An Overview of Levees and Reservoirs in England

Dr Chrissy Mitchell[1], Owen Tarrant[1] and Tony Deakin[1]

[1] *Environment Agency*

Abstract

The Environment Agency regulates 2039 reservoirs in England under the Reservoirs Act, 1975, which includes all bodies of water over 25,000m3 above ground level. With 759 different owners for these reservoirs, there is considerable diversity in the way they are managed. Water companies own the majority (~one third), closley followed by private landowners and farms. It is an aging portfolio, with the average age being 125 years old and the oldest being 800 years old. Of the ~5million properties at risk of flooding, 1million are identified as at risk from flooding from a reservoir (www.gov.uk/check-flood-risk). This is a conservative estimate due to the calculations being based on the unlikely scenario of a complete failure of a reservoir. In the future the flood maps will categorise reservoir flooding into categories of risk (high, medium and low), providing managers and emergency responders with a more informative understanding of potential impact to support such decisions as evacuation.

In regards to linear raised flood defences there is an estimated 9000km in England (EA National Strategy, 2011) which mainly consist of soil embankments (levees), but also include linear defences such as flood walls. These defences protect properties from fluvial and coastal flooding, where 2.4million properties are at risk (www.gov.uk/check-flood-risk). These defences, alongside their point structure assets such as flood gates have recently been collated into one national database of information called AIMS – the 'Asset Information Management System'.

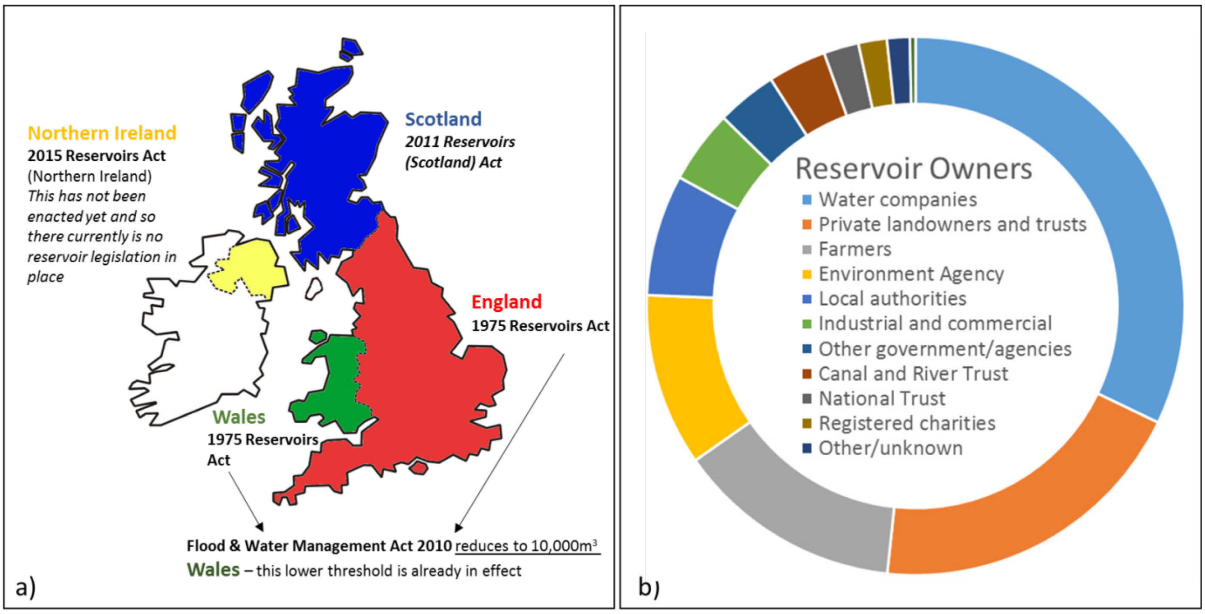
There has been considerable research and development considering overflow in the past decade, enabling the use of fragility based tools for national investment planning and specific modelling tools for overtopping. Consideration of surface protection has recently been reviewed and future research in grass/surface protections and soil is under consideration. Closley connected to this research we have also been considering transitions, animal disturbance, design (steep faces) and the connected failure mechanisms leading to breach.

1 Characteristics of levees and reservoirs in England

The Environment Agency regulates 2039 reservoirs in England (2017), which comprises all bodies of water over 25,000m^3 (10 x Olympic swimming pools) as per the Reservoirs Act, 1975 (Fig.1). There is a considerable diversity in ownership of these reservoirs with 759 different owners. The water companies own the majority, closely followed by private landowners and farms. It is an ageing portfolio of reservoirs, with an average age of 125 years old and the oldest being 800 years old. The largest reservoir by volume is ~200Mm^3 (80,000 x Olympic swimming pools). The International Commission of Large Dams (ICOLD) defines small dams as less than 15m, which applies to around 80% of the dams in England.

The last loss of life due to failure of a dam in England was in 1925, with the average number of incidents (since 2004) being 8 per year. Of the ~5 million properties at risk of flooding (www.gov.uk/check-flood-risk) in England, 1 million are identified as at risk from flooding from a reservoir. This is a conservative estimate due to the calculations being based on the unlikely complete failure of a dam. In the future the flood maps will categorise reservoir flooding into high and low risk, providing managers and emergency responders with a more informative understanding of potential impact to support such decisions as evacuation.

Figure 1 a) Legislative Acts of the UK regulating floods and reservoirs. b) Reservoir Owners in England



In regards to linear raised flood defences, there are an estimated 9000km in England, which mainly consist of embankments (levees), but also include linear defences such as flood walls, mainly in the higher populated areas. These defences protect properties from fluvial and coastal flooding, where 2.4million properties are at risk (www.gov.uk/check-flood-risk). These defences, alongside their point structure assets such as flood gates, have recently been collated into one national database of information called AIMS – the 'Asset Information Management System'.

There continues to be ongoing incidents relating to the overflow of levees and reservoir dams, with examples provided in Figure 2. Incidents of premature failure include some of the levee local irregularities of the Summer 2007 floods (Fig.2c) and the masonry spillway at Ulley Reservoir (Fig.2a). When considering levees (Fig.2b-e) the conditions at the time of failure were often above the design standard and the majority caused by local irregularities or transition/low spots. A review of reservoir incidents highlighted that erosion by flood overtopping was the main mechanism of deterioration (Fig.3)(Environment Agency, 2013).

Figure 2 Recent dam and levee incidents (adapted from Simm, 2017)

a) Ulley Reservoir, 2007. Built: 1875 Capacity: 580,000m³ Height: 14m
Construction: Earthfill (Puddle Clay).
Incident: Spillway overflow and erosion

b) Blacktoft, 2013 – Humber Estuary partial breach

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

c) Summer floods 2007 - 1000km levees tested, 500km overtopped. 4 breached - overtopped: geotechnical, caused by local irregularities
Challenge to predict breach based on visual condition Focus more on local irregularities, transitions

d) Winter floods 2013/14 – 83 structural failures. Majority due to coastal overtopping in 'above design' event. 'Historic' non-formally designed levees, transitions.
Improving inspections: trigger expert involvement; Non-visual aspects; focus on transitions, irregularities, historic changes
Dealing with low spots

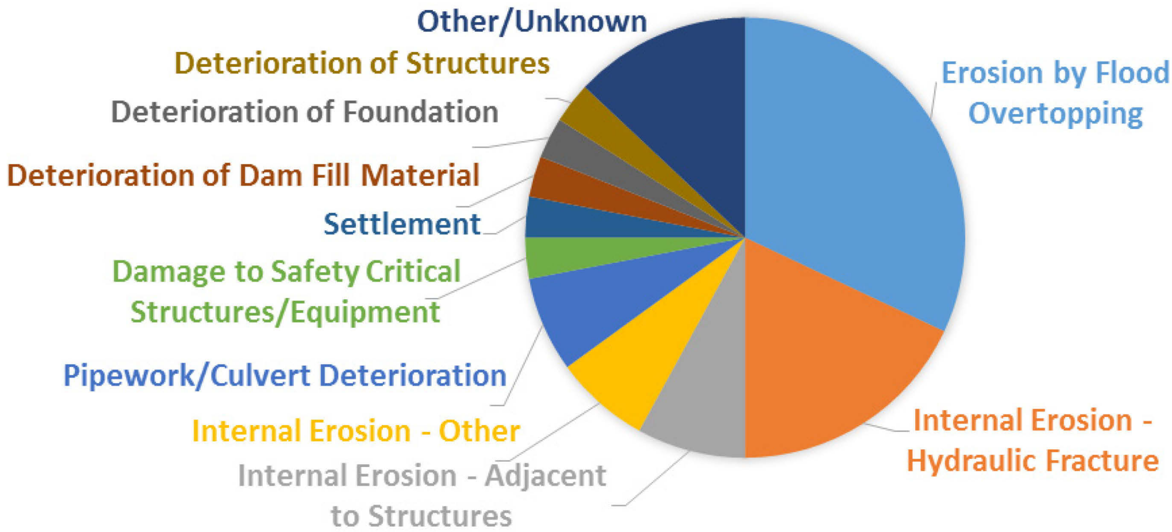
e) Winter floods 2015/16 - 6 fluvial levee breaches: 3 overtopped, 3 geotechnical. Steep slopes, local irregularities, 'historic' levees. Low consequence levees with reduced maintenance

Careful with 'historic', steep-sloped but low consequence levees

f) Cumbria 2009 - One full breach despite widespread overtopping

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

Figure 3 Breakdown of the 76 reservoir incidents (2004-13) by mechanism of deterioration (Environment Agency, 2013)



2 Current practice in managing overflow erosion and breach of levee embankments

Flood embankments are categorised using a risk based approach by the Environment Agency. They are categorised by their potential consequence (or impact of flooding) and the high consequence defences are visually inspected by accredited Environment Agency staff every 6 months while the low consequence assets may be visited once every 2-5years. On inspection they are categorised into five condition grades ranging from 1(excellent – cosmetic defects and no effect on performance) to 5(very poor – severe defects resulting in complete performance failure). The result triggers further inspection and assessment where appropriate (www.gov.uk/government/publications/flood-risk-asset-inspection-research-to-improve-interventions). When considering future flood investment programmes in defences the Environment Agency considers the fragility of flood embankments (alongside 61 other flood defence types, each represented by a generic fragility curve (Fig.4)(Simm & Tarrant, 2017). These generic curves apply to approximately 85% of UK assets. More detailed customised methods are available for complex or high risk assets. This concept of fragility provides a snapshot in time which although valuable for planning has a limitation if considering failure over a time period.

Simm *et al.,* 2017, recently reviewed the performance of levees in five major flood events in England during the period from 2007 to 2016. The review showed that English levees rarely breach, concluding that if the levees do breach, this usually happens for levees categorised as of low consequence and as a result significant flood damage is avoided. However, it is recognised as important to learn from these failures to improve supporting guidance and help refine management approaches. Simm*,* 2017 highlights the dominant failure mechanism as overflow and rear face erosion, impacted further by local irregularities. The key areas of concern being;

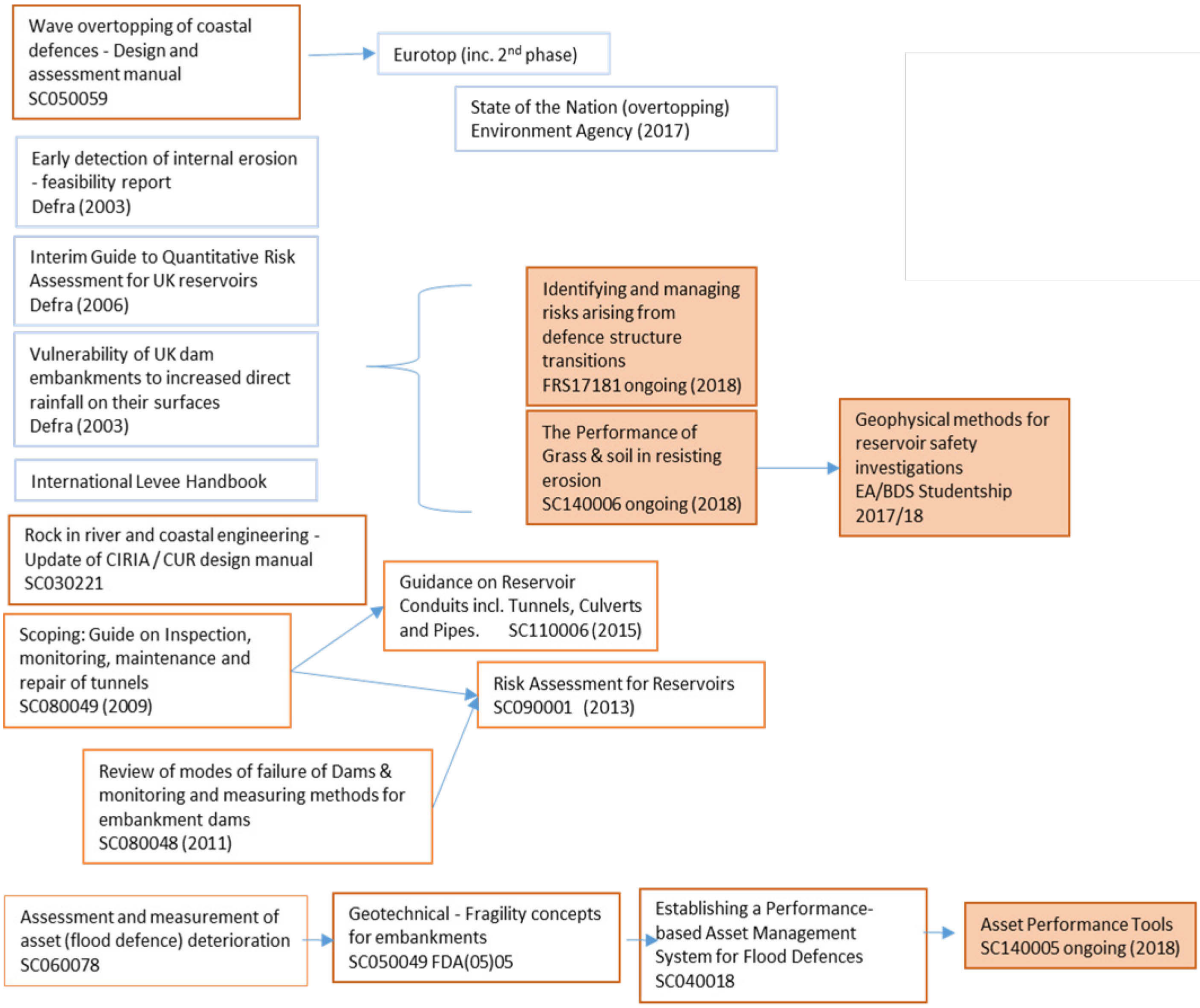
- overly steep rear faces
- poor grass cover or damaged surface protection
- vermin infestation
- at transitions within an asset
- heterogeneous foundations
- lack of formal design of historic assets
- historical channel crossings (palaeochannel irregularities)
- local low spots

3 Research developments

Welsh Government, Natural Resource Wales, Defra and the Environment Agency carry out research on reservoir and asset management levees together under the Joint R&D Flood and Coastal Erosion Risk Management Programme (www.evidence.environment-agency.gov.uk/FCERM/en/Default/FCRM.aspx). The Reservoir Safety Advisory Group (RSAG) supports this programme, led by Defra and the ICE British Dam Society.

There are a wide range of issues relating to the vulnerability of embankments to damage and failure under overflow (Mitchell *et al.*, In Press). These relate to safety (likelihood of breach) and the surveillance needed to assure this as well as decisions as to best use of available investment funds, whether in maintenance or in upgrading in spillways. A recent scoping project reviewed research needs into the resistance of grass cover to overflow erosion (www.evidence.environment-agency.gov.uk/FCERM/en/Default/FCRM .aspx). This project was limited to identification of the onset of damage rather than the probability of failure. There is intention to update the CIRIA guide 116 on the 'Design of Reinforced Grass Waterways' (CIRIA, 2003) (www.ciria.org/ItemDetail?iProductCode=R116D&Category=DOWNLOAD&WebsiteKey=3f18c87a-d62b-4eca-8ef4-9b09309c1c91) to assess allowable velocities over grass or surface cover protection under overflow conditions. A scoping study of breach research requirements completed in Spring 2018, helping to inform the future direction in this field by taking into account all of the international (Table 2) and UK based developments (Fig 7).

Fig 7 Research completed (clear box) or underway (coloured) in connection with the Reservoir Safety Advisory Group (RSAG) and the Joint R&D Flood and Coastal Erosion Risk Management Programme (www.evidence.environment-agency.gov.uk/FCERM/en/Default/FCRM.aspx)



The EURCOLD Overflow workshop held in the French Alps in December 2017 (Roberts J, In press) confirmed that there is still a need for research into fundamental processes governing the onset and rate of erosion under overflow. An overview of the target outcomes that would be desirable for reservoir dams provided in Table 1.

Table 1 Overview of target outcomes from research into overflow erosion

	Definitions	Key features to be included in research
Risk based	Probability x consequence	Models of soil/ grass erosion, and failure mechanism - ductile or brittle? and thus options to inhibit Agree definition(s) of damage Tools to quantify annual chance of failure (release of retained water)
Time to failure? (Tf)	Failure is catastrophic release of dam	Surface cover varies from woodland leaf litter to grass maintained by machine cutting/ sheep Soil varies sand to heavy clay Some dams zoned (granular shoulders with clay core) Surface geometry of dams very variable, for example crest can be wide (>5 times height) and "surface cover" often includes tarmac/ gravel crest road Slope varies angle of repose (1.5H:1V) to 6H:1V Define parameters defining Tf e.g. Both Hydraulic-(volume and peak overtopping flow), and geotechnical parameters
Grass reinforced spillways		Update CIRIA 116 to include failure, how convert real hydrograph to constant equivalent flow? How long would a clay "underlayer" delay failure? Innovative grass reinforcement techniques
Maintenance		Best practice. Frozen ground, desiccation cracks, climate change etc

It is anticipated that practical outcomes from this research in the UK may include

- Improved quantification of the likelihood of failure of small dams with scour resistant cover layers (e.g. tarmac road), which may mean that many could be classified as 'not high risk' instead of 'high risk'
- Improved understanding of works which improve resilience to overflow breach, for example the importance of spreading out flow uniformly along the crest of dams, which could be a viable alternative to large new concrete spillways
- Improved methods of assessing vulnerability of spillways located on abutments to erosion of the underlying soil/ rock
- Improved understanding of vulnerability of levees to overflow erosion, including separating out those which would fail rapidly (silt construction) from those built of clay which would take much longer for failure to progress to breach

4 Summary

The UK has mature asset management systems, but these still require adjustments to reduce the risk of damage occurring. Continuing incidents related to the structural integrity under overflow confirms the need for further research and development to better understand the risks associated with overflow of levees and reservoir dams, both in terms of the likelihood of failure (breach), and the consequence of failure

References

CIRIA (2013) The International Levee Handbook. CIRIA report C731. London: CIRIA

Environment Agency (2013) Learning from experience: post incident reporting for UK dams. Bristol: Environment Agency

Environment Agency (2016) Reservoir Safety Research Strategy – Report SC130003. Flood and Coastal Erosion Risk Management Research and Development Programme: Environment Agency

Institution Of Civil Engineers (1996) Floods and Reservoir Safety: An Engineering Guide

Mitchell C & Brown AJ (in press) Report on EURCOLD Workshop on overflow of dams and levees Aussois. Dams and Reservoirs

Mitchell C, Brown AJ & Morris M (in press) Overflow erosion of levees and dams – current practice and research needs. Dams and Reservoirs.

Morris M (in press) Overtopping erosion of course materials embankment dams, a literature review. EURCOLD

Morris M & West M (in press) A Guide to Breach Prediction. Dams & Reservoirs

Roberts J (in press) International Workshop on Overflowing erosion of dams and dikes.EURCOLD

Simm J. (2017) Levees in England. ICOLD

Simm J & Tarrant O (2017) Development of Fragility Curves to Describe the Performance of UK Levee Systems. ICOLD

Tarrant, O and Cambridge, C (in press 2017) Enhancing our flood defences condition assessment capability - Remote sensed data and products. Bristol, Environment Agency.