ensure that floodwater is not displaced elsewhere with potential adverse impacts. If compensatory storage is provided at another level, it will already be full (if lower) or still be empty (if higher) when the storage is required, and the characteristics of the floodplain at this location will be altered.

In some cases, there may be no suitable areas of land within a development boundary to provide compensatory storage. The location of on or offsite compensatory storage should relate hydraulically and hydrologically to the location of the development. Compensatory storage could be provided by either direct or indirect replacement of floodplain volume. Direct replacement is the preferred method; however, the feasibility of providing direct replacement is largely dependent on there being available land at an appropriate level. Even where there is available land, direct replacement may not be acceptable if it has detrimental impacts on the environment, landscape or cultural heritage or where there are long-term issues relating to land ownership. Although we will assess the hydrology of each case on a site-by-site basis, other factors will be matters for the Planning Authority to assess.

Indirect replacement of lost floodplain volume may not be acceptable if it is considered unsustainable. It is unlikely to be sustainable if it will require frequent inspection and maintenance regimes, have intakes and outfalls that may be prone to blockage and a storage facility with a capacity that is likely to be diminished by siltation. To help assess this, information should be provided on the frequency of inspection and maintenance regimes, what measures will be included to avoid or manage blockage of intakes and outfalls, and siltation on storage facilities. Such measures would have to be maintained in perpetuity.

9.2 Compensatory Storage Proposals

The preferred method for providing compensatory storage is 'like for like' volume. To determine the volume of compensatory storage required SEPA recommend that the area of raised ground is divided into 5-10 'slices' and the volume of each slice is calculated (Table 1). Compensatory storage can then be designed so that a volume, at least equal to each slice of raised ground, will be provided at the same level as that it is replacing.

Slice between:	**Volume lost as a result of development (m^3)**	**Volume gained by proposed compensatory storage (m^3)**
5.50 – 5.75 mAOD		
5.75 – 6.00 mAOD		
6.00 – 6.25 mAOD		
6.25 – 6.50 mAOD		

Table 1: Example of table for reporting 'like for like' storage volumes

Compensatory storage proposals will be considered on a site-by-site basis, but generally, the following proposals are unlikely to be acceptable:

- Raising land within an area of natural/ undeveloped floodplain.
- Excavating a hollow in the floodplain below the level of the development. It is likely that this would not replicate the characteristics of the floodplain and offer no storage potential.
- Excavating a landlocked area isolated from the floodplain, or linked by a narrow access, such as culverts. These are prone to accidental blockage or infilling, especially if they are only used infrequently.
- Providing low-level compensation to match high-level development or vice versa. This affects the timing of operation of the compensatory storage relative to the pre-development situation.
- Works that may place surrounding properties at risk, such as lowering ground levels close to other properties that may already be at risk, and therefore increasing flood risk elsewhere.

- An engineering solution, such as Storm cells or similar, that is dependent on frequent maintenance to maintain its design capacity and efficient operation. This is unlikely to be sustainable over the lifetime of the development and beyond.

- Where a bunded storage area is required to provide compensatory storage as it increases flood risk elsewhere should it fail, would require maintenance throughout the lifetime of the development, and is reliant on informal defences to enable development. This is not deemed by SEPA to be a sustainable approach.

9.3 Modelling Issues

Hydraulic models may not be appropriate for assessing the impact of loss of storage capacity. This is because steady state 1D models cannot accurately represent the loss of upstream storage, and fully dynamic 1D models cannot fully represent the complex hydraulics associated with floodplain processes. Therefore, modelling the removal of flood storage is likely to introduce further uncertainty, especially as the majority of models are uncalibrated due to a lack of data. The application of complex 2D models with additional survey data may reduce the level of uncertainty; however, uncertainty with parameterisation and the lack of calibration data may remain.

Although 'like for like' compensatory storage is the preferred method, there may be exceptional circumstances where other approaches are required. In these cases, modelling uncertainty must be reduced as far as possible so models should be calibrated where data is available. Sufficient information should be supplied to demonstrate model stability, and sensitivity to changes in key model parameters (Chapter 5). In addition, information should be supplied on model run/simulation parameters to provide to provide a full breakdown on the modelling process, and SEPA may request the model files are provided for further review. A satisfactorily robust model should clearly demonstrate the alternative mitigation proposals and that there would be no increase in flood risk upstream or downstream of the development. However, SEPA emphasises that the preferred method is to provide 'like for like' storage, and that taking a modelling approach immediately should not be considered as an alternative.

Appendix 1: SEPA Flood Risk Assessment Checklist: this must be completed prior to submitting an FRA to the Local Authority. Without it, SEPA will not accept an FRA for review - click here

Flood Risk Assessment (FRA) Checklist

SS-NFR-F-001- Version 14 - Last updated 28/05/2019

This docur lent must be attached within the front cover of any Flood Risk Assessments issued to Local Plant", Authorities (CPA) in support of a development proposal which may he at risk minutes of flood. The document will take or I a few to complete and will assist SEPA in reviewing ERAS. when consulted by LPAs. This document should not he a substitute for a ERA.

Deveko mentPror.sal Summa

Site Name:

Grid Reference: ED-0,g rqc IF, I Local List

Planning Reference number (if known):

Nature of the development: If residential, state type:

Size d the development site: He

Identified Flood Risk: Source name:

Lan. Use'1•nnin.

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Is the site identified within the local development plan' — Select horn List — Local Development Plan Name: • ear o u

If yes, what is the proposed use for the site as identified in the local plan? — Select f tom List — mber / Reference: If Other ase specify: If so, please cify: thepr9-,DIs repre,

Does the local development plan and/or any pre-application advice, identify any flood risk issues with or requirements for the site. — Select f tom List — , n —Allocation

What iFe • r • ogedl¯d itse vuln f -Hlifff· — Seleat List — In an,

Supporting Information

FRA (including topographic and flood inundation plans)? — Select from List

} lactiffininnt c. tnnmrtiRg information in line with our Techmin, ,1.,,, he.n provided? For example. gitenlanq nhntnq tnnwrenhininfnrmatinn CWW,WAW. Information and other site soecific information, — Select from List

Hasa historic flood search been undertaken? — Select from List — If flood fe,Dfds in vicinity of the site please provide details:I

Is a formal flood prevention scheme present? — Select from List — If known, state the standard of protection offered.

Current / historical site use:

Is the site considered vacant or derelict? — Select from List

ree•oar•on •esignwater eve: — In off

Is safe/ dry access and egress available? — Select(torrmList — ,JD — Min accesskgiess level: — "rrI A'L'iC:

Design levels: IIlrf FFL

• ti.n

Can development be designed to avoid all areas at risk of flooding? — Select horn List

Is mitigation proposed? — Select from List

If yes, is compenstory storage necessary? — Select from List

Demonstration of compensatory storage on a "like for like" basis? — horn List Select

Should water resistant materials and forms of construction be used? — Select horn List

SE PA/

Flood Risk Assessment (FRA) Checklist

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Hydrology

s there a requirement to consider fluvial flooding? — Select from List

Area of catchment: — km² — Is a map of catchment area included in FRA? elect from Lis

Estimation method(s) used (please select all that apply): — Pooled Analysis / e Site Anal sis / Enhanced Single Sit ReFH2 / FEH RRM / Other — If Pooled analysis have group details been included? — 1,1231IrZ ist

If other (please specify methodology used):

Estimate of 200 year design flood flow: — nOs

filmed estimate: — m³/s — Method: Select from list

Statistical Distribution Selected: — Sel ect from List — Reasons lot selection:

H draulics

Hydraulic modelling method: — Select from L. — o tw are use — Select from List — If other please specify:

Number of cross sections: Source of data (i.e. topographic survey, LiDAR etc): — Date obtained /surveyed:

Modelled reach length: Any changes to default simulation parameters? — If yes please pry/idol

Model timestep:

Model grid size: Any structures within the modelled length? Maximum observed velocity: — O c t — m2s — Specify, if combination:

Brief summary of sensitivity tests, and range:

variation on flow (X) — Please specify climate change scenario considered:

variation on channel roughness (X)

blockage of structure (range of X blocked)

Eoundary conditions: — Upstream — Downstream

(1) type — Select from List — Select from List

Specify if other — Specify if other:

(2) does it influence water levels at the site? — Select from List

Has model been calibrated (gauge data / flood records)? — Select from List

Is the hydraulic model available to SEPA? — Select from List

DesigWrliiid levels: — 200 year — m AOD — 200 year plus climate changel_I m ADD

Cross section results provided? — Select from List

Long section results provided? — Select from List

Cross section ratings provided? — Select from List

Tabular output provided e velocifie

Mass

Coastal — Select From

Estimate of 200 year design flood level: — m AOD

Estimation method(s) used: — Select From List — If other please specify methodology used:

Allowance for climate change (m):

Allowance for wave action etc (m):

Overall desi • n flood level: — m AOD

Comments

Appendix 2: Sources of Flooding

It should be noted that flooding might occur due to a combination of more than one type of flood process.

Fluvial: Flooding originating from a watercourse either natural or culverted. Fluvial flooding is normally caused when the river channel, or culvert capacity is exceeded and water flows out of bank onto the floodplain. A floodplain is the areas of land adjacent to a watercourse, of any size, where floodwaters naturally flow/and or are stored during times of flood.

Coastal: Flooding originating from the sea (open coast or estuary) where water levels exceeded the normal tidal range and flood the low-lying areas that define the coastline. As stated in Chapter 6, coastal flooding can occur due to physical elements either acting on their own or in combination with each other:

- Predicted astronomical tide: Expected sea water level due to the gravitational effects of the sun and the moon.
- Storm surge residual: Elevated sea level caused by the combined effect of low pressure, and persistent strong wind. For every millibar drop in pressure, a 10mm rise in the sea surface elevation occurs.
- Wave effects: A function of both wind strength and open water 'fetch' length. Due to high winds, waves can also be associated with low-pressure systems, which cause storm surge effects as described above.
- Local bathymetric effects: topographic funnelling due to the forcing of a large volume of open seawater into a restricted coastal embayment e.g., estuary, tidal basin, or sea loch, which will elevate water levels locally.

Surface Water (Pluvial): Urban or rural flooding which results from rainfall-generated overland flow before the runoff enters any watercourse, drainage system, or sewer.

Surface Water (Drainage): Flooding due to surcharging of man-made drainage systems including combined sewers where the capacity of the system to discharge runoff has been exceeded.

Infrastructure Failure: Flooding due to the collapse/failure of man-made infrastructure including hydro-dams, water supply reservoirs, canals, flood defence structures, underground conduits such as sewers, water treatment tanks.

Groundwater: Flooding due to a significant rise in the water table, normally because of prolonged and heavy rainfall over a sustained period. Groundwater flooding is normally associated with catchments where porous substrate and/or aquifers exist, and can last for a considerable period, i.e., weeks or months. Different types of groundwater flooding include:

- Clearwater Flooding: Where prolonged heavy rainfall may cause the water table to rise above the ground surface or above the floor level of underground structures such as basements. Scottish aquifers are not as susceptible to Clearwater flooding as is the English Chalk aquifers. It is most likely to occur in unconsolidated sand/gravel deposits with a very shallow water table and in fractured sedimentary bedrock aquifers with relatively large seasonal fluctuations in groundwater level, and/or a shallow water table.

- Alluvial and Coastal Groundwater Flooding: Where an aquifer (such as a deposit of river gravel) is in hydraulic continuity with a river, if sustained for a long enough period of time

high river levels will lead to high groundwater levels within the aquifer. This type of groundwater flooding will occur even when the river remains in bank. If groundwater levels exceed the elevation of the floodplain, or basement, then flooding will occur. It is most likely to occur in superficial sand and gravel aquifers in river valleys. A similar mechanism can occur where a coastal aquifer is in hydraulic continuity with the sea or estuary. An extreme high tide can result in groundwater flooding. Alluvial groundwater flooding is considered the most likely source of groundwater flooding in Scotland due to the widespread deposits of alluvial sand and gravel aquifers in major river valleys.

- <u>Groundwater Rebound</u>**: A reduction in groundwater abstraction will cause groundwater levels to rise locally. Where groundwater rebound occurs water may issue from previously dry spring lines. Where dewatering activities associated with mining have stopped, this will also cause local groundwater levels to rise, a process known as mine water rebound. Where this occurs, water may issue from previously dry shafts or enter previously dry opencast workings. Mine water rebound can be a particular problem in Lothian, and Fife.**

- <u>Ground Subsidence:</u> **This is caused by the collapse of underground voids created by mining or the dissolution of highly soluble rocks. If subsidence takes the ground surface below the water table then groundwater flooding will occur. Due to the typical geology of Scotland, subsidence flooding is more likely to be linked to past mining activities.**

- <u>Artificial Obstruction of Groundwater Flow</u>**: Obstructions such as foundations, pipes, and flood protection schemes may create a dam for groundwater and cause levels to rise. If such obstructions are extensive, they may reduce the storage capacity and transmissivity of the aquifer. If former quarries or mine workings are infilled with a material with a lower permeability, this may cause a diversion of groundwater flow and generation of new discharge areas.**

- <u>Artificial Conduits for Groundwater Flow:</u> **Inappropriately constructed, uncapped, or damaged boreholes may allow groundwater to leak upwards from confined aquifers. If unlined trenches intercept aquifers with high groundwater levels, the trenches may fill with groundwater. The trenches may act as artificial springs and conduits for water. This could potentially overwhelm any drainage network with which they are connected, and therefore the potential for groundwater flooding should be assessed as part of an appropriate drainage impact assessment.**

- <u>Artificial Recharge</u>**: This can be a particular issue in urban areas, where leaking drains, sewers, and water supplies may artificially recharge aquifers. Infiltration drainage systems may also locally raise groundwater levels.**

Appendix 3: Potential Sources of Flood Risk Information

Source	**Sub-source**	**Type**	**Comments**
Local Authority	Flood Prevention Authority and/or Planning Authority	1)Biennial Flood Reports / flood photos. 2)Flood Prevention Scheme studies 3)Strategic Flood Risk Assessment Flood Risk Assessments for planning	1)Often available on Council website. 2)Feasibility studies are often undertaken for areas where no formal flood prevention measures currently exist. Many councils have an e-planning website.
Scottish Water		Flood incident reports.	
SEPA	Flood Risk Hydrology. National Flood Risk Assessment	Flood photos, post-flood survey data. Digitised records of past flooding from multiple sources	SEPA flood risk hold information on past flood events in Scotland in various formats Available via SEPA website here
Scottish Government	SEPA	SEPA Flood Map (2014).	Available on-line here
British Hydrological Society	University of Dundee	Chronology of British Hydrological Events	Available on-line at http://www.dundee.ac.uk/geography/cbhe/
Media	Television and Newspaper	Flood reports/ photographs.	Material may be found on-line.
SNIFFER	Coastal Flooding in Scotland: A Scoping Study 2008	Final report and GIS data can be found here	Information on past coastal flood events in Scotland as well as the dominant coastal processes.
Academia	Academic staff and/or students.	Flood studies for specific areas.	
Local Flood Groups	Local residents	Anecdotal accounts of flooding and/or flood photos.	
Library/Archives	Books, journals, magazines, newspapers, church records.	Historical flood information & photos.	
Internet	Web search	Accounts of flooding and photos.	Numerous data sources exist on-line.
Buildings/bridges	Can be on a plaque	Epigraphic flood data	Often levels of past extreme floods are marked on buildings and bridges.

Appendix 4: Flood Probability

The annual probability of flooding is the statistical chance (or risk) that a location will flood in any given year and relates to a particular size or magnitude of flood, e.g., the 0.5% AP event is smaller in size than the 0.1% AP event (although a 1% AP event will occur more frequently than a 0.1% AP event).

For any given location, the 0.5% AP flood should (in theory) affect a smaller spatial area, *or*, will inundate the same area to a lesser depth (if the floodplain is constricted by topography), than the larger 0.1% AP flood. The chance of experiencing the larger 0.1% AP flood, however, is smaller as explained below:

- ☐ For the same location, the **0.5% AP** flood can be expressed as 'the flood which has a 0.5% chance of occurring in any given year' (i.e., there is a 1 in 200 chance of experiencing a flood of that size, at that location). It is also referred to as the 200-year flood or the flood with a return period of 200 years.

However, it does not follow that if a location suffers the 0.5% AP flood this year, it will not be flooded again to this extent for 199-years. Statistically, the chance or probability of experiencing the 0.5% AP flood remains the same in any given year. Furthermore, it also does not follow that over any 200-year period, the 0.5% AP (200-year) flood will definitely be experienced, e.g., statistically the chance of experiencing the 200-year flood within a 200-year period is only 63% (see Table 1 below).

	FLOOD EVENT			
DESIGN LIFE (years)	***50yr (2% AP)***	***100yr (1% AP)***	***200yr (0.5% AP)***	***1000yr (0.1% AP)***
1	2	1	0.5	0.1
10	18	10	5	1
20	33	18	10	2
50	64	39	22	5
70	76	50	30	7
100	87	63	39	10
200	98	87	63	18

Table 2: Probability of experiencing a range of flood events over different periods (design life)

Appendix 5: Glossary

Afflux: A rise in water level above the normal surface of water in a channel that is caused by a partial obstruction.

Annual Probability (AP): The estimated probability of a flood of a given magnitude occurring in any year. As an example, a 200-year flood can be expressed as having a 0.005 AEP (Annual Exceedance Probability), or a 0.5% Annual Probability of occurrence. Other terms include 200-year return period, or a 1 in 200 chance of occurring in any given year. AEP is the reciprocal of return period.

Antecedent Conditions: The condition of a catchment area at the start of a rainfall event. In terms of hydrological modelling, it is standard to consider rainfall total over the three days prior.

Aquifer: A source of groundwater comprising water-bearing rock, sand, or gravel capable of yielding significant quantities of water.

Boundary Condition: A specified variable, typically water level or flow, which is defined at the edge of the spatial extent of the model to allow the model to solve its governing equations.

Catchment: The upstream area contributing to flow or runoff to a particular point on a watercourse.

Conveyance Capacity: The theoretical capacity to pass flow (discharge) at a fixed point, defined as a product of channel cross-sectional area and hydraulic radius, reduced by hydraulic roughness. Factors that affect conveyance capacity include, shape of channel cross-section, type and grade of in channel material, bank material, bed slope and wetted perimeter.

Culvert: Covered or enclosed channel or pipe that forms a watercourse or conduit below ground level.

Design Event: An historic or notional flood event of a given annual flood probability against which the suitability of a proposed development is assessed and mitigation measures, if any are designed.

Design Flood: Magnitude of the flood adopted for the design of a site, or flood protection scheme. Usually defined in relation to the severity of the flood in terms of its return period.

Discharge: Rate of flow of water normally expressed as cubic metres per second (m^3/s)

Erosion: Process where sediment is removed by action of flowing water or waves. Refer also to Sediment Transport.

Flood Event: A flooding incident characterised by its peak level or flow, or by its level or flow hydrograph.

Flood*: The temporary covering of water, from any source, not normally covered by water, but not including the overflow of a sewage system.

Floodplain*: The generally flat, naturally formed areas adjacent to a watercourse or the sea where water flows in time of flood or would flow but for the presence of flood prevention measures. The limits of a floodplain are defined by the peak water level of an appropriate return period. See also Functional Floodplain.

Flood Probability: The estimated probability of a flood of given magnitude being equalled or exceeded in any specific period. Refer also to Annual Probability and Return Period.

Flood Risk*: An expression of the combination of the flood probability and the potential adverse consequences associated with a flood, for the human health, the environment, cultural heritage, and economic activity.

Flood Storage: The temporary storage of excess runoff or river flow in ponds, basins, reservoirs, or on the floodplain

Flow: Volume of water that passes through a channel cross section in a given unit of time. Normally expressed as cubic metres per second (m^3/s).

Freeboard: The difference between the design flood level and the finished floor levels of a development, or soffit /deck levels of a bridge or culvert

Froude Number: Dimensionless number representing ratio between inertia and the force of gravity in a fluid, taking the value of unity for critical flow, i.e., Supercritical flow >1; Critical flow = 0; Subcritical flow <1.

Functional Floodplain*: The areas of land where water flows in times of flood which should be safeguarded from further development because of their function as flood water storage (and conveyance) areas. For planning purposes, the functional floodplain will generally have an equal to or greater than 0.5% (1 in 200) probability of flooding in any year.

Hydrograph: A graph that shows the variation with time of the level or discharge in a watercourse, as well as providing the total volume of runoff for that specific event.

Inlet: Entry point into a culvert

Invert: The lowest internal point (entry point) of any cross section in a culvert or pipe.

Mitigation Measure: An element of development design that may be used to manage flood risk to the development, or to avoid an increase in flood risk elsewhere.

Outlet: Exit point from a culvert

QMED: Median annual flood or the 1 in 2-year flood (or the 50% Annual Probability).

Return Period: A term used to express flood probability. It refers to the estimated average time gap between floods of a given magnitude e.g., 1 in 200-year flood. The definition differs whether the estimate was made using Annual Maximum Data or Partial Duration Data. Either way, it does not mean that if a location experienced an estimated 200-year flood, that it will not be flooded again for 200 years. Therefore, use of the annual probability term may be preferred.

Roughness: A measure of the resistance to flow in a channel, representing the irregularity, type and grade of the bed and bank materials/ vegetation, and other factors that act to impede flow. Roughness is a key variable in the determination of conveyance capacity. The most commonly applied definition of roughness is Manning's Coefficient (n).

Runoff: The total flow of water (minus any losses) from a catchment or smaller defined area, for any given rainfall or snowmelt event.

Scour: Erosion of bed or banks of watercourse by moving water. Can be associated with structures especially around bridge piers.

Sediment transport: is the movement of solid particles (sediment) typically due to a combination of gravity acting on the sediment, and/ or the movement of the fluid in which the sediment is entrained. Sediment transport occurs in natural systems where the particles have clastic origins, e.g., sand, gravel, boulders, mud or clay and is related to both erosion and deposition. All of these are common to fluvial/ riverine sediment transport. Sediment moved by water can be larger than sediment moved by air because water has both a higher density and viscosity. In rivers, the largest sediment moved is normally of sand and gravel size, but floods can carry larger grade material like cobbles and even boulders, which can lead to other flood related issues both during and after flooding. Fluvial sediment transport can result in the formation of ripples and dunes and in the development of floodplains.

Soffit: The highest internal point of any cross section in a culvert or bridge. Flows above the soffit level will surcharge.

Standard of Protection: The SoP is the Return Period associated with the flow used to design a flood protection scheme, e.g., a scheme designed to a 200-year event/ 0.5% AP event. An SoP can include an allowance for Freeboard and/or Climate Change over and above the initial design flow. Expressed another way, it is the estimated probability of an event occurring which is greater than those against which an area is protected against by a flood scheme.

Water Table: The level of groundwater in soil and rock, below which the ground is saturated. Often also known as the Piezometric surface.

*NB: * indicates as defined by Scottish Planning Policy*

ENDS