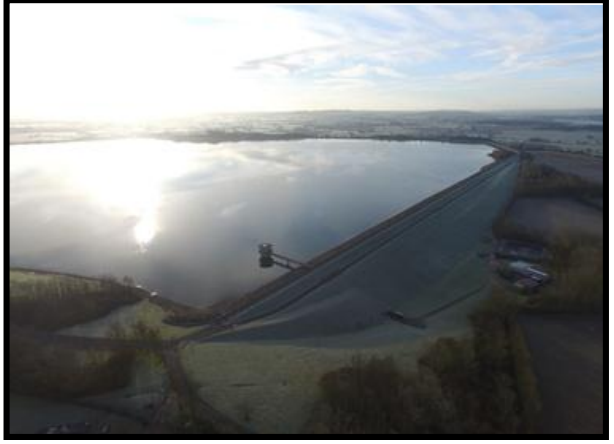
# The Dam Owners' Perspectives: Issues and Engineering Needs

**Dr Chrissy Mitchell**

11th December, 2017. Aussois, France

*EURCOLD International Workshop on overflowing erosion of dams and dikes*



Draycote Reservoir (Severn Trent)

Ramsden Reservoir (Yorkshire Water)

Drift (South West Water)

Carsinton Reservoir (Severn Trent)

Ladybower Reservoir (Severn Trent)

Vyrnwy Reservoir (Severn Trent)

Howden Reservoir (Severn Trent)

Clywedog Reservoir (Severn Trent)

Foremark Reservoir (Severn Trent)

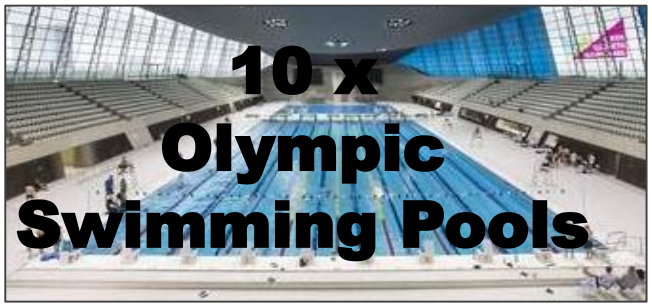
# UK Regulation

**2039**

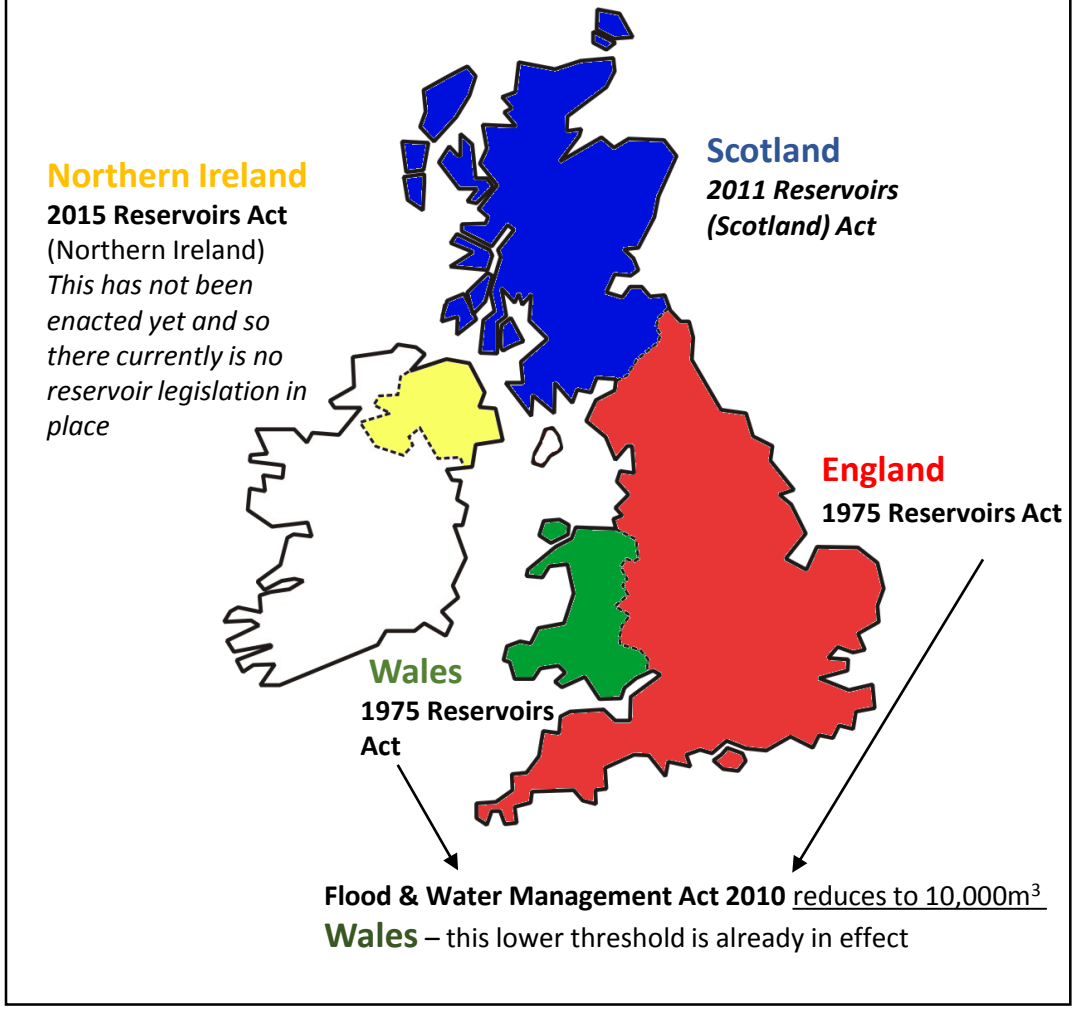
Env. Agency Regulated Reservoirs

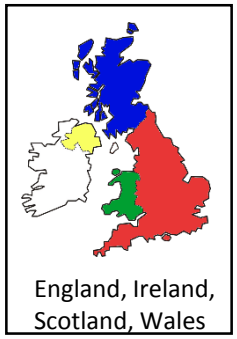
2017

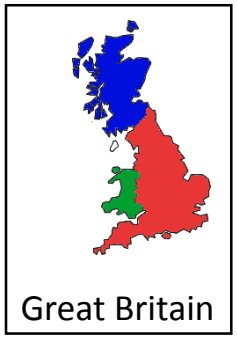
Includes all over 25,000m³

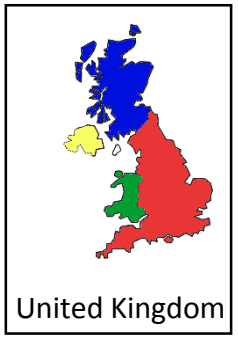



Environment Agency





England, Ireland, Scotland, Wales


Great Britain

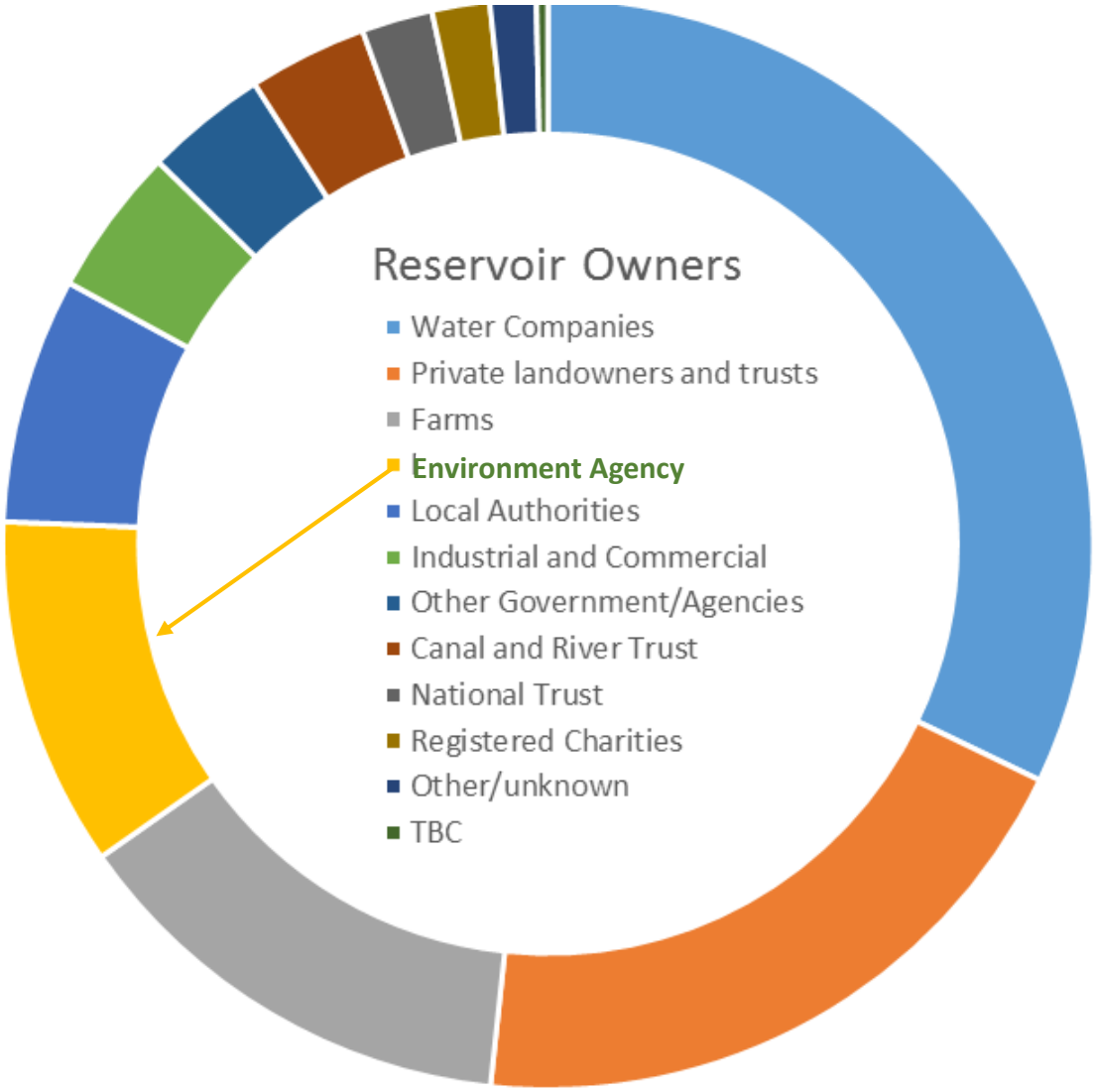

United Kingdom

# Reservoir Owners

RESERVOIR SAFETY ADVISORY GROUP

Flood and Coastal Erosion Risk Management R&D Programme

The British Dam Society | ice Institution of Civil Engineers | Department for Environment Food & Rural Affairs | Llywodraeth Cymru Welsh Government | Cyfoeth Naturiol Cymru Natural Resources Wales | Environment Agency




**Diversity in ownership**

759 different owners

For 2039 reservoirs

England, 2017

Environment Agency

# Reservoirs (England & Wales)

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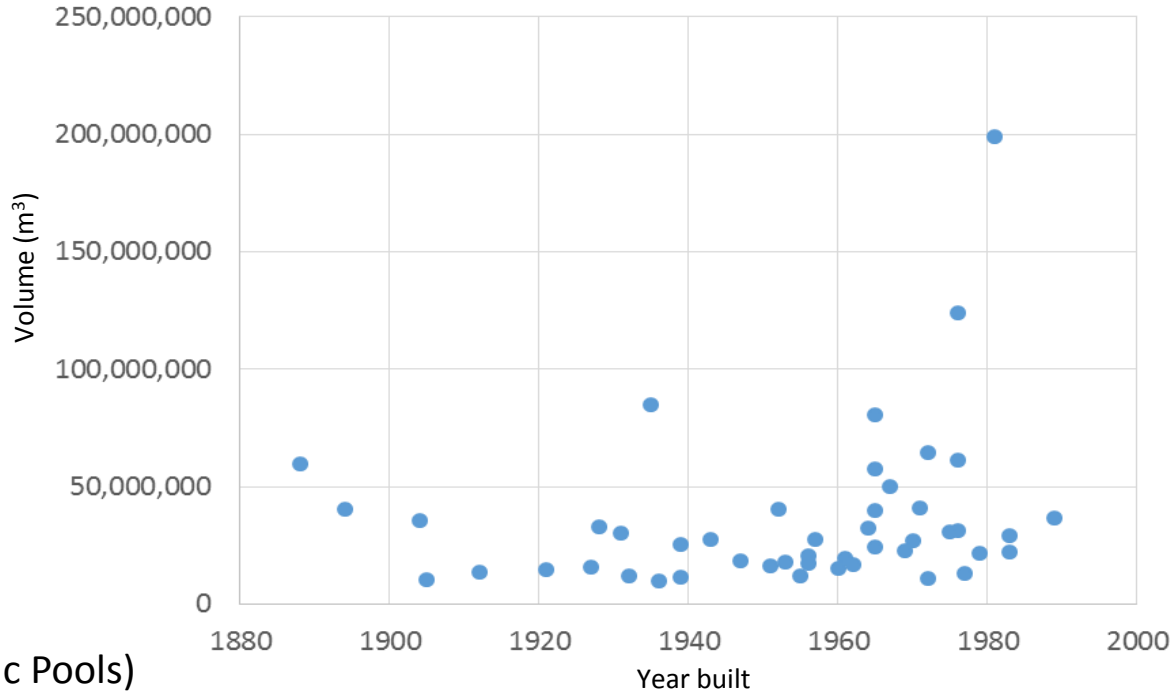
**Aging**
Average age is 125yrs
Oldest is 800yrs
Largest volume ~200m $m^3$ (80 Olympic Pools)




**Average incidents** per year (since 2004) is 8

Last loss of life was in 1925

5 million properties at risk of flooding

1 million of these are at risk of flooding from a reservoir

90% of these properties are at High Risk

Statistics for England and Wales, Environment Agency 2017

# Ulley Reservoir – June 2007

**Built:** 1875 **Capacity**: 580,000m³ **Height**: 14m
**Construction**: Earthfill (Puddle Clay)

**Lessons:** Spillway overflow. Keep documents on site. Access to site

**Blacktoft – Humber Estuary partial breach Dec' 13**

Buried cable & concrete headwall of old in-filled drainage channel

## Summer floods 2007

1000km levees tested, 500km overtopped, 4 breached - overtopped: geotechnical, caused by local irregularities

Lessons:

- Breach is difficult to predict based on visual condition
- Focus more on local irregularities, transitions

*Credit: Jaap Flikweert RHDHV, CIWEM Presentation*

# Cumbria 2009

One full breach despite widespread overtopping

Lessons:

- Minor improvements and regular maintenance help
- Careful with steep slopes and young grass



*Credit: Jaap Flikweert RHDHV, CIWEM Presentation*

# Lincolnshire 2012

Two small breaches -
close to 2007 breaches

Both breached before they were overtopped:

- geotechnical
- steep slopes and local irregularities

Lessons:

- How to deal with ‘historic’, steep-sloped but low consequence levees




*Credit: Jaap Flikweert RHDHV, CIWEM Presentation*

# Winter floods 2013/14

83 structural failures. Majority due to coastal overtopping in ‘above design’ event

‘Historic’ non-formally designed levees, transitions

Lessons:

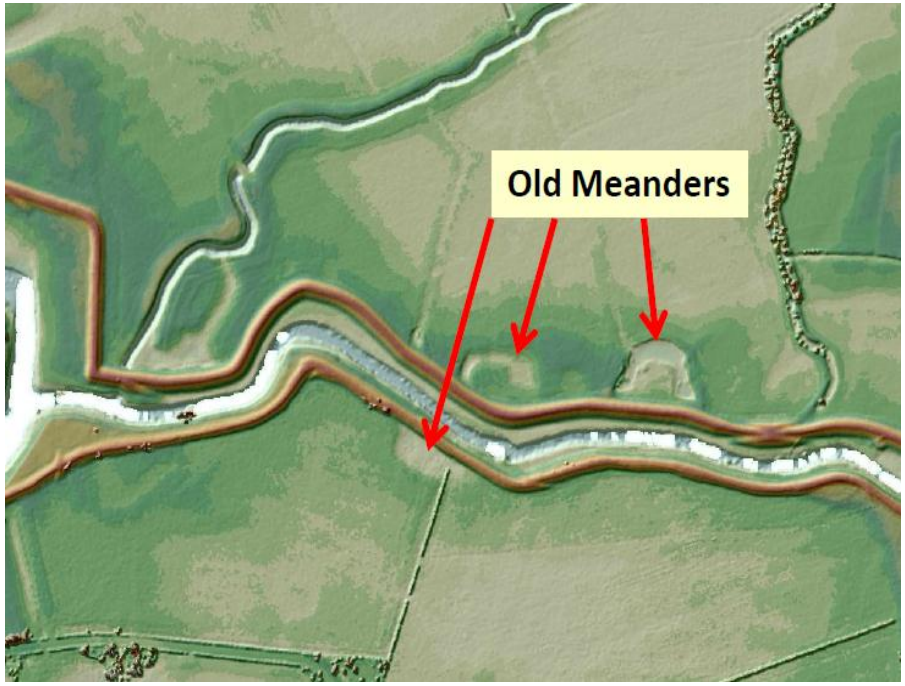
- Improving inspections: trigger expert involvement;
- Non-visual aspects; focus on transitions, irregularities, historic changes
- Dealing with low spots

*Credit: Jacobs for Environment Agency*

# Winter floods 2015/16

6 fluvial levee breaches:

- 3 overtopped, 3 geotechnical
- Steep slopes, local irregularities, ‘historic’ levees
- Low consequence levees with reduced maintenance




Lessons:

- How to deal with ‘historic’, steep-sloped but low consequence levees

# Deterioration – differential settlement

Flood storage area near Crowland (Lincolnshire)

# Research & Development

RESERVOIR SAFETY ADVISORY GROUP

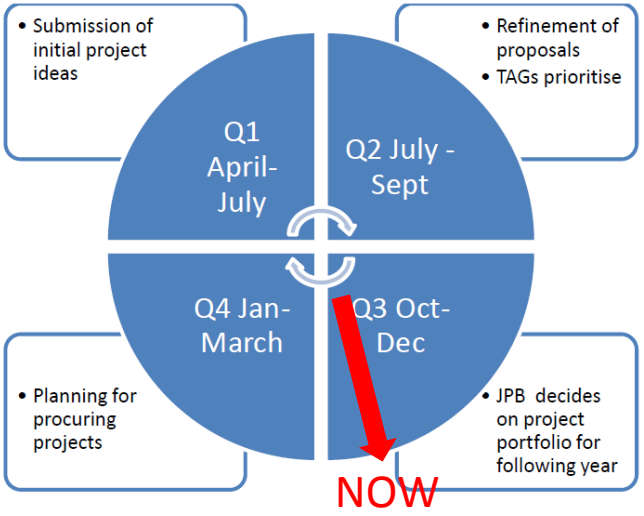
Flood and Coastal Erosion Risk Management R&D Programme

## The Reservoir Safety Advisory Group (RSAG)

*Advises on R&D priorities*

# Funding





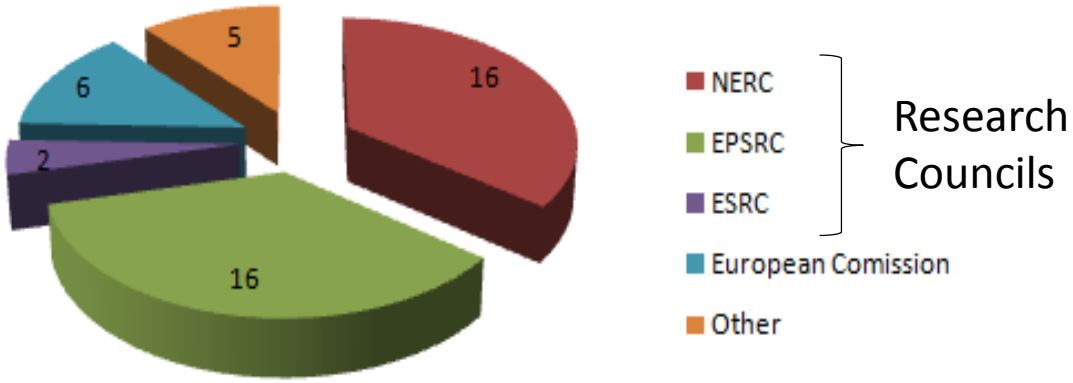

Flood and Coastal Erosion Risk Management R&D Programme

Department for Environment Food & Rural Affairs; Llywodraeth Cymru Welsh Government; Cyfoeth Naturiol Cymru Natural Resources Wales; Environment Agency

Joint Programme is involved in 45 partnerships totalling £32.4m (or which it funds £421k) £ = *Whole life cost of research*

2016/17 Joint programme budget is £1.15m

2017/18 not agreed yet




Joint Programme: http://evidence.environment-agency.gov.uk/FCERM/en/Default/FCRM.aspx
Newsletter. Subscribe here: http://evidence.environment-agency.gov.uk/FCERM/en/Default/FCRM.aspx
Programme definition document: http://evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Documents/PDD_June_2015.sflb.ashx

Standing Committee on Structural Safety

Reservoirs Committee

Welsh Assembly Government

Defra

Specialist Advisor (3yr appointment)

Scottish Environmental Protection Agency

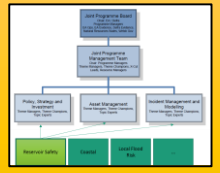
Northern Ireland Environment Agency

Institute of Civil Engineers

Natural Resources Wales

Environment Agency

British Dam Society
*Is 'UKCOLD'*



Joint R&D Programme
RESERVOIR SAFETY ADVISORY GROUP

R&D Projects

EA Reservoir Safety Team

Reservoir Managers Group

Hydro (International, Europe & Asia)

European ICOLD (EURCOLD)

EU & EC R&D Calls e.g. Horizon 2020

Academia
Universities
*Research Councils – EPSRC, NERC, ESRC Studentships*

ICOLD
International Commission of Large Dams
*Meets twice a year*

World Commission on Dams

*Rijkswaterstaat*

Consultants

CIRIA

Utilities
Water Companies
UKWIR …

African Regional Club (ARC)
Asia Pacific Group (APG)
Australian National Committee (ANCOLD)
South African National Committee (SANCOLD)
Etc…

CDA – Canadian Dam Association

*Centre for Energy Advancement through Technological Innovation,* CEATI

International Centre for Carbonate Reservoirs

British Geotechnical Association (BGA – ISSMFE & AJB)

ICOLD National Committee of the Americas (INCA)

- Federal Emergency Management Agency (US)
- USSD
- USBR United States Bureau of Reclamation
- Association of State Dam Safety Officials [USA] ASDSO
- USDA

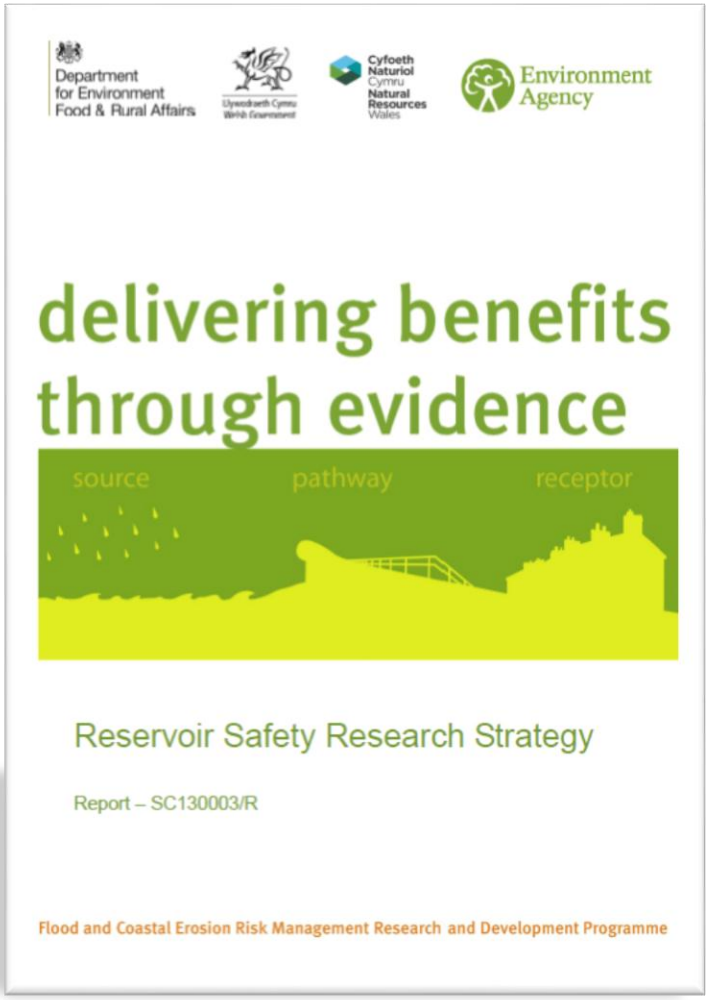
US Army Corp of Engineers
USACE (RMC & ERDC)

**Reservoir Safety R&D Connections**

# R&D Strategy

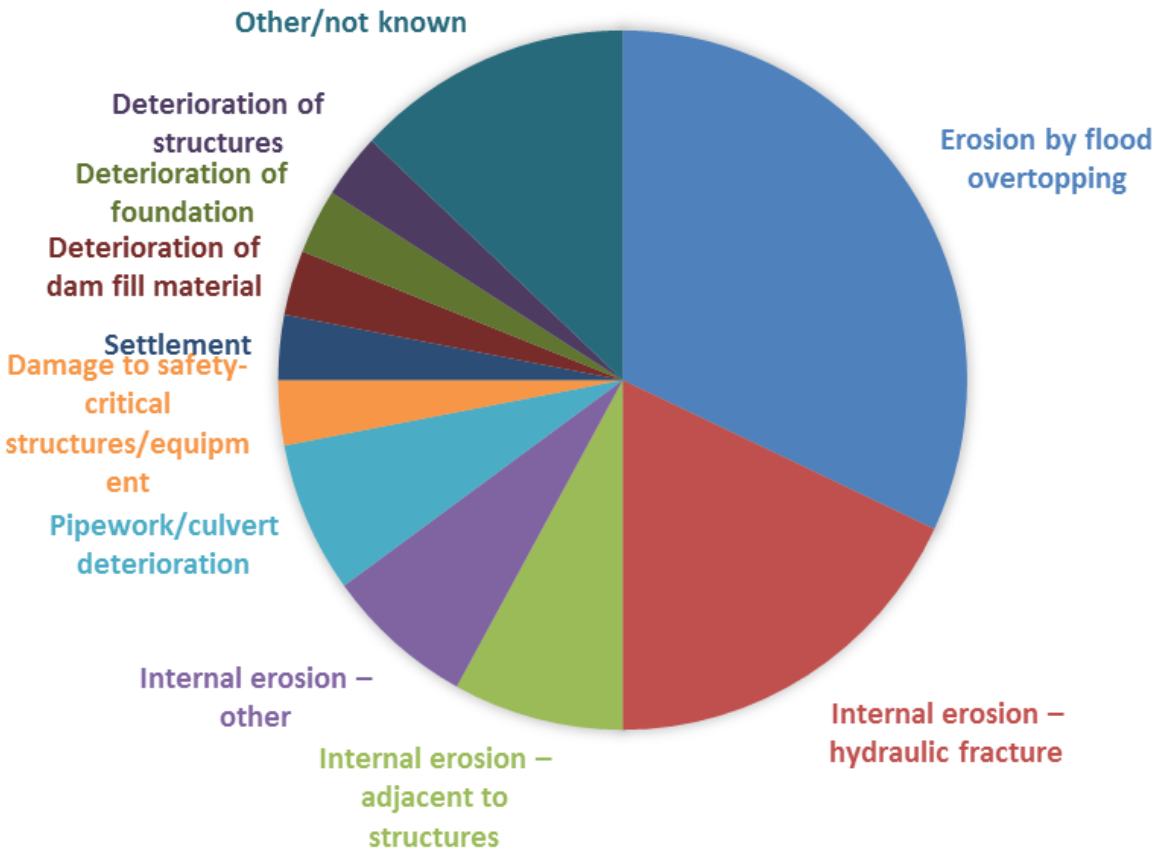


## Reservoir Safety Research Strategy, 2015




https://www.gov.uk/government/publications/reservoir-safety-research-strategy

# Breakdown of the 76 reservoir incidents (2004-13) by mechanism of deterioration




**Other notable causes of incidents include**:

- spillway damage during floods, causing erosion of the downstream shoulder (for example, Ulley and Boltby)
- rapid drawdown (for example, Sutton Bingham)
- leakage at dams where crest has been raised, during a flood or during sustained operation with an abnormally high water level
- poor surveillance effectiveness due to surface vegetation
- blockage of low level outlets (for example, Cwm Ebol)
- human error (for example, blocking spillways and incorrect operation of gates or valves)
- leakage due to unknown pipes/structures within or under the dam
- burrowing animals
- poor design

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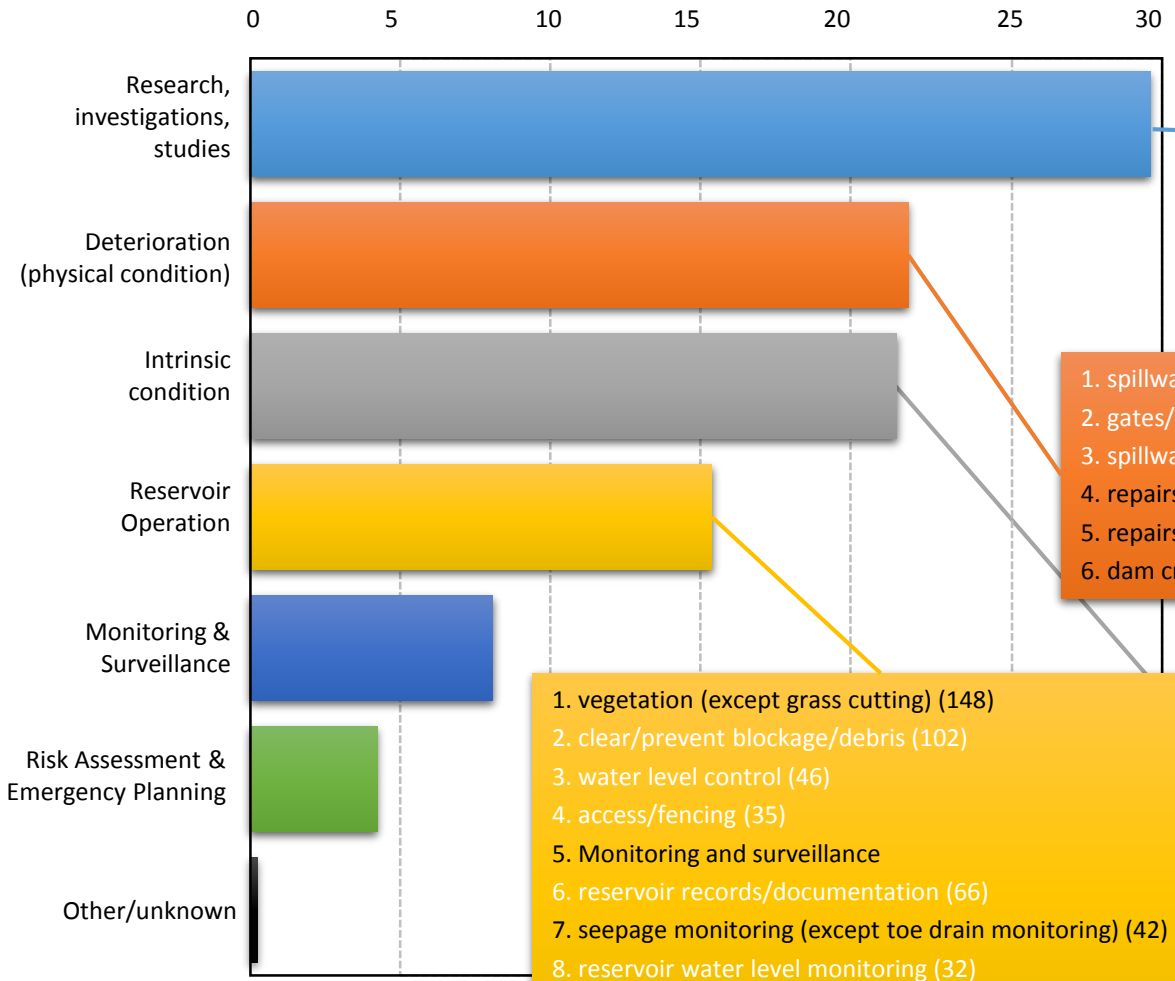
*The RSAG R&D Strategy (2015)*

# Breakdown of statutory reservoir safety measures by type (2004 – 2013)

*A total of **3155** recommendations made from **1104** reservoir safety inspection reports*




1. reservoir flood study (203)
2. hydraulic analysis/modelling (151)
3. topographic survey (123)
4. stability analysis (81),
5. seepage investigation (60)
6. condition survey – internal structures (57)
7. condition survey – CCTV (45)
8. material investigation of dam fill material (43)
9. condition survey – other (33)
10. condition survey – surface structures (32)

1. spillway – minor repairs (117)
2. gates/valves (100)
3. spillway – major repairs (72)
4. repairs to the dam upstream face (67)
5. repairs to the downstream face (except due to internal erosion) (49)
6. dam crest repair (except due to overtopping) (30)

1. spillway capacity improvement (213)
2. crest levelling (69)
3. crest raising (57)
4. erosion protection to the dam crest and/or downstream face (54)
5. drainage improvements (49)
6. other (46)
7. grouting/sealing (except of dam core) (37)

1. vegetation (except grass cutting) (148)
2. clear/prevent blockage/debris (102)
3. water level control (46)
4. access/fencing (35)
5. Monitoring and surveillance
6. reservoir records/documentation (66)
7. seepage monitoring (except toe drain monitoring) (42)
8. reservoir water level monitoring (32)
9. Risk assessment and emergency planning
10. emergency drawdown planning (53)
11. emergency action planning (50)

Environment Agency

**Source**: *EA Research, based on the number of reservoir safety inspection reports submitted to the Environment Agency or Natural Resources Wales for reservoirs in England and Wales between 2004 and 2013 have been reviewed to categorise the safety recommendations made by Inspecting Engineers under Section 10 of the Reservoirs Act 1975. Safety recommendations made under Section 10 of the Reservoirs Act 1975.*

# Flood defence infrastructure

**£2.3bn = investment in infrastructure 2015-21**

**£30bn = replacement cost of flood defence infrastructure**

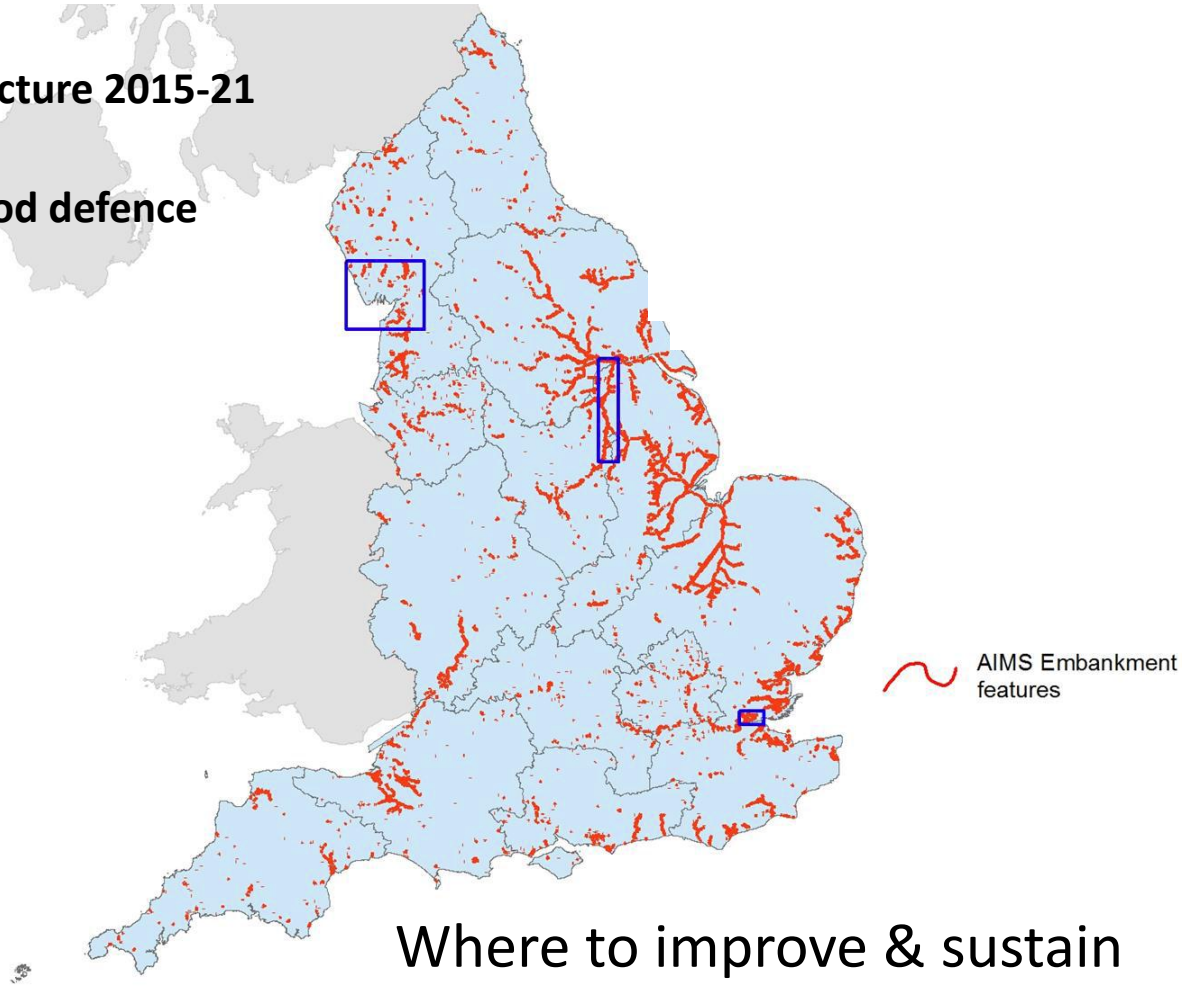
- 36,426 km main river

**Defences**

- 5890 km fluvial
- 1537 km tidal
- 1013 km coastal

**Structures**

- 19430 fluvial
- 1778 tidal
- 1193 coastal




Where to improve & sustain defences? Risk-based optimisation

# Asset Performance Review

*Technical Analysis 2015/16*


| Location | Asset Type | CG | Water level vs crest | Failure mechanism | Description |
|---|---|---|---|---|---|
| Corbridge - Dilston Haughs | Narrow Bank | 3 | +0.2-0.4m | Overtopping > partial breach | Overtopping at transition, landward face scour |
| Corbridge - Wide Haugh Site | Narrow Bank | 3 | -0.3m | Breach, below crest level | vermin, scour, poor material |
| | | | | | Landward scour |
| | | | | | Landward scour |
| | | | | crest | Internal erosion – vermin |
| Slip | Ground | | | ilure | Potential toe scour > instability |
| Temple Hirst | Narrow Bank | 3/4 | 0m | Wave damage, potential instability | Wave damage at high-water line, potential instability of bank |
| Torcross Sea Wall | Sea Wall | 4 | - | Global Instability | Beach drawdown |
| Teignmouth Sea Wall | Sea Wall | 3 (4) | - | Undermining | Beach drawdown, washout of material |

*"Flood defence managers should focus more on identifying and resolving these local irregularities, such as transitions, historical channel crossings and local low spots."*

## Dominant Failure Mechanisms

- overly steep rear faces
- poor grass cover or damaged surface protection
- vermin infestation
- at transitions within an asset
- Heterogeneous foundations
- lack of formal design of historic assets

# Overflowing erosion of dams and dikes

## Current/completed R&D

RESERVOIR SAFETY ADVISORY GROUP

Flood and Coastal Erosion Risk Management R&D Programme

The British Dam Society | ice Institution of Civil Engineers | Department for Environment Food & Rural Affairs | Llywodraeth Cymru Welsh Government | Cyfoeth Naturiol Cymru Natural Resources Wales | Environment Agency

Wave overtopping of coastal defences - Design and assessment manual SC050059

→ Eurotop (inc. 2nd phase)

State of the Nation (overtopping) Environment Agency (2017)

Early detection of internal erosion - feasibility report Defra (2003)

Interim Guide to Quantitative Risk Assessment for UK reservoirs Defra (2006)

Vulnerability of UK dam embankments to increased direct rainfall on their surfaces Defra (2003)

International Levee Handbook

Identifying and managing risks arising from defence structure transitions FRS17181 ongoing (2018)

The Performance of Grass & soil in resisting erosion SC140006 ongoing (2018)

→ Geophysical methods for reservoir safety investigations EA/BDS Studentship 2017/18

Rock in river and coastal engineering - Update of CIRIA / CUR design manual SC030221

Scoping: Guide on Inspection, monitoring, maintenance and repair of tunnels SC080049 (2009)

→ Guidance on Reservoir Conduits incl. Tunnels, Culverts and Pipes. SC110006 (2015)

→ Risk Assessment for Reservoirs SC090001 (2013)

Review of modes of failure of Dams & monitoring and measuring methods for embankment dams SC080048 (2011)

Assessment and measurement of asset (flood defence) deterioration SC060078

→ Geotechnical - Fragility concepts for embankments SC050049 FDA(05)05

→ Establishing a Performance-based Asset Management System for Flood Defences SC040018

→ Asset Performance Tools SC140005 ongoing (2018)

Joint Programme:
http://evidence.environment-agency.gov.uk/FCERM/en/Default/FCRM.aspx

- Significant link with RSAG/Joint R&D Prog.
- In touch with, but not leading
- No fill = completed

# Performance of grass and soil in resisting erosion

Project Manager: Andy Tan, Environment Agency
Steering Group Members include Mark Morris & Alan Brown

## Phase 1

*Underway, completes early 2018*

(i) Review grass performance in relation to existing international guidance; confirm gaps in knowledge and approach.

(ii) Scope a programme of basic and applied testing to provide data that will allow updating and expansion of grass performance curves

(i) Provide a summary of the current state of understanding of soil erodibility (surface soil not core) and scope available data that might be available to support guidance

## Phase 2

2018+

(i) Implement the programme of testing for grass performance and use data to update guidance

(ii) Establish an open access database for the collation of soil parameters which support estimation of soil erodibility

(iii) Explore how new models and data on soil erodibility and grass performance can be used to improve risk analysis, via the construction of appropriate limit state equations and subsequent reliability analysis.

(iv) Provide updated guidance and an online tool that uses the updated performance data to allow users to develop acceptable grass cover designs or assess existing structure performance.

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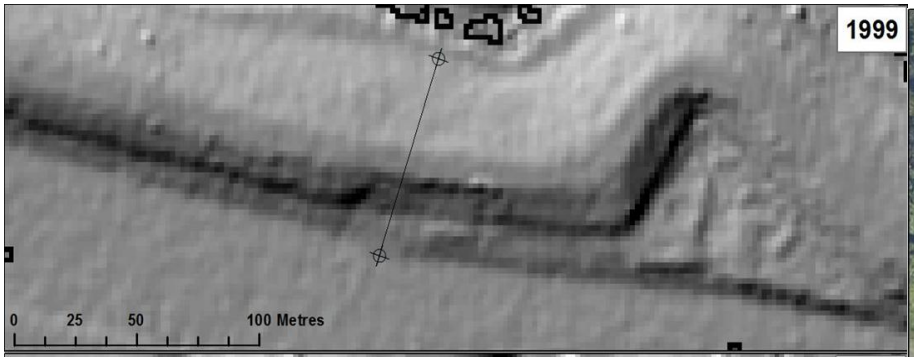
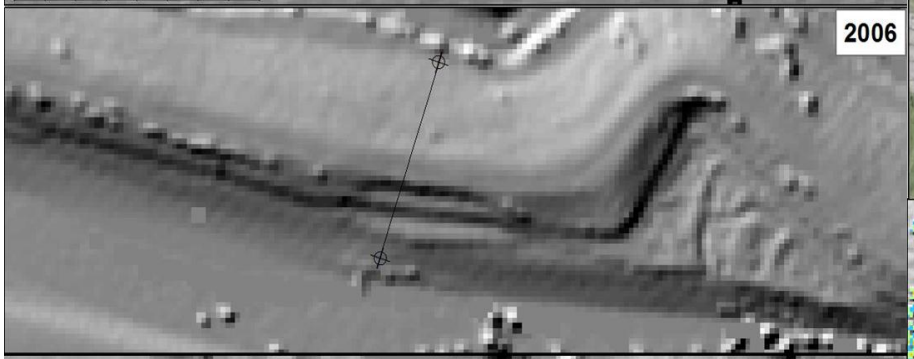
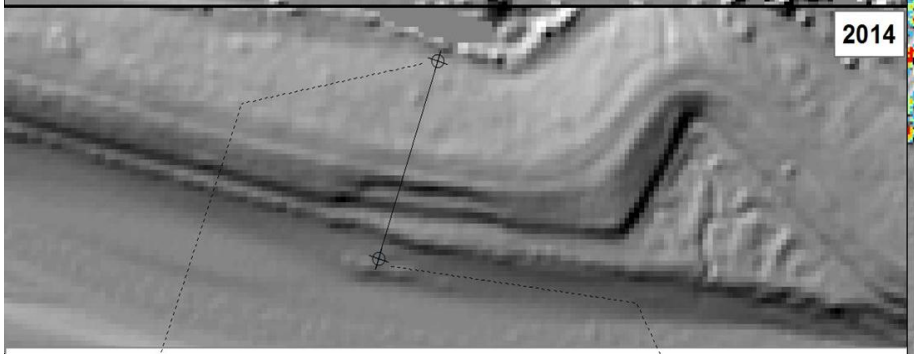
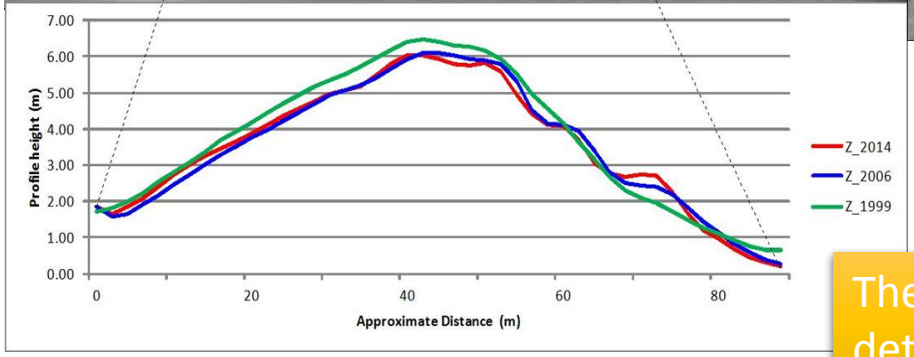
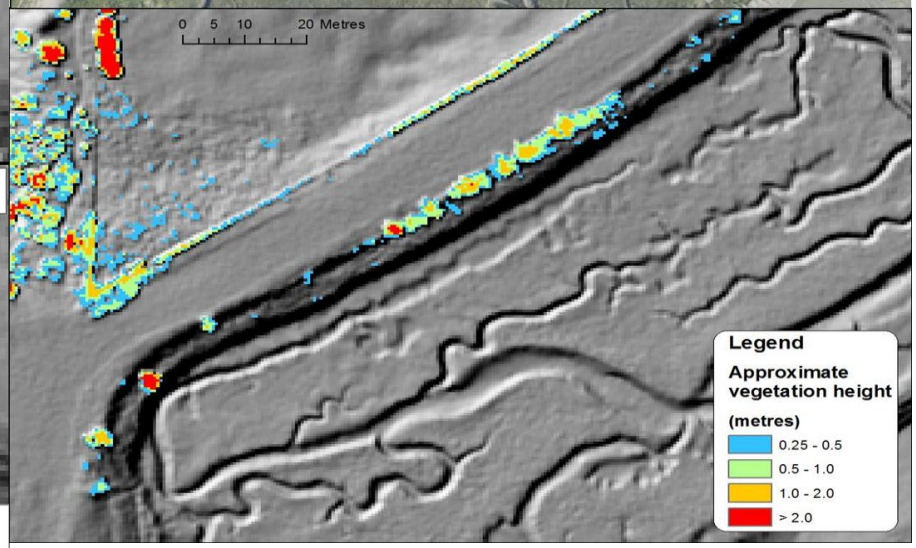


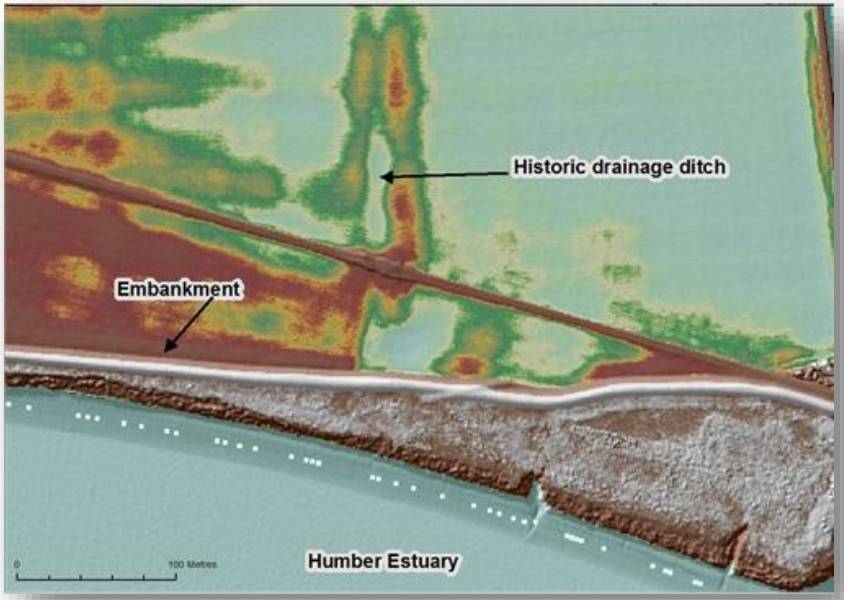



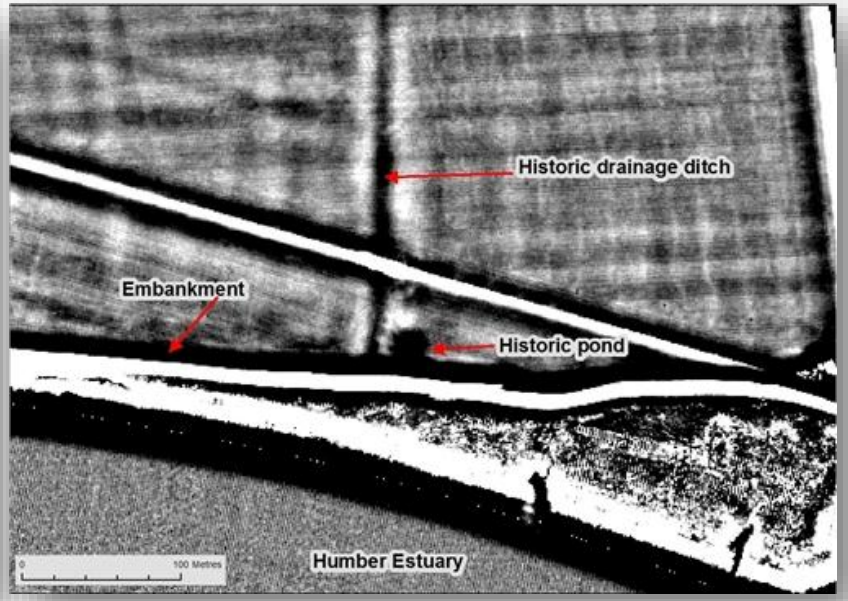




# Environment Agency LIDAR

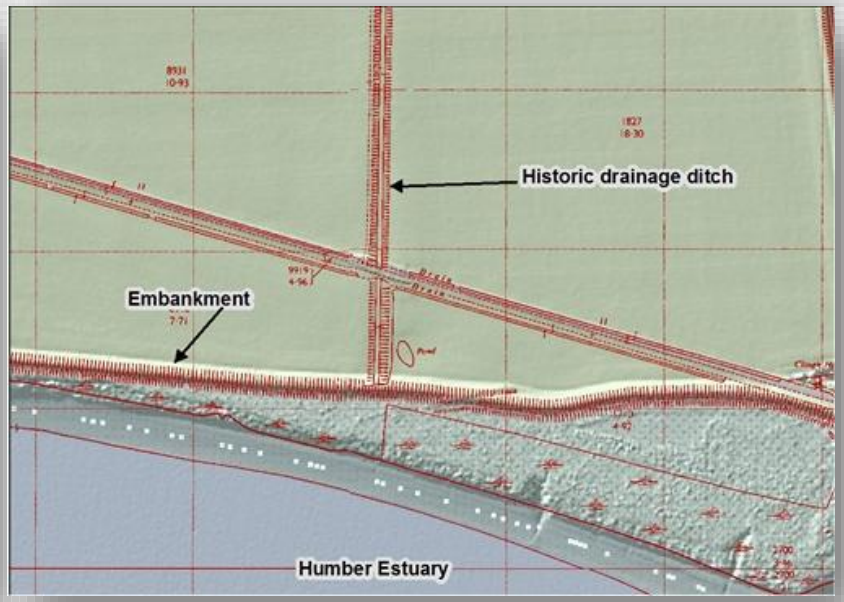
## Change detection

The potential for exploring time dependant deterioration processes is yet to be fully explored





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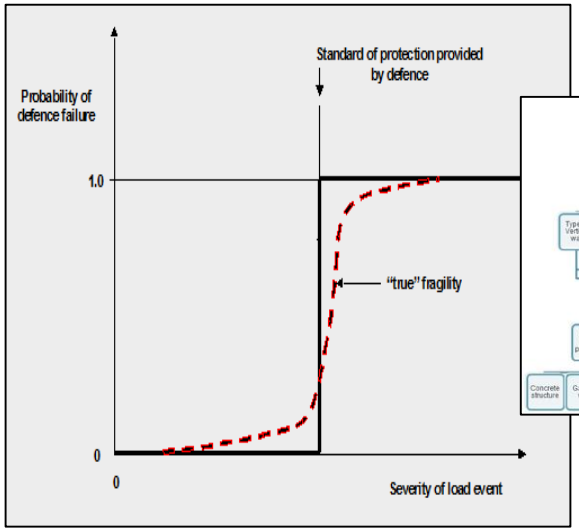
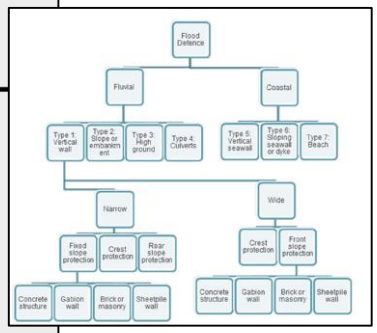
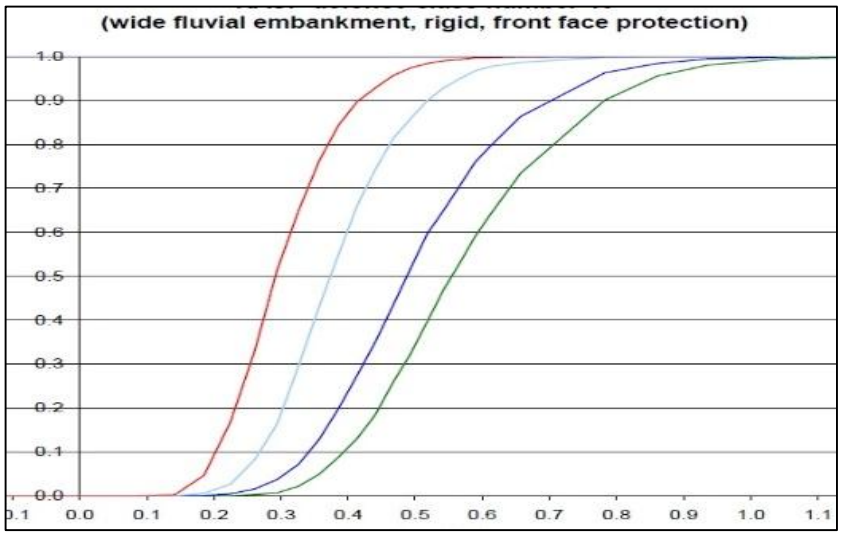
# UK fragility curves - help prioritise investment (national and local level)



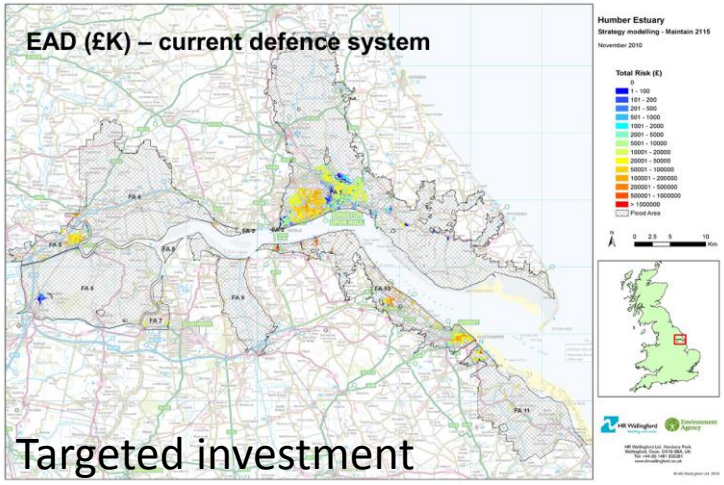

National set of generic curves - applicable to >85% of UK assets (approximation)




61 generic Fragility curves, routinely improved to reflect real performance




R&D periodically improves the condition grading info.




Targeted investment


More detailed customed methods available for complex and high risk assets

The concept of fragility only provides snapshot in time. This becomes a critical limitation when failure processes are governed by time-dependant deterioration

Updates to Calculations in 2017 include:

- Overtopping and rear face erosion
- Soil Types
- Piping

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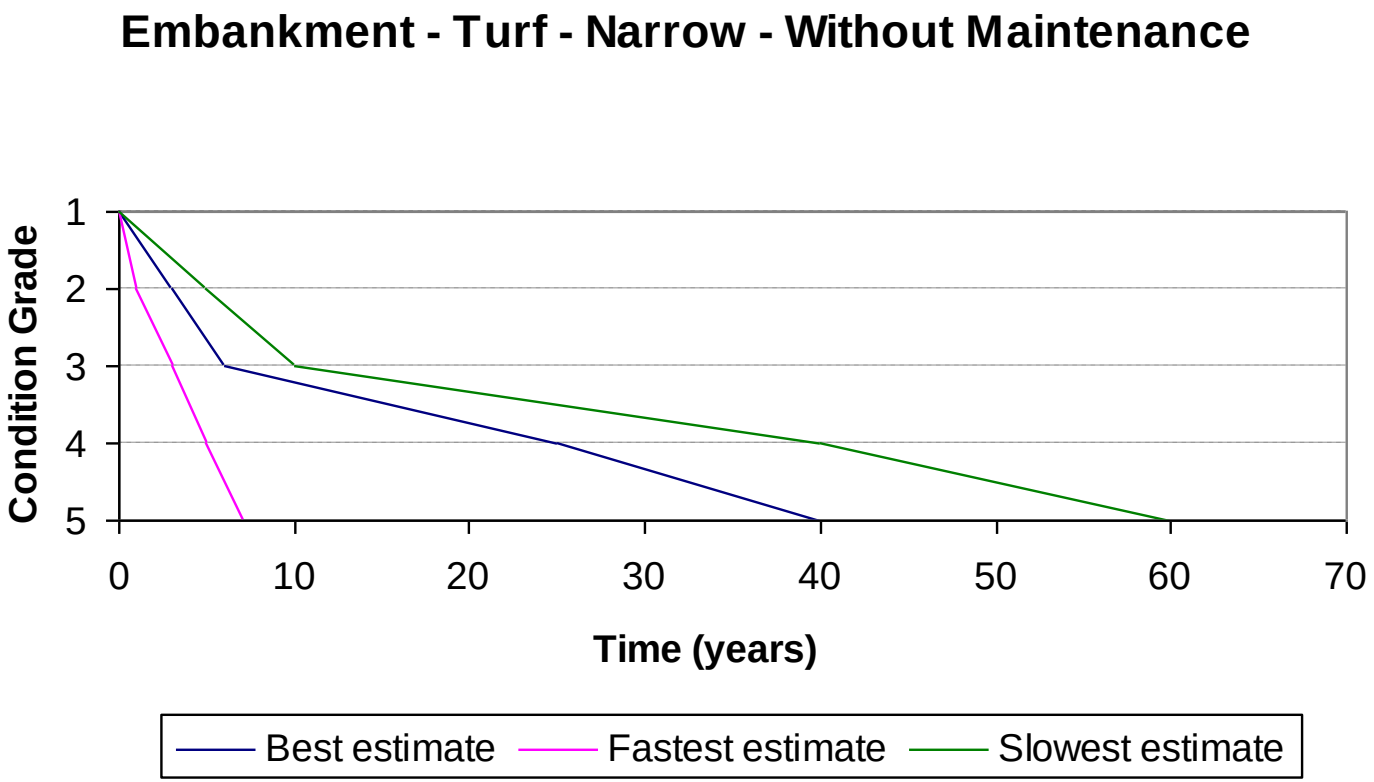
# Deterioration rates




Nationally applicable deterioration curves are suitable for estimation of future asset condition and expected residual asset life, taking into account characteristics related to environment, asset age, material type and construction, and past and intended (future) maintenance practices

Environment Agency

# International research partnerships

| RWS | EA | USACE |
|---|---|---|
| Piping | | Piping |
| Overtopping | Overtopping | Overtopping |
| Stability | | Transient seepage |
| Anomalous conditions | Irregularities | Site Characterization |
| Heterogeneity | Heterogeneity | |
| Transitions | Transitions | |
| | Remote sensing/inspection and monitoring | Remote sensing/inspection and monitoring |

Environment Agency

# Likely research in 2018

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## Managing reservoir leakage and seepage


- Improving Identification, review, surveillance and monitoring.
- Including biological factors, drainage, case histories & new technologies
- Impounding reservoir research (where loading increases in an event) beneficial to wider flood levee management including flood storage embankments.
- Potential to make schemes viable, that might not be currently considered.

## Dam & Levee Breach Scoping

- To review and agree a future framework of priorities
- Dam break, geotechnics, vegetation cover, Soil, processes, internal erosion, model comparisons …

## Benefits of repurposing reservoirs

- Costs associated with upkeep and legislative review requirements mean owners may look to decrease numbers of reservoirs
- Providing evidence to support the value of the asset and help to support/entice owners to 'do the best for the environment'
- Potential environmental and diversity benefits to be understood (as well as engineering) so that principles can easily be applied.

CEATI INTERNATIONAL

Trees and Vegetation

# ‘Wish List’

RESERVOIR SAFETY ADVISORY GROUP

Flood and Coastal Erosion Risk Management R&D Programme

The British Dam Society | ice Institution of Civil Engineers | Department for Environment Food & Rural Affairs | Llywodraeth Cymru Welsh Government | Cyfoeth Naturiol Cymru Natural Resources Wales | Environment Agency

## Cost effective sustainable management & maintenance

- Minimise risk of catastrophic breach / risk to life – improving guidance/assessment techniques
  - remove inconsistencies (e.g. in parameters used by different professions)
  - understand ALL the processes and assumptions that lead to breach
    - vulnerability – due to original design or an aging problem?
    - Interconnections and dependencies clearly understood?
    - Improved deterioration rate understanding (vegetation/animals/dessication etc.)
    - A focus on irregularities – *e.g. transitions (underway) & paleochannel intersections*

- Minimise cost in maintenance, maintaining effectiveness
  - Serviceability v limit state
  - Standards based v Risk based *(Risk based approach is working with Levees)*
  - Futureproofing (whole life cost, optioneering perspective?)

**Consider a shared data platform?**

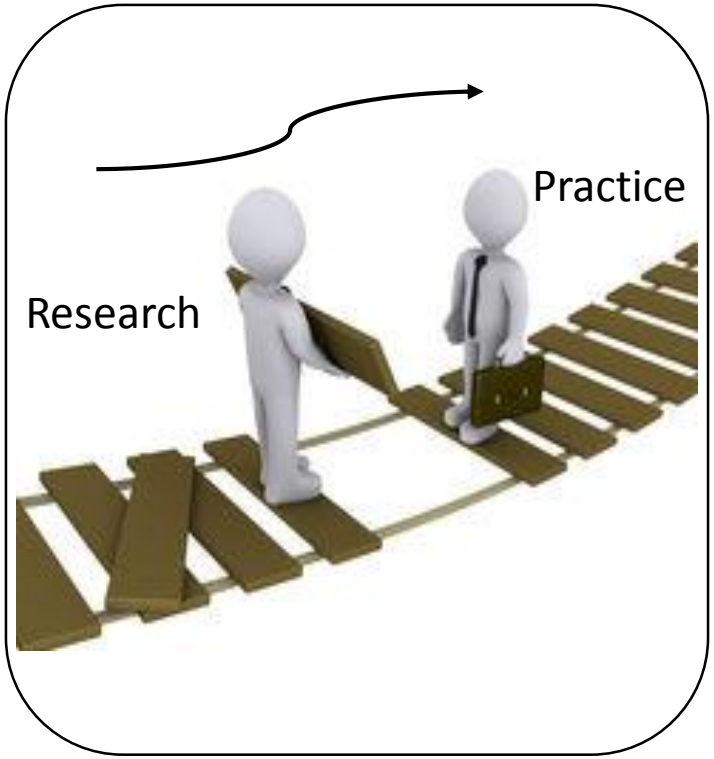
A collaborative home for accessible data / experience

**British Dam Society Conference 2018**
Will host the next Reservoir Safety R&D Workshop to consult with industry/academia


Christabel.Mitchell@environment-agency.gov.uk

# Considerations when proposing research

- Who's involved and how the governance will work
- Timescales and any known dependencies
- Level of Support/partnership requirement – time, cost, data etc.
- Description
- Key deliverables
- What's the value in doing this? How this meets priorities
- Who are the likely end users of this research and how is it intended to be used?
- Is it possible to translate the outputs of the research into application – how?
- Dissemination & additional Training expectations
- Communication & Engagement – roles of different parties involved
- What does success look like?




http://evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Documents/01_Research_Partnership_Form_v5_1.sflb.ashx