Stillwater Associates
Reservoir Safety & Water Consultancy

Overflowing erosion of bedrock (through crest overflowing or spillway flow impact)

British Dam Society perspective

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Overflowing erosion of bedrock Failure modes for dams

	Failure mode	Application to UK
1	Crest overflow onto d/s bed undermines dam	Most UK dams have concrete protection over rock in river bed
2	Crest overflow onto abutments	Spillways on large dams generally sized to pass PMF Wave overtopping caused limited damage
3	Service reservoir – overflow or burst main erode foundation	
4	Lateral spills over sides of spillway chute	Sometimes overlooked until Boltby incident Reinforced with grass matting, or chute enlarged
5	Erosion of spillway lining	Masonry lining e.g. Ulley – chute lost Concrete lining – no incidents to date
6	Erosion of spillway channel down rock abutment	Common problem on small dams (< 10m) Operational problem/ cost
7	Erosion of d/s face of Hard fill embankment dams	• Some RCC dams vulnerable to overflow erosion • Need guidance on use of lime stabilised soils
8	Erosion d/s of flip buckets	• Both at low flows and after sweep out

3. Range of dams and dikes in UK

UK concrete dams

Table 1. National population of dams

Country	No. of dams	Percentage of total population			
		All	Embankment	Concrete/ masonry	Service
England	1705	64	57	5	2
Scotland	752	28	20	7	1
Wales	196	8	6	1	1
Total	2653	100	83	13	4

Historical development of concrete dams given in 1996 CIRIA report 148

Concrete spillways (on earth dams)

- Bellmouth
- Over embankment face
- **Down mitre**
- On abutment remote from dam

3. Incidents at UK dams

Figure 7 - Damaged spillway at Boltby in 2005


In extreme events
• surface runoff can scour mitres
• Rain can saturate downstream face/ cause slope instability

Ulley

Figure 3 - Scour hole photographed on Tuesday 26 June, 2007

2008 BDS Conf. P28 Hinks et al

Figure 1 - Works in progress filling scour hole

Abutment erosion

Figure 2.17 Examples of invert failures of stepped masonry spillways

4. Current UK guides (tools) and engineering practice

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

Current UK Engineering guides (tools) relevant to erosion of bedrock

	Feature	Comment
1991 (2007)	CIRIA Rock Manual	The use of rock in hydraulic engineering
1993	Practical guidelines for the design of flip buckets and plunge pools	Paper by Peter Mason in Water power and dam construction, sept/ Oct. p 40-45
2010	Guidance for the Design and Maintenance of Stepped Masonry Spillways	Model testing of stepped masonry, lessons learnt from Ulley
2013	RARS	Guide to quantitative risk assessment – published 2013 (update of 2004 Guide)
2017	Spillway chutes: practical design considerations and design details	Paper by Peter Mason in Hydropower and dams. Issue five . P79-86

6. UK research needs

Model tests – stepped masonry spillways

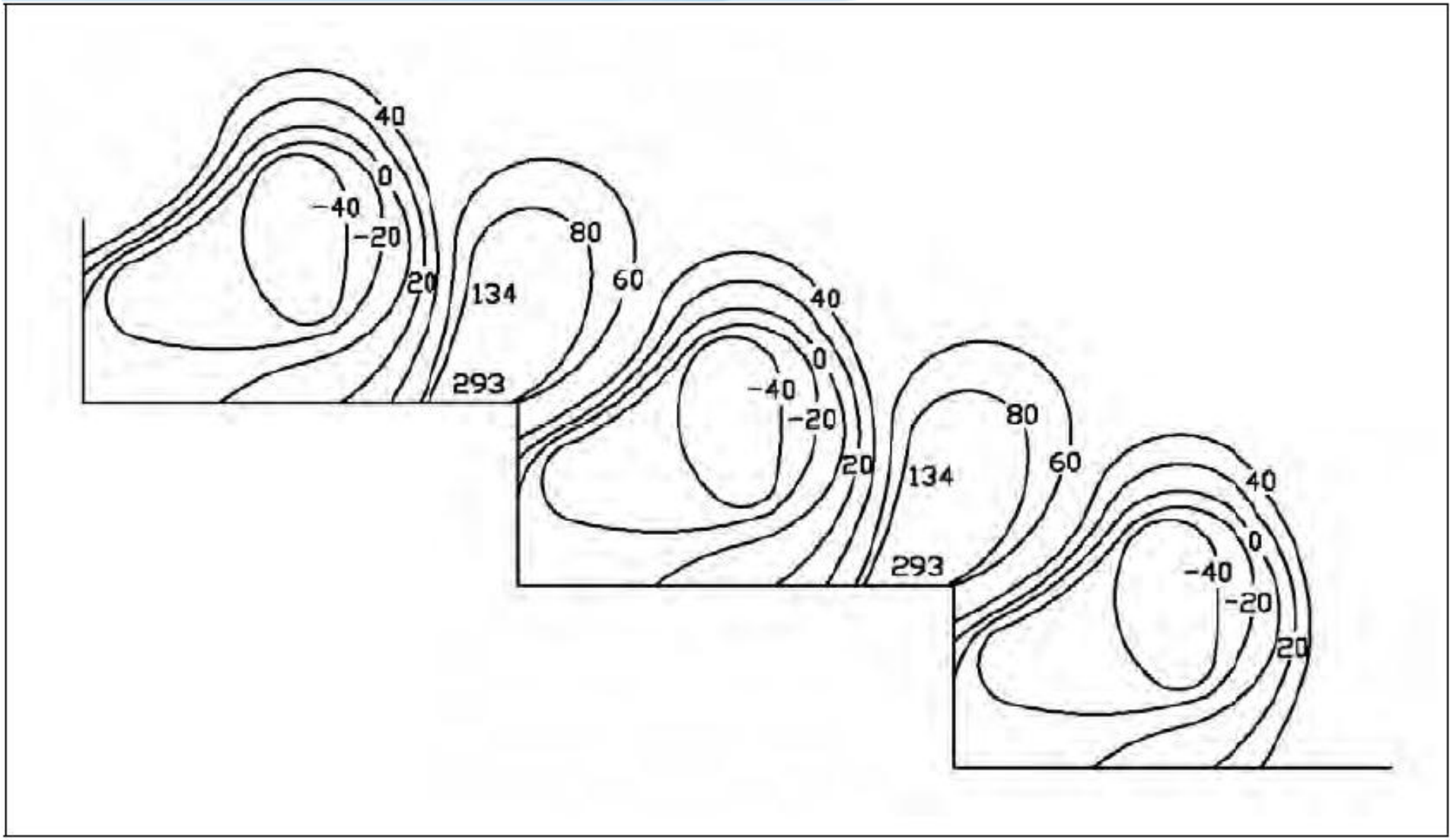

Figure 4.7 Mean pressure contour plot for flow over a set of steps

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

Need	Detail
Vulnerability of existing structures to rock erosion (annual probability of failure?	• Crest overtopping • Chute overtopping
Tools for risk assessment	• Likelihood of damage/ failure in one flood event • How to balance opex vs capex – rate of erosion under normal operation, and in extreme flood
Emergency planning	• How quickly will the reservoir be released? • Is it realistic to warn/ evacuate people?
Maintenance	• How should I maintain/ treat exposed rock to maximise resilience to overflow?
Surveillance	• How to identify and manage vulnerabilities e.g. open joints

What should research deliver?

Q	Definitions	Key features to be included in research
Risk based	Probability x consq	a) Models of rock 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, and uncertainty in these estimates
Time to failure? (Tf)	Failure is catastrophic release of reservoir	a) Define parameters defining Tf e.g. a) Hydraulic -volume/ peak overtopping flow b) Rock jointing/ dip/ weathering
Maintenance		Best practice. Frost damage, seepages, weathering