Guide to Risk Assessment for Reservoir Safety Management – Erratum
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This Guide was produced under the EA-Defra flood risk management R&D programme and published in June 2013, being the update to the Interim Guide (ICE) published in 2004. It can be downloaded from
https://publications.environment-agency.gov.uk/skeleton/Publications/Default.aspx

It comes in three volumes, Volume 1 (32 pages) provides a high level overview of the use of quantitative risk assessment, Volume 2 (312 pages) provides the methodology, whilst Volume 3 reports on the pilot studies which were used to test the process and provide feedback on how it could be improved. Volume 2 is in two parts, the first presenting the three tiers of assessment (qualitative, simplified quantitative and quantitative), and the second part providing supporting information on different aspects of each part of the risk assessment.

Feedback on its use has identified a number of typographic and other corrections required, which are set out below.

Readers are encouraged to use the Guide as part of Section 10 assessments and other reservoir safety engineering activities.

Supervising Engineers are encouraged to use Step1a, the identification of failure modes, as described in Section 7.1 (pages 58 to 63), with supporting information in Section 16.4. Where more detailed evaluation is warranted the event tree process described in Section 8.3.1 can be applied to any failure mode.

All users are encouraged to feedback any additional corrections, areas for improvement or for further research to Mike Wallis (m.wallis@hrwallingford.co.uk), or to Dave Hart at the Environment Agency (david.hart@environment-agency.gov.uk).

The following amendments should be made to the guide as published in June 2013. In due course these will be incorporated in the pdf version available on the internet.

Section	**Page**	**Erratum**
Figure 7.1	59	In step iii, add “The core threats that should always be included are those shown in Table 3.1”
Table 8.2 Figure 8.1	72 71	Current condition 1 should be modified to 0, so horizontal axis on figure runs from 0 to 10 (current condition score can be zero, if in very good condition)
Table 8.2	72	Text on Bottom row of right hand columns should read “multiply base probability by “Intrinsic score x 1000/ cap defined above” to give probability for anchor point 10
Section 8.2.	79	In step iv add the following text “note the user should use the actual crest levels which normally vary along the crest, so flow over the crest will need to consider a compound weir, with critical depth at the low spot, and lesser depth of overtopping elsewhere. Typically at failure overtopping would only occur at the low spot(s), which may be only a few metres along the crest)”
Figure 8.6	83	a) Step 1 – also calculate the head difference from the reservoir flood level (as crest overweiring in Section 8.2.2) to the top of the wall b) add a new step after step 3 to check that the energy head required for water to overtop the sides of the chute sufficiently to erode the adjacent grass is physically achievable i.e. does not exceed the potential energy due to elevation below reservoir flood level. c) Step 6 - Correct formula (Manning’s) $Q = A R^{2/3} I^{0.5} / n$

Section	**Page**	**Erratum**
Box 8.7	85	This Box has been changed to reflect the above amendment. Replace it with the new Box 8.7 provided.
Section 8.2.4	87	Reference in text at top of page to Table 8.should be changed to “Example in Box 8.10”
Figure 8.8	87	Add additional step at bottom, as extra box “Probability of failure (release of the reservoir) = probability of load x Conditional probability of slope given load x conditional probability of release of reservoir given slope failure”
Box 8.10	89	This Box has been changed to reflect the above amendment. Replace it with the new Box 8.10 provided.
Table 8.17		This is incorrect, and should be replaced by the new table provided
Table 8.20	112-113	This is incorrect, and should be replaced by the new table provided
Figure 8.12, 8.12	126	Figures should be reversed, as Figure 8.12 shows the index safety factor under earthquake and Figure 8.13 under static conditions
Section 10.3	150	Equation for CPF This intended to be a present (not annualised) value, so it should read: ‘CPF = (Cost of risk reduction measures – Present value (change in annual damage)) / present value (change in annual LLOL)'
Box 10.1	152	This Box has been changed to reflect the above amendment. Replace it with the new Box 10.1 provided.
Section 20.2.1	256	Reference to the Life Safety Model (UK) added
Section 20.3.2	263	Supporting paragraph on LSM added

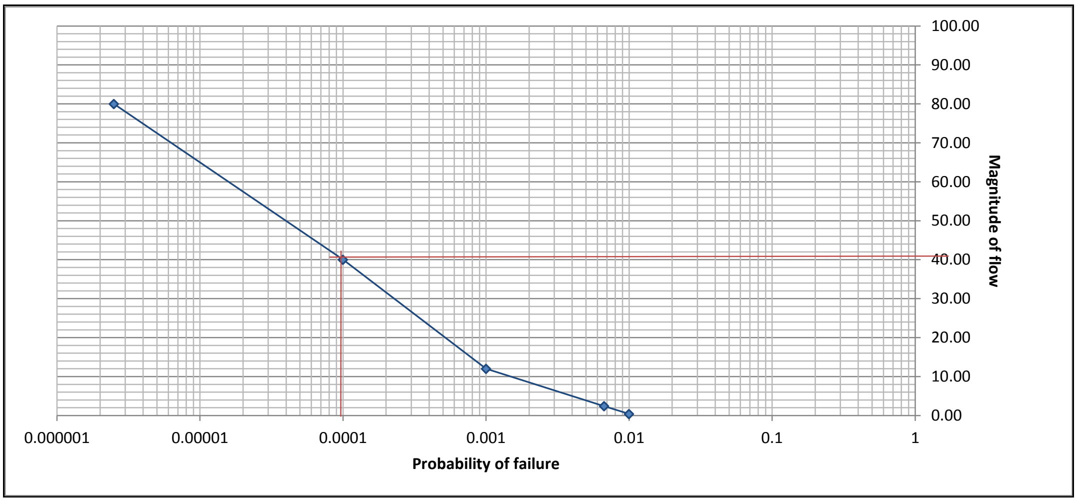
Box 8.7 Example output for spillway chute overtopping

	Symbol	Location 1	Complete for each location down the spillway channel	
Weir crest		60	mOD	Prescribed form, used as datum
Inert bed level		50	mOD	Levelled on site
Bed slope	I	0.10	V:H	Measured from drawings
Wall height	H	1.2	mOD	On site measure
Channel width (w)	W	3	mOD	
Manning's	n	0.04	mOD	Masonry
Dam face adjacent to top of spillway wall - critical erosion velocity V_C for each location		4	m/s	This can be calculated using the example in the Crest Overtopping
Critical depth of water above top of wall		0.35	m	Taken from Figure 8.7
Critical flow depth in chute		1.55	m	Critical depth of water above top of wall + wall height
Equivalent blackwater water depth adjusted for Bulking (air entertainment)		1.291	m	Critical flow depth in chute / 1.2
Water area (blackwater) $A_S = d * w$	Ab	3.87	m	A_S = adjusted water depth * channel width
Wetted perimeter	Pb	5.58	m	Wetted perimeter = Channel width + (2 * Wall height)
Effective channel radius R = flow area /wetted perimeter	CR	0.69	m	= As / Wetted perimeter
Flow down chute, when whitewater depth above walls is at critical velocity for grass		24.0	m^3/s	$Q_{out} = A_b CR^{2/3} I^{0.5} / n$
Implied blackwater velocity		6.20	m^3/s	Blackwater = Q_{out} / Ab
Equivalent energy head		1.96	m	$= v^2 / 2g$
Is this credible?		yes		
Reservoir routing factor	R	0.70		calculate for crest overtopping (example in Box 8.6)
$Q_{in} = Q_{out} / R^{1.5}$		41.0	m^3/s	$Q_{in} = Q_{out} / R^{1.5}$

Magnitude vs. annual probability

Factor to appropriate return period	Return period (years	Annual Probability	Equilivant fraction of PMF for rapid	Q (m^3/s)	Remarks
Extrapolated from factors in FRS	PMF	1.00E-06	1	80.00	Calculate Q_{in} for each return period
	10,000 - Year	1.00E-04	0.5	40.00	Q_{in} = Routed inflow * fraction of PMF for rapid
	1,000 - Year	1.00E-03	0.3	12.00	
	150 - year	6.70E-03	0.2	2.40	
	100 - year	1.00E-02	0.17	0.41	

Plot of the Magnitude vs. annual probability



Annual Probability of failure	1.0E-04	Use the graph plotted above considering the failure discharge

Box 8.10 Example output for slope instability

	Symb	Score / Value	Units	Remarks
Key parameters				
Dam crest width	Cw	9	m	Taken from the PFR
Dam height	H	12	m	Taken from the PFR
Downstream slope 1v:		2.5h	V:H	Taken from the PFR
Downstream shoulder width	Sw	30	m	Taken from the PFR
Adding outer third of crest	Swa	33	m	=Sw+Cw /3
Revised downstream slope 1:v (External slope angle)		2.75h	V:H	= Swa/H
Probability of slope failure in normal operation				
Soil type	Phi	25^{o}		Clayey sand - use Table 8.6
Phreatic surface	Ru	0.25		Normal operation use Table 8.6 Ru = groundwater level / depth of soil
Slope Index Factor		1.35		Using figure 8.9
Annual Probability of failure	PSF	0.06667		1 in 15 years using Figure 8.4
Reasonable?				Yes steep slope, probably stable because of vegetation
Probability of reservoir release given slope failure				
Base probability (1 in)	PRR|SF	3000		Table 8.7
Adjustment of conditional probability for Crest width	CFw	5	m	Normal is 3m, this dam is 9m so probability x 5 i.e. less likely to fail
Freeboard	CFf	3	m	1.82 to crest, neglect wave wall, normal is 1m, say probability x 3
Vertical wall along edge	CFw	0.5		Wave wall extends 0.5m below crest, adjust by 0.5
Surveillance visits	CFs	0.7		Visits every 7 days, normal is 3 days
Type of fill	CFf	0.5		Old dam so not compacted to modern standards. Local geology is sandy clay. Say 0.5
Adjusted probability of reservoir release given slope failure (1 in)		7,875		= Base PF * Crest * Freeboard * Vertical wall * Surveillance * Fill
Adjusted overall probability of reservoir release		8.5E-06		Probability of slope failure in normal operation x Conditional probability of reservoir release given slope failure

Note:
PFR = Prescribed Form of Record. A legal document that holds all key data bout the dam. Also known as the 'Blue Book'

Table 8.17 Guidance on scoring intrinsic condition embankment dam (Tier 2)

				Fallback where no dam specific information is available: Assume typical for date of construction					
					Pennine dam type				
Construction feature	Max score	Guidance on Scoring	Common potential failure mode(s)	18th C	Pre 1865	1865-1880	1880-1945	Post 1945	Post 1960
Embankment									
Downstream shoulder does not act as filter to core or incompatibility between zones	5	1 for uniform homogeneous embankment	Internal erosion of core into shoulder	5	2	1	1	1	1
No positive (filtered) drainage in downstream shoulder	2		Seepage emerging at ground surface may lead to piping, or on-going loss of fines	2	2	2	2	2	0.5
Erodible core material (predominantly sandy, silty, or dispersive material); or other vulnerable watertight element	2	Non plastic Note that "puddle" relates to the process, not the material, as some dams were homogenous in material type with the central zone "puddled" to form a core zone. Where unknown score 1, likely 1.5 and unlikely 0.5	Rate of internal erosion would be rapid once it commenced	Varies. Moffat (2002) describes the wide range of fill types in Pennine type dams, including Lias clay, boulder clay, soft organic alluvial clay with classification varying from ML to CV, and some being dispersive. Assume 2 if non-plastic (silt) or dispersive; 1 for CL					
High hydraulic gradient (i) across watertight	2	Calculate using the typical section drawing showing the dam construction Score 2 if $i \geq 5$, 0 if $i \leq 1$	Increased risk of hydraulic fracture, rapid internal erosion	2	2	2	1.5	1.5	0

element										
Inadequate freeboard from top of watertight element (core) to spillway overflow	2	Score 2 if below TWL; and 0 if > 100 year flood	If there is a modern wave wall, it can usually be assumed that this has been designed to minimise seepage underneath, therefore this would score 0. The width of the dam crest is important in assessing the risk, and thus score	Internal erosion during flood events when reservoir high	2	2	2	1	1	0
Steep abutment slopes (over height ≥ 20% dam height)	2	Score 2 if >45 deg; 0 if < 30 deg	Angle measured over steepest 20%. Determine from photographs, Inspecting Engineers reports, or discussion with the Supervising Engineer. Note this steepest 20% of height may be over steps either natural or excavated for structures	Risk of preferential seepage along interface between dam and abutment, due to reduced contact stresses	Varies					
Steep downstream slope	2	Score 2 if steeper than 2H:1V; 0 if 2.5H:1V	Determine from drawings, or the Inspecting Engineers Report. 2 if ≤1.9H:V, 0 if 2.5H:1V, linear interpolation between		Not applicable as can be measured					
Foundation										
Erodible or compressible soil foundation e.g. organic	2		Rock and stiff clays would score 0. Where drawings are available, these may indicate whether alluvium or other drift deposits are present.	Shoulder may experience differential settlement leading to stability failure or varying loss of support to core, resulting in internal erosion	2	varies, dependent partly on practice of Engineer responsible for engineering of the original dam				0

Downstream shoulder does not act as filter to soil foundation	2		Is there a filter blanket, as in modern dam construction? If not is the shoulder fill fine such that it may act as a filter? On rock score as 0	Leakage along soil foundation erodes foundation into downstream shoulder	2	2	2	2	2	0.5
No foundation treatment on open jointed hard rock foundation (slush grout, dental concrete)	2		Only score 0 when you are sure there is foundation treatment.	Erosion of upstream fill/ core along untreated open joints; for example in core trench, or downstream side of core	2	2	2	2	1	0
No foundation cut-off	2		Determine whether there is a cut off from key drawings; typical construction practice at the time.	Increased risk of internal erosion within foundation; or high pwp downstream which could cause stability problems	2	1	1	0.5	0.5	0

Table 8.20 Current condition of surface structure

Construction feature	Max score	Guidance on Scoring	Common potential failure mode(s)	Suggested score for various degrees of uncertainty		
				Unlikely	Not known; could be occurring	Likely
Uncontrolled large quantity of seepage from cracks/ joints into/through structure, or emerging in vicinity of structure	4	a) The intention is that this is only scored if the quantities of seepage are higher than would normally be expected - thus the assessment should include an assessment of what the expected seepage would be and the score would be 0 for normal seepage. b) Where the local geology is such that significant seepage could be occurring undetected into permeable deposits in the valley floor (e.g. cobbles/ clean gravels?), consider whether some score should be allocated for this uncertainty	Deterioration may lead to sudden failure; high flow increases risk of fines being transported	0.2 - It is possible but unlikely	0.8 - E.g. end of structure submerged by downstream reservoir; or founded on deep very permeable deposits	2- e.g. there has been evidence of large volumes of seepage during the dams life and this could be occurring again
Seepage into/ from structure increasing at same reservoir level	6	Considers increase in seepage and whether it is linked to reservoir level or rainfall	Changing conditions indicate deterioration	0.3	1.2	3
Seepage into/ from structure carrying fines	8	If there is no seepage, score 0. If the seepage is running clear, score 0. Where the seepage is due to water entering from the spillway cute, downstream of the watertight element, score half.	Loss of fines from the dam implies incipient failure	0.5	1.6	4
Deformation						
New cracks/ widening of existing cracks,	3	If there are no cracks, score 0. Where cracks has been remediated and there is no new cracks score as zero (except if the cause of the movement was not fully understood score half marks). Where the movement is longstanding and stable score half marks		Not applicable as can be seen in the field		

Deformation of embankment above/ adjacent to structure e.g. sinkholes	8	Discussion with the Supervising Engineer and the Inspecting and Supervising Engineers reports. If the depressions are not adjacent or local to the structure under consideration, score 0 here (this should be picked up in Sheet 4.4, or in relation to the other structure)	These are indicative of internal erosion and concentrated leaks along the contact between the structure and fill	Not applicable as can be seen in the field		
Other						
Scour at outlet from structure	2	Is there any evidence of erosion in the downstream structure/ channel? If the outlet to the structure is not close to the embankment and could not affect the stability of the dam, score 0	Scour can lead to structural collapse of the structure, and may also expose pervious foundation strata through which internal erosion could occur.	Not applicable as can be seen in the field		
Material deteriorating	3	Is there any evidence that the material making up the structure is deteriorating, If there is definitely no signs, score 0.	Where the structural material is deteriorating, then this increases the vulnerability to structural collapse, or perforation which would allow a concentrated leakage which could erode fill material	Not applicable as can be seen in the field		

Box 10.1 Example output assessing proportionality

Proportionality		
Example works through one method to reduce the risk.		
ASLL for no warning Economic damages (£M) VPF (£M)	7.9 3.58 1.70	
Option to reduce risk:	Inspection of gunite (10 yearly)	
Probability of failure		
Before mitigation With mitigation	1.00E-04 1.00E-05	
Present value of overall project cost (capital works) (£M)	1	
Cost of damages		
Existing * Economic damage (£/ year) After works * Economic damage (£/year)	10,728.00 1,072.80	
Present value in saving in cost of damages £M	0.29	
ASLL per annum		
Existing * ASLL per annum After works * ASLL per annum	7.9E-04 7.9E-05	
Present value of reduction in life risk	2.1E-02	
Cost of preventing a fatality £M		
(Cost of works - Reduction in damages) / Present value of saving lives	33.3	including damages
(Present Value) / Present value probability reduction	46.9	Life only
Proportion factor		
Cost of preventing failure / VPF	20	including damages
Cost of preventing failure / VPF	28	Life only
Conclusion	Cost of works disproportionate to reduction in risk	