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Working with water

Investigation and assessment of interfaces (or transitions) with earthen levees

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ASFPM conference 2019, Cleveland OH

Project team

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US Army Corps of Engineers

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Project Board

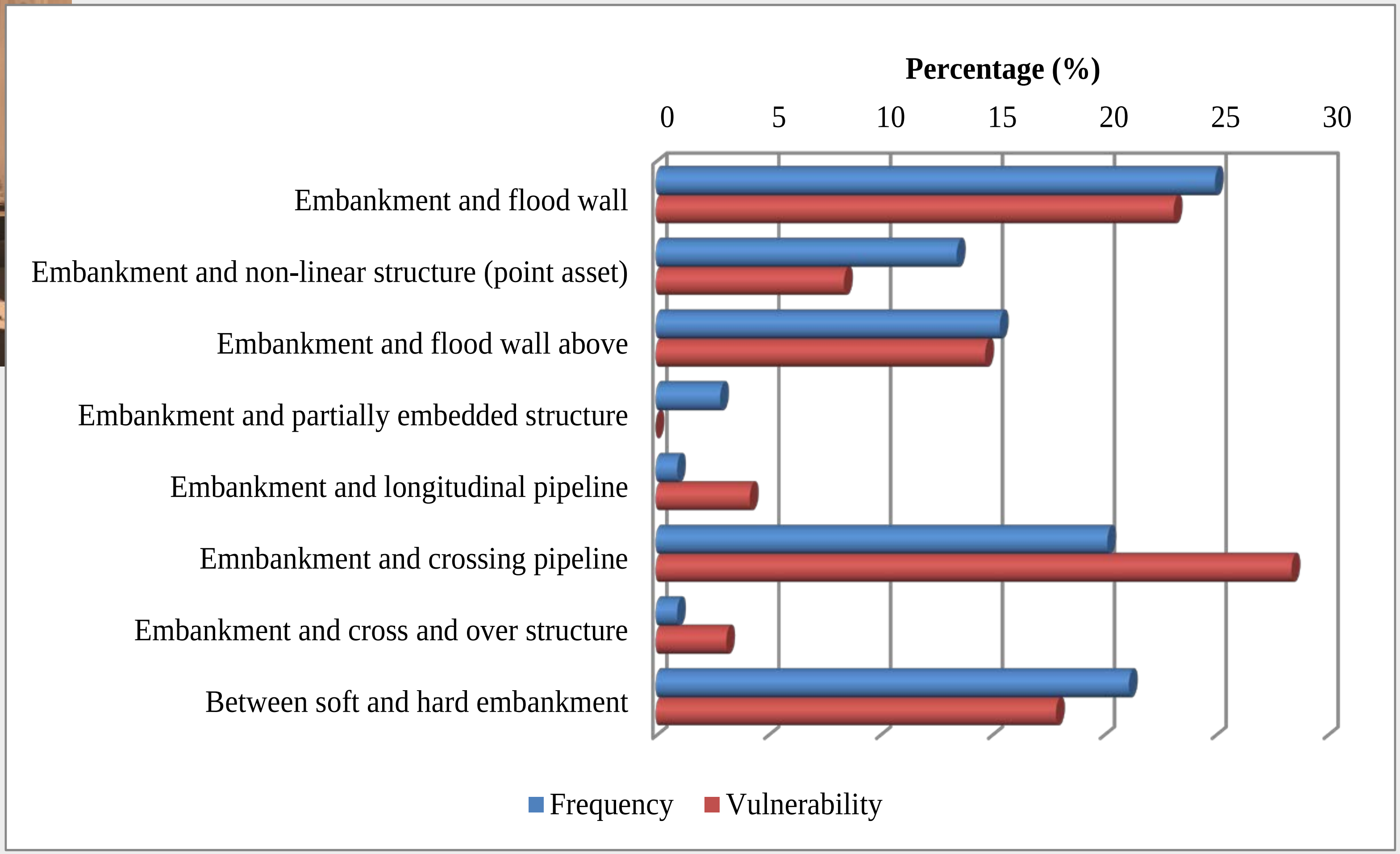
Environment Agency

Help risk management authorities to:

- **consider the presence** of transitions during flood defence condition assessment;
- **quantify the effects** of transitions on defence performance (fragility) and flood risk;
- **manage the risk** of transition with improved design and retrofitted solutions for existing defences

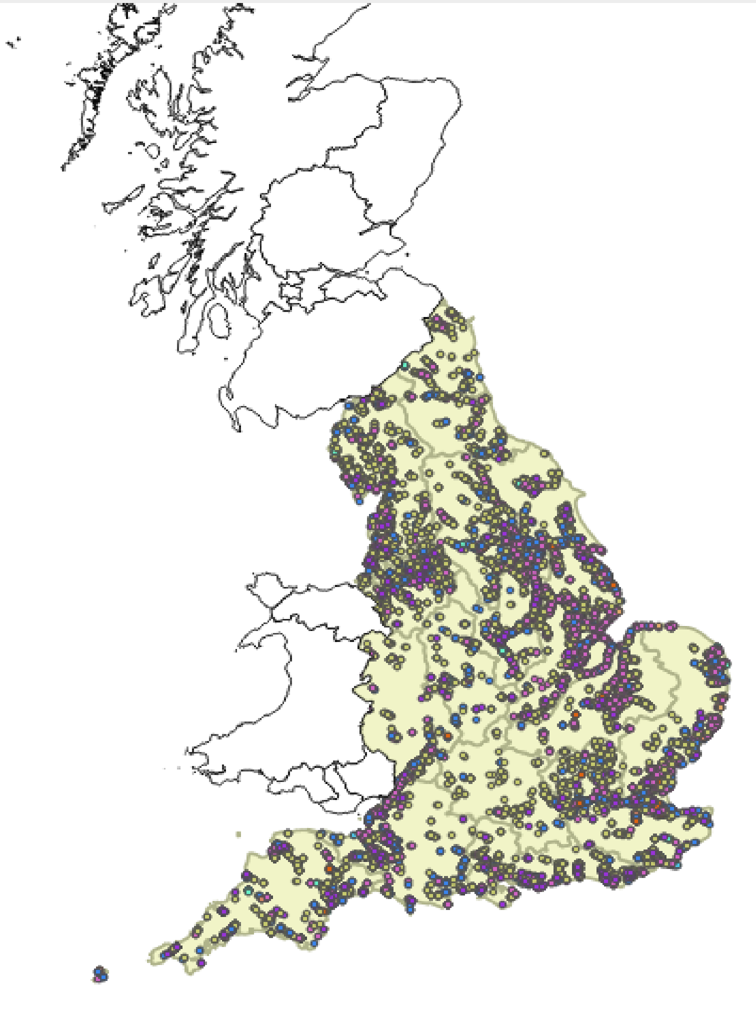
Interface types in England

Stakeholder feedback

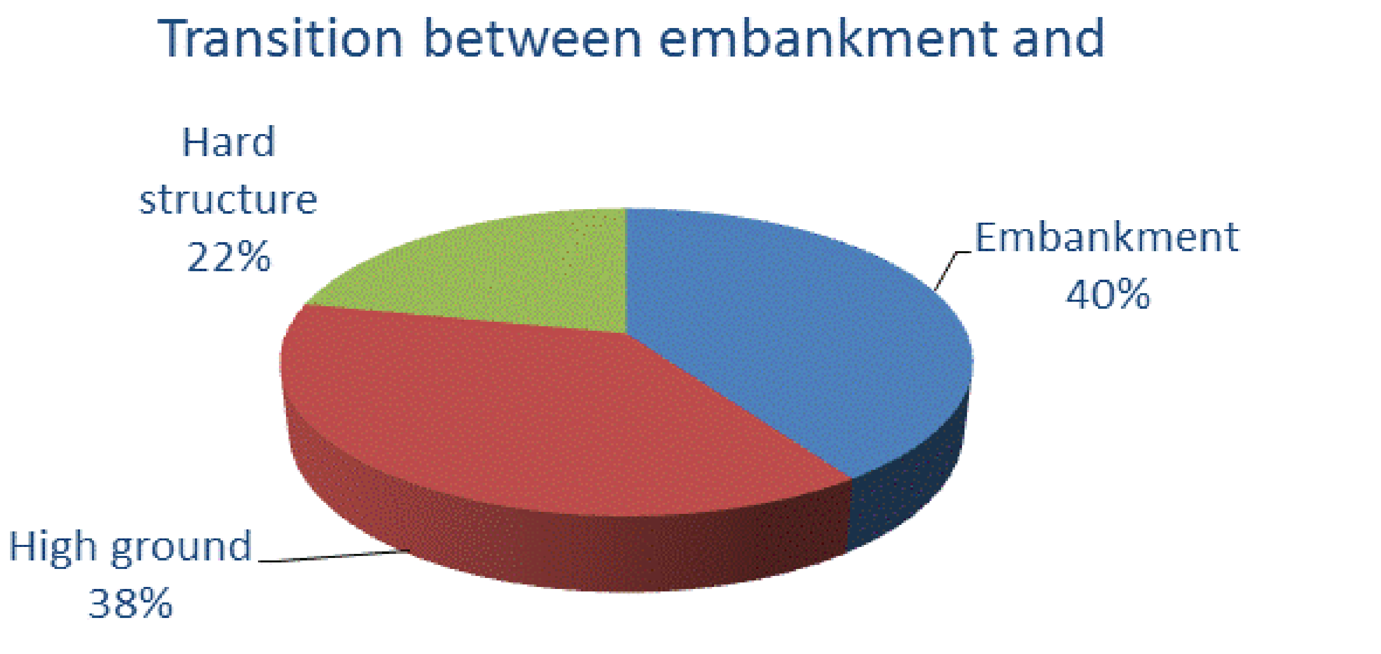


Interfaces types in England

Spatial analysis

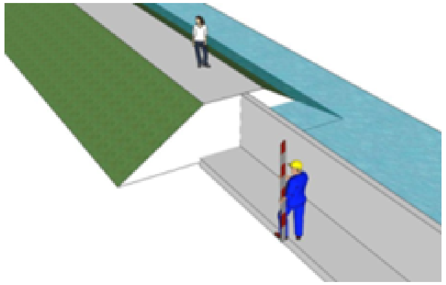
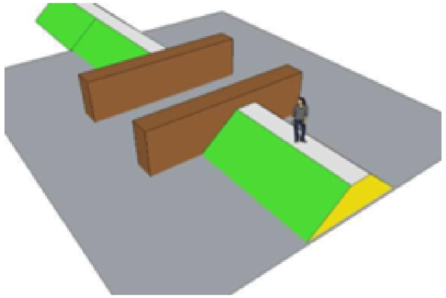
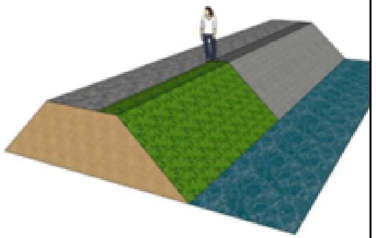
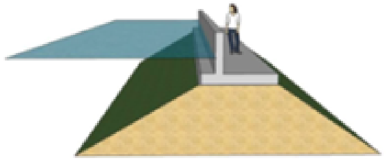
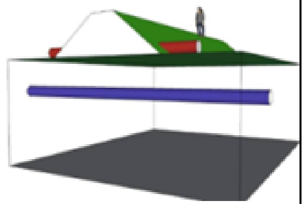


- 167,500 transitions
- 12% involving embankments



- (3/4 of hard structures are walls)
- ~1/3 are between hard and soft revetments

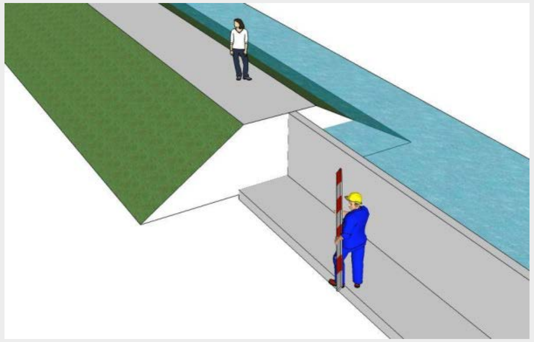
Types considered by the project

Longitudinal transitions			Cross-sectional transitions	Crossing pipelines
Between an embankment and a flood wall 	Between an embankment and a non-linear structure (point asset) 	Between soft and hard embankment revetments 	Between the embankment and a flood wall above 	Between an embankment and a crossing structure 

Longitudinal change from flood wall to earth embankment

Additional issues

- External erosion
  - Flow velocity increases and focussing of flow on vulnerable areas
  - Existing limit state equations could be used if we can estimate change in shear stress via increase in velocity



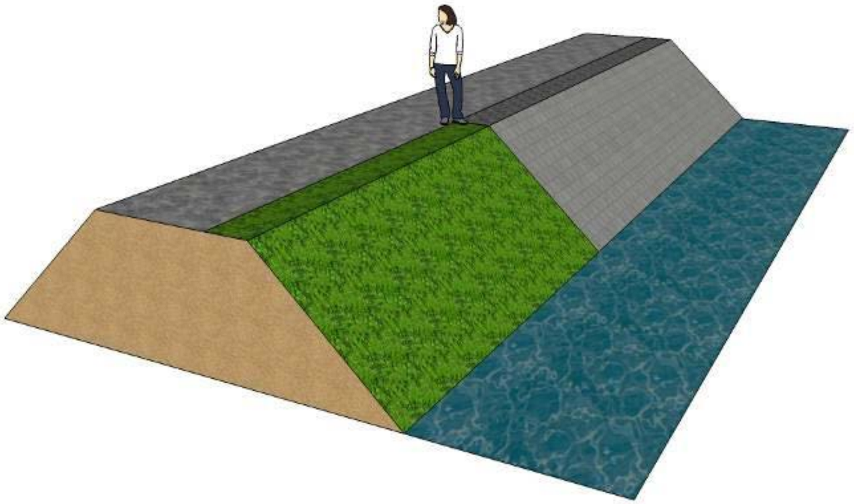
Examples of failures

- New Orleans – Katrina
- UK failures

Longitudinal change in external structure/protection of levee

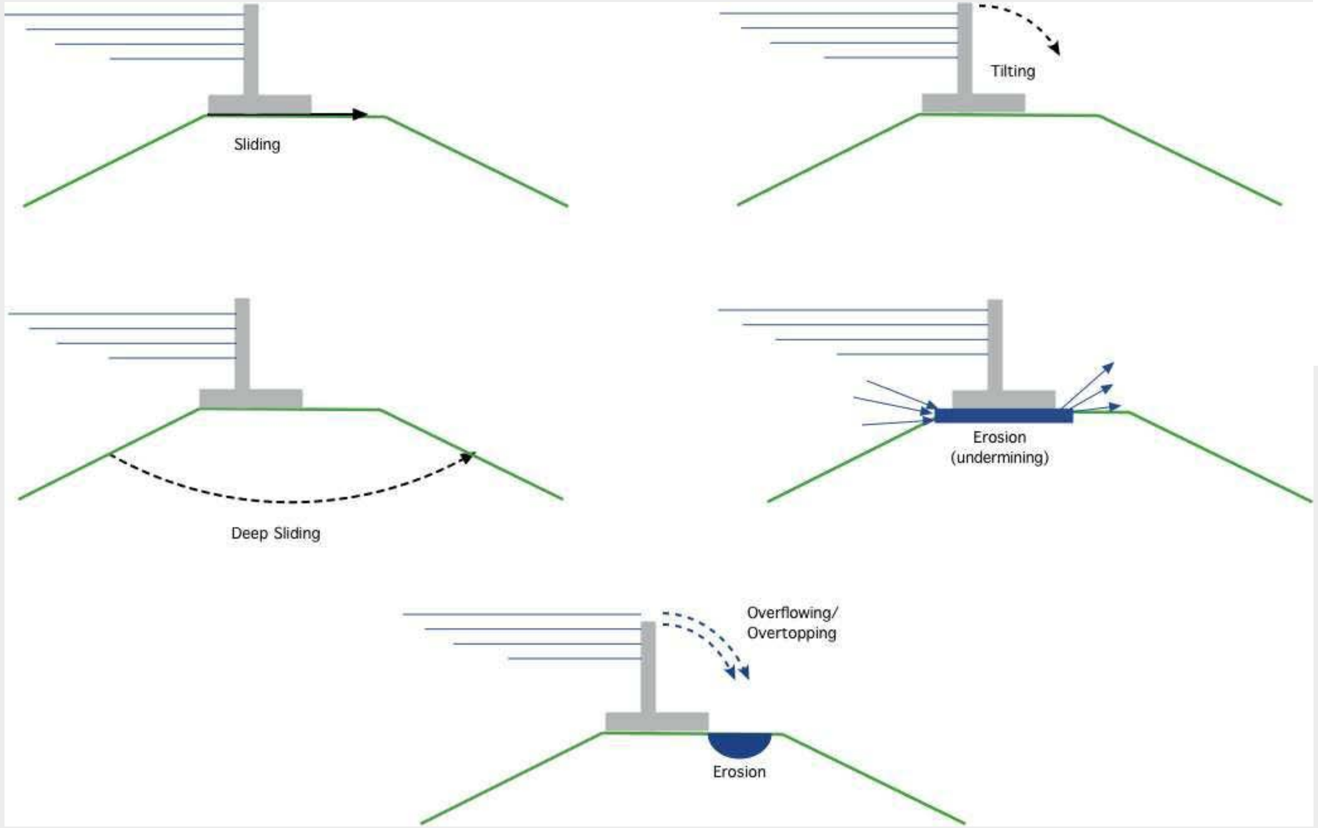
Additional Issues

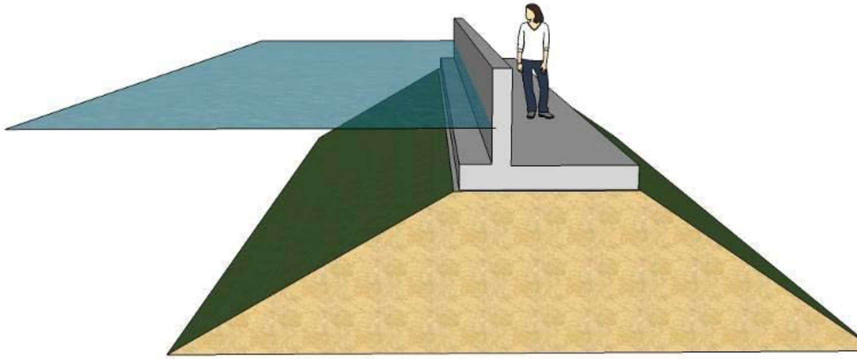
- External erosion due to weakened soil (as previous slide)
- Plus increased turbulence



Transverse change at interface between levee and flood wall

Additional Issues





- Internal erosion and deep sliding is sometimes missed when the levee is raised by a flood wall

New Orleans – IPET report Vol V on performance of levees and floodwalls

A common problem … was the scour and washout found at the transition between structural features and earthen levees.

- In many cases, the structural features were at **higher** elevations than the adjacent earthen levee, resulting in scour and washout at the end of the structural feature. … the dissimilar geometry **concentrates the flow of water** at the intersection of the levee with the structure, causing high flow velocities and turbulence.
- In some cases, the structures were **lower** than the connecting earthen levees. At these sites, the flow of the water is channelled over the structural feature, causing erosion of soil on the protected side of the structure.

Scour and Erosion on the Protected Side of the IHNC Adjacent to the 9th Ward in the Vicinity of the South Breach

New Orleans – IPET report Vol V on performance of levees and floodwalls

The performance at transitions could be improved by:

- fully embedding the structural walls within the levee fill, and using the levee to transition the difference in elevation from the structure to the levee.
- providing erosion protection on the protected side of the structures and along the transition section.

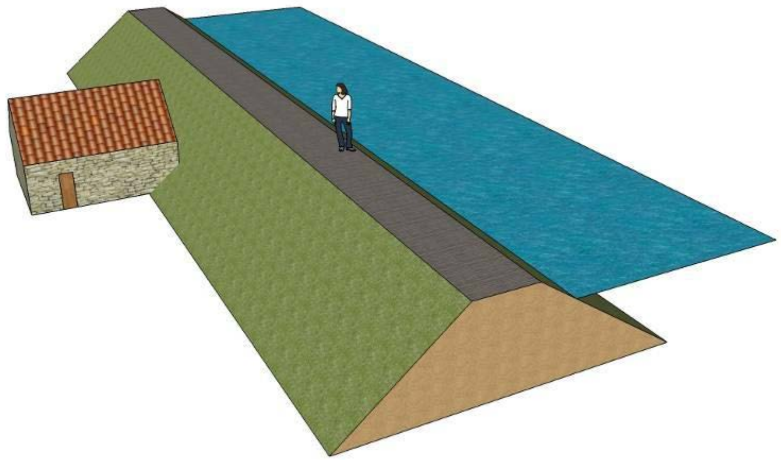
Non-linear partially embedded structure

Additional Issues

- External erosion due to weakened soil alongside structure (see discussions above)
- Internal erosion due to enhanced hydraulic gradients
- Failure of the structure itself (e.g. exploding) and thereby damaging the levee

Examples

- Many examples (e.g. house built into a levee on the River Loire)

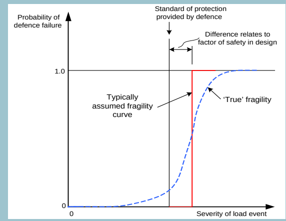


Products

PRODUCT 1

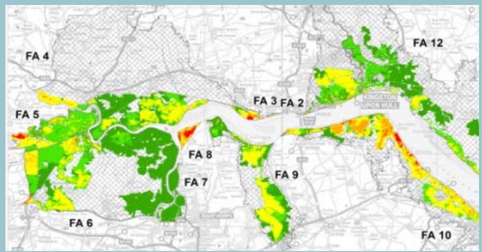
Improved guidance for the inspection of interface zones

PRODUCT 2



New methods and tools for the reliability analysis of flood defences with interfaces

PRODUCT 3

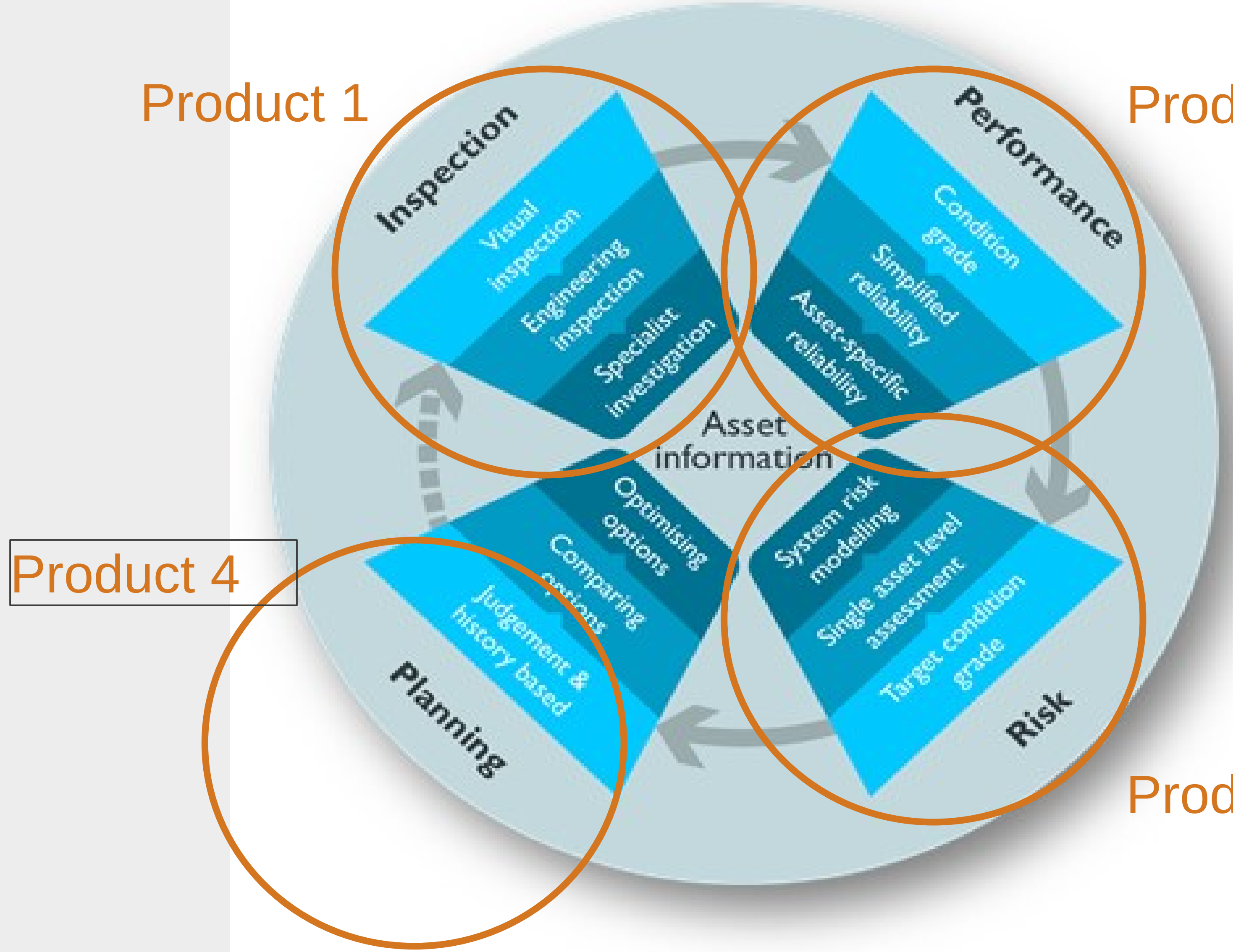


New methods to account for interfaces in flood risk systems analysis

PRODUCT 4

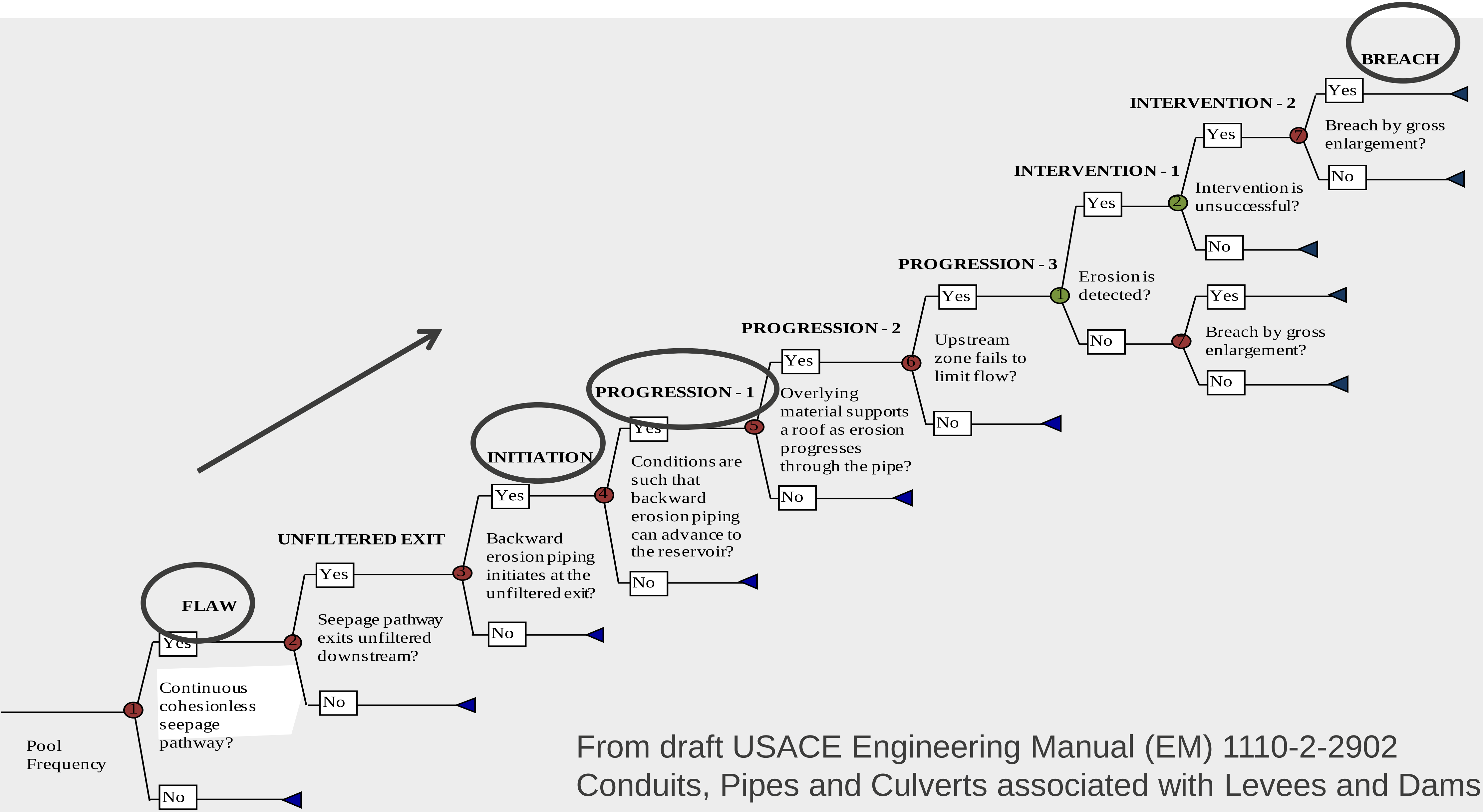
Contents list for new guidance supporting design, maintenance and repair

Products in relation to Asset Performance Propeller



Interfaces research

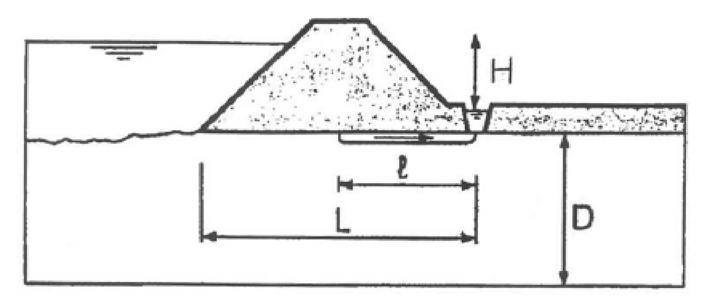
Fault/event trees – focus on failure initiation



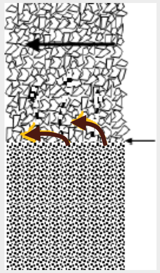
From draft USACE Engineering Manual (EM) 1110-2-2902
Conduits, Pipes and Culverts associated with Levees and Dams

Failure mechanisms

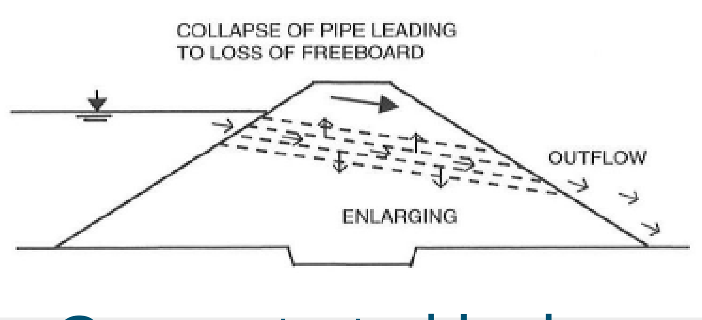
Mechanism	Description
External erosion	Surface erosion as a result of shear stresses or turbulence
Instabilities	Including sliding, collapsing, settlement
Internal erosion	Related to the detachment and transport of particles by seepage



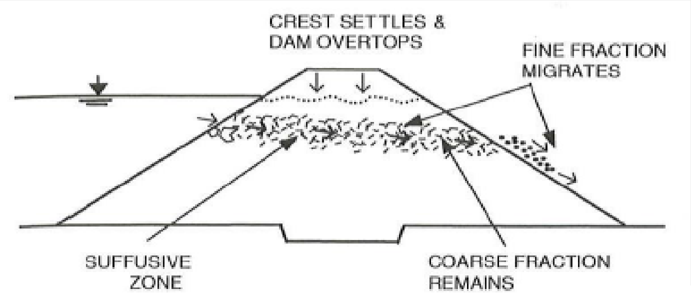
Backward erosion



Contact erosion

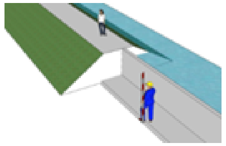
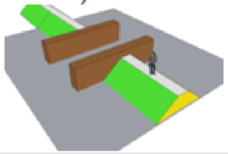
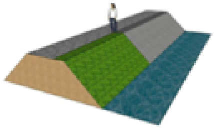
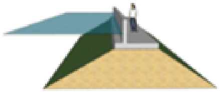
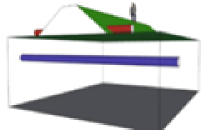


Concentrated leak erosion



Suffusion

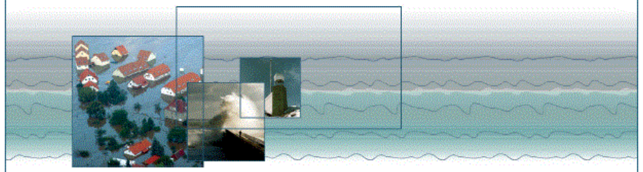
Interfaces research
Mapping of failure mechanisms

	Longitudinal transitions			Cross-sectional transitions	Crossing pipelines
	Between an embankment and a flood wall 	Between an embankment and a non-linear structure (point asset) 	Between soft and hard embankment revetments 	Between the embankment and a flood wall above 	Between an embankment and a crossing structure 
Slope instability	✓	✓	✓	✓	✗
Structure instability	✓	✓	✓	✓	✗
External erosion of landside slope	✓	✓	✓	✓	✓
External erosion of waterside slope	✓	✓	✓	✓	✓
Crest degradation	✓	✓	✓	✓	✓
Internal erosion	✓	✓	✓	✓	✓

FLOODsite report – One source of inspiration for failure modes and limit state equations

Integrated Flood Risk Analysis and Management Methodologies

FLOODsite



Failure Mechanisms for Flood Defence Structures

Date	February 2007
Report Number	T04-06-01
Revision Number	4_1_P01
Deliverable Number:	D4.1
Due date for deliverable:	April 2006
Actual submission date:	Feb 2007
Task Leader	HR Wallingford Ltd

FLOODsite is co-funded by the European Community
Sixth Framework Programme for European Research and Technological Development (2002-2006)
FLOODsite is an Integrated Project in the Global Change and Eco-systems Sub-Priority
Start date March 2004, duration 5 Years

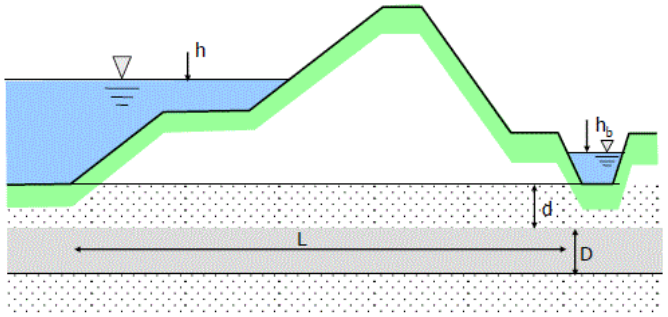
Document Dissemination Level

PU	Public	PU
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Co-ordinator: HR Wallingford, UK
Project Contract No: GOCE-CT-2004-505420
Project website: www.floodsite.net

Ba 1.5aiii Uplifting of impermeable layers behind earth embankment

Summary: Uplifting behind embankments occurs if the difference between the local water level h, and the water level "inside", h_b is larger than the critical water level h_c



Reliability equation:
The reliability function is expressed by:

$$z = m_0 \cdot h_c - m_h \cdot \Delta h$$

where:

- h_c = critical water level [m]
- Δh = difference between local water depth in front of dike and water level in the floodplain [m]
- m_o = model uncertainty factor [-]
- m_h = model uncertainty factor for damping[-]

Loading equations:	Resistance (strength) equations:
$\Delta h = h - h_b$	$h_c = \frac{\gamma_{wet} - \gamma_w}{\gamma_w} d$

Parameter definitions:

- γ_{wet} = saturated volumetric weight of the impermeable soil layers
- γ_w = volumetric weight of the water
- d = thickness of the impermeable layers
- h = water level on the river [m]
- h_b = water level in the floodplain [m]

Sources of failure mechanism equations / methods:
Vrouwenvelder et al. (2001)

Sources of uncertainties in failure equations / input parameters:
Vrouwenvelder et al. (2001)

Limit State Equations (LSEs)

To evaluate the ability of a defence to resist a certain failure mechanism under a certain type of loading

$$Z = R - S \qquad < 0 \ \text{- Failure}$$

Reliability Strength Load

Transitions ⇩ ⇧

$$Z = R - S$$

Transitions ↓ ↑

Weakness = 1/R (R, Strength)
Uneven crest elevation
Geometric irregularities at the contact surface
Steep slopes
Poor material condition at the transition
Leakage from/into pipelines
Poor grass cover
Toe erosion
Crack/fissures
Debris accumulation
Rainfall softening

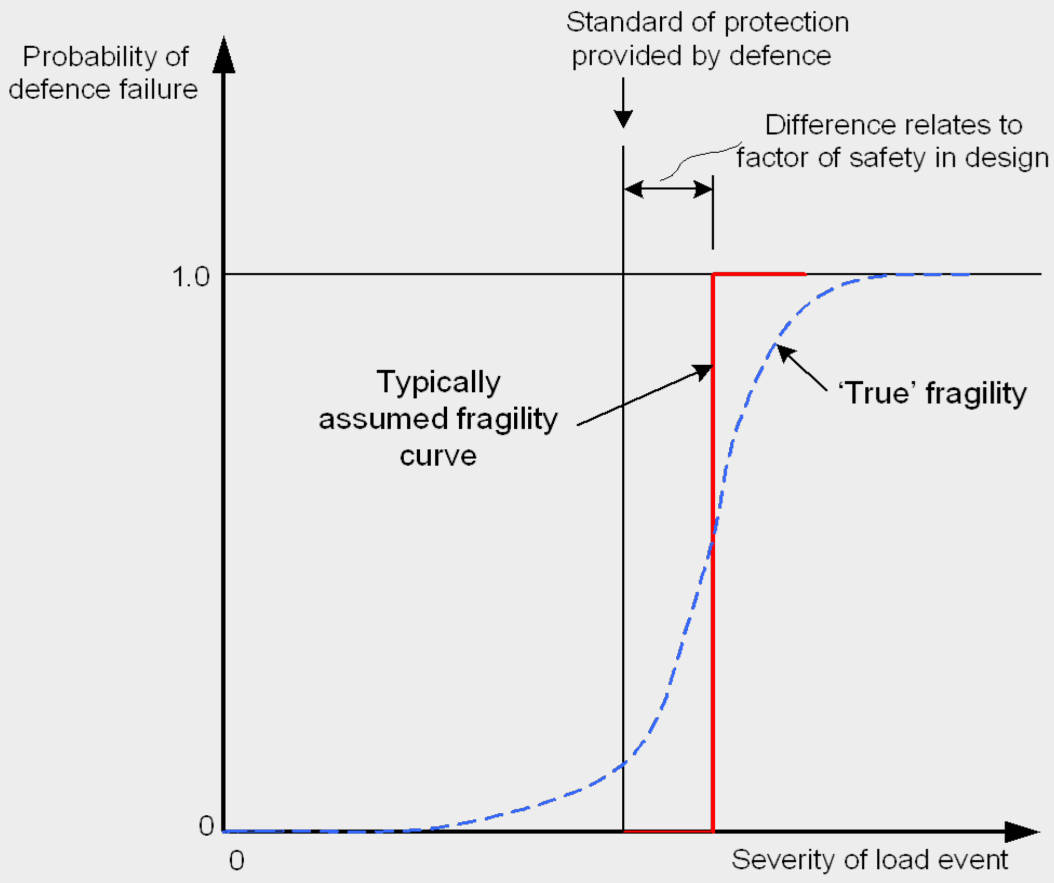
S, Loads
Water levels
Waves
Longitudinal flow
Overtopping
Overflowing
Turbulence
Hydraulic gradient
Pipeline vibration

Product 1: Guidance on identification and inspection

Tiered approach:

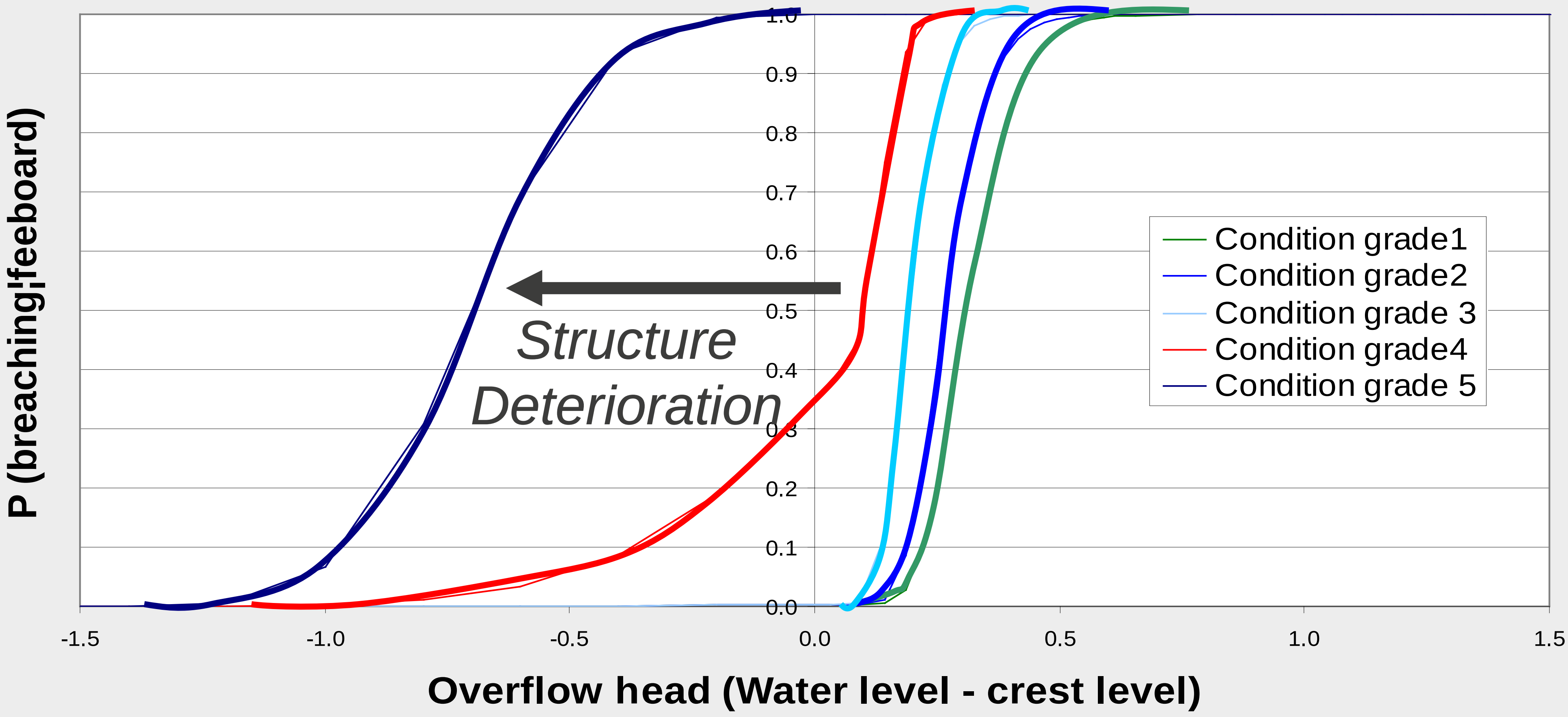
Tier	User	Techniques	Output	Format of guidance	Nr of types
1. CAM-type basic inspection	Field team	Visual	Condition Grade	CAM-style	4
2. Intermediate Non-intrusive	Watershed Engineer or equivalent	Visual plus desk study	Condition Grade	Note with specific recommendations per type, typically 2-3 pages, see Appendix 14-25 in SC110008/R2	Up to 10 (subs of 4 Main types)
3. Detailed	Specialist	Surveys, modelling	Condition Grade + parameter values	Transition-specific comments on Appendix 26-29 in SC110008/R2	4 types of investigation

Product 2 - Fragility curves

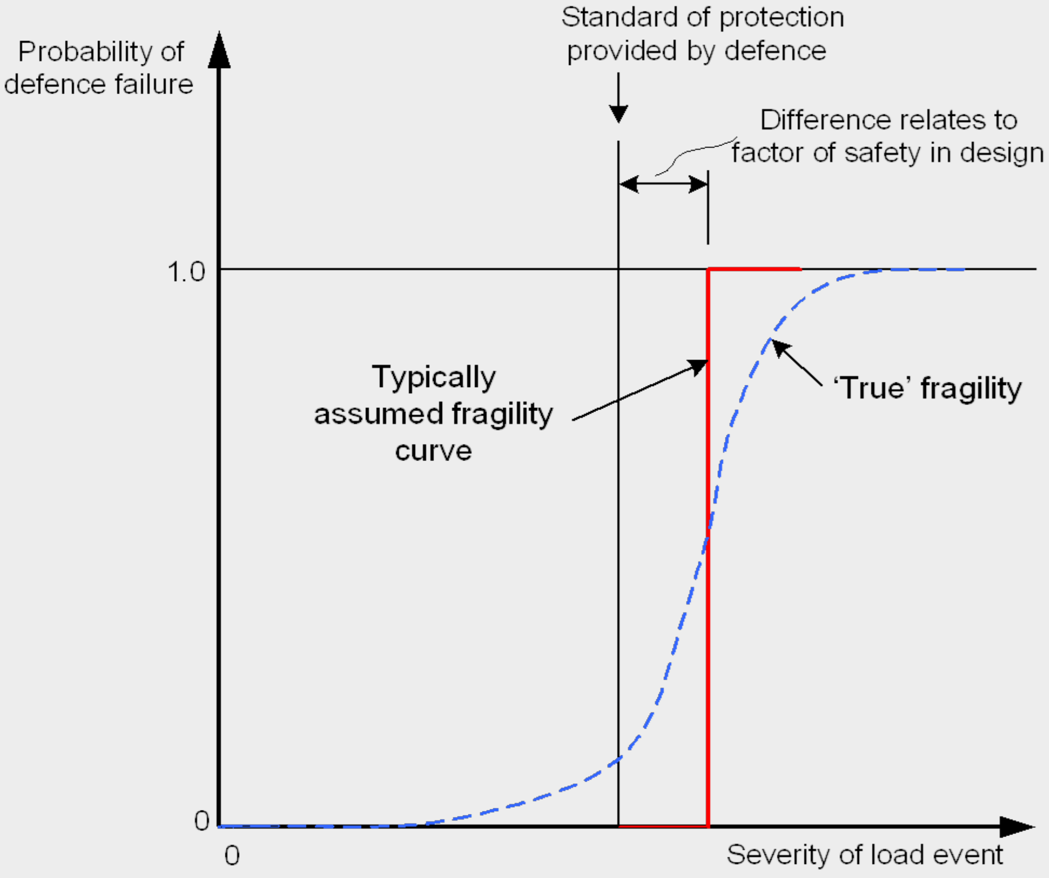


- Express varying probability of failure with load
- Can be generalised for broad scale or bespoke for local system or individual asset

Fragility curves – example UK generic curves



Product 2 - Fragility curves



- Express varying probability of failure with load
- Can be generalised for broad scale or bespoke for local system or individual asset
- Generated by evaluation of Limit State Equations, but expert judgement can also be used to adjust them

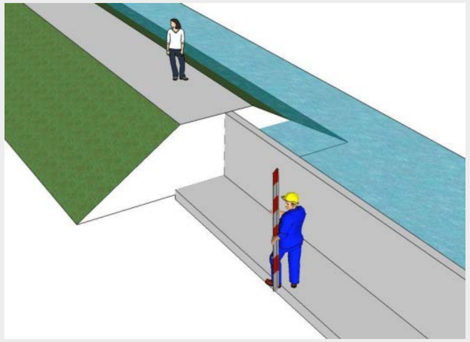
Product 2: reliability analysis/fragility curves

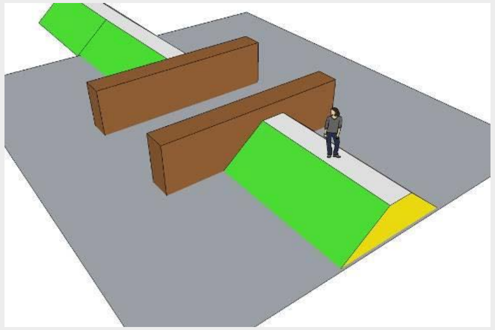
Process for generating fragility curves:

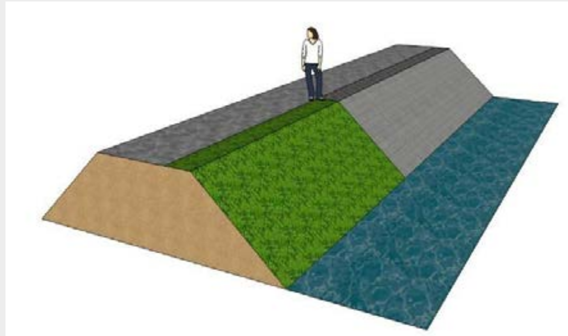
- Identification and analysis of all relevant failure modes
- Identification of Limit State Equations (LSE's) or models for all failure modes (recast into reliability format: I.e. *Z* (*reliability*) = *R* (*strength*) – *S* (*loading*))
- Preparation of a schedule of engineering parameters (and their uncertainties)
- Preparation of fault trees specifying the logical sequence of all possible mechanisms leading to defence failure
- Performance of many reliability analyses, for a single hydraulic loading across a range of parameter uncertainties (i.e. Monte-Carlo sampling). For each loading analysed, the probability of failure is the proportion of times that $Z<1$. (Repeated for other hydraulic loadings and the resulting fragility curve plotted)

Product 2 – implications of transition type for fragility curves

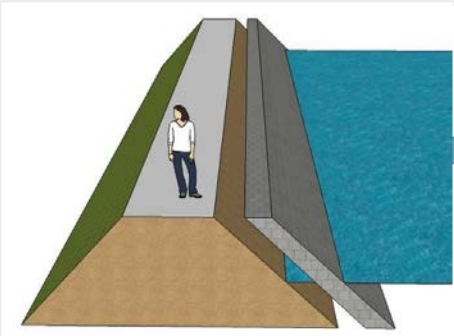
- Longitudinal transitions
  - separate element in system risk analysis
  - separate Frag. Curve

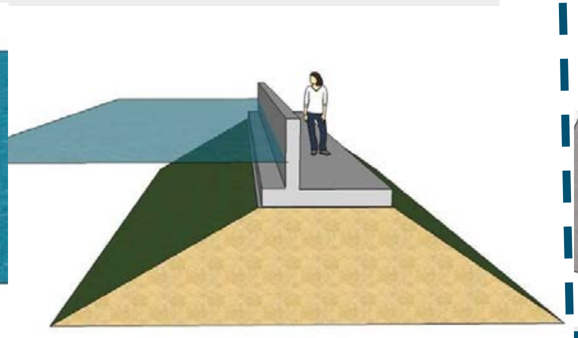


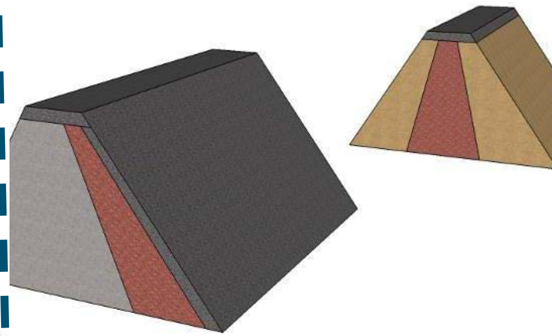




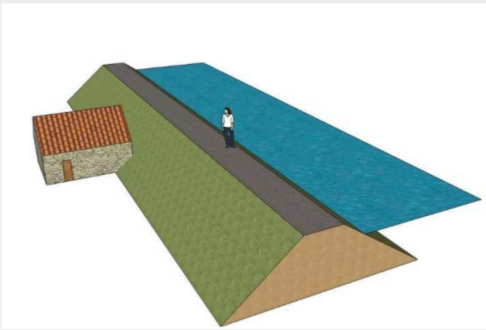
- Changes within a cross section
  - affects component fragility curves within a segment

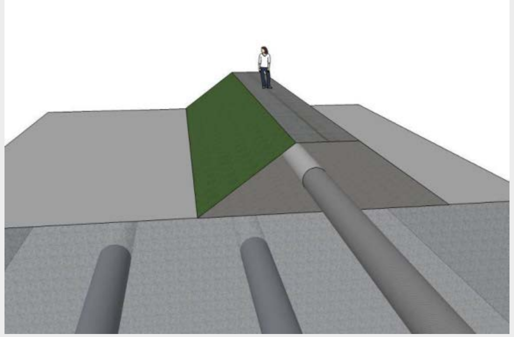


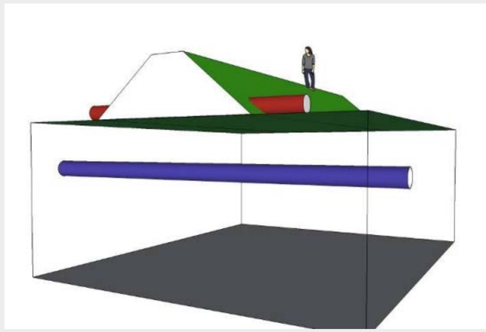




- Embedments or encroachments
  - cf. USACE EM 1110-2-2902 Conduits Culverts and Pipes
  - affects segment fragility curve

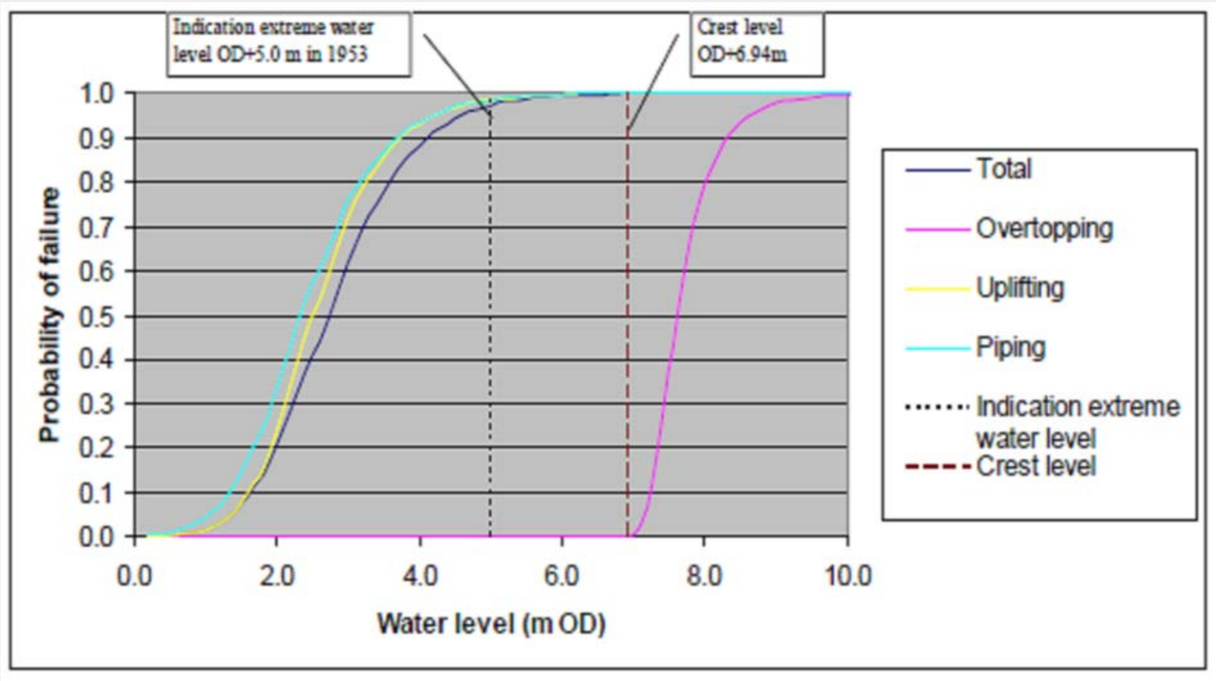


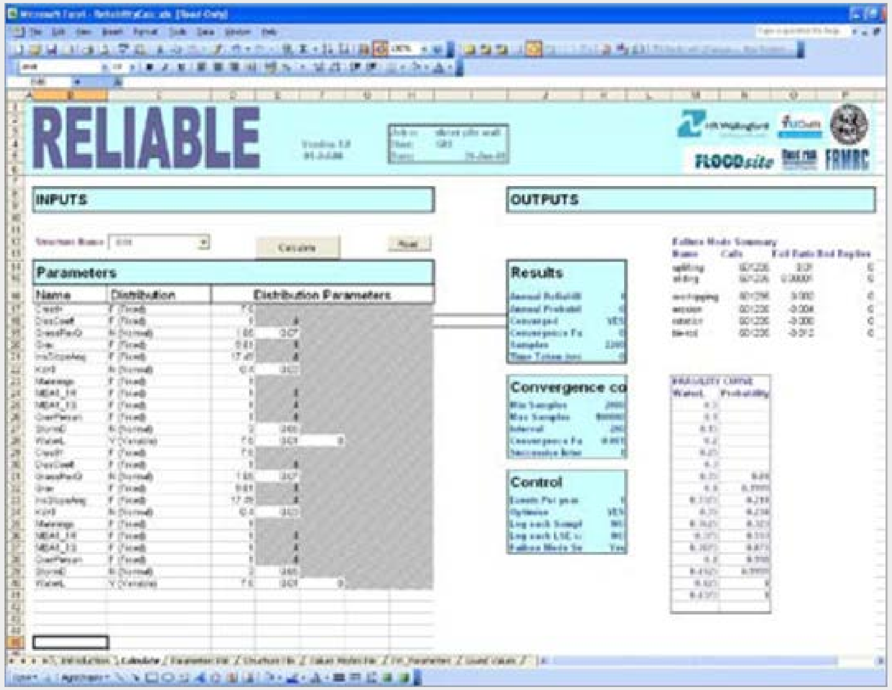




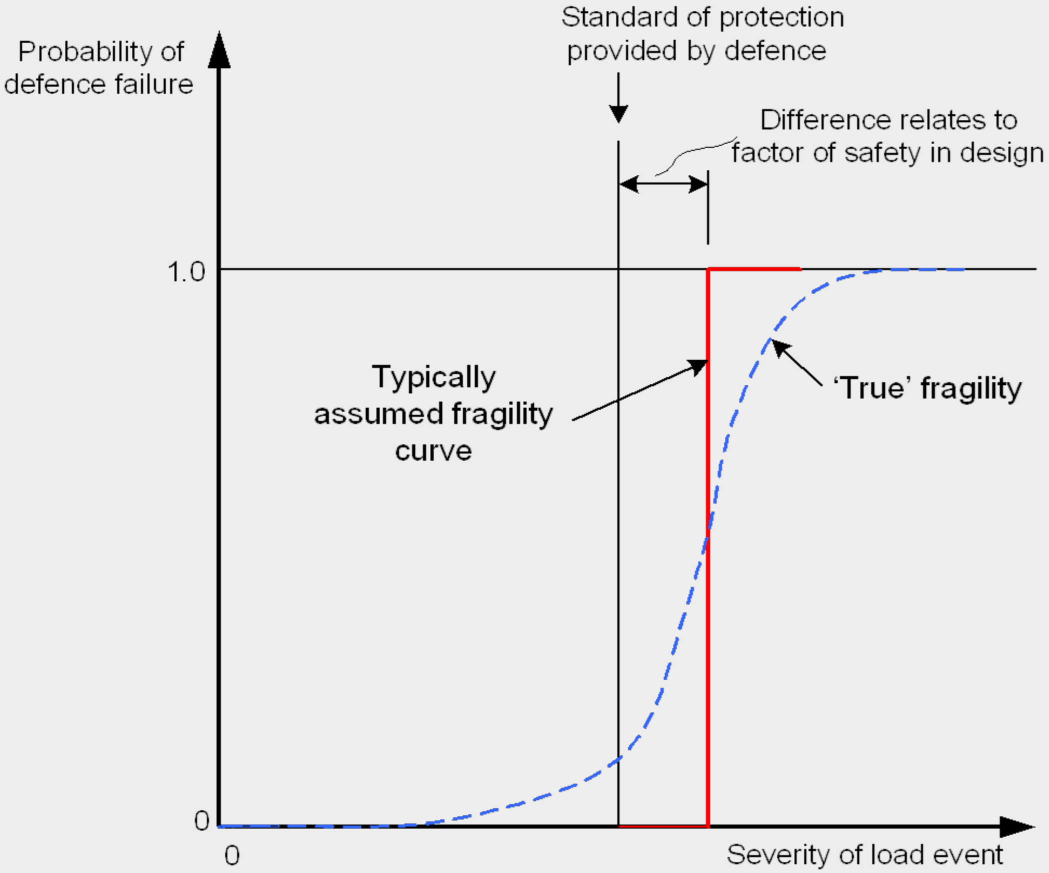
Product 2: combining fragility curves for different mechanisms

- If failure modes are independent of each other then fragility curves can be combined to provide an overall probability of failure by using De Morgan's Law: $\Pr(f) = 1 - \{[1 - \Pr(f_1)] \times [1 - \Pr(f_2)]\}$
- If they are dependent then it is better to use appropriate tools such as 'RELIABLE' which can deal with this complex issue. (This tool was developed by researchers under the FLOODsite and FRMRC projects for this purpose)



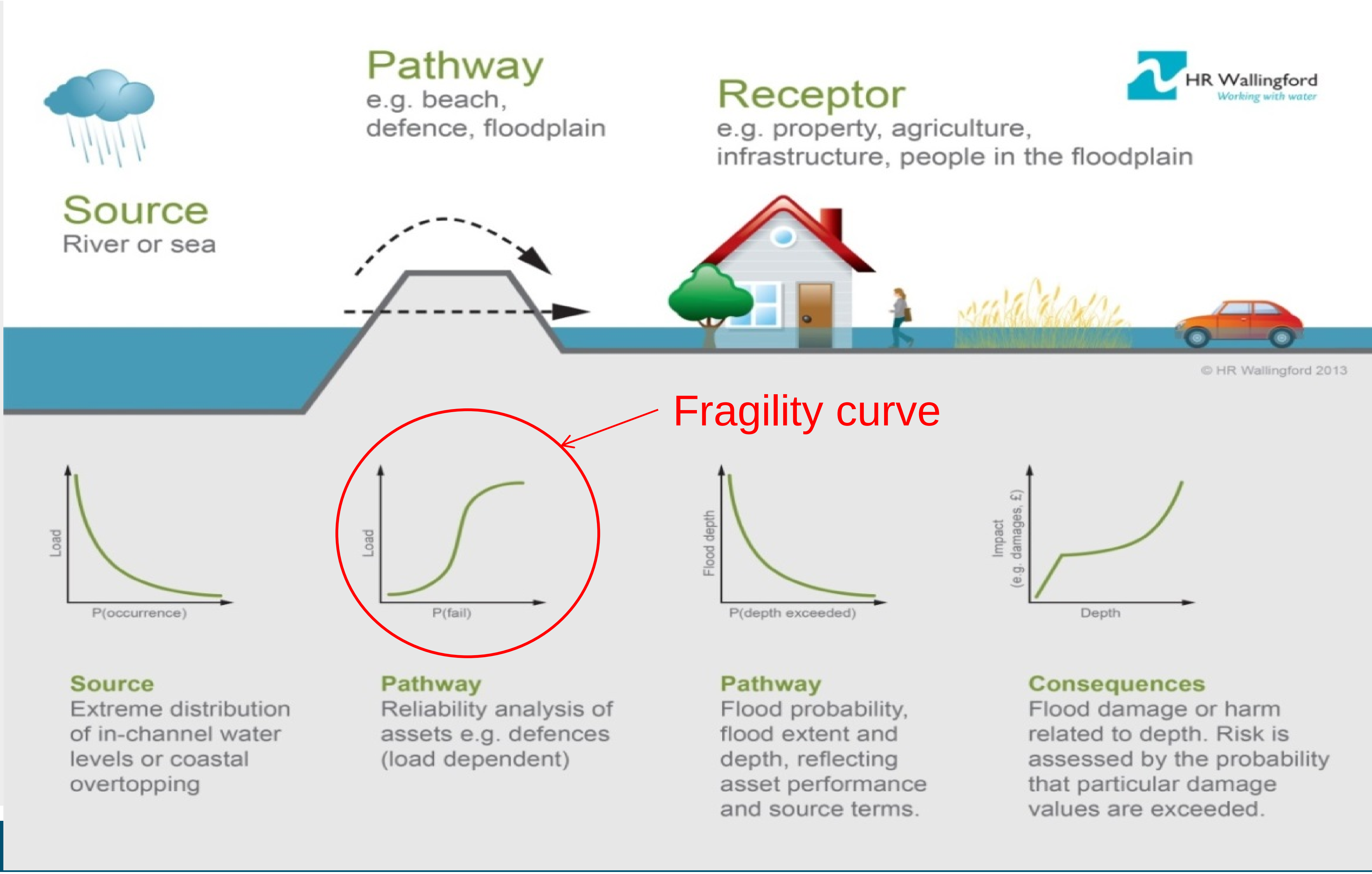


Product 2 - Fragility curves



- Express varying probability of failure with load
- Can be generalised for broad scale or bespoke for local system or individual asset
- Generated by evaluation of failure Limit State Equations, but expert judgement can also be used to adjust them.
- Create understanding of the performance of a defence, especially when including defence performance in flood systems analysis

Product 3: Incorporation of transitions in flood risk systems analysis

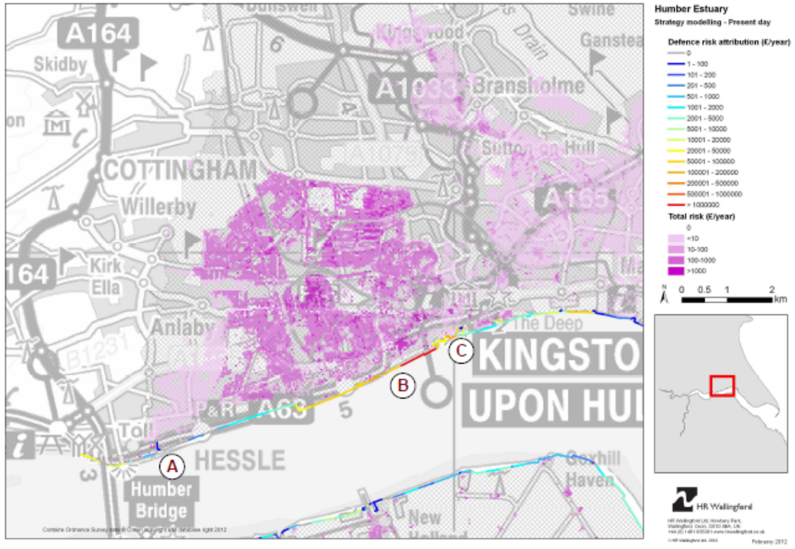


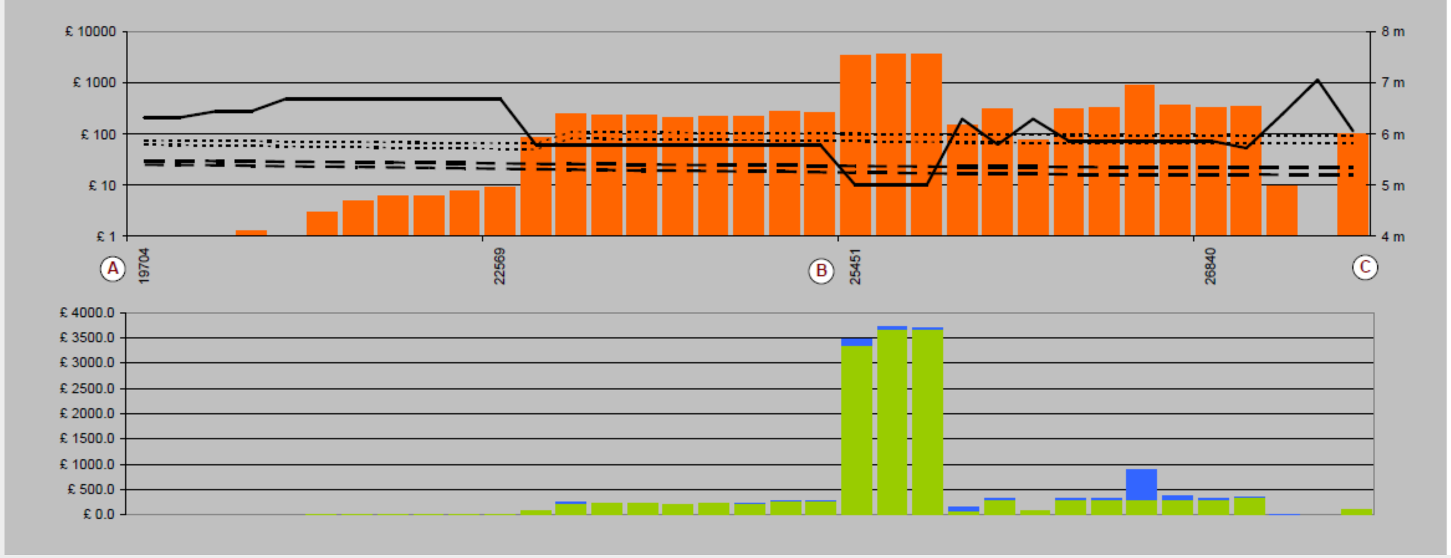
Product 3: Incorporation of transitions in flood risk systems analysis

Flood area 6 – Hull West (Hull Barrier to Hessle Haven)

Key information	
Size of flood area	9,471 ha
Number of properties in floodplain	79,974
Area of agricultural land	5,191 ha
Length of defences	8.4 km
Current standard of protection	Generally 0.5% (1 in 200) but locally 5% (1 in 20)
Remaining life of defence	Generally 10 to 20 years, locally 5 years
Defences managed by	Mixed; Hull City Council, Associated British Ports and Environment Agency

Hessle Haven A
B
Hull Barrier C





Defence risk attribution (£/m/year)

Crest level (mOD)

200-year and 75- year water level (mOD)

200-year and 75- year with wave height (mOD)

Chainage (m)

Contribution to risk (£/m/year)

from overflow

from breaching

Product 4: Design & management guide

Users:

- Specialist designers and asset managers

Approach:

- Build on conceptual understanding & classification (Task 2)
- Tiered approach:
- Standard details
- Suggested approaches for special cases

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Product maturity

Product maturity

Invention	Concept validation	Prototyping	Piloting	Introduction to business	Business as usual
• Basic principles first observed • Concepts developed	• Proof of concept applications developed • Analytical studies	• Application validated against known end user needs • Application verified against sample data	• Critical functionality of application tested in relevant environment • Typical and critical functionality demonstrated	• Full application demonstration in operational environment • Application rolled out to representative range of location	• Application adopted by all relevant areas of business • Full benefits start to be realised and monitored

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PRODUCTS

Product	Description	Product maturity	Possible next steps
1	Improved guidance for the identification and inspection of transition zones	Piloting	• Continued use • Embed in post inspection process
2	New methods and tools for the reliability analysis of flood defences with transitions	Piloting	• Dissemination: standard R&D route plus take to Operations Managers' assets portfolio
3	New methods to account for transitions in flood risk systems analysis (e.g. NaFRA)	Concept validation/ Prototyping	• Dissemination: standard R&D route plus discussion with CAMC programme about piloting and further development
4	a) Contents list for a new guidance supporting the design, maintenance and repair of transitions b) Development of the new guidance	Invention Piloting	• Commission the development of the guide • Continued use • Embed in post inspection process

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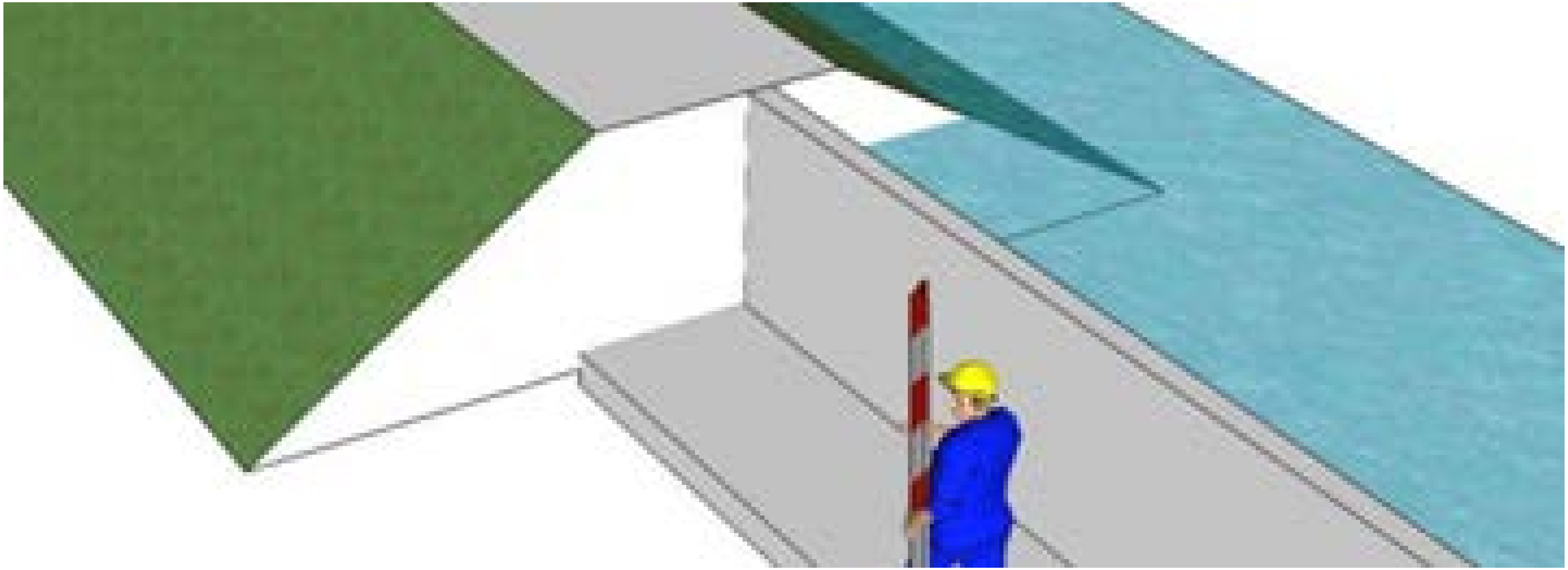

Assessing and managing risks with soil/structure transitions in flood defence structures

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