The British Dam Society

Developing a new hazard classification for Reservoir Safety in England and Wales

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SYNOPSIS Following the major incident at Toddbrook Reservoir in August 2019 and a subsequent independent review, the Department for Environment, Food and Rural Affairs (Defra) and the Environment Agency (EA) have established the Reservoir Safety Reform Programme (RSRP). Workstream 1 of the RSRP is developing a new reservoir classification system that will underpin new legislation in England and Wales.

This paper presents the main elements of work completed to date which include reviews of international reservoir legislation and other UK high-risk industries, and development and testing of potential classification options. A new approach that uses a multi-criteria classification system is proposed and this will now be taken forwards for further refinement ahead of wider public consultation and drafting of new legislation.

INTRODUCTION

In August 2019 a major incident occurred at Toddbrook Reservoir, located upstream of the town of Whaley Bridge in Derbyshire. Following significant heavy rainfall, part of the spillway collapsed. The embankment dam did not breach, but as a precaution, some 1,500 people in Whaley Bridge were temporarily evacuated while the dam was made safe (Wilson, 2020).

After the incident, the Secretary of State (SoS) for Environment, Food and Rural Affairs commissioned an independent review to evaluate the effectiveness of reservoir legislation and regulations concerning Toddbrook specifically, and the reservoir stock in England as a whole. The initial Part A Review focussed on the Toddbrook incident and identified systemic weaknesses, rather than isolated issues, in the safety regime and poor safety management practices (Balmforth, 2020). The Part B Review considered the safety regime across the reservoir sector and the legislation governing it - the Reservoirs Act 1975 (HMG, 1975). It made 15 strategic recommendations for improving the safety regime, including establishing a new risk/hazard-based safety regime, where safety requirements are in proportion to risks (Balmforth, 2021).

In response to the recommendations made in the Part B report, the Department for Environment, Food and Rural Affairs (Defra) and the Environment Agency (EA) have established the Reservoir Safety Reform Programme (RSRP). The vision of the RSRP is “to create a safety regime for reservoir dams in England which protects our communities, by making us ready for and resilient to climate change – today, tomorrow and the future" (Defra and EA, 2024). This will be delivered in a phased way over several years.

The reform programme comprises six main workstreams (Figure 1). In collaboration with the Welsh Government and Natural Resources Wales (NRW), Defra and the EA have commissioned the Workstream 1 project to develop a new hazard classification system for reservoir safety in England and Wales. The new classification system will apply to reservoirs with a capacity of 10,000m^3 or more above natural ground. It will form the core of a new safety framework that builds on, modernises, and improves the current safety regime, ensuring risks are managed to as low as reasonably practical (ALARP). The project will inform the evidence base for new legislation on reservoir safety.

This paper presents the work undertaken to date to develop and test practical options for the new classification system that is proposed for use in England and Wales.

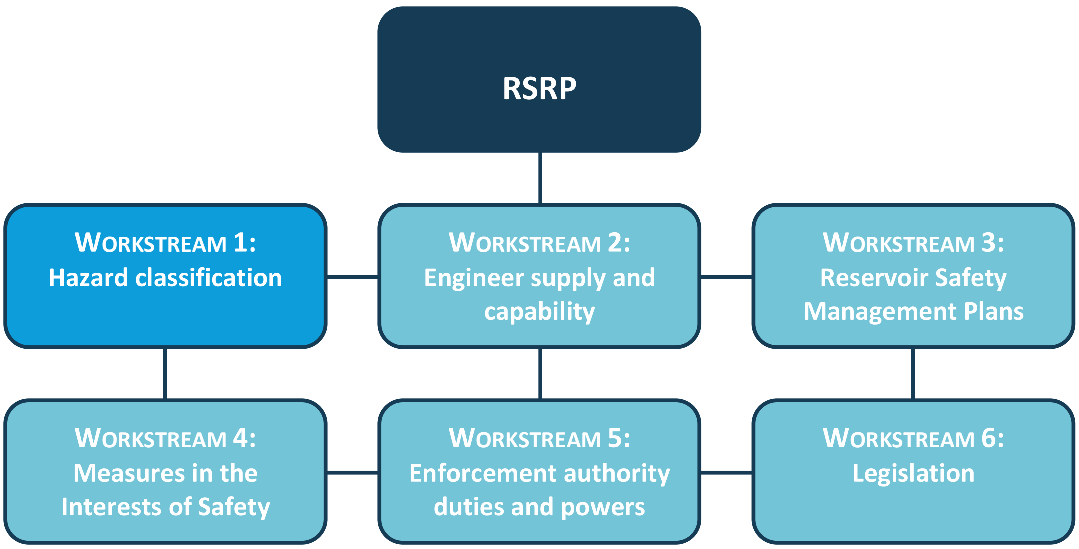

Figure 1. Structure of the RSRP. Workstream 1 is the focus of this paper.

BACKGROUND

Reservoir safety legislation in England and Wales

Calls for the introduction of reservoir safety legislation in Great Britain emerged after several major dam failures in the 1800s (Wright, 1994). However, it was the Dolgarrog dam disaster in November 1925, which claimed 16 lives in North Wales, that finally prompted the introduction of legislation (Charles, Tedd, & Warren, 2011). Since then, there have been no fatalities resulting from dam failures, although major incidents have occurred. For example, the EA recorded a total of 108 major reservoir incidents in the 16 years from 2004-2020.

Since 1930, reservoir safety in Great Britain has been regulated by Acts of Parliament. The Reservoirs (Safety Provisions) Act 1930 (HMG, 1930) required the owners of reservoirs with a capacity of more than five million gallons (22,700m^3) above the natural level of any part of the surrounding ground, to provide for their inspection by a qualified civil engineer who was a member of a panel of civil engineers. The Reservoirs Act 1975 went beyond the provisions of the earlier Act in a number of ways. Local authorities were designated as enforcement authorities, being required to keep registers of all raised reservoirs (defined as those with a capacity greater than 25,000m^3) and to ensure that undertakers, usually the owners, complied with the requirements of the Act. The duties of undertakers, enforcement authorities and engineers appointed to the various panels were laid down in the 1975 Act or set out in regulations.

A major change in reservoir safety occurred on 1 October 2004 when responsibility for the enforcement of safety legislation in England and Wales was transferred from 136 local authorities to the Environment Agency (later Natural Resources Wales in Wales) under the provisions of the Water Act (HMG, 2003), thereby ensuring a uniform application of safety legislation across the country. The Reservoirs Act 1975 was subsequently amended in July 2013 by the Flood and Water Management Act (FWMA) (HMG, 2010). FWMA made provisions for lowering the regulatory threshold from 25,000m^3 to 10,000m^3. To date this has only been enacted in Wales.

Existing categorisation of reservoirs

Registered reservoirs in England and Wales are currently assigned three different classifications:

1) **FWMA 2010 risk designation.** Reservoirs are classified as either 'high-risk' or 'not high-risk' based on whether an uncontrolled release of water could endanger human life. 'High-risk' reservoirs require regular inspection and reporting, while 'not high-risk' reservoirs have reduced requirements due to their lower hazard.

2) **Dam category – Flood safety.** During each Section 10 inspection, typically every ten years, reservoirs are classified by the Inspecting Engineer based on potential consequences of a catastrophic and uncontrolled release of water. Inspecting Engineers follow the standards-based consequence categories given in the Institution of Civil Engineers' (2015) 'Floods and Reservoir Safety, 4th Edition' (FRS4) guide:

    - Category A: Breach could endanger lives in a community (10+ persons affected).
    - Category B: Breach could endanger lives not in a community or cause extensive damage including infrastructure disruption.
    - Category C: Breach poses negligible risk to life and limited damage.
    - Category D: No foreseeable loss of life and very limited additional flood damage.

3) **Dam category – Earthquake safety.** Inspecting Engineers assess dam adequacy under seismic loading, typically using the 'Engineering Guide to Seismic Risks to Dams in the UK' (Charles et al., 1991) and the associated Application Note (Institution of Civil Engineers, 1998). This follows the categorisation in ICOLD Bulletin 72 (ICOLD, 1989).

Reservoirs in England and Wales

According to public register information, there are 2,136 registered reservoirs in England and 402 in Wales. A large proportion of these (80% and 66%, respectively) are designated as 'high risk', meaning they could endanger human life if the dam fails and causes an uncontrolled release of water. The regulation of reservoirs, which aims to keep the likelihood of failure low, protects over two million people and one million households, properties and businesses.

Managing Risks for Dams and Reservoirs

Over three quarters of the registered reservoirs are impounded by embankment-type dams. Reservoir ownership varies from large to small organisations and includes water companies, private landowners and trusts, farmers, flood risk authorities, central and local government, and many private owners.

CLASSIFICATION PROJECT SET-UP

The main project team for Workstream 1 comprises a consortium of JBA Consulting, Ove Arup and Partners Ltd, Risktec, and Paul Sayers and Partners Ltd. A Project Board has been formed to ensure that the overall aims and objectives of the project are met, providing healthy challenge in an open and transparent manner to achieve a successful outcome. The Board consists of representatives from Defra, the EA, NRW, and the Welsh Government. In addition, a High-Level Engagement Group (HLEG) has been established. The purpose of the HLEG is to enable the views and experience of professionals and representative groups, working in the dams and reservoirs sector, to help shape and test approaches for the application of a new risk-based management regime for reservoir safety. This is a broad group representing various stakeholders, including the Reservoir Research and Advisory Group, Defra, the EA, NRW, the UK Panel Engineer Committee, the Major Reservoirs Owners Group, and small owners.

PROJECT SUCCESS FACTORS

Ten key project success measures were established at the inception of the project, specifying that the new classification system should:

1. Cover the whole (existing) reservoir stock from 10,000m^3 upwards.
2. Be robust and transparent.
3. Support a continuous safety improvement culture.
4. Enable reservoirs to be classified in a proportionate and straightforward way.
5. Distinguish between mandatory actions and good practice for owners.
6. Work with the reservoir flood risk mapping data and modelling.
7. Be flexible and responsive to changing risks.
8. Be understood and accepted by stakeholders.
9. Be proportionate in cost/benefit terms.
10. Take into account regulation under other regimes.

EVIDENCE REVIEW

Global reservoir industry

Evidence was collected from other countries about the nature of the dams, dam safety regulation and classification systems. Existing material including ICOLD Bulletin 167 Regulation of Dam Safety: An Overview of current practice worldwide, and ICOLD European Club – Working Group on Safety of Existing dams Report was supplemented by the responses to questionnaires sent to survey contacts from ten countries. The technical review of reservoir safety regimes in other countries was focused on the classification systems used in each country and the criteria/thresholds adopted for regulation. It considered the scope of structures included in the classification, the hazards, risks, and consequences considered, the thresholds for these and how they are determined, and how the criteria and thresholds are applied. The key findings from the review were:

- No international regulatory framework was found which has been prepared for a similar reservoir stock to that of the UK (England, Wales, Scotland and Northern Ireland).
- The majority of countries have regulations that apply to dam safety, although there are some provinces and territories that rely on guidelines of other bodies. A mixture of regulation supported by industry guidance and best practice is therefore common.
- Most countries with reservoir regulations use both height of dam and reservoir volume to define which dams are legislated, i.e. a hazard-based approach to designation.
- The methods by which regulated dams are classified vary. Examples include systems being based on physical properties of dams, consequence of dam failure, risk of dam failure and a combination of these criteria. The most common method of classification is consequence of failure, including impacts on population, environment, property, economy, infrastructure, cultural heritage and public services.
- The number of categories used for classification varies between three and seven, with thresholds varying. Some systems are defined in detail in regulations whilst others are less defined and additional industry guidance is provided to allow categorisation.

Other high-risk UK industries

Evidence was gathered about approaches taken by other high-risk UK industries including nuclear, oil and gas, chemical, rail and aviation. The regulations are typically goal-based, rather than prescriptive, and focus on reducing risk to levels that are ALARP. The key findings were that all sectors studied:

- have a strong regulator to enforce regulations, funded by the duty holder. They require the preparation of formal safety cases, which are produced by or on behalf of the duty holder, with clear identification of safety-critical elements.
- employ some form of hazard screening to reduce the burden on resources. At the highest level, screening can be built into regulation (e.g. Control of Major Accident Hazards (COMAH) regulations (HSE, 2015)), and/or can apply defined levels of unmitigated hazard frequency, unmitigated hazard consequences or unmitigated risk below which no further assessment is warranted.
- employ the concept of proportionality to reduce the burden on resources. This takes the form of applying effort in proportion to risk in respect of risk assessment and ALARP assessment. All sectors employ the ALARP principle in their decision-making process (for tolerable risks). Cost benefit analysis may be used but should not be the sole basis for discounting any option.
- require the preparation and implementation of an effective Safety Management System. This includes emergency planning for incidents and accidents.

Managing Risks for Dams and Reservoirs

Criteria Review

Drawing on evidence from overseas reservoir safety practices and other high-risk UK industries, potential criteria for classifying dams in England and Wales were explored. Table 1 provides an overview of the criteria considered, including evidence of their application elsewhere and whether the criteria were taken forward into option development.

Table 1. Overview of potential criteria for classifying dams

Criteria / Characteristic	Thresholds / Examples used by others	Taken forward to option development?
Volume of water stored	>10,000m³ (Norway) to >1Mm³ (Italy, with height)	Yes
Dam height	>2m (France, Norway) to >15m (Italy, with volume)	Yes
Type of dam construction	Used in parts of Canada	No
Type of liquid/material stored	Most exclude mine wastes due to separate legislation	No
Uses of water in reservoir	No examples found in other countries	No
Age of key structures	Used in Canada for risk assessment and classification	Yes
Condition of key structures	Used in Canada for risk assessment and classification	Yes
Consequences of dam failure	Common criterion, varies by country (quantitative, qualitative)	Yes
Simpler measure of societal risk	Uses potential consequences (e.g. >100 fatalities)	Yes
Environmental consequences	Used with other criteria in matrices	Yes
Other consequences	Includes property, economy, infrastructure, cultural heritage	Yes
Risk of dam failure	Used in Canada	Yes
Categories from FRS4	Four categories based on population at risk	Yes
Categories from Building Research Establishment (BRE) Seismic Guide	Four categories using hazard and consequence criteria	Yes

A comprehensive dataset of consequence metrics exists for reservoirs registered under the Reservoirs Act 1975. These metrics, derived through 2D reservoir flood modelling, include the maximum population at risk (MPAR), the average societal life loss (ASLL), and property damages. ASLL quantifies the potential overall impact on society of a dam failure (Bowles, et al., 2013). For instance, an ASLL of 1.0 does not refer to a specific individual but indicates that, on average, multiple people each have a certain probability of death due to dam failure (e.g., two people each with a 50% chance of death). ASLL stands out as a strong candidate for a classification criterion because it represents the most critical consequence of dam failure. As a result, it features prominently in several of the long- and short-list options.

However, these consequence metrics are currently unavailable for the 1,500 or so smaller reservoirs in England with volumes ranging from 10,000m^3 to 25,000m^3. To address this gap, the feasibility of a simplified classification method that does not require reservoir flood modelling has been explored. To date, the focus has primarily been on dam height and reservoir volume, which dominate in dam classifications in other countries. These parameters have been evaluated both individually and in combination.

Although there are meaningful positive correlations between dam height, reservoir volume, and ASLL, substantial variability exists in ASLL values among dams with similar height and/or volume, as illustrated in Figure 2. For instance, the Coefficient of Variation (CV) for ASLL values exceeds 200% across dams of comparable height. This variability underscores the critical influence of receptor location (i.e., the proximity of people and property to the dam) on ASLL. A simplified classification method based solely on the physical characteristics of dams fails to capture this critical aspect, potentially leading to a disproportionate regulatory burden.

However, there is potential to use physical characteristics as part of a multicriteria approach to classification and for pre-screening. Of particular interest is the relationship used in the classification of dams in French regulations which use dam height, H (m) and reservoir volume, V (m^3) in the equation $H^2 \times V^{0.5}$.

This formula aligns with energy-related principles in physics and demonstrates a stronger correlation with ASLL for reservoirs in England and Wales than either dam height or reservoir volume alone.

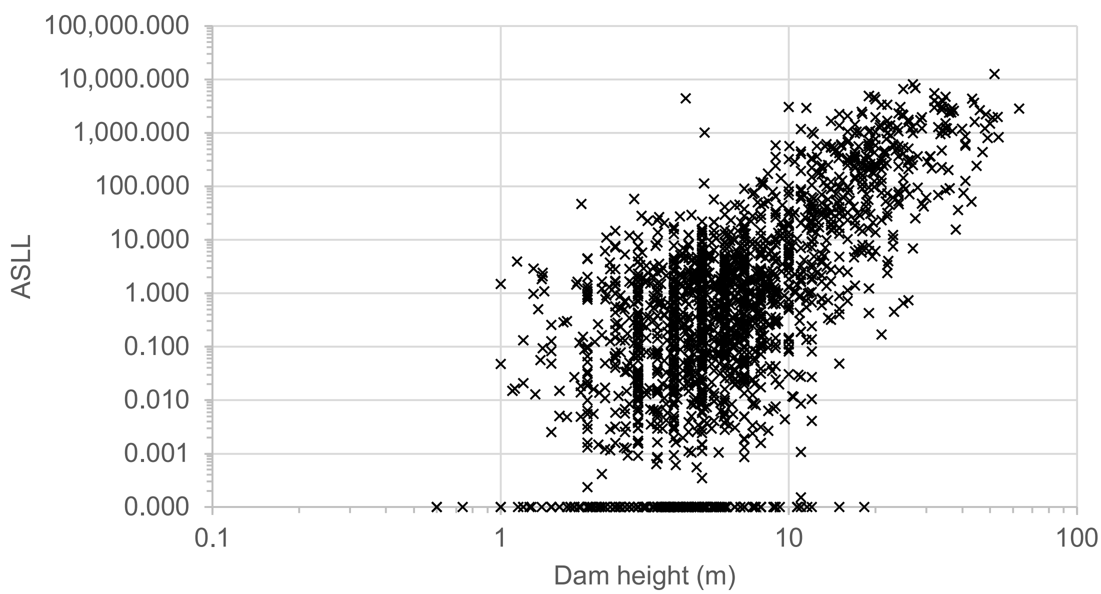

Figure 2. Variation in ASLL with dam height

OPTIONS DEVELOPMENT

Initial Options List

From the research conducted, a total of 15 options were developed as the 'long list'. These included: deregulation of all reservoirs; maintaining the existing approach; adapting existing classification systems such as FRS4 and seismic classification; options based on different consequence thresholds; consideration of wider consequences beyond loss of life such as economic, environmental and heritage damages; risk-based classification; and the use of surrogate for consequence such as dam height or stored volume.

Stakeholder Consultation

Stakeholder engagement has been central to the development and refinement of the options. Throughout the project, meetings and workshops have been conducted with the Project Board and the HLEG. Draft reports have been issued to both groups for review and feedback. The preferred option will be subject to public consultation at the project's conclusion. Key themes emerging from the engagement to date regarding the new classification system include:

- **Hazard versus risk:** While a risk-based classification is desirable, practical implementation poses significant challenges. For instance, many dams built before the 1900s lack detailed construction records, making it difficult to assess their probability of failure. Stakeholders generally agree that classification should be consequence-based, with risk managed through a comprehensive safety management framework.
- **Type of consequences:** There is a general consensus that classification should primarily focus on the potential loss of human life. While the inclusion of wider consequences, such as environmental impacts, heritage, and critical infrastructure, is important, incorporating these within the classification itself could introduce unnecessary complexity. Instead, it is recommended that these be considered outside the classification but within the overall safety management regime. Additionally, it was suggested that the benefits of reservoirs, such as amenity value and water supply, be considered alongside the consequences of failure to provide a balanced perspective.
- **Proportionate regulation:** Aligning with Balmforth's (2021) recommendations and a primary objective of the project, stakeholders have emphasised that regulation should be proportionate to the hazard and risk posed by reservoirs. Setting appropriate thresholds between hazard classes, supported by evidence where available, is crucial.
- **Support for small owners:** Stakeholders have particularly stressed the importance of proportionate regulation that does not overburden small reservoir owners. Recognising that these owners may lack the resources and expertise to comply with detailed regulations, there is a need for clear guidance and support.
- **Classification structure and terminology:** Stakeholders have called for distinct naming conventions to avoid confusion with existing categories. Additionally, there should be transparency in how the new system maps across from current dam categories.
- **ASLL and other consequence metrics:** There is a general consensus that the derivation of ASLL and other consequence metrics through reservoir flood modelling should be conducted by the enforcement authorities to ensure consistency. As techniques and understanding evolve over time, the approach to reservoir flood modelling is expected to undergo refinement.
- **Pre-screening and exclusions:** Emphasising the importance of efficiency, there is a need for a straightforward screening process to identify reservoirs that do not pose significant hazards. This would enable early exclusion of structures that do not require regulation, ensuring that regulatory efforts are focused on higher-hazard reservoirs.

Options Shortlist

Considering stakeholder feedback, the options were shortlisted to:

A. Existing high-risk reservoirs are divided into three classes depending on the hazard created by the reservoir. Class 1: 100 ≤ ASLL; Class 2 : 1 ≤ ASLL < 100; Class 3: ASLL < 1; Class 4: Existing 'not high risk'

B. Class 1: 1,000 ≤ ASLL; Class 2: 100 ≤ ASLL < 1,000; Class 3: 1 < ASLL < 100; Class 4: ASLL < 1; Class 5: ASLL < 0.1.

C. Class 1: 100 ≤ ASLL; Class 2 : 0.1 ≤ ASLL < 100; Class 3: ASLL < 0.1; Class 4: minimal hazard assessment based on volume, height, peak outflow and containment of a breach in the downstream channel.

D. As Options A to C with additional consideration of infrastructure, economic impacts, societal impacts

E. High risk – 1 ≤ ASLL; Medium risk – ASLL <1; Low risk – existing 'not high risk'

F. Classification based on the BRE seismic guide with scoring for capacity, dam height, population at risk and potential downstream damage.

SAFETY MANAGEMENT PRACTICES

A Reservoir Safety Management System is proposed, informed by the evidence review. The key components are:

- **Reservoir Safety Case (RSC):** Serving as the cornerstone of risk-informed reservoir management under the new system, it sets out the key safety elements of the reservoir's design and operation and includes a risk assessment to identify risks and failure modes.
- **Reservoir Safety Management Plan (RSMP):** Describes how the owner will operate and manage their reservoir safely.
- **Panel Engineer Supervision:** Similar to the current Supervising Engineer role, with annual reporting that includes a review of compliance with the RSMP.
- **Periodic Safety Review:** Similar to the current Inspecting Engineer role, involving a physical inspection of the reservoir plus a detailed review of the RSC and RSMP.

OPTIONS TESTING

The evaluation of the shortlisted options has comprised three primary components: categorising the existing reservoir stock into hazard classes for each option, estimating the costs to reservoir undertakers of implementing the safety management system, and analysing the performance of each option using ten case study reservoirs. Due to the unavailability of metrics related to the wider consequences of dam failure, Option D has not been tested.

Allocation of existing reservoir stock

Over 2,000 existing reservoirs were classified under each proposed option. This revealed significant differences in distribution between the current legislation and the shortlisted options, particularly Options A, B, and F. Under the current system, 81% of the dataset is classified as 'high risk', with 14% classified as 'not high risk' and the remaining 5% yet to be designated. In contrast, Options A, B, and F distribute the reservoirs across multiple classes, with the majority in lower hazard categories.

Option E, which splits the current high-risk category in two, does not perform as well, categorising 41% of reservoirs in the highest hazard class (ASLL ≥ 1). Similarly, Option C results in a large proportion (52%) falling into Class 2 due to its wide ASLL range (0.1 ≤ ASLL < 100).

Only a limited number of reservoirs in the dataset have an ASLL value exceeding 1,000 (Class 1 under Option B). This relatively small proportion in the highest hazard class raises security concerns by making individual extreme-consequence reservoirs more identifiable. Therefore, setting an upper threshold of ASLL > 100 is more desirable, as it would include a significantly larger proportion of reservoirs and therefore reduce security risks. Additionally, this threshold aligns with upper thresholds in other countries and safety regulations in other UK industries.

Costing of options

Industry advice was used to establish cost estimates for the various safety management practices. These were used to assess national-scale costs to reservoir undertakers of implementing the proposed safety management system under each shortlisted option.

Figure 3, based on the existing reservoir stock, illustrates that Options A and F are the most expensive, followed by Option E. The costs of Options B and C are comparable to the current regime. Option A incurs higher costs primarily because it retains the 'not high risk' category, resulting in nearly 50% fewer reservoirs in the lowest hazard class compared to Options B and F. In other words, Option A subjects more reservoirs to stringent regulation under higher hazard classes compared to Options B and F. Option F's elevated costs are due to its scoring system, which does not consistently align with the ASLL threshold values used in other options. As a result, the scoring for Option F has undergone further refinement.

Case study analysis

To further evaluate the performance of the shortlisted classification options, ten case studies suggested by the HLEG and Project Board were analysed. These case studies have a variety of attributes including dam type, reservoir volume, dam height, and existing classifications.

A key finding from this analysis is that having more hazard classes for reservoirs with lower consequences provides clearer step changes in safety management requirements and hence costs for undertakers. Specifically, Options B, C, and F lower costs for some case study reservoirs compared to the current regime by creating distinct classes for ASLL values below 1, with no mandatory safety management practices proposed except for incident reporting.

The case study analysis has also highlighted the need to refine the scoring system in Option F to optimise threshold settings and achieve more proportionate regulation.

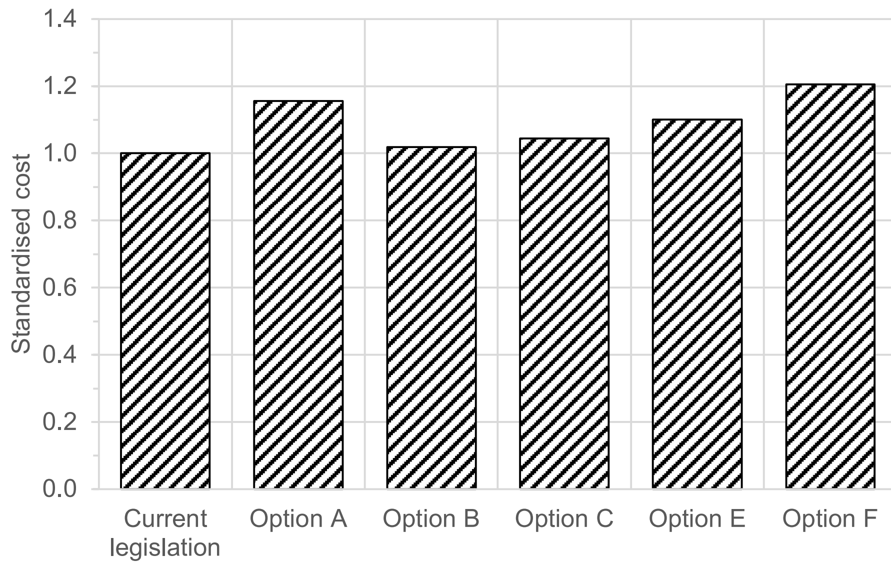

Figure 3. Standardised national costs relative to the current regime for reservoir safety management by undertakers over a 20-year period (based on existing reservoir stock)

Narrowing down and refining options

Following detailed analysis and extensive stakeholder feedback, the following conclusions regarding the shortlisted options were made:

- **Reject Option C:** The ASLL range of 0.1 to 100 in Class 2 is too wide, failing to achieve the desired proportionality.
- **Reject Option D:** This option introduces unnecessary complexity and lacks sufficient stakeholder support.
- **Reject Option E:** The high-risk category is too broad, failing to achieve the desired proportionality and is not favoured by stakeholders.
- **Recommend combination of Options A and B (Option AB):** A hybrid approach combining the strengths of Options A and B, with an upper ASLL threshold of 100 and the elimination of the existing 'not high risk' category. It performs well in meeting project success measures.
- **Recommend Option F with a refined scoring system:** This option employs a multi-criteria classification, enhancing robustness. It shows strong performance in meeting project success measures. The inclusion of property damages in the total classification factor adds valuable information for a more nuanced classification and thus more proportionate regulation. A refined version of Option F is presented in Table 3.

Table 3. Refined version of Option F (subject to further refinement)

a) **Component classification factors**

Classification factor	Value range	Weighting points
$H^2 \times V^{0.5}$	≥ 100,000	6
	8,000 to < 100,000	4
	356 to < 8,000	2
	< 356*	0
ASLL	≥ 100	16
	10 to < 100	12
	1 to < 10	8
	0.1 to < 1	4
	< 0.1	0
Potential downstream damage	Extreme	12
	High	8
	Moderate	4
	Low	0

b) **Total classification factor (TCF, sum of weighting points)**

Hazard class	Threshold values
Class 1	28 ≤ TCF
Class 2	14 ≤ TCF < 28
Class 3	6 ≤ TCF < 14
Class 4	TCF < 6

*The lower threshold of 356 is based on a dam height of 1.5 m and reservoir volume of 25,000 m3

PREFERRED OPTION AND NEXT STEPS

The RSR Programme Board has reviewed the findings and concluded that both Options AB and F are viable for the new classification system. However, they have chosen to advance Option F for further development because its multi-criteria approach offers greater robustness.

Two versions of Option F will be considered: one based on reservoir flood modelling utilising ASLL, and one less dependent on modelling and using Population at Risk. The latter is intended to allow for preliminary classification before consequence metrics from standard modelling are available. Option F, along with the reservoir safety management system, will be further refined in collaboration with the Project Board and HLEG.

Upon the project's conclusion in Autumn 2024, the preferred option will undergo public consultation ahead of the UK Government bringing forward new legislation for England and Wales in the late 2020s.

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