Observations on the boundary between high and lower risk reservoirs

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SYNOPSIS. The 2010 Flood and Water Management Act makes provision for amendment of the Reservoirs Act 1975 in particular to distinguish between reservoirs that are "high-risk" and others. Definition of this boundary is critical to deciding which dams are classified as lower risk, and which will therefore be exempt from Panel Engineer overview and other regulatory processes. The paper examines the categorization of risk for dams and also in other industries in the UK such as chemical, illustrating the options for the position of this boundary with reference to data from quantitative risk assessment of UK reservoirs. The paper concludes by suggesting key issues which need to be considered in defining the position of the boundary, if public confidence in the regulatory system is to be retained.

INTRODUCTION

The regulation of reservoir safety in UK has worked well since introduction of the first Reservoirs Act in 1930, with no dam failures leading to loss of life since then. However, there is no room for complacency in management of reservoir safety as several near misses involving emergency drawdown continue to occur each year. The reservoirs element of the 2010 Flood and Water Management Act moves from a hazard based system, where all reservoirs containing more than 25,000m³ of water are regulated, to a risk based approach where reservoirs as small as 10,000m³ could be regulated, but where some much larger reservoirs could be defined as lower risk with no regulatory oversight. Traditionally, risk assessments take account of both probability and consequences. However, current proposals by the Environment Agency and SEPA would assess reservoir risk only on the basis of consequences. This paper discusses the considerations in setting the boundary between high risk and lower risk reservoirs.

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DEFINING WHAT CONSTITUTES A LOWER RISK RESERVOIR

The challenges in defining a lower risk reservoir, for the purposes of the UK reservoir safety regulation, will include consideration as to when downstream risk is sufficiently low as to justify exemption from regulatory oversight. At early 2012 the existing risk classification systems to classify hazard/consequences of failure of UK dams for the purpose of checking adequacy under floods and earthquake, and risk management, are summarized in Table 1(note there is no assumed equivalence between the different classification systems). These show a significant variability in both the parameters used to assign risk level and subdivision of risk level. This paper explores some of the practical issues in defining the boundary.

Table 1: UK Systems to classify reservoir hazard/ consequences of failure

Guide	Feature	Highest	↔		Lowest
Floods (Table 1 of ICE, 1996)	Dam Category	A	B	C	D
	"could endanger lives"	In a community (>10)	Not in a community (1-10)	Negligible	None foreseen
	% of UK dams in each class[1]	56	19	18	7
	Design return period (general standard)	Probable Max. Flood	10,000	1,000	150
Seismic (Charles, 1991 and ICE, 1998)	Cons. class[2]	IV	III	II	I
	Evacuation requirements (No. of persons)[3]	>1,000	100-1,000	1-100	None
	Recommended design return period	30,000 (or Max Credible Earthquake)	10,000	3,000	1,000
Risk Man. CIRIA, 2000	Impact value (S 5.3)	High	Medium		Low
	PAR[4]	>1,200	200- 1,200		<200
	LLOL[4]	>600	60 - 600		<60
	Recommended design return period		"probability considered inappropriate" (Section 5.6)		

Guide	Feature					
Interim Guide, ICE, 2004	Consequence class	A1	A2	B	C	D
	LLOL	> 100	100- 10	3 – 0.1	< 0.1	< 0.01
	Design standard	FN chart used to define tolerable risk				

1) Tedd P, Skinner and Charles, 2000
2) Consequence class for seismic load assumes that the risk to life and damage and loss are balanced such that Classes I to IV correspond to columns one to four in Table 2 of the seismic guide (classification factors)
3) ICOLD Bulletin 72, 1989
4) Interpolated from Table 3.2 of KBR, 2002, which was inferred from impact scoring system

CATEGORISATION OF RISK IN OTHER INDUSTRIES

Principles

Where the public are at risk from neighbouring activities such as transportation, a nuclear power station, or a "major hazard" storing large quantities of hazardous materials, the risks need to be managed.

In general, those creating a risk have a responsibility to reduce the risks to the public so as to be "As Low As Reasonably Practicable" ('ALARP').

The qualification that risks should be reduced so far as reasonably practicable has been a feature of safety legislation for over 100 years. The term has been the subject of a number of legal judgments including that in Marshall v Gotham Co Ltd (1954) AC 360, indicating that if the "*time, trouble and expense*" of a proposed precaution are "*disproportionate*" to the reduction in risk that the precaution would achieve, then that precaution is *not* reasonably practicable.

This principle is reflected in HM Government guidance on the Value of Preventing a statistical Fatality ('VPF') and the Value of Preventing an Injury ('VPI'). Currently the VPF is approximately £1.5m. Whilst the values vary, a similar approach has been adopted in many countries across the globe.

Levels of tolerable risk

Drawing on guidance previously published in "The tolerability of nuclear power stations" (HSE, 1988), the Health & Safety Executive published "Reducing risks, protecting people" ('R2P2'. www.hse.gov.uk/risk/theory/r2p2.htm) in 2000 with the HSE's views on defining levels of tolerable risk.

In R2P2, HSE sets out its views as to levels of individual and societal risk that may be tolerable, as regards risks associated with existing hazards, and to a much lesser degree, proposed developments.

HSE indicates that R2P2 sets out a framework for *"decision making by HSE which would ensure consistency and coherence across the full range of risks falling within the scope"* of the Health and Safety at Work etc Act 1974.

This framework recognises that the level of risk may vary from a "*Broadly acceptable region*" through a "*Tolerable region*" (where the risks should be reduced to *ALARP*) and, into an *"Unacceptable region"*.

R2P2 sets out HSE's views as to the boundaries between these regions as regards *"individual risk of death per year"* ('Individual Risk' or IR), in general terms as follows:

- boundary between the Tolerable and Unacceptable – 1 in 1,000 (10^{-3}) for workers, and for members of the public who have a risk imposed on them "in the wider interest of society" this limit is judged to be an order of magnitude lower – at 1 in 10,000 (10^{-4})

- boundary between the Tolerable and the Broadly Acceptable – "*HSE believes that an individual risk of death of one in a million per annum (10^{-6}) for both workers and the public corresponds to a very low level of risk and should be used as a guideline for the boundary between the broadly acceptable and tolerable regions*"

In short, in terms of risk of death to individual members of the public, HSE suggests that the Tolerable region is two orders of magnitude for individual risk of death from 10^{-6} to 10^{-4} or from 1 case per million (cpm) to 100 cpm per annum as illustrated in Figure 1.

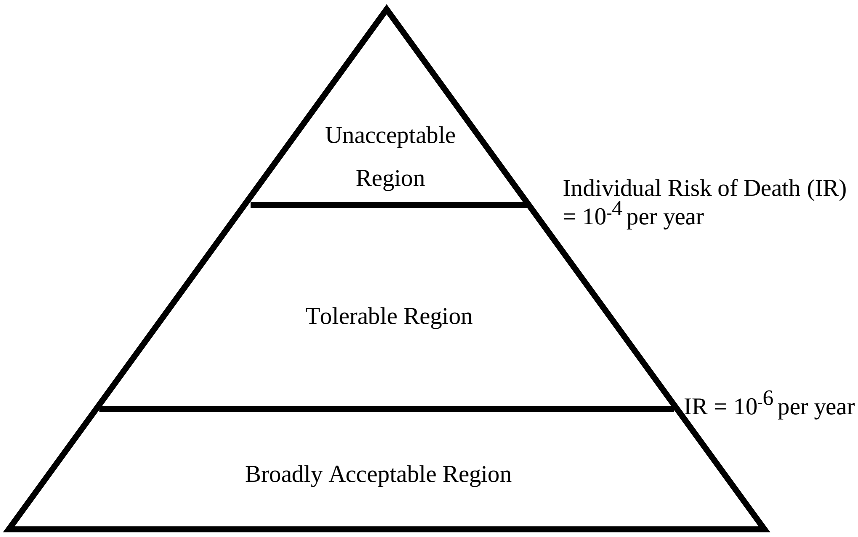

Figure 1. HSE framework for the tolerability of risk of death to the public

Where the risk is in the Broadly Acceptable region, further attempts to reduce risk may be unnecessarily risk averse and wasteful of resources. In simple terms rather than a "better safe than sorry" approach, one that is "safe *and* sorry".

The Individual Risk is that to the average member of the population – the "statistical person" and not that to each and every member of this population – some will be at greater risk, some at lesser risk, for reasons associated with numerous variables.

The Individual Risk can be calculated as follows:

IR = Annual probability of failure x Fatality Rate, where the

$$\text{Fatality Rate} = \frac{\text{Likely Loss of Life ('LLOL')}}{\text{Population at Risk ('PAR')}}$$

R2P2 also considers societal risk proposing that "*the risk of an accident causing the death of 50 people or more in a single event should be regarded as intolerable if the frequency is estimated to be more than one in five thousand per annum*".

R2P2 does not indicate why this particular threshold was selected, and HSE apply criteria in 'FN curves' (plotting the frequency of events that might kill N or more people) to the assessment of off site risks associated with major industrial installations.

At paragraph 135 of R2P2, HSE indicates its view that the criteria in these FN curves "*may not* be valid for very different types of risk such as *flooding from a burst dam* or crushing from crowds in sports stadia". (***Our italics***)

Land use planning in the vicinity of major hazard sites (COMAH)
HSE applies a not dissimilar approach to land use planning in the vicinity of major hazard sites to which the Control of Major Accident Hazards Regulations 1999 ("COMAH") apply.

R2P2 is supplemented by a methodology and software decision support tool, "PADHI" ("Planning Advice for Developments near Hazardous Installations". www.hse.gov.uk/landuseplanning/padhi.pdf)

PADHI uses two inputs to a decision matrix to generate a response to any proposed development to *"Advise Against"* ('AA') or *"Do not Advise Against"* ('DAA'). These inputs are:

- which of the consultation zone(s) that HSE sets around the major hazard site, the proposed development lies in – there are usually three consultation zones, the Inner, Middle and Outer.
- which of four "*Sensitivity Levels*" the proposed development falls under

Where HSE applies a risk-based approach, the consultation zones are set at contours to reflect its assessment of individual risk to a person at the proposed development of a "*dangerous dose or worse*" with the Inner Zone representing a risk of greater than 10^{-5}, the Middle Zone 10^{-6} to 10^{-5} and the Outer Zone 3 x 10^{-7} to 10^{-6} per annum as shown in Figure 2.

In this context, the definition of "*dangerous dose or worse*" is a level of harm which would result in:

- severe distress to all
- a substantial number requiring medical attention
- some requiring hospital treatment
- some (about 1%) fatalities

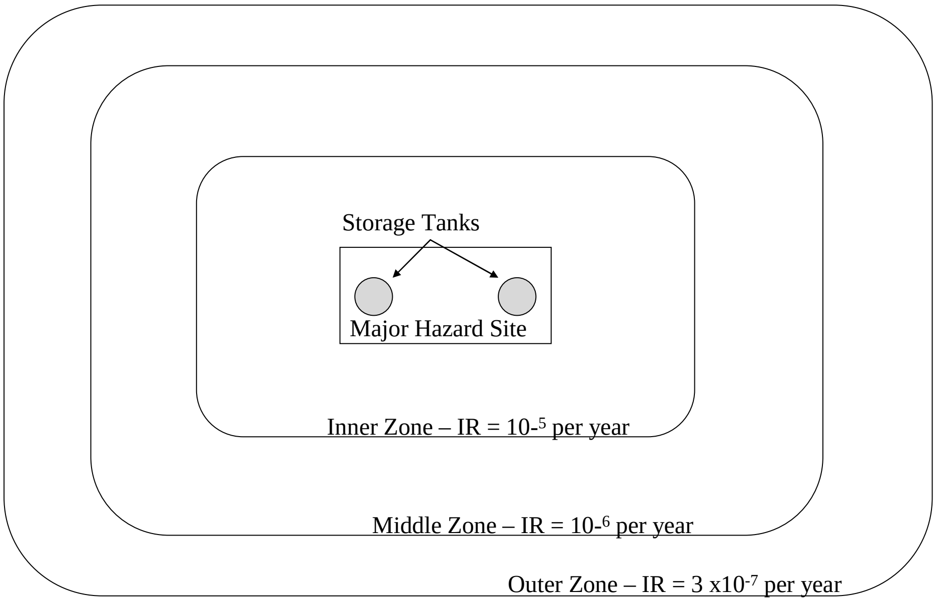

Figure 2. Consultation Zones set around a COMAH site

The Outer Zone is set to reflect an individual risk that is a fraction of that indicated as *broadly acceptable* in R2P2 – reflecting that some of those at risk may be more sensitive than the typical person at risk.

Whilst the costs of risk reduction measures are relevant to establishing whether any measure is reasonably practicable, neither R2P2 nor PADHI considers any economic impact that might result from a significant incident such as could occur in a reservoir failure.

Recent developments

We would note that R2P2 commits HSE to a "*risk-based*" approach. However, for the purposes of land use planning around most COMAH sites where the primary hazard, e.g. that of LPG, is fire/explosion rather than toxicity, HSE adopts a "*protection-based*" approach.

This means that HSE identifies the "*Representative Worst Case Major Accident*" as a "*Cautious Best Estimate*" – in effect a worst case scenario.

Amongst other commentators, the Buncefield Major Incident Investigation Board ('MIIB') has recommended ("Recommendations on land use planning and the control of societal risk around major hazard sites". www.buncefieldinvestigation.gov.uk/reports/comahreport3.pdf) that HSE adopts more consistent application of a "*risk-based*" approach to land use planning, whilst at the same time having greater regard to incremental societal risk. HSE has set up a Technical Advisory Group to develop methodologies for the latter recommendation as regards societal risk (HSE, 2009).

When the protection-based approach was adopted, models to quantify risk (‘Quantified Risk Assessment’ or ‘QRA’) were not readily available, but substantial progress has been made in this area both in the U.K. and internationally. MIIB comments that the protection-based “*system is showing its age after three decades of application*”.

Part of the decision of the Secretary of State in the Oval cricket ground public inquiry (www.communities.gov.uk/documents/planning-callins/pdf/britovalderestricted.pdf) was that application of a “protection-based” approach to the setting of consultation zones around a gasholder COMAH site was appropriate as there is insufficient recent historical data on incidents to apply a risk-based approach. In contrast this is not the case for LPG storage, where there is sufficient data to allow a risk based approach.

LIKELIHOOD OF FAILURE OF UK DAMS

As part of a recent research project the authors carried out an assessment of the extent to which it was possible to link physical characteristics of reservoirs to the level of risk, by examining data compiled from a number of groups of dams (350 total, Dataset F) on which detailed quantitative risk assessment had been carried out, with an example shown in Figure 3. As might be expected although broad trends can be seen (on log-log plots) there is no simple relationship between level of risk and a single physical characteristic which could be used to set a limiting value of physical characteristics for use in defining high risk. The current proposal for England and Wales of using consequences to define a lower risk reservoir is therefore considered a reasonable approach.

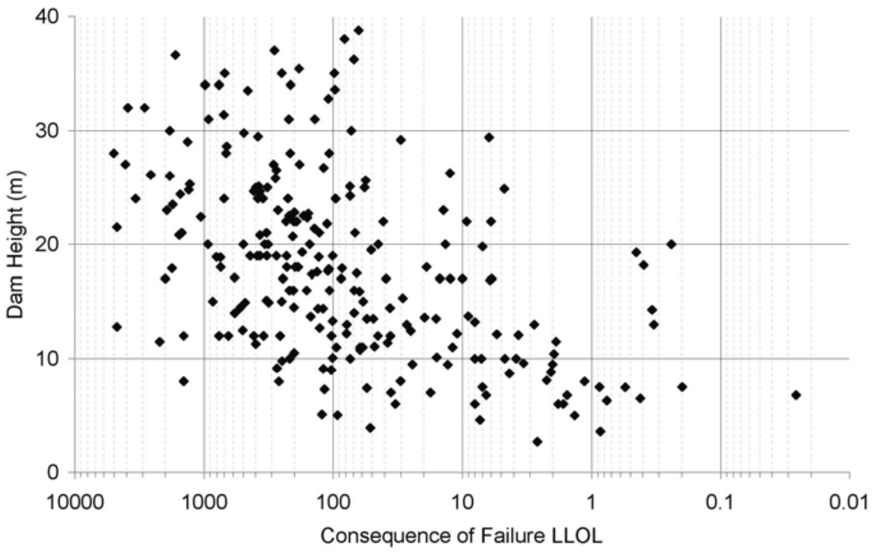

Figure 3. Dam height vs. Likely loss of life for Dataset F

Figure 4 shows the cumulative distribution of overall probability of failure for Dataset F, suggesting that for these dams which are regulated under the Reservoirs Act the annual chance of failure of most (10% to 90%) varies between 1 in 1000 and 1 in 50,000 per year, reflecting the design standard (no damage) in Table 1 varying from 1 in 150 to greater than 1 in 10,000 chance per year.

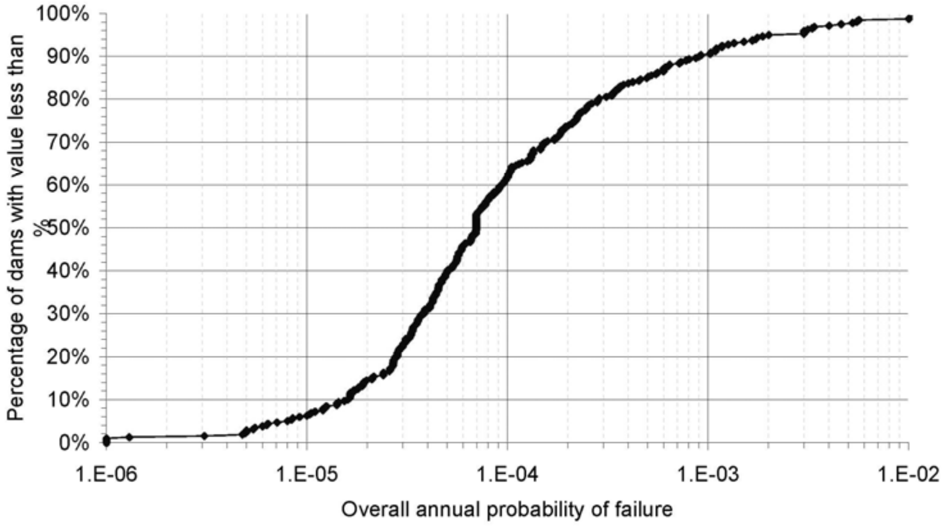

Figure 4.Cumulative distribution of overall probability of failure (Dataset F)

POTENTIAL CONSEQUENCES OF FAILURE OF UK DAMS

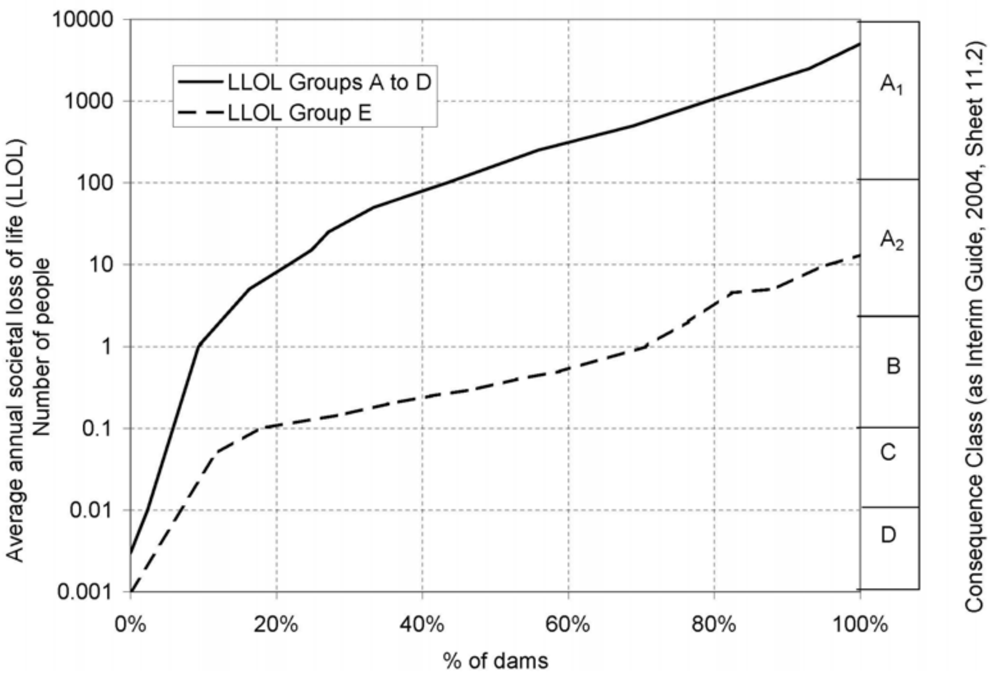

Figure 5. Cumulative distribution of annual average societal life loss

The proposal to use consequences as the basis of screening out “lower risk” reservoirs is considered reasonable, with an estimate of the likely range of potential consequences shown in Figure 5; the groups being described in Brown *et al* (2008), all being greater than 25,000m³ and regulated under the Reservoirs Act 1975 with A to D owned by major owners and E a group of “small dams”. The wide range of consequences of six orders of magnitude should be noted.

DISCUSSION

The risk of failure of a dam can never be reduced to zero, but the threshold of “lower risk” should be a reasonable balance between the cost the nation is prepared to pay for regulation (and the benefits provided by the reservoir) and the risk posed.

In terms of societal risk one approach would be to consider whether the risk has been reduced “as low as reasonably practicable”, with Figure 6 showing how the cost to save a life increases as the annual average societal life loss (LLOL) (used as the boundary of “lower risk reservoirs”) changes. The average annual cost is taken from the 2009 regulatory impact assessment of the proposed 2010 Act by Defra, which estimated the average annual cost to the reservoir owner and regulator as £36,000/year (the average cost of the 500 small raised reservoirs which will be brought into the scope of the Reservoirs Act of £18.9M split over all 500 reservoirs). Using a Disproportionality Factor of around 10 and value of saving a life of £1.5M (product of £15M) suggests that an average societal life loss of around 0.25 would be proportionate position for the boundary of “lower risk reservoirs”.

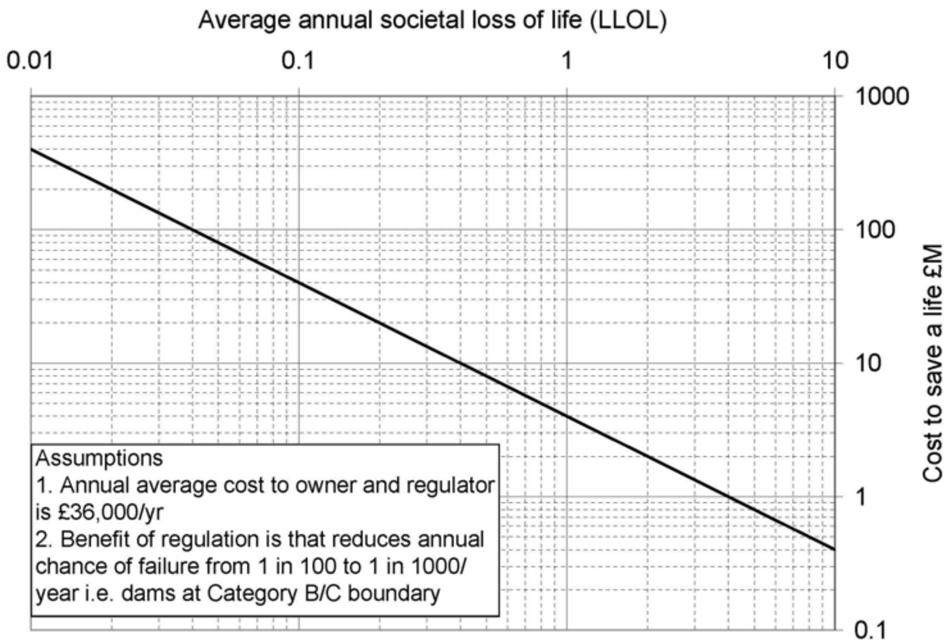

Figure 6. ALARP calculation of “Cost to save to a life” vs. LLOL

It is also necessary to consider the risk to an individual. Figure 7 shows how the fatality rate varies with unit discharge of the dambreak flood for three different methods

a) Step function proposed as fit to data on observed fatality rates in historical dam failures and flash floods by Bureau of Reclamation in DSO-99-06 (1999)

b) Linear relationship to the same data fitted in Interim Guide (ICE, 2004)

c) Environment Agency Research Report FD2321 (2006)

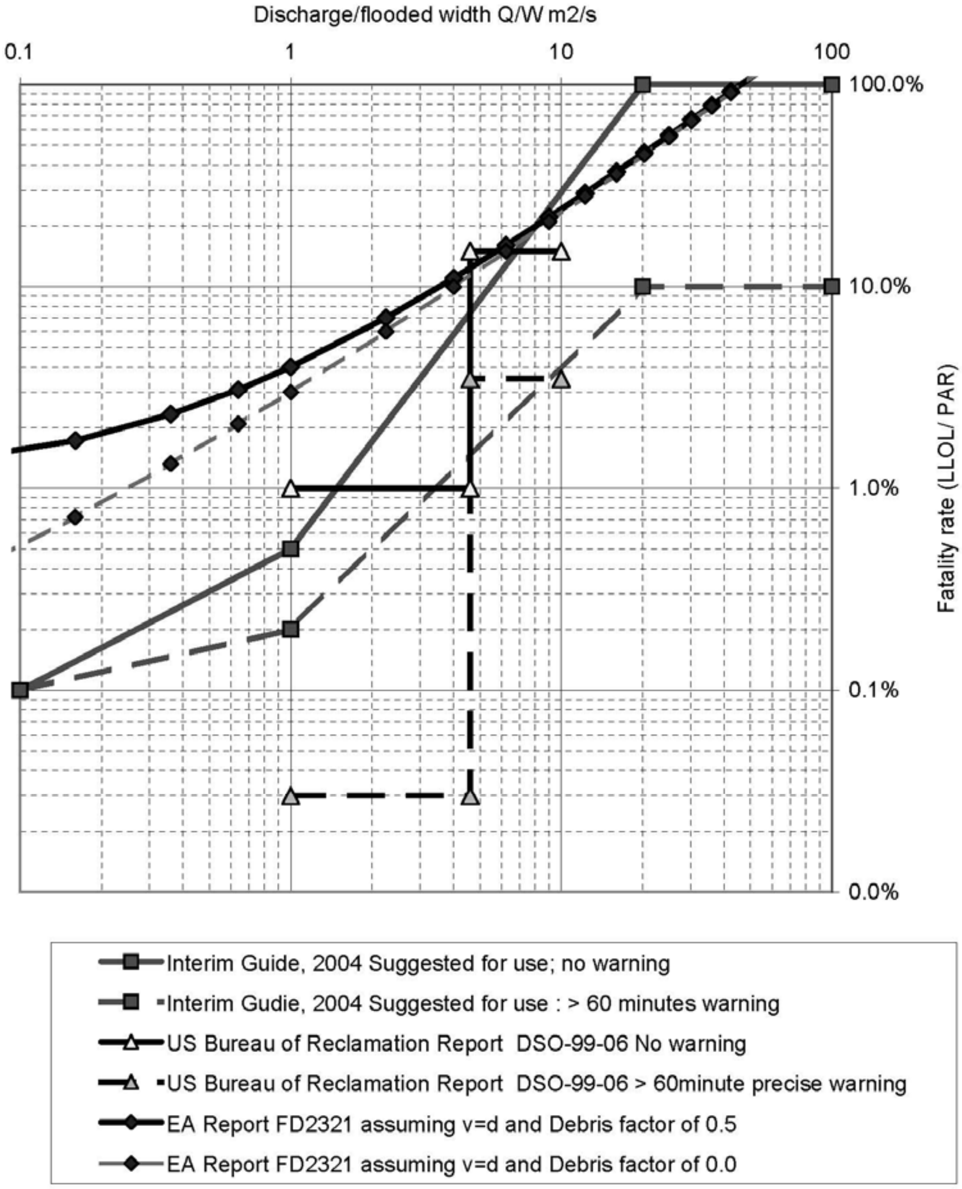

Figure 7. Variation of fatality rate with unit flood discharge

It is suggested that "c" applies to people in the open, whilst "b" is more applicable to the majority of those at risk being in buildings or other "shelters".

The conditions for the annual risk of death due to dam failure to an individual in the inundation area downstream of a dam to be less than 1 in 10,000 (as suggested by HSE) are assessed as follows

- assuming that the annual chance of failure of a currently unregulated reservoir is 1 in 100 (i.e. ten times higher than the 1 in 1000 for Category C/D implied by Figure 4)
- assuming that a house is occupied say 80% of the time
- then the fatality rate due to dambreak would need to be less than 1.25%.

Using approach "b" then to be lower risk the unit discharge would need to be less than $1m^3/s/m$. This is likely to be the governing factor for lower risk, so where an individual house is present immediately downstream to meet the HSE guidelines for individual risk the reservoir would need to be classified a "high risk", such that the owner of the reservoir then reduces risk ALARP in relation to that house.

CONCLUSIONS

The reservoir industry has the opportunity to move towards a risk based regulatory system with the implementation of the 2100 Act. The definition of the boundary between "high risk" and other reservoirs must recognize that risk can never be zero, with the boundary being determined by a balance between the cost to society of increased regulation, and the level of residual risk which is considered tolerable.

Reducing risk, protecting people (HSE, 2000) remains the key reference document in terms of defining tolerable risk in UK. In the chemical industry progress is being made in moving away from a "protection based" approach to decide if development can take place in proximity to high hazard installations, towards more consistent application of a risk based approach.

In the reservoir industry a risk based approach to defining which reservoirs should be subject to the panel engineer review system will be based on a consequences only system as offering an appropriate level of simplicity (although probability can be used for determining whether risk has been reduced ALARP).

The position of the boundary defining "lower risk" reservoirs needs to consider both societal and individual risk. In terms of average societal life loss an ALARP calculation of the societal cost of regulation against the benefits suggests a LLOL of 0.2 could be appropriate, although other factors also need to be considered. However, individual risk is considered likely to dominate the determination of whether a reservoir is lower risk, to ensure that occupants of buildings just downstream of a dam do not have an imposed additional annual risk of death due to dam failure of greater than 1 in 10,000. We suggesting that in the absence of better assessment of annual probability of failure of unregulated reservoirs this is most simply interpreted as that any reservoir where the downstream unit discharge at the first house in the event of dam failure is greater than $1m^3/s/m$ should be considered as high risk.

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