Relating asset condition to flood risk

Development of supporting field based tools and techniques

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Summary

Relating asset condition to flood risk

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A simplified spreadsheet based tool (so-called RAFT – Risk Attribution Field Tool) has been developed to relate the condition of an asset to its contribution to flood risk. The project is focused on providing outputs to operational staff in the field and enables the importance of an asset in terms of its contribution to risk to be assessed without resource to more complex office based modelling. The RAFT tool enables:

- the annual probability of asset failure to be assessed
- the consequences associated with failure of an asset to be determined
- the additional risk associated with a given asset being in a condition below its target condition when compared to being in target condition expressed in terms of 'additional households at risk'

RAFT is designed to minimise the data or modelling requirements, with the majoirty of data used embedded directly wihtin the tool itself. Some asset specifc data is required but this has been chosen to be either readily available or easily gathered by the RAFT user through a field- or desk-based investigation of the asset and its environs.

In estimating the probability of an asset that is in a condition below target failing, RAFT utilsies basic physical characteristics entered by the user to identify the most suitable RASP fragility curve from a library of fragility curves held in the tool. It uses this fragility curve alongside a user specified asset length and extreme water-level data to estimate the annual probability of failure. The potenital consequences of failure are provided by the user directly to the RAFT tool (however, in the absence of other data, basic guidance on the potenital flood extent is provided to help gudie the user).

The RAFT tool is spreadsheet based, easy to run and user friendly. 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 – taking advantage of both the strong charting and reporting capabilities of Excel, as well as its widespread use and familiarity within the Agency.

For further information please contact either Dr Marta Roca or Paul Sayers at HR Wallingford.

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1. Introduction

The Environment Agency (EA) has a considerable portfolio of flood defence assets. Each asset has a target Condition Grade of 1, 2, 3, 4 or 5. If the actual Condition Grade is either:

- two or more grades below this target, or
- in condition 4 or 5 when the target is 3 or better

then the asset is considered to be below required condition.

This project aims to provide an approach and associated simplified tools (where needed) to relate the condition of an asset to its contribution to flood risk.

The project is focused on providing outputs to operational staff in the Agency Asset Management Teams, enabling the importance of an asset in terms of risk to be assessed without resource to more complex office based modelling.

Linear assets (including culverts) and point assets (flood gates, flap valves) are considered. Other assets such as the river channel itself are currently not included.

2. Objectives

The project has the following objectives:

- To develop a simplified method to assess the probability of an asset below required condition failing due to breaching, given it remains in its current (nominally below required) condition, whilst taking account of the asset fragility (based on limited and readily available asset data) and exposure to loading.

- To develop a simplified method to assess the potential consequences of a given asset failure and describe these consequences.

- To develop a simplified method and tool (spreadsheet or similar) to assess the criticality of an asset below required condition in terms of its role in risk management. This will take account of its probability of failure (from above – item 1) and the potential consequences of failure (from above – item 2).

- To develop the approach for both linear assets and more minor point assets (excluding major point such Thames Barrier, pumping stations etc as it is assumed that these would be subject to a more detailed reliability assessment).

3. Method of assessment – Linear assets

A simplified method has been developed to assess:

- the annual probability of failure for an asset at current and target condition.
- the potential consequences of a given asset failing

- the additional risk incurred due to an asset being below its target condition

The approach to each of these issues is outlined below.

3.1 ANNUAL PROBABILITY OF FAILURE

3.1.1 General method

The probability of an asset failing when exposed to a given load (water level, wave condition) can be expressed through a fragility curve that describes the relationship between the load on an asset and its conditional probability of failure (Figure 1).

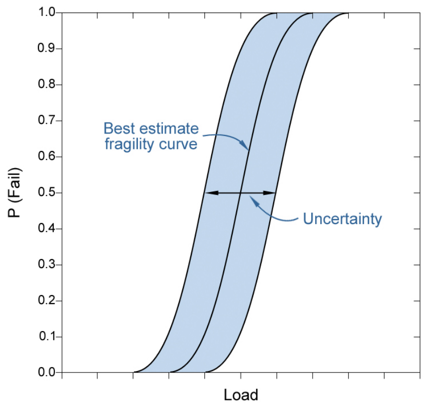

Figure 1 Fragility curve (Sayers et al,2002)

Currently, there are fragility curves available for 61 defence types developed for the Risk Assessment for Systems Planning approach (RASP) and utilised within National Flood Risk Assessment (NaFRA) (Table 1). For each defence type there is a fragility curve corresponding to each Condition Grade, five in total (from 1 – very good to 5 – very poor) (Defra/EA, 2005a). The fragility curves used with RAFT have been obtained as the best estimate between an upper and lower band.

Table 1 List of types of protections (Adapted from Defra/EA, 2007)

ClassNo	Description	Narrow/Wide	FP	CP	RP	Coastal/Fluvial	Type	Material
1	Type 1, FP, Gabions	Narrow	Y			Fluv	Vertical Wall	Gabion
2	Type 1, CP, Gabions	Narrow	Y	Y		Fluv	Vertical Wall	Gabion
3	Type 1, RP, Gabions	Narrow	Y	Y	Y	Fluv	Vertical Wall	Gabion
4	Type 1, FP, B&M	Narrow	Y			Fluv	Vertical Wall	Brick & Masonry or Concrete
5	Type 1, CP, B&M	Narrow	Y	Y		Fluv	Vertical Wall	Brick & Masonry or Concrete
6	Type 1, RP, B&M	Narrow	Y	Y	Y	Fluv	Vertical Wall	Brick & Masonry or Concrete
7	Type 1, FP, Piles	Narrow	Y			Fluv	Vertical Wall	Sheet Piles
8	Type 1, CP, Piles	Narrow	Y	Y		Fluv	Vertical Wall	Sheet Piles
9	Type 1, RP, Piles	Narrow	Y	Y	Y	Fluv	Vertical Wall	Sheet Piles
10	Type 2, FP, Turf	Narrow				Fluv	Slopes or Embankments	Turf
11	Type 2, FP, Rigid	Narrow	Y			Fluv	Slopes or Embankments	Rigid
12	Type 2, CP, Rigid	Narrow	Y	Y		Fluv	Slopes or Embankments	Rigid
13	Type 2, RP, Rigid	Narrow	Y	Y	Y	Fluv	Slopes or Embankments	Rigid
14	Type 2, FP, Rip-rap	Narrow	Y			Fluv	Slopes or Embankments	Rip-rap
15	Type 2, CP, Rip-rap	Narrow	Y	Y		Fluv	Slopes or Embankments	Rip-rap
16	Type 2, RP, Rip-rap	Narrow	Y	Y	Y	Fluv	Slopes or Embankments	Rip-rap
17	Type 2, FP, Flexible	Narrow	Y			Fluv	Slopes or Embankments	Flexible
18	Type 2, CP, Flexible	Narrow	Y	Y		Fluv	Slopes or Embankments	Flexible
19	Type 2, RP, Flexible	Narrow	Y	Y	Y	Fluv	Slopes or Embankments	Flexible
20	Type 3, High Ground	-				Fluv	High Ground	
21	Type 4, Culverts	-				Fluv	Culvert	
22	Type 5, FP, Piles	Narrow	Y			Coas	Vertical walls	Sheet piles
23	Type 5, CP, Piles	Narrow	Y	Y		Coas	Vertical walls	Sheet piles
24	Type 5, RP, Piles	Narrow	Y	Y	Y	Coas	Vertical walls	Sheet piles
25	Type 5, FP, Conc	Narrow	Y			Coas	Vertical walls	Concrete
26	Type 5, CP, Conc	Narrow	Y	Y		Coas	Vertical walls	Concrete
27	Type 5, RP, Conc	Narrow	Y	Y	Y	Coas	Vertical walls	Concrete
28	Type 5, FP, B&M	Narrow	Y			Coas	Vertical walls	Brick & Masonry
29	Type 5, CP, B&M	Narrow	Y	Y		Coas	Vertical walls	Brick & Masonry
30	Type 5, RP, B&M	Narrow	Y	Y	Y	Coas	Vertical walls	Brick & Masonry
31	Type 6, FP, Perm	Narrow	Y			Coas	Dykes or embankments	Permeable revetment
32	Type 6, CP, Perm	Narrow	Y	Y		Coas	Dykes or embankments	Permeable revetment
33	Type 6, RP, Perm	Narrow	Y	Y	Y	Coas	Dykes or embankments	Permeable revetment
34	Type 6, FP, Imperm	Narrow	Y			Coas	Dykes or embankments	Impermeable revetment
35	Type 6, CP, Imperm	Narrow	Y	Y		Coas	Dykes or embankments	Impermeable revetment
36	Type 6, RP, Imperm	Narrow	Y	Y	Y	Coas	Dykes or embankments	Impermeable revetment
37	Type 7, Dune	-				Coas	Beaches	
38	Type 7, Shingle	-				Coas	Beaches	
39	Type 1, W, FP, Gabions	Wide	Y			Fluv	Vertical Wall	Gabions
40	Type 1, W, CP, Gabions	Wide	Y	Y		Fluv	Vertical Wall	Gabions
41	Type 1, W, FP, B&M	Wide	Y			Fluv	Vertical Wall	Brick & Masonry or Concrete
42	Type 1, W, CP, B&M	Wide	Y	Y		Fluv	Vertical Wall	Brick & Masonry or Concrete
43	Type 1, W, FP, Piles	Wide	Y			Fluv	Vertical Wall	Sheet piles
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45	Type 2, W, FP, Turf	Wide				Fluv	Slopes or Embankments	Turf
46	Type 2, W, FP, Rigid	Wide	Y			Fluv	Slopes or Embankments	Rigid
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48	Type 2, W, FP, Rip-rap	Wide	Y			Fluv	Slopes or Embankments	Rip-rap
49	Type 2, W, CP, Rip-rap	Wide	Y	Y		Fluv	Slopes or Embankments	Rip-rap
50	Type 2, W, FP, Flexible	Wide	Y			Fluv	Slopes or Embankments	Flexible
51	Type 2, W, CP, Flexible	Wide	Y	Y		Fluv	Slopes or Embankments	Flexible
52	Type 5, W, FP, Piles	Wide	Y			Coas	Vertical walls	Sheet piles
53	Type 5, W, CP, Piles	Wide	Y	Y		Coas	Vertical walls	Sheet piles
54	Type 5, W, FP, Conc	Wide	Y			Coas	Vertical walls	Concrete
55	Type 5, W, CP, Conc	Wide	Y	Y		Coas	Vertical walls	Concrete
56	Type 5, W, FP, B&M	Wide	Y			Coas	Vertical walls	Brick & Masonry
57	Type 5, W, CP, B&M	Wide	Y	Y		Coas	Vertical walls	Brick & Masonry
58	Type 6, W, FP, Perm	Wide	Y			Coas	Dykes or embankments	Permeable revetment
59	Type 6, W, CP, Perm	Wide	Y	Y		Coas	Dykes or embankments	Permeable revetment
60	Type 6, W, FP, Imperm	Wide	Y			Coas	Dykes or embankments	Impermeable revetment
61	Type 6, W, CP, Imperm	Wide	Y	Y		Coas	Dykes or embankments	Impermeable revetment

Both fluvial and coastal assets are subject to hydrostatic loads (i.e. from a head of water) but coastal assets are exposed to an additional hydrodynamic load associated with wave overtopping. Therefore, the loading conditions in the fragility curves for both types of assets are different: water levels for fluvial defences and overtopping discharge rates for coastal defences (defined as defences where the influence of sea waves is essential).

The probability of failure is a function the type of defence, its condition, loads to which it is exposed and the length of the asset. In this case the probability of asset failure, P_{fi} (taking account of its length) is given as:

$$P_{fi} = 1 - (1 - P_{fCg(i)})^n \qquad [1]$$

Where

$P_{fCg(i)}$ = The probability of a single independent section of a given asset in Condition Grade *i* failing (calculated by integrating the appropriate loading and fragility curve – an in-built function in RAFT)

n = The number of independent defence lengths that can be considered to be in Condition Grade *i*

The calculation of *n* enables the asset length to be considered. For example, consider two assets identical in every aspect except one is significantly longer than the other. It is intuitive that the longer asset the more likely it is to experience a failure under a given load. This is because the longer asset does not behave as a single length but acts as a system of defence lengths. Within the RASP High Level Analysis, an asset of less than 300m in length (for hard defences such as walls) and 600m (for natural soft defences such as dunes and beaches) was considered to behaviour as a single unit. In longer assets, independence is likely to exist between parts of the asset; increasing the chance of failure. To reflect this behaviour within the calculation the number of independent defence lengths (*n*) is calculated as follows:

$$n = \frac{x}{300 \ or \ 600} \qquad [2]$$

Where

x = the length of the asset (m) in Condition Grade *i*

In some instances, the condition of a single asset may not however be uniform. For example, a given asset may have localised problems over a short length (described, say, as Condition Grade 4) with the remainder of the asset in a higher condition grade (say, Condition Grade 3).

If this case, the probability of failure of the asset is calculated by first considering the proportion of the length in Condition Grade *i* and the proportion in Condition Grade *j*.

For example, let, *x* equal the length of the asset in Condition Grade *i* defined as:

x = percentage of the total asset length in Cg*(i)* * total asset length (m).

The probability of failure for the part of the asset in Condition Grade i is given by Eq [1]. The probability of failure of the proportion of the asset in Condition Grade j can be found similarly as follows:

Let y equal the length of the asset in Condition Grade j:

y = percentage of the total asset length in Cg(j) * total asset length (m).

In this case the probability of failure for the part of the asset in condition Grade j is given by:

$$P_{fj} = 1 - (1 - P_{fCg(j)})^m \qquad [3]$$

Where

$P_{fCg(j)}$ = The probability of a single independent section of a given asset in Condition Grade j failing (calculated by integrating the appropriate loading and fragility curve – an in-built function in RAFT)

m = The number of independent defence lengths that can be considered to be in Condition Grade j defined as:

$$m = \frac{y}{300\, or\, 600}$$

P_{fi} and P_{fj} are then combined probability to provide a third estimate of asset failure as follows:

$$P_{fc} = 1 - (1 - P_{fi}).(1 - P_{fj})$$

The actual probability of failure assigned to the whole asset is then the maximum of the three estimates, i.e:

$$P_f = \max\lfloor P_{fi}, P_{fj}, P_{fc} \rfloor$$

Where

P_f = The probability of asset failure assigned to the whole asset

This process ensures that the strength of the asset is now greater than its weakest link (regardless of length) whilst reconsidering that an increasing asset length will increase the chance of failure (with all other aspects remaining unchanged)

Figure 2 shows how the probability of failure (Pf) changes with increasing length in three example cases:

a. The asset has a uniform Condition Grade of 3 (100% Cg 3)
b. The asset has an equal (by length) proportion of Condition Grade 3 and 4
c. The asset has predominance of Condition Grade 4 (covering 75% by length of the asset) the remainder at Condition Grade 3.

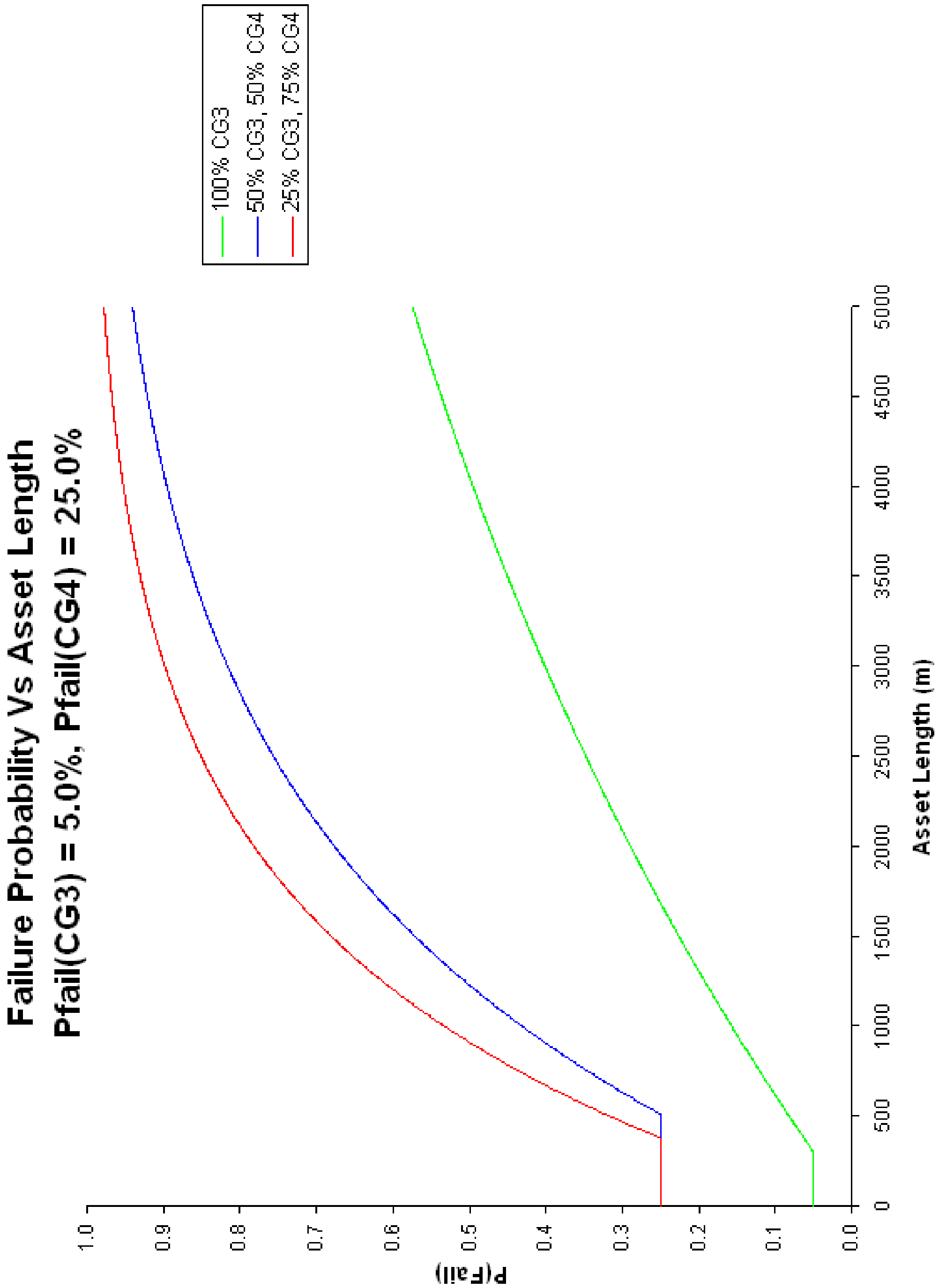

Figure 2 Probability of asset failure against asset length

The annual probability of failure, Pf_{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 3).

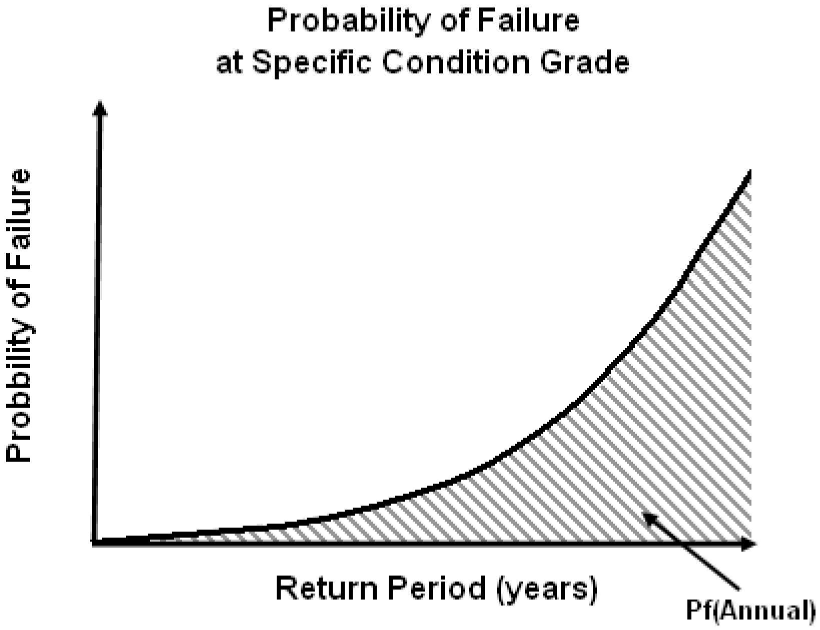

Figure 3 Annual probability of failure obtained by integrating the conditional probability of failure (given load) and annual probability of exceedance for a given load

Within the RAFT tool the annual probability is expressed as a percentage rather than a "1 in x years" expression to avoid confusion. The later could give the impression that the asset failure is related to one event (the one in x year event) whilst in reality is an annual probability that considers all the possible events and their probabilities in one year. Values close to one means a high probability of failure in any given year and values close to zero a low probability.

3.1.2 Defining the loading conditions - Fluvial loading conditions

The fluvial loading condition is defined as:

- The in-river extreme water level (for a range of different return periods) minus 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 (Figure 4). To aid the accuracy of the interpolation it is recommended that at least one of the user provided points corresponds to a short return period and another to a long one.

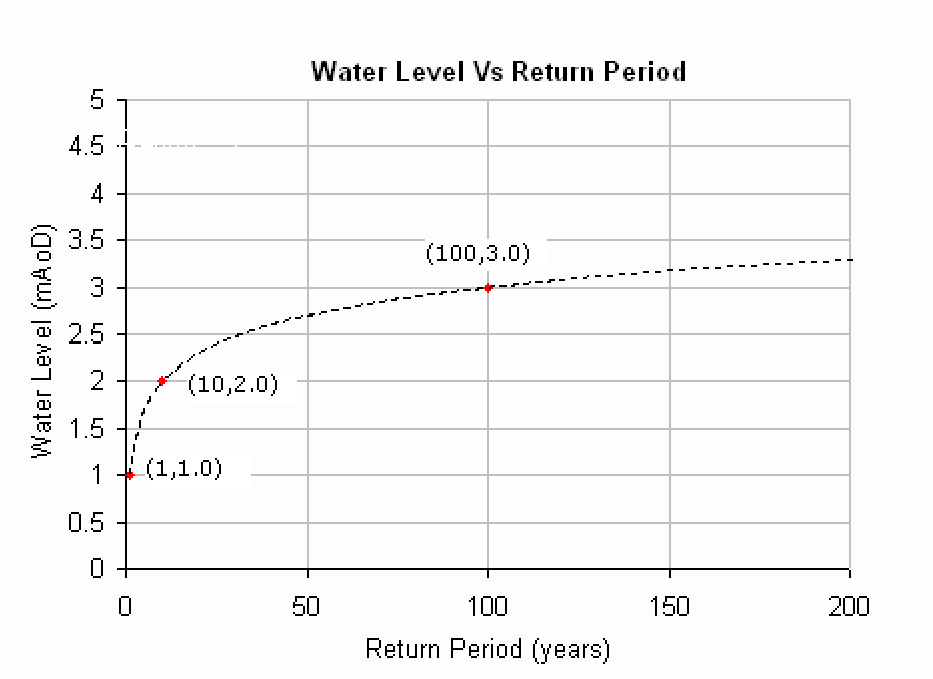

Figure 4 Example of loading conditions defined from three known water levels

If it is not possible for the user to provide the relation between water levels and return periods then two points are constructed as follows:

a) The user is asked to enter the water level in the river, expressed as a distance below the crest level, when inspected or for a typical flood event. In the former, it is considered that water level corresponds to non-storm event and a 1 year return period is assigned. In the latter, the bank full return period is assumed and given a notional 3 year return period.

b) The water level at the Standard of Protection of the asset is estimated by considering the user defined crest level minus 0.35m.

Using these two points an extremes curve is then generated.

RAFT warns the user that this is may be a poor estimation of the loading conditions and that a list of water levels versus return periods will be always a better input.

3.1.3 Defining the loading conditions - Coastal loadings

Coastal loadings are defined as an overtopping rate that depends on:

- the type of defence
- the coastal region where the defence is located; England and Wales are divided in 52 coastal regions (Figure 5)
- the crest level of the defence
- the toe level of the defence (Figure 6).

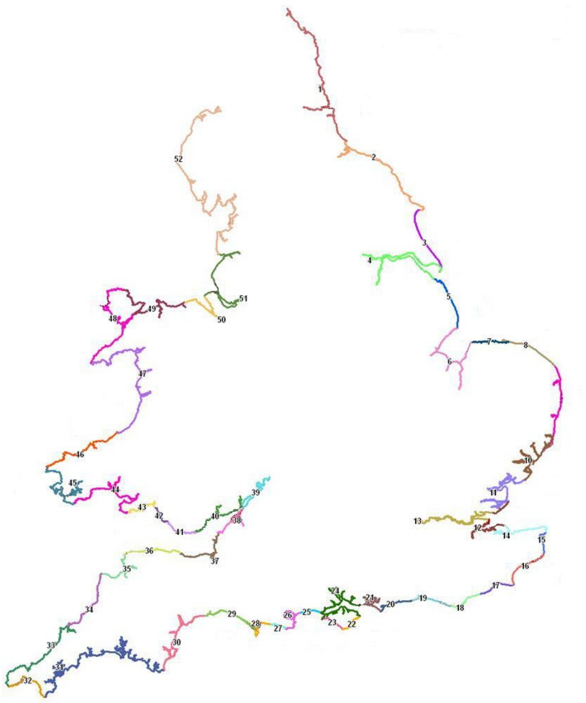

Figure 5 England and Wales division of coastal Regions

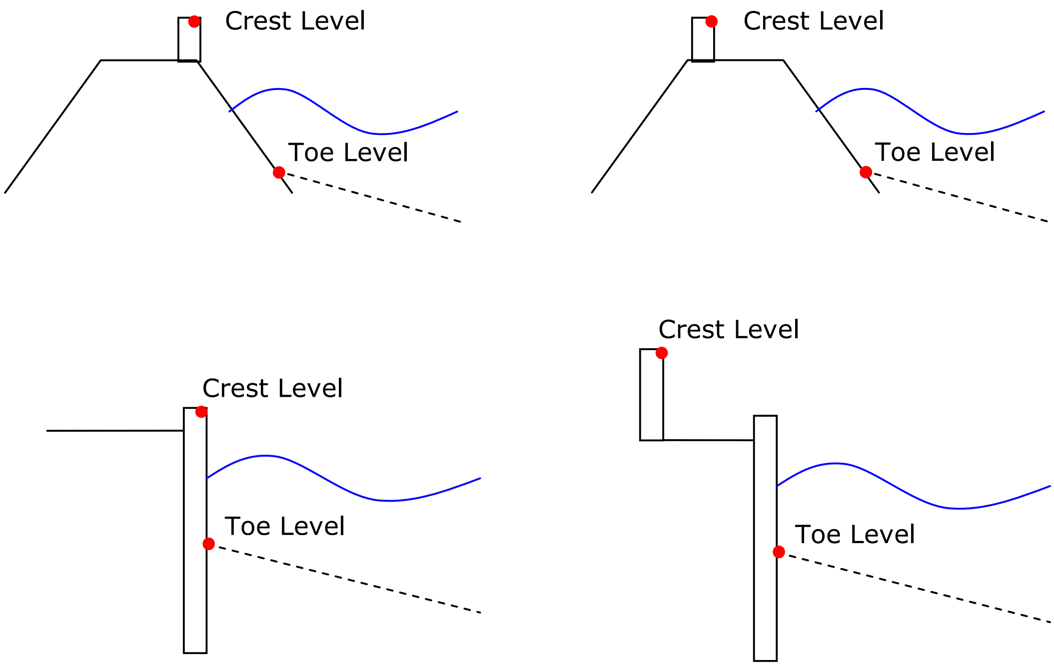

Figure 6 Definition of toe and crest levels for different types of coastal protection (simplified)

The volume of water overtopping of a coastal asset will vary with return period and is a function of both water level (i.e. tides and surges) and wave height.

Lookup tables developed by Wallingford as part of the National Flood Risk Assessment (NaFRA) provide overtopping rates for assets within each of the coastal regions (Figure

6) as a function of return periods taking account of the joint probability of wave and water levels. For example, a 1:200 year overtopping event may be generated from either a very high water level (long return period) with minimal wave action (short return period), or extreme wave action (long return period) and a frequently occurring water level (short return period). .

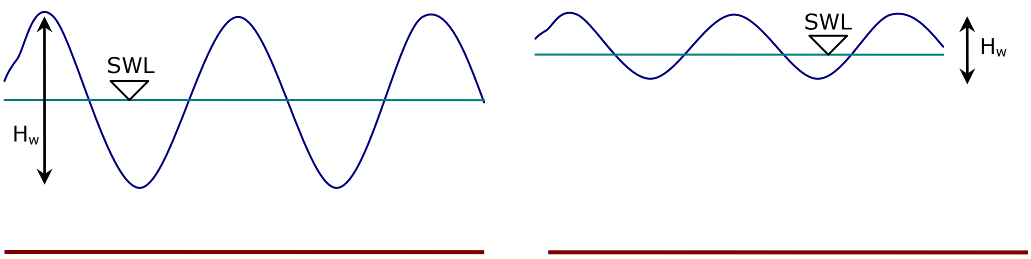

Figure 7 Two events of same Return Period (shown to same datum) but different sea water levels (SWL) and wave height (H_w) could lead to the same overtopping

Within RAFT marginal extreme water level (i.e. the return of the water level excluding consideration of the wave return period) curve is displayed graphically to the user.

3.2 ASSESING THE POTENTIAL CONSEQUENCES OF FAILURE

A constraint on this project was to ensure that the potential consequences of asset failure cold be estimated without recourse to additional modelling. Instead it is assumed that the local asset managers are able to directly estimate potential extents of flooding due to an asset failure with sufficient accuracy.

To guide the user, a typical flood extent that may result from an asset failure is provided within RAFT. The "typical flood extent" is based on the assumption of a flat floodplain leading to concentric flood areas centred at the breach location (Figure 8).

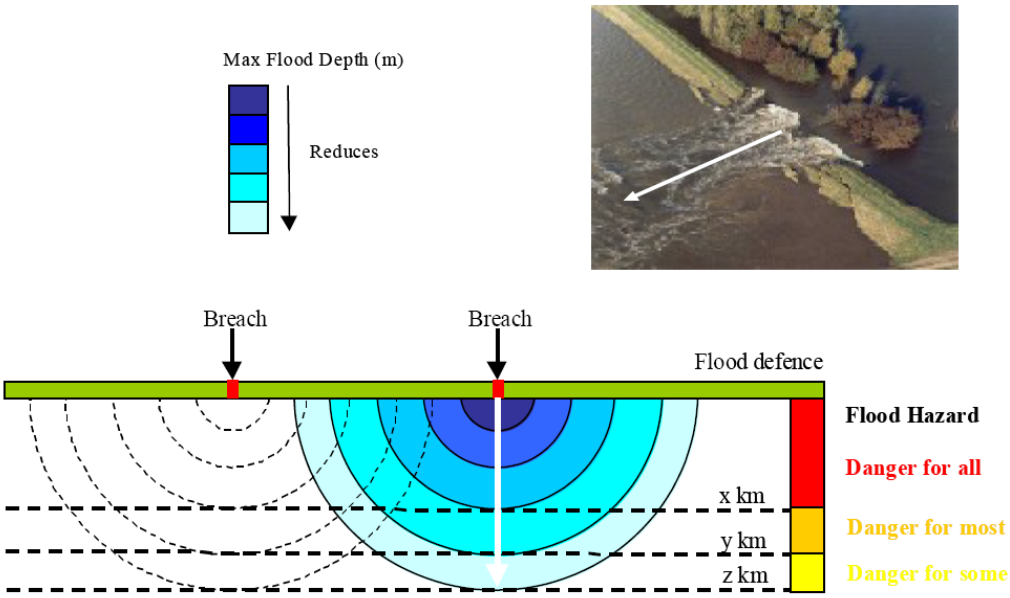

Figure 8 Flood depths for a particular scenario interpreted as danger to people (from Defra/EA 2005b)

The user should not real upon this simply description of the flood extent and, where available, utilise more detailed flood risk studies or local knowledge based on previous experience to refine the potential inundation area.

The extent of the inundated area can be 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, 2005b). This relationship is shown in Table 2 below. The maximum inundation extent is assumed to coincide with the limit of "Danger for some".

Table 2 Typical inundation extent and danger to people from breaching relative to distance from the defence (Defra/EA, 2005b)

Distance from breach (m)	Head above floodplain (m)						
	0.5	1	2	3	4	5	6
100							
250							
500							
1000							
1500							
2000							
2500							
3000							
3500							

	Danger for some
	Danger for most
	Danger for all

Note: The maximum flood extent is provided within RAFT as a guide only. For example, as shown in Figure 9, as a minimum the area determined by the RAFT method must be augmented by the Flood Zones data to avoid properties outside of the floodplain being identified as at risk.

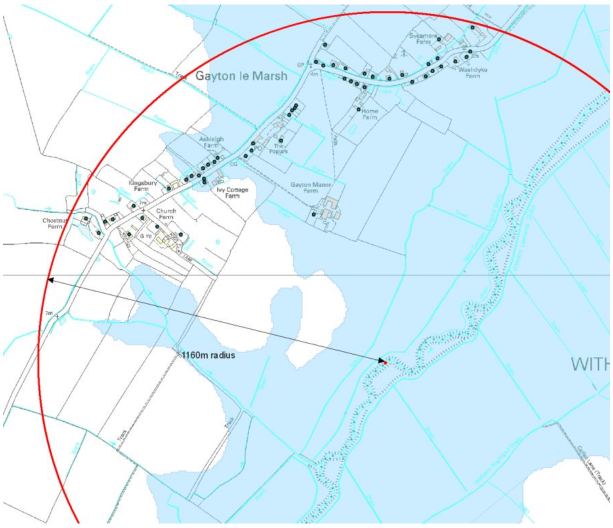

Figure 9 Combined the RAFT guidance with Flood Zone data

The consequences of asset failure are then 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).

In areas where the number of residential properties is low other consequences should be considered.

Given the simplified nature of RAFT different consequence types (see Table 3). Each consequence is first recorded in their native parameters (for example the number of schools flooded) before conversion to a House Equivalent (HE) value to enable simply aggregation and comparison between sites (also shown in Table 3).

Table 3 Non residential properties and their House Equivalent (HE) conversion factor (HE values based on John Chatterton / Agency discussions)

Receptor	Input parameter	HE	Average area (m2)
Shops	number	1.2	1175
Office	number	2.9	1086
Factories and Warehouses	number	4.2	1355
Police/Fire/Ambulances	number	1.5	530
School/Day nurseries	number	7.1	1086
Campsite/caravan parks	number of caravans	0.11	
Main roads	number	0.89/road + 14.47	
Railways		11.0	
Arable land	Area (ha)	6.39/100 ha	
Open grass land	Area (ha)	0.61/100 ha	

3.3 CALCULATING RISK

To determine the risk associated with a given asset (chance of failure * consequences of failure). Economic damages are not calculated within the RAFT tool therefore information on the annual probability of failure (P*fannual*) and the consequences of flooding (described in native and HE terms) is calculated as follows:

Expected Annual Receptors flooded (EARf) = P*fannual* * number (or area) of receptors

A new term is introduced within RAFT the Expected Annual Properties flooded (EAP*f)* that is an equivalent term to the EAD more normally calculated when depth versus damage data is available as is calculated as follows:.

$$EAPf = pf_{annual} \cdot NP$$

where *EAPf* is the Expected Annual Properties flooded that results from multiplying the annual probability of an asset to fail, pf_{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 (EHE*f*) is also calculated. In this case, the number of properties in the previous equation, NP, is substituted by the Number of House Equivalents, NHE. This total number is obtained adding to the number of properties to the house equivalents obtained making the conversions detailed in Table 3.

Note:

RAFT considers the risk associated with breach only. The flood risk associated within overtopping or overflow without a breach is ignored (i.e. an infinitely strong but low standard defence will be identified contributing zero risk with RAFT, even if regularly overflowed). The presence of a low crest level will however increase the likelihood of breach and hence will feature indirectly the risk estimate).

Where RAFT estimates the risk (EARf) to be zero this does not mean the total flood risk is zero. The asset may still be subject to overflow/overtopping and the hinterland subject to flooding.

3.4 ADDITIONAL RISK INCURRED DUE TO AN ASSET BELOW TARGET CONDITION

To determine the additional risk incurred due to an asset being in a state below its target condition established by comparing the risk (chance of failure * consequences of failure) with the asset in its *current* condition compared to the risk that would exist if the condition was improved to *target*.

The additional risk (the primary output of the RAFT tool) is a value of the additional properties at risk due to change in the condition grade of the defence, and it is expressed as:

$$AdditionalEAPf\ (or\ AdditionalEHEf) = (pf_{annualCCG} \cdot NP - pf_{annualTCG} \cdot NP)$$

Where

PfannualCCG = annual probability of failure assuming the asset to be in its current condition

PfannualTCG = annual probability of failure assuming the asset to be reconditioned to its minimum target Grade throughout its length

NP – number of residential properties (or House Equivalent non-residential receptors)

The Additional Expected Annual Properties flooded (or Expected House Equivalents' flooded) as a result of the asset (or part of the asset) remaining at a condition grade below target can then be directly calculated.

4. Method of assessment - Culverts

4.1 GENERAL APPROACH

The same framework of analysis used for linear assets is repeated for culverts.

To enable the framework to be applied it has first been necessary to:

- ***Develop culvert specific fragility curves*** – Although culverts are included in Table 1 associated fragility curves do not current exist. A new fragility curve has therefore been specifically developed based on work within Thames 2100 project, the Defra/EA (2003a) report, the Condition Assessment Manual (EA, 2006a) and expert judgment.

- ***Revise the definition of failure*** – The notion of a breach is not appropriate for a culvert. Therefore failure is defined in terms of blockage to the flow (based on an assumption of either complete blockage or no blockage – partial blockage is ignored). The condition grade of a culvert however relates to structural features such as cracks, corrosion, mortar loss, deformation, etc. Blockage resulting from debris from the upstream catchment is not currently considered within the RAFT tool.

The culvert fragility curve (describing the load on the x axis and the probability of failure on the y axis) is presented in Figure 10. The probability of failure (i.e. blockage – see below) for Condition Grades from 1 to 3 is shown as low. Probability of failure increases substantially as the water level rises above the invert level for Condition Grades 4 and 5. The loading conditions along the x -axis are represented by the area of the culvert full of water, being 0 completely empty and 100 completely full. Values higher than 100 indicate water levels above the soffit of the culvert.

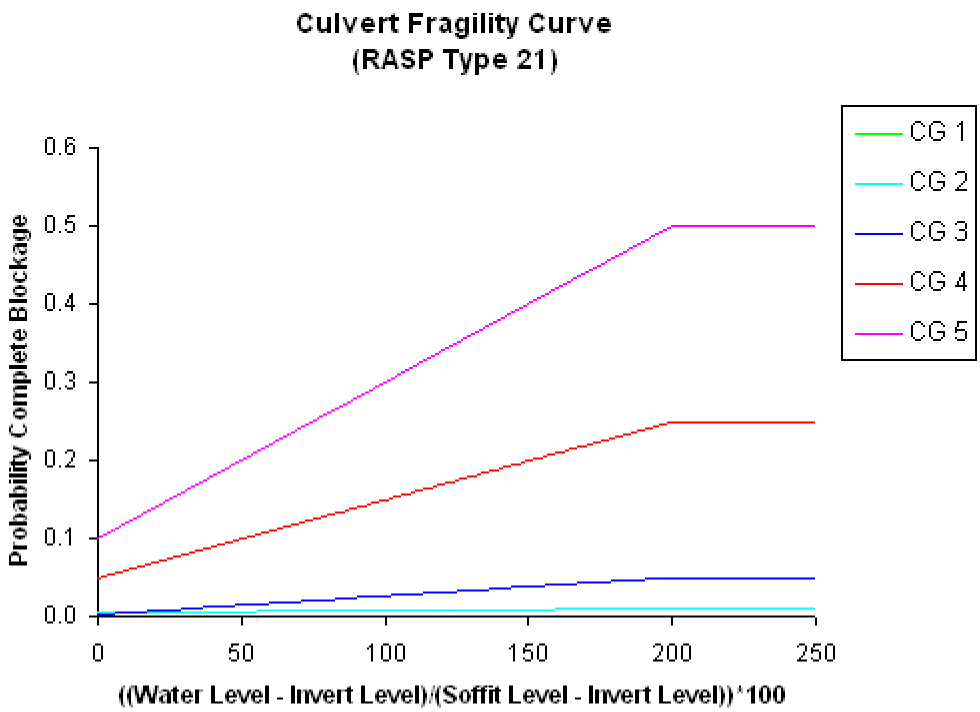

Figure 10 Fragility curve for in-line culverts

4.2 AREA OF INUNDATION

In absence of other information, the RAFT tool provides the user with advice on the dimensions of the flooded area around the culvert. The advice is based on Jacobs (2008) report "Culvert Prioritisation Phase 2. South Area" where a corridor of risk is considered based on the 100 years flood event (Table 4).

Table 4 Buffer radius for culverts (from Jacobs 2008). The radius corresponds to B or A/2 in Figure 11

Water discharge (m^3/s)	Radius (m)
No flows	25
< 5	50
5-25	75
> 25	100

To define the area at risk from full blockage of a culvert, it is assumed that the culvert has been designed to carry the 1 in 100 year flow when full. To estimate the magnitude of the flow associated with this case, Mannings' equation is used to estimate the capacity of a circular conduit with the same cross-sectional area and length as the culvert, assuming a notional 1 in 100 water surface/bed gradient and a typical Mannings roughness coefficient for concrete. This analysis has been tested for sensitivity to Mannings' roughness, conduit shape and water surface gradient. Given the insensitivity of Table 4 to these parameters, a simple approach requiring minimal additional data has been adopted.

Depending upon the capacity of the analogous system, the area at risk is defined using Table 4 to inform Figure 11 (below), in which 'A' is read from Table 4 and B = A/2.

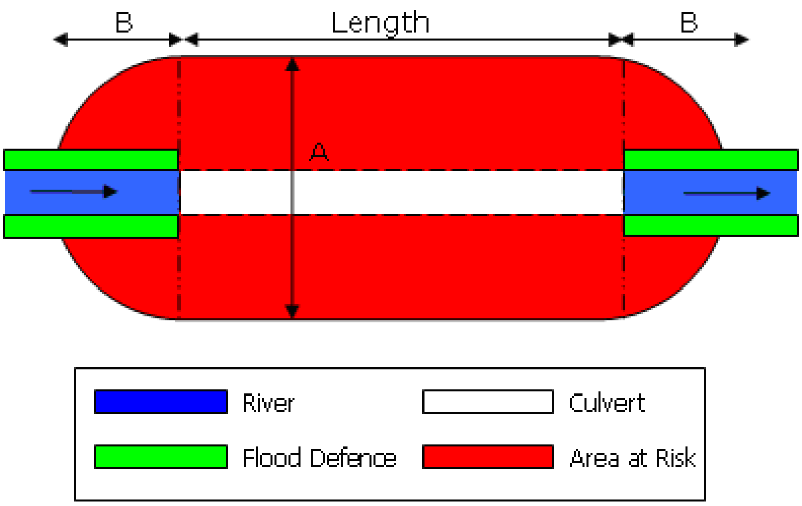

Figure 11 Dimensions of the area at risk for a culvert

4.3 ASSESSING THE CONSEQUENCES

This step proceeds as described for the linear assets in Section 3.2.

4.4 CALCULATING THE RISK

This step proceeds as described for the linear assets in Section 3.3.

4.5 CALCULATING THE ADDITIONAL RISK

This step proceeds as described for the linear assets in Section 3.4.

5. *Method of assessment - Point assets*

5.1 GENERAL APPROACH

The point assets considered in the RAFT tool are flood gates, flap valves and any other similar assets. The same framework of analysis used for linear assets is repeated for point assets, but with the following modifications:

Develop point asset specific fragility curves – As for culverts, there were no fragility curves associated to those assets. They have been specifically developed for this project based on previous works on the Thames 2100 project, the Defra/EA (2003a) report, the Condition Assessment Manual (EA, 2006a) and expert judgment. The fragility curves developed use the same loading conditions, related to differences between water levels and invert or crest levels, independently whether they are exposed or not to sea waves.

Figure 12 and Figure 13 show the fragility curves developed for flap valves and flood gates.

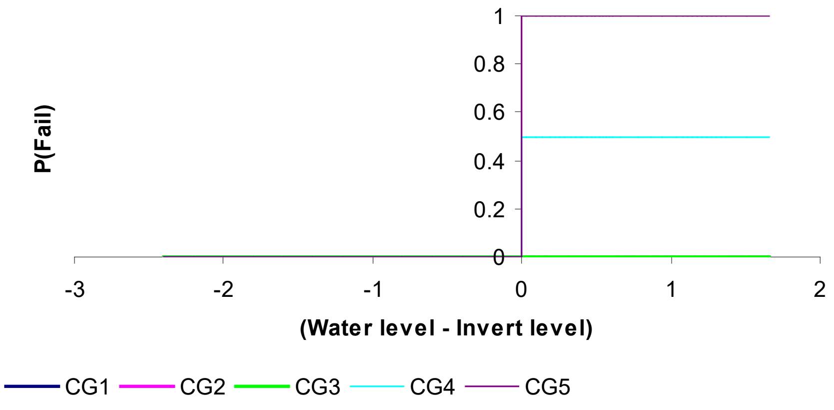

Figure 12 Fragility curves for flap valves. The probabilities for CG1 to 3 are 0

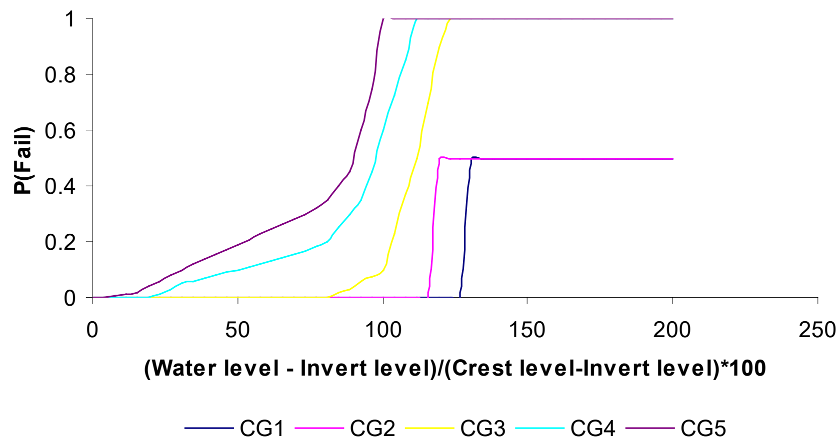

Figure 13 Fragility curves for flood gates

Revise the definition of failure – for point assets the definition of failure can vary. Within RAFT it is assumed that the mode of failure is an inability to close and the resulting flood extent can be calculated in a similar manner to linear asset (i.e a semi-circular area centred on the point asset). The potential inflow volume based on a consideration of the cross-sectional area of the flap value or gate is used to scale values in Table 2 (based on inflow head).

6. Basic user manual - RAFT tool

6.1 GENERAL

RAFT has been implemented as a Microsoft Excel spreadsheet and features a simple graphical user interface created from custom user forms and dialog-boxes. It is anticipated that the users of the tool will have a broad familiarity with Microsoft Excel and the issues associated with calculating flood risk. The tool has been written in

Visual Basic for Applications (VBA) and designed to work using only those external references available with a standard installation of Microsoft Office 2003, on Microsoft Windows XP.

6.2 DATA REQUIREMENTS

To estimate risk (and the additional risk of an asset being below its required condition) the user must first provide asset-specific data. These data are outlined below.

6.2.1 Project information

Project information is essential and must be provided by the user before the tool can be used. These data are summarised in Table 5.

Table 5 Project Information TAB

Essential Data	Non-essential Data
NFCDD Asset Reference Number	National Grid Reference
Flood Risk Management System Reference	Local Asset Name
User Name	Notes

6.2.2 Asset data

Minimum asset data is required including a structural identification of the asset, its condition grade and some of its geometric characteristics, local water level data and the number of residential and non-residential receptors immediately behind the asset (Table 6). This essential information is entered into the tool via two pages within the GUI.

Depending on the data available to the user, additional pages become available to assist with data entry as required and described below in the following sections.

Table 6 Data entry TAB

	Required Data	Asset Type Applicable
1	RASP Type Number	All
2	Water Level Data Coastal Region	Fluvial Assets Assets exposed to Sea-Waves
3	Asset Length Cross Sectional Area	Linear assets and culverts Point assets
4	Crest Level Soffit Level	Linear Assets and Flood Gates Point assets and Culverts
5	Toe Level Invert Level	Assets exposed to Sea-Waves Culvert and Point Assets
6	Current Condition Grade (CCG)	All
7	% of Asset at CCG	All except Point Assets
8	Target Condition Grade (TCG)	All
9	% of Asset at TCG	All except Point Assets
10	Number of Receptors at Risk	All

RASP Type Number

If the RASP type number is not known, the 'Asset Data' tab (Table 7) can be used to identify which of the RASP types is most suitable for the Asset under investigation, by means of a series of structured questions. The questions asked within this tab are given below. The user is only asked to answer those questions that are necessary to identify the unique RAFT type number; once a positive identification has been made, the data-entry is complete.

Table 7 Asset Data TAB

Question	Applies to
Is Asset exposed to Sea Waves?	All
Asset Type	Al
'Narrow' or 'Wide'	'V' or 'E' only
Front-face Protection	'V' or 'E' only
Crest Protection	'V' or 'E' only
Rear Face Protection	'V' or 'E' only
Asset Material	'V' or 'E' only

Where 'V' relates to vertical wall structures and 'E' relates to embankments or sloped structures. For all other assets, only the first two entries are required to make a positive identification of the RASP type.

Water Level Data

If the asset is not exposed to waves (i.e. a fluvial asset – subject to water level loads only) a Water Level Vs Return Period curve must be specified. If at least two pairs of Water Level Vs Return Period data are available from NFCDD or from the Flood Risk Mapping and Data Management Team, these should be entered in the 'Water Level' Tab.

If this data is not available, the Standard of Protection of the Asset should be provided. If this is not known, the user must estimate the return period of the event that would cause the asset to overtop. Additionally, an estimate of the "Asset Crest-Level - Water Level" must be made. This level can either be for an event that would be expected to occur at least once a year, or for a previous inspection of the asset. Once this data has been obtained, a generic curve is fitted through these two points, assuming that a logarithmic relationship exists.

Coastal Region

If an asset is exposed to sea waves, it is necessary to identify which of the 52 generic coastal regions the asset is located in. From this, the joint probability data is read from look-up tables contained within the tool.

Asset length

The user is asked to enter the total length of the asset expressed in meters.

Cross-sectional data

For point and culvert assets only - An estimation of the area of the culvert, flap valve or the flood gate, expressed as square meters, is required.

Crest and soffit level

The crest level of linear defences and flood gates or the soffit level in culverts and flap valves (expressed as m AOD) is required.

Toe and invert level

In linear assets exposed to sea-waves a toe level is required. This is a fundamental input as depending on the difference between crest and toe levels a different lookup table, hence, different loading conditions will be considered.

The toe level is defined as the point where the embankment begins to interact with sea waves. Any energy passing that point must be dealt by the structure and not by the beach. The toe level required in the RAFT tool is the lowest historical or post-storm beach level at the structure. It is not the lowest point of the structure.

For point assets and culverts exposed to sea waves the toe level of the beach (as defined in Figure 6) is not required but the invert level.

Current Condition Grade and percentage

The user is based to describe the current condition of the asset using (up two) Condition Grades and an associated percentage of the total asset length for which that Condition Grade persists. For assets of a length less than 300m (hard defences) or 600m (soft defences) it is likely that only a single condition grade will be assigned (although this is not a requirement).

Target Condition Grade and percentage

The target condition grade of the asset is entered manually by the user. Usually, this would be 3, although higher (or lower) targets are possible. It is not necessary for the user to assign a percentage of the asset to target condition grade, as this is calculated by the RAFT tool (i.e. Percentage at Target = 100 – Percentage at Current).

Number of Receptors at Risk

The number of residential properties and other receptors at risk from flooding (breach, blockage or failure to close) is entered via the GUI. If this value is not known, guidance is provided to help the user identify the area at-risk. This guidance is obtained by clicking the ‘Advice’ button (see below).

If non-residential properties are important in the area of study they can be introduced in a separate window considering the categories described in Table 3. The area at risk to be considered should be determined in the same way than for residential properties.

Advice on area “at risk”

If advice is requested by the user, for linear assets, it is necessary to enter the ground level immediately adjacent to the defences. From this, a ‘head’ above the floodplain is calculated and a radius ‘at risk’ estimated and displayed to the user. For culverts and point assets, their cross-sectional area is required. This must be estimated and entered into the tool. From this information, the tool outputs an at-risk ‘corridor’ for culverts and a radius for the other point assets..

7. Potential developments

The RAFT tool is a simplified approach to relate asset condition to risk. Through discussion with the Agency Teams, several development suggestions to further increase the current capabilities of the tool have been made. These are summarised below.

- **User specific fragility curves** - The possibility to introduce user developed fragility curves, if a better understanding of those curves is available. In recent years (through Floodsite) a standalone tool to assess the reliability of an individual asset (taking account of multiple failure modes) has been developed by HR Wallingford. An appropriately simplified version of the so-called RELIABLE tool could provide capable of deriving site-specific fragility curves.

- **Extension to include standard of protection** - The RAFT tool relates asset condition to flood risk, considering breaching alone. It would be possible to extend the tool to incorporate overtopping and overflow, wherever water levels are higher than crest levels of defences. The additional risk associated with overtopping / overflow would be reported separately and in combination with the additional risk arising from breaching.

- **Additional asset types** – The RAFT has been designed to allow risk to be attributed to individual linear and point assets, within larger systems. The tool presently takes no account of other asset types – maintained or unmaintained channels, M&E plant etc. It would be possible to extend the RAFT tool to incorporate additional asset types not presently considered within KPI965.

- **Future impacts** - RAFT could be extended to incorporate asset deterioration and climate change and could be used to estimate present and future risk (current, 5 years and 25 years, for example) for both ‘maintained’ and ‘unmaintained’ policies.

- **Extension to include a direct estimate of economic damages** – At present RAFT requires the user to provide information on the potential damages (expressed in receptor counts). The tool could be extended to incorporate data functions – either based on asset specific look-up tables or a simplified direct calculation.

- **On-going updates** - As better data becomes available, revised estimates of ‘House Equivalents’, generic fragility etc., will become available. These could be incorporated into the RAFT tool. At present however no mechanism exists to maintain the data.

- **On-going support** – A simplified website and training material would help support users and address Frequently Asked Questions etc.

- **Future opportunities to add the field assets -** In the future, the risk attribution methods within RASP will provide the information required through application of NaFRA, MDSF2 and PAMS. The application of such techniques to pilot sites would allow exploring how the full risk attribution methods would (in the future) be used to support the risk attribution and to validate the simplified approach.

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