Reservoir safety risk assessment – a new guide

Mark Morris[1,2], Mike Wallis[1], Alan Brown[3], David Bowles[4], John Gosden[3], Dr Andy Hughes[5], Alex Topple[1], Paul Sayers[6] and Keith Gardiner[7]

[1] HR Wallingford
[2] Samui France
[3] Jacobs Engineering UK Ltd
[4] RAC Engineers and Economists
[5] Atkins Ltd
[6] Sayers and Partners
[7] United Utilities

Presented at the British Dam Society Annual Conference, Leeds, 2012

Abstract

Since the House of Lords Select Committee review of dam safety in 1982 there have been various attempts to introduce a more quantified approach to the assessment of dams and reservoirs, including the CIRIA guide to risk assessment methods for UK reservoirs and the Interim Guide to Quantitative risk assessment for UK reservoirs. Unfortunately none of these have gained universal acceptance. The need for a commonly agreed and widely accepted risk assessment method for reservoir safety is now a pressing requirement, both in terms of supporting asset and business management as well as minimising risk to lives and the environment and the increasing use of a risk based approach in government management and regulation of risk to society (HSE, 2001).

The main objective of this project is to develop a risk assessment method that is technically robust, scalable and proportionate across the wide range of UK reservoirs. This paper reports on the framework and associated methods that have built upon existing Environment Agency, British Standards (and other) concepts and projects, providing continuity of assessment from small flood control structures through to large dams. The methodology has evolved through initial scoping, method development and pilot testing, taking into account industry feedback via questionnaires and a series of team and industry workshops.

Introduction

Following a recommendation by the House of Lords Select Committee review on dam safety in 1982, there have been various attempts to introduce a more quantified approach to the assessment of dams and reservoirs, including the CIRIA guide to risk management for UK reservoirs (Hughes et al., 2000) and the Interim Guide to Quantitative risk assessment for UK reservoirs (Brown and Gosden, 2004). Unfortunately none of these have gained universal acceptance and the need for a commonly agreed and widely accepted risk assessment method is now a pressing requirement. Publication of Reducing Risk Protecting People (HSE, 2001) provides a good basis for risk evaluation, whilst Implementation of the Flood and Water Management Act (2010) (HMSO, 2010) introduces the concept of applying risk based approaches for reservoir safety management.

Project aims

The principal objective of the project was to develop a risk assessment method that was technically robust, scalable and proportionate across the wide range of reservoirs found in England and Wales, but also generally applicable in the UK. The framework and associated methods were to build upon both existing Environment Agency concepts, including the approach for fluvial and coastal risk assessment, and practice in the reservoir safety management both in UK and internationally. Critically, the approach should be of value to, and widely accepted by, owners and practitioners within the dams industry.

Key challenges

One of the key challenges was to provide a proportionate approach to support reservoir safety management suitable for both a small dam (or flood defence structure) with, for example, one house at risk of shallow inundation damage in event of dam failure, through to a large reservoir above a major urban conurbation with the potential for the loss of many lives and major structural damage to buildings. This led to the adoption of a tiered approach as described in subsequent sections. The second was the wide range of attitudes to the use of quantitative risk assessment (QRA) by the UK dams industry (owners and panel engineers), which led to the definition of Tier 1 as being a qualitative assessment.

Intended users

The guide is intended to provide practical advice and guidance to anyone who wishes to use and apply methods of risk analysis, assessment and management to reservoirs in England and Wales. It provides:

- an introduction to and explanation of a framework for reservoir safety risk management, as the context within which reservoir safety risk assessment is applied;
- an explanation of a tiered and proportionate approach to using risk assessment methods to support reservoir safety management – whether for an Owner of a single, small earth dam or a multinational organisation responsible for many different types and sizes of dams and reservoirs;
- a tiered, structured procedure for potential failure modes identification as a preliminary step in all risk assessments;
- an explanation of and reference to potential tools and approaches for predicting (i) internal and external threats and loads; (ii) reservoir and dam response; (iii) release, routing and consequences of flood water from reservoirs;
- guidance that may be used by *Reservoir Owners*, *Inspecting Engineers* and *Supervising Engineers* to assist in using the outcomes of risk assessment for managing reservoir safety and to meet the requirements of legislation in England and Wales;
- guidance that supports *Reservoir Owners t*o assist in using the outcomes of risk assessment in managing operational and management risks efficiently and effectively;
- worked examples for a variety of pilot site applications.

Figure 1 shows the key routine and non-routine activities conducted under existing UK reservoir safety practice with the decision points (diamond shapes) that can be informed using the outcomes from risk assessment. The initial screening stage allows Owners to establish whether or not their reservoir(s) pose a risk such that they might require a more formal risk assessment (i.e. use of the guide).

By following the processes shown, the impact of potential measures taken on reservoir safety risk can be assessed. Many of the risk assessment activities can be undertaken as part of the existing inspection and management process. Year-to-year changes in the assessed risk posed by a given reservoir can be recorded alongside expenditure in managing risks (surveillance, measures taken, etc). Such recording of activities and tracking of changes in risk and expenditure may be of interest especially to owners of portfolios of reservoirs, and should be encouraged as good practice

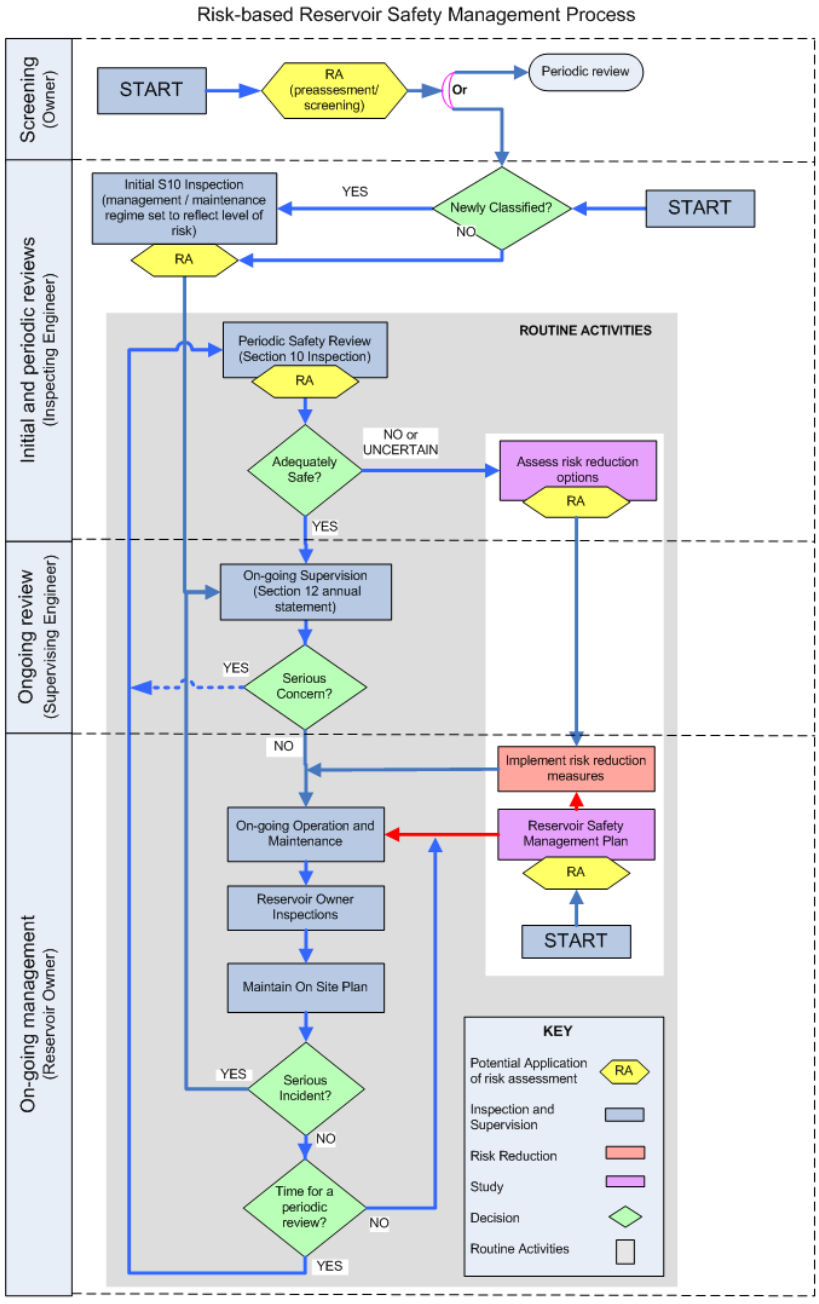

Figure 1: UK reservoir safety management process illustrating the potential role of risk assessment in decision making

The value of applying risk assessment methods includes:

- demonstration that 'good endeavours' and procedures have been used to ensure that risks, and risks to the public, are as low as reasonably practicable and tolerable
- to improve and inform the dam risk management process and ultimately to improve reservoir safety as well as business risk management
- to programme works, to justify funding for both maintenance and capital expenditure, to prioritise and justify urgency of works, and to identify where the largest benefits and greatest reductions in risk can be achieved
- to build a defensible business and safety case, particularly for owners with large portfolios of reservoirs, but even perhaps for the owner of a single dam where there are conflicting demands on resources
- identification of potential modes of failure (now recognised as good practice in the UK and overseas), which is then used to target activities including surveillance and monitoring
- the likelihood and consequences of failure to be related to other risks facing their organisation and to communicate this to stakeholders
- use by Inspecting Engineers to carry out their responsibilities as part of S10 periodic safety reviews, post-incident reviews and proposed risk reduction measure approval, supervision and post-implementation review S10(6).

The guide has been structured so that it offers guidance that is aligned with current reservoir safety regulation for England and Wales, but which should also be widely applicable for the UK and which can be updated in a modular fashion as aspects of practice or policy evolve. It should be noted that it is not a legal requirement to apply these methods as part of reservoir safety management in England and Wales.

Framework for analysis

The level of detail included in a risk assessment should depend on the level of confidence that is required to support various types of reservoir safety decisions. This can be expected to vary with the level of risk posed by a specific reservoir and the Inspecting Engineer's and Owner's requirements for confidence and defensibility in supporting their decisions. The guide therefore uses a tiered approach to risk assessment. The different tiers in this approach provide tools and methods that are proportionate, in terms of level of effort required, detail considered, and confidence in their outcomes. Table 1 provides a summary of the tiered approach. Tier 1 is the simplest approach, comprising a qualitative assessment of risk; Tier 2 introduces basic quantitative analysis and Tier 3 more detailed quantitative methods. Failure modes identification (FMI) underlies each of the Tiered approaches.

This framework and its associated tools and methods provide an approach that allows the Reservoir Owner, Inspecting Engineer and Supervising Engineer to better understand and evaluate reservoir safety risk in a structured way. This in turn allows for risk-based decision making - that reduce risks to people, the environment, the economy and the owner, while maintaining an important reference to accepted good practice.

Table 1: Tiered analysis

Tier	Type of Risk Assessment	Description
1	Qualitative	Ranking of potential failure modes, and order of magnitude likelihood and consequences using a descriptive risk matrix. Optional sensitivity analysis.
2	Simplified Quantitative	Threshold analysis using hand calculations i.e. with basic calculator. Optional sensitivity analysis.
3	Detailed Quantitative	Range of levels. Include system response curves, with range of initiating events (threats) using computer software for risk calculations. Uncertainty dealt with by formal sensitivity to full uncertainty analysis.

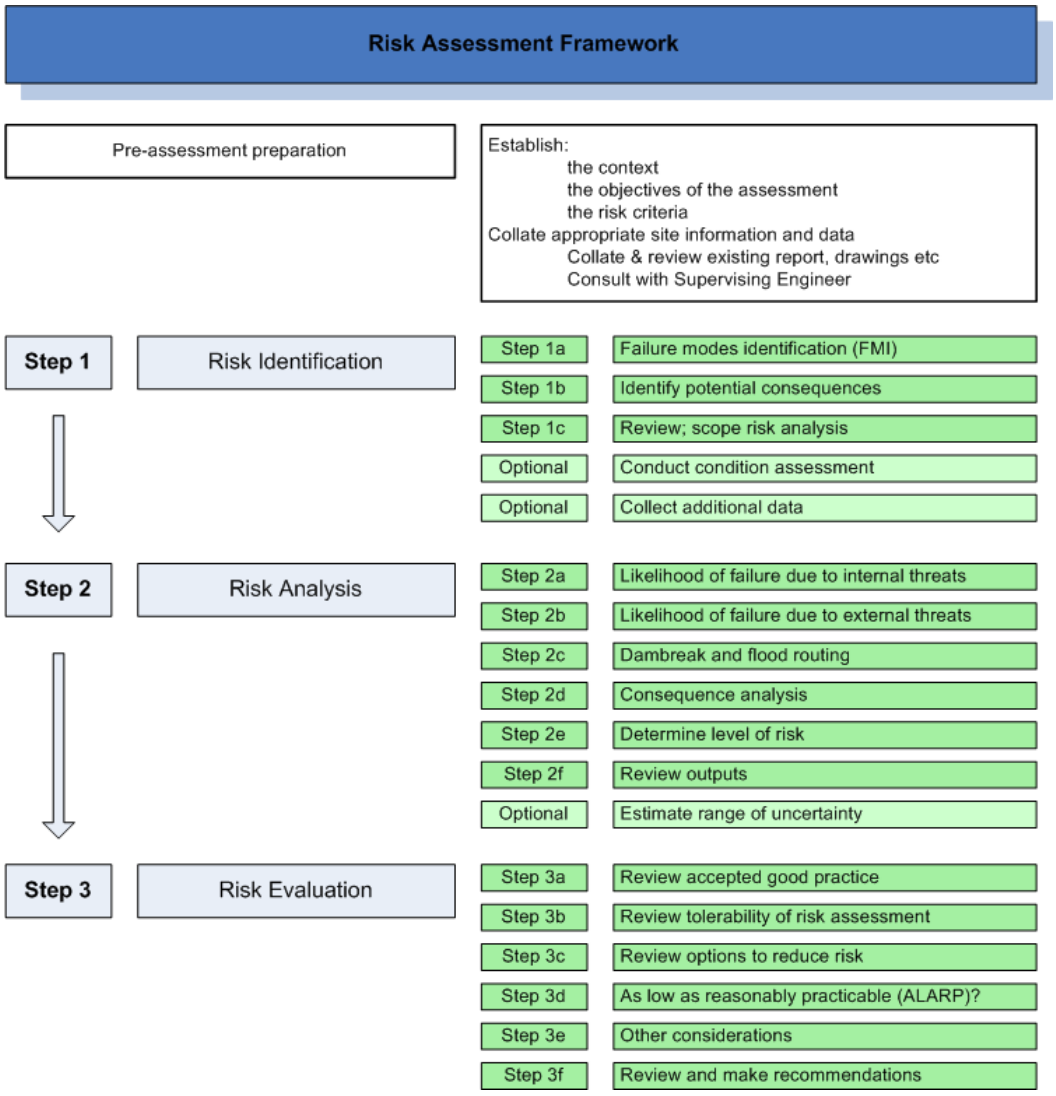

Figure 2: The basic steps in a risk assessment process

Figure 2 shows the basic and expanded steps that feature in the risk assessment process; the basic steps of risk identification, analysis and evaluation are consistent with the UK flood risk management framework (Environment Agency, 2004) and the British Standard BS EN 31010:2010, on risk assessment techniques.

Note that the same steps apply under each of the three proposed tiers of analysis, but the complexity of analysis differs between the tiers.

Pre-assessment and screening

The pre assessment preparation sets out what level of assessment is required and what level of confidence is required in the results. It should include a clear definition of its purpose. This includes identification of the decisions that the results of the risk assessment are intended to inform, including all decision bases and the desired level of confidence as determined by the Reservoir Owner and other stakeholders.

In order to undertake the risk assessment it is important to identify and collate information on the dam. The amount of information available will vary enormously from site to site. Consulting with the Supervising Engineer will identify any issues of concern, and it is considered an essential part of the process of gathering information for the risk assessment.

STEP 1 – Risk Identification

The first step in the process of risk assessment is selecting the extent and level of detail or complexity for the risk assessment. In this process, potential failure modes are considered, including the relationship between each failure mode, and the types of consequences of failure. This step also includes the determination of the system loading conditions that are to be used in the risk analysis – the next step.

STEP 2 – Risk Analysis

Risk analysis involves an estimation of the level of risk. It involves performing calculations using the probability and consequences estimates to obtain estimates of the probabilities and consequences for all significant failure modes, and to present results in a suitable format so that they can be readily interpreted and used to support reservoir safety decision-making. Traditional engineering analysis, reliability analysis and engineering experience and judgement are all important in estimating these system responses.

STEP 3 – Risk Evaluation

The process of examining and judging the significance of the estimated risk is termed risk evaluation. Having calculated the risks, what do they mean and how does one use this information?

It is important to note that in each of these steps some actions are optional and maybe appropriate for certain types of reservoir or Owner only.

Choosing and applying the risk analysis methods

How to select your tier of assessment

The choice of which Tier of risk assessment should be undertaken for a particular reservoir will depend upon a number of factors including the magnitude of the risk, especially the potential consequences, and hence the level of confidence with which the risk assessment should be conducted. Thus Tier 1 will likely be sufficient for small reservoirs in remote areas with small potential consequences whereas as large capacity reservoir with a high dam and very large potential consequences of failure will likely require the level of confidence that only a Tier 3 assessment can provide. Exceptions might be that a Tier 1 assessment might be sufficient for the large reservoir as an initial assessment to prioritise investments in future efforts for more detailed risk assessment including supporting studies, and for risk reduction actions. It is worth noting that initial risk assessments that have been completed as portfolio risk assessments for large reservoirs in the UK have generally been conducted at a level of detail in the range of Tier 2 to entry-level Tier 3.

The Tier 1 analysis provides a simple, systematic but effective and transparent method. Much of the effort needed to conduct a Tier 1 analysis is typical of what might be expected to be undertaken by an Inspecting Engineer when performing a Section 10 Inspection. The process works through a failure modes identification process and a qualitative assessment of risk. This can be performed relatively quickly and provides a base assessment of risk which will help identify whether the reservoir has any risk issues of concern. Where the potential for high risk exists, this may suggest that a more detailed Tier 2 or 3 assessments would be appropriate to resolve uncertainties and support management decisions.

A Tier 2 analysis provides a base quantitative estimate of reservoir risk, whereas a Tier 1 analysis provides a qualitative estimate. A Tier 2 level of analysis may be undertaken when risk issues have been identified at a Tier 1 level, or it may selected as the initial level of risk assessment when the risk needs to be quantified to support appropriate management actions.

The Tier 3 analysis introduces more complex methods for analysing failure modes and associated consequences and interdependencies between them. This level of analysis entails the use of more complex models and more in-depth methods for identifying potential failure modes and the integration of these analyses within the overall assessment of risk. The extent to which the analyses may be undertaken varies, and will depend upon the desired level of understanding and confidence desired for decision making. The effort required for analysis in each of the Tiers is generally proportionate to the level of risk. A Tier 3 level of analysis is may be undertaken where an earlier Tier 1 or 2 analyses has identified high potential risks and the magnitude of these risks justifies the effort required to analyse and reduce the uncertainties around the prediction, so supporting management decisions and risk reduction actions. In some case a Tier 3 analysis may be selected as the initial level of analysis.

In conclusion, it is anticipated that most UK reservoirs will have a Tier 1 or Tier 2 level of analysis to quantify the risks. Tier 3 methods will only be appropriate for selected reservoirs where risks and uncertainties are high, so justifying the effort required for the more detailed assessment to achieve a higher level of confidence in decision making.

A Tier 1 analysis

A Tier 1 risk assessment might be undertaken routinely for all reservoirs as an initial assessment and data collection exercise. A key step in the Tier 1 analysis is undertaking a Failure Modes Identification process for

defined core failure modes. Having reviewed the different potential failure modes, qualitative descriptions of the failure likelihood and failure consequences for these different failure modes are mapped onto a simple risk matrix (Figure 3**Error! Reference source not found.**). Guidance is provided on how to assess the likelihood and consequences of different load conditions and failure processes for a dam, building from expert judgement of the conditions. This provides a simple, systematic but effective and transparent method for identifying risks.

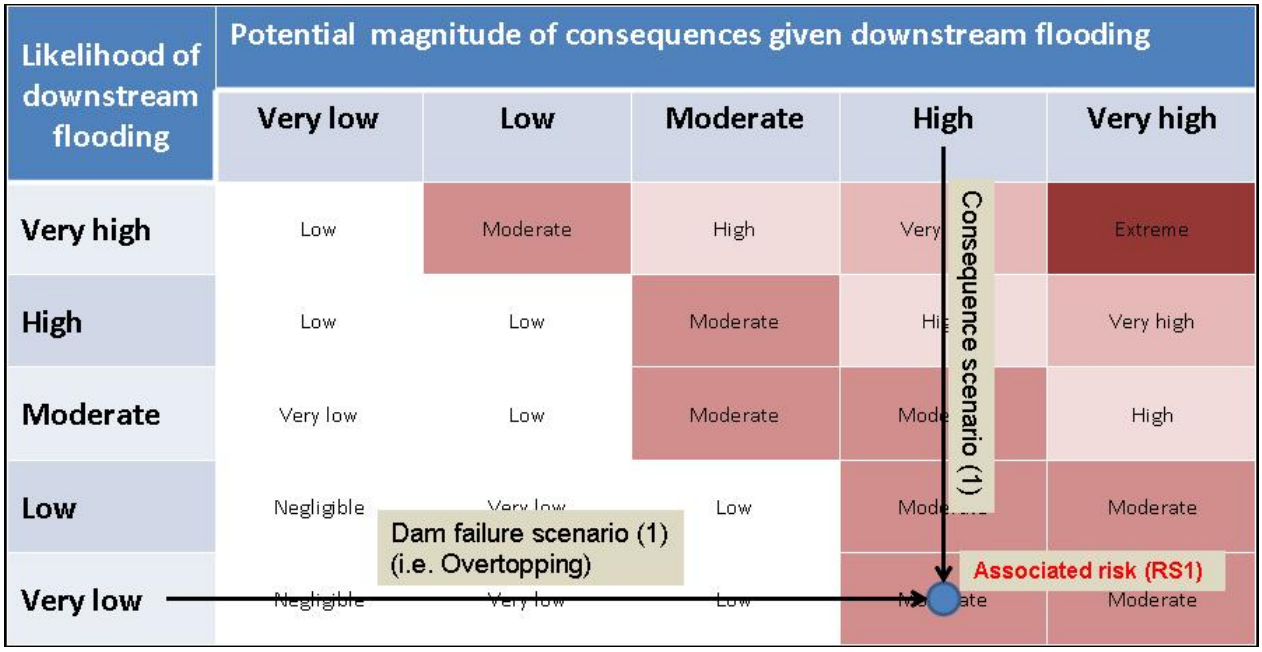

Figure 3: The Tier 1 risk matrix

A Tier 2 analysis

The Tier 2 risk assessment builds from the analysis undertaken in Tier 1 and is undertaken where a quantitative rather than qualitative assessment of risk is required. A Tier 2 risk assessment starts with a FMI analysis, as do all tiers, however, the level of FMI analysis for Tiers 2 and 3 is more detailed than for Tier 1). The Tier 2 assessment comprises a simple quantitative assessment of risk using existing available data. The assessment comprises a number of steps of analysis, including items such as estimating probability of failure due to external, internal and other threats; assessing the hydraulics of dam break and flood routing; estimation of economic damages and likely loss of life; risk analysis calculation and tolerable risk evaluation, including ALARP assessment. Each of these steps are undertaken using simple or simplified methods that allow the overall assessment to be undertaken within 1-2 per days effort and without the need for analysis software. As with Tier 1, some of the Tier 2 steps are optional and not essential for the risk assessment.

Typical outputs from a Tier 2 analysis include FN curves showing the annual probability of failure versus fatalities and plots of risk versus annual event probability, showing potential economic, environment, loss of life etc. damages.

A Tier 3 analysis

A Tier 3 risk assessment builds from the analysis undertaken for a Tier 2 (and hence also a Tier 1) analysis. A Tier 3 analysis would be undertaken where a Tier 2 analysis has identified areas of concern and a more detailed understanding of the risks, and the uncertainties involved, is required in order to support decision making. It can also be the starting point for risk analysis if it was recognised that this level of analysis was needed from the outset.

A Tier 3 analysis comprises methods for a more detailed quantitative assessment of risk. The methods of analysis may extend to more complex numerical methods, including a more rigorous analysis of failure modes and their interdependencies using event trees, along with uncertainties. A Tier 3 analysis may also be used to identify deficiencies in knowledge and hence define areas where investigation and / or additional data are needed to support the assessment of risk. Outputs from a Tier 3 analysis are more comprehensive, allowing a range of data on specific risks to be analysed in more detail and with a greater level of confidence (e.g. Figure 4).

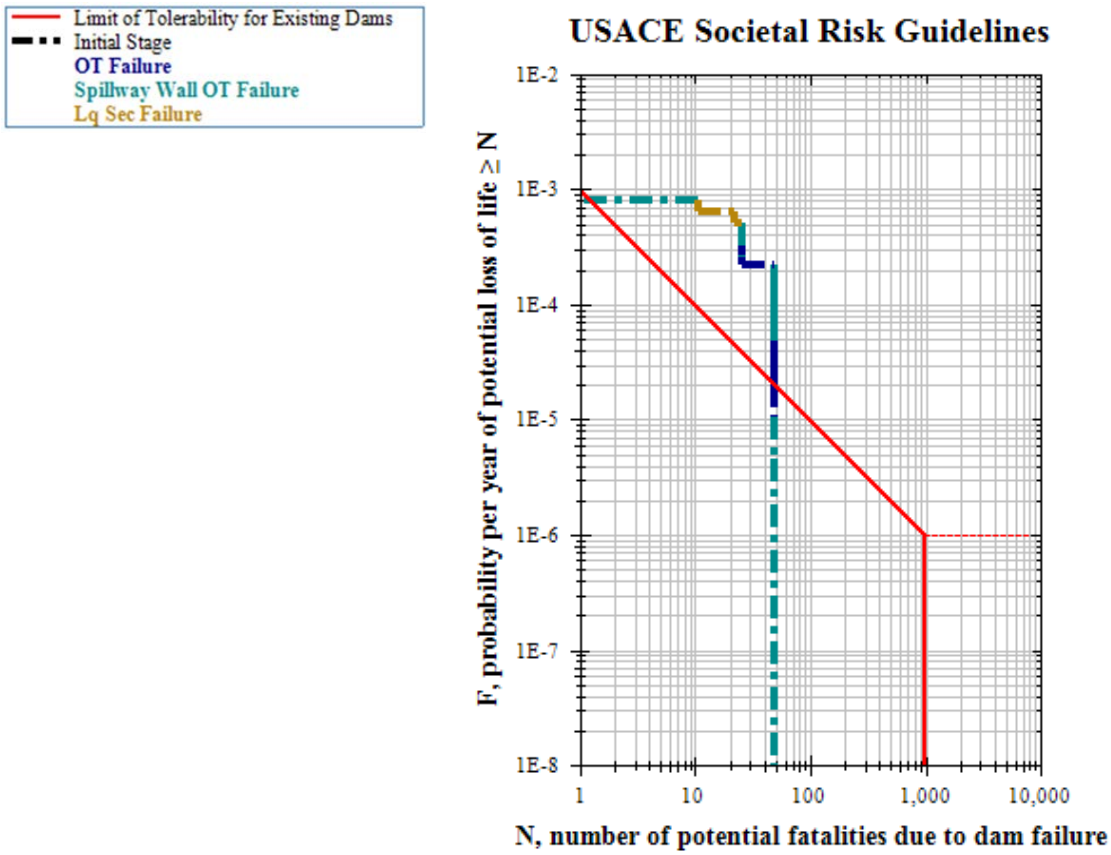

Figure 4: Example analysis for societal risk against USACE guidelines (from DAMRAE)

Pilot testing

A programme of pilot testing was also developed against which the risk assessment framework and methodologies could be evaluated and refined. At the time of writing, the pilot programme was about to be implemented.

The aim of the pilot testing was to identify a range of different dams considering parameters such as type of dam, function, age, size, consequence of failure, type of owner etc. Since a limited number of pilot studies could be funded under the original project, industry support for further pilot applications was sought. At the time of writing it appeared likely that ~14 dams would be assessed, along with additional offers to review usability of the guide.

Two phases of assessment were envisaged, namely:

Phase 1 Initial assessment of 3 reservoirs; review of methodology and refinement

Phase 2 Wider assessment of ~an additional 11 reservoirs; review of methodology and refinement

Within the pilot testing programme, efforts were also being made to compare assessments for the same dam by different assessors to assess the consistency of method applicability. At least one of these assessors was one of the project team – the other was either an owner (where technical competence is equivalent to a Supervising Engineer), an Inspecting or a Supervising Engineer. Feedback was also being sought from the assessors on the application of the methodologies and use of the guidance. This included information on, for example, ease of application, time taken to complete, difficulties encountered, the need for greater detailed guidance or for simplification. Conclusions from the pilot applications will be reported at the BDS conference 2012.

Conclusions

Considerable progress has been made in the UK over the past decade in developing risk concepts and tools to support the analysis and management of flood risk from fluvial and coastal sources. However, within the UK dams community there has not been universal acceptance of proposed methods despite initiatives such as the CIRIA guide to risk assessment and the Interim Guide.

The proposed RARS approach offers a tiered (complexity) approach of analysis, ranging from qualitative through to quantitative methods. The framework is consistent with existing reservoir safety practice in UK and internationally, Environment Agency flood risk concepts and the more general British Standard for risk assessment. The methods proposed should be of value to individual owners of small dams through to international companies owning multiple reservoirs. A programme of consultation, including three workshops, has been included in the development programme to help ensure that different needs and perspectives are catered for.

Following pilot testing and method refinement during the summer, it is anticipated that the new guidance will be published towards the end of 2012.

References

Brown, A.J. and Gosden, J.D. (2004) *Interim guide to quantitative risk assessment for UK reservoirs,* Thomas Telford Ltd., London.

HMSO (2010). *Flood and Water Management Act 2010*. HMSO

HSE (2001) *Reducing risks; protecting people,* Health and Safety Executive (HSE), HMSO.

Hughes, A.J., Hewlett, H.W.M., Samuels, P.G., Morris, M.W., Sayers, P.B., Moffat, I., Harding, A. and Tedd, P. (2000) *Risk management for UK reservoirs,* CIRIA Report C542, CIRIA, CIRIA, London.