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HRPP 468

Flood risk attribution to river defences

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Reproduced from a paper presented at:
River Flow 2010
Germany
8-9 September 2010

FLOOD RISK ATTRIBUTION TO RIVER DEFENCES

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Key Words
Flood Risk Attribution, Probability, Flood Defences, Management

Abstract
A flood risk-based approach to flood risk management is a proactive approach where resources and efforts are targeted at the locations and communities where greatest benefit can be achieved. To support the management decision a simplified approach to relate the condition of fluvial defences to its contribution to risk has been developed; the RAFT tool. The tool is focused on providing outputs to operational staff in the field to enable the importance of a fluvial defence in terms of risk to be assessed, without recourse to more complex office-based modelling. This paper presents the probabilistic concepts underpinning the flood risk attribution process and an overview of the RAFT tool. This approach is used to support both the management and the public understanding of flood defences, for example assessing the impact of different management strategies of flood risk reduction.

1 Introduction

The effective management of river defences represents a considerable challenge to flood risk managers given the financial burden associated with maintenance and the implication of failing to provide adequate protection to exposed communities. Where floodplains and lowland areas have been heavily developed or where critical infrastructure is present, the consequences of failing to maintain river defences can be grave.

Despite the undesirable consequences associated with flooding, it is rare that sufficient funds are made available to undertake all necessary improvement activities. It is in the face of limited budgets that the role of a flood risk manager becomes one of damage limitation; difficult decisions must be taken in order to decide how and where limited resources should be invested and, conversely, where intervention is not financially viable. The difficulties inherent in these decisions are compounded by the continuing need for floodplain development, and the emerging threat of climate change (Evans et al 2004).

Flood risk managers are in the position where they must find effective ways of measuring and quantifying risk in order to inform their decision-making. For a long time, the flood management strategies were based on historical flood events and focussed on reduction of the flood hazard. All the measures were based on raising embankment levels after each flood and training works to increase the discharge capacity of the river. The application of probabilistic techniques allows a change of flood control strategies (Kersting 2010): the desired safety levels are chosen based on the acceptable probability of flooding. The probabilistic techniques can also be adequate tools for flood managers to optimize their management decisions on a wide range of different levels, from National policy to the level of day-to-day maintenance decisions.

Understanding the performance of the individual assets within an asset system is the first step towards understanding how best to manage them. This includes knowledge about geometry and structural features, the loads experienced (e.g. water levels) and the associated probability of failure. Inspection methods (intrusive and non-intrusive) and reliability analysis are vital aids to this process. Reliability analysis is used to express the performance of an asset in a given condition in terms of its likelihood of failure under a particular hydraulic loading (Melchers 1999).

While the use of high-level probabilistic techniques is increasingly important to flood risk managers for high-level assessment and to test the effectiveness of management strategies, there is also a need to undertake a similar analysis at asset level. At this level, the analysis is required to help prioritise maintenance activities within flood management systems. The ability to consider the contribution to overall risk at the level of individual assets within a larger system makes it possible to directly estimate the risk attributable to its condition (for example) in a system. This paper outlines a risk assessment methodology, the RAFT tool (Risk Attribution Field-based Tool) that has been developed for application in the United Kingdom at an asset-level.

The high (or system) and asset level methods are intrinsically hierarchical, where data and analysis from one level of detail informs and refines the analysis at another – providing an efficient means of developing a level of accuracy that is appropriate to the decisions being made (Sayers and Meadowcroft, 2005).

The RAFT tool has been produced for the Environment Agency by HR Wallingford (HR Wallingford 2010). RAFT enables the local knowledge of Environment Agency staff to be captured in a probabilistic analysis for the first time. It provides the Environment Agency with a bottom-up risk attribution tool that can be used to quantify the benefits of specific management activities, such as maintenance and asset reconditioning without requiring a full high level analysis. Using the RAFT tool, it is possible for asset managers to employ techniques similar to those used for high-level decision making, to inform day-to-day flood management decisions.

2 Probabilistic methods for flood risk analysis

Within flood management, risk is typically defined as the product of probability and consequence. A risk-based analysis is any where the consequence of an event is considered distinctly from its probability of occurring. To undertake a probabilistic flood risk assessment of a fluvial defence system, there will be two separate steps:

1. Evaluation of possible system-response to a range of different loading conditions.
2. Estimation of consequence associated with each different system-response.

Only with these two elements in place can the flood risk be quantified. The quantification of risk usually takes the metric of flood damages per year (€/year), however it can be expressed in any other suitable units, for example hectares of habitat lost per year.

The value of a probabilistic approach when compared to a traditional deterministic approach is that it is free of the assumptions of loading and response. However, a probabilistic approach requires a different type of analysis – often with considerable numerical modelling when applied at a system level.

The probabilistic method that provides the framework for the development of the RAFT tool is the one described elsewhere (Gouldby et al, 2008 and Environment Agency, 2009). It has evolved from the Source-Pathway-Receptor concept (Sayers et al 2002) shown in Figure 1, where:

- S*ources* are the meteorological factors that include rainfall, waves, water levels and their associated probability of occurrence (singularly or jointly).
- *Pathways/Barriers* are the behaviour of defences as the hydrological and hydraulic factors that determine the patterns and volume of run-off.
- *Receptors* are the exposure and vulnerability of the people, property and environmental features that may be harmed by a flood.

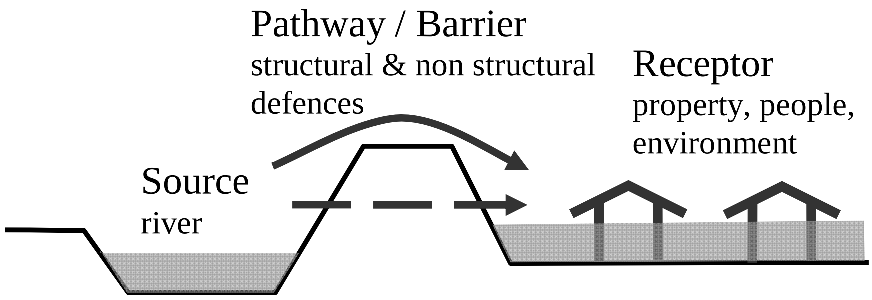

Figure 1 Source-Pathway-Receptor model of flood risk (from Environment Agency 2009).

The resistance to flooding of any one of the individual defence units allows the likelihood to fail under a given loading to be estimated. In a fluvial context, the failure of a defence reflects the inability of a structure to resist the hydrostatic source loading that is applied to it.

The probability of failure of any one defence under a load can be estimated using fragility curves (Figure 2). A fragility curve is a formal expression of the likelihood of defence failure, conditional on a specific load. For fluvial defences, fragility curves usually consider two mechanisms of breach – piping of water through the defences and erosion of the defence by overtopping. For fluvial systems, the loading on a defence is typically taken to be related to the freeboard of the asset at a given water level.

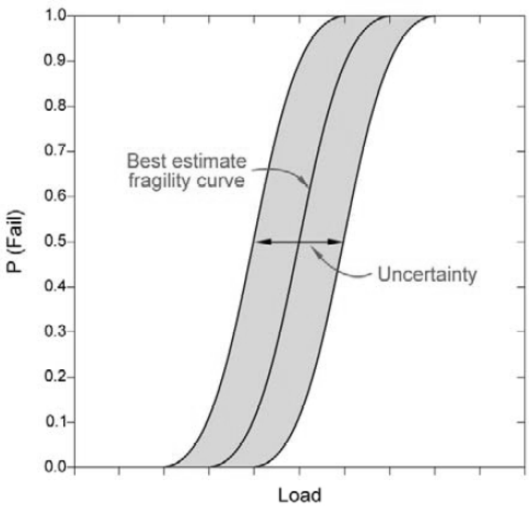

Figure 2 Generic 'Best Estimate' Fragility Curve.

As site-specific information for each defence unit is unlikely to be available, it is necessary to use generic expert-derived 'fragility curves' rather than an asset-specific fragility curves. Figure 2 highlights the range of values and confidence in the ability of a defence to resist hydrostatic loading.

A typical probabilistic analysis of a flood defence system requires both the linear and point defences of the network (embankments, culverts, flood gates, etc.) be considered as discrete units. Each separate unit is prescribed an independent (and, therefore, potentially different) resistance to flood loading. The condition of independence means that if any one defence unit fails, it is considered that adjacent units will not be at increased risk of breach as a result. CUR (1990) has identified the assumption of independence to be reasonable for lengths up to 600m for hard defences (i.e. one with a significant man-made component) and 300m for natural/soft defences. Therefore, it is necessary for any defence with common properties that is greater than the independence length, to be divided into two or more independent lengths to satisfy the conditions of analysis.

For a probabilistic analysis to be most useful for flood management decisions, it is necessary that the risk can be attributed to the individual defences within a system. By considering the contribution to the total risk from each individual flood defence of a larger system, it is possible to determine where management intervention will have the greatest benefit on a system.

Figure 3 obtained from Environment Agency (2009) is included as example to show how a system level probabilistic analysis can yield results at the level of individual assets within the defence system. For the defence system shown below, the expected annual contribution to risk (in the metric of £/year) has been assigned to each 300m length of flood defence. The results of this analysis clearly show where investment in flood defences can yield the greatest benefit to the overall system risk.

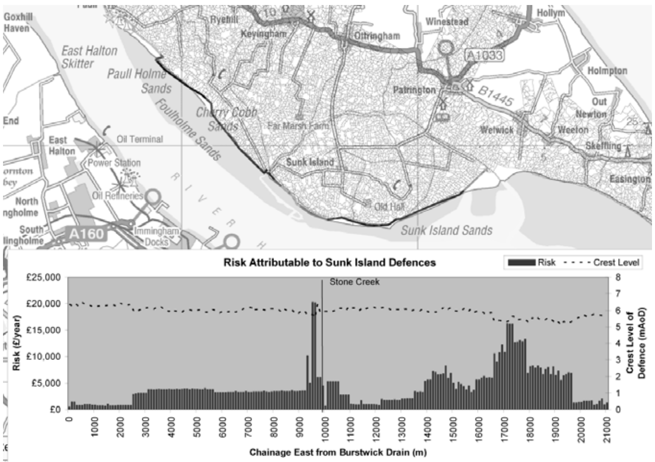

Figure 3 Defence Risk Attribution (from Environment Agency 2009).

3 Description of the approach

The RAFT tool is described in this chapter following the Source-Pathway-Receptor model shown in Figure 1.

3.1 Source

The fluvial loading condition, i.e. the source, is defined as the in-river extreme water level (for a range of different return periods) minus the crest level of the defence (excluding any allowance for freeboard). The RAFT tool requires the user to provide at least three extreme water levels adjacent to the asset of interest and the asset crest level. These values are then interpolated using a logarithmic best-fit to obtain loading conditions for a full range of 39 return periods between 1 and 1000 years.

3.2 Pathway

The pathway is represented by the fluvial defences and their probability of failure. In RAFT, the probability of an asset failing when exposed to a given load (water level) is a function of the load but also of the type of defence, its condition and the length of the asset. For each condition of the defence, defining condition in a scale from 1 to 5 as explained above, a fragility curve can be defined. Then, the probability of defence failure, P_f, taking account of its length, is given as:

$$P_f = 1 - (1 - P_{f\,C\,i})^n \qquad (3)$$

where P_{fCi} is the probability of a single independent unit of a given defence in condition i (i from 1 to 5) (calculated by integrating the appropriate loading and fragility curve) and n is the number of independent units within the defence that can be considered to be at condition i.

The annual probability of failure, $P_{f\ annual}$, is obtained by combining the P_f for a given load (given above) with a full range of loads and their annual probability of exceedance (return period) (Figure 4).

Within the RAFT tool the annual probability is expressed as a percentage rather than a “1 in x years”. Values close to one means a high probability of failure in any given year and values close to zero a low probability.

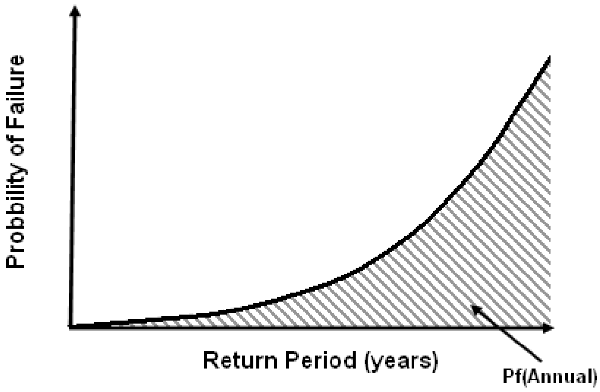

Figure 4 Annual probability of failure obtained by integrating the conditional probability of failure (given load) and annual probability of exceedance for a given load.

3.3 Receptor

A constraint when developing the RAFT tool was to ensure that the potential consequences of asset failure could be estimated without recourse to additional modelling. Instead it is assumed that the users of the tool (local asset managers) will be able to directly estimate with sufficient accuracy the receptors, hence, the potential extents of flooding due to a defence failure. To guide the user, a typical flood extent that may result from a defence failure is provided. The “typical flood extent” is based on the assumption of a flat floodplain leading to concentric flood areas centred at the breach location (Figure 5).

The extent of the inundated area is related to the driving head (i.e. the head of water above the ground level at the breach location). RAFT embeds generic lookup tables relating the maximum inundation extent to the driving head based on findings of the flood risk to people studies (Defra/EA, 2005).

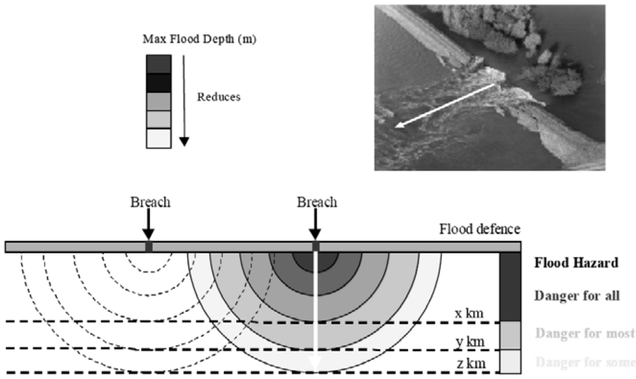

Figure 5 Flood areas due to breaching interpreted as danger to people (from Defra/EA 2005)

The consequences of failures are evaluated as the number of residential properties within the area of inundation. Only those properties directly affected by the flood (internal flooding) should be considered (excluding for example upper floor properties).

3.4 Establishing the risk

Economic damages are not calculated within the RAFT tool therefore, to determine the risk associated with a given asset (chance of failure by consequences of failure), a new term is introduced within RAFT, the Expected Annual Properties flooded, EAP*f*:

$$EAPf = P_{f\,annual} \cdot NP \qquad (4)$$

where *EAPf* results from multiplying the annual probability of an asset to fail, $P_{f\,annual}$, by the number of properties, *NP*, in the area of risk.

When non-residential properties are also included as consequences the Expected Annual House Equivalents flooded is also calculated. In this case, the number of properties in the previous equation, *NP*, is substituted by the Number of House Equivalents. This total number is obtained adding to the number of properties to the house equivalents obtained making the appropriate conversions (HR Wallingford 2010).

RAFT considers the risk associated with breach only. The flood risk associated within overtopping or overflow without a breach is ignored.

3.5 Interface

The RAFT tool is spreadsheet based. The interface of the tool has been designed so that it can be used with the minimum additional training and is as user-oriented as possible. The required information is entered into a single custom dialog box, which polls users for the data as required. It has been written in Visual Basic for Applications (VBA) and is run from within Microsoft Excel. The input data required by RAFT is the minimum required to undertake a probabilistic assessment of the defences. An important consideration for an asset-level analysis tool is the user interface; it is important that the appropriate data is obtained for analysis, but that it can be input quickly and easily by a large number of different users, with varying experience.Recognising that data records for large flood defence systems can often be incomplete, the RAFT tool has been designed to allow different types of data to be used:

- If existing model data and databased information is available, the user can input this directly into the tool.
- If limited information is available, the tool prompts the user to enter field measurements.
- By recording the decisions taken by the user during input, the tool ensures traceability of the results (Figure 6).

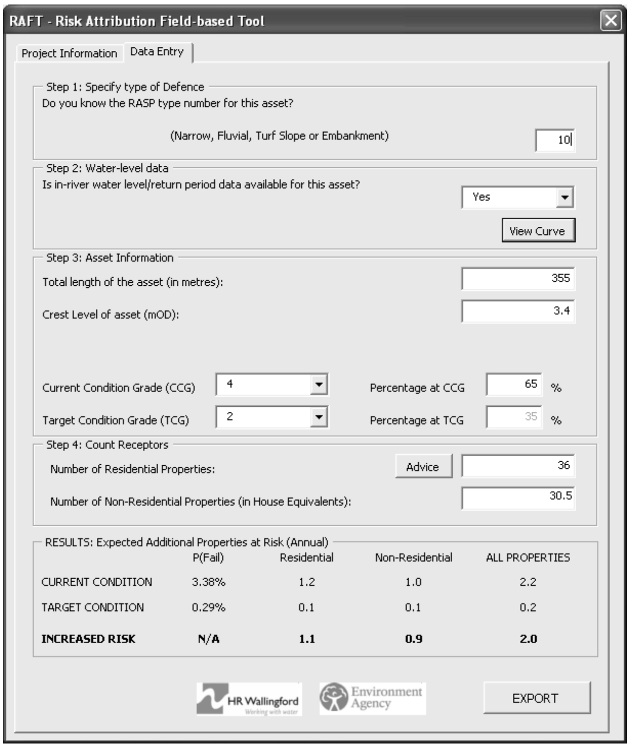

Figure 6 RAFT tool interface displaying the results and main user inputs

4 Discussion and conclusions

A simplified tool, RAFT (Risk Attribution Field-based Tool), to assess the criticality of an asset in terms of its role in risk management has been developed. The RAFT tool has been designed to allow a system-wide analysis to be built from asset-level observations. To achieve this, the tool needs to be used by large groups of different users, without the need for comprehensive training. A consideration of this approach is the variability that might be introduced from large numbers of different users accessing the tool.

In producing a tool for broad dissemination, it is necessary to make a number of simplifications in order to aid usability. At the level of individual-assets, this type of simplification can result in a more coarse representation of the risk. However, when considered over a large system these simplifications help ensure a uniform standard of analysis resulting in a more reliable system level assessment, which does not vary according to user experience or aptitude.

The method detailed in this paper represents a step change in the level of performance over traditional flood risk methodologies.

The RAFT tool can be widely used to provide a useful first assessment of the criticality of individual defences through a simple field based activity. However, because this approach cannot deliver full and justifiable economic analysis, more detailed system approaches should be reserved for situations wherever this is important.

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