Department for Environment Food and Rural Affairs

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Scoping study for a guide to risk assessment of reservoirs

Report: SC070087/R1

Flood and Coastal Erosion Risk Management Research and Development Programme

The British Dam Society at the Institution of Civil Engineers

The British Dam Society aspires to be a forum for professionals involved with dams to meet and exchange ideas and to be a body of people with authority and/or interest on dam-related issues. It monitors and contributes to the agenda on the provision of technical guidance and wider research on dams for the UK and also promotes best practice in all aspects of the planning, development, maintenance and operation of dams and reservoirs.

In this context it is pleased to support the Environment Agency's production of this report as part of a programme of carefully targeted research aimed at improving the understanding of dam related issues and also the safety of the UK's stock of reservoirs, however, this does not imply endorsement of any particular report recommendations.

Current research projects are being carried out by the Environment Agency and Defra following a review of research priorities and direction by the Reservoir Safety Advisory Group (RSAG) of the Institution of Civil Engineers (ICE).

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This report is the result of research commissioned by the Environment Agency's Evidence Directorate and funded by the joint Environment Agency/Defra Flood and Coastal Erosion Risk Management Research and Development Programme.

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Miranda Kavanagh

Director of Evidence

Executive summary

The *Interim Guide to Quantitative Risk Assessment for UK Reservoirs* was published in 2004 to provide a tool for the management of reservoir safety. It provided a screening level framework for decision-making by experienced dam professionals on the annual probabilities of occurrence, consequences and tolerability of the risk of reservoir failure. The Guide was in the form of a Microsoft Excel workbook with explanatory text providing users with guidance on the methodology to be used.

The Guide was always intended to be a document which would need to be reviewed and perhaps modified after a few years of use. The scoping study described in this report is a first phase of reviewing the guide to risk assessment of reservoirs and seeks to provide reasons and evidence for a second phase.

As part of this scoping study the team sought the views of the profession, not only in trying to find out what problems had been experienced in application of the Interim Guide but also to try to establish the needs of the profession.

Ensuring acceptable performance and managing risk from dam assets in the short to longer term (through physical interventions to maintain, repair, improve or replace assets, while avoiding unnecessary expenditure) is a considerable challenge.

The concepts of risk and performance provide the dam manager with a consistent framework to analyse and understand the critical components of their dam, and the system within which it sits, and target effort in further data collation, assessment or physical intervention appropriately.

The report concludes that a second phase for the project is required and lists key stages of work for this phase. These are summarised below, and the full details can be found in the main body of the report.

1. **A framework and methodology for UK reservoir safety risk management** – to provide the philosophical foundation, principles and methodology for the procedural, analytical and management aspects of the development of a risk-informed approach to UK reservoir safety risk management. The methodology should encompass a wide range of potential purposes for reservoir safety risk assessment. It should provide for both qualitative and quantitative approaches with scalability/proportionality. A clear link will be demonstrated between the potential of the quantitative risk assessment (QRA) methodology and the implementation of dam safety inspections and recommendations for remedial works. This stage/task should be delivered in a 12-month period. It should provide an approach that satisfies the unique needs of the UK reservoir owners and other stakeholders in UK reservoirs. The framework and methodology for analysis will need to be detailed in a technical report.

2. **A structured procedure for potential failure modes identification** – to provide an immediately applicable and beneficial procedure that can be applied to all types and sizes of UK reservoirs, both as a separate tool and as a first step (or high level) within reservoir safety risk assessment. This approach is likely to be of significant help to individual owners of small earth dams and could also provide a system for supporting decision-making without the need for detailed risk assessment and evaluation. It should be delivered within the first 6 months and achieved by also coordinating with work on another science project entitled ‘Modes of Failure Scoping Study’.

3. **Supporting science on failure modes** – A key aspect of the risk analysis framework will be our ability to identify, analyse and predict failure modes arising from different combinations of load and structure response. Structure performance may be represented in the form of fragility curves. A fragility curve summarises information about the probability of failure of an engineering system, such as a dam embankment, in response to a specific range of loads (e.g. high water levels). Understanding and predicting performance requires best use of deterministic analysis, available data, expert judgement etc. This knowledge may be drawn from a range of projects and sources.

4. **A guide for UK reservoir safety risk analysis** – a simple to read and use guidance document explaining and guiding the user through the concepts, science and application of the risk-informed approach for reservoir safety management for UK reservoirs. To be delivered 6 months after completion of the framework and methodology, the guide will be suitable for a range of potential end users by providing an introduction and explanation of basic concepts and uses through to detailed application of the methods.

5. **A software tool for UK reservoir safety risk analysis** – to provide the core engine to support dam safety risk analysis calculations and hence ensure that a consistent and theoretically correct approach is available for use by reservoir engineers. This may evolve from existing software and will be delivered 6 months after completion of the framework and developed in parallel with the guidance. The software will ensure that sound science and any links to existing frameworks and relevant analysis tools/methods are addressed.

6. **Workshops for consultation** – Regular workshops, at 6-monthly intervals are envisaged to provide opportunities for consultation during development of the framework, methodology, software and guidance.

7. **Workshops for training** – These workshops are spread across the 24-month duration at key points in concept and tool/method development.

8. **Pilot site application** – It will be important to identify a number of exemplar sites for use in developing, testing and piloting the QRA method. The QRA project will develop a specification for this once the initial framework has evolved, allowing flexibility in identifying key issues that exemplar sites should address. It is considered that a minimum of six different sites need to be identified and used to support development and testing.

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1 This study

This project was initially let by Defra to revise the ‘Interim Guide to Quantitative Risk Assessment for UK Reservoirs’, published by Thomas Telford in 2004. Atkins offered an approach using a ‘team’ built up of Atkins, HR Wallingford and Dr David Bowles to carry out the work.

Subsequently, as a result of changes in the management of research projects, Atkins and the associated team were asked by the Environment Agency to produce a scoping study to define the needs of a second phase to actually produce ‘a revised guide’.

The project was managed by Atkins over the period April 2008 to April 2009.

2 Introduction

2.1 Background

Ensuring acceptable performance and managing risk from dam assets in the short to longer term (through physical interventions to maintain, repair, improve or replace assets, while avoiding unnecessary expenditure) is a considerable challenge. The wide variety in dam types and forms and physical settings further complicates the task. Within the context of this complex setting, the concepts of risk and performance provide the dam manager with a consistent framework to analyse and understand the critical components of their dam, and the system within which it sits, and target effort in further data collation, assessment or physical intervention appropriately.

Over the past 20 years various organisations (CIRIA 2000, Morris *et al.* 2000, ANCOLD 2003, USSD 2003, Brown and Gosden 2004, ICOLD 2005) have been working with the dam owners to develop the principles, methods and tools to help support better dam management decision. They have recognised the need to prioritise limited investment to best effect, taking account of both the cost and benefits over the long term. In 2000 CIRIA published ‘Risk Management for UK Reservoirs, 2000’.

This provided guidance on the application of risk assessment and risk management procedures to UK reservoir practice. It was written primarily for UK reservoir owners, panel engineers, regulators, insurance companies and others concerned with reservoir safety. It was to complement the guidance that had previously been produced on floods, seismic risk, valves and pipework etc, to assist those undertaking duties in accordance with the Reservoirs Act 1975. The risk assessment methodology outlined in that report was to enable owners to rank their dams in terms of qualitative risk and hazard, and to assist them in prioritising any works needed.

Following identification of a problem with the application of the Flood Estimation Handbook (FEH) to estimate extreme floods and the implied potential for major upgrading of spillways of a significant number of UK reservoirs, a review of research needs identified a requirement to compare the risk of failure from floods with other risks to dams.

In 2001 Defra awarded a competitively bid contract to KBR to try to develop a tool which integrated approach to failures of dams from a number of threats, under the project ‘Integration of Floods and Reservoir Safety’. A prototype was developed and trialled on 10 dams with the research report (KBR 2002) available on the Defra website from 2002 to 2007. The ‘Interim Guide to Quantitative Risk Assessment for Reservoirs’ (Brown and Gosden 2004) was produced as a second stage.

The purpose of the Interim Guide was to provide a tool for the management of reservoir safety by the provision of a screening level framework for decision-making by experienced dam professionals on the annual probabilities of occurrence, consequences and tolerability of the risk of reservoir failure. The Guide was in the form of a Microsoft Excel workbook with pro forma calculations on a CD provided at the back of the Guide and accompanying explanatory text.

The Interim Guide was found to be a good first step in introducing the concept of a screening level Quantitative Risk Assessment (QRA) tool to assist in dam safety management in the UK.

However, a number of areas of improvement were identified by a number of practitioners who had used the Guide and who provided feedback to the Atkins team as part of the initial part of this study. This initial part had included a questionnaire sent out to all panel engineers and the major undertakers and owners.

To date, approaches to dam safety risk assessment have not all been solely risk based and are based on limited science. This has led to a limited uptake of risk assessment techniques. This scoping study seeks to build upon previous dam studies and, importantly, the advances made within the flood and coastal erosion risk management community (Sayers *et al.* 2002, Sayers and Meadowcroft 2005, Simm *et al.* 2008a, 2008b).

In making use of the Interim Guide to Quantitative Risk Assessment for Reservoirs in the UK a number of difficulties were experienced including those listed below:

- It was noted that the methodology was selective in the risks for which it provided ready made evaluation worksheets. However, it did invite the user to consider the criticality on non-core threats (Sheet 6.1) and provided event trains for seismic and wind threats.
- The method required familiarity with the use of Excel workbooks, which some found difficult to use, and the accompanying notes gave limited guidance on how to make decisions when required to do so and also the likely effect of those decisions on results.
- While some have felt that the Interim Guide was too complicated, it would be more accurate to state that the Interim Guide methodology was not clearly explained. In fact, some aspects of the methodology were oversimplified in a way that may distort results. For example:
    - While the event trains required consideration of all potential failure modes, they did not incorporate a robust quantitative potential failure modes analysis step.
    - It uses a dam critical event concept that does not include consideration of the range of probability of failure with magnitude of loading.
    - It uses a dam critical event concept that does not allow for consideration of multiple failure modes at a reservoir.
    - It does not provide guidance for handling failure modes associated with different dam sections for the same reservoir and non-mutually exclusive failure modes for the same dam section.
    - It does not provide for the use of fragility relationships to represent variability in estimated dam performance although it is accepted that fragility relationships/curves are a comparatively recent and difficult concept for many and are not used by many practising dam professionals.
    - The spreadsheet calculation approach is based on embankment dams and cannot be readily adapted to the range of failure modes that are important across the portfolio of UK reservoirs or for considering phased risk reduction measures, for example. This was recognised at the time it was written and stated at the time. As another example, the effects of a range of severities of spillway plugging by debris can only be considered by sensitivity analysis and not as a set of possible

conditions, weighted by their probability of occurrence, in the estimation of overall risk of failure during floods.

- Simplifications in the approach to estimating the consequences of failure, which may be appropriate in some cases, require additional sheets in the workbook if they are to be replaced by alternative approaches when these are justified.

- The underlying science was not always clear within the Guide, such that reference had to be made to the preceding research report.
- There was a lack of transparency of the underlying science.
- The method developed in 2001 was not directly consistent with government policy on risk methods and there was a lack of transparency of the underlying science.
- The scope of the Interim Guide was to compare the risk from floods with other threats to dams. It is therefore limited in applicability for the wide range of applications (see Section 9.1) for which dam safety risk assessments can be beneficially used.
- There has been difficulty in achieving consistency in the outputs by practitioners and between practitioners (i.e. if two people were trying to analyse the same dam/situation).

As a result, although the methodology is used by some members of the profession, it has not generally been widely used. The Interim Guide was always intended to be an interim document which would need review after a few years' use. As part of this scoping study the team (Atkins, HR Wallingford and David Bowles) sought the views of the profession, not only in trying to find out what problems had been experienced in application of the Interim Guide but also to try to establish the needs of the profession. Thus a review of the methodology was undertaken with United Utilities, MWH and Halcrow, all of whom had tried to apply the Interim Guide, and a programme of consultation with the profession was instigated. These actions were to investigate and confirm (or not) the issues which were thought to exist and to enable recommendations to be made as to steps needed to solve the issues.

A questionnaire was sent to all panel engineers and the larger reservoir owners, to try to establish whether they understood the concept of risk, to establish whether they felt that a guide to risk assessment would be of use, and what they would use it for, and also to ask whether they had used the Interim Guide and what, if any, problems had been experienced.

In addition, following results from the questionnaire survey, members of the team interviewed a key author of the Interim Guide (Alan Brown) to explore the issues raised and, in particular, to understand the reasoning behind the approaches used and the underpinning science. More recently a workshop was held at Atkins' offices in Epsom with an invited audience of panel engineers, owners and Alan Brown, Environment Agency representatives and other interested parties to explore what was required in any future risk assessment tool produced.

3 Terms of reference

During the period 2004–2006 Defra and its advisors sought the views of the profession on the value and use of the Interim Guide to Quantitative Risk Assessment.

In pursuing the objectives, the views of all panel engineers and the major water undertakers and owners were sought via a questionnaire which tried to establish whether the profession felt that a guide to quantitative risk assessment was required, whether they had used the Interim Guide and to what use it had been put, and whether they found the Interim Guide easy to use.

A number of meetings with Defra were held to inform them about international practice in the field which led to the request to produce a revised Guide to Quantitative Risk Assessment. The brief was very limited in as much as the Atkins team were asked to produce a revised Guide to Quantitative Risk Assessment. However, the Terms of Reference for this piece of work is for a scoping study for the work required to produce a 'new' guide.

4 The scope

The objective of the ‘revised Guide’ is to provide a framework for a risk-based approach to reservoir safety management in the UK.

It is necessary to set this within a framework for UK reservoir safety risk management which is understood and adopted by practitioners. This in itself will need to start with the introduction of the philosophy and principles of a risk-based approach but then must move on to other issues such as failure mode identification.

Hence, the proposed guide will need to not only integrate with government policy, and build on the earlier work in the Interim Guide, but through a more structured approach integrate with other research initiatives (failure modes/masonry spillways etc) and other risk-based strategies being worked on by others (e.g. flood and coastal erosion strategies).

5 Target audience

The target audience for a revised guide (i.e. revised or adapted methodology and clear user guidance) will be panel engineers undertaking their duties under the Reservoirs Act 1975 and under the proposed new Reservoirs Act. Reservoir owners are also key to the revised guide as they will be making decisions on expenditure taking into account advice from panel engineers.

In addition, it should be recognised that such a methodology will also be of interest to a wider audience including, among others, the Environment Agency Risk Policy Group, the Pitt implementation team, the Floods and Water Bill team, and the public.

6 Challenges for modern dam risk management

An effective risk assessment methodology, supporting the risk-based management of dams in the UK, needs to be flexible enough to cope with a range of different structures and proportionate in effort and analysis required to suit the assessment of simple, small structures through to complex large structures. The methodology needs to be of practicable value to different types of users and reservoir owners, from those managing individual dams, perhaps on limited budgets, through to those managing portfolios of many reservoirs with access to larger resources. In addition, any methodology needs to be consistent with wider government policy and build from lessons learnt over the past decade in the analysis and assessment of flood risk.

The following sections provide a brief summary of key factors that influence the development of a revised approach to risk assessment and management:

- Nature of dams in the UK.
- The Pitt Review.
- Forthcoming legislation.
- Lessons learnt from the Interim Guide to QRA.

6.1 Nature of dams in the UK

More than 80% of dams in the UK are earth fill embankment dams with an average height in the range of 7 to 8 metres. The maximum height of dams in the UK is of the order of 90 metres but the majority of dams are in the range of 4 to 20 metres in height. The average age of dams in the UK is now more than 110 years and there are concerns about deterioration pressure that might exist.

Water and energy utility companies are often responsible for a series of dams and reservoirs requiring a portfolio management approach. However, a majority of owners are individuals or small organisations responsible for a single dam – some 75% (1575) of the dams subject to the Reservoirs Act 1975 – often a small earth structure. Such owners are also often without access to the resources and asset management skills available to utility companies.

6.2 The Pitt Review

Recommendation 58 of the Pitt Review was that the Government should implement the legislative changes proposed in the Environment Agency biennial report on dam and reservoir safety through forthcoming flooding legislation. This recommendation was accepted by the Government and included adoption of better risk-based definitions of dams (safety assessment) within the Act.

6.3 Legislation

The Pitt Review helped advance the development and likely implementation during 2010/11 of new legislation regarding flood risk management. The Floods and Water

Bill includes a number of items affecting operation and management of dams and reservoirs. Owners of reservoirs falling within the Act will be required to follow defined inspection and operational procedures and to develop emergency action plans. While the use of a risk analysis methodology to underpin such safety procedures is unlikely to be written within the Act, any methodology which allows simple and transparent assessment of risks, supporting risk management actions, and which is proportionate to the magnitude of risk, would be beneficial.

Revisions to the Act will probably include a change in the way in which reservoirs are determined to fall within or outside legislation. The current approach defining any reservoir storing more than 25,000 m^3 of water as within the Act, will be replaced by a method based upon the risk posed by the reservoir. It is likely that all reservoirs storing more than 10,000 m^3 will be reviewed and categorised according to consequence of failure. The potential for loss of one or more lives in the event of failure may be used to categorise a ‘high risk’ dam. The effect of such legislation is that many smaller reservoirs are likely to fall within the proposed new Act, significantly increasing the number of individual dam owners for whom an effective, proportionate risk analysis method would be beneficial. Estimates suggest that the number of reservoirs falling within such legislation would rise to around 7500 from the current 2100 in England and Wales. (There are already another 760+ reservoirs in Scotland and there could be many more.)

6.4 Lessons learnt from the Interim Guide to QRA

While the Interim Guide was viewed as a good first step in introducing a screening level QRA as a tool to assist in dam safety management in the UK, it was recognised by the authors and from practitioners who responded to the questionnaire that some improvements could be made in the proposed revision.

Brown *et al.* (2008) identified a number of areas for improvement, and the questionnaire showed that the profession as a whole would like a technique that was explained in simple terms, that was easily understood, and that gave more explanation on how to apply the technique and how to make the decisions in the workbooks.

In addition, from knowledge of the use of risk assessment techniques around the world it was recognised that it would be advantageous to explain the techniques in simple terms and to point out the uses to which the techniques might be put. This element would include information on the benefits and disbenefits and the uses and misuses of risk assessment techniques.

7 Barriers to more integrated approaches to risk management

An integrated risk-based approach is being proposed for the risk management of dams and reservoirs; the introduction of such methods can be difficult both in terms of complexity and general acceptance within industry. This has been demonstrated by the difficulties encountered in adoption of the Interim Guide to Quantitative Risk Assessment, as explained in Section 2. Many of the difficulties reflect mistrust of new approaches and misconceptions around the complexities of risk-based methods.

From experience within the wider flood risk management community it is known that a range of barriers and opportunities can arise when developing and implementing these approaches. Some examples of these are outlined below:

i. *There is often difficulty in communicating risk-based results to the public and professionals alike:*

   Action – Develop improved methodologies for communicating risk and uncertainty. Make available basic training material.

ii. *There remains scepticism as to the credibility of techniques*:

   Action – Develop CPD and demonstration programmes to encourage the uptake of risk-based methodologies supported by more accessible techniques and tools.

iii. *Limited data is often cited as a reason for not adopting probabilistic descriptions of performance:*

   Action – Develop and demonstrate risk-based characterisations of performance capable of using available evidence (e.g. fragility curves used to describe asset condition based on observational evidence). However, it is also noted here that many dams are better studied and understood than flood risk management assets, and hence more direct measures of performance may be available.

iv. *The 'Interim Guide to Quantitative Risk Assessment for UK Reservoirs' applies methods with a deterministic outcome without acknowledging uncertainties:*

   Action – Methodologies need to be developed to enable uncertainties to be understood and handled transparently and these methodologies should be demonstrated to encourage uptake.

v. *Many practitioners fear that risk techniques are over complex:*

   Action – Adopt tiered methodologies to provide a range of proportionate approaches from the simple to the more complex. These will need to be consistent with the philosophy of an integrated risk-based framework, the available data and the significance of the risk being managed.

vi. Disparate and complex research strands are progressed separately:

Action – Develop a programme of forward activities, integrated through a common conceptual framework (covering principles, process and analysis) and guidance structures.

These barriers, and others like them, will need to be actively managed, to ensure the success of introduction of a risk-based approach for the dams and reservoirs industry that is practicable and valuable while also providing a common framework that links reservoir risk management with wider government approaches to flood risk management. Many of these issues were originally identified in the Government's *Guidelines for Environmental Risk Assessment and Management* (DETR 2000), as introduced in the following section.

7.1 Adopting consistent terminology and philosophy

The adoption of consistent terminology will play an important role in achieving effective and efficient risk assessment and management.

Definition of terms, processes and identification techniques must be provided in any new guidance and will need to be consistent across the range of techniques which will be presented, from simple observational techniques through to fault tree and event tree analysis and the assignment of probabilities to elements in a mode of failure.

This will include:

i. All risks should be considered in terms of a source, path, receptor and consequence model used widely across government and within flood risk management. This will promote an understanding of system behaviour and avoid inappropriate focus on individual elements of the flood system (See Section 8).

ii. Although a simple average measure of risk may be calculated by risk = probability * consequence, this definition has significant limitations for application to the management of low probability – high consequence reservoir safety risks. A more general definition is that risk is a 'Measure of the probability and severity of an adverse effect to life, health, property, or the environment.' (ICOLD 2005).

iii. Spatial and temporal variability of both likelihood and consequence should be considered.

It will also be important to identify the difference between risk and uncertainty and their respective roles in risk management. Section 8 introduces key characteristics of an integrated risk management framework.

8 Common characteristics of an integrated risk management framework

8.1 Guidelines for environmental risk assessment and management

The Government *Guidelines for Environmental Risk Assessment and Management* (DETR 2000) provides a framework for the assessment of risk (Figure 8.1). The House of Lords select committee report on 'Government Policy on the Management of Risk' (2006), quotes '… Government has developed a sound and potentially useful framework for the assessment of risk. The key issue is whether this framework is applied properly'.

All government departments and agencies have to comply with the relevant risk policy framework. This framework has been used as the basis for the development of risk-based analysis and management procedures for flood and coastal risk management in the UK and many of the concepts embedded here are being used more widely in evolving flood risk analysis and management tools and methods. There are some key concepts here that could be used directly to underpin the development of risk-based methods for the management of dams and reservoirs.

In particular, the environmental risk assessment and management (ERAM) framework (Figure 8.1) sets out requirements for risk screening and a tiered approach to risk assessment where the level of effort put into assessing each risk is proportionate to its priority (in relation to other risks) and its complexity (in relation to an understanding of the likely impacts).

This approach is consistent with the needs of the UK dams industry, where there is a wide range of both types of dam and types of dam owner. It is essential that any revised risk assessment and management methodology is flexible enough for use on a simple, small earth dam owned by an individual (e.g. a small fishing lake or farm water supply lake) or on a large concrete structure, forming one of many dams owned by a commercial water supply company. It should also be recognised that the purpose of the risk assessment and management approach is to provide an effective, practicable approach to risk assessment and management; the approach should be as 'simple as possible, but not simpler' (Einstein)….

8.2 Applying ERAM concepts to dams and reservoirs

It has been recognised for a long time that many common concepts exist between risk assessment and management for dams and reservoirs and that for fluvial and coastal flood risk management. This is not surprising, since there is a gradual transition between fluvial and coastal flood management structures and dams; in particular, it can be difficult to determine the difference between a large flood embankment and a small earth dam. The value of adopting a framework that includes probabilistic and uncertainty concepts, adopts a risk-based approach, and offers a potential route for meshing risk assessment and management for dams and reservoirs with that of flood embankments has been acknowledged (HR Wallingford 2008).

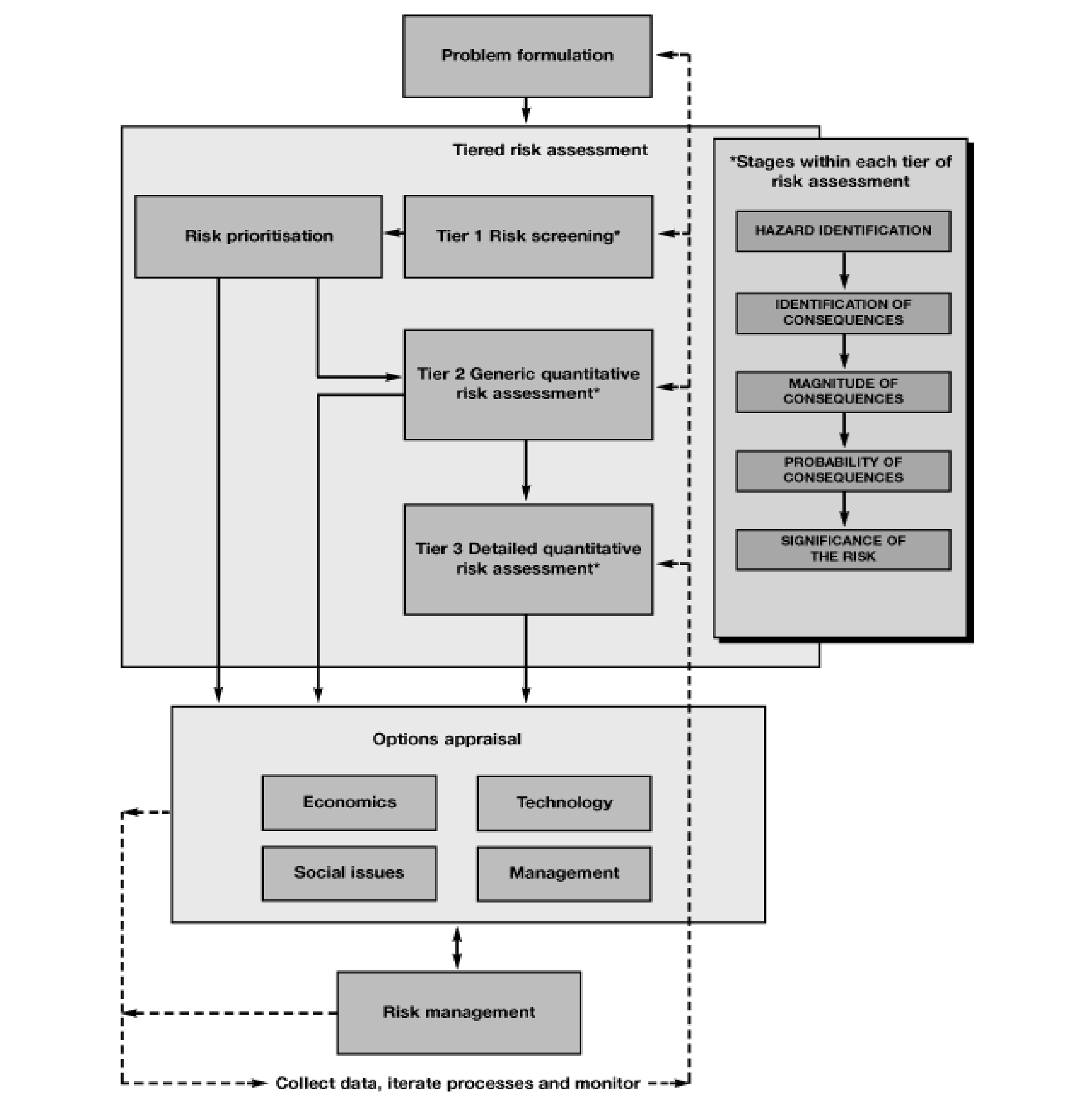

Figure 8.1 The UK Government's recommended framework for a tiered approach to environmental risk assessment and management (DETR 2000).

Risk-based approaches provide a subtle and adaptable framework for supporting decision-makers in addressing difficulties, risks and uncertainties. The aim is not to replace the judgement and expertise of decision-makers by prescribing preferred options, but to make sense of some of the complexities and uncertainties, in appropriate ways, that reflect the needs of specific decision problems.

The concept of appropriateness (finding the balance between uninformed decision-making and paralysis by analysis, depending on the circumstances and consequences of any particular decision) is well established in risk management. Within the dams and reservoir industry it is proposed that this concept is translated into a tiered risk assessment methodology which builds on the risk screening and tiered risk assessment principles set out in the Government's guidelines (DETR 2000)(Figure 8.1).

It has always been recognised that new tools and techniques will need to be progressively introduced; strengthening and replacing existing inspection, maintenance and improvement approaches with a more organised approach that utilises a coherent cohort of risk-based methods. We have already seen this in action through the introduction of various aspects of PAMS (Performance-based Asset Management) including updates of the Condition Inspection Manual, deterioration, and tiered reliability analysis as well as the underlying Risk Assessment for Strategic Planning (RASP) methods into Flood and Coastal Erosion Risk Management (FCERM) activities. Such an approach supports more integrated risk management and is founded on a number of principles developed within the Government's guidelines (DETR 2000, Sayers *et al.* 2002):

- Appropriateness – Appropriate level of data collection and analysis reflecting the level of risk associated with a dam and the uncertainty within the decision being made.
- Understanding – Improved understanding of dams and their likely performance.
- Transparency – Transparency of analysis enabling audit and justification.
- Structured – Structured knowledge capture encapsulated through fault tree, breach potential etc.
- Collect once, use many times – Reusing data by refining existing data.
- Tiered screening, assessment and decision-making – In terms of both data and modelling approaches, where the risk management process cascades from high-level policy decisions, based on outline analysis, to detailed designs and projects, which require more detailed analysis.

As well as reviewing the use of risk, uncertainty and performance in 'everyday' decisions, it is proposed that this project points the way to the development of more integrated risk management approaches.

8.3 A tiered approach to risk assessment for dams and reservoirs

This section introduces the use of the Source–Pathway–Receptor (SPR) model, combined with a tiered approach to provide a framework for assessing and managing risks for dams and reservoirs.

The SPR conceptual model has been widely used to assess and inform the management of environmental risks across government (DETR 2000) and has been adapted to describe the fluvial and coastal flooding system (Sayers *et al.* 2002). The SPR model also provides a convenient framework for dams and reservoirs risk assessment and management (Figure 8.2). The model provides a simple classification system through which different components of the system may be categorised and assessed. For example, ‘source’ would reflect the hydraulic loading, perhaps magnitude of storm or volume of water retained. The ‘pathway’ is represented by the dam and the route for flood water to pass to ‘receptors’. Receptors may be people, property, environment etc. By analysing the nature of sources, performance of pathways and impact on receptors, the overall risk may be assessed in a logical, transparent and robust way (Figure 8.2).

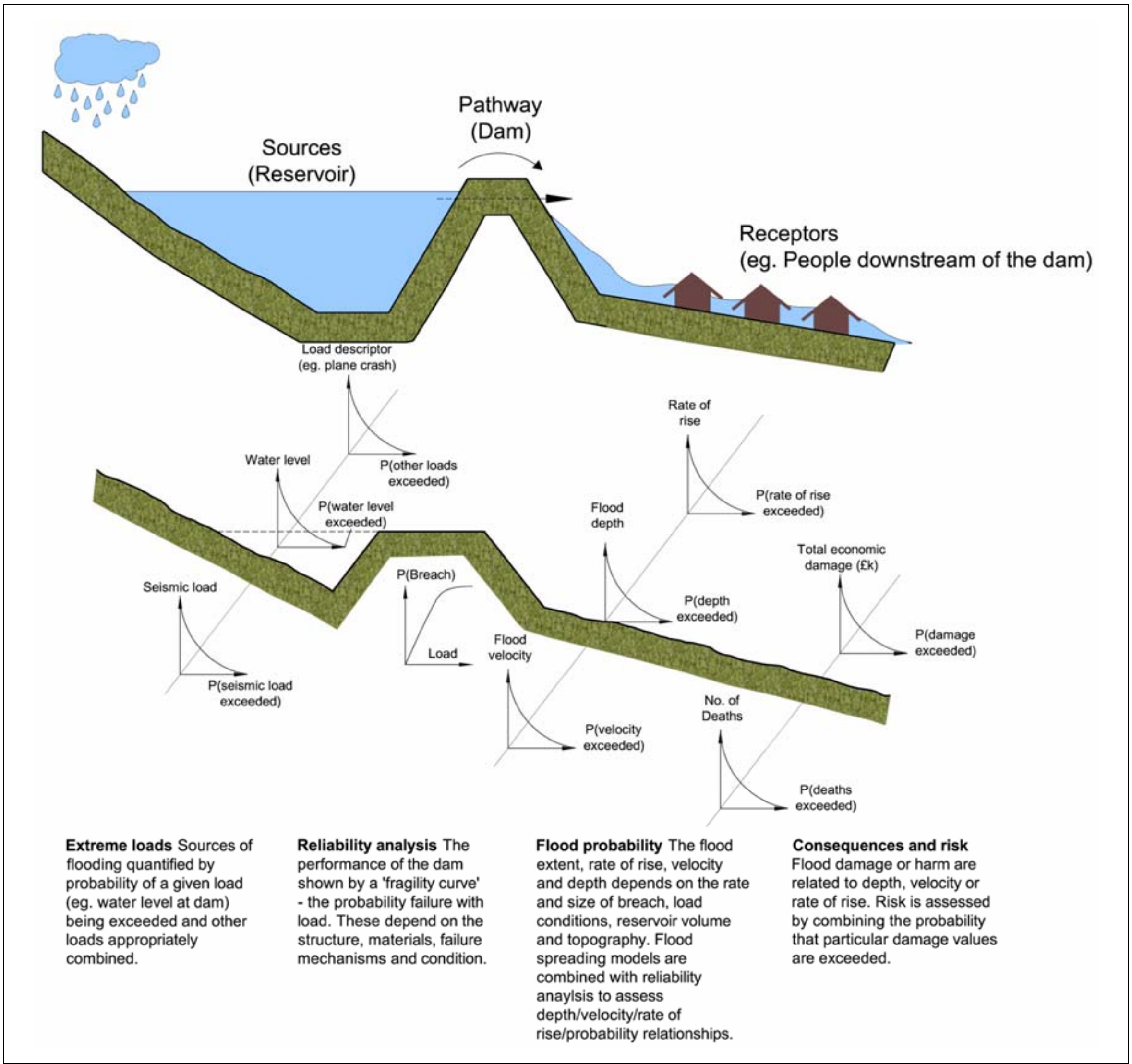

Figure 8.2 Source–Pathway–Receptor framework for the assessment of dams (Morris *et al.* 2009).

The level of detail and approach adopted to assess each of the SPR components can vary, based upon the complexity of the dam and the risk posed, reflecting the potential downstream consequences. Table 8.1 shows a tiered approach demonstrating how such a method might be applied to reservoir safety. This approach was used in developing the RASP methodologies used for the assessment of fluvial and coastal flood risk.

Table 8.1 Hierarchy of RASP methodologies, decision support and data required adapted to reservoir safety.

Level of decision	Decisions to inform	Data sources	Methodologies
High	National exposure to dam floods Categorisation of dams Raising public awareness at national scale Broad-scale emergency planning	Dam type Basic geometry – height, volume, crest length Property and land use	Single extreme event Assumed catastrophic failure Downstream propagation modelling
Intermediate	*Above plus:* Local emergency planning Investment planning Intermediate monitoring and surveillance	*Above plus:* Structural properties	Visual inspection and data review Failure mode and reliability analysis Breach growth Single (or limited number) of extreme events
Detailed	*Above plus:* Optimisation of investment and emergency response	*Above plus:* Time-series rainfall Upstream catchment characteristics Detailed structure properties	Reservoir routing *In situ* structure testing Simulation-based reliability analysis Optimisation of management response

Regardless of the level of detail and data used, the generic steps within the analysis remain the same. For example, consider the ‘Pathway’ component. A dam’s performance under load can be expressed in terms of a fragility curve (Figure 8.3).

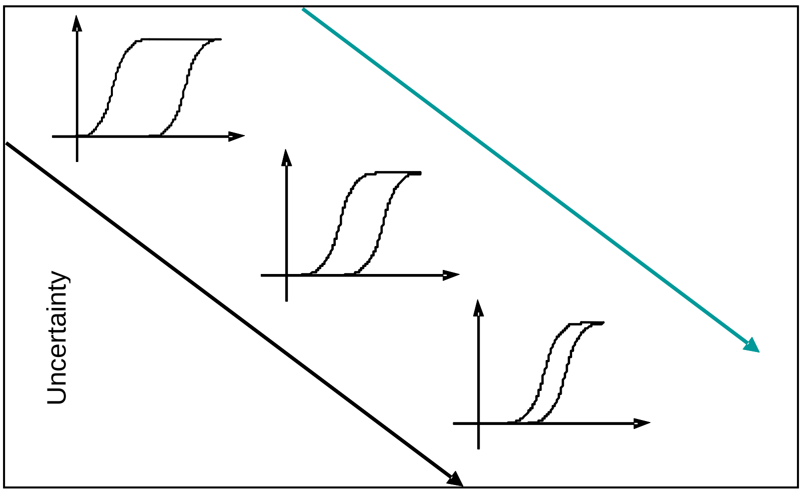

Figure 8.3 Progressively reducing uncertainty in dam performance through tiered assessment (adapted from Sayers *et al.* 2005).

As the level of analysis, understanding and associated data increases, the uncertainty around the fragility curve diminishes. The overall fragility curve for the dam can be built from an approach (methodology; degree of detail etc) that is considered appropriate and proportionate. There is also no need for common levels of understanding or analysis across all dam components or failure modes. The overall degree of uncertainty can be determined by the use of tools such as the Reliability Tool developed in the FLOODsite project or the DAMRAE package, and by extending the application of conventional deterministic analysis and also applying some generic information (Environment Agency 2004, Simm *et al.* 2008). This generates structure-specific fragility curves, based on a reliability analysis of multiple potential failure modes linked by fault trees.

Particular effort has been applied to the development of performance-based asset management techniques in establishing a logical framework linking (a) potential failure modes of assets, to (b) their inspection and monitoring for condition assessment with 'performance features', to (c) understanding the risk reduction associated with a management intervention (e.g. increasing the crest level of a flood embankment).

A framework as described above can be used to provide 'a structured approach that draws on common principles and processes'. It can be applied to projects and the related guidance so as to achieve consistency wherever possible and appropriate.

Figure 8.4 illustrates a possible high level framework, which demonstrates a staged analysis process, where the level of analysis undertaken is appropriate to the risk.

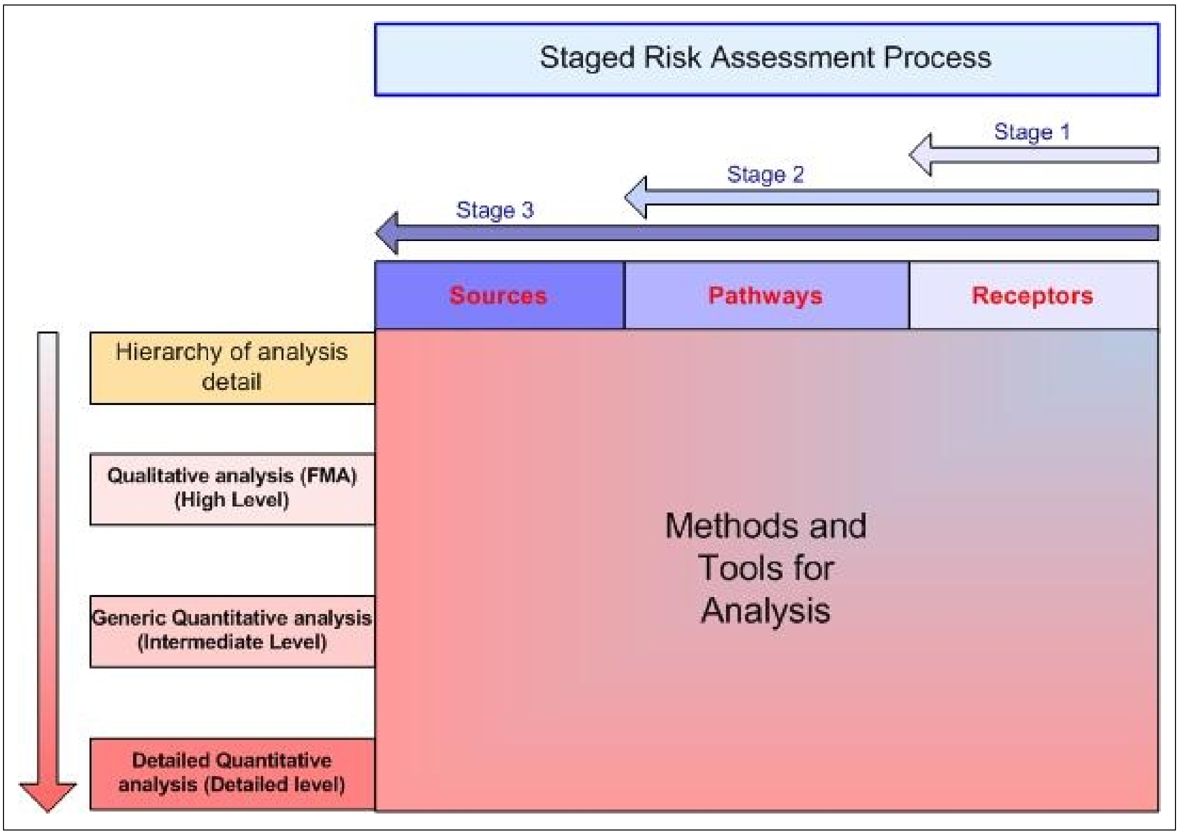

Figure 8.4 Possible high level framework.

9 Perspectives on reservoir safety risk management

9.1 Components of risk management for dams

This review draws mainly on the practice in reservoir safety risk management in the USA and Australia. Reservoir safety risk management comprises the various component processes that are represented schematically in Figure 9.1. At the highest level, risk management combines risk assessment, risk control and decision-making on all aspects of reservoir safety. Risk assessment comprises risk analysis, risk evaluation and the formulation of decision recommendations. Risk analysis involves both risk identification and risk estimation.

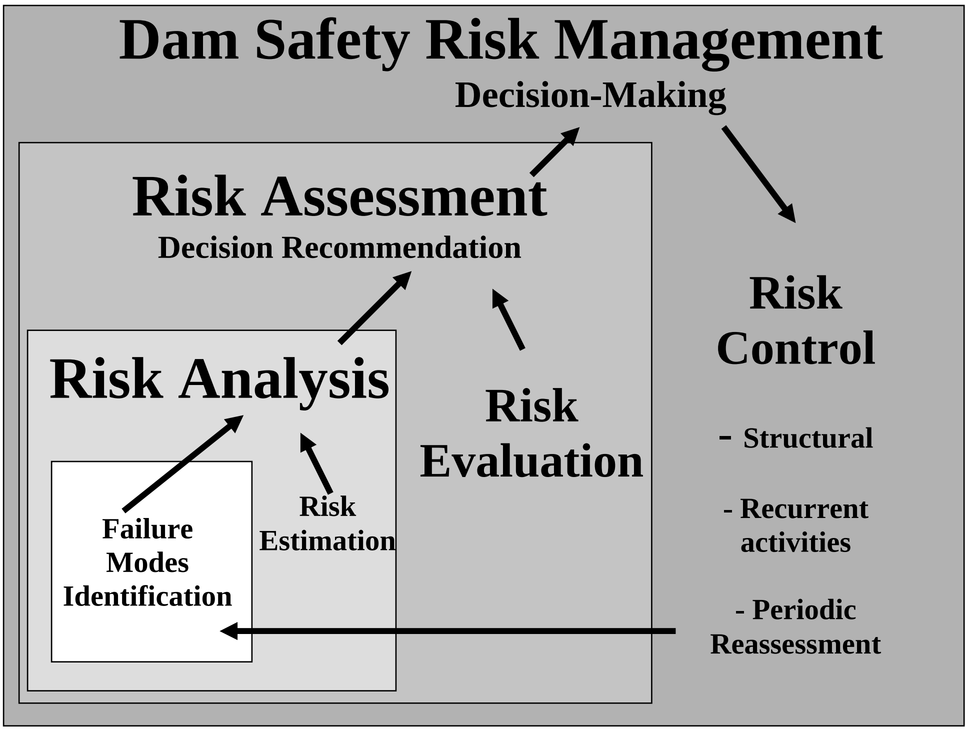

Figure 9.1 Interrelationship between components of risk assessment and risk management (adapted from Bowles *et al.* 1999).

A risk assessment commences with a clear definition of its purpose. This includes an identification of the decisions that it is intended to use the results of the risk assessment to inform, including all decision bases and the desired level of confidence as determined by the reservoir owner and other stakeholders. Consistent with the UK flood risk management framework (Environment Agency 2004b), it also includes an identification of the drivers and pressures affecting reservoir safety decision-making. Examples of some of the purposes for reservoir safety risk assessment have included the following:

- To systematically identify and better understand potential failure modes.

- To identify, justify and prioritise investigations and analyses to reduce uncertainties in risk estimates for individual dams and portfolios of dams.
- To strengthen the formulation, justification and prioritisation of risk-reduction measures for individual dams and portfolios of dams.
- To justify decisions on reservoir operating restrictions.
- To identify ways to improve reservoir safety through changes in reservoir operation, monitoring and surveillance, safety management systems, staff training, emergency action planning and business decisions related to dam safety.
- To identify opportunities to improve the effectiveness of warning and evacuation plans.
- To identify cost-effective options for more rapidly achieving reduced dam reservoir safety risks.
- To justify expenditures on reservoir safety improvements to owners and economic regulators.
- To provide a framework for quantifying engineering judgment and communicating technical issues with reservoir owners in a more open and transparent manner.
- To facilitate the evaluation of reservoir safety risks to the public in a manner that allows comparison with other infrastructure and technological hazards.
- To provide a non-technical basis for communicating reservoir safety risks to the public.
- To provide a basis for development of a safety case or safety demonstration for owners and regulators.
- To assess the adequacy of insurance coverage.
- To strengthen the basis for corporate governance related to dam safety risks.
- To strengthen the exercise of the owner's duty of care, due diligence and legal defensibility with respect to dam safety incidents or dam failure.

The process of scoping and selecting the extent and level of detail or complexity for a risk assessment builds on the statement of purpose and on a failure modes identification process. In this process, all potential failure modes for the subject dam are enumerated and described, including the relationship between each failure mode and those types of consequences of failure that it is relevant to consider to satisfy the statement of purpose. Investigations and analyses may be identified to assess the physical plausibility of some failure modes. A structured and systematic process is followed to adequately complete the potential failure modes identification. The scoping process continues with a narrowing of the list of physically plausible failure modes to a subset of those that it can be justified to include in the risk assessment to achieve the statement of purpose with the desired level of confidence. These can be referred to as ‘significant’ failure modes. The list of failure modes that are considered to be significant, and other aspects of the scoping of a specific risk assessment such as the level of detail and types of consequences that are addressed, can vary for the same dam with different risk assessment purposes.

The next step of risk estimation is the process of quantifying probabilities and consequences for all significant failure modes. System response or fragility relationships are developed for each failure mode with a level of detail and associated effort that can vary with the scope that is justified for the risk assessment. Traditional engineering analysis, reliability analysis and engineering experience and judgement are all important in estimating these relationships. Dam break modelling provides the basis for the estimation of dam failure consequences for each failure mode and for a range of exposure conditions affecting potential life loss. A dam safety risk analysis tool is needed to perform these calculations and to present results in a suitable format so that they can be readily interpreted and used to support reservoir safety decision-making.

The process of examining and judging the significance of the estimated risk is termed risk evaluation. The UK Health and Safety Executive (HSE 2001) has a well-established framework for risk evaluation in the UK context. It is widely used for regulating the risk associated with hazardous industries in the UK. It has also significantly influenced the development of risk evaluation approaches for dams in Australia (ANCOLD 2003) and the USA (Munger *et al.* 2009). The HSE framework for the tolerability of the risk can be used to assess the estimated risk for an existing dam. Other factors, such as business or legal considerations of the dam owner can also be considered in the overall risk evaluation process. This process is not complete until the extent to which the risk can be reduced has been evaluated to be 'as low as reasonably practicable'[1] or 'ALARP'. This requires the formulation of risk control (treatment) options that can include structural measures and strengthened recurrent dam safety management activities, such as monitoring and surveillance, emergency action planning and staff training. It also includes periodic reassessments of dam safety, consistent with traditional reservoir safety practice, including updates of any earlier risk assessments in a mature risk-informed reservoir safety programme.

A variation of the complete dam safety risk management framework is illustrated in Figure 9.2. The approach is currently required by the Federal Energy Regulatory Commission in the USA, which regulates more than 2500 hydropower dams. It does not include the quantitative risk analysis and risk assessment steps, but involves proceeding directly from the outcomes of a failure modes identification process to decision recommendations. It is therefore a form of qualitative risk assessment. A similar approach, which incorporates the underlying principles of risk assessment and risk management but without the development of quantitative risk estimates, may be appropriate for small UK reservoirs in terms of the required level of effort and the potential benefits derived.

The overall risk assessment framework is summarised in Section 9.2. The risk analysis, risk evaluation, and risk control components of reservoir safety risk management are summarised in Sections 9.3 to 9.5. These sections are adapted from Bowles *et al.* (1998) and USSD (2003).

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[1] HSE (2001) refers to the implementation of the ALARP principle as requiring a 'gross disproportion' test applied to individual risks and societal concerns, including societal risks. The gross proportion is between the cost of an additional risk reduction measure and the estimated amount of the risk reduction.

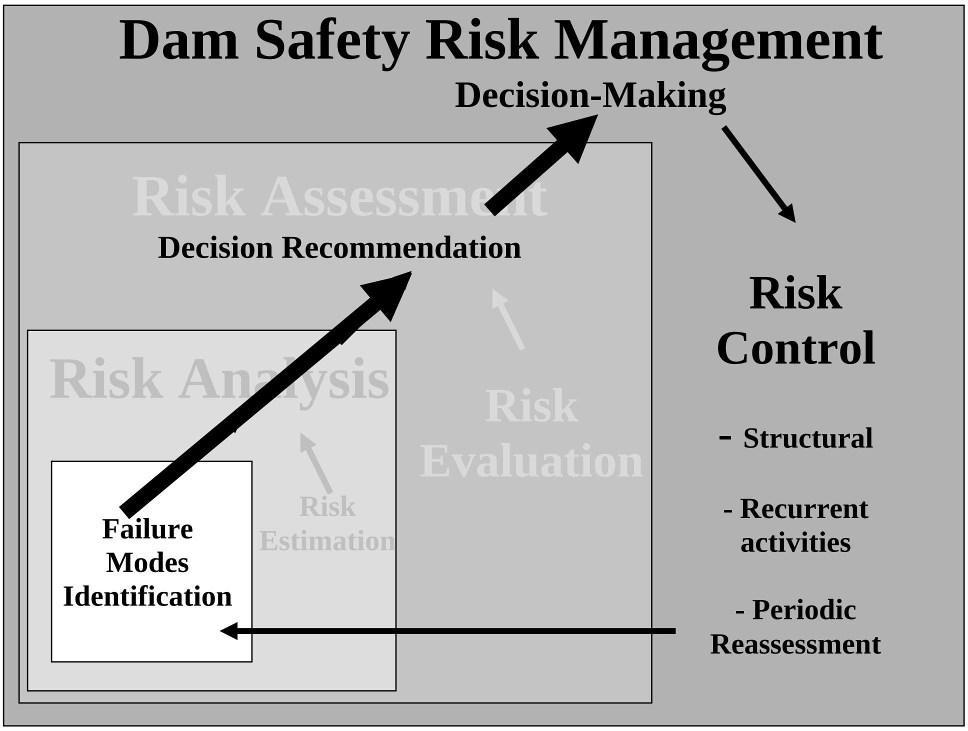

Figure 9.2 Illustration of a qualitative approach to risk assessment and risk management (adapted from Bowles *et al.* 1999 – ANCOLD).

9.2 Overall risk assessment framework

An overall framework for reservoir safety risk assessment is presented in Figure 9.3. As shown by the 'column' structure in this figure, the risk analysis process follows a five-step sequence of modelling the states sources or initiating events and pathways including system responses, outcomes and exposure factors, and the impacts of consequences to receptors. This approach is consistent with the UK flood risk management framework. Both external (e.g. floods, earthquakes and upstream dam failures) and internal (e.g., the initiation of piping through an embankment dam under static loading) initiating events are considered. Each external initiating event is divided into a number of loading intervals to achieve numerical precision in the risk analysis calculations. Several substeps may be necessary to adequately characterise the system response to a range of magnitudes of initiating events that can lead to the outcome of dam failure or no failure. These steps can involve event tree, fault tree and logic tree models. Various types of consequences of dam failure may be considered, such as loss of life, economic damages, financial impacts on the owner, environmental damages and societal effects.

There are four major components in a risk assessment, as illustrated by the 'row' structure of Figure 9.3. These are as follows: 1) risk identification, 2) risk estimation, 3) risk evaluation, and 4) risk treatment. In Figure 9.3, the term 'risk treatment' refers to the consideration of risk management (control or reduction) alternatives using risk analysis and risk assessment.

Various levels of effort have been proposed for performing risk assessments (McCann and Castro 1998), but underlying these is the concept that risk assessments should be staged (Bowles 1998), with additional detail being justified by the expected gains in understanding, defensibility and the desired level of confidence in decision-making to manage the risks. This is referred to as a 'decision-driven' approach in a National Research Council (NRC 1996) report, which states: ‘Risk characterization (analysis) should be a decision-driven activity, directed toward informing choices and solving problems.’

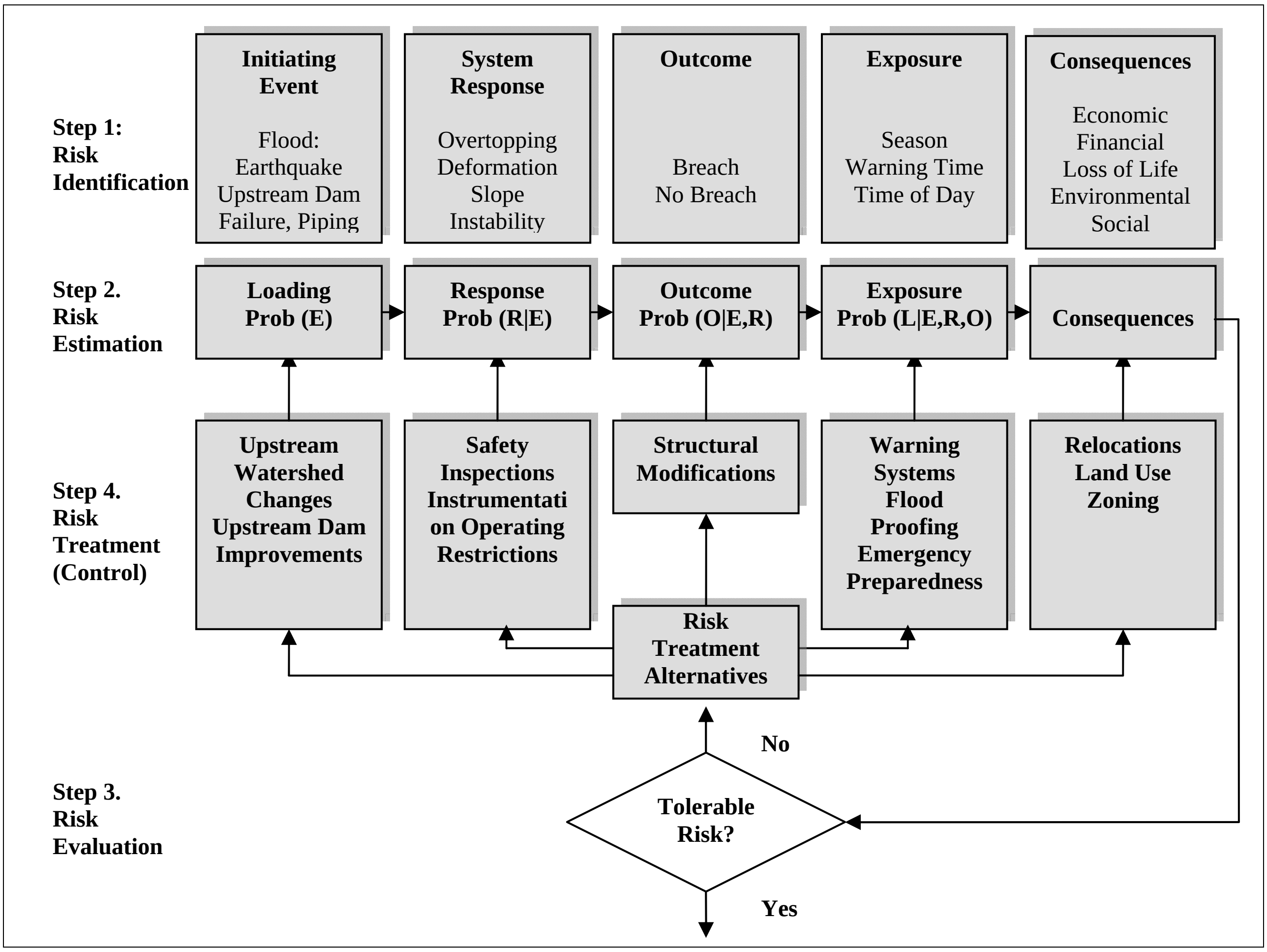

Figure 9.3 Framework for reservoir safety risk assessment (Bowles 1998).

9.3 Risk analysis

Risk analysis involves both risk identification and risk estimation (first two rows in Figure 9.3). Risk identification is the process of recognising the hazards (initiating events) to which the dam is exposed, potential dam failure modes, and the resulting adverse consequences. Dam failure modes are often represented using event trees, fault trees and logic trees, which comprise a risk analysis model. The proper application of these approaches requires some specialised expertise, similar to the need for specialised engineers to apply unsteady-state flood routing or finite element stability analysis models in dam engineering, for example. Senior engineers routinely oversee the application of these models and interpretation of their results, although they may not personally have the hands-on skills to apply them. In a similar way, senior engineers can develop the necessary skills to effectively oversee the application of risk analysis tools to dams.

Risk estimation consists of determining loading, system response and outcome probabilities, and the consequences of various dam failure scenarios. No-failure scenarios are considered so that incremental consequences can be defined as the difference between the consequences estimated for failure and no-failure scenarios. Probability and consequence estimates are then input to the risk model. Consequences are a function of many factors including, the nature and extent of the breach, the extent and character of the flooding, the season of the year, the warning time, and the effectiveness of evacuation and emergency action plans. Risk reduction alternatives are developed and analysed in a similar manner to the existing dam with selected inputs, such as system response probabilities, changed to represent the improved performance estimated for each alternative.

9.4 Risk evaluation

Once risks have been identified and quantified for an existing dam or various risk reduction alternatives, they are evaluated against tolerable risk guidelines, including the ALARP principle in the case of risk reduction measures. These guidelines can serve a useful role in the development of the safety or business cases for addressing reservoir safety issues. However, reservoir safety decisions should be made by those responsible for ensuring dam safety after all the relevant factors have been assessed and weighed; they should not be the automatic result of applying a tolerable risk guideline to the outcomes of a risk analysis (Bowles 1999). The appropriate use of risk assessment currently incorporates reference to traditional engineering standards. This is referred to as a risk-enhanced approach. This is the approach that is widely practised in Australia (by the Bureau of Reclamation) and in the USA (by the US Army Corps of Engineers), and in other fields, such as the nuclear, offshore and process industries where risk assessment is used.

9.5 Risk control

From a business or management perspective, risk control (treatment) options can be grouped into the following categories (Figure 9.4), although these are 'not necessarily mutually exclusive or appropriate in all circumstances' (AS/NZS 1995):

- 'Avoid the risk' – this is a choice, which can be made before a dam is built, or through decommissioning an existing dam.
- 'Reduce (prevent) the probability of occurrence' – typically through structural measures, or reservoir safety management activities such as monitoring and surveillance, and periodic inspections.
- 'Reduce (mitigate) the consequences' – for example by non-structural approaches such as effective early warning systems or by relocating exposed populations at risk.
- 'Transfer the risk' – for example by contractual arrangements or sale.
- 'Retain (accept) the risk' – 'after risks have been reduced or transferred, … residual risks … are retained and … may require risk financing (e.g. insurance).'

While the first three options reduce the risk to which third parties are exposed, the fourth and fifth options only affect the risk that the owner is responsible for, and not the risk to which third parties are exposed.

Risk assessment does not prescribe dam safety decisions. These decisions need to be made by the dam owner in conjunction with the regulator, if applicable, and other stakeholders. However, each party can expect to be in a better position to make informed decisions and to prioritise dam safety work when they supplement traditional engineering approaches with insights obtained from an appropriately conducted risk assessment.

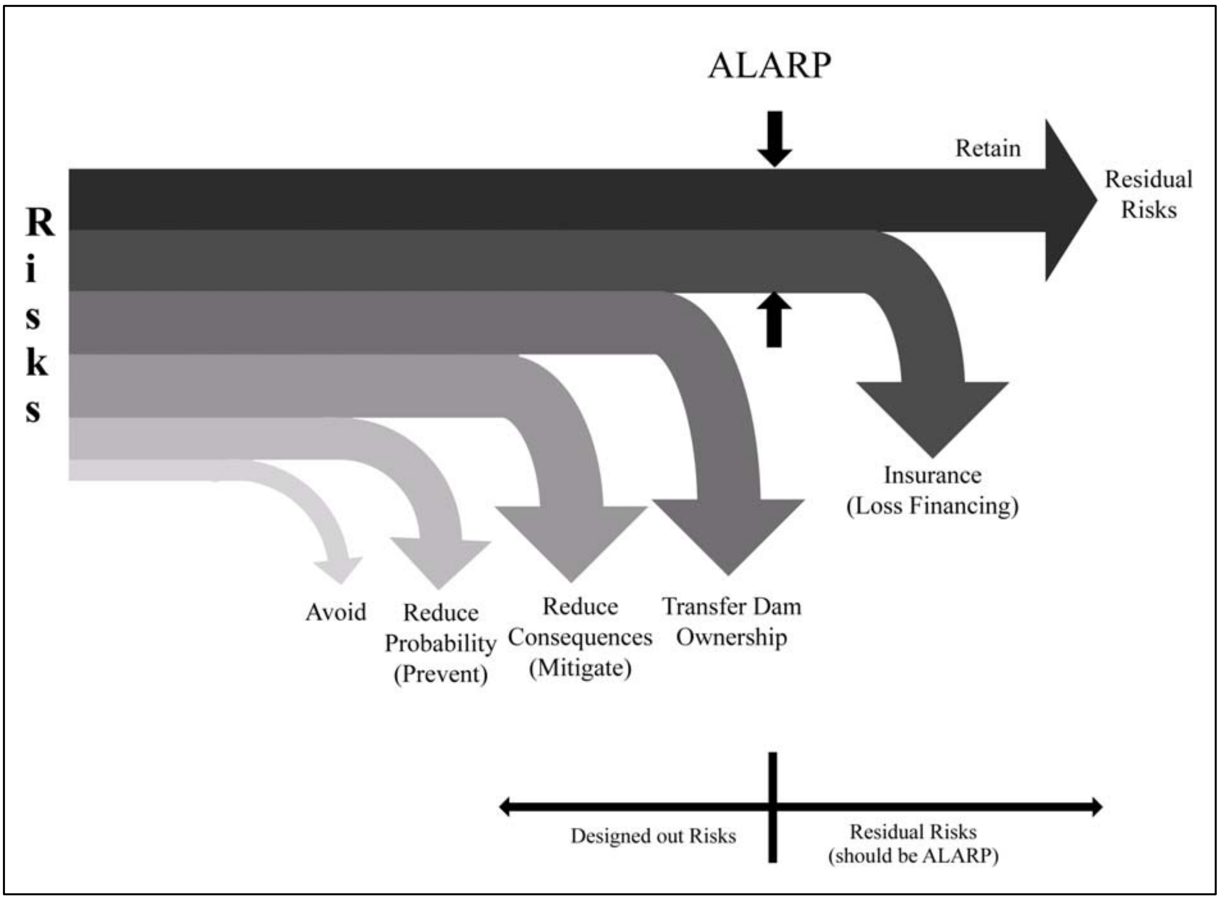

Figure 9.4 Risk control options (adapted from Bruce *et al.* 1995).

10 Conclusions and recommendations

Recommendation 58 of the Pitt Review recommended legislative change for reservoir safety as proposed in the Environment Agency's biennial report. The fundamental change within those proposals was a move to a risk-based approach and away from one based on volume alone.

The Interim Guide has been used by a number of owners and panel engineers who recognised that while the Guide needed improvement the underlying principles of risk assessment provides a useful tool as part of the development of a risk-based approach to reservoir safety management.

In this report, the requirements of Pitt Review and the demands of the profession as confirmed by the workshop to define the strategy for future research in the reservoir field in the UK has recommended that a second phase of the QRA project needs to be implemented.

The elements of the approach and the outputs are defined later in this chapter.

The 'Interim Guide to Quantitative Risk Assessment for UK Reservoirs' (Brown and Gosden 2004) has provided an initial approach to reservoir safety risk assessment. However, the approach includes simplifications and assumptions that limit its general applicability, as identified by the authors and practitioners who responded to the questionnaire survey.

It is proposed that this initial work is built upon within the wider assessment framework described previously to provide a system that meets a wider range of reservoir owner and industry needs, as well as meshing into current UK Government flood risk assessment policy and practice.

The introduction of a risk-informed approach to reservoir safety management in the UK will involve not only the development of risk analysis tools and procedures but also a change in the underlying paradigm for managing reservoir safety. Typically such changes do not take place quickly. In addition, to be effective in realising the potential benefits of a risk-informed approach, the engineering profession, reservoir owners, safety and economic regulators, and other stakeholders should be involved in the development of an approach that meets the unique requirements of UK reservoir safety and the associated change process.

10.1 Phase 2: A risk-informed approach for reservoir safety management in the UK

Considering the above, it is recommended that the second phase of the QRA project implements a set of closely coordinated activities, as well as supporting a number of others. These are shown schematically in Figures 10.1 and 10.2 and described below. These comprise a series of parallel activities that will take a period of approximately 24 months to complete. The following descriptions may be used as the basis for developing a work specification.

Figure 10.1 provides an overview of the different proposed actions and, critically, how these should build from ongoing initiatives and link with existing national frameworks and policy for flood risk analysis and management. Key aspects of the proposed approach are (a) ensuring the overall framework fits with government guidelines, (b) meshing the core concepts used for reservoir risk assessment with those being used and developed for fluvial and coastal defence, and (c) progressively developing and implementing the QRA process. Environment Agency projects such as PAMS (Performance-based Asset Management System) have undertaken a huge amount of R&D already that can be built upon, while projects such as FLOODsite and FRMRC1 and 2 provide ongoing and evolving science to underpin the QRA framework.

In addition to building from ongoing initiatives and linking with existing national frameworks and policy for flood risk analysis and management, Phase 2 should meet the unique needs of the UK reservoir owners and other stakeholders in UK reservoir safety and deal with the issues and problems associated with influx of a large number of 'small' reservoirs subject to the proposed new Reservoirs Act. It is intended that the risk assessment methodology will cover all types of dam and leave the user to develop techniques for rarer types in the UK. In this regard some of the needs are listed below:

- Applicability by inspecting engineers as part of their inspection activities with possible updating by supervising engineers.
- Scalability of the overall approach to reservoirs that span a wide range of sizes, potential consequences of failure, and owners varying from the typically under-resourced private owner of a single reservoir to water utilities who manage a portfolio of reservoirs and other assets. The range of risks posed by UK dams varies by several orders of magnitude and therefore there is a need for a simple (screening) method of quantitatively assessing risk which would take a panel engineer no more than 1 to 2 days to complete and more sophisticated tools for use on higher risk dams where the likely loss of life would be several hundred lives.
- A need to provide guidance and tools that will result in consistency in risk assessment outcomes across the wide range of reservoir sizes, types and settings while making it possible to conduct reservoir safety risk assessments in a cost-effective manner.
- A range of purposes for which risk assessment can potentially provide value.
- A range of stakeholders other than owners who have an interest in obtaining information for reservoir safety risk assessments.

Figure 10.2 provides an indicative schedule for Phase 2. It is anticipated that this core work can be achieved within 24 months. Key deliverables are listed in the yellow boxes at the base of the diagram.

Key stages of work for the QRA Phase 2 project are listed below. Each numbered item is shown schematically in Figures 10.1 and 10.2:

1. **A framework and methodology for UK reservoir safety risk management** – to provide the philosophical foundation, principles and methodology for the procedural, analytical and management aspects of the development of a risk-informed approach to UK reservoir safety risk management. The methodology should encompass a wide range of potential purposes for reservoir safety risk assessment (see Section 8.1). It should provide for both qualitative and quantitative approaches with scalability/proportionality. In particular, it should include provision of a high level qualitative approach likely to be of significant help to individual

owners of small earth dams (see Section 8.1 and item 2 below). A clear link will be demonstrated between the potential of the QRA methodology and the implementation of dam safety inspections and recommendations for remedial works. In particular the benefit of identification of failure modes will be demonstrated. It should also address the issue of terminology. This stage/task should be delivered in a 12-month period. It should provide an approach that satisfies the unique needs of the UK reservoir owners and other stakeholders in UK reservoir safety, and link with the existing science and policy frameworks. The methodology will identify key links between risk assessment and inspection and intervention to manage and reduce risks. The framework and methodology for analysis will need to be detailed in a technical report.

2. **A structured procedure for potential failure modes identification** – to provide an immediately applicable and beneficial procedure that can be applied to all types and sizes of UK reservoirs, both as a separate tool and as a first step (or high level) within reservoir safety risk assessment. As outlined in Section 8.1, this approach is likely to be of significant help to individual owners of small earth dams and can also provide a system for supporting decision-making without the need for detailed risk assessment and evaluation. It should be delivered within the first 6 months and achieved by also coordinating work on the parallel (separately funded) Failure Modes Phase I project.

3. **Supporting science on failure modes** – A key aspect of the risk analysis framework will be our ability to identify, analyse and predict failure modes arising from different combinations of load and structure response. Structure performance may be represented in the form of fragility curves. Understanding and predicting performance requires best use of deterministic analysis, available data, expert judgement etc. This knowledge may (and should) be drawn from a range of projects and sources (Figure 10.1) as part of Stage 1 above. It is recognised, however, that as the project evolves and draws from a wide range of science, it may be necessary to specify the development of additional supporting tools, procedures, underpinning science etc. These will be dealt with separately should the need arise. However, specific inputs may be developed to support reservoir safety risk analysis by coordinating work on the Failure Modes Phase 2 project such that the Failure Modes Phase 2 project produces specific fragility curves/failure mode information suitable for use within the QRA framework.

4. **A guide for UK reservoir safety risk analysis** – a simple to read and use guidance document explaining and guiding the user through the concepts, science and application of the risk-informed approach for reservoir safety management for UK reservoirs. It should be delivered 6 months after completion of the framework and methodology. The document will guide the user in identifying and undertaking different (appropriate and proportionate) levels of risk analysis from risk screening to full risk analysis, including the use of supporting software where appropriate. The guide will be suitable for a range of potential end users by providing an introduction and explanation of basic concepts and uses through to detailed application of the methods.

5. **A software tool for UK reservoir safety risk analysis** – to provide the core engine to support dam safety risk analysis calculations and hence ensure that a consistent and theoretically correct approach is available

for use by reservoir engineers. This is likely to evolve from existing software and be delivered 6 months after completion of the QRA framework and developed in parallel with the guidance on QRA. The software will ensure that sound science and any links to existing frameworks and relevant analysis tools/methods are addressed.

6. **Workshops for consultation** – Regular workshops, at 6-monthly intervals are envisaged to provide opportunities for consultation during development of the framework, methodology, software and guidance (Figure 8.4). The timing of such workshops initially should be to provide input to the definition of requirements for the overall framework. As the framework is formulated, further consultation should allow integration of feedback from industry participants into the evolving methods and tools. Additional dissemination within the UK dams industry should be encouraged, for example by hosting technical and/or discussion sessions at the ICE (BDS technical meetings, Water UK etc). The goal should be that the overall framework for UK reservoir risk management (Stage 1) will gradually become widely integrated into practice and that it will evolve with use.

7. **Workshops for training** – Three types of workshops are envisaged to provide opportunities for training within industry. These workshops are spread across the 24-month duration at key points in concept and tool/method development (Figure 10.2).

   - Two training workshops will be designed to equip reservoir engineers to start applying the structured procedure for potential failure modes identification (Stage 2) as soon as possible. They will include hands-on exercises on selected UK reservoirs.

   - Two training workshops will be held for training the first group of ‘hands-on’ users. The prerequisite requirements for these trainees should be carefully determined to ensure that software operators have the appropriate background knowledge.

   - Two training workshops will be held for risk assessment facilitators to help them develop the skills to lead the reservoir safety risk assessments from the formulation and scoping stage through risk estimation and analysis, to risk evaluation, alternatives evaluation as appropriate, and presentation of results, including making a case for a decision recommendation.

8. **Pilot site application** – It will be important to identify a number of exemplar sites for use in developing, testing and piloting the QRA method. The QRA project will develop a specification for this once the initial framework has evolved, allowing flexibility in identifying key issues that exemplar sites should address. It is considered that a minimum of six different sites need to be identified and used to support development and testing.

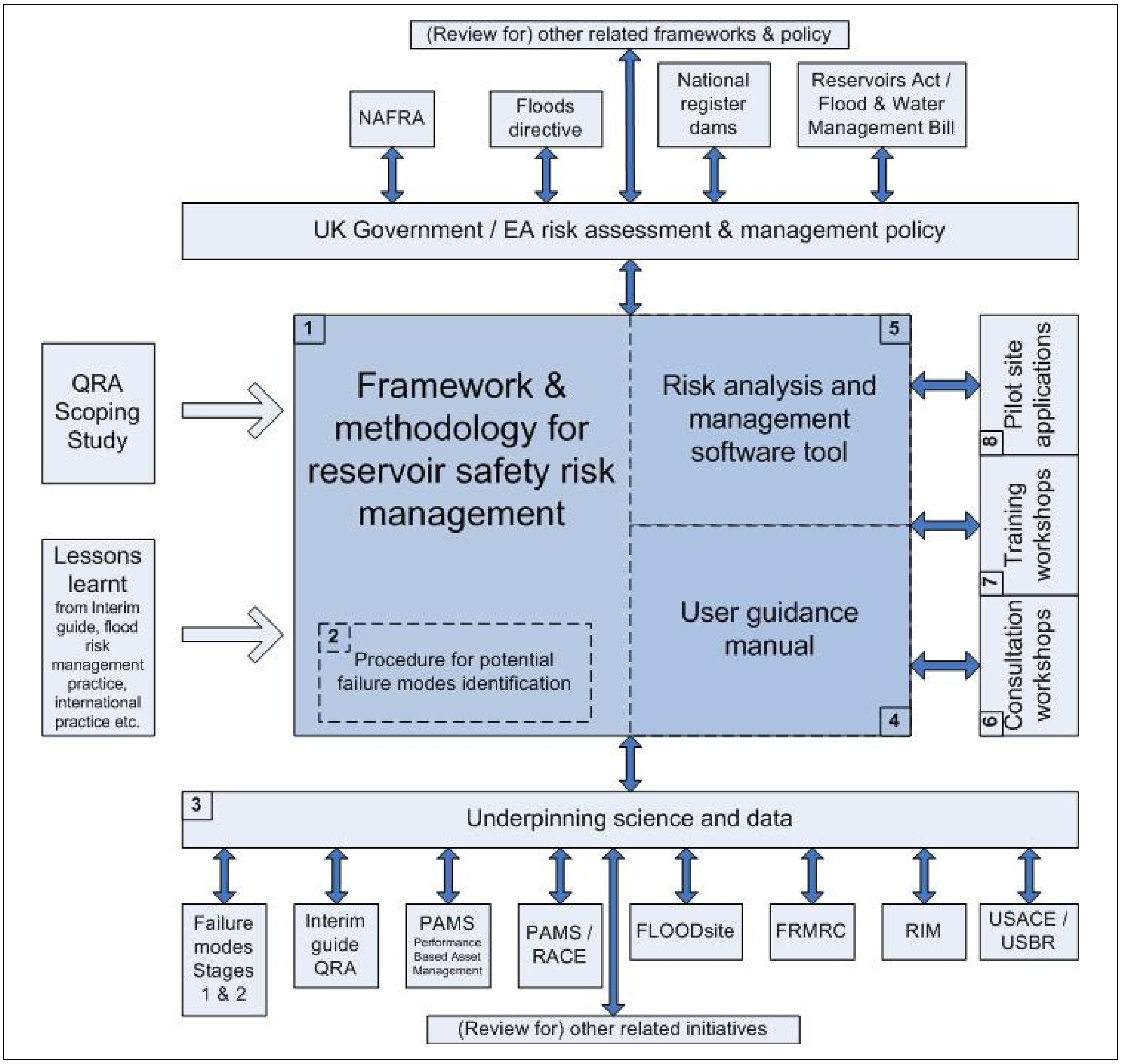

Figure 10.1 Overview of project links and outputs.

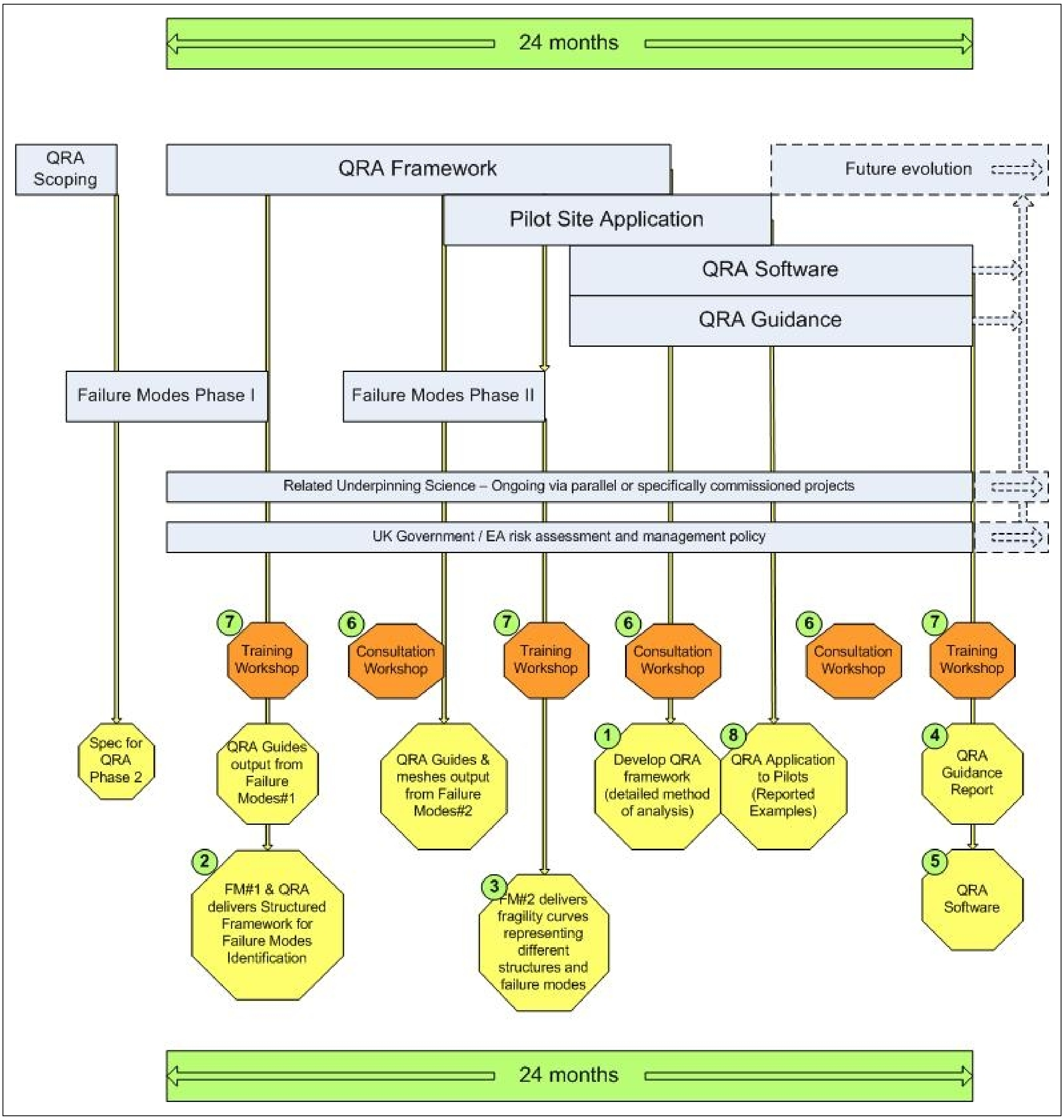

Figure 10.2 Programme showing main links and outputs.

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