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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: FD2641

2. Project title:
   Scoping the process for determining acceptable levels of risk in reservoir design

3. Contractor organisation(s):
   HR Wallingford
   Howbery Park
   Wallingford
   Oxfordshire
   United Kingdom
   OX10 8BH

4. Total Defra project costs (agreed fixed price): £ 56,970

5. Project: start date ..... 18 February 2010
   end date ..... 8 October 2010

6. It is Defra's intention to publish this form.
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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

Risk-informed regulation of reservoirs: An outline regulatory framework

Introduction

The Flood and Water Management Act 2010 requires a risk-informed approach to reservoir regulation but offers no detail as to how this should be achieved; expecting secondary legislation and guidance to provide this clarity. Defra commissioned this research project to scope a new risk-informed approach to reservoir regulation and provide the first stage in the evidence base to develop procedures to impose differential requirements for reservoir safety.

Approach

A risk-informed regulatory framework has been developed through discussions with industry stakeholders and with reference to international practice. The proposed framework provides:

- A structured and transparent framework
- Consistency with the current legal framework in England and Wales
- A varying burden on the Enforcement Authority consistent with the level of risk
- A varying burden on undertakers consistent with the level of risk

Within the framework, effort has been made to:

- Provide clear roles and responsibilities between undertakers, planning authorities, the Enforcement Authority and other stakeholders
- Encourage collaboration amongst stakeholders to manage risk down
- Ensure a process of on-going review

Guiding principles

Two important considerations have guided the development of the framework:

- **Simplicity** – It is important that the framework of regulation proposed is appropriately simple, yet credible and readily understood by undertakers and the Enforcement Authority alike. A clear message from the workshops was that to be workable the framework must be appropriately simple so as to be readily understood.

- **Industry capacity for change** – the capacity for change is limited and, where possible, consideration should be given to the staged implementation of a risk-informed framework.

Risk thresholds and regulatory framework
Fundamental to risk-informed regulation is clarity on the thresholds used to define different levels of risk. To help inform the development of these, the principles of tolerability of risk have been translated into clearly identified risk thresholds for regulating and managing reservoir safety (see Figure 3.1). These thresholds lead to the definition of the following risk categories for reservoirs, listed in order of increasing regulatory requirement:

- **Low hazard** - The physical characteristics of the dam, the reservoir it retains, and the potential flooded area are such that any breach wave would not pose a significant hazard to people or property regardless of the present or future downstream land use. These reservoirs would be excluded from the Act, and thus there would be no need to register low hazard reservoirs.

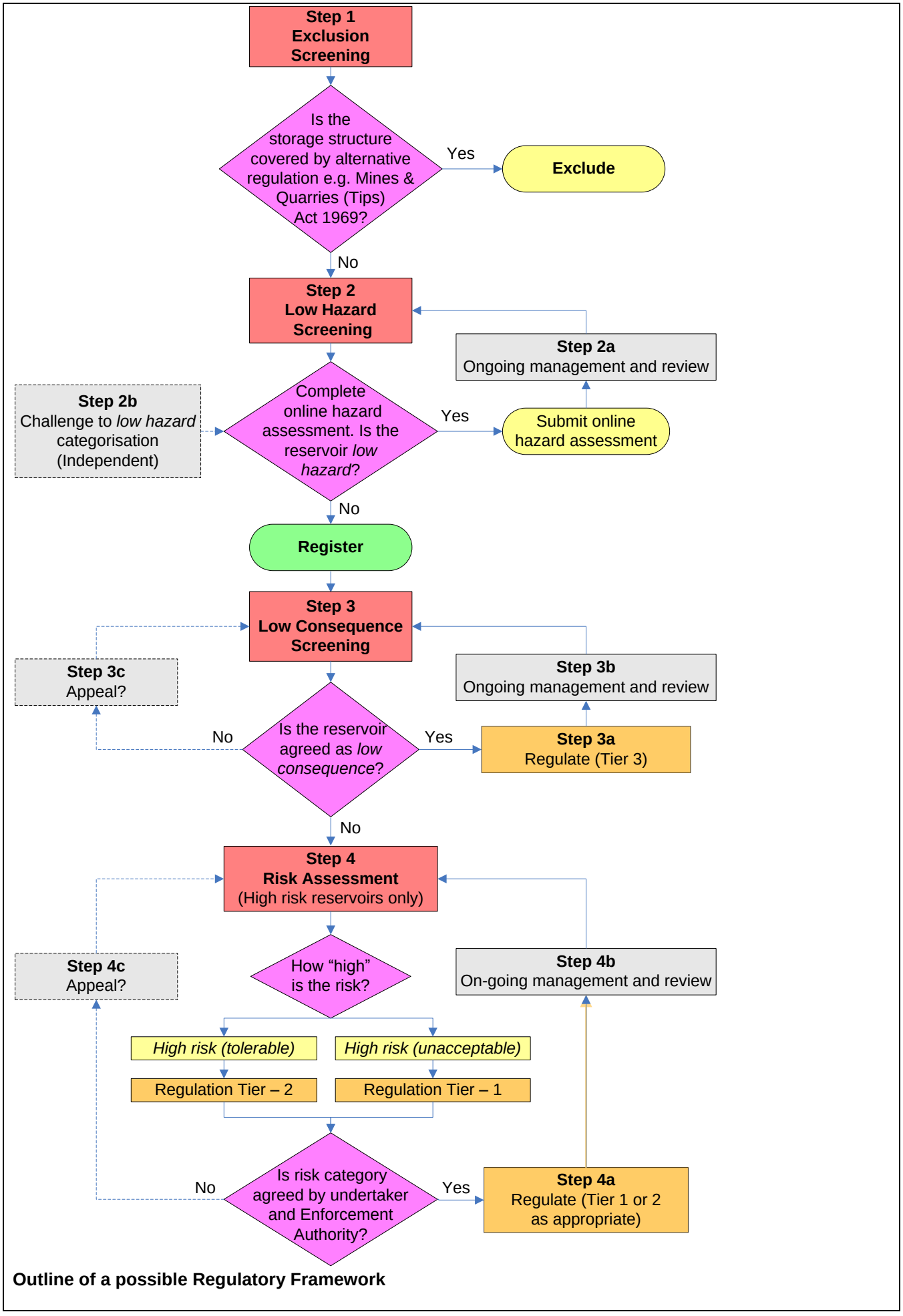
- **Low consequence** - The absence of people and property etc in the potential flooded area implies that no-one is likely to be harmed in the event of failure. Thus any reservoir (including a large reservoir capable of producing a large breach wave) could be classed as a low consequence reservoir, if no vulnerable receptors are in the potential floodplain. Low consequence reservoirs must be registered.

- **High risk** - Those reservoirs where both the hazard and the potential consequences are significant. For such high risk reservoirs, the undertaker will be expected to reduce risk to a level that is as low as reasonably practicable. In some instances the risk may be so high as to be considered unacceptable (so-called high risk (unacceptable)). In such cases, all practical measures (irrespective of cost) should be explored to reduce the risk. Where this is not possible, the undertaker will need to agree an exemption with the Enforcement Authority that confirms the undertaker has taken all practical steps and that the societal benefits accrued by the reservoir outweigh the risks. High risk reservoirs must be registered.

The proposed risk-informed regulatory framework utilises the risk thresholds presented above to define appropriate roles and responsibilities for both the regulated parties and the Enforcement Authority that can be associated with each risk category. An overview of the framework is shown in the figure below.

More details of the framework and recommendations on the priorities for moving from research to practice are provided in the main report.

For further information contact Mark Morris of HR Wallingford or Paul Ditchfield at Defra.



Outline of a possible Regulatory Framework

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
   - the scientific objectives as set out in the contract;
   - the extent to which the objectives set out in the contract have been met;
   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Transfer).

Scoping the Process for Determining Acceptable Levels of Risk in Reservoir Design - Project Report

1. Introduction

1.1 Background

The Flood and Water Management Act 2010 [2] promotes a more risk-informed approach to the regulation and engineering assessment of reservoirs. The objectives of this research project are to:

- Scope a risk-informed framework of regulation for reservoir safety management that requires the regulatory effort to be commensurate with the risk posed thus reflecting the wide range of sizes and settings for UK reservoirs.

- Highlight, where required, updates to the existing cohort of standards-based engineering guides with a view to providing consistent risk-informed support to reservoir safety management.

1.2 Motivation for the research

The drivers for the project are derived from the replacement of the prescriptive 1975 Reservoirs Act [1] with the Flood and Water Management Act 2010 [2] that requires a risk-informed approach, but offers no detail as to how this should be achieved in the expectation of secondary legislation and guidance. The motivation for this research is therefore threefold:

1) The current engineering design standards have been in place for some time and do not necessarily reflect current best practice or wider societal views on the level of risk that is acceptable or tolerable for the type of risk posed by reservoirs.

2) The desire to avoid incurring unnecessary expense whilst maintaining adequate safety. The current standards-based approach can focus effort inefficiently.

3) Current analysis methods can be overly complex and by inference costly. Not all reservoirs demand the same level of analysis or regulation. For example, a full Quantitative Risk Assessment (QRA) may be justified for high risk situations in which a high level of confidence is needed, or where risk reduction is very costly; but less rigorous analysis may be appropriate for cases where risks are small or the needed actions are obvious. Tiered risk analysis, from initial screening to more detailed methods, that reflect the importance of the decisions being made is required.

This research provides a move towards a more risk-informed approach to reservoir safety in England and Wales. However, as stated in the Defra Specification document for this project: “This project forms the first stage in the evidence base to develop procedures to impose differential requirements for reservoir safety.”

1.3 Scientific objectives

The specific objectives of the project are to:

- Develop and scope a possible tiered approach to reservoir safety risk management and provide staged recommendations to progress towards a full risk-informed framework. This has been achieved and outlined in the following report.

- Provide a conceptual framework for regulation that is risk-informed by screening out lower risk reservoirs and providing a focus on higher risk reservoirs. This has been achieved with the inclusion of low hazard, low consequence and high risk categories.

- Provide a way to differentiate between the level of risk for higher risk reservoirs, where the regulatory effort and extent of risk reduction measures by the undertaker are proportional to the risk. This has been achieved through the inclusion of different risk categories, including the use of an unacceptable risk category for the highest risk dams.

Note: It is not the aim of this project to develop the supplementary legislation and engineering guides that will be needed to support risk assessment, remedial action and regulatory or management decision making. This guidance will need to be developed once the regulation framework is agreed.

1.4 Overall approach to the project

1.4.1 Research structure

To achieve the specific objectives of the project, the work was organised in five tasks as shown in Figure 1.1. The first three tasks formed the basis for the scoping of a tiered approach to risk-informed reservoir safety management that was specifically developed in Task 4. Three Interim Papers (Bowles et al, 2010 [3], Brown et al, 2010 [4] and Sayers et al, 2010 [5]) were produced as outcomes of the four tasks, upon which this final report is based.

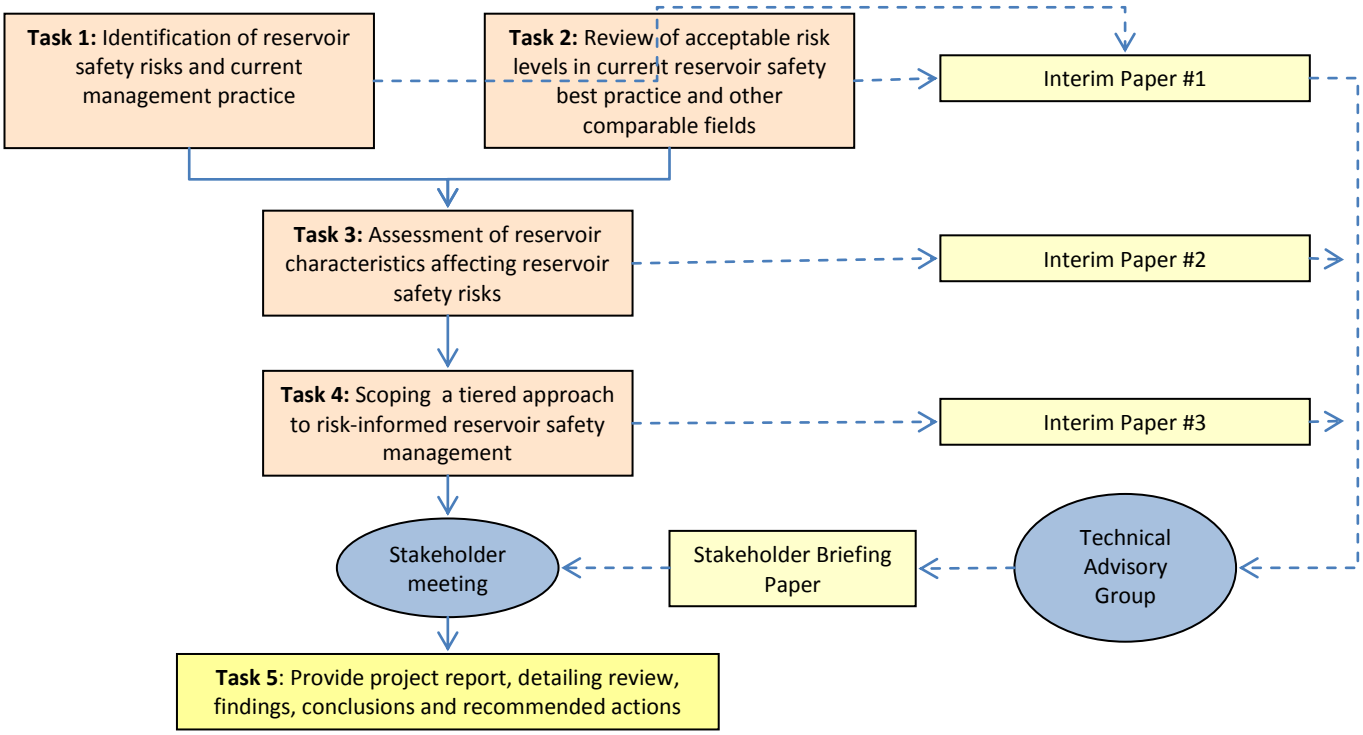


Figure 1.1 Overall approach to the project

1.4.2 Consultation process

Throughout the project, significant effort has been devoted to incorporating expertise from outside of the project team through extensive consultation, including discussion with:

- **A Project Board** (led by Paul Ditchfield of Defra) - including members of Defra and the Project Team with knowledge in the fields of dam safety and flood management policies.

- **A Technical Advisory Group (TAG)** - comprising selected dam and reservoir owners, including water companies and representatives of farmers and sport clubs as well as international experts on risk management in general. The TAG was involved throughout the development of the project through regular web teleconferences and provided valuable input at key points of the project.

Technical Advisory Group	Organisation – Role
Ian Hope	Severn Trent Water – Dams & Reservoirs Manager
Keith Gardiner	United Utilities – Regional Reservoir Manager
Jon Green	Thames Water – Asset Condition & Risk Assessment Manager
Tung Chung	Dwr Cymru Welsh Water
Tony Deakin	Environment Agency – Reservoir Safety Team representative
Derek Holliday	Country Land & Business Association – Head of Environment
Jenny Bashford	National Farmers Union – Water Policy Advisor
Dafydd Jarrett	Farmers Union of Wales Cymru
Marcus White	English Golf Union
Mark Owen	Angling Trust – Environmental Campaigns Manager
Jean Le Guen	Independent expert – Health & Safety Executive (retired)

Table 1.1 Members of the Technical Advisory Group (TAG)

- **The wider industry** - including dam and reservoir owners as well as consultants and experts in dams, Panel Engineers and representatives from the British Dam Society engaged through written correspondence as well as face-to-face workshops held in Reading and Leeds, to give people based in the north and in the south equal opportunities to take part in the workshops, and therefore broadening the likely attendance. Thirty-six people participated in total. The discussion at these workshops has been vital in shaping the framework presented in this report.

1.5 Success criteria – A goals not process focused framework

The desirable attributes of a successful regulatory framework have been defined as providing the following:

- A structured and transparent framework of regulation
- Consistency with the current legal framework in England and Wales
- A varying burden on the Enforcement Authority consistent with the level of risk
- A varying burden on undertakers consistent with the level of risk

with:

- Clarity of responsibilities between undertakers, planning authorities, the Enforcement Authority and other stakeholders
- Encouragement of collaboration amongst stakeholders
- A process of on-going review
- Regulatory costs appropriately limited without compromising safety.

In seeking to achieve these criteria, it is important that the regulatory framework proposed is focused on the outcomes to be achieved (i.e. it is goals not process focused). Therefore, the detail within which the regulatory framework is enacted and administered is excluded from this report. For example, details of how to undertake a risk assessment are not covered here, but can be developed in future studies.

The "goal" of the regulation is to achieve or ensure:

If possible:

"No significant incremental increase in consequences (loss of life and other metrics) in the event of failure"

Where this cannot be achieved:

"The risk has been reduced to be tolerable, including as low as reasonably practicable"

Noting that:

"No reservoir should present an unacceptable level of risk, except in exceptional circumstances when justified because of the societal benefits that it provides"

These goals, and hence the regulations proposed here, apply equally to new and existing reservoirs.

1.6 Outline of the report

Following this introductory chapter, this report is structured as follows:
Chapter 2 Guiding principles used to develop the framework
Chapter 3 Risk-informed Regulatory Framework (an outline)
Chapter 4 Roles, responsibilities and reporting requirements
Chapter 5 Recommended next steps

The framework presented builds upon a series of interim papers developed during the course of the project (Bowles et al, 2010 [3], Brown et al, 2010 [4] and Sayers et al, 2010 [5]) and is supported by a series of appendices to this report, including:
Appendix A - Glossary of terms
Appendix B - Understanding the meaning of "risk"
Appendix C - Defining risk thresholds
Appendix D - Example applications to reservoirs of varying risk

2. Guiding principles used to develop the framework

2.1 Introduction

Two important considerations have guided the development of the framework:

- **Simplicity** – It is important that the framework of regulation proposed is appropriately simple, yet credible and readily understood by undertakers and the Enforcement Authority alike. This was the clear message from the workshops.

- **Industry capacity for change** – the capacity for change is limited and, where possible, consideration should be given to the staged implementation of a risk-informed framework.

With these two overriding criteria in mind, this chapter presents an overview of principles that have been used to shape the framework (presented later in the report) and include:
- The constraints and opportunities presented by the Flood and Water Management Act, 2010 [1]
- Other common criteria and considerations.

These aspects are discussed in turn below.

2.2 Flood and Water Management Act 2010 – Constraints and opportunities

The Flood and Water Management Act 2010 [2] (the Act) received royal assent on 08 April 2010 and was published on the internet on 15 April 2010. The Act is deliberately broadly worded and has been interpreted as appropriate within this project. It makes the following important provisions that influence the risk-informed regulation of reservoir safety outlined in this scoping report:

- **The Minister to make regulations** – As such the Act [2] places no specific constraints upon the development of the risk-informed regulatory process; leaving all issues to be argued and agreed through secondary legislation and guidance.

- **Exclusions** – For the purposes of the Act [2], a structure that retains water and is not adequately regulated through alternative legislation is defined as a reservoir and included under the Act [2]. However, a structure that retains water is excluded under the Act [2] if:
    - They hold less than 10,000m3 or where the Minister substitutes a different volume of water (Section 2 A1(7) of the Act [2]).
    - Where the Minister excludes "specified things not to be treated as large raised reservoirs" (Section 2 A1(8) of the Act [2]).

  For example, a structure that retains water could be excluded by specifying a different minimum volume to a specific type of structure. Limitations of storage volume alone are not an appropriate basis for exclusion from the Act [2]. However, the burden placed upon both the Enforcement Authority and undertaker must be appropriate.

- **Environment Agency to designate high risk reservoirs** – Section 7 2C of the Act [2] requires the Environment Agency to designate high risk reservoirs. There is, therefore, a clear need to define high risk.

- **Registration** – It is not a requirement of the Act [2] to register **ALL** reservoirs. It is accepted that it may be desirable or practical to register only those reservoirs that have the potential, (i.e. given failure) to provide a significant increase in potential consequences in comparison with the consequences resulting from the same inflow but without a reservoir failure. This would mean that reservoirs that pose a low risk would not require registration under the Act [2]. This would not, however, diminish the requirement for the undertaker to maintain the reservoir and associated risk level under review.

2.3 Other common issues and considerations

Through the process of consultation and discussion, a number of issues and considerations, and sometimes misconceptions, have emerged that are important in the development of an efficient risk-informed regulatory framework. The most important issues are discussed below. In this discussion, the term reservoir is deemed to include the dam(s) retaining that reservoir, with the risk category being that of the highest risk dam.

- **Reservoir risk types (levels**) – There are peculiarities in the application of a risk-informed approach in this sector. The main one is that it is not possible to lay down in legislation broad criteria that with any degree of objective certainty will identify one type of reservoir construction as being more or less likely to fail than another type of construction, e.g. earth embankment construction as compared to a concrete construction. A wide range of factors affect likelihood of failure, which can be assessed only on an individual reservoir basis by engineering experts where detailed information on the components of the dam is available. Therefore, in the context of risk-informed regulation, no effort is made to distinguish between one type of construction and another or between different purposes served by the reservoir, such as a service reservoir or a flood control reservoir. Instead, in context, reservoir type refers to the level of the risk posed. This is important as it avoids the need to provide a comprehensive, and no doubt incomplete and unsatisfactory, description of the structural reservoir forms or reservoir purposes.

- **Cascades and interconnected reservoirs** – A risk-informed approach provides a structured and flexible framework, which avoids the need for special consideration of cascades or interconnected reservoirs. In this case, it is assumed that the undertaker is responsible for the on-site performance of any individual reservoir. If failure of that reservoir heightens the chance of a downstream reservoir failing, and the realisation of consequences associated with the failure of a downstream reservoir, the "additional" risk posed needs to be incorporated into the assessment of the upstream reservoir. The risk assessment tools and techniques would, of course, need to be developed through supplementary guidance.

- **Enforcing unregistered reservoirs, (i.e. those posing a low hazard**) – It is proposed that those reservoirs considered as presenting a low hazard (as defined in Section 3 of this report) by the undertaker will be excluded from the Act [2] and not be registered under Section 2 A1(8). This raises the concern that these reservoirs will be "unknown" to the Enforcement Authority and, therefore, the Enforcement Authority cannot ensure that appropriate compliance has been achieved. To address this concern, it is proposed that ALL undertakers are advised to submit a record of their assessment (through an online form, for example) to the Enforcement Authority. If a reservoir was incorrectly classified as low hazard, in addition to common law legal liabilities, the Enforcement Authority should be able to demand a reclassification of the reservoir risk category and may "fine" the undertaker, if appropriate. It is recognised that submitting the assessment form is voluntary and therefore undertakers may not comply with this advice, however, if they do comply, this would pre-empt any challenge by the Enforcement Authority. Note: It is also the case that some forms of unregistered reservoirs will be visible to Government via alternative vehicles; for example, farm reservoirs may be licensed for water abstraction. This is not provided as justification for non-registration, but rather to highlight an opportunity for cross-government information sharing.

- **Co-responsibility** - It is emphasised that the Enforcement Authority would not share any responsibility with the undertaker in the event of a collapse or any other liabilities associated with the reservoir site. This does not diminish the co-responsibilities that may already exist, for example, under the Control of Major Accident Hazards (Amendment) Regulations 2005 [6] (COMAH) as administered by the Health and Safety Executive (HSE), but no further co-responsibilities would be implied.

- **Influence on legal responsibilities** – Current and future legal responsibilities should not impact the development of a risk-informed framework of regulation. It is recognised that the regulatory framework should seek to encourage a notion of shared responsibility between the undertaker, the local authority, emergency responders and others. It is, however, noted that this should be done without diminishing the legal responsibility of the undertaker to manage the on-site performance of the reservoir.

- **Who pays for risk reduction actions** – Risks change over time for various reasons and also the same level of risk can be viewed differently by society over time. Drivers of change in risk include changes to the dam performance, but also changes in the land use of the downstream valley (not controlled by the undertaker), such as new development, and the implementation of improved or degraded off-site emergency plans (again not controlled by the undertaker). It is widely accepted that a close working relationship between these various groups is desirable. The Local Resilience Forum (LRF) provides an appropriate vehicle for bringing together interested stakeholders and within the framework, the role of the LRF should be reinforced to ensure on-site and off-site planning is as integrated as reasonable. Closer working may provide an opportunity, in the future, for cost sharing between all those with a responsibility to manage risk, i.e. not only undertakers, but also developers and local authorities, ensuring an optimum mix of on-site and off-site actions. The framework for developing such multi-funded actions and the issue of who pays is outside of the scope of this project, but this is partly being tackled by some government initiatives (for example, through funding and grants provided by the Cabinet Office and Defra). The creation of a focused Reservoir Group (as proposed as part of this framework), facilitated, but not paid for, by the reservoir undertaker, within the umbrella of the LRF may, however, be appropriate.

- **Supplementary guidance** – In support of the framework, supplementary guidance will need to provide detailed procedures through which the framework should be interpreted and enacted. For example, guidance on methods providing a hierarchy of risk assessment methods appropriate to the level of risk (both qualitative and quantitative) form part of the recommendations from this scoping project.

3. Risk-informed Regulatory Framework (an outline)

Fundamental to risk-informed regulation is clarity on the thresholds used to define different levels of risk and how the regulatory requirements will vary in accordance with them. To help inform the development of these, the principles of tolerable risk developed by the HSE [7] and widely used across government and internationally have been translated into clearly identified risk thresholds for regulating and managing reservoir safety (Figure 3.1).

Within the framework of tolerable risk, the following risk categories for reservoirs, listed in order of increasing risk, have been defined:

- **Low hazard** - The physical characteristics of the reservoir and the potential flooded area are such that any breach wave would not pose a significant hazard to people or property regardless of the present, or future, downstream land use.

- **Low consequence** - The absence of people and property etc in the potential flooded area implies that no-one is likely to be harmed in the event of failure. Thus any reservoir (including a large reservoir capable of producing a large breach wave) could be classed as a low consequence reservoir, if no vulnerable receptors are in the potential floodplain.

- **High risk** - Those reservoirs where both the hazard and the potential consequences are significant. For such reservoirs, the undertaker will be expected to reduce risk to a level that is as low as reasonably practicable (ALARP). In some instances the risk may be so high as to be considered unacceptable (so-called High Risk (unacceptable)).

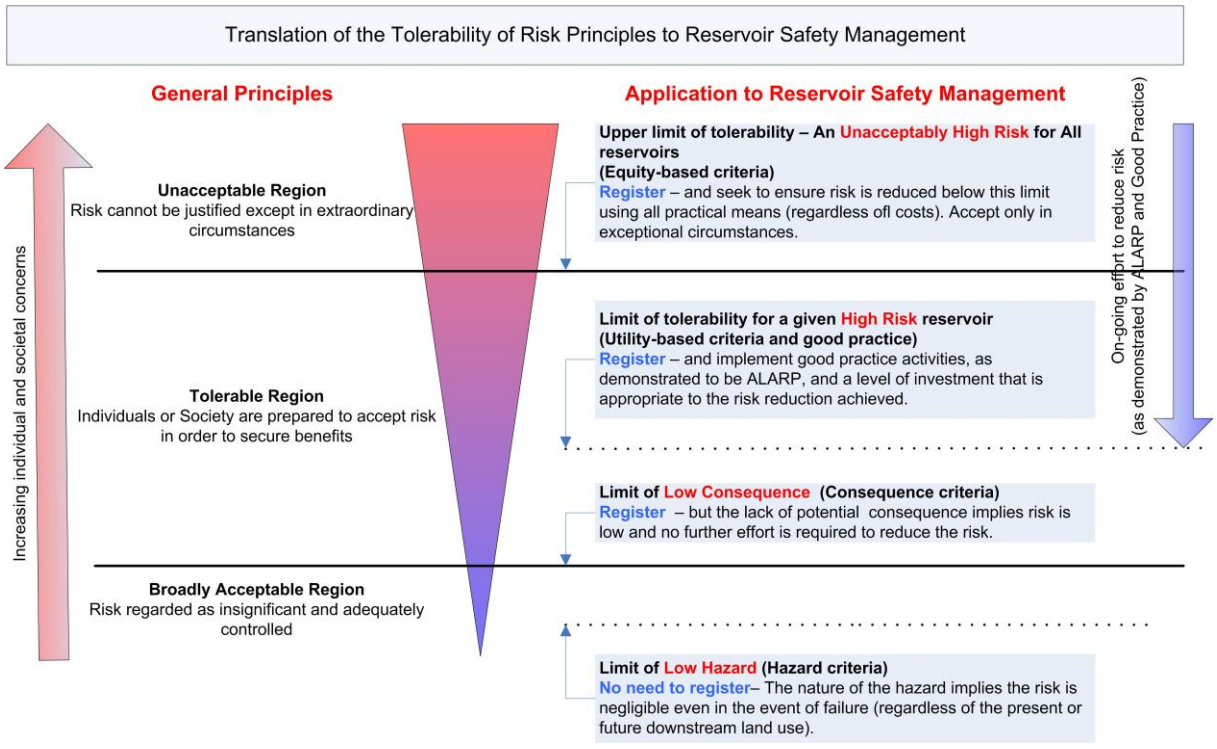


Figure 3.1 Translation of the tolerability of risk principles to reservoir regulation and management (adapted from HSE, 2001 [7])

Definitions for the terms, including 'equity' and 'utility' are detailed in the glossary within Appendix A.

The proposed risk-informed regulatory framework utilises the risk thresholds presented above (and are discussed and defined further in Appendix C) to define appropriate roles and responsibilities for both the regulated parties and the Enforcement Authority that can be associated with each risk category. An overview of the framework is shown in Figure 3.2, followed by a step-by-step discussion of this. After the discussion of each step, specific issues that may require further discussion prior to full implementation are highlighted. These issues are then prioritised within Chapter 5.

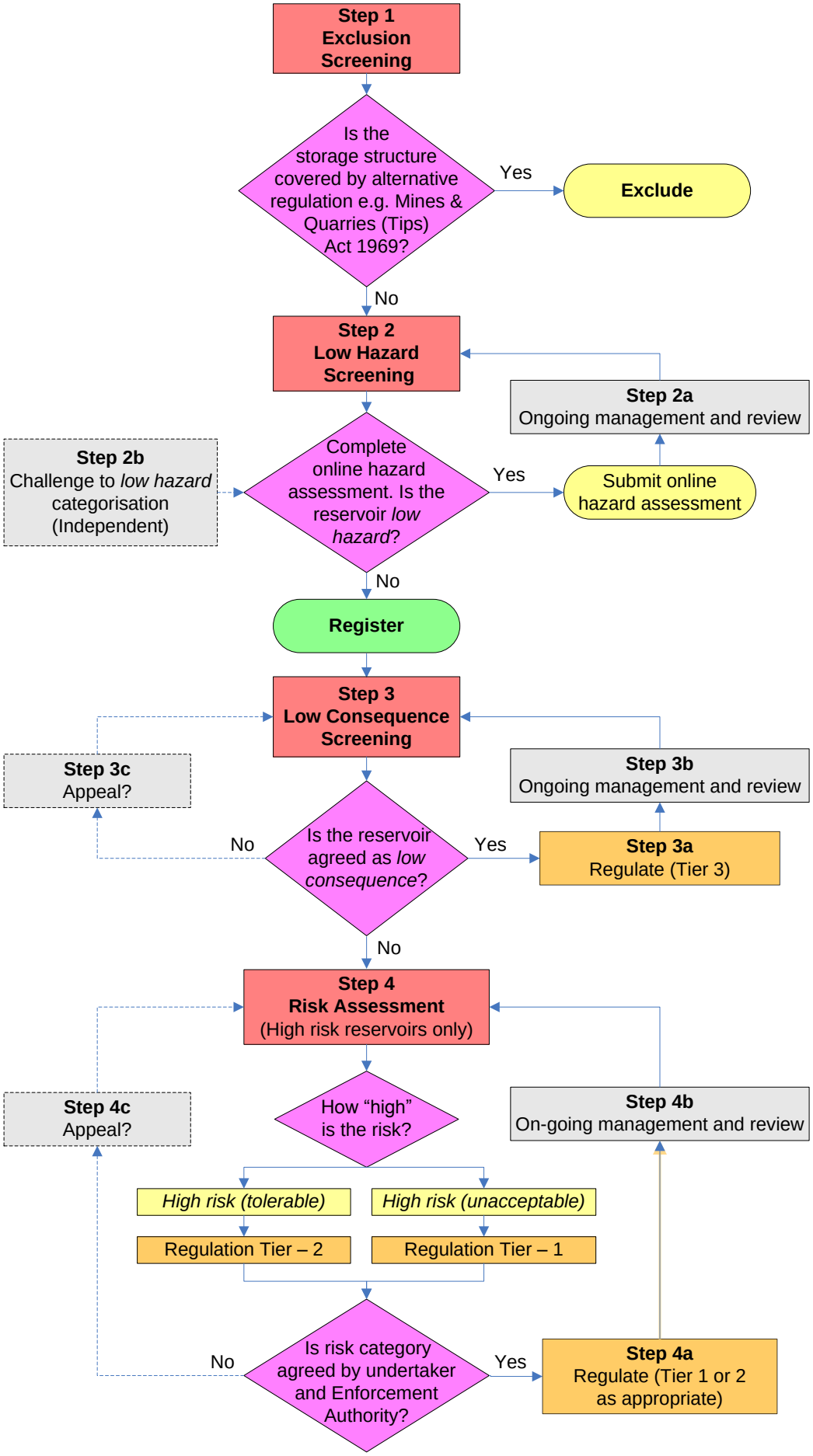


Figure 3.2 Outline of a possible Regulatory Framework

3.1 Step 1 - Exclusion screening

An initial review by the undertaker establishes whether or not they believe the structure under consideration is within the Act. If the storage structure is appropriately covered by alternative regulation, for example, the Mines and Quarries (Tips) Act 1969 [8], then the structure is excluded from the Flood and Water Management Act 2010 [2]. In addition, the Reservoirs Act 1975 [1] specifically excludes "a canal or inland navigation". No other exclusions are possible, unless the Minister substitutes a different volume of water for the specified volume of 10,000m3 (Section 2 A1(7) of the Act [2]) or where the Minister excludes "specified things not to be treated as large raised reservoirs" (Section 2 A1(8) of the Act [2]). Under Step 2, the low hazard definition provides a vehicle for excluding specific reservoirs and limiting registration under the Act [2] reflecting, amongst other aspects, impoundment volume.

Note: No other exclusions would be allowed. For example, it would not be appropriate to exclude a reservoir from the Act [2] on the basis of the type of reservoir undertaker or the type of reservoir structure as this would not be a defensible risk-informed approach. During this project, it was suggested that concrete service reservoirs owned by Water Companies and flood storage reservoirs managed by the Environment Agency could be excluded from the Act [2]. However, since these can be screened out through later steps in the framework, if appropriate, it was concluded that these should not be excluded.

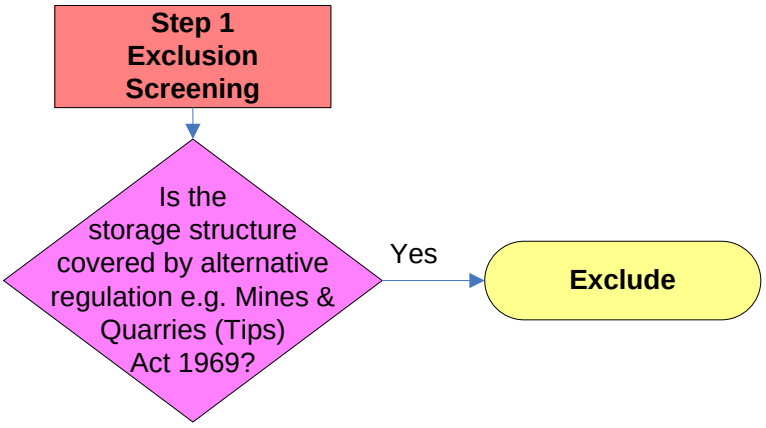


Figure 3.3 Step 1 - Exclusion screening

Recommendations for further discussion #1

A key issue for further discussion:

- **Practical regulation of previously excluded structures as specified in the Reservoirs Act 1975 [2], where no alternative regulations exist, e.g. canal embankments**

This point is discussed further in the Recommendations section of the report.

3.2 Step 2 - Low hazard screening

An initial process of low hazard screening is undertaken (commissioned) by the undertaker to identify whether or not the reservoir can be classified as low hazard. This is undertaken by answering a simple online set of sequential questions and submitting this assessment form to the Enforcement Authority. If the results of the assessment indicate the reservoir is low hazard, the reservoir is not registered for regulation. The undertaker, however, maintains a duty to maintain their assessment under review. If the undertaker is unclear on any question, they may seek further advice. If the reservoir is not classified as low hazard, the reservoir is recorded on the Reservoir Register and attracts specific risk-informed regulation.

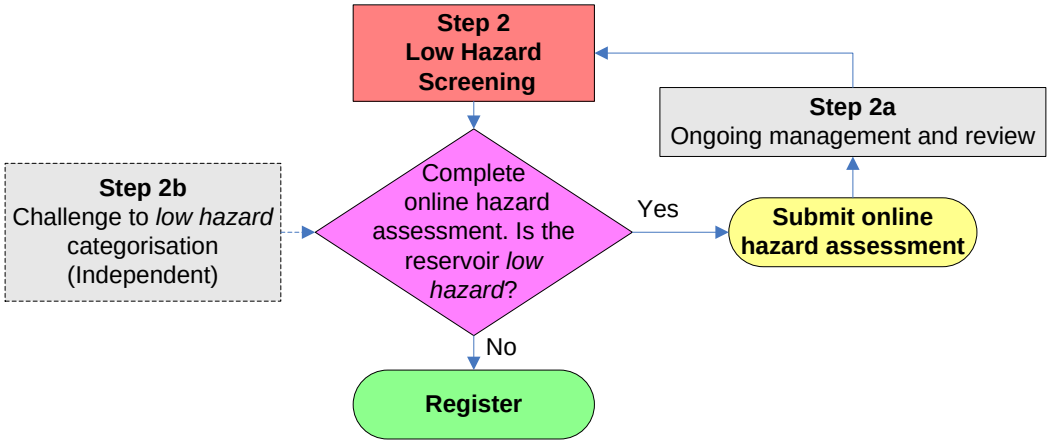


Figure 3.4 Step 2 – Low hazard screening

Recommendations for further discussion #2

Four key issues for further discussion:

- **Definition of low hazard**
- **Development of a simple online assessment form with a set of sequential questions.**
- **The appropriateness of entrusting the undertaker to complete/commission an appropriate low hazard screening**
- **Whether to include within the Act1 and register low hazard reservoirs or not**

All of these points are discussed further in the Recommendations section of the report.

3.3 Step 3 - Low consequence screening

This process determines if the reservoir, regardless of its physical size and construction, poses a threat to people or other receptors. If not, through virtue of the absence of receptors, the reservoir can be considered to be a low risk and, therefore, to require only a 'light touch' regulation. Importantly though, the assessment for such a reservoir must be maintained under review and could change category in the event of downstream development.

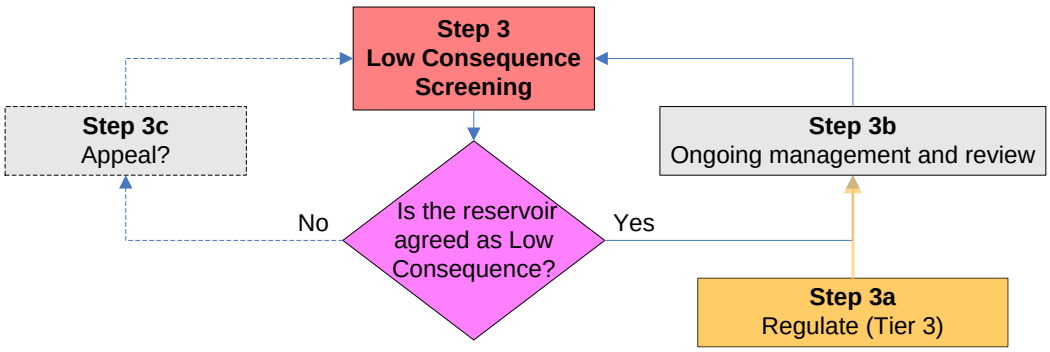


Figure 3.5 Step 3 Low consequence screening

Recommendations for further discussion #3

A key issue for further discussion will be:

- **Definition and assessment of low consequence**

This point is discussed further in the Recommendations section of the report.

3.4 Step 4 - Risk Assessment

Given the reservoir must be high risk, this step determines if the risk is tolerable or unacceptable (as defined in the glossary of terms in Appendix A) and the associated level of regulation required. An appropriate risk assessment is completed (commissioned) by the undertaker to determine whether the risk posed by the reservoir is:

- *High risk (unacceptable)* – i.e. the risk posed is in excess of the upper limit of tolerability (Figure 3.1) as defined by either the risk to an individual or society. In this case, the undertaker is required to take steps to reduce the risk further where practical regardless of cost. The risk can only be tolerated in exceptional circumstance to be agreed on a case-by-case basis. Regulation in this case would be stringent (see Tables 4.1 and 4.2).

- *High risk (tolerable)* – i.e. Reservoirs, not classified as either high risk (unacceptable), low consequence or low hazard, as defined above, are considered to be in the region of tolerable risk as illustrated on the left side of Figure 3.1. However, such reservoirs are subject to the process of seeking to reduce the risk to satisfy the principles of ALARP, including accepted good practice as they relate to a specific reservoir. Thus, an individual reservoir does not meet the requirements of tolerable risk until the principles of ALARP are satisfied, (i.e. the risk has been reduced to a level "as low as reasonably practicable").

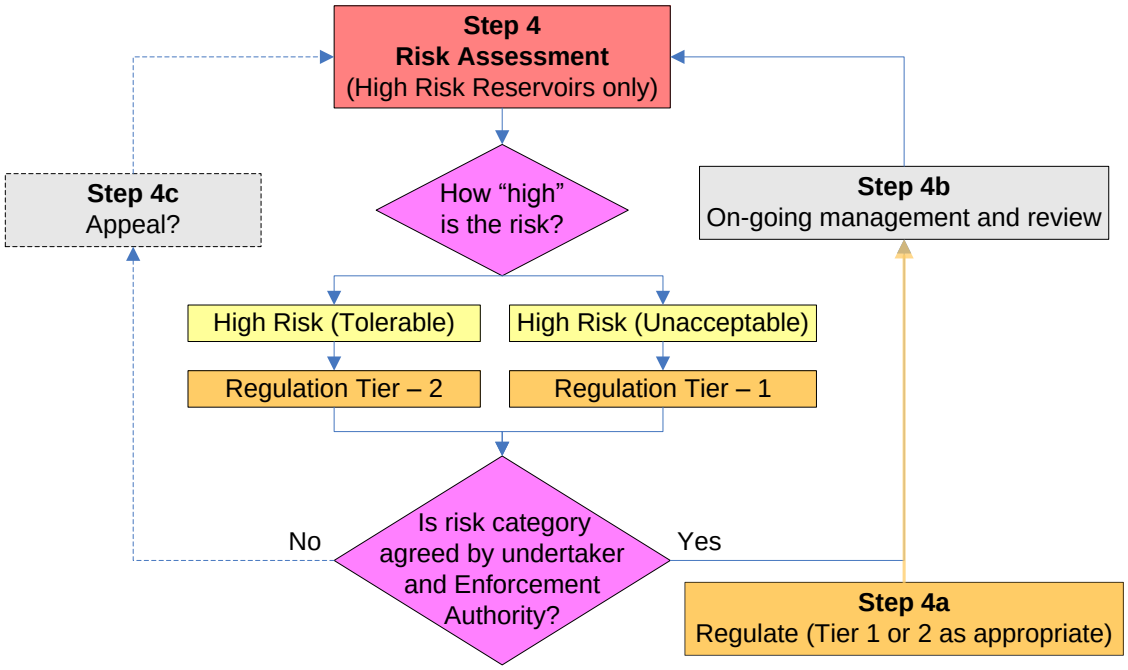


Figure 3.6 Step 4 - High risk screening

The scope and depth of regulation for a high risk reservoir will then depend upon the assessed risk at any point in time (see Tables 4.1 and 4.2).

- **Step 4a Regulate** – The process of enforcing the regulation and the undertaker maintaining, monitoring and implementing actions as required under the regulation.

- **Step 4b On-going management and review** – The assessment is repeated and updated on an on-going basis.

- **Step 4c Appeal** – The undertaker or the Enforcement Authority are able to appeal against the categorisation, process of assessment or compliance.

Note: It is not implied that all high risk reservoirs would require a common level of full Quantitative Risk Assessment (QRA) analysis, but a hierarchy of methods will need to be developed from qualitative through to quantitative. The methods applied to the assessment of risk would, therefore, vary in the level of effort, reflecting the complexity and scale of the risk and the decision to invest in reservoir management activities.

Recommendations for further discussion #4

Four key issues for further discussion:

- **Assessing high risk and disproportionate investment**
- **Determining unacceptable individual and societal risks**
- **Definition of "exceptional circumstances"**
- **The language of the framework – is the term "unacceptable" useful?**

All of these points are discussed further in the Recommendations section of the report.

4. Roles, responsibilities and reporting requirements

It is proposed that the assessed level of present-day risk is utilised in determining the requirements placed upon both the Enforcement Authority and the regulated parties. This includes placing varying obligations upon both the Enforcement Authority and the undertaker of the reservoir. This chapter presents an outline of the proposed risk-informed roles and responsibilities, and the associated reporting requirements.

4.1 What responsibilities would the undertaker have?

To commission, develop, submit and implement the:

- **Inspection Report (IR)** – for all high risk reservoirs, comprising a periodic independent safety review. Within this report, the undertaker will ensure:
  - New and remedial works are appropriately developed according to accepted good practice and guides. This would include:
    - For *high risk (unacceptable)* reservoirs, works to reduce risk to tolerable levels. These would always be considered to be "matters in the interest of safety".
    - For all *high risk* reservoirs, works to achieve ALARP. Urgent and less urgent actions should be specified.
  - The risk posed by the reservoir is appropriately assessed according to supplementary guidance.
  - An appropriate regime for periodic safety review by an independent Inspecting Engineer and on-going review by a Supervising Engineer is developed and followed (as currently required in the Reservoirs Act 1975 [1]). This will be open to scrutiny by the Enforcement Authority, including the records of surveillance and dam performance (as currently required in the Reservoirs Act 1975 [1]). The regime for the Inspection and Supervision safety reviews would vary with risk with regard to the timescales and scope and should be set out in the IR.

- **Reservoir Management Strategy (RMS)** – In some instances, the undertaker may have responsibility for multiple reservoirs or structures. In such cases, it may be beneficial (in terms of taking both effective and efficient action to reduce risk) to consider the performance of the portfolio of reservoirs for which they are responsible. In this way, efficiencies in work scheduling, surveillance etc can be optimised in a way that is not possible when managing risk on a reservoir by reservoir basis. To provide a means for the undertaker to optimise their investment to minimise risk, it is proposed that the undertaker can, if they wish, elect to produce an RMS. The RMS would detail the management activities across the undertaker's portfolio of reservoirs and how they plan to monitor and maintain their assets. The RMS would only be appropriate where the undertaker would like the Enforcement Authority to consider their approach to risk management and planned investment across all reservoirs under their management. In outline, the RMS would:
  - Include details for each reservoir owned by an undertaker and the associated risk categorisation.
  - Summarise the IRs for individual contributing reservoirs.
  - Present the actions for each individual reservoir, taking account of the capacity to implement works, and perhaps more-rapid and cost-effective prioritisation through consideration of a portfolio of reservoirs rather than individual reservoirs. The RMS will include:
    - Inspection regime (that would vary with risk).
    - Short-term management practice.
    - Medium to longer term investment plan, e.g. works scheduling etc.
    - Emergency plan including linkage with the LRF and creation of a Reservoir Group.

- **An appropriately funded programme of activities** - The undertaker will be obliged to ensure that an appropriate and funded programme of investment is in place and that ALARP principles have been appropriately applied in developing the proposed actions contained within the plan. The plan should include structural measures and on-site and off-site non-structural actions as appropriate. This will be open to scrutiny by the Enforcement Authority.

- **Periodic reviews (such as surveillance and monitoring in accordance with the IR or, if submitted, the RMS)** - The undertaker will be obliged to ensure an appropriate process of review is planned and implemented within the required timescales and scope. This will be open to scrutiny by the Enforcement Authority.

- **Emergency planning (formation of a Reservoir Group)** – For high risk reservoirs only, the undertaker may choose to facilitate a *Reservoir Group.* The formation of such a group is not intended to be onerous. Its purpose is simply to aid communication between parties with an interest and / or responsibility related to the reservoir. Flood emergency plans required under Section 12A of the Reservoirs Act [1] and the discretionary power under the Water Act 2003 [9], being due for implementation in 2010/11, would need to be developed for high risk reservoirs. The content of the plans would vary with need. Guidance on the development of appropriate on-site and off-site emergency plans is currently under review. By working closely with the LRFs, the undertaker will be in a position to ensure that reservoir issues are appropriately highlighted to the LRF. This will ensure, where required under the regulation, that integrated management of the reservoir is coordinated amongst undertakers, local authorities and community groups. Where multiple high risk reservoirs are owned by a single undertaker within an LRF, these might be coordinated as a group. Different owners of reservoirs in a cascade of reservoirs may be required to cooperate in forming a joint group. This would provide a forum within which an integrated on-site and off-site risk management strategy can be coordinated and future developments addressed. This will be open to scrutiny by the Enforcement Authority and it may be that the Enforcement Authority has a role within the forum.

Recommendations arising for further discussion #5

Two key issues for further discussion:

- **Timescales and the scope of the periodic safety reviews by Inspecting Engineers and Supervising Engineers.**

- **Who has responsibility for the establishment of a Reservoir Group and should they be obligatory or optional.**

These points are discussed further in the Recommendations section of the report.

4.2 What responsibilities would the Inspecting Engineer have?
The Inspecting Engineer would be required to:

- **Provide an independent Inspection Report (IR) for an individual reservoir** – commissioned by the undertaker. The content of the IR should cover, as a minimum, the points outline in the previous section.

- **Develop the IR in context of the Reservoir Management Strategy (RMS)** – where an RMS exists, the Inspection Engineer should take account of this in the development of proposed specific surveillance and maintenance activities. The presence of an RMS should not modify the recommendations made by the Inspecting Engineer for remedial works, nor should they seek to prioritise the needs of one reservoir with another since this is the role of the RMS.

Recommendations arising for further discussion #6

A key issue for further discussion:

- **Can the same Inspecting Engineer act to develop the Inspection Report and the Reservoir Management Strategy**

This point is discussed further in the Recommendations section of the report.

4.3 What responsibilities would the Supervising Engineer have?

The Supervising Engineer would be required to:

- Act in accordance with the Act including "matters" noted in the latest Inspection Report or, if submitted and approved, the RMS.
- Refer issues to the Undertaker and when required, the Enforcement Authority, as and when required.

4.4 What responsibilities would the Enforcement Authority have?

The Enforcement Authority has two primary responsibilities:

- For all reservoirs (regardless of the level of risk), the Enforcement Authority should be prepared to receive, and where necessary, commission a review of:
  - Risk category (and challenge through the process of an appeal, if necessary).
  - Inspection Report (IR) and all other communications currently required under the Act.
  - Updates to the IR. Updated reports to be submitted for high risk reservoirs by the undertaker in accordance with an agreed programme as defined in the previous IR or RMS.
- For high risk reservoirs, the Enforcement Authority should be prepared to receive, and where necessary, commission a review of:
  - The Reservoir Management Strategy, where submitted by the Undertaker.
  - Agreement of exceptional circumstances, where necessary.

4.5 Summary of actions required from various parties

The following tables present a summary of the roles and responsibilities that would be placed upon both the Enforcement Authority and the undertaker in the context of the risk-informed regulatory framework proposed in this report.

	Of interest for review by the Enforcement Authority				
Assessed residual risk (present day)	Tier of Regulation	Inspection Report (IR)	Review process	Reservoir Management Strategy (RMS)	Agree as an exception
High risk (unacceptable)	1	Yes (required)	Yes (required)	Optional	Yes (required)
High risk (tolerable)	2	Yes (required)	Yes (required)	Optional	No
Low consequence	3	No	Yes (required)	No	No
Low hazard	None	No	No	No	No

Table 4.1 Risk-informed variation in regulation and duties by the Enforcement Authority

	Undertaker responsibilities							
Assessed residual risk (present day)	Duty level	Register	IRs	Commission appropriate reviews	RMS	Emergency Plan	Reservoir Group	Agreed as an exception
High risk (unacceptable)	1	Yes	Yes	Yes	Optional	Yes	Optional	Yes
High risk (tolerable)	2	Yes	Yes	Yes	Optional	Yes	Optional	-
Low consequence	3	Yes	No	Yes	No	No	No	-
Low hazard	4	No	No	No	No	No	No	-

Table 4.2 Risk-informed variation in regulation and duties by the undertaker

5. Recommended next steps

It is anticipated that a working suite of secondary legislation and guidance should be in place and operational by approximately 2014. Achieving this, following delivery of this scoping study, will require a significant development effort, review, consultation and legal drafting prior to full implementation. It is, however, possible to implement the most important aspects in a staged approach (to provide maximum benefit in terms of better regulation of reservoir risks at minimum cost to both the Enforcement Authority and undertakers alike).

Once the concepts underlying the proposed framework are agreed, a number of specific issues will need to be confirmed through further dialogue, research and development. In particular, this includes the development of tools and techniques for a hierarchical approach to Quantitative Risk Assessment (QRA), including the updating of supporting engineering guides, as well as developing a consensus on the roles and responsibilities for both the Enforcement Authority and undertakers.

It is clear that there is a willingness to move towards a risk-informed approach throughout the reservoir safety community. However, it is also recognised that business capacity for change is limited and a number of difficult implementation issues need to be worked through. It will, therefore, be important that an appropriately staged approach to implementation is developed and followed.

The most important issues that will need to be resolved are summarised below.

An initial priority indicator is provided reflecting the criticality of the issue to the successful rollout of a new risk-informed regulatory framework. Two levels of priority are provided:

- **Critical** – an issue that is a "must do" to enable progress to be made in the short term.
- **Important** – an issue that can follow in the future to help clarify the framework, but is unlikely to stop an initial implementation.

5.1 Critical – Must be resolved prior to implementation

Three issues have been highlighted as critical to the successful rollout of the proposed framework. These are summarised below.

Critical #1

Confirming the need for inclusion in the Act[1] and registration of low hazard reservoirs or not

Considerable discussion was held during the project regarding the proposal to exclude *low hazard* reservoirs from the Act[1] and the Reservoir Register. Many small owners saw this as an advantage, accepting that they would maintain a duty to ensure that the reservoir was appropriately managed. Others were concerned that unregistered reservoirs would be "unseen" to the Enforcement Authority with no way of confirming the appropriateness or otherwise of a *low hazard* classification. To address this concern, it is proposed that ALL undertakers are advised to submit a record of their assessment (through an online form, for example) to the Enforcement Authority. If a reservoir was incorrectly classified as *low hazard*, in addition to common law legal liabilities, the Enforcement Authority should be able to demand a reclassification of the reservoir risk category and may "fine" the undertaker, if appropriate. It is recognised that submitting the assessment form is voluntary and therefore undertakers may not comply with this advice, however, if they do comply, this would pre-empt any challenge by the Enforcement Authority.

This issue will require further discussion and an online assessment form developed under Critical #3, if this is agreed as the way forward.

Critical #2

Overall roles and responsibilities

This report presents a series of risk-informed roles and responsibilities. It will be important to confirm these prior to implementation and, in particular, to scrutinise the proposed reporting and review requirements and agree appropriate expectations at each level. The content and level of detail of the reports need to be clearly defined through guidance and examples provided to avoid wasted effort. Also, guidance will be needed on the frequency and level of the safety reviews such as for Supervision and Inspections, as well as for surveillance and how to assess an appropriate investment plan, etc.

Equally, whether Table 4.2 contains all areas where the Enforcement Authority wishes to place a duty on the Undertaker should be considered further. Are the reviews of these duties appropriately covered by the on-going Supervision and Inspections as an instrument of the Enforcement Authority?

Critical #3

***Risk assessment – Defining thresholds and providing supporting* guidance**

Prior to rollout of the framework it will be critical that clarity is given to the:

- Definition and assessment of *low hazard*

  This will require clarity of what structures comprise *low hazard*. Then, to assist undertakers to assess whether their structures are *low hazard*, a simple online assessment form will need to be developed with a set of sequential questions to determine whether the reservoir is *low hazard.*

- Definition and assessment of *low consequence*

- Definition and assessment of *high risk*

  This will require methods to be developed that are appropriate to the risk posed and the decisions to be informed. A hierarchical approach to risk assessment (both qualitative and quantitative) will need to be developed that includes a range of methods that reflect the risk and complexity of the investment decisions.

  There is also the possibility of developing general and somewhat conservative "fall-back" requirements for reservoir safety that would minimise the level of effort needed to conduct a risk assessment. This would provide the undertaker with the option to conduct a simple risk assessment to examine the appropriateness of whether these "fall-back" requirements are appropriate for a particular reservoir or whether the additional effort required in undertaking a full quantitative risk assessment is justified in terms of the potential benefits.

  In practice, the benefits of reservoir safety risk assessment can include either a savings in the investment in risk management or an improved understanding of the risk, which may justify a higher level of investment.

  Note: The Environment Agency plan to initiate a study on risk assessment within their research and development programme for 2010/11.

- Definition and assessment of ALARP and disproportionate investment

  Currently, there is no consistent framework for assessing what is, and what is not, a disproportionate level of investment and other ALARP requirements for reservoir safety. However, extensive guidance has been developed by HSE[13, 14, 15] for other hazards and these should be considered in developing guidance for reservoir safety. The methods developed should be tiered in nature, and hence commensurate with the level of risk, and capable of practical application.

- Definition of unacceptable individual and societal risks and "exceptional circumstances"

  What is meant by "exceptional circumstances" and hence a valid exception from the need to reduce the risk associated with *"unacceptably" high risk* reservoirs will need to be clarified prior to implementation of the framework. A process for approval of exceptions will also need to be developed including the identification of the approving entity.

- The language of the framework – is the term "unacceptable" useful?

  Although this term is well used within international research literature and HSE guidance[10, 11], some stakeholders have expressed concern that the term "unacceptable" implies non-compliance and even wrong-doing on the part of the undertaker or perhaps government in its oversight role. On the other hand, it was pointed out that when appropriately used the term can serve to motivate both the undertaker and the enforcement agency to take action to change the classification. Consideration will need to be given to the use of this term prior to implementation of the framework.

5.2 Important – to be resolved prior to future stages of implementation

The following issues are marked as important, but not critical to the first stage implementation of a risk-informed regulatory process. No attempts have been made to prioritise or group these issues further and hence they are provided as a simple listing.

Important #A

Who should be responsible for assessing low hazard screening?

The appropriateness of entrusting the undertaker to undertake an appropriate *low hazard* screening was challenged in the workshops. This reflected concern about undertakers having the necessary qualifications and knowledge of the Act to perform such an assessment and their objectivity. Although no firm view was determined, the balance of opinion is that an independent qualified party and not the undertaker should be responsible for the *low hazard* screening step. However, if this party was the Environment Agency, it would impose a major workload on them at the outset of implementation of the Act[1].

Note: Within the proposed framework an opportunity for independent challenge to the definition of *low hazard* has been provided to help accommodate a potential checking role by the Enforcement Authority. This could be undertaken through random "spot checks" to confirm the validity of the assessment forms submitted online by undertakers.

Important #B

Can the same Inspecting Engineer act to develop the Inspection Report and the Reservoir Management Strategy?

It is likely that an Inspecting Engineer will be employed to aid the undertaker to develop and update the RMS. The appropriateness of the same Engineer being employed for the IR and in assisting with the development and updating of the RMS needs to be discussed and a policy established.

Important #C

Responsibility for the establishment of a Reservoir Group

Although generally accepted as a good idea, many undertakers have expressed concern that it should be the responsibility of the LRF, and not the undertaker of a *high risk* reservoir, to ensure appropriate planning is in place in the case of a dam failure. The proposed approach presented here follows the lines of the COMAH Regulations[6] for major installations where the undertaker has a duty of care to present the LRF with information that could be useful in the event of failure. No suggestion is made here that the undertaker should be responsible for the "off-site" plan. It is, however, suggested they have a lead role in ensuring the potential risk is brought to the attention of the LRF. The details of such a Group will need further discussion and refinement before being taken forward.

Important #D

Engineering guidance

Currently, the engineering guidance is not consistent with the philosophy of a risk-informed approach and some will need to be reconfigured in the context of risk analysis. Clear and transparent guidance will be required for Panel Engineers. For example, the 1996 ICE publication "Floods and Reservoir Safety[12]" will need to be updated as this provides the current categorisation of A to D and strictly was intended for impounding reservoirs.

Important #E

Accepted good practice

Users will need guidance on those practices that can be considered "good" regardless of any risk assessment. These guides may be practically appropriate for *low risk* reservoirs. In other industries, HSE has established guides[13, 14, 15,] which define good practice, which meets ALARP. However, the question should be asked of whether this approach is achievable for reservoir safety considering the wide range of settings of reservoirs that affect flood loading and foundation conditions, for example.

Important #F

The role of, and linkage to, Local Planning Authorities (LPAs)

LAs have a role in controlling the growth of reservoir failure consequences and in assuring effective warning and evacuation in the event of actual or anticipated dam failure. For example, linking with the Local Resilience Forums and the cross-government task group led by the Cabinet Office, which has sought resolution of the competing interests of various stakeholders, and a consensus on the objectives in major hazard control at source regulated under COMAH[6] and land-use planning. At a minimum, it is suggested that the reservoir safety community track progress made by this group and should possibly consider some level of participation given the common challenges faced in the reservoir safety field.

Appendix A: Glossary of terms

As low as reasonably practicable (ALARP)*: That principle which states that risks, lower than an upper limit of tolerability, are tolerable only if risk reduction is impracticable or if the cost is grossly disproportionate (depending on the level of risk) to the improvement gained. ICOLD 2005 [16]*

Consequence*: In relation to risk analysis, the outcome or result of a risk being realised. This includes impacts in the downstream, as well as other areas resulting from failure of the dam or its appurtenances. ICOLD 2005 [16]*

Disproportionality ratio*: A cost / benefit ratio (i.e. inverse of the benefit / cost ratio) in which the economic benefits are subtracted from the annualised costs in the numerator and only the (health and) safety benefits are considered in the denominator. The benefit may be described in monetarised or non-monetarised forms. For reservoir safety, the life-safety benefits are often the focus and are typically valued using the value per fatality (VPF published annually by the Department for Transportation, 2007 [17]). The disproportionality ratio provides a measure of the degree of disproportionality associated with a potential risk reduction measure [see Appendix 3 of R2P2 (HSE 2001 [18])]. The approach can be useful in the justification of dam safety risk reduction measures based on information obtained from a risk assessment. HSE 2002b, paragraph 25 [13] refers to this ratio as a Proportion Factor. Bowles 2003 [19]*

Exceptional circumstances*: The qualifier "except in exceptional circumstances" used in the definition of unacceptable risk refers to a situation in which Government, acting on behalf of society, may determine that risks exceeding the upper limit of tolerability may be tolerated based on special benefits that "the dam brings to society at large". "The justification for tolerating such high risks is the wider interests of society. Risks, which would normally be unacceptable, can be tolerated on account of the special benefits, which the dam brings to society". ANCOLD 2003 [20]*

Efficiency*: In the context of society's use of resources, is a principle which seeks to gain greatest benefit from the available resources. ICOLD 2005 [16]*

Equity*: In this context, is a principle which holds that the interests of all are to be treated with fairness and that individuals and society has the right to be protected. ICOLD 2005 [16]*

Hazard*: Threat; condition, which may result from either an external cause (e.g. earthquake, flood, or human agency) or an internal vulnerability, with the potential to initiate a failure mode. A source of potential harm or a situation with a potential to cause loss. ICOLD 2005 [16]*

Incremental consequences of failure*: Incremental losses or damage, which dam failure might inflict on upstream areas, downstream areas, at the dam, or elsewhere, over and above any losses which might have occurred for the same natural event or conditions, had the dam not failed. ICOLD 2005 [16]*

Individual risk*: The increment of risk imposed on a particular individual by the existence of a hazardous facility. This increment of risk is an addition to the background risk to life, which the person would live with on a daily basis if the facility did not exist or, in the context of dam safety, if the dam did not fail. ICOLD 2005 [16]*
Large raised reservoir – no specific definition (deliberately so)

Qualitative risk analysis*: An analysis, which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur. ICOLD 2005 [16]*

Quantitative risk analysis*: An analysis based on numerical values of the potential consequences and likelihood, the intention being that such values are a valid representation of the actual magnitude of the consequences and the probability of the various scenarios which are examined. ICOLD 2005 [16]*

Risk*: Measure of the probability and severity of an adverse effect to life, health, property, or the environment. In the general case, risk is estimated by the combined impact of all triplets of scenario, probability of occurrence and the associated consequence.*

Risk management*: The systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, mitigating and monitoring risk. ICOLD 2005 [16]*

Risk-informed decision making*: An approach to decision making that supplements a risk-based approach with the recognition of subjective trade-offs and issues of equity. Adapted from ICOLD 2005 [16]*

Small raised reservoir*: no specific definition (deliberately so)*

Societal concern*: Concerns engendered by those hazards which impact on society at large and harm the social fabric through the socio-political response to their risk being realised, leading to a loss of trust in the regulatory system, the Enforcement Authority, industry, etc. HSE 2009 [21]*

Societal risk*: The risk of widespread or large scale detriment from the realisation of a defined risk, the implication being that the consequence would be on such a scale as to provoke a socio/political response, and/or that the risk (that is, the likelihood combined with the consequence) provokes public discussion and is effectively regulated by society as a whole through its political processes and regulatory mechanisms. Such large risks are typically unevenly distributed, as are their attendant benefits. Thus the construction of a dam represents a risk to those close by and a benefit to those further off, or a process may harm some future generation more than the present one. The distribution and balancing of such major costs and benefits is a classic function of Government, subject to public discussion and discussion. ICOLD 2005 [16]*

Standards-based approach*: The traditional approach to dams engineering, in which risks are controlled by following established rules as to design events and loads, structural capacity, safety coefficients and defensive design measures. ICOLD 2005 [16]*

Tolerable risk*: A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk that we do not regard as negligible or as something we might ignore, but rather as something we need to keep under review and reduce it still further if and as we can. ICOLD 2005 [16]*

Unacceptable risk*: A level of risk that cannot be justified except in extraordinary circumstances (typically where the continuation of the risk has been authorised by government or an Enforcement Authority in the wider interests of society). Adapted from ICOLD 2005 [16]*

Uncertainty*: Previously used to refer to situations where the likelihood of potential outcomes can not be described by objectively known probability density functions. Now used to describe any situations without sureness, whether or not described by a probability distribution. In the context of dam safety, uncertainty can be attributed to (i) inherent variability in natural properties and events (aleatory uncertainties), and (ii) incomplete knowledge of parameters and the relationships between input and output values (epistemic uncertainties). Adapted from ICOLD 2005 [16]*

Appendix B: Understanding the meaning of "risk"

"Risk" means different things to different people. In the context of this, the following important principles have been defined:

- **Risk-informed** – The framework of regulation is risk-informed in the context of both:
    - The burden placed upon the Enforcement Authority, i.e. a higher regulatory effort will be demanded of the Enforcement Authority for higher risk reservoirs compared to lower risk reservoirs.
    - The burden placed upon the undertaker, i.e. the undertaker of a higher risk reservoir will be expected to commit greater resources in the assessment and management of the reservoir compared to the undertaker of a lower risk reservoir.
- **Risk is described using multi-dimensions (risk metrics)** for the purpose of evaluating the tolerability of risk:
    - *Individual risk* – The likelihood that a particular person in some fixed relation to a hazard, (e.g. at a particular location, level of vulnerability, protection and escape) might sustain a specified level of harm (HSE 2009 [21]). It is the increment of risk imposed on a particular individual by the existence of a hazardous facility. This increment of risk is an addition to the background risk to life, which the person would live with on a daily basis if the facility did not exist or, in the context of dam safety, if the dam did not fail (ICOLD 2005 [16]). When evaluating individual risk, it is the highest risk posed to any individual and not an "on average" risk that is compared against individual tolerable risk guidelines.
    - *Societal risk* – The relationship between frequency and the number of people sustaining a specified level of harm in a given population due to the realisation of specified hazards. This factor can help to reflect societal concerns that arise, e.g. when multiple fatalities or injuries occur in planning advice (HSE 2009 [21]). It is noted that simplified representations of societal risk such as obtained using an integrated "expected annual risk"[1] or a risk integral, do not preserve the important distinction between high probability and low consequence events and those of low probability and high consequence – a distinction that is important when setting tolerable risk thresholds and making evaluations against these thresholds or limits.
    - Economic, heritage, environmental and cultural risk – Multiple additional risk metrics could be used to determine the tolerability of a risk, e.g. the impact on an internationally important habitat or structure. These broader impacts also have an important role to play, but are not considered further here.

Note: The means of combination and the relative weighting given to one metric over another is not addressed here. Guidance will need to be developed following on from this project once a framework has been agreed.

- **Acceptance of variations in risk levels** – It is not practical to reduce the risk arising from all reservoirs to a common, "broadly acceptable" level. Rather for some, the cost of risk reduction measures will be too high, and for many practical options to reduce the risks to a broadly acceptable level simply do not exist, and therefore higher risks may need to be tolerated. This is an important assertion, and mitigates against a prescriptive definition of tolerable risk levels based on risk alone, but recognises that tolerability of risk will, in some instances, depend upon the level of investment needed to reduce the risk. It is, however, noted that accepted good practice should always be implemented (regardless of its assessed utility) and that in some instances the risk posed may be unacceptable, and can only be tolerated in exceptional circumstances because of the benefits that it brings to society.

[1] Expected Societal Risk = annual probability of reservoir failure x probability of multiple individuals being exposed to the flood wave x probability of multiple individual dying x the number of fatalities summed over all failure modes and exposure scenarios. The "expected risk" provides a useful expression of the risk when comparing the benefits and costs associated with a given action to reduce risk or when comparing or prioritising levels of societal risk across different reservoirs.

Appendix C: Defining risk thresholds

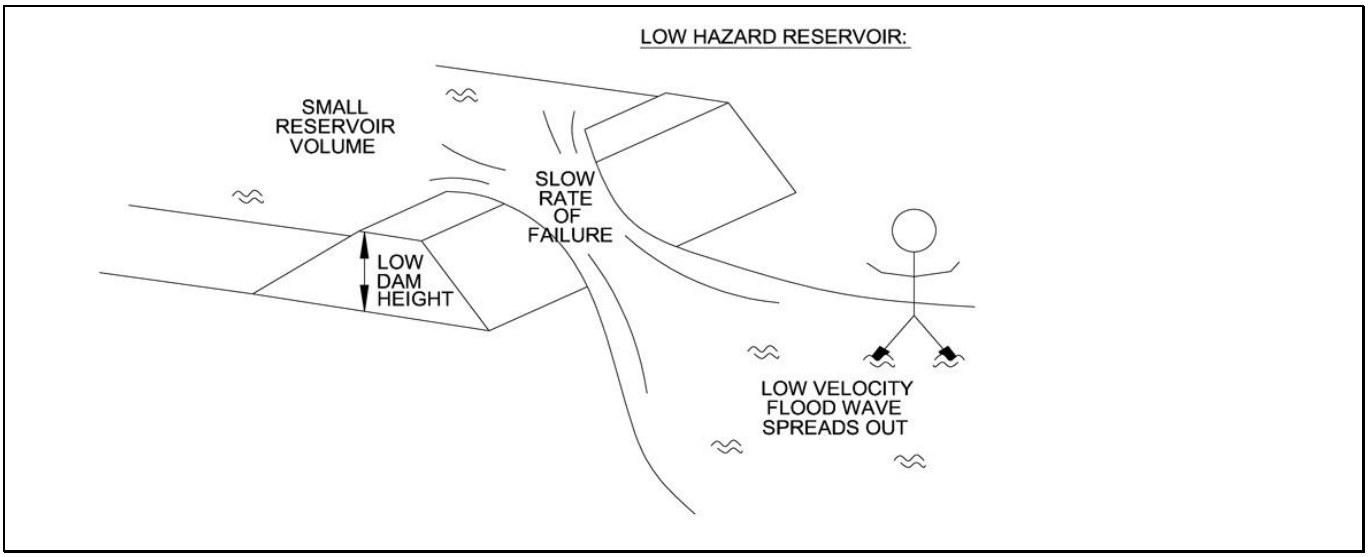
The definitions of each of the thresholds referred to in the main report are discussed below.

Low hazard (the lowest category of "risk")
The low hazard threshold is introduced to accommodate the situation where:
"given failure of the reservoir, no significant incremental consequences would occur regardless of future changes in the downstream land use/population"

Therefore, the definition of low hazard involves an assessment of the reservoir without consideration of probability of failure or the resulting consequences.
The use of a low hazard threshold provides a focus on the nature of the storage, the impounding structure and the floodplain. Low hazard reservoirs are by definition also low risk reservoirs (and would remain so regardless of the present or future downstream land use). An outline of the criteria that could be used to define a low hazard reservoir is given in Table C.1 below:

Test	Criterion	Interpretation	Nature of supporting guidance
1	No significant incremental increase in hazard, e.g. *For impounding reservoirs this could be considered in the context of not significantly altering the extent, velocity or depth of the without reservoir 1:20 year return period floodplain (i.e. the functional floodplain) or alternatively, specifying a maximum allowable depth on the floodplain such as 500 or 600mm.* *For a non-impounding reservoir, an alternative but workable guide would be needed.* Note: Other definitions will need to be explored prior to finalisation.	Assessed through consideration of the **worst case** resulting flood wave (taking account of both rainy day and sunny day failure scenarios).	Guidance defining the characteristics of the reservoir and flood plain for a low hazard reservoir will need to be clear and appropriately simple considering both: (i) The **source** of the potential hazard – this should be **limited**, (e.g. reflecting the physical characteristics and setting of the reservoir, for example, height above floodplain and retained volume etc). (ii) The **pathway** of the potential hazard – this should be **benign**, (e.g. reflecting the physical characteristics of the downstream valley, for example, slope and width). Note: It is unlikely to be appropriate to base the assessment of low hazard solely on volume (see box below).

Table C.1 Examples of a test to determine a low hazard reservoir



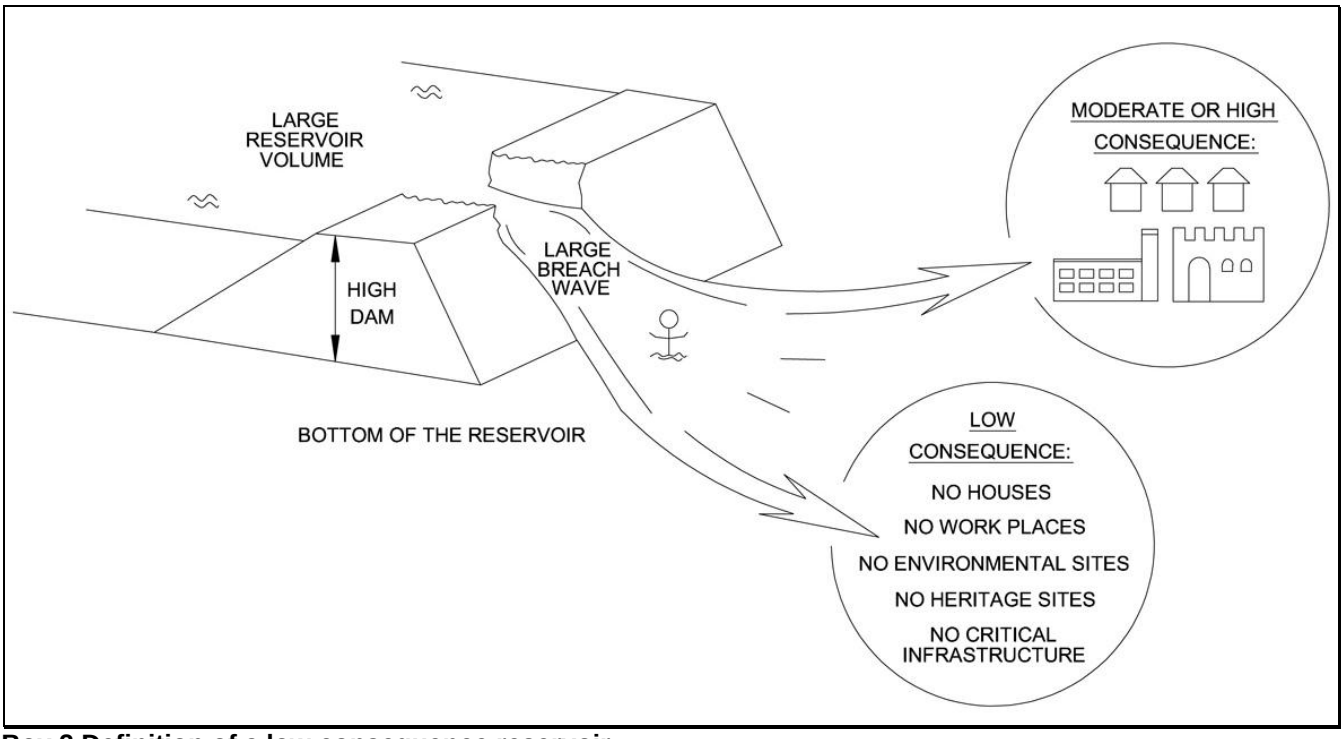
Box 1 Definition of a low hazard reservoir

Low consequence (the second lowest category of "risk")
A low consequence reservoir would cause no (or very limited) consequences regardless of the volume of water released; hence a categorisation of low consequence would be independent of reservoir size.

For a reservoir to be considered as low consequence there should be no significant increase in potential consequence in the event of failure compared to the no-failure case. An outline set of criteria for defining a reservoir as low consequence are set out in Table C.2 below. It should be noted however that in the event of land use change, the risk category of a low consequence reservoir could easily change (to high risk) and, therefore, there would of course be a requirement for the undertaker to keep this under review.

Test	Criterion	Interpretation	Nature of supporting guidance
1	In the event of failure, the reservoir presents no significant increase in potential **consequences**.	The absence of receptors in the potential flooded area means that the potential exposure to loss of life, economic damage or other impact is very limited, e.g. (i) **People** - In the event of an uncontrolled release, the risk to people is low. (ii**) Other consequences** - In the event of uncontrolled release, damage to the economy, environmental sites, heritage sites, and/or critical infrastructure would be insignificant.	Methods of varying complexity will need to be developed and employed to assess the potential consequences ranging from simplified property counts (as a proxy for people) to more complex loss of life, dam break and evacuation modelling, and whether impact on environmental and heritage sites should be included. These methods will need to be provided in supplementary guidance, taking account of available data where possible.

Table C.2 Examples of a test to determine a low consequence reservoir



Box 2 Definition of a low consequence reservoir

High risk (the second highest risk category)
Within the region of tolerable risk (Figure 3.1 of this report), effort needs to be made to reduce the risk posed by a particular reservoir to a level that is "as low as reasonably practicable" (ALARP) through a process of optioneering and implementation. The degree to which it is reasonable to reduce the risk will reflect the principles of ALARP that includes a process of both investment and reward trade-offs, but also the application of accepted good practice (regardless of any risk assessment). In this region of Figure 3.1, it is likely that the Enforcement Authority would have a role in reviewing:

- The assessment of the present-day risk posed
- The credibility of the undertaker's planned investment to reduce risk as appropriate.
- The planned process of ongoing review and inspection

Determining the point at which ALARP, including the application of good practice, is satisfied will depend upon:

- **The definition of "gross disproportionality"** – the ratio of "investment to reward" must be considered and, unlike traditional benefit cost ratio (BCR), the investment must be considerably more than the reward to warrant the investment to be considered impracticable.

- **What is accepted as good practice** – good practice must be implemented regardless of any consideration of risk, unless the cost is excessive as demonstrated using disproportionality considerations. The point at which a cost becomes excessive will be reservoir-dependent and will require supplementary guidance.

The way in which this is done will be an important aspect of any supplementary guidance provided alongside the regulatory framework (see for example the discussion on the proportionality factor and disproportionality ratio in Interim Paper 1 [3] under Task 2). An example the influence of disproportionally is shown in Figure C.1 below:

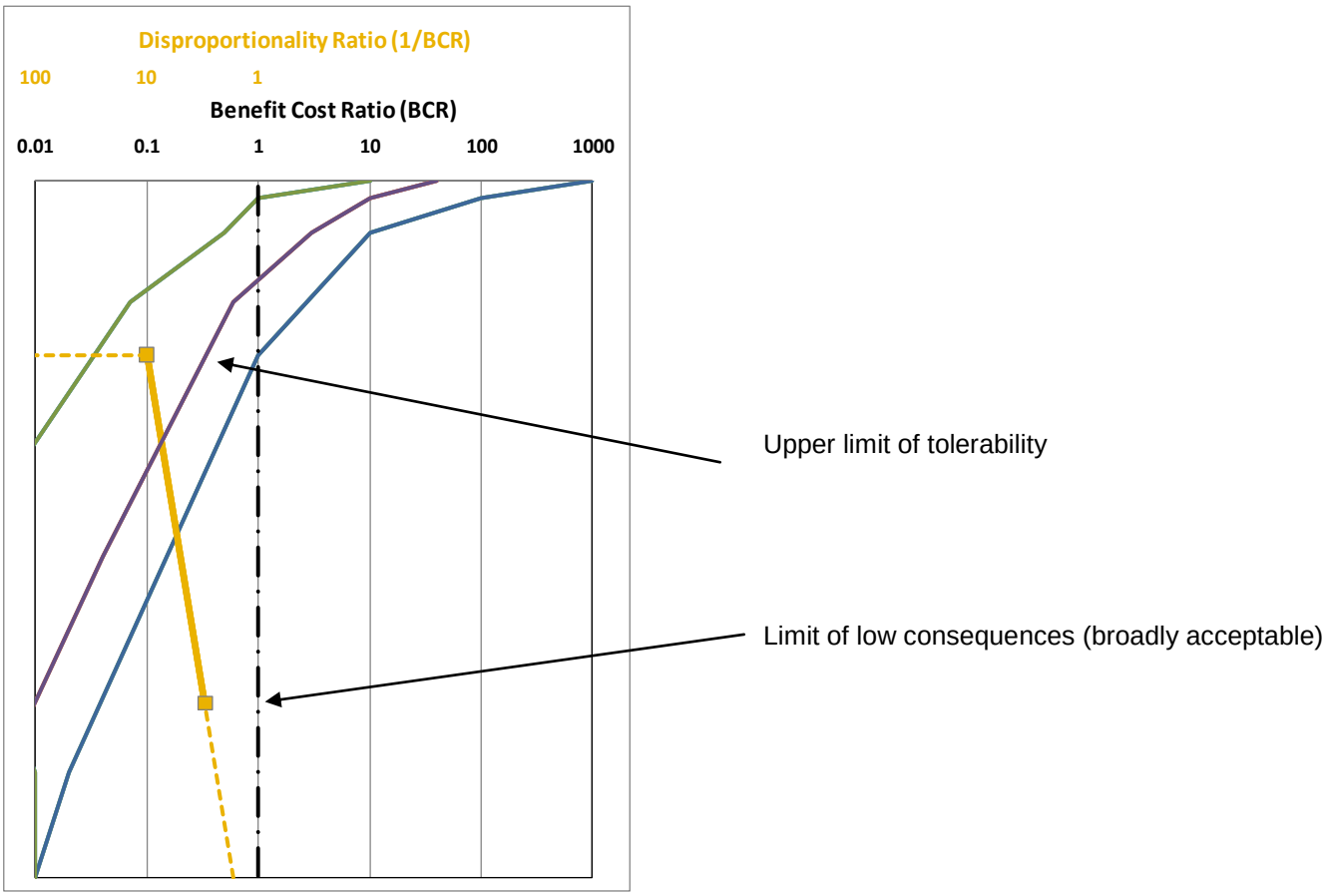


Figure C.1 An example of the application of disproportionality.

This shows that investment is required to reduce the risk further below the upper limit of tolerability even when the traditional BCR < 1 in which life safety benefits are included in the benefits. For higher risk dams the acceptable level of disproportion increases with the risk prior to reduction (Bowles et al [3] using HSE guidance [13] on disproportionality).

Unacceptable risk (the highest risk category)
Unacceptable risk represented by the region near the top of the triangle in Figure 3.1, would be "regarded as unacceptable whatever the benefits" unless they can be reduced to fall in a lower region or "there are exceptional reasons for the activity or practice to be retained" (HSE 2001 [18]). This includes situations where it is technically impossible to reduce the risk further, yet the benefits accrued by the reservoir are considered critical to society. For example, the siting of airports near cities to meet tolerable risk guidelines would have required Schipol Airport to be located in the North Sea at enormous cost and perhaps at an impractical distance from Amsterdam. Some flood detention dams above a city may pose an unacceptably high residual risk after all reasonable risk reduction measures have been implemented, but their removal would result in an even higher level of risk. It is, therefore, unacceptable for the risk associated with any reservoir to lie within this region, expect in such exceptional circumstances. Where the assessed risk is higher than the upper limit of tolerability, immediate remedial actions are required, regardless of cost, including interim measures while long-term measures are being implemented.

It is proposed to define the threshold of tolerability through an equity-based criterion[2] based on consideration of both:

- Individual risk using thresholds that would need to be developed (see Figure C.2 for an example from NSW DSC 2006 [22] for existing dams).

- Societal risk using thresholds on an F-N chart that would need to be developed (see Figure C.3 adapted from an example from USACE 2010 [23] for existing dams and an example taken from flood risk management, for information in contrast to existing reservoir thresholds).

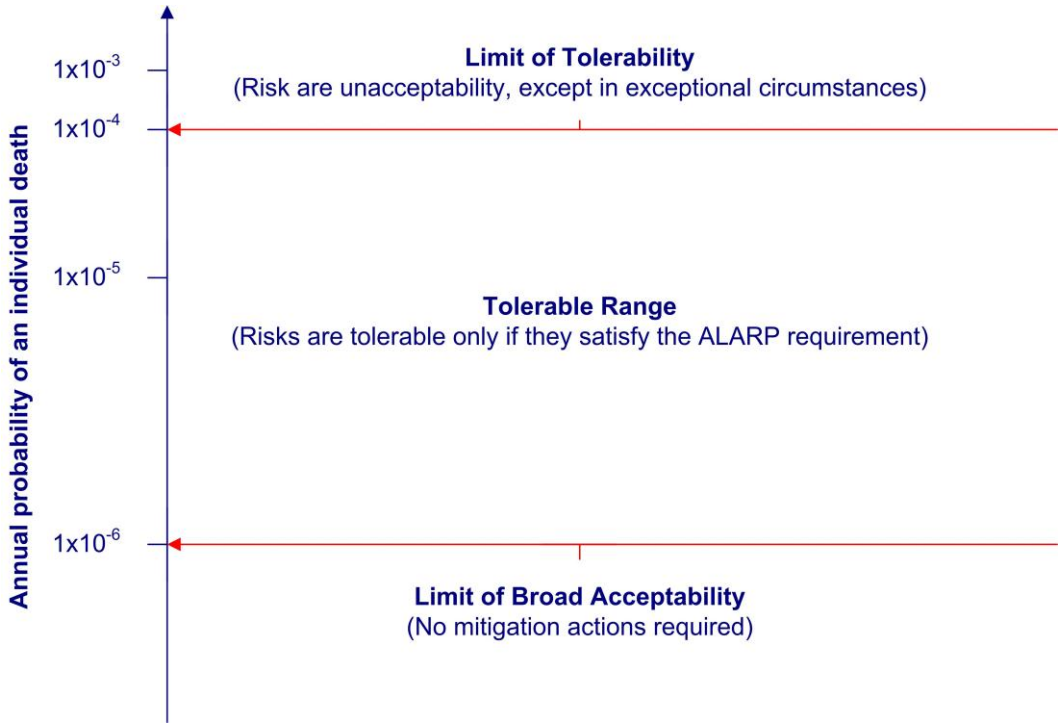
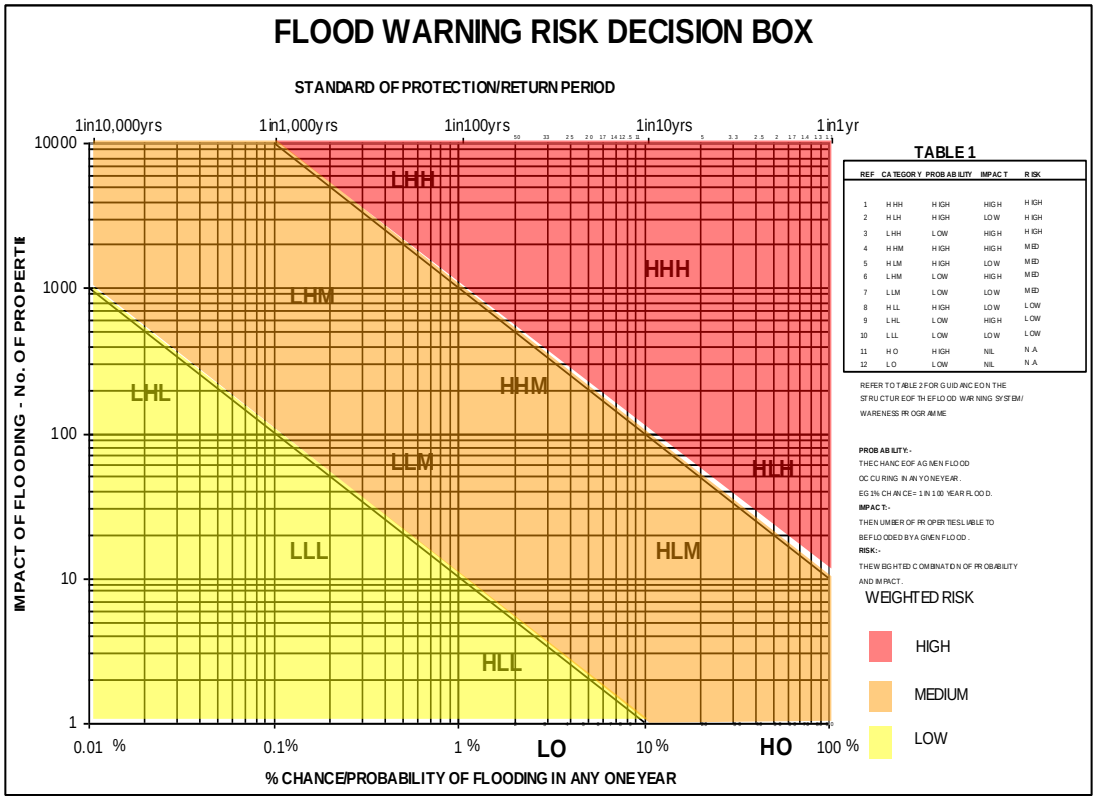


Figure C.2 Example of the limits of tolerability and broad acceptability for individual risk for existing dams (NSW DSC 2006 [24])

Note: The limits shown above are provided in context of reservoir safety regulation, and ultimately, in the event of dam collapse and loss of life. It may be that existing common law provides a more stringent view as to what would be considered tolerable and broadly acceptable. In translating to a final regulatory framework, future work will be required to explore such associated legal issues.

[2] **Equity-based criteria** are founded on the "premise that all individuals have unconditional rights to certain levels of protection. In practice, this often converts to fixing a limit to represent the maximum level of risk above which no individual can be exposed. If the risk estimate from the risk assessment is above the limit and further risk control measures cannot be introduced to reduce the risk, the risk is held to be unacceptable whatever the benefits." (HSE 2001[18])



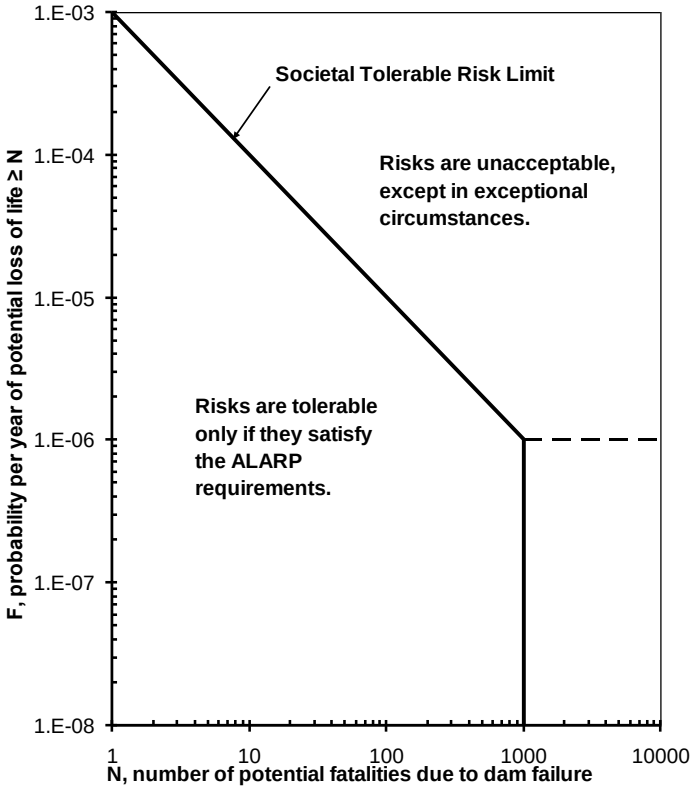


Figure C.3 Defining the unacceptable threshold based on societal risk (through separate consideration of probability and consequence)

Note: Top graph is adapted from the Environment Agency Flood Warning decision matrix. Bottom graph is from the Societal Tolerable Risk Guidelines for Existing Dams example from USACE 2010 [23].

Appendix D: Example applications to reservoirs of varying risk

This section provides an interpretation of the thresholds described above in the context of typical reservoir settings as follows:

Case I - A reservoir that is considered to pose a low hazard

Gravel pit used for ash disposal
This example relates to a worked out gravel pit in the flood plain of a major UK river, being used for disposal of ash from a nearby power station. Ash was transferred by pumping as a slurry. The surface area of the pit was 100,000m2, with the water level 0.5m above the base of a 1m deep outflow ditch. An Inspecting Engineer had determined that as it held 50,000m3 above lowest natural ground level (definition of this given in Statutory Instrument 1985 No 177 Schedule 2 [24]) and it should be registered as a reservoir. In practice, the pit only took a couple of years to fill with ash, so it was discontinued as a large reservoir almost immediately following issue of the final certificate.

This is clearly a case of low hazard reservoir, as if the outlet structure failed, the floodwater would be contained entirely within the watercourse

In this case, the consequences, assuming failure, would be small regardless of the downstream land use, hence the reservoir could be defined as low hazard, excluded from the Act1 and not require registration.

Summary of Case I

	Current Regulation	**Proposed Regulation**
Consequence category	D	Low hazard
Action by Undertaker	Full application of 1975 Act	Complete and submit an online assessment form. Maintain a record of the assessment and maintain the position under review.
Requirement for Registration	Yes	None
Required actions by the Enforcement Authority	All elements of 1975 Act	None

Case II - A reservoir that is considered to pose a risk that is low consequence

Reservoir formed by enlargement of the channel adjacent to the flood plain
Lake X is on a major river in southern England. It is a 35,000m3 reservoir retained by a dam with a crest about 1.5m above the invert of the outlet channel. The river has a 237km2 catchment to this point, so the flood plain is wide with the watercourse typically in at least two channels, running from mill to mill, often slightly above the base of the valley, partly to feed mills and also to allow summer flooding of historic water meadows. This reservoir was constructed as a landscaping feature in conjunction with a large country house, partly by excavation of a channel on the north side of the flood plain and partly by construction of a weir and a small (0.7m high) embankment. The whole reservoir is shown as being within the 1 in 100 year flood outline. In the event of failure, the risk to the public is small with the peak dam breach flood estimated as being slightly less than the 1 in 100 fluvial flood on the river. The dam has consistently been classified as Flood Category D.

The risk to the public is not negligible, as it is conceivable that if a sunny day failure occurred the following would be at risk:

a) A group of school children on one of the footpaths crossing the valley just downstream of the valley.

b) A farmer could allow camping in the summer on a field in the flood plain just downstream.
The risk is clearly small, but not negligible and would require registration.

Summary of Case II

	Current Regulation	Proposed Regulation
Consequence category	D	Low consequence
Action by Undertaker	Full application of 1975 Act	Register the reservoir and maintain a record of the assessment and maintain the position under review.
Requirement for Registration	Yes	Yes
Required actions by the Enforcement Authority	All elements of 1975 Act	Review assessment and ensure periodic reviews submitted.

Case III - A cascade of reservoirs that is considered to include both low and high risk reservoirs
This example (Brown, A. and Gosden, J., 2000 [25]) comprises of six reservoirs in cascade, all owned by private individuals by virtue of being attached to large houses. An aerial photo of Reservoirs 2 to 5 is reproduced in Figure C.4 below and principal dimensions are summarised in Table C.2. Originally, three reservoirs were registered under the 1975 Act, but one was discontinued by removing some stop logs from the outlet structure.

There are two groups of receptors affected by the cascade:

a) A large house (old manor) 1m downstream of a vertical retaining wall supporting the downstream edge of the crest to the Mill Pond, with three other houses to the right on slightly higher ground.
b) A housing estate 1km downstream of the cascade with houses about 1m above the sides of the watercourse, the topography is relatively flat and the depth of flooding would be limited (< 0.5m).

The two lower dams are registered under the 1975 Act and categorised as Flood Category C. This is on the basis that the consequences in the event of failure of the dams to the second group of receptors are small.

	Reservoirs (from Figure C.4)	Capacity (m3)	Dam height (m)	Comment
1	Small pond	Not known < 10,000?		Neglected in 2000 paper
2	Upper Pond	24,000	4	
3	Lower Pond	29,500 reduced to 23,000	4	Discontinued in 1998
4	Mill Pond	9,000	1.5	
5	Upper Fishing Pond	50,000	3	Flood Category C. Time averaged PAR 31, LLOL 0.03
6	Lower Fishing Pond	30,000	3	Flood Category C. Time averaged PAR 23, LLOL 0.02

Table C.2 Example of a cascade of small reservoirs

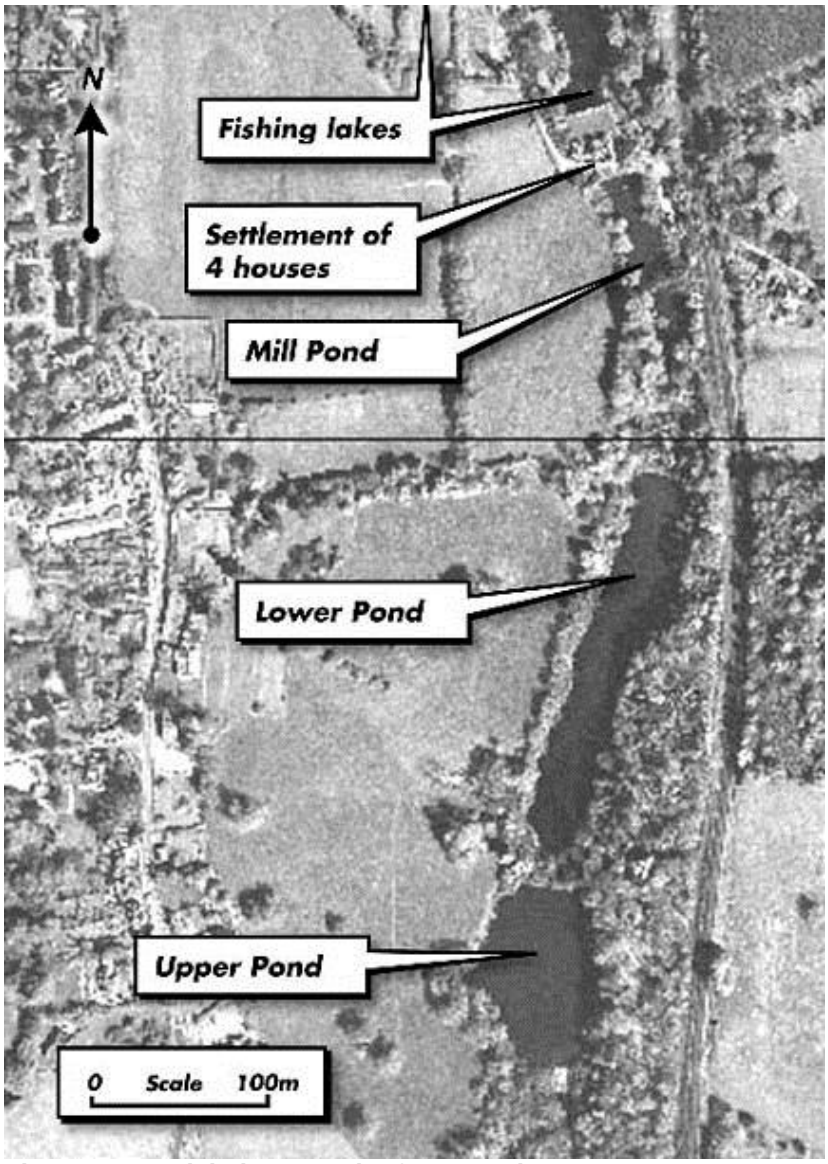


Figure C.4 Aerial photograph of Reservoirs 2 to 5

Summary of Case III - Mill pond (Reservoir 4 in cascade)

	Current Regulation	**Proposed Regulation**
Consequence category	Not applicable	High risk – Tier 2b (based on individual risk to occupants of Manor House)
Action by Undertaker	As volume < 25,000m3, not included in 1975 Act	Accept Designation by EA (or appeal). Carry out structural works to reduce risk (according to ALARP and accepted good practice).
Requirement for Registration		Yes
Required actions by the Enforcement Authority		Require registration (note: even though capacity < 10,000m3). Regulate aspects of the reservoir safety management as outlined in Tables 4.1 and 4.2 of this report.

Summary of Case III - Lower Pond (Reservoir 5 in cascade)

	Current Regulation	Proposed Regulation
Consequence category	C	Low consequence
Action by Undertaker	Full application of 1975 Act	Register the reservoir and maintain a record of the assessment and maintain the position under review.
Requirement for Registration	Yes	Yes
Required actions by the Enforcement Authority	All elements of 1975 Act	Review assessment and designate as low consequence (if agreed). Regulate aspects of the reservoir safety management as outline in Tables 4.1 and 4.2.

Case IV - A reservoir that is considered to pose a risk that is unacceptable
(i.e. a risk higher than the limit of tolerability, but there are exceptional circumstances)

Reservoir Z is a 20m high dam impounding a 5Mm3 reservoir on the hills above a town, for which it is the sole source of drinking water. The dam was built in 1800 and there are no records of its construction. The spillway was enlarged to pass PMF in 1995. If the dam failed and released the reservoir there are 4000 people who would need to be evacuated, and the likely loss of life in a sunny day failure would be 800. The high consequence of failure and uncertainties over details of construction of the dam means that it is unlikely that it can ever be conclusively demonstrated that the total probability of failure is such that it is in the ALARP zone. The town has expanded up the valley such that there are now houses built at the toe of the dam, meaning that there is no room to add filters or a stabilising berm. If the reservoir were drained down to allow reconstruction of the dam to modern standards, this would cut off water to the town, as there is currently no alternative source.

Summary of Case IV - Unacceptable risk, but exceptional circumstances

	Current Regulation	Proposed Regulation
Consequence category	A	Unacceptable
Action by Undertaker	Full application of 1975 Act	Accept designation by EA (or appeal). Apply requirements of 2010 Act. Present case supporting exception – critical water resource asset with no further risk reduction practicable. Ongoing risk management programme.
Requirement for Registration	Yes	Yes
Required actions by the Enforcement Authority	All elements of 1975 Act	Designate as unacceptable, but tolerated due to exceptional circumstances. Regulate all aspects of the dam safety as outlined in Tables 4.1 and 4.2 of this report.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

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