Preliminary feedback on the Interim Guide to Quantitative Risk Assessment for UK reservoirs, 2004

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SYNOPSIS The Interim Guide to Quantitative Risk Assessment for UK Reservoirs (the Interim Guide) was launched at the last BDS Conference, in June 2004 at Canterbury, for a five year period of extended trialling. After a year of use of the Interim Guide feedback was sought on the use of the Guide and its application through a series of face to face feedback sessions with a sample of All Reservoirs Panel Engineers, supplemented by a questionnaire. This paper summarises this feedback and then discusses both the role for QRA in dam safety management and how the Guide may be finalised to produce the definitive Guide to Quantitative Risk Assessment for UK reservoirs.

INTRODUCTION

The Interim Guide to Quantitative Risk Assessment (Brown & Gosden, 2004a) was launched in June 2004 at the last BDS Conference at Canterbury. The programme for review and updating of the Interim Guide was given on page 11 of the Interim Guide, being anticipated as the five years to 2008. In a letter to Panel Engineers in July 2004 Defra stated that *"The Interim Guide is a tool for the management of reservoir safety enabling a screening level assessment to be made to inform decision-making by dam professionals on the annual probability of occurrence of reservoir failure, the consequences and the tolerability of that risk."*

The Water Act 2003 amends the Reservoirs Act 1975 to give the power to the Secretary of State to require dam owners to prepare flood plans, with the requirements for such flood plans being currently under development (Brown & Gosden, 2006). It is proposed that the overall consequence class embodied in Section 11.2 of the Interim Guide is adopted as the basis to evaluate whether a reservoir will be required under the Water Act 2003 to have a flood plan.

Improvements in reservoir construction, operation and maintenance. Thomas Telford, London, 2006

In parallel the authors are producing guidance on the early detection of internal erosion, which includes relating the surveillance regime to the risk posed by the dam.

It was therefore decided it would be timely to seek feedback on the first year of use of the Guide, and at the same time seek views on what criteria should be used to determine which reservoirs would have flood plans and the surveillance regime adopted at any dam.

STRATEGY FOR OBTAINING FEEDBACK

The issues on which it was wished to obtain feedback comprise:

- the principles of the application of quantitative risk assessment (QRA) to dam safety management,
- the detailed features in the Interim Guide,
- use of overall consequence class to determine whether a flood plan is required
- use of some measure of risk to determine the level of surveillance (Brown & Gosden, 2004b)

Questionnaires were used in early 2003 to elicit the opinions from 120 dam professionals on approaches to incident reporting (Gosden and Brown, 2004) and the possibilities for the early detection of internal erosion (Brown & Gosden, 2004b), achieving a response rate of 43%. However, questionnaires on a proposed draft strategy for early detection of internal erosion given out at a BDS meeting and accompanying material on the BDS website only achieved two responses.

It was therefore decided that a proactive approach would be adopted to obtain feedback, with the first step being a number of face to face feedback sessions with selected All Reservoirs Panel Engineers. At these sessions a short (two page) questionnaire was handed out at the end of the meeting for later completion, both to obtain a written summary but also to allow feedback to be sent directly to Defra and thus to remain anonymous to the authors of the Guide. This questionnaire was also sent to all other Inspecting Engineers and the Reservoir Safety Managers of major dam owners.

FEEDBACK OBTAINED

Eight face to face meetings were held, two with groups of independents and six with all the Panel AR Engineers at a particular consulting engineering company. Each meeting typically lasted about three hours and comprised about one third the presentation of the author's experience with the application of the Interim Guide and two thirds, structured discussion on the experiences of the other attendees with the Guide. It is noted that these

were carried out under a Defra research contract which was novated to Jacobs Babtie in December 2005, along with the TUPE transfer of consultancy staff. As well as feedback on the use of the Interim Guide, the sessions provided an opportunity to resolve queries on the Interim Guide and discuss the level of accuracy of particular elements of the calculations.

Questionnaires were sent to all Inspecting Engineers, and the Reservoir Safety Managers of the companies who own the greatest number of dams, with responses as shown in Table 1.

Table 1: Summary of numbers of feedback questionnaires

Group	Number		% response
	In group	Returning questionnaire	
Panel AR attending face to face meeting	18*	8	44%
Panel Engineer who did not attend meeting (AR, NI, SR), for whom email address available	36	8	22%
Reservoir safety managers for major dam owners	13	3	23%
Total	67	19	28%

* 30 invited, some could not attend.

SUMMARY OF FEEDBACK FROM MEETINGS AND QUESTIONNAIRE

Use of QRA for reservoirs

All respondents considered that the use of a rapid (screening level) method of quantitative risk assessment for reservoirs should be encouraged. Half had used the Interim Guide for Inspections and a further 26% in some other context. Only three respondents had used the ALARP approach to determine upgrading works. In terms of promoting use of the Interim Guide as part of a Section 10 Inspection 56% had a strong or slight preference for this, 11% were neutral and the remaining 33% would not promote its use as part of a Section 10 Inspection. Comments generally supported the principle of QRA, but included a “note on client resistance”, and the wish for “a simple non computer based system”.

Excel workbook

The great majority found the workbook complicated initially, often preventing them using it, or requiring several determined attempts. However, in general once they had managed to put aside some uninterrupted time to work through it they found it useful, with 70% of those using the

workbook having unprotected the sheet and modified it for their own use. It was generally felt that it would take about 2 days to complete the assessment for a dam, once familiar with the workbook. Feedback on the format of the spreadsheets is given in Table 2; the majority of those who had used the workbook considered that only minor improvements were required.

Table 2: Summary of feedback on format of Excel spreadsheets

Sheets relating to	Feedback score			
	0	1	2	Blank
Probability of failure (Sheets 2 - 7)	1	6	3	9
Consequences of failure (Sheets 8-10)	1	7	2	9
The tolerability of risk (Sheets 11-12)	3	5	2	9

Note: Score : 0- means no immediate improvement required to Interim Guide; 1- minor changes; 2- major changes;

In terms of ease of use the majority asking for the spreadsheets to be made simpler, although all but one of the respondents considered that some form of workbook was worthwhile. The approach of colour coding in yellow the essential data input cells was considered very helpful, with some respondents just completing these as an initial pass, to gain an overview of the workbook. Suggestions of how to make it more user friendly included

- adding a “black box” interface from which prompts asked for specific data,
- adding more comments within workbook cells,
- providing the facility to skip sheets where not applicable e.g. no upstream reservoir, spillway designed to pass PMF with full wave freeboard and no risk of blockage where probability of failure would be less than 10^{-6}/ annum
- adding more explanation within the sheets.

Technical content

In terms of the improvements required to the technical content the response is summarized in Table 3. It can be seen that of those who completed this section the majority felt no, or only minor, changes were required. The responses to Q10, asking for comments on features that need improvement and how this could be done were generally limited to criticism of particular features, rather than providing any suggestions of how improvement could be made. This outcome is probably a reflection that the Interim Guide has only been available for one year, most respondents are starting to explore its use and have not yet had time to formulate opinions of the reliability and uncertainty of estimates made by the workbook.

Extension of the Interim Guide to Concrete Dams and Service Reservoirs

The questionnaire also asked what priority should be put on extending the Interim Guide to concrete and masonry dams, and service reservoirs, with the responses as shown in Table 4. Twelve and eight respondents respectively considered this should be by collecting data on historical incidents and developing event trains and associated guidance; the remainder leaving this question blank. There is some ambiguity in the question, but the majority indicated this should be in the medium term, implying there was a desire that a supplement covering these should be issued in advance of the review and updating of the Interim Guide.

Table 3: Summary of feedback on technical content in Interim Guide

Element of calculation in workbook (Section number; ref Figure A.1 in Interim Guide)	Feedback score			Blank	Research priority (R)
	0	1	2		
Event trains (Sections 2.2, 2.7.1, sheets 2.2, 3.2, 4.2, 5.2, 6.2, 6.3)	4	6	3	6	1
Annual probability of failure due to extreme rainfall (S 2)	3	7	2	7	1
Annual probability of failure due to upstream reservoir (S 3)	5	6	1	7	1
Annual probability of failure due to internal threats (S 4, 5)	1	11	1	6	4
Inclusion of other threats (S 6)	3	7	3	6	0
Rapid inundation analysis (S 8)	1	6	4	8	3
Consequence assessment – likely loss of life (S 9)	2	6	3	8	3
Consequence assessment – third part damage £M (S 10)	2	6	3	8	1
Assessment of "tolerable risk" (S 11)	5	4	3	7	1

Key: Feedback Score 0- means no immediate improvement required to Interim Guide; 1- minor changes; 2- major changes;

R - the priority order for future research (the number of responses putting this element in the top three, noting that only 8 respondents completed any of this question; with one noting it was too early to say)

Table 4: Summary of feedback on priority for extending to concrete/ masonry dams and service reservoirs

	Not required	Medium term	Prior to issue of definitive Guide	Left blank
Concrete/ masonry dams	1	9	5	4
Service reservoirs	7	7	1	4

IMPROVEMENTS IN RESERVOIRS

Risk management of UK reservoirs

The other key area for feedback was the extent to which quantified estimates of risk should be used to determine dam safety management issues, such as which reservoirs should have flood plans and the level of surveillance for internal erosion (Brown & Gosden, 2004b). The feedback for these is summarised in Table 5.

It can be seen that there are approximately equal numbers supporting Consequence Class and risk, as alternative criteria to determine which reservoirs should have flood plans. In relation to the basis for determining surveillance there is a wide disparity of views, with 50% giving "other criteria" and the remainder spread over the three options in the questionnaire. The suggestions for "other" for the level of surveillance included

- "amplification of condition" to include vulnerability to erosion,
- judgement of the panel engineer
- while risk is the theoretically best criterion, I do not have sufficient confidence in the assessment of risk to advocate using it in this way.

Table 5: Summary of feedback on criteria to determine level of measure to control risk from a dam

Preferred dam classification system	Determine which reservoirs have flood plans?	Determine the level of surveillance?
Overall Consequence Class (A1 to D)	9	3
Conseq. Class x Condition	Not app	1
Risk (probability of failure x conseq.)	7	4
Other	0	7
Left blank	3	4

OTHER SOURCES OF FEEDBACK

Experience in application of QRA

Early experience comprised a trial of the prototype system on ten dams, written up in a research report on the Defra website (KBR, 2002) and for Dam 4 in Brown & Gosden (2005). Since the launch of the Interim Guide several major dam owners are using the system in a variety of ways, including as part of Section 10 Inspections (Gosden & Dutton, 2006), to prioritise surveillance and to produce a portfolio risk assessment. The authors also now routinely use the consequences element as part of Section 10 Inspections, to provide the dam consequence category which is then used to inform the decision as to which recommendations made in an inspection are "in the interests of safety". This has identified a number of areas for improvement, the main points being:

Section	
2	A methodology for quantifying the risk of flows down the spillway chute causing failure by scour along the sides of the structure (Row 24 in sheet 2.3)
4, 5	More detailed guidance is required on scoring current condition, to deal with both indicators smaller than the guide value and where the magnitude of the indicator is not known
8	In some cases the attenuation length, la, over which flow attenuates to 37% of its initial value is excessively long (in excess of 100km)
9	More detailed guidance would be helpful in estimating the number of houses, area of non-residential property and population at risk

Review of technical aspects

Eddleston & Carter (2006) present a comparison of three methods of estimating the annual probability of failure due to internal threats, one being that given in the Interim Guide. It is noted that the UK experience of a large number of serious incidents leading to emergency drawdown with few failures leads to a modest annual probability of failure for dams in current condition score 8. This relies on a high standard of surveillance and prompt intervention, as some of these incidents would have developed into failure if there had been no intervention.

Ackers et al (2006) present an updated summary of detailed inundation analysis, including valuable case history data on the attenuation length estimated from detailed dambreak.

Guide to Emergency planning

In developing the forthcoming Engineering Guide to Emergency Planning (Brown & Gosden, 2006) the authors have applied the consequence elements of the QRA workbook to the example to be included with the Guide to Emergency Planning. This has provided useful feedback on technical aspects of the consequences estimation, which it is anticipated will be published as a supplement to the Interim Guide.

DISCUSSION

The following text sets out the authors' views on the possible ways in which the Interim Guide could be improved. These are to promote debate, and hopefully promote detailed feedback to Defra by others, using the sheet on page xiii of the Interim Guide.

Benefits of QRA for dam safety management

Some of the strategic drivers for QRA were given in Brown and Gosden (2002); including the benefits of a documented safety case for dam operation, and transparency in the level of risk which is considered tolerable. At an operational level QRA provides value in

- promoting critical consideration of potential modes of failure
- determining which recommendations in a Section 10 Inspection under the Reservoirs Act should be in "the interests of safety"?
- determining which upgrading measures are proportionate in terms of cost relative to the reduction in risk achieved (ALARP analysis)?
- targeting the surveillance regime, and other dam safety management measures
- for commercial companies, to rank risk from their dams with the other infrastructure that they are responsible for

The feedback supported this view of the potential benefits of QRA, whilst requiring further experience of the use of QRA to decide whether the Interim Guide in its current state was the vehicle to deliver them.

What is a proportionate level of technical detail in analysis?

QRA can be carried out at many different levels of detail and sophistication, with a categorisation of risk analysis levels given by McCann (1998) reproduced in Table 6. The authors' suggest that the Interim Guide is intended to be a screening level of quantitative analysis, appropriate for use as part of Section 10 Inspection and/ or portfolio risk assessment on most UK dams and not taking more than say two days to complete. As such it would be equivalent to Levels 2 to 3 in Table 6. On this basis it might be argued that CIRIA Report C542 (2000) represents Level 1 in Table 6.

Table 6 : Summary of risk analysis levels as McCann, 1998

	Level	Scope/ Application
1	Scoping	Qualitative assessment of failure modes
2	Ranking	Quantitative analysis of all elements of a risk analysis
3	Detailed	Results can be used to justify dam safety modifications
4	Comprehensive	A higher degree of defensibility than level 3
5	Full scope	Where the highest degree of defensibility is required due to the level of consequences ($billions), the technical complexity

Some of the feedback suggests that the respondents consider the analysis in the Interim Guide is too complex; although the comments often do not differentiate between the technical content and the format of the

spreadsheet. It is therefore unclear whether the feedback suggests QRA at this level should not be used for inspections, or whether the use of Excel as a medium for calculations is too complex.

Various tests to assess whether the technical complexity of the analysis incorporated in the spreadsheet is appropriate for use in a Section 10 Inspection are discussed below:

1. One comparison is with the rapid method for floods, which comprises six sheets in Floods and Reservoir Safety (ICE, 1996). The Interim Guide may be viewed as comprising nine separate calculations, five relating to probability of failure from different threats, three relating to consequences and one of tolerability of risk. The 57 sheets in Appendix C of the Interim Guide therefore represent an average of 6.3 sheets per calculation, comparable with the rapid method for floods.
2. Another test is to consider what would be a reasonable cost and complexity for a periodic (10 yearly) safety review of a hazardous installation which if it failed could lead to loss of life. An additional two days to add QRA does not seem excessive. The total time for an Inspection is likely to be less than the time spent on comparable safety reviews in the chemical industry. It is marginally less than required for a principal bridge inspection (Highways Agency, 1994, 1995), which has a six year inspection cycle and is applied to all the many hundred of thousands of bridges in UK. It is acknowledged that the cost of a QRA assessment is probably disproportionate for a Category C or D dam, but the author's experience is that a significant proportion of such dams when the consequences are assessed quantitatively often move up to be Category B.
3. A third test is the level of detail adopted overseas. As well as the Interim Guide there have been three other recent publications on estimation of risk posed by dams, namely the ANCOLD Guidelines (2003), Risk and Uncertainty in dam safety (Hartford, 2004) and ICOLD Bulletin 130 (2005). Of these only the Interim Guide provides a spreadsheet methodology, with the others limited to principles only; generally implying a more complex analysis.

On balance the authors consider that the level of analysis is appropriate for most UK reservoirs as part of a Section 10 Inspection, or portfolio risk analysis. Where a dam retaining a reservoir is Category C or D, and there is a documented auditable case for this, then it may be reasonable to either rely on judgment alone, or perhaps carry out a qualitative analysis, using the event trains only.

Future research and development

The main item identified from the feedback is the need to extend the Interim Guide to cover concrete and masonry dams, preferably by the issue of a supplement prior to issue of the definitive Guide.

Excel workbook with the Interim Guide to QRA

Most of the comment relates to the format and ease of use of the Excel workbook included with the Interim Guide. Table 7 sets out three options, at a strategic level, for improving the ease of use of the spreadsheet. The feedback favoured Option 2. The choice then reduces to the style to be adopted which the majority would favour. Design of the structure of the existing workbook took the view that

a) the input data was all input in Section 1, except that
b) input data which has a large effect on the analysis was better located in the sheet where the calculation took place (to facilitate the role of judgement, by seeing the effect of the input assumption on the output).

It is suggested that as part of the review of the Interim Guide a number of options for the structure and format of the Excel workbook be identified, and subjected to a consultation process to identify the option which the majority preferred.

Table 7 : Strategic options for improving ease of use of Excel workbook with the Interim Guide

	Option	Comment
1	Delete spreadsheet, rely on description of principle only	The feedback was overwhelming against this
2	Improve spreadsheet format and ease of use	The advantage of the spreadsheet approach is that it can be reviewed and edited by all those involved in the safety analysis, and does not require “specialist operators”. Moreover it can readily be edited to suit an individual dam. It does, however, require familiarity and comfort in working in Excel.
3	Turn workbook into a black box, with simplified input requirements (similar to commercial software for slope stability and retaining wall analysis)	This would make it more difficult for the engineer to exercise his judgment, as the analysis could not be easily amended to suit the individual dam. This is therefore not favoured

SUMMARY AND CONCLUSIONS

This paper has summarised both preliminary feedback on the use of the Interim Guide, based on a series of face to face meetings and a questionnaire, and ongoing use of the Interim Guide which is providing additional feedback. This shows significant support for use of QRA for UK reservoirs. In relation to the Interim Guide 76% have used it in some context and 55% of respondents would promote its use as part of a Section 10 Inspection. Persistence is needed to use the Excel workbook included with the Interim Guide; all those who used the workbook considering it worthwhile with 70% of these having unprotected the workbook and modified it for their own use. It was generally considered that once familiar with the system it takes about 2 days to complete the assessment for a dam.

The paper then discussed feedback on ways in which the Interim Guide can be improved, the majority considering that only minor changes are required before the Interim Guide is reviewed and finalised. It is noted that the feedback suggests that a supplement should be issued prior to review of the Interim Guide, to cover concrete and masonry dams.

Finally there is a spread of views on the extent to which QRA should be used to determine the type and magnitude of dam safety measures, with approximately equal numbers supporting risk and consequence class for flood plans, and no clear outcome to determine the level of surveillance.

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