Stillwater Associates
Reservoir Safety & Water Consultancy

Overflow erosion of embankments
UK dam owner's perspective

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- *Steering Group – SCSC140006 – Scoping research into overflow*
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2. Features which may vary from Europe
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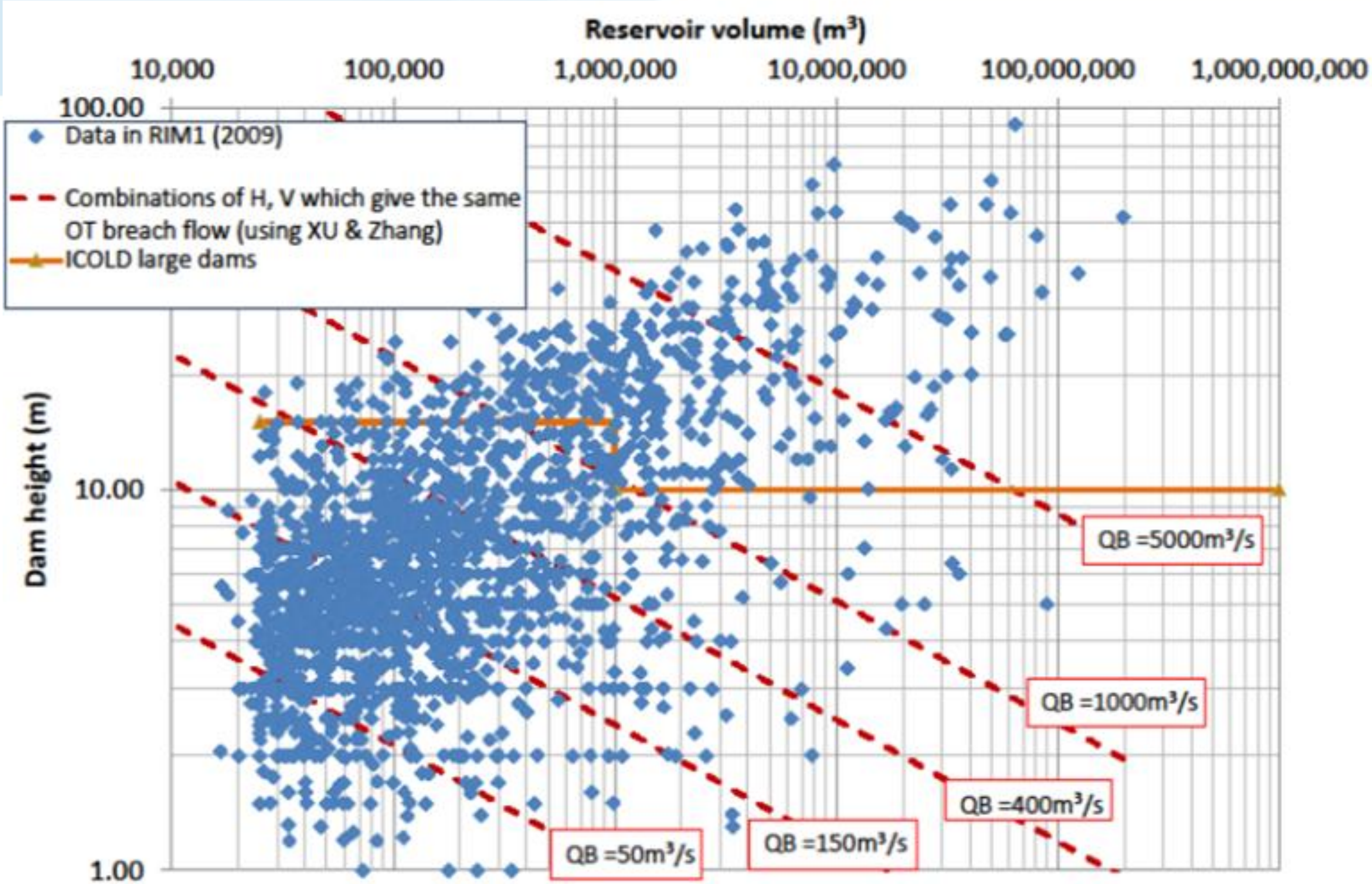
Types of reservoir owner in UK (reservoirs > 25,000m3)

Owner type	Number	%
Water company	644	36
Private landowner	241	13
Other Public utility	185	10
Environment agency (flood storage)	161	9
Agriculture (farms and fisheries)	145	8
Canals (British waterways)	71	4
Other/ unknown	352	20
Total	1799	

2007 EA Biennial report to Defra

Range of UK dam height / reservoir volume



2016 BDS Conf. Deakin et al

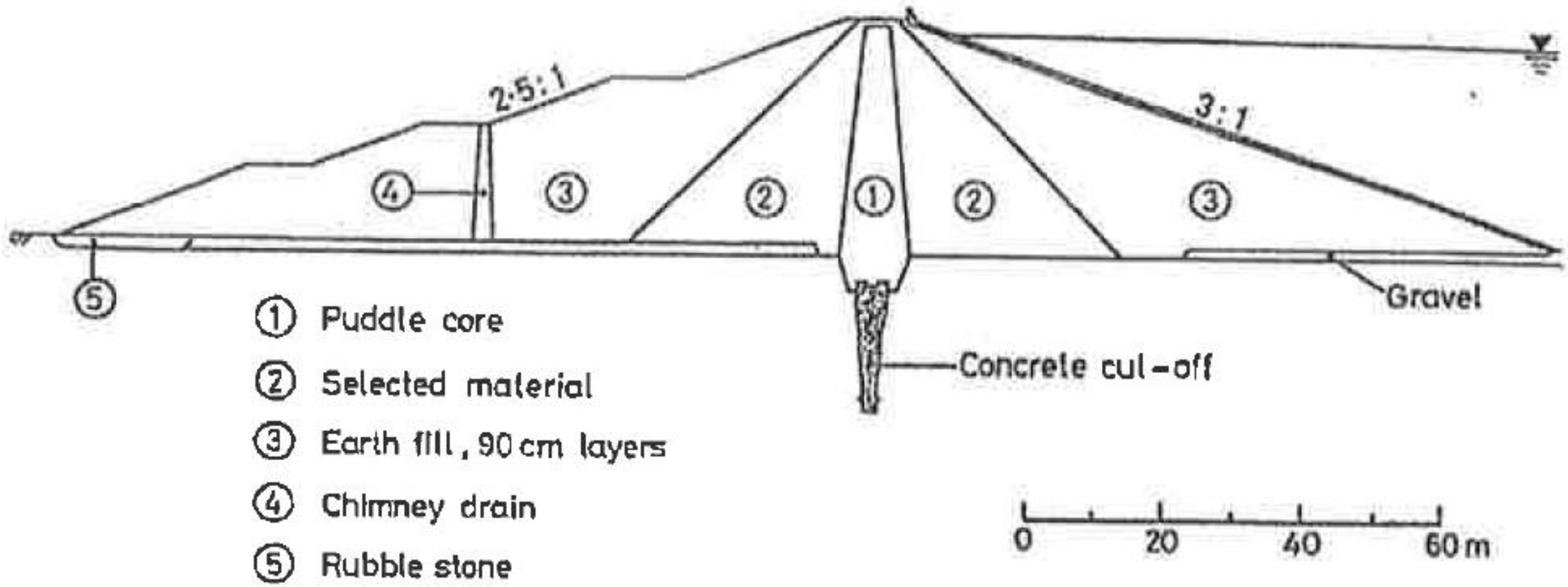
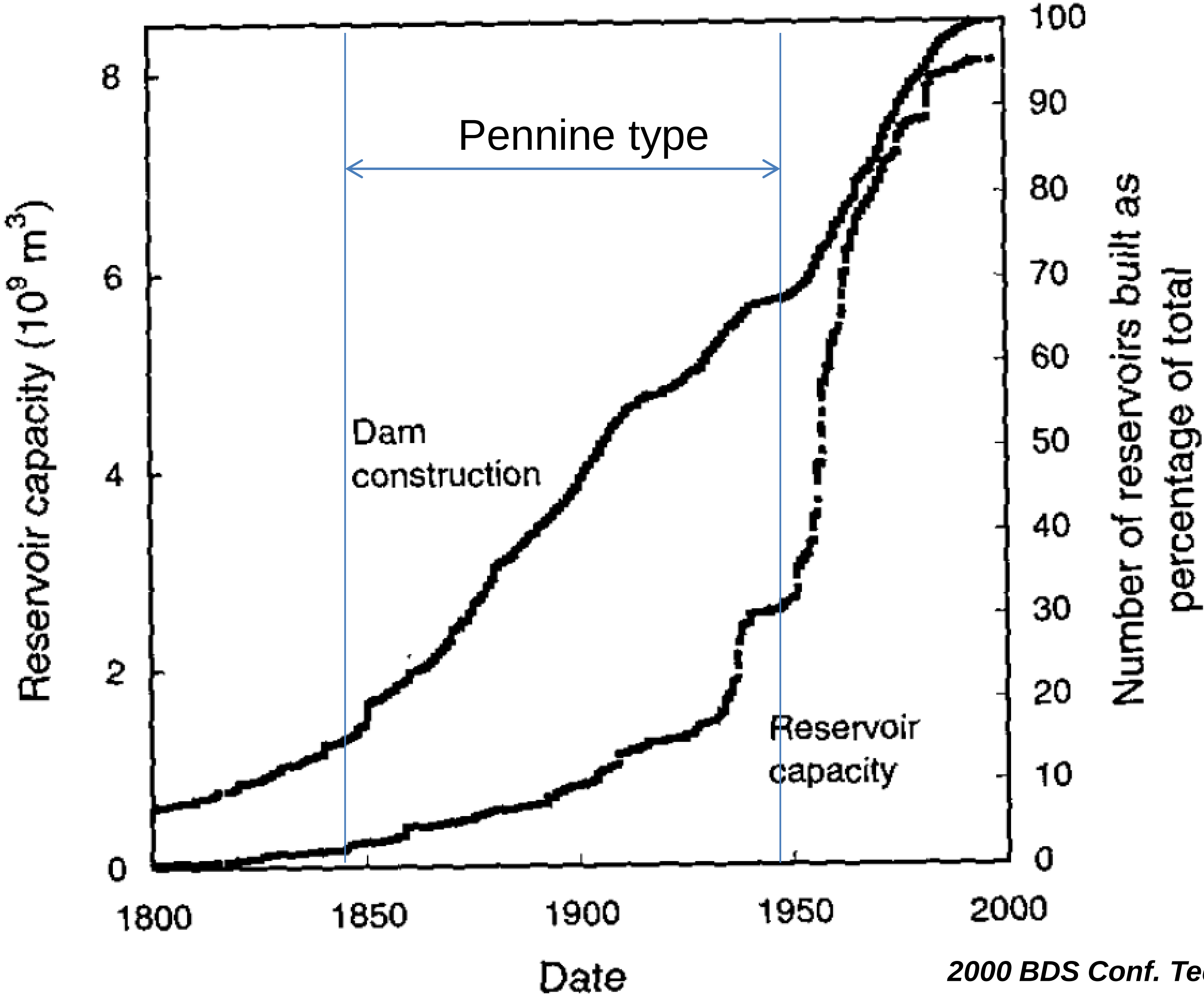


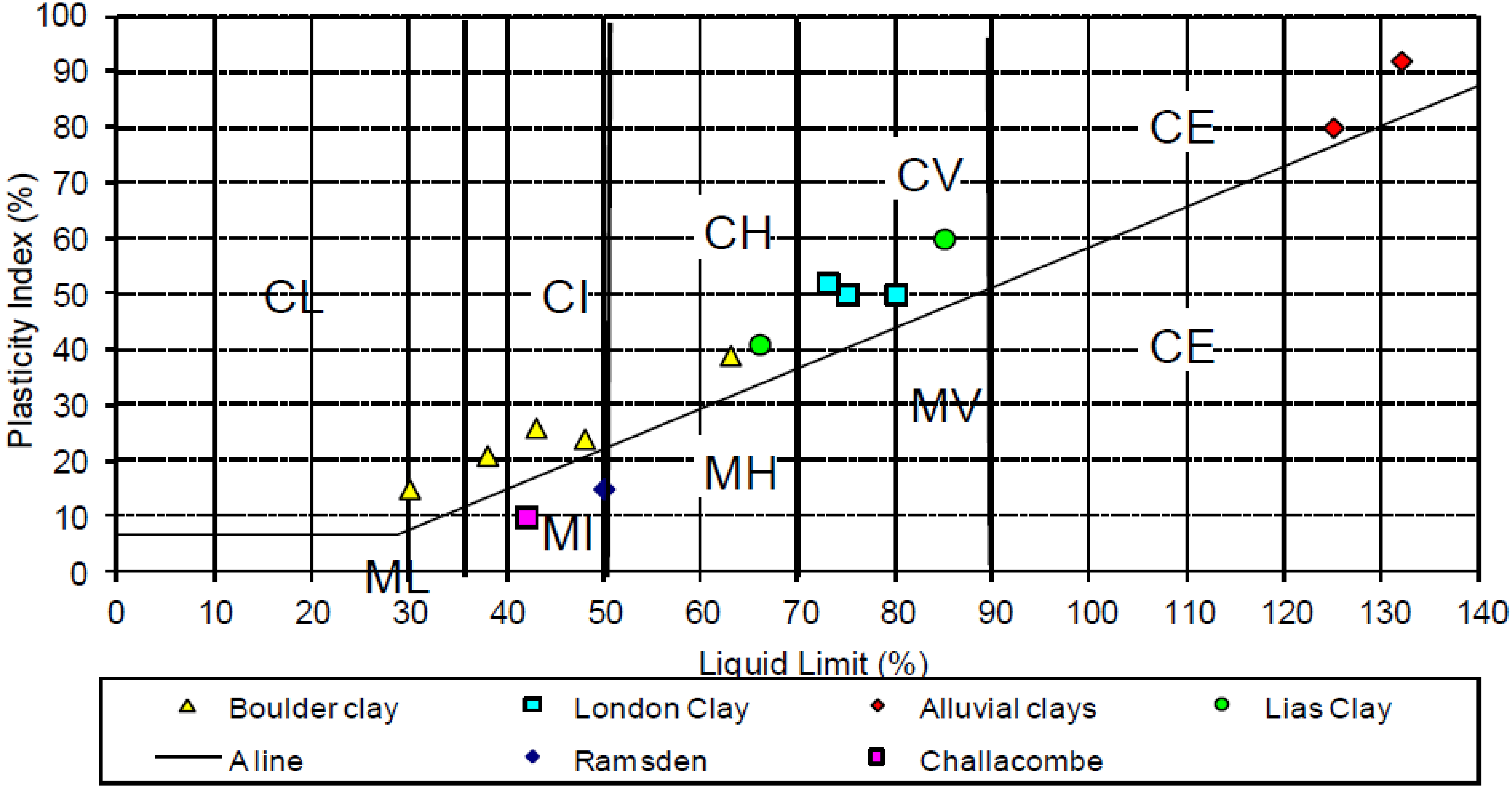
Fig. 2. 'Pennines' embankment: c.1900 (Phase 3) (after Skempton, 1989)

Age of UK dams



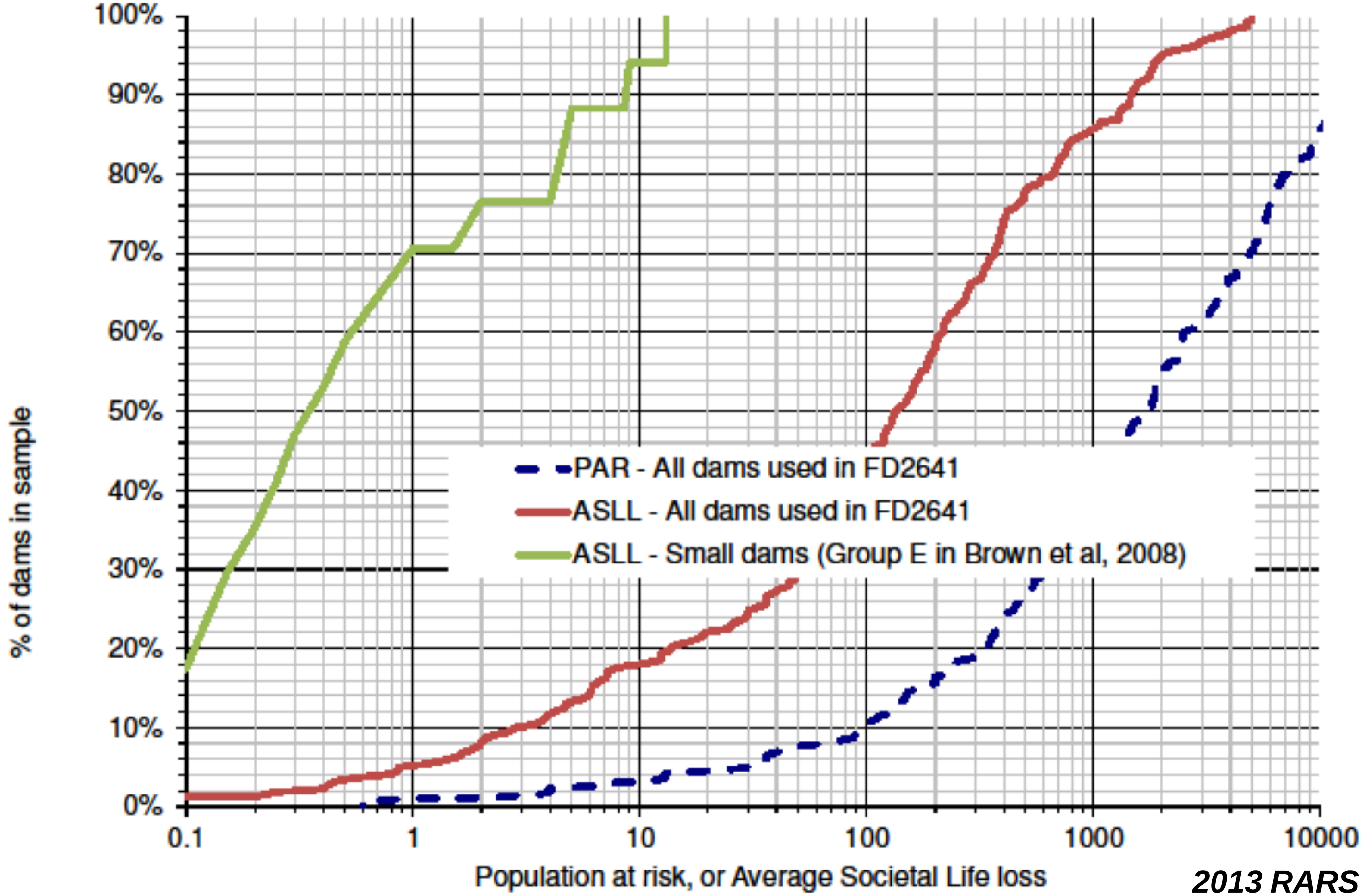
2000 BDS Conf. Tedd et al

Plasticity of some "puddle clays" - as Table 3 of Moffat, 2002



Range of consequences of failure of UK reservoirs

Figure 15.2 Indicative distribution of population at risk and average societal life loss (Defra and Environment Agency 2010. Unpub)



2013 RARS

2. Features of UK dams which may vary from Europe

Surface features of UK dams that would ideally be included/addressed in research scope

	Feature	Research need	Comment
1	Tarmac road on dam crest	Erodibility of tarmac road to overflow	• Applies to both dam failure and • consequential failure of downstream transportation embankments
2	Downstream face of dam is woodland	Erodibility of leaf litter over tree roots	
3	Fence posts/ telegraph poles along crest	Methods of evaluating increase in erosive force around obstructions	Fill may include boulders that cause channelling under overflow
4	Wave walls	Erosion on d/s side (drop off)	
5	Grass reinforcement alongside concrete chute	Loading different from crest overflow?	
6	Wide range of duration of overflow		Includes pumped inflows, small catchments (< $3km^2$?) and large catchment

UK dams – internal zoning

%	Date	Impervious element	Shoulders
20%	18Th century	Hetro/ homogenous	
50%	Pennine 1840-1950	Thin Puddle , then “pugged” clay	Random, then select fill, internal drainage in later dams
30%	Post Pennine Water supply etc	Rolled clay core	Engineered i.e. zoned compacted with drainage etc
	Irrigation/ flood storage	Homogenous clay Upstream geomembrane	Compacted, may not have filtered internal drainage (e.g. when Ht < 5m(

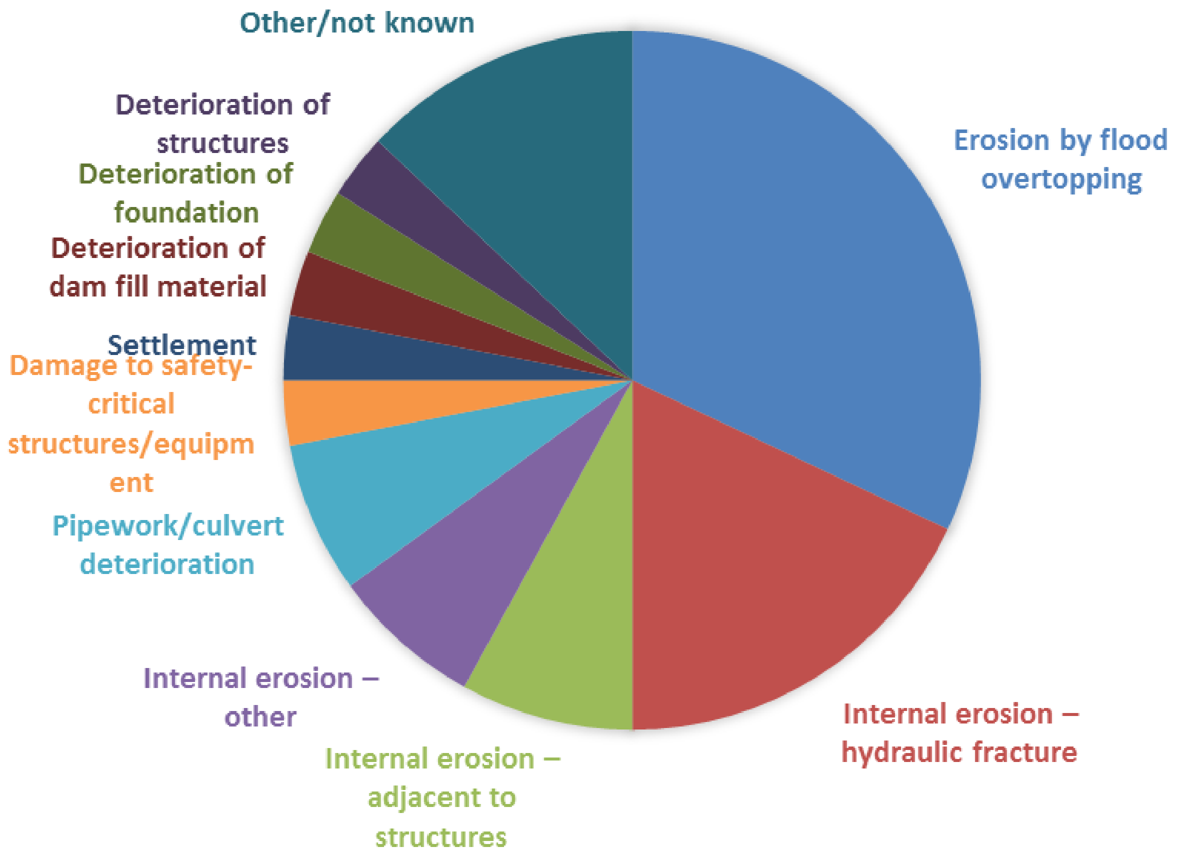
Relevance to this research – would ideally have a suite of different dam types covering the different types pf European dam

Other dam types – through flow rockfill

Adapted from 2000 BDS Conf , Moffat

3. Overflow Incidents at UK dams

Breakdown of the 76 UK 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

The RSAG R&D Strategy (2015)

Ulley – an embankment scour incident

2008 BDS Conf

- **Ulley reservoir, Yorkshire 23 June 2007**
- Hundreds of people were evacuated from their homes in Yorkshire today after record rainfall led to a "significant risk" that a dam containing a reservoir could burst.
- Firefighters were trying to drain the Ulley reservoir, which is less than a mile from the M1 motorway and near a power station that serves most of Sheffield.
- The M1 was closed northbound between junctions 32 and 34 due to fears about the Victorian dam, which holds more than 455,000 cubic metres (100m gallons) of water. It was also shut southbound between junctions 34 and 36.
- Speaking near the scene of the operation Adam Wilkinson, the strategic director for environment for Rotherham Council, said the engineers had managed to stabilise the situation by pumping out as much water as was coming in via brooks and streams.
- He said more than 700 people had been evacuated and that the dam's state was "critical but stable".

Levee performance last 10 years

Flood Event	Nature of flood event	Number of breaches		Comment
		Overflow/ overtop	Seepage, internal erosion, uplift.	
Summer 2007	Fluvial; 1000 km of levee tested	0	4	All caused by local irregularities
Cumbria 2009	Fluvial; widespread overtopping	1	0	
Lincolnshire 2012	Fluvial	0	2	All caused by local irregularities
Winter 2013/2014	Coastal; widespread overtopping	83(ish)	?	Most breaches caused by coastal overtopping
Winter 2015/2016	Fluvial	3	3	All caused by local irregularities
Winter 2015/2016	Coastal		2	Beach erosion

(slides from Phil Smith, Haskoning)

4. Current UK engineering practice and guides (tools)

UK dam safety – regulatory structure

	Role/ Comment
Dept. Food, Agriculture, Rural affairs (Defra)	Set policy on flood risk management
Environment Agency	• Regulator (certificates as to inspection/ complete safety measures) • Commission/ publicise inundation maps on internet + emergency planners (includes consequence of failure) • Risk designation of reservoirs • Promote research into all forms flood risk
Regulations	1930, updated in 1975, 2010
Owners	Responsible for dam safety
Institution of Civil Engineers	"Reservoirs Committee" vets Panel Engineers on behalf of Defra Promote Good practice/ Guides (RSAG)
All Reservoirs Panel Engineers	Over see design and construction of new reservoirs (+ modifications) Ten yearly safety inspections – against standards current at the time
Supervising Panel	Annual visit / statement – any change that could affect safety

Current UK practice – management strategy

Feature	Deterministic	Risk based
Consequence of failure	Regulator produces flood maps (available on internet) and numeric estimates of population at risk and likely life loss under EU Floods Directive	
Objective of 10 yearly safety review	Comply with current guides	• Assess failure modes • Estimate probability and consequences of failure • Tolerability of risk • Reduce risk into ALARP/ Tolerable zones
Risk management	New guides published in response to incidents	Portfolio risk assessment (Completed by most major water companies)
Weakness	Rely on precedent (is the past a reliable guide to the future?)	Treatment of uncertainty

Notes

1. 10 year review by "independent Panel Engineer" is still main driver for review of overflow capacity
2. Still getting spillway upgrades (often due to increase in downstream consequences)
3. UK spend on reservoir upgrades could be c €50-100M/ year

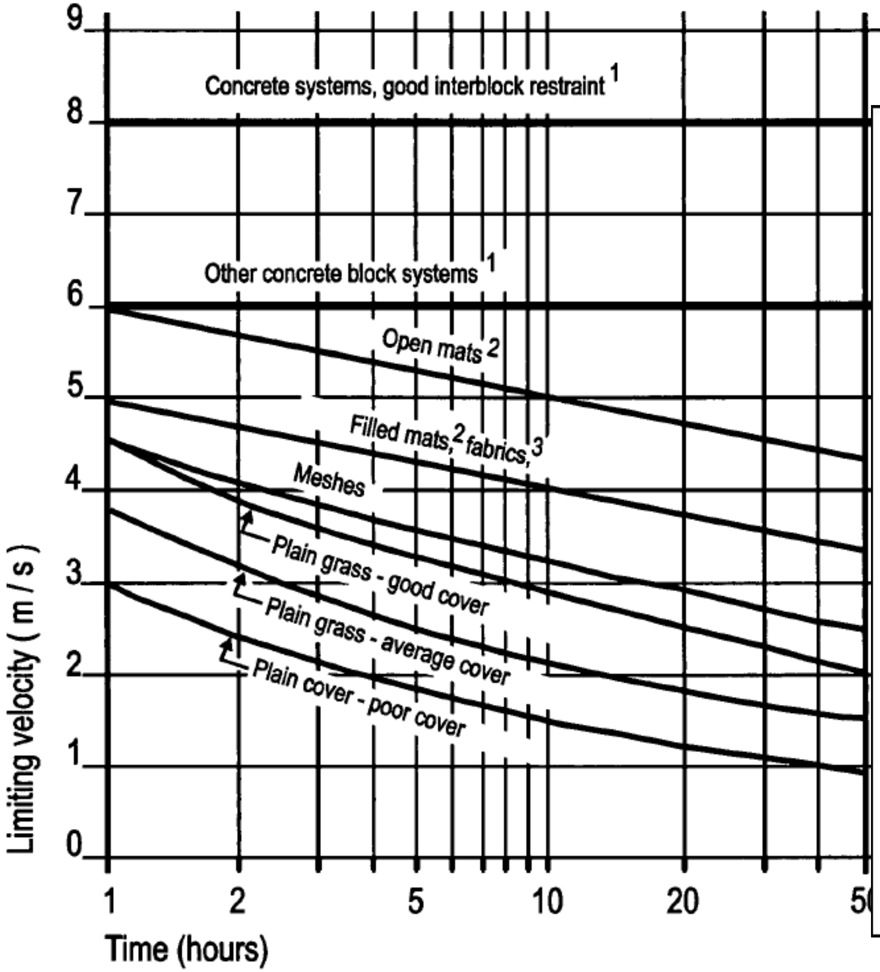
Overflow erosion: Current UK practice Engineering guides (tools)

	Feature	Comment
1976 (2000)	Flood Estimation	1933 – Flood of record 1976 – Flood studies report 2000- Flood estimation hand book **Continuing adjustments, plus climate change allowance**
1976 (2015)	Floods and reservoir safety, ICE	Defines "Design standards" First published 1976. Fourth edition in 2015 **introduced risk based approaches alternate to "deterministic standard"**
1986	CIRIA 116 Design of reinforced grass waterways	Based on large scale field tests at Jackhouse reservoir Provides allowable velocities (but not failure velocities
2004 (2013)	Quantitative risk assessment , Online	Guide to risk assessment for reservoir safety management (update of 2004 Interim Guide to QRA)
2009	Consequence of failure	National reservoir flood mapping 2009 (on internet), about to be updated to new (2016) specification **For small reservoirs RFM often identified houses at risk that had been overlooked**

Overflow - Current UK guidance

CIRIA 116, 1986, ILH section 8.4.2

RARS Fig 8.5, CIRIA TN71



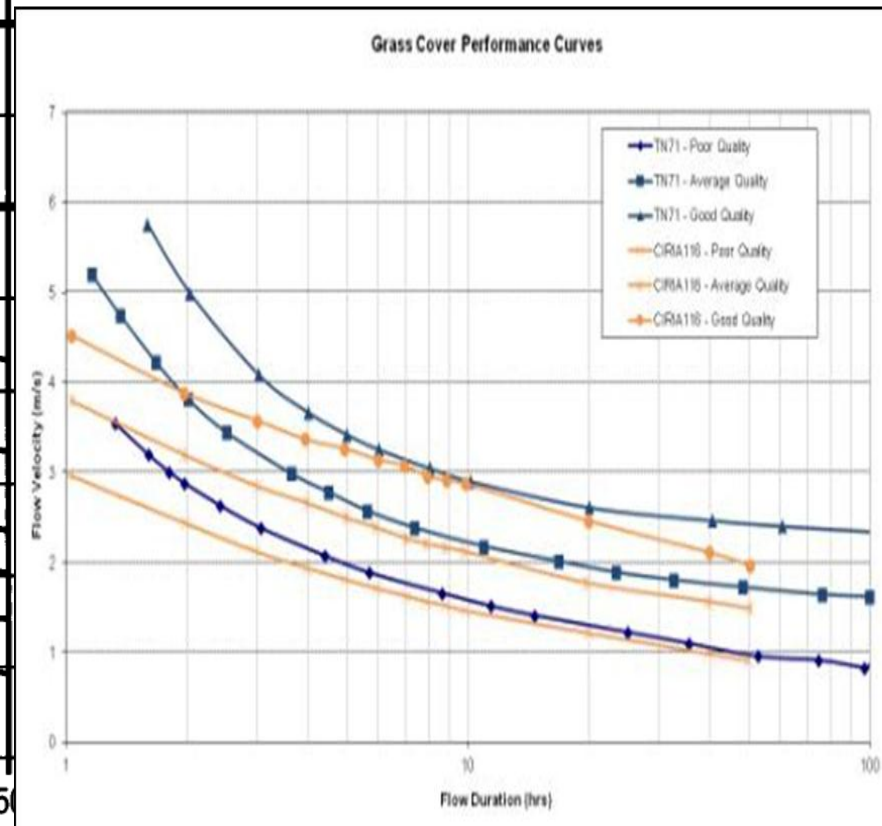


Figure 9 *Recommended limiting values for erosion resistance of plain and reinforced grass*

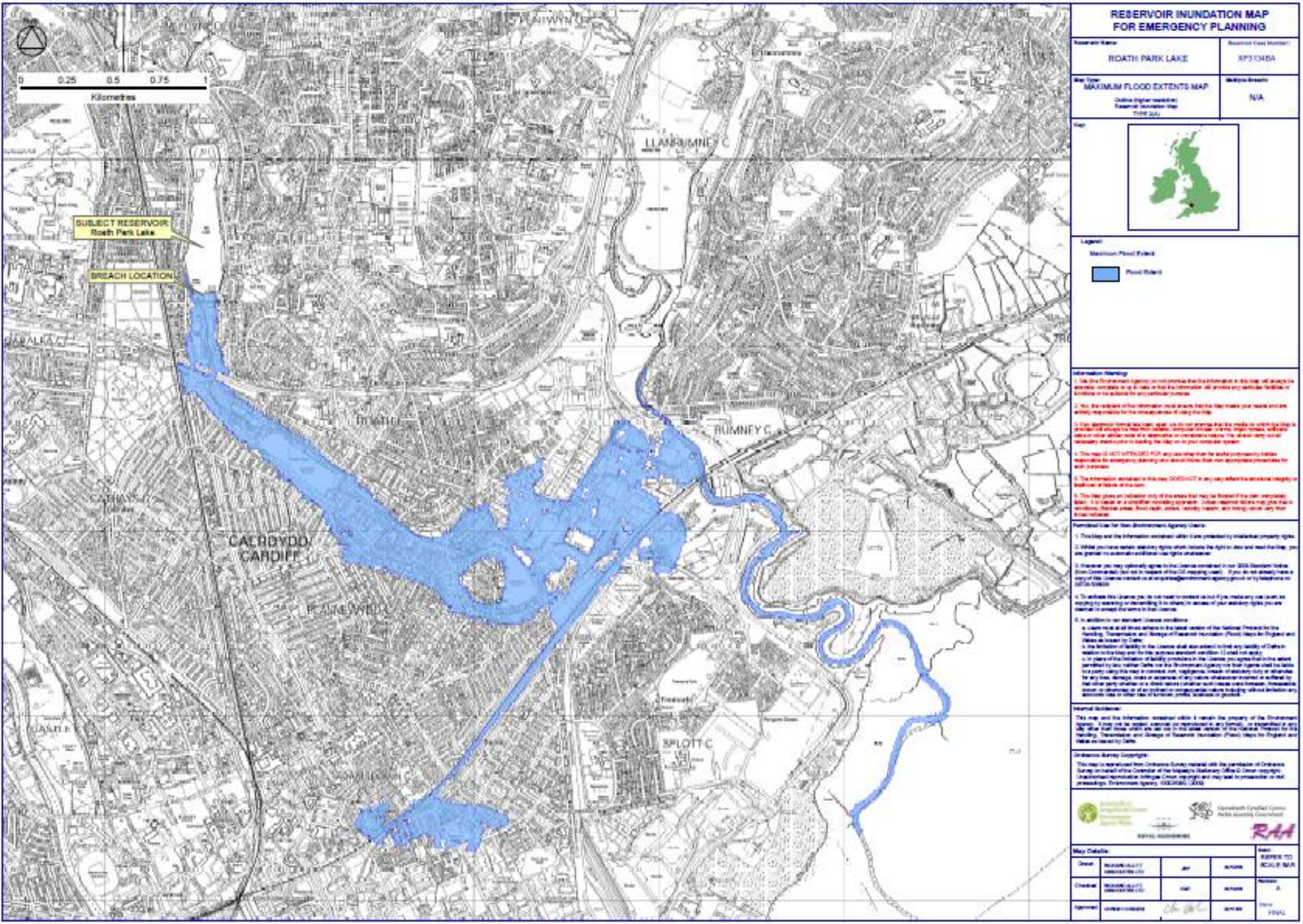
Overtopping (Waves): Extract from section 3.3.3 of EuroTopII (2016)

Table 3.1 Limits for wave overtopping for structural design of breakwaters, seawalls, dikes and dams

Hazard type and reason	Mean discharge q (l/s per m)	Max volume V_{max} (l per m)
Rubble mound breakwaters; H_{m0} > 5 m; no damage	1	2,000-3,000
Rubble mound breakwaters; H_{m0} > 5 m; rear side designed for wave overtopping	5-10	10,000-20,000
Grass covered crest and landward slope; maintained and closed grass cover; H_{m0} = 1 – 3 m	5	2,000-3,000
Grass covered crest and landward slope; not maintained grass cover, open spots, moss, bare patches; H_{m0} = 0.5 – 3 m	0.1	500
Grass covered crest and landward slope; H_{m0} < 1 m	5-10	500
Grass covered crest and landward slope; H_{m0} < 0.3 m	No limit	No limit

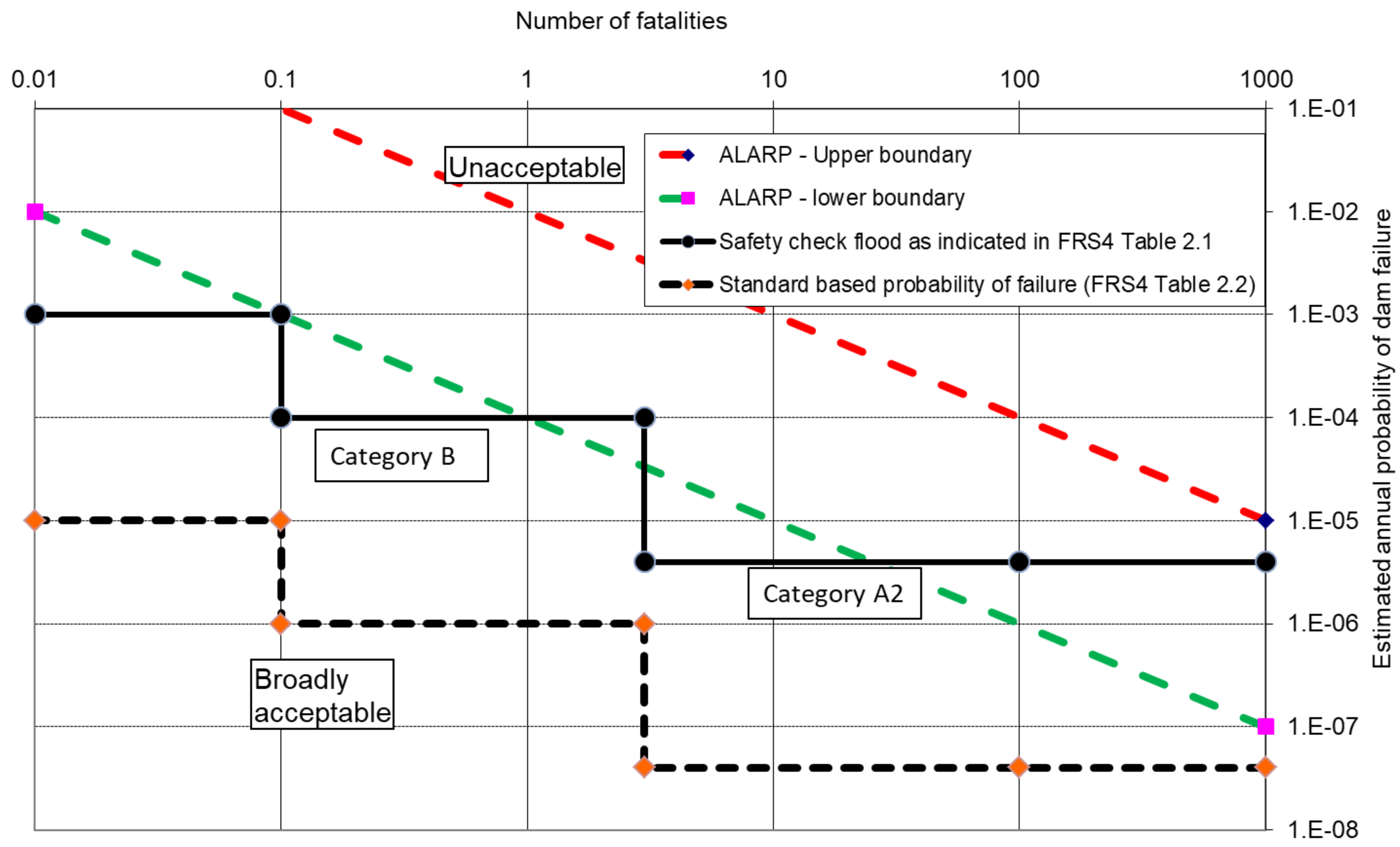
European Overtopping Manual
http://www.overtopping-manual.com/

Limit in FRS4, 2015 Table 6.2– 1 l/s/m



RESERVOIR INUNDATION MAP
FOR EMERGENCY PLANNING
ROATH PARK LAKE
MAXIMUM FLOOD EXTENTS MAP
N/A
0 0.25 0.5 0.75 1
Kilometres
SUBJECT RESERVOIR:
Roath Park Lake
BREACH LOCATION
CAERDYDD/
CARDIFF
RUMNEY C
SPLOTT C

Engineering: Both risk-based “Dam critical flood” and standard-based “safety check flood”



5. UK recent/ ongoing research

European overflow erosion projects with significant UK input

Date	Projects	Comment
2000	CADAM	BDS Conf 2000, 2002, mark Morris
2004	IMPACT	BDS Conf 2002, mark Morris
2012	Flodoprobe	available international methods to assess overtopping behaviour in Report WP03-01-10-06, chapter 4
2007 2016	EUROTOP	European Overtopping Manual.

Scoping stage project “Assessing the Performance of Grass and Soil in Resisting Erosion – SC140006

- Awarded by the Environment Agency to CH2M and the University of Dundee. This scoping project has eight aims with the outputs being:
  - Produce a state of knowledge review
  - Scope and design an experimental testing programme to address identified gaps in knowledge
- Workshops June 2017 (inception), Sept 2017, Dec 2017
- Current scoping limited to serviceability, not ultimate limit state, of grass cover system

Possible future UK projects

- 2015-8 Tolerability to sustained overflow – Stage 1B (ultimate limit state)
- 2015-19 Updated breach methodology

- From MM strategy, Nov 2016

6. UK research needs

Reservoir owners needs (largely driven by ten yearly inspection cycle)

	Dam safety		Investment	
	Is risk tolerable?	**Surveillance**	**Capex**	**Opex**
Modelling	Failure modes			
Asset management	Tools to assess probability of damage/ failure	Frequency? Condition indicators?	Options to reinforce grass Ranking dams for upgrade	Maintenance of surface cover
Forecasting/ flood warning	Time to failure? Time to evacuate?			Emergency plans

Need to update existing tool

CIRIA 116 , 1987, Design of reinforced grass waterways

- No allowance for erodibility of subsoil
- now ageing with need to understand options at higher unit discharge
- **limited to allowable velocity (serviceability) – does not guide assessment of limit state** (failure with release of retained water) which is required to apply ALARP
- No guidance on time varied flow

Target structures

Height of dam		% of UK emb. dams	UK levees	UK – predominant dam type
Very large	>50m	3%?		Zoned/ concrete
ICOLD large dam	> 15m	17%		Various
Medium	5-15m	50%		Puddle clay core
Small	< 5m	30%		Homogenous
	Total	2500 dams	8400km	
Annual capex (€M)		50-100	500	

What should research deliver?

Q	Definitions	Key features to be included in research
Risk based	Probability x consq	a) Models of soil/ grass erosion, and failure mechanism - ductile or Brittle? and thus Options to inhibit b) Agree definition(s) of damage c) Tools to quantify annual chance of failure (release of reservoir)

Time to failure? (Tf)	Failure is catastrophic release of reservoir	a) Surface cover varies from woodland leaf litter to grass maintained by machine cutting/ sheep
		b) Soil varies sand to heavy clay
		    a) Some dams zoned (granular shoulders with clay core)
		c) Geometry
		    a) Crest can be large (>5 times height) and “soil” often includes tarmac/ gravel road
		    b) Slope varies angle of repose (1.5H:1V) to 6H:1V
		d) Define parameters defining Tf e.g.
		    a) Hydraulic -volume/ peak overtopping flow
		    b) Geotechnical parameters

Grass reinforced spillways		a) Update CIRIA 116 to include failure , how convert real hydrograph to constant equivalent flow? b) How long would a clay underlayer delay failure? c) Innovative Grass reinforcement techniques
maintenance		Best practice. Frozen ground, desiccation cracks, climate change ETC