RIVER MEDWAY (FLOOD RELIEF) ACT 1976

Proof of evidence of Ben Gibson: **Appendix 1**

Environment Agency
Asiantaeth yr Amgylchedd

Computational modelling to assess flood and coastal risk

Operational instruction **379_05** **Issued** 27/10/10

What's this document about?

This document is a guide for assessing flood and coastal risk using computational modelling. It gives an overview of good practice to consider when we carry out modelling. It supports our requirement to take a risk-based approach to managing flood and coastal risk.

We assess flood and coastal risk (for instance for improvement schemes), as do developers or consultants (for instance for development purposes). We also work with our partners to develop modelling, especially lead local flood authorities and water companies.

This document focuses on modelling for flooding from rivers and/or the sea. It does not focus on other types of modelling (such as for surface water flooding or groundwater flooding) although much of the guidance can be applied to these types of modelling. Other documents are available which focus on modelling for local flood risk (for example WaPUG guides). References to these are provided in the related documents section of this document.

Who does this apply to?

Environment Agency staff in Flood and Coastal Risk Management (FCRM), particularly Flood Risk Mapping and Data Management teams and National Capital Programme Management Services (NCPMS), but also applicable to Flood Forecasting, Asset Systems Management, etc.

It can also be shared with partners or other third parties (such as developers) to help with their work, as long as it is made very clear that this document was developed for internal purposes. When supplying it you must also enclose/include a copy of Special Licence (Copyright) (Word, 78KB).

Contents

Document details

Related documents

Feedback

Contact for queries

1. FRM&DM OTL

2. FCRM Helpdesk

3. Helen James

1. Background

Contents

This chapter describes the background to computational modelling in the context of Flood and Coastal Risk Management:

FCRM Modelling Strategy

This document supports the principles of the FCRM Modelling Strategy 2010-2015. It particularly applies to the following principles:

- Modelling will be developed and shared with partners;
- Uncertainty in our modelling will be understood;
- Modelling will be managed effectively, in partnership;
- Our modelling will continue to be an asset;
- We will be an intelligent client with adequate resources to carry out that role;
- Technology will support our modelling.

Using models to assess flood and coastal risk

Consider these points when deciding whether to use modelling to assess flood risk:

- You do not have to use hydraulic modelling to assess flood and coastal risk;
- It may be technically acceptable and cost effective to recycle previous models rather than develop new ones, but only if the recycled model is fit for purpose.
- In less complex assessments simple hydrological and hydraulic analysis may be sufficient;
- Even if you do not use modelling, assess the impact of any proposed development on runoff using Flood Estimation Handbook techniques, or most appropriate equivalent.

Approach to the project

Consider these points when approaching the project:

At the start

- Clearly define our objectives and required outputs, and those of our partners (whether within the Environment Agency or external partners such as local authorities and Local Resilience Forum (LRF) members). Confirm what each partner is going to contribute in terms of budget, resources, data, etc.. Review the work against these intentions both at intervals and at completion;

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Approach to the project continued

- Clarify the boundary conditions and other design parameters;
- Do a one-off request for information held by other Environment Agency departments at the very beginning of the project since this affects selection of method etc, and could prevent further information coming to light at a later stage and complicating matters;
- Make sure you complete a Data Management Plan (see 183_05 Data Management Plans for Flood Risk Management Projects)

Locations

- Consider which sources of flood risk affect a location, and what level of detail and accuracy is required when planning a modelling study;
- Discuss requirements at specific locations with local experts and partners to ensure that any site-specific factors are identified, which may require special treatment when modelled;
- Where the modelling is being undertaken in relation to a development, ensure the study area is sufficient to demonstrate the effects of the development on locations away from the project site;

Choice of model

- Ensure the most appropriate modelling approach is agreed on and used (see section 2 of this document for more information). Numerical modelling is not always necessary to assess flood and coastal risk. In less complex assessments, simple hydrological and hydraulic analyses may be sufficient;
- A value for money approach avoids unnecessary complexity, whilst ensuring that the key processes in the real world system are well represented and the required level of detail and outputs are achieved to satisfy the modelling objectives. Be clear how the approach you have taken meets the outcomes of the study;
- Ensure the approach chosen is fit for purpose, but think about possible future uses too, so that the modelling can be re-used;
- Proof of appropriateness should include, but not be limited to, a defence of the modelling software choice, dimensionality (1D, 2D, linked 1D/2D, etc), state (hydrodynamic, steady state, routing), characteristics (strengths / limitations) and scale (detailed / national generalised).

Documentation

- Ensure that the modelling methods are documented to a level of detail sufficient to allow us to replicate the work and use the model in the future. Follow the SFRM performance scope (available from www.sfrm.co.uk). See section 7 of this document for more information.

Support for modelling

If there is any doubt whether modelling is required, discuss the situation with the Area Flood Risk Mapping & Data Management team at the earliest opportunity. They will also be able to provide suitable information to help with the modelling.

Modelling skills

In all modelling, the experience of the modeller adds value so ensure that suitably qualified and experienced people carry out the work. Technical Development Frameworks are available to assess skills against required competencies for modelling.

Historic information

Collect and use historic data from such sources as:

- Historic flooding (such as newspaper articles, photos, flood marks), including information on historic flooding prior to the periods covered by hydrometric data, to guide the extent of any survey and to aid the modelling process. Such data is particularly valuable as it can provide information for model calibration and verification;
- The internet (for example, the Chronology of British Hydrological Events, http://www.dundee.ac.uk/geography/cbhe);
- Alterations and additions to the watercourse and associated structures, to coastal defences, or within the flood plain, since the date of the recorded flood event;
- Area Flood Risk Mapping and Data Management teams.

Probabilistic modelling

Currently the majority of modelling done to assess risk in the Environment Agency is deterministic. The main exception to this is the Risk Assessment for System Planning (RASP) approach used for the National Flood Risk Assessment (NaFRA). Our FCRM Modelling Strategy 2010-15 states that we will move towards a probabilistic approach to understanding risk as our standard approach.

Research is underway to understand how we can validate the outputs of probabilistic models and how we can re-use our existing detailed deterministic models in a probabilistic way. Once these two areas of research are delivered we will review this guidance to include more detail about using computational modelling to produce probabilistic outputs.

2. Model selection

Contents

This chapter describes how to choose the appropriate modelling approach and software, what data inputs should be considered and what to think about before starting model building, and includes the following topics:

Uses of modelling

Modelling is used to calculate:

- flow and water level conditions in rivers, tidal rivers, estuaries and at the coastline;
- boundary wave conditions for tidal flood risk assessments;
- the flood extent, depth, velocity, hazard, timing, duration and flow paths over the fluvial or tidal flood plain;
- loadings on defences.

Qualitative description of risk

Before deciding upon the approach to modelling or the software used, it is first very important to understand the processes that influence the flood or coastal risk. The source-pathway-receptor concept is widely accepted as a means of categorising these processes. You should seek to understand locally important factors that are relevant to and significant for the flood and coastal mechanisms under consideration.

Source: where and how floodwater is generated

Pathway: where and how floodwater is conveyed and stored through the catchment or reach

Receptor: where the floodwater impacts and the features affected by flooding

The treatment or absence of the recorded features in the final model may also be used to inform statements of confidence and uncertainty attached to the modelling. It is important to understand if / how features known to be important are represented in the model. The implications and reasons for not including such features should be clearly understood.

Choice of software – some considerations

These are important points to remember when choosing software:

- use modelling software capable of producing the required output that has been demonstrated to be suitable for your needs;
- the software should be suitable for the application intended according to available benchmarking tests. If the available tests are not appropriate, you may need to have independent benchmarking tests / peer reviews carried out to prove the proposed modelling software is appropriate;
- you do not always have to develop a complex solution. Consider the outcomes required and the level of risk before deciding which modelling approach is most appropriate and what the minimum output requirements of the model are. Use the simplest modelling approach compatible with the desired outcomes;
- hydrological and hydraulic analysis, without using modelling software, though perhaps in association with GIS software, may be all that you need;
- software is often updated so be aware of available features when making a selection and record which version you use in the metadata.

Modelling dimensions – 1D, 2D and 3D

Flood modelling methods currently used in the UK can be classified by their dimensions or the way they combine different dimensions. Those that currently support most modelling applications necessary for Flood and Coastal Risk Management are one-dimensional (1D) or two-dimensional (2D).

Both 1D and 2D models are now in common use, as are linked 1D/2D models. The latter are particularly useful where there is a strong linear component to one part of the flow yet a two dimensional aspect elsewhere, for example where a river (1D) has an irregular flood plain (2D). Some 2D models also have an integral 1D component for simple representation of channels within the 2D domain.

In principle, model 1D situations in 1D, and model 2D situations in 2D; link these if both 1D and 2D situations apply.

2D models

2D models can provide information on flood depth, flow direction, velocity and timing, as well as providing outputs that are available from 1D modelling, such as flood inundation extent and predicted water levels.

External drivers for 2D modelling have arisen from:

- The Flood Risk Regulations 2009 which requires the prediction of flood hazard over high risk areas. This in turn requires an assessment of flood depth and flood water velocity. 2D hydraulic models provide a relatively low cost means of predicting these;
- The Pitt Review following the 2007 floods in England recommends:
  - better visualisation of the Environment Agency’s flood mapping data;
  - developing maps that consider surface water risks;
  - creating inundation maps arising from possible reservoir dam failure;

  all of which can be enhanced by using 2D models.

3D models

Three-dimensional (3D) methods are currently not in common use for estimating flood risk within the Environment Agency. Examples of where they are used occasionally are for analysing bridge pier scour or understanding deep water movement in estuarine or coastal environments.

Modelling state

The choice of which model to use should be made between:

- a hydrodynamic 1D or 2D model
- hydrodynamic combined 1D/2D model
- steady–state 1D model
- river flood routing model

A full hydrodynamic model, that is one in which flows and water levels vary with time, must be used if the study area contains either structures whose operation varies with time (for example pumps, sluices and tidal outfalls) or involves representation of tidal conditions. This should also be employed where there is significant flood plain storage or where a watercourse is subject to rapid increases and decreases in flow.

In other cases, either a steady-state or hydrodynamic model may be chosen. It should be noted that a steady-state model, that is one in which flows and water levels are constant over time, is unlikely to give a reasonable estimation of water levels where these are influenced by storage effects.

A flood routing model can be used in preference to a full hydraulic model if detail of flood water levels is not needed.

Modelling characteristics

The three tables below list respective characteristics of 1D, 2D and linked 1D/2D models with respect to their simulation of flows and water levels in channels and over floodplains.

Using 1D and 2D models to generate tidal boundary conditions is described later.

1D models

The table below lists the strengths, limitations, and applications of 1D models:

Strengths	Limitations	Applications
▪ Simulate flows for a large range of hydraulic structures such as weirs, gates, and sluices. ▪ Simulate effects in tidal rivers. ▪ Can have a storage cell approach for the simulation of floodplain flow added to represent a simplified version of 2D modelling (pseudo 2D) for broad-scale modelling.	▪ Limited to where direction of water movement is aligned to the centre-line of the channel. ▪ Assumes unidirectional flow. ▪ Flow velocities are depth averaged across the cross-section ▪ Conveyance can be severely over- or under estimated. ▪ Cannot simulate floodplain flow unless flow routes are known beforehand. ▪ Crude representation of floodplain storage capacity. ▪ Assumes uniform flood water level at each cross-	▪ River and tidal river flood risk modelling. ▪ Urban drainage modelling. ▪ Can be extended to modelling of flow in compound channels (channel + floodplain) but need to remember that floodplain flow is assumed to be parallel to main channel ▪ Particularly appropriate for narrow floodplains where there is no separation of the channel from the floodplain by embankments / levees.

	section. This may lead to no discernment between levels in the river and those behind raised defences, or on a floodplain at lower level than the river, if the model is not schematized correctly. ▪ Often assumes constant roughness values throughout the event, regardless of varying flow depth. ▪ Very rarely appropriate for modelling coastal flooding.	

2D models

The table below lists the strengths, limitations, and applications of 2D models. The 2D benchmarking R&D desktop review and report, provides a fuller description of the different types of 2D model type available and their relative strengths.

Strengths	Limitations	Applications
▪ Provides information on the magnitude and timing of depth, flow direction and velocity, as well as flood inundation extent and predicted water levels. ▪ Simplified versions are available to use where quicker run-times are required (review benchmark test results to decide which type of software package is appropriate for your needs). ▪ Quick to set up. ▪ Quick to generate flood maps. ▪ Can be linked with existing 1D models to ensure re-use of existing models (making best use of previous investment in modelling). See below.	▪ Integral 1D component gives only a simple representation of linear channel flow within the 2D domain. ▪ Not suitable if river channels are expected to act as important conduits of tidal ingression inland. ▪ Requires significant computation power and can take a considerable time to run if a fine grid is used. ▪ Can take longer to calibrate than 1D. ▪ Can take longer to run than 1D. ▪ The model accuracy can be dependent upon the grid size as well as the quality of the Digital Terrain Model (DTM) data used. ▪ Requires large data storage capability for results. ▪ There is a lack of	▪ River modelling where detail is required on floodplain inundation. ▪ Coastal and estuarine flood risk modelling. ▪ Surface water flood risk modelling. ▪ Reservoir inundation risk modelling (note that hydraulic jumps are more accurately modelled if the software incorporates a shock capturing scheme). ▪ Where hazard (depth and velocity) outputs are required.

	available data for verifying the results of 2D models.	

1D and 2D linkage models

The table below lists the strengths, limitations, and applications of 1D and 2D linkage models:

Linkage	Strengths	Limitations	Applications
1D-2D sequential linkage	▪ If the flood path is simply one of overtopping with no significant return to the source river or tide, during simulation, separate 1D and 2D models may be more straightforward to construct	▪ Not helpful for recession of river or tidal breach.	▪ Flood cell inundation
1D – 2D dynamic linkage	▪ Uses the strength of 1D modelling for the linear features (water courses) and the strength of 2D modelling for flows over the floodplain (computational savings over structured fully-2D approaches where a finer grid would be required to correctly represent channel geometry). ▪ Can also link 1D piped network model to 2D floodplain model. ▪ Can simulate tidal effects in both channel and floodplain.	▪ Requires significant computation power and can take considerable time to run if a fine 2D grid is used. ▪ Can take longer to calibrate than 1D. ▪ Can have instability issues; ▪ Requires large data storage capability.	▪ River, tidal river and estuary modelling where thorough representation of the channel is required along with detail of floodplain inundation.

Re-using existing modelling

We may hold existing river modelling useful for flood risk assessment (for instance produced during flood mapping studies, the design of flood alleviation schemes, for flood forecasting purposes or for Flood Risk / Consequence Assessments).

Consider whether you could use this, either directly or with some modification, as part of the flood risk assessment.

Verifying the model for re-use

Verify the fitness for purpose of existing modelling before re-using it. Some points to consider are:

- Is the model coverage and level of detail suitable for the new purpose?
- Is the representation of channels, floodplain, structures and defences still valid?
- Is the schematisation acceptable?
- Are the hydrological inputs suitable?
- Does the model run satisfactorily? how long does it take to run?

You can find such information by running the model and reading the modelling reports.

Check surveys

If modelling or survey data are provided by us or third parties, arrange check surveys at key locations to ensure that the data provided is compatible with current conditions.

Re-use: cost, licensing and intellectual property

Resolve any cost, licensing and Intellectual Property Rights issues associated with the use of existing modelling.

Intellectual Property

Intellectual Property (IP) refers to assets that originate from our or others' creativity. Examples of IP assets are datasets, databases, software, and maps. Intellectual Property Rights (IPR) are the legal rights that protect our IP assets. They include patents, trademarks, copyright, design rights.

When we receive IP assets from others, ownership does not transfer to us unless a contract says it does. If others retain ownership, we need to know what we are allowed to do with it and, when practical, make the way we intend to use it transparent to them.

There are a few documents which explain Intellectual Property in more detail. You can access these from the related documents section of this document.

Charging and licensing

Refer to 98_07 charging and licensing for flood risk information for more details.

National generalised modelling

The table below helps explain the differences between detailed modelling and national generalised modelling.

For further details on the National Generalised Modelling data for Flood Zones you should refer to 229_06 Provision and fitness for purpose of the National Generalised Modelling (JFLOW/HYDROF) including climate change depth difference data.

Feature/characteristic	Detailed model	Generalised model
Ground levels	Detailed site survey / LIDAR / Photogrammetry	National DTM – broad scale
Output data calibrated and verified? (QA'd)	Yes – when possible	No
Model Inflows	Calculated or from recorded data	Automated
Input data QA'd	Locally	Nationally

Mannings ‘n’	Locally set	Globally set
Schematisation	Detailed using local knowledge	Simple
Structures	Takes account of existing infrastructure	Bare earth simplification
Application	Tailored to the specific needs	Not generally appropriate for detailed decision making

Integrated modelling

Both the Water Framework Directive and the Pitt review call for an integrated approach, which requires modelling of whole catchments or entire urban drainage systems.

Integrated modelling should be seen as more than just linking models together. It is about: developing community where knowledge is shared; providing business processes that support appropriate re-use of models and data, and strong management of models so that a clear audit trail is available. In fact, developing the models is probably the smallest challenge facing integrated modelling.

There are three ways that integrated modelling can take place:

(1) By linking separate models so the outflows of one model are used as inflows to the other(s);

(2) By coupling models using wrapping software to allow models to interact with one another in a more integrated manner than (1);

(3) By using fully integrated modelling software which enables the hydraulics and hydrology of the environment to be incorporated into a single model.

Each approach has advantages and disadvantages and the modeller should consider which existing data and models are already available, and decide on an approach that is best value for money to achieve the desired outcomes of the study.

3. Model construction

Contents

This chapter advises on sources of data from which to build a model and on the selection of model parameters. It includes the following topics:

Survey data

This table describes what to consider when assembling survey data and commissioning new survey, (ground survey, LIDAR or other).

Further guidance on survey standards should be obtained by reference to the Environment Agency National Survey Specification.

Item	Action
Survey scale	▪ Define the upstream and downstream limits by the objectives of the assessment, rather than to the limits of the immediate project area; ▪ Include the full extent of likely flooding in the lateral extent of the survey (guidance on this extent may come from flooding records and from flood maps); ▪ When in doubt, specify a greater survey extent, particularly where limited LIDAR coverage exists; ▪ Continue the survey far enough downstream so that uncertainty in the boundary condition does not significantly influence the estimated flood levels.
Survey features	▪ Ensure the cross sections surveyed are representative of the channel and floodplain; ▪ Determine cross-section spacing and orientation from the appropriate software documentation and textbooks (for example, the online manuals supplied with specific software packages). For 1D modelling, cross-sections should be orientated at right angles to the direction of flow; this may mean the floodplain part of a cross-section has a different orientation to the channel part; ▪ Consider a greater density of cross-section in areas where detailed flood depths or extents are needed; ▪ Sufficient spot levels should be taken along the river banks or coastal defences to ensure that the variation in the bank levels is adequately represented in the model; ▪ Survey all structures (upstream & downstream faces, culvert dimensions, bridge deck levels) unless they have no potential to affect flood flows/flood levels; ▪ Ensure that information on structures, flood routes, potential blockages/obstructions to the channel and channel roughness are gathered;

	▪ Similarly, ensure information on obstructions across the floodplain, for example as given by road infrastructure and flood plain roughness, is gathered; ▪ Where tidal bathymetry is needed, for example for wave modelling, ensure this is sufficiently detailed so shoaling, refraction and similar effects will be calculated accurately; ▪ Ensure cross-sections of raised defences cover the full section, identifying base levels (as may be needed for breaching calculations) as well as profile slopes, wave wall geometry and surface type, for example grass/concrete (the type is particularly relevant if wave overtopping may need to be calculated).
Other considerations	▪ Ensure that the extent of the survey work is defined jointly by those undertaking the modelling and those undertaking the survey in conjunction with advice from the Area Flood Risk Mapping & Data Management team; ▪ Locate all cross sections and other survey information in plan relative to the British National Grid; ▪ The survey data should be provided in a model ready format or in a format that can be easily converted with minimum time and effort; ▪ Photographs of the channel should be taken at the time of the survey. Additional photographs of roughness and blockage should be taken at the time of a walkover by the modeller; ▪ We may hold existing hydrographic and floodplain survey data which may be of use in a flood risk assessment; ▪ LIDAR and local topographic surveys should be reconciled to ensure common datum and spatial coherence; ▪ Consider wider uses of survey data, for example obtaining defence crest levels for use in NFCDD (and subsequent use for NaFRA).

Representing hydraulics - features

Modelling can be used to represent:

- the key flood flow routes;
- flood storage;
- barriers to flow;
- structures in the study area.

Before building the model, schematise these features, preferably on a map background, so their location and points of interactions are clearly understood.

Representing hydraulics - considerations

Structures / features:

- Include the effect of operational structures, such as sluice gates, although you can adopt a fixed setting if this is the likely situation within the events being modelled;
- Where raised features cross a floodplain, also identify openings through these (for example a subway or culvert under a road) so potential flow paths are not overlooked in the modelling;

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Representing hydraulics – considerations continued

- Use data from detailed ground level survey for spill points in a 1D/2D model. Building such a model purely on standard remote-sensed DTM data is unwise, though the use of high resolution LIDAR (for example 0.25m grid) may be sufficient;

Topography:

- 2D model accuracy is affected by the accuracy of DTM data, representing the terrain and features crossing it, how it is processed and filtered by the data provider, and how it is processed to a grid;
- Use both unfiltered and filtered LIDAR to maximise the benefit of the complete LIDAR set and to minimise any shortcomings with the filtered data;

Checking outputs:

- Check 2D models in detail (especially mass balance at suitable time intervals and plausibility of velocity/depth variations);
- Run model animations (1D as a longitudinal profile animation; 2D as a flood spreading animation) to check the flow characteristics look plausible.

Hydraulic coefficients

Determine the coefficients used in the model (such as channel roughness, weir coefficients) with guidance from standard textbooks. Reference these texts in the modelling report.

Further information on roughness can be obtained from the Conveyance Estimation System.

Advice on afflux is given in the Afflux Estimation System.

Roughness values in 2D models

2D models allow spatially-varying roughness and some also allow roughness parameters to vary with depth and time. There is a lack of text-book values of roughness for 2D models though values are suggested in some software manuals.

Good practice

As good practice, all 2D models should be run for a 'reference case' of 0.1 Manning's n roughness for the entire 2D model domain with the grid based on a filtered Digital Elevation Model (DEM). The model report should then show the difference between the chosen roughness/grid against this (in terms of differences in level, flood extent).

You can identify variations in surface roughness in your model to reflect differences in land use. However, avoid large scale variation in roughness values beyond mapping values to key land use types (such as roads, open farmland, etc.).

Roughness values should generally increase with model grid size. Mannings 'n' values should increase for shallow depths of flow.

Representing buildings in 2D models

The table below describes the four modelling approaches in common use:

All are based on a filtered DEM, thereby removing buildings and vegetation as a starting point.

	Approach	Description
1	Apply an increased roughness value to the overall floodplain area, taking account of the mixed land use this encompasses.	Simple. The most suitable for modelling where local detail is not needed for example Flood Zone and ABD assessments.
2	Superimpose the buildings, for example by using OS Mastermap data. Increase roughness values over the footprint of the buildings to represent how they impede flood flow.	Allows for impedance to flow given by the buildings and for flood volume to be dissipated within the area of the buildings. Gives more detail than approach (1).
3	Edit buildings to be 'stubby buildings' (typically set to the threshold level if known, or to a uniform 250-300mm above ground level). Assign the 'stubby buildings' a higher roughness value to represent how they impede flood flow.	Attributes as approach (2) but adds for the obstruction to flow given by the building footprint between ground level and the threshold level. This improves representation of flow paths and velocities at shallow depths. Often the best choice for detailed modelling.
4	Represent the buildings as solid blocks, perhaps 5m high.	Confines flood flow and dissipation of flood volume to the space between the buildings. Gives the worst case, for example, for flood hazard on roads, provided the model grid size is small enough to represent the road space between the buildings. Can be useful for emergency services planning. The solid blocking leads to underestimation of the flood extent.

Breaching

Where a site has raised flood defences, you may want to demonstrate the potential consequences in the event of a breach in those defences.

Breaching can occur even in defences that supposedly have a high structural standard, for example due to an undetected weakness. Wave overtopping can be very damaging in a coastal situation.

Potential breaching of defences depends on their form, size and condition. Areas teams usually have their own standard criteria, of width, base level and timing within the event, to be used in setting breaching parameters.

Also see breaching guidance used in Wales.

4. Fluvial boundary conditions

Contents

This chapter outlines principles for generation of fluvial boundary conditions, given under the following topics:

Hydrometric data

Collate river flow, river level and rainfall data relevant to the study area where available.

This data is most likely to be sourced from the Area Environmental Monitoring (Hydrometry and Telemetry) team. Seek an understanding of the uncertainty and confidence within this data, for example the reliability of flow gauge rating curves, from its local custodian.

Use the Flood Estimation Handbook and the UK HiFlows project as sources of hydrological data.

Hydrological assessment

Do a hydrological assessment of the flood flows using the methods described in our Flood Estimation Guidelines.

If you use hydrodynamic modelling, include consideration of peak flows, flood volumes and shape of the hydrograph in the hydrological assessment.

If the problem includes storage (for example floodplain or reservoir storage or a tide-locked watercourse) you must identify the critical duration storm for storage (which often differs from the critical duration for peak flow). If you use a steady-state model, this is limited to consideration of peak flows.

Consider the possible effects of climate change on river flows through use of the appropriate contingency allowances.

Upstream boundary (inflows)

Develop the upstream boundary or boundaries, together with lateral inflows, during the hydrological assessment described above.

For some models, one single upstream inflow per flood event may be sufficient, whilst for others, many upstream boundaries may be needed if a number of tributaries or other inflows are present.

Locate the inflows based on hydraulic considerations, not on the upstream limit of the development. The upstream boundary should be far enough upstream to allow the full impact of the development on upstream water levels to be identified.

Downstream boundary (levels)

Locate the downstream boundary where the relationship between level and flow is well defined, (for example at a weir). Where this is not possible, locate it sufficiently downstream of the area of interest so that any errors in the boundary will not significantly affect predicted water levels at the proposed development site or other area of relevance.

For a typical fluvial river, a rule of thumb is that a backwater effect extends a length, L,

$$L = 0.7D/s$$

where

- D = bank-full depth
- s = river slope.

Hence if the downstream boundary is greater than L from the site it is likely that any errors in the rating curve at the boundary will not affect flood levels at the site.

Tidal boundaries

If the downstream boundary is tidal, locate it where you can accurately define a tidal curve. Outfall structures should be adequately represented to simulate 'tide-locking' where this may occur.

We hold extensive extreme tide information from flood risk mapping studies. Consider joint probability carefully. See also Tidal boundary conditions below.

5. Tidal boundary conditions

Contents

This chapter outlines principles for generation of tidal boundary conditions, given under the following topics:

Boundaries

For a tidal flood risk assessment boundary conditions are needed for direct tidal flooding; also for flooding due to wave overtopping or wave run-up if wave action may be present.

The model's tidal boundary needs to allow for the return of water to the sea where this could occur, such as at a breach or with wave action at promenades.

Extreme sea levels: data and rates

Extreme sea levels for the UK coastline are being defined in a current Environment Agency R&D project, due to report in 2010. When this data is available you should use it, but until it is available sea levels can be obtained from:

- Regional datasets, derived from analysis of local gauge data, perhaps combined with modelling approaches. In some instances these datasets include levels for estuaries/tidal rivers;
- POL Report 112;
- New analysis of tide gauge data;
- Historic observed levels.

If data from the more distant past is analysed, adjust it to present-day values by applying a correction to compensate for the historic rate of sea level rise.

Rates are given in

- POL Report 112 (they are generally about 2mm/year);
- POL's website (www.pol.co.uk/psmsl).

Extreme sea levels: set-up

Sea levels at the coastline can be raised by wave set-up. The amount of set-up depends on the location's exposure to the pertaining wave conditions. Calculation of potential set-up is given by the CIRIA Beach management manual and is a feature of some wave modelling software.

Extreme sea levels: estuaries and tidal rivers

Levels in estuaries and tidal rivers can be different (often higher) than at the coast, especially if narrowing occurs to give a funnelling effect on the incoming tide.

Estimation

You can estimate design levels by establishing a relationship between observed high tide levels in the estuary and equivalent high tide levels at a nearby coastal location (for which definitive sea level / return period values should be available). The level to level relationship between the coastal and estuary points can then be used to estimate return period tide levels in the estuary.

Modelling

You can calculate levels through modelling, but this is only valid if you can calibrate it to observed levels. The hydraulics of estuary flow is more complex than for rivers, and the assumptions you make in river modelling are not all valid for estuaries.

Tide and surge curves and their combination

The total tide curve for an event is a combination of:

- the astronomical tide (the tide caused by the gravitational effects of the moon and the sun and given in published tide tables);
- tidal surge (the additional elevation of the sea caused by weather conditions).

Select a sequence of tides around a very high spring tide, even Highest Astronomical Tide (HAT), as the astronomical tide component. An overall duration of about five days is often needed. You can use software to calculate this, or you can select a suitable record out of tide gauge data.

Note: we hold detailed astronomical tide predictions for 142 sites around the country. These are available on our National Flood Forecasting System and web service.

The growth and decline of a tidal surge can be estimated using data from the nearest Class A tide gauge. For larger events the surge is likely to have duration in the range 36 – 60 hours.

Producing a total tide curve

In order to produce a total tide curve, add the surge shape to the astronomical tide, putting peak to peak, and scaling the surge height so the total peak sea level is as desired. Do not scale the surge duration.

Surge curves suitable for design and assessment purposes will be an outcome of a current R&D project.

Wave conditions

Types of wave

There are two classifications of waves:

- Wind waves: generated by a local storm and generally of period (time for one complete oscillation of a wave) up to 12 seconds;
- Swell waves: generated remotely over the wider ocean then running into the coastal waters. Swell has a longer wave period. Because it has a greater energy than wind waves, swell can be highly damaging to coastal structures.

Sources of information

Some sources of information on offshore and nearshore wave conditions are:

Continued on next page…

Wave conditions continued

- Shoreline Management Plans;
- Met Office hindcast modelled data;
- Wave buoys (for example data from WaveNet, Met Office), though most do not have a long record;
- Swell atlas. Updated swell parameters for UK coastal waters will be with an output from a current R&D project.

Raw wave data may need processing to estimate return period values of wave height and wave period. In doing this, consider which wave directions the site of interest is exposed to rather than lumping all the wave data together. For most places around the coastline there is a dominant wind wave direction, not necessarily being the most common wind direction, likely to apply coincident with the higher extreme sea levels; see FD 2308/TR1.

Considerations when modelling

- If the only wave data available is for a point offshore, you need to transform the wave parameters to the nearshore for flood modelling purposes. Wave conditions can be converted from offshore to the coastline using a spectral wave model;
- 2D modelling includes for refraction, etc. as the waves move shoreward. Some models do not handle wave reflection;
- For good results in any wave transformation model you need good bathymetry, for example from Admiralty digital charts supplemented close to the shore by local survey, for example beach profiles or LIDAR (if flown at low tide);
- You can also estimate wind wave conditions at the coastline by considering potential wind speed, duration and fetch length; see BS 6349 or relevant software. This method is particularly useful for estuaries and enclosed waters;
- Since wave heights are limited by the depth of water available, it is not unusual for the wave height at the coastline to be “depth limited”. In this case the maximum wave that can reach the coast may be almost independent of the offshore return period wave height adopted. This could stop the need for wave transformation modelling;
- In general, you can consider the effect of wind waves and of swell waves separately. Also see joint probability.

Climate change

Contingency allowances for sea level rise in response to climate change are given in Defra guidance and PPS 25 / TAN 15. These allowances apply to mean sea level. Tidal range is predicated to stay unchanged; hence you can represent future tide curves by shifting present-day curves upwards by the set amount.

Storminess

The latest UKCIP projections suggest that storminess will remain unchanged for the future. Thus there is no need to adjust currently estimated offshore wave heights, though waves reaching the coast can be higher because of the greater water depth with sea level rise.

Joint probability

Joint probability needs to consider how likely it is for the respective phenomena to occur together, not just in the same year or on the same day but at the same time.

Phenomena with a short duration are less likely to be coincident than those of long duration.

The "Norfolk method" is one way of allowing for duration in considering joint probability.

Joint probability: tide/wave flow

Extreme tide levels are caused by severe weather, therefore they generally are associated with strong winds and the notable wave action generated by those winds. Thus there is usually a good correlation between the occurrence of extreme tide level and high wave action.

Conversely, high winds and associated extreme waves can occur with modest tide levels. This situation is not normally of such interest as the extreme tide plus wave combination, in part because of the potential "capping" of wave height at the coastline due to depth limiting. Establish the actual position by site-specific assessment.

FD 2308/TR1 gives advice on tide/wave correlation strengths and on the dominant storm direction around the coast. It also presents tables showing variable combinations of tide and wave return period for a range of joint return periods. As a caveat to the tables you should not accept small wave heights as a combination with extreme tide levels, for the physical reason outlined above.

Research shows the occurrence of swell waves is independent of wind wave occurrence so their joint probability can be assessed from this standpoint.

Joint probability: tide/river flow

FD 2308/TR1 also gives advice on correlation between high river flow and high tide levels.

This advice is conservative as the studies only considered coincidence on the same day rather than at the same time. In practice correlation tends to be low since the causative weather patterns are often mutually exclusive.

High catchment rainfall, giving high flows, tends to be associated with fairly static weather whereas extreme tide levels tend to be associated with highly mobile low pressure systems.

Commonly it is either the extreme fluvial or the extreme tidal event, rather than some intermediate combination that will dominate flood extents. For these it should be sufficient to consider respectively:

- A high river flow with a mean high water spring tide;
- An extreme tide with QMED river flow.

Modelling must, however, evaluate the circumstances of each location individually. The relative timing of high river flow and extreme sea levels can be assessed by comparison of respective gauge data.

River flow in combination with a mean neap tide may need to be considered. During neaps the tide level does not fall as low as during spring tides. This impedes fluvial discharge capability at low tide, possibly giving the dominant flood risk scenario.

Tidal overtopping and breaching

Direct tidal overtopping will be calculated by considering weiring over the defence or other coastline feature as the tide level rises and falls through the event. A suitable boundary condition can be set up in the software being used.

The EurOtop manual gives quantitative advice linking wave overtopping rates to potential damage at the coastal frontage.

Also consider potential breaching of defences.

Wave overtopping

Calculate wave overtopping using one of these options:

- methods in the EurOtop manual;
- methods in our own overtopping manual;
- specialist software.

In each case experienced judgment is needed to assess whether the results are plausible, since no method is particularly reliable. In view of this, calibrate all wave overtopping calculations against some past experience, perhaps including "near miss" events when no significant overtopping occurred in spite of the prevailing wave action.

Different calculation methods

The EurOtop methods are suitable for frontages having a simple and fairly regular profile, or can be approximated to this. Calculation is possible via an on-line tool on. The EurOtop empirical method is particularly easy to use.

For other than simple profiles, specialist software should be used as this will generally facilitate better representation of the frontage shape. In principle this should improve the quality of the results, though whether this achieved in practice is not certain as there is little calibration evidence to real-life experience.

Source of information

All methods need information on the frontage crest level and profile, extending to the beach foreshore. This information can be obtained from local surveys or high resolution LIDAR.

Calculations

The total volume of wave overtopping is found by considering overtopping rates at different sea levels through the expected rise and fall of the tide in the event, then integrating the answers. It is usually sufficient to consider the wave action as lasting for only 12-24 hours even if the total tidal event is longer. This is because the waves will then diminish as the storm moves and the wind changes direction.

The extent of wave run-up can also be relevant, for instance in assessing whether properties are likely to be affected by wave water. EurOtop gives methods of calculation.

Shingle

Shingle beaches are mobile under wave action. In part this is helpful to flood protection as they tend initially to deform and create a higher ridge landward of the original crest. Further deformation can lead to collapse of this ridge, leading to overwashing of the frontage.

If …	then …
you can assess the potential for overwashing to occur	use the Bradbury method.
overwashing is found to be a potential problem	estimate the new shingle profile after wave action using the Powell method.

Both methods lend themselves to a spreadsheet calculation. The methods are approximations only, so should not be relied upon for critical situations.

Specialist software is available to estimate shingle or dune movement under wave action.

6. Calibration, verification and sensitivity testing

Uncertainty analysis

In modelling flood risk there are uncertainties throughout the process, in the input data, in the mathematical equations, in the modellers skills and in the outputs. We need to be open about the uncertainty involved in modelling and find ways to present this uncertainty to help people make more informed decisions.

Uncertainty can be expressed through the results of sensitivity analysis.

Whilst we can use probabilistic methods to help us understand and communicate uncertainty, most current modelling remains deterministic.

Currently research is underway to understand how we can validate the outputs of probabilistic models and how we can re-use our existing detailed deterministic models in a probabilistic way. Once these two areas of research are delivered we will review this guidance to include more detail about using computational modelling to produce probabilistic outputs.

Calibration

Wherever practical, calibrate the hydrological assessment and the hydraulic modelling against recorded flows and/or water levels and flood extent from observed flood events.

The events need not have caused extensive flooding as it is also valid to show the model correctly predicts water not reaching particular areas.

Availability of calibration data

If calibration data is …	then …
available	calibrate using at least three separate events.
not available	carry out a ‘reality check’ on the predicted flows, levels and water level profiles using photographs, historic information and anecdotal accounts of flooding.

Considerations

- Only vary the coefficients used in the calibration process within the possible ranges suggested in the standard textbooks. Consider flow and flood levels when calibrating steady-state modelling. Also consider the timing of the flood peak, flood volume and shape of the flood hydrograph when calibrating hydrodynamic models.
- In 2D modelling of floodplains consider whether the flood extents, depths and flow paths given by the model appear plausible when set against what is known of the area.
- Models for flood forecasting purposes require more emphasis on the timing at the rise in flood level than is generally needed in models for flood risk assessment purposes only.
- Target accuracies for calibration are provided in the SFRM specification.

Verification

After calibration, run one or more separate observed events through the model to verify the adjustment of parameters.

Sensitivity testing

Test the modelling outputs by adjusting key parameters within the model.

The aim here is to assess the possible circumstances that could cause flooding to be significantly more severe than the modelled best estimate.

Adjusted parameters should include

- model inflows;
- downstream boundary condition;
- channel and floodplain roughness;
- key structure coefficients.

Reflect uncertainties, possible changes due to climate change and variations in hydraulic coefficients (for example from seasonal changes or periodic maintenance) in the range of parameters used in sensitivity tests.

Test sensitivity to blockage of critical structures.

7. Mapping and reporting

Contents

This chapter provides advice on the presentation of modelling outputs, mapping and reporting:

Mapping

Mapping of flood extents and other parameters (for example flood depth), is a direct output from 2D modelling.

With 1D modelling it is generally made by projecting water levels over the DTM at each cross-section and interpolating between these. There are potential shortcomings in projecting water levels at sections where the water level on the floodplain and the water level in the river are not well connected. It is important that appropriate engineering judgement combined with suitable GIS techniques should be applied in mapping and flood extent for these situations (for example mapping bypass flows).

Isolated dry areas

In each case, isolated dry areas ("dry islands") may exist within the overall flood extent. In accordance with national guidance, dry islands of less than 200m^2 in size should be removed from the mapping (infilled).

Isolated wet areas

Similarly, isolated wet areas may be shown beyond the general flood extent. You should consider whether the flood water would actually reach the remote area or whether it is only an inadvertent product of water level projection. In the latter case the isolated wet area should be removed entirely. If the isolated wet area is plausible it should remain in the mapping, though isolated wet areas of less than 200m^2 in size should be removed as being inconsequential.

Tidying up

It may be appropriate to tidy up flood outlines, usually though a mixture of automated and manual routines. In some cases the mapped outputs may imply that the flood outline in large because there are areas of very shallow water in the model outputs. Given the uncertainties in the modelling, we don't have much confidence in the very shallow depths being realistic. It is advisable to remove all depths less than 0.1m because this gives (by eye) a clearer representation of the areas that are flooded (so there is more focus on the areas flooded to a greater depth).

Report content

Write a report describing the modelling so that the model structure and results can be evaluated.

It should be a self-contained report that will provide sufficient information to allow us to use the model in the future, including enough detail should we need to replicate the work. The detail of the report should be appropriate to the complexity of the modelling.

The SFRM performance specification (available from www.sfrm.co.uk) details exactly what is expected from the report. This specification must be used by any consultant who carries out a project involving modelling for us.

Report format

The report must be easy to copy and transmit electronically, and must include plans and schematics on an appropriate scale mapping backdrop. All relevant features, structures and watercourses shall be shown and named.

Adobe pdf files are preferred for the report.

Data

- Copies of the model data files together in an appropriate format (not Adobe pdf) with sufficient instructions to run and view the models, for example a text file containing start time, finish time, time-step, runtime, information on non-default parameters etc.
- Include initial condition files.
- Flood level nodal data, and other data, required for NFCDD.
- Copies of flood outlines and other required modelled outputs in GIS format.

Future use

Write a statement to accompany the report and the model data on the allowable future uses of the model and its associated documentation. This is described in the SFRM performance specification in more detail (available from September 2010)

Complete the metadata (refer to 199_07 Flood Risk Management Metadata Standards).

Quality assurance and audit trail

Throughout the study, define and report on an audit trail.

Include all relevant documentation and a link with the appropriate quality assurance procedures of the organisation carrying out the study.

Make sure the relevant documentation is available to others who may use the modelling inputs and outputs in future.

Related documents

Strategies and policies

- FCRM Modelling Strategy, FCRM Data Strategy, FCRM Risk Mapping Strategy. Visit our publications catalogue and enter the words "Modelling Strategy", "Data Strategy" or "Risk Mapping Strategy" in the publication title field of the search.
- Risk Management: A Risk-Based Approach (261_05)

Modelling approach

Specifications

- Flood Mapping Specification for the Strategic Flood Risk Management Framework (www.sfrm.co.uk);
- SFRM performance specification (available from September 2010);

R&D reports

- Fluvial Freeboard Guidance Note (W187) (visit our publications catalogue and type "fluvial freeboard" in the publications search);
- Joint probability: dependence mapping & best practice, FD 2308/TR1. HR Wallingford. 2003. (visit the FCERM evidence web page and type "FD2308" into the search, select the research project option before clicking on search)
- Wave overtopping of seawalls. Design and assessment manual. (W178). February 1999. (visit our publications catalogue and type "overtopping of seawalls" in the publications search);
- FRMRC Research Outcomes in the Application of 2D Flood Inundation Models for Flood Risk Management. 2008. (available by contacting Helen James);

Internal guidance

- 145_07 Real-time model development for flood forecasting
- 229_06 Provision and fitness for purpose of the National Generalised Modelling (JFLOW/HYDROF) including climate change depth difference data
- 303_09 Flood Risk Management: Strategic Flood Consequence Assessments for Wales
- DRAFT Dry islands on the Flood Map/Flood Zones, 2006

External guidance

- CIRIA Report C624, Development and Flood Risk – Guidance for the Construction Industry, CIRIA, London 2004 (available from the CIRIA website www.ciria.org, search their bookshop (enter C624 into their search engine);
- WaPUG guides http://www.ciwem.org/groups/wapug/modelling.asp
- BS6349 Maritime Structures – Part 1: Code of Practice for General Criteria (visit the BSI shop http://shop.bsigroup.com/en/ and enter BS6349 into their search engine);
- Beach management manual. CIRIA Report 153, 1996.
- Defra FCDPAG3 Economic Appraisal: Supplementary note to Operating Authorities – climate change impacts. October 2006.
- EurOtop. Wave overtopping of sea defences and related structure: Assessment manual, August 2007. An on-line calculation tool is available at www.overtopping-manual.com/calculation_tool.html

Modelling approach, continued

- The Norfolk Method was originated by Mantz and Wakeling (ICE, 1979). The general expression is given in "Tidal Flood Risk Areas – Simply Credible. Worth and Cox, 35th MAFF Conference of River and Coastal Engineers, 2000."
- Bradbury, "Predicting Breaching of Shingle Barrier Beaches – Recent Advances to Aid Beach Management" (35th MAFF Conference of Coastal and River Engineers, 2000).
- Powell, "Predicting short term profile response for shingle beaches" HR Wallingford Report SR 210, February 1990.

Data

- 199_07 Flood Risk Management Metadata Standards
- 197_08 Flood Estimation Guidelines
- UK Hiflows project
- 687_06 Data auditing – guidance for flood risk mapping and data management teams
- 183_05 Data management for Flood Risk Management projects and good data management considerations
- Defra/Environment Agency R&D Project SC060064: Development and dissemination of information on coastal and estuary extremes (visit the FCERM evidence web page and type "SC060064" into the search, select the research project option before clicking on search)
- Proudman Oceanographic Laboratory Internal Document No.112 – Spatial Analyses for the UK Coast. Dixon and Tawn, June 2007
- Class A tide gauge data is available for download from www.bodc.ac.uk
- WaveNet data is available from www.cefas.co.uk/data.aspx
- Swell and bi-model wave climate around the Coast of England and Wales. HR Wallingford Report SR 409, November 1997

Software

- R&D Report 'Benchmarking of hydraulic river modelling software packages' (W5-105) – visit our publications catalogue and enter the word "benchmarking" in publication title field of the search
- 2D benchmarking – visit our publications catalogue and enter the word "2D benchmarking" in publication title field of the search

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Survey

- Environment Agency National Survey Specification is available from O:\National Flood Mapping\Survey Specification
- Refer to Assessment of Flood Risk – Hydrographic and Topographic Survey. For further information on the appropriateness of survey, you should refer to the operational instruction The Preparation of Survey data for Flood Risk Assessments (195_05)
- Royal Institute of Chartered Surveyors http://www.rics.org/guidance

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Hydraulic Coefficients

- Chow (Ven Te Chow, Open Channel Hydraulics, McGraw-Hill 1959) and Hicks & Mason (Roughness Characteristics of New Zealand Rivers. D.M.Hicks & P.D.Mason. 1999) can provide some guidance.
- Information on roughness can also be obtained from the Defra/Environment Agency Conveyance Estimation System (CES) – http://www.river-conveyance.net/
- R&D Project W5-110, Afflux Estimation System, EA/Defra science project SC030218, 2007 (visit the FCERM evidence web page and type "SC030218" into the search, select the research project option before clicking on search)

Intellectual Property

- 1139_08 Intellectual Property
- Intellectual Property e learning course
- 437_07 Use of 3rd party Intellectual Property from Flood Risk / Consequence Assessments
- 213_05 How do I add, update or delete an entry in the Information Asset Register?
