Independent Reservoir Safety Review Report

By Professor David Balmforth

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Foreword

This Government is committed, now and in the future, to ensure our reservoirs can and do operate safely, without posing a risk to the public. The incident at Toddbrook reservoir in 2019 demonstrated the potential for disaster that an uncontrolled release of water could have.

In March 2020 we published Professor David Balmforth's first report which considered the causes of the spillway damage at Toddbrook, and made recommendations from this learning to apply across the reservoir sector. These are being taken forward.

The Secretary of State asked Professor Balmforth to go further, and take a wider look at the current legislation and its implementation. He has now completed this work, and I thank him for this report which provides a comprehensive and in-depth assessment of current practice. In doing so it draws on the experience of reservoir owners and engineers, other regulated industries and international practice, resulting in a range of recommendations to further strengthen and modernise our approach and culture for reservoir safety, for government and the industry to consider.

These recommendations provide an opportunity to explore developing a new risk-based approach, engender a continuous improvement culture to safety across the industry and secure a robust, and proportionate regulatory approach.

Professor Balmforth's report demonstrates the need for owners, engineers, the regulator and Government to work together. **Owners** must take their responsibilities seriously, and ensure their reservoirs are proactively managed and maintained to minimise the risk of failure; **engineers** need to undertake robust surveillance and inspection, and communicate their findings and directions for necessary works clearly and without ambiguity; **the regulator** needs to be able to assure the overall safety processes, and provide leadership for continuous improvement as well as take action to secure compliance. As Government, we need to make sure the legislative framework provides clear direction and expectations on all.

I encourage all of you to maximise the opportunity that this report and its recommendations provide - to improve what and how we apply the best possible practice in reservoir safety now. In return, I commit to exploring, with you, how Government can support this through the legal framework to assure public safety and confidence, whether they live, work or play near these important and iconic structures.

Rebecca Pow MP
Parliamentary Under Secretary of State

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Executive summary

Reservoirs are an essential part of the fabric of our society, providing water for drinking and public health, navigation and the irrigation of crops. They also support biodiversity and amenity, and provide for sport and recreation. They have become an indelible part of our landscape. However, reservoirs are also a significant hazard due to the possibility of an uncontrolled release of water.

England has a well-established process of manging the safety of its reservoirs, and the legislation that supports it is well understood by all those involved. Currently there is 97% compliance with that legislation. There are many examples of well managed reservoirs with appropriate surveillance, operation and maintenance in place. However, there are some other reservoirs where a lack of investment has led to poor levels of surveillance and incomplete maintenance. This is compounded by cases of inadequate supervision and poor reporting of statutory inspections by reservoir engineers, potentially driven by a method of engagement that focusses more on keeping costs low than on securing good service. Such deficiencies should be a matter for the Regulator to address. Reservoir owners must also comply with Health and Safety legislation. This has important implications for reservoir safety management. Obligations under this legislation are not so well understood across all of the reservoir community and this in some way may go towards understanding why compliance with reservoir legislation may not always assure that reservoirs are safe.

This raises the question of what is meant by “safe”. In other infrastructure sectors and with reservoirs in other countries, safety is assured by managing risk, and by reducing that risk so far as is reasonably practicable – the terms “reasonable” and “practicable” being well understood in practice and in law. For a reservoir, risk is defined as a combination of the likely failure of the dam (or other reservoir structure) and the impact that an uncontrolled release of water would have on the area downstream, particularly the likely loss of life. I have therefore recommended that in future the assurance of reservoir safety should be managed on the basis of risk, and that the amount of effort (and cost) associated with that process should be in proportion to that risk. In this way the public can be assured that the hazard posed by reservoirs is being managed in an objective and transparent way.

The owner[1] is responsible for the safety of a reservoir and for implementing systems that assure that the reservoir risk is reduced so far as is reasonably practicable. Owners of large raised reservoirs designated as high risk are currently required by law to employ a Supervising Engineer to be available at all times to advise the owner on the safety of the reservoir, and to engage an Inspecting Engineer to undertake a periodic inspection of the condition of the reservoir. Both the Supervising Engineer and the Inspecting Engineer can direct the owner to make improvements to the condition of the reservoir and the way it is managed on a day to day basis. Understandably owners rely heavily, and sometimes exclusively, on the directions given by their reservoir engineers. It is evident that there are two problems with this. Firstly, an effective system of surveillance, operation and maintenance cannot be effectively defined by directions issued as a result of periodic supervision and inspection. The owner must set this in place and properly implement it on a day-to-day basis. Secondly, the directions from Supervising and Inspecting Engineers must be robust – an owner must be able to understand and trust the advice and direction of a qualified reservoir engineer. On the basis of the evidence provided for this review I have found that there can be significant variability in the reports and directions provided by reservoir engineers.

I have, therefore, made recommendations for there to be an obligation on owners of high risk reservoirs to prepare and implement an effective Reservoir Safety Management Plan, and for new guidance to be prepared for Supervising and Inspecting Engineers in undertaking their duties. This is to be supported by more effective measures for reservoir engineers to attain the necessary competence. Because of the responsibility that owners carry for the safety of the public I have also recommended that more attention is paid to the way that owners are supported and encouraged to improve the way that they manage their reservoirs.

This then leads onto the role of the Regulator. A Regulator's primary function is to ensure that the safety management process specified in the legislation and associated regulations is delivered with the appropriate quality and in a timely manner. Where the quality is in question, or there is a delay in delivering a statutory obligation, then appropriate enforcement action should be taken. In essence, the Regulator is there to ensure that the protection for the public, provided for in the legislation, is actually delivered.

At the present time the Environment Agency is only able to fulfil one of these two functions, that is to ensure that the various elements of the legislation are delivered in a timely manner. It appears to have neither the powers nor duties to undertake quality oversight of the process. This is a significant drawback of the current system. I have therefore recommended that additional duties and powers be given to the Environment Agency, as the Regulator, so that they can fulfil this wider role. I have also recommended that they have the necessary resources to fulfil these additional duties, paid for by the reservoir owners.

My report explains how I have conducted my review and collected the evidence on which to base my conclusions. My findings are summarised towards the end of this report together with my recommendations. These are complementary and in addition to the recommendations in my earlier report.

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1. Legally, the responsibility for the safety of a reservoir lies with the undertaker, the entity who undertakes to operate the reservoir. In most cases the undertaker is the owner. In this report the term "owner" is exclusively used to mean the "undertaker".

1. Introduction

In March 2020 I completed my Report on the Toddbrook Reservoir Incident of 2019. This considered the partial collapse of the dam as a result of heavy rainfall that occurred in July and August that year, and the lessons that should be learnt. As a result of that Review I made 22 recommendations. That report can be found on the Government Web Site https://www.gov.uk/government/publications/toddbrook-reservoir-incident-2019-independent-review. Subsequently the Secretary of State has asked me to undertake a wider review of safety across the reservoir sector to determine if any further recommendations for change are needed. The Terms of Reference for this review are set out below. This is my report on that work.

Terms of Reference

Purpose: To review the application of current legislation for reservoir safety and report on whether the regulation of reservoirs remains effective and robust in securing the ongoing safety of this critical infrastructure. This will include:

a) how far the interpretation and application of current legislation is consistent with all those who have responsibility for reservoir safety, and secures the ongoing safety of reservoirs;

b) consideration of the competency needs, assessment, appointment and roles of panel engineers to ensure appropriate, timely and independent advice to undertakers and the regulator

c) whether current legislation and/or associated regulations require updating

Objectives

This independent review will:

1. Determine if the interpretation and delivery of the current legislative framework, and associated guidance, by undertakers (owners and operators), engineers and the regulator provides sufficient assurance of reservoir safety.
2. Determine how far current legislation and associated regulations supports (or otherwise) the ongoing safety of reservoirs.
3. Review the frequency, scope and reporting for reservoir inspections, (including the specification and delivery of associated requirements and recommendations.
4. Review the role, competence needs, and number of panel engineers required to deliver the intent of the legislative framework, and for future need in accordance with any recommendations for change made by the review.
5. Review the level of independence and accountability within the supervision and inspection process, the governance of decision making at strategic and reservoir

level, and the role provided by the regulator and industry bodies (including for example the Institute for Civil Engineers and British Dam Society).

Reporting

As well as reporting on evidence based findings, the final report may:

- comment on any instruction needed to further strengthen the responsibilities and accountability of all those involved in reservoir safety;
- propose any necessary future changes needed to current legislation and/or regulations to ensure that they support reservoir safety now and into the future;
- make recommendations for improving guidance to (and or training of) undertakers (owners and operators) and engineers/inspectors to ensure application of legislation secures high confidence of reservoir safety;
- offer proposals on any other areas of reservoir safety as identified by the review.

In reporting findings and offering any recommendations the review will reflect:

- public expectations;
- sustainability, and in particular the impact and costs on government and the industry, including whether these are proportionate and deliverable;
- that the Reservoirs Act 1975 is equally applicable in Wales where different subordinate regulations apply;
- the mix of both the purpose of reservoirs and ownership within the industry;
- potential impacts of climate change and potential need for increase reservoir storage;
- consequences of aging infrastructure;
- risk management and regulatory good practice from other similar sectors/international experience.

A full and final report will be provided to the Secretary of State by end February 2021

Out of scope

- Recommendations specific to individual reservoirs.
- Incident response (although incident reporting may be considered).
- Policy decisions on whether the legislation should be expanded to include small raised reservoirs.

Approach to the review

In my Report on the Toddbrook Reservoir incident I summarised how we keep our reservoirs safe, the roles of the individual parties (owner[1], reservoir engineers and the Regulator[2]) and the associated legislation and regulations that govern the process. A key finding from my Review at that stage was that Toddbrook Reservoir fully complied with reservoir legislation and regulations and had always done so, but was not necessarily safe. This gap between compliance and safety forms the starting point of Part B of my Review.

To address the objectives set out in the Terms of Reference I have investigated the effectiveness of the current reservoir legislation and the associated regulations, how it is applied and enforced and the competency needs of the various engineers who are central to its effectiveness. I have reviewed the role that owners play in assuring safety, taking into account particularly the variation in ownership from owners of single reservoirs to those owners who manage portfolios of reservoirs. And I have reviewed the role and effectiveness of the Regulator, a role that is fulfilled in England by the Environment Agency.

As reservoirs are by no means unique to the UK, I have compared practices with those in other countries to see what lessons might be learnt. And I have reviewed how the safety of other high risk infrastructure is managed in the UK, and the legislation and practices that are in place to support that.

Over the period of my Review I have consulted many individuals in the UK and overseas who represent the various organisations that influence reservoir safety (see Appendix C). I have brought together representatives of owners, engineers and regulators to help inform me of current practice and to explore areas for improvement. I have reviewed reservoir engineers' reports and guidance documents. In particular I have sought help from those who manage safety in different legislative environments and established a Task and Finish Group to advise me. Details of the membership of that Group are included in Appendix D. I am grateful for the excellent support I have received from all whom I have consulted.

The following sections explain my work in more detail and the lessons learnt. Towards the end of this Report I summarise my findings and recommendations.

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2. The Reservoir Regulator for England is the Environment Agency. It is also the body responsible for enforcing the reservoir legislation. Similar bodies exist in Wales and Scotland. There are differences between the legislation that applies in England and Wales compared with Scotland and Northern Ireland.

2. The effectiveness of current legislation

Reservoir safety

The safety of a reservoir depends largely on the quality of construction of the Dam. Most of the reservoirs in the UK were built before any general standards were in place and therefore relied on the competence of the individuals involved in their construction. There were a number of early failures resulting in loss of life. For this reason the 1930 Reservoirs Act was passed to require owners to employ a qualified engineer to certify that a new reservoir was safe to fill. Subsequent legislation has built on this earlier legislation and retains the principle of engaging qualified engineers to supervise the construction of reservoirs, and to carry out periodic inspections. Further information is contained in my previous report.

Present day safety is managed by ensuring that the condition of a reservoir is maintained so that it can withstand future loads (such as earthquakes and flood flows) and that it does not deteriorate or develop flaws that might lead to failure. This requires regular and appropriate surveillance, monitoring, maintenance and operation, and plans to manage an emergency should it occur.

The early detection of defects is a vital part of reservoir surveillance and monitoring. Movements in the structure of a dam, the development of cracks, or the presence of sediments in water seeping from a drain can be early indicators of a defect that might rapidly develop into a serious incident. Early remediation of defects and continued vigilance through surveillance and monitoring can prevent a sudden and unforeseen breach. Routine maintenance, for example, to seal joints in spillways, maintain monitoring equipment or lubricate valves is important. Assuring this is completed on a regular basis is an essential part of reservoir safety management.

A thorough inspection of a dam at periodic intervals provides an opportunity to undertake a more in-depth appraisal of its condition. Identifying and evaluating potential failure modes are an important part of this.

As the incident at Toddbrook illustrated, having a comprehensive plan in place to manage emergencies, and in particular to rapidly draw down the level of a reservoir in the event of an incident, is also important.

Summary of the legislative process

Reservoir safety in England is currently legislated through the Reservoirs Act 1975 as subsequently amended by the Water Act 2003 and the Floods and Water Management Act 2010. In addition to the legislation, the Secretary of State has made various regulations, as provided for by the Acts, to ensure their effectiveness. In summary, for all raised reservoirs greater than 25000m^3 in capacity and designated by the Enforcement Authority[2] as high risk, the legislation requires that:

- A qualified Construction Engineer is appointed to certify all work associated with construction of a new reservoir or alterations to the capacity of an existing reservoir (applies also to reservoirs that are not designated as high risk).

- A qualified Inspecting Engineer is appointed to inspect the reservoir at least every 10 years (known as Section 10 inspections as they refer to Section 10 of the Reservoirs Act 1975), and to require the owner to implement measures in the interests of safety (MIOS) and/or specific maintenance (known as statutory maintenance).

- A qualified Supervising Engineer is appointed to oversee the reservoir and its surveillance, monitoring, operation and maintenance, and to be available at all times to advise the owner over its safety.

The owner is responsible for appointing reservoir engineers in accordance with the legislation. Further details of this process are given in my first report and on the Government web site https://www.gov.uk/guidance/reservoirs-owner-and-operator-requirements.

The owner must provide details of the appointment of qualified engineers to the Regulator at the times specified in the legislation. Failure to do so is a criminal offence. Construction Engineers must issue certificates to the owner when works at a reservoir are completed to their satisfaction, Inspecting Engineers must issue their inspection reports to the owner as soon as practicable, and Supervising Engineers must visit the reservoir at least once per annum, report to the owner on their visit(s) and issue an annual statement of the reservoir's condition to the owner. The legislation specifies the outline contents of reports and certificates, and the Institution of Civil Engineers (ICE) has provided guidance[3,5,6]. When an Inspecting Engineer requires measures in the interests of safety, a mandatory completion date must be specified. These works must be overseen by a Qualified Civil Engineer who must certify the work once completed.

Copies of reports and certificates must also be delivered to the Regulator. The Regulator keeps records of the appointment of engineers and the dates of submission of certificates, reports and statements.

Owners must also comply with other legislation, more notably Health and Safety legislation. This is covered in more detail in Section 4.

The regulator

The Environment Agency, as the regulator and enforcement authority for reservoir safety in England, is the body that ensures compliance with the reservoir legislation. It monitors compliance at all 2095 large raised reservoirs in England. Its duties include:

- ensuring that reservoir owners comply with the legislation, by monitoring compliance and engaging with them at regular intervals
- maintaining a register of all reservoirs under the legislation
- ensuring that owners appoint a construction engineer to design and supervise the construction or alteration of large raised reservoirs
- designating reservoirs as 'high-risk'
- ensuring that owners appoint a supervising engineer for their high-risk reservoirs
- ensuring that owners have their high-risk reservoirs inspected by inspecting engineers at the appropriate intervals
- ensuring that owners carry out any measures in the interests of safety required by inspecting engineers, including investigations, studies, repairs and improvements
- when an owner does not comply with the legislation, appointing engineers and commissioning safety work on their behalf (owners are charged for this work)
- appointing engineers and taking any other action necessary in an emergency, to protect people and property against an escape of water from a reservoir
- ensuring that owners report reservoir incidents and share lessons learnt from them
- as the Environment Agency also owns reservoirs, ensuring that it observes and complies with the requirements of the legislation for its own reservoirs.

The Environment Agency oversees compliance with the reservoir legislation by monitoring the dates that appointments are made and reports and certificates are issued, and any additional steps as outlined above. It reports biennially on compliance to the Secretary of State for the Environment. The last report published was 2017-18, and in this period, 37 new reservoirs were built. Compliance, which improved slightly since the previous report, is summarised in table 1 below, taken from the 2017-18 report. This shows a compliance rate of between 97% and 99% depending on category.

Table 1. Reservoirs non-compliant on the 1st January 2017 and the 31st December 2018.

	Situation on 1st January 2017	Situation on 31st December 2018
Number of Supervising Engineers not appointed	8	3 [a]
Inspection due and no Inspecting Engineer appointed	13	8 [b]
Section 10 inspection overdue by more than a year, but an inspecting engineer has been appointed	7	6
Measures in the interests of safety that have not been completed by the deadline set by the inspecting engineer	48	55

a excluding 15 reservoirs awaiting a risk designation
b excluding 16 reservoirs awaiting a risk designation

Where the Environment Agency is unable to persuade owners to make the relevant appointments or to complete the safety measures, one option is to serve an enforcement notice, giving a deadline to comply. Over the past two years the Environment Agency has served 24 notices at 22 reservoirs. Half of these were to private landowners and trusts. It also issued 12 formal written warnings to reservoir owners. Two reservoirs are under investigation and further enforcement action may be taken. In some cases the Environment Agency chose to issue advice and guidance to reservoir owners in cases where a formal warning or further enforcement action was not considered appropriate. Having reviewed information provided on enforcement and compliance provided for this Review, it is evident that owners are given every opportunity to comply with the legislation and regulations. In some cases this has led to a drawn-out process but ultimately ensures good levels of compliance.

In the Floods and Water Management Act, 2010, the Environment Agency was given the powers to require owners to report incidents that occur at their reservoirs so that lessons might be learnt from these by other owners and their engineers. More information on incident reporting is included in Section 3 of this report.

Unlike Regulators in some other infrastructure sectors, the Environment Agency currently does not have a duty to review or assess the quality or completeness of the work of Supervising and Inspecting Engineers, or the powers to challenge that work if they identify issues. Whilst an owner can appeal an Inspecting Engineer’s report and the measures required in the interest of safety, the Environment Agency has no such power. And whilst it can issue guidance, the Environment Agency currently is unable to ensure that the regular (day to day) surveillance, monitoring, operation or maintenance of any reservoir is completed, or require an owner to have a plan in place to cover an emergency.

The Environment Agency's work therefore focusses largely on compliance. There are twelve officers within the core EA reservoir safety regulatory team within its Head Office function, covering the 2095 Large Raised Reservoirs in England. Although the core team is relatively small, it is supported by nearly 50 trained operational Flood and Coastal Risk Management (FCRM) enforcement officers within its area FCRM teams across England. The role of an FCRM area enforcement officer may include: accompanying reservoir engineers on site visits (for example, where the reservoir safety team has appointed the engineer under reserve powers), taking statements, contributing to enforcement or prosecution case files, and supporting prosecutions actions.

The owner

In this report the term "owner" refers to the owner and operator of a reservoir. Sometimes these are not the same and the legislation uses the term "undertaker" to refer to the entity responsible for operating a reservoir and ensuring its safety. In this report the term "owner" has been used consistently to mean the undertaker to aid the understanding of readers unfamiliar with practice in the reservoir sector.

The owner (undertaker) is responsible and liable for the safety of a reservoir. To investigate how well owners understand their responsibilities I met with two groups representing the population of owners in general. One of these consisted of representatives of the owners with portfolios of many reservoirs, who are referred to in this report as the "large owners". These include water companies, for example. The second group represented owners who may only have responsibility for one or two reservoirs. They are referred to here as the "small owners" and included organisations such as farmers and landowners. There are very significant differences in capacity and capability across the range of owners. In both groups, owners typically have other assets to manage that also pose significant safety or commercial risks.

In general, owners understand the need to comply with reservoir legislation which explains the good level of compliance reported by the Environment Agency in their biennial reports. However, there are considerable differences in approach, with some owners taking a proactive approach whilst others are reactive, undertaking work only if it is required by an Inspecting Engineer, and at times delaying important maintenance. There is some evidence that in a (small) number of cases owners seek deliberately to avoid their responsibilities and are obstructive to reservoir engineers. Some do not respond promptly to the Environment Agency when they are not compliant with the legislation such that the Environment Agency then has to issue formal notices or take legal action.

Large owners, who usually employ a complement of their own reservoir engineers and technical staff, are better placed to understand the technical aspects of reservoir safety and are typically proactive in managing the safety of their portfolio. Most have established their own internal safety assurance processes. They also tend to provide training for operatives as well as their own Supervising Engineers.

Smaller owners are less well placed. Some complain that the reports issued by Inspecting Engineers are at times impenetrable and that the reasons behind measures required in the interests of safety are not always clear. They tend to rely (understandably) on their visiting Supervising Engineers to advise them on how to keep their reservoirs safe. Many have no in-house operational experience. In addition, small owners often have proportionally less available funds with which to maintain their reservoirs, and competing demands for these funds. It is difficult for them to understand how to prioritise investment against these different demands. Also, they and their staff (some of whom could be volunteers) do not have access to the same training and support that large owners have available, and may therefore not be able to undertake surveillance, monitoring, operation and maintenance as effectively. However, there is a distinct willingness amongst many of them to address this if the right sort of support could be developed.

Many owners are largely reactive and undertake the work required by an Inspecting Engineer or as directed by a Supervising Engineer, but often do little more than that.

As well as complying with reservoir legislation, reservoir owners are also subject to the requirements of the Health and Safety at Work Act 1974 which places general duties on employers and the self-employed to conduct their undertakings in such a way as to ensure, so far as is reasonably practicable, that persons other than themselves or their employees are not exposed to risks to their health or safety. Most large owners appear to be aware of this legislation and how it applies to the safety management of their reservoirs. Small owners are not so aware. It is possible, and in some cases likely, that reservoir owners may be fully compliant with reservoir legislation but not with the Health and Safety at Work Act. This is explained more fully in Section 4 of this report.

Reservoir engineers

The current legislative approach to reservoir safety relies heavily on the competence and integrity of reservoir engineers. As explained above, reservoir owners understandably rely on the advice and direction given by their engineers. Under the current legislation, the Environment Agency has a duty to ensure compliance with the legislation but has no duties or powers to review the quality of individual inspections or supervision.

To gain a better understanding of the work of reservoir engineers and the effect this has on reservoir safety, I reviewed a selection of the latest inspection reports and the latest two annual statements from Supervising Engineers at eight high risk large raised reservoirs chosen at random from the register held by the Environment Agency. Certificates for completion of statutory requirements and details of any enforcement actions were also made available. The random selection was undertaken in a way that ensured no duplication of owner, Supervising Engineer or Inspecting Engineer. The reservoirs had dams that were mainly of the earth embankment “Pennine” type, but also included a concrete gravity dam and a flood retention embankment. Two additional reservoirs were added to the list. The first was the reservoir identified by the recent Environment Agency’s review of reservoirs in England with spillway characteristics similar to Toddbrook, and the second was a reservoir with a history of disputes over ownership included at the request of the Environment Agency. It is important to note that the inspection reports and annual statements were not written with the purpose of informing an overarching view of reservoir safety in England. Also, a sample size of ten is small in terms of drawing statistically significant conclusions. However, they formed a useful means of drawing conclusions for the purposes of this Review.

Reports and annual statements from Supervising Engineers were variable. Some annual statements were detailed and reported both on progress with measures in the interests of safety (MIOS) and operation and maintenance. Others were less detailed, and a few provided only the most minimal information. Almost all reported on progress with delivering the MIOS required by Inspecting Engineers. However, it was not always clear from Supervising Engineers’ reports and statements how well routine surveillance and maintenance was being delivered. Out of the ten reservoirs reviewed, Supervising Engineers reported maintenance not being completed at four. At a further three reservoirs, issues remained about the regular recording of levelling data. It was unclear to what extent Supervising Engineers were engaged with owners over these deficiencies.

The Reservoirs Act 1975 sets out what an Inspecting Engineer should attend to during a reservoir inspection, including such aspects as movement of surrounding land which might affect the stability of the reservoir, and the adequacy and condition of the overflow. It also specifies what the Inspecting Engineer should report on, for example, the maintenance of the reservoir and any MIOS together with the period for their completion. The Act is supported by various guidance, which includes the ICE Guide to the Reservoirs Act[3] that sets out the minimum requirements for inspection reports, the Environment Agency’s Risk Assessment Guidance[4] that recommends that inspecting engineers formally identify and evaluate the potential failure modes at the reservoir, the Environment Agency’s Guide to Drawdown Capacity[5] and the ICE’s Floods and Reservoir Safety Guidance[6] that relates to assessing the required capacity of spillways.

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3. A Guide to the Reservoirs Act 1975: 2nd Edition. Institution of Civil Engineers (2014). Thomas Telford, London.
4. Guide to risk assessment for reservoir safety management. Environment Agency (2013)
5. Guide to drawdown capacity for reservoir safety and emergency planning - Environment Agency (2017)
6. Floods and Reservoir Safety, 4th Edition, Institution of Civil Engineers, London, 2015

There was considerable variability in the inspection reports reviewed. Some were detailed and adequately addressed all the items set out in the legislation and guidance. Where defects in a dam were identified, the evidence on which these were based was clear, and various measures to remedy them were appropriately specified. In some reports this was not the case. Not all the items listed in the legislation or the associated guidance were commented on so it was not possible to tell whether these had been considered but required no action, or whether they had not been considered at all. The capacity of the spillway was often checked but then there were no comments on its structural adequacy. In too many inspection reports there were adverse comments about routine maintenance not being completed. In one case the requirements for MIOS resulted in measures being delivered without any details of those measures being recorded. There is no requirement for the certificate of completion to indicate the work that has been completed.

I was provided with separate information on compliance issues at the sampled reservoirs. This included copies of completion certificates, correspondence between the Environment Agency and the owner, and notices issued. At three of the sample of ten reservoirs, certificates for completion of measures had been issued late. In most cases reports and certificates were issued just in time. Only in a few cases were reports issued well within the time limit. In some cases measures were completed on time but there was then a delay in certifying the work.

Gosden undertook a survey of 15 inspection reports written by 15 different Inspecting Engineers in preparation for the ICE Binnie Lecture, 2020[7]. All reports but one related to inspections undertaken since 2018, and covered a range of reservoir owners and reservoir types. The reports sampled were taken from those completed by 30 current Inspecting Engineers. These covered a cross-section of reservoir owners: the large owners who operate ten reservoirs or more, small public authorities who operate fewer than ten reservoirs and private individuals or companies who operate fewer than ten reservoirs. Gosden's findings were generally consistent with my own. He found that the content of inspection reports was quite variable. Although there was generally a consistent set of headings, the quality of the evaluation contained within the reports was variable. Application of the guidance was inconsistent, and too much reliance appeared to be placed solely on visual assessment under relatively benign loading conditions. Because underlying defects may be exposed by extreme loading conditions, it is advisable to undertake a thorough search for such defects. Gosden felt that the depth of study undertaken in preparing an inspection report may, in some cases, be restricted by commercial considerations, since inspections are often completed for a lump sum fee, which can be subject to competitive tender or benchmarking constraints.

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7. Gosden J, "45 Years of Dam Engineering", ICE Binnie Lecture 2020

Gosden found that failure modes were not discussed explicitly in over a third of the reports. Typically it was only in those inspections where a quantitative risk assessment had already been completed by the owner and was provided to the Inspecting Engineer, that there was much explanation beyond a statement of potential significant failure modes. The adequacy of the dam itself was referred to in all the inspection reports examined but only in a minority of reports was there evidence of any form of analysis.

The Reservoirs Act 1975 as amended does not allow for Inspecting Engineers to be a direct employee of the reservoir owner. This is to ensure that Inspecting Engineers act independently in arriving at their findings and requirements. In essence they should be impartial and not be influenced by the owner in any way. But the Act is clear that an Inspecting Engineer may be appointed by a reservoir owner who then pays the fee for the inspection. This is appropriate because the Inspecting Engineer must act in the interests of the owner. It is the owner who is responsible and liable for the safety of the reservoir.

However, the distinction between employing an Inspecting Engineer and appointing one as an independent consultant has become blurred over the years with competitive tendering and term contracts. These forms of procurement tend to tie an Inspecting Engineer more closely to the owner in a not dissimilar manner to a contract of employment. It is possible, therefore, that the Inspecting Engineer might not act entirely independently in such circumstances and may weight any findings or requirements in favour of the owner. However, I have found no evidence of this in my Review. There is nothing to suggest, for example, that the variability in the reports of Inspecting Engineers is due to any bias on their part. Gosden has referred to current forms of competitive tendering and benchmarking which can lead to a limit on the number of hours that an Inspecting Engineer may spend on their work. The same may be true for Supervising Engineers appointed in a similar way. This is a plausible explanation but again I have not found any evidence of this.

I have considered whether a different arrangement for securing the services of reservoir engineers might be better. Reservoir engineers could be appointed by the Regulator, for example, but this would then transfer some of the responsibility for safe management of the reservoir away from the owner and onto the Regulator. Alternatively, the Regulator could nominate an Inspecting Engineer for an owner to appoint, but it is unclear what the rational basis might be for doing this. I have concluded, therefore, that the legislation should remain unchanged in this respect, subject to the following observations.

Inspecting Engineers should not enter into a contract which limits the time they spend in their work to less than that needed to fulfil their professional obligations. They should spend the time that is needed to complete a thorough inspection of a reservoir and report in a comprehensive and timely manner, in accordance with statutory requirements and guidance. Owners have to rely on the competence of Inspecting Engineers in order to discharge their own duties with due diligence. It should therefore be in the interests of both the owner and the Inspecting Engineer to avoid inappropriate terms of engagement.

Summary

There is considerable variability in how owners approach assuring the safety of their reservoirs. Some owners are proactive and drive the process because they need to ensure due diligence and don't wish to expose themselves to financial or reputational damage. At the other end of the scale, some owners defer to a reactive approach and rely entirely on their Inspecting Engineers to give them direction every 10 years, and on their Supervising Engineers to interpret this annually. These owners may do little to manage safety on a day-to-day basis. However, they may believe that in complying with the legislation by employing Supervising and Inspecting Engineers they have done all that is necessary to discharge their responsibilities. This may be a misguided belief.

Given the hazards posed by some reservoirs, it is remarkable that some owners are not more engaged in how they operate and maintain their reservoir(s). In other infrastructure sectors, and for reservoirs in some other countries, the duties of owners are more explicitly set out and there are incentives and penalties in place to foster good practice (see Section 4 of this report). The lack of this in the reservoir sector may go some way towards explaining the variability between different owners.

It is the public that are exposed to the hazards of reservoirs. The role of a Regulator is to act in the interests of the public to assure that infrastructure is being maintained and operated safely. The Environment Agency monitors the appointment of engineers, the submission of their reports and the timely certification of works. It is currently tasked with ensuring compliance with reservoir legislation but not with assuring the quality of the work undertaken within that process, by owners, operators and especially engineers. It has neither the duties nor powers to do so.

When the requirements of the legislation are not met, the Environment Agency takes action, but this can be a drawn-out process in some cases. It is not clear that the balance between allowing time for an owner to comply, and taking formal enforcement action, is appropriate in all cases. In part this may be due to the Environment Agency not having the powers to issue fines rather than pursuing a prosecution.

The Environment Agency is also tasked with investigating and reporting on incidents and for intervention in the case of an emergency. Given the large number of large raised reservoirs in England (2095), the Environment Agency's core team of twelve seems to be small, even allowing for the temporary support it can call on.

Neither the Environment Agency nor some reservoir owners currently have the in-house technical capability to critically review the work of Supervising Engineers or meaningfully appraise inspection reports. The Environment Agency currently relies on the independence and professional competence of Supervising and Inspecting Engineers when they report on the condition of a reservoir and make recommendations, as does the owner. Given that the safety of reservoirs relies so much on the competence and professional judgement of

Supervising and Inspecting Engineers, the variability in their reports is disappointing. It is important that such reports are sufficiently comprehensive and that where findings and recommendations are made then the evidence and analysis on which these are based are also made clear. This will give confidence to the owner and the Regulator that all the salient features have been properly considered and evaluated, and will help to ensure that owners not only comply with the legislation but are duly diligent in assuring their safety. It is therefore vital that Supervising and Inspecting Engineers are able to spend the time they need to complete their work, and that they do so in a thorough and comprehensive manner.

In other infrastructure sectors the inspection, surveillance and maintenance of assets is subject to independent scrutiny by their Regulator. This assures that the set procedures for assuring safety are being properly implemented, in the interests of the public. At present the Environment Agency has neither the duties nor powers to do the same in the reservoir sector.

3. Assuring the competence of reservoir engineers

Assessing the competence of inspecting and supervising engineers

The English and Welsh Governments appoint reservoir engineers to their respective Panels under the Reservoirs Act 1975. Similar provision is made in Scotland, while Northern Ireland reservoir safety legislation is yet to commence. There are four Panels, specified by the Ministers, whose members are those engineers qualified to act as reservoir engineers:

- The All-Reservoirs Panel (engineers qualified to undertake the duties of Inspecting Engineer and Construction Engineer for all reservoirs, and also act as Supervising Engineers)
- The Non-impounding Reservoirs Panel
- The Service Reservoirs Panel
- The Supervising Engineers Panel

Appointments are made following recommendation by the ICE Reservoirs Committee, which has been established to advise English and Welsh Ministers (and equivalent in Scotland) on the suitability of candidates. Appointments are for 5 years, and before their term expires engineers may apply for reappointment for a further term.

Applicants are examined on their professional qualifications, experience of work on dams and reservoirs, related knowledge such as hydraulics, hydrology, geotechnics and structures, their knowledge of reservoir legislation and their continuous professional development. The assessment for suitability is based on the competence of the individual to carry out the tasks required of the respective Panel Engineer, using the applicant’s information provided and an in-depth interview.

Competence is assessed on the basis of satisfying a set of defined attributes required for each Panel. The applicant is interviewed and tested against these attributes by a sub-committee comprising three members of the Reservoirs Committee, who are themselves practicing Panel Engineers, often accompanied by an independent observer from the Environment Agency. The Reservoirs Committee includes a representative of the Governments of England, Wales, Scotland and Northern Ireland, and their respective Regulators (as observers), as set out in the Reservoirs Act 1975 as amended, and equivalent legislation in Scotland.

I have observed meetings of the sub committees at which the initial applications have been reviewed and assessed, the interviews, post interview meetings of the sub-committees and the meeting of the Reservoirs Committee at which final recommendations were made. I have done this for a new application and re-application for both Supervising Engineer and Inspecting Engineer, that is four in total. I have also reviewed all completed documentation and guidance material available to applicants. The process for the assessment of applicants for membership of reservoir panels is, in general thorough, but there are areas for improvement.

The application and review process has been progressively improved over the last six years. Candidates must now demonstrate in their application, and at interview, that they meet the attributes and have appropriate experience. Comprehensive guidance is available for candidates and the process of assessment and interview is objective, fair and transparent. Appropriate records are kept using pro-formas and there is a documented complaints procedure. There is often independent observation of interviews by the Environment Agency, and new members of the Reservoirs Committee receive appropriate training. Where any of the Regulators has information on non-compliance in submitting reports or certificates on time, this information is made available to the Committee.

However, it can often take several applications for appointment before a candidate is successful. This is particularly true for candidates applying for appointment as Inspecting Engineer. There are a variety of reasons for this, but the overall conclusion must be that they are not always adequately prepared. Whilst there is training available, the quality of some of the training has been questioned. And whilst some of the larger employers provide coaching and mentoring, this is not universally available to candidates. Supervising Engineers who are employed by a reservoir owner and wish to progress to Inspecting Engineer may find this particularly difficult as the owner will not have Inspecting Engineers on their payroll. At the moment there is no formal system for secondments that might allow Supervising Engineers to gain experience of the inspection process. Both Supervising and Inspecting Engineers rely largely on written reports to communicate their findings and recommendations, and are required to submit two specimen reports with their application. But there is no written element on the day of their interview. A written element might better test a candidate’s ability to communicate clearly and concisely in writing and to be able to make a coherent argument whilst under pressure.

The reapplication process can be less searching since candidates reapplying every 5 years can be recommended on the basis of their written reapplication alone (the sub-committee that assesses applications has discretion over whether or not to call a candidate for interview). Their continuing professional development in such cases is judged on the basis of a list of events attended rather than on any lessons learnt. Equally, there does not appear to be any systematic scrutiny of reports written by the applicant in the preceding period. Addressing these aspects more thoroughly would improve the robustness of the process. It would be no more onerous than the assurance processes adopted in other infrastructure sectors or in other professions where safe practices are critical. Information gained from a more thorough review of reapplicants could be fed back anonymously into an industry wide body of knowledge which the ICE could then use to assess not only the effectiveness of its own processes, but the wider challenges of professional development in the reservoirs community. They could report on this annually.

The Pitt Review recommended that the ICE should look to introduce a system of quality assurance for reservoir inspections, and this was allowed for in the Floods and Water Management Act 2010. However, this has not so far been carried into effect. Having such a system in place could significantly improve the quality and consistency of supervision and inspection, but it would be more appropriate for it to be implemented and managed by the Environment Agency in their role as the Regulator.

However, these recommendations must be set in the context that current members of the Reservoir Committee receive no remuneration for their work. A significant proportion of the Committee are All Reservoir Panel Engineers, and their numbers are limited, as explained below. Relying on their goodwill to support such recommendations may prove to be unsustainable in the longer term.

Review of the supply of inspecting and supervising engineers

Currently there are 143 Supervising Engineers and 30 Inspecting Engineers (the 143 number allows for the fact that most Inspecting Engineers will be a member of the All Reservoirs Panel and therefore able to act as a Supervising Engineer). The subject of the numbers of engineers appointed to the Panels has been the source of much discussion within the reservoir community over the past decade due to an underlying concern of declining numbers of Inspecting Engineers. Figure 1 shows the variation in Supervising Engineer and Inspecting Engineer numbers over the past 10 years.

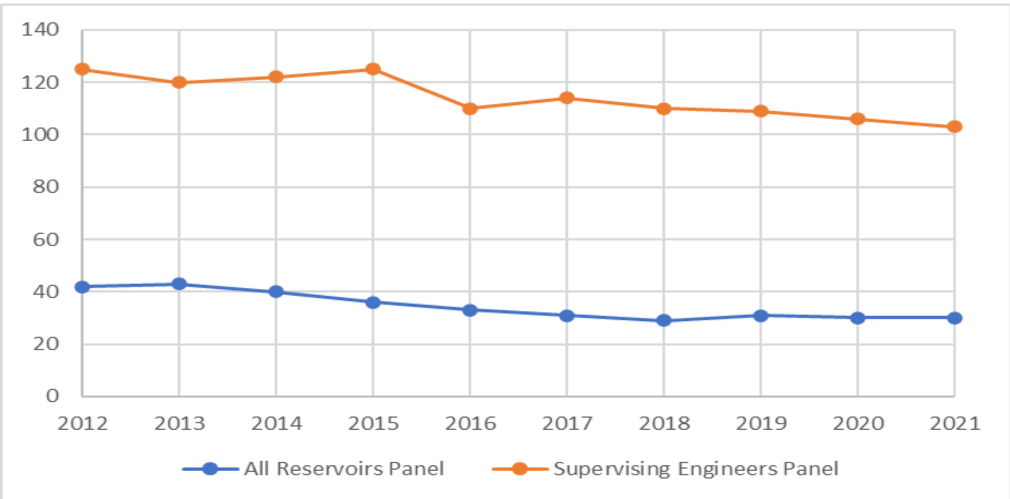

Figure 1. Variation in the number of supervising and inspecting engineers by year
(an All Reservoirs Panel Engineer may act as an Inspecting Engineer or a Supervising Engineer)

In 2015 a working group was established to investigate whether this was a real issue, and if so, the possible causes and suggested solutions. The number of members of each panel at the time were 134 Supervising Engineers and 31 Inspecting Engineers. All members of the All Reservoirs Engineers Panel were canvassed on their planned retirement dates. The results showed a predictable decline in numbers, unsurprising as these senior members of the profession would decide to retire over time. As the (almost) exclusive source of candidates for the Inspecting Engineer Panel were Supervising Engineers, the intentions of the members of the Supervising Engineers Panel towards progression were directly relevant to the potential numbers of Inspecting Engineers in the future. The final response rate to the questionnaire was 78%. Nearly 60% of Supervising Engineers who responded were definitely not considering progressing to Inspecting Engineer. This figure could have been significantly higher if the engineers who did not respond fell into the “no” category. The majority of those who said they would not consider applying for an Inspecting Engineer Panel identified their age as the main reason. The most common additional requirements anticipated by those intending to apply to become Inspecting Engineers were: required construction experience, further supervision experience, further design experience and further technical experience.

Prospective Inspecting Engineers have commented that applying to the Reservoirs Committee for recommendation for appointment to a Reservoir Panel is a daunting process, for the reasons set out above. Also, the benefits of progressing from Supervising Engineer to Inspecting Engineer are not obvious to such candidates. If successful they may have to change employer to practice as an Inspecting Engineer because an owner may not appoint an Inspecting Engineer who is an employee.

The 2015 research identified that Supervising Engineers were well past the halfway point in their careers and may not wish to change employer at this time. Also, reservoir inspection may not be that attractive to employers given that the current mechanisms for employing Inspecting Engineers has driven down fees whilst liabilities remain high. Some employers justify the work as a “loss leading” activity that can lead to other work, but there are plenty of examples to show that often this does not materialise.

Wales has recently enacted a lower threshold of 10000m^3 to include high risk small raised reservoirs which will increase the total number of reservoirs to be inspected in Great Britain from 2892 to 3547[8]. It could be considered on a pro-rata basis that this will require a minimum increase to 37 Inspecting Engineers. If the threshold of 10000m^3 were to be implemented in England and Scotland, the total number of reservoirs requiring inspection would be around 4000. If the same ratios were assumed this would require approximately 40 Inspecting Engineers to undertake the work.

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8. Numbers are for reservoirs currently designated as high risk and above 25000m^3 in England and Scotland, and above 10000m^3 in Wales

As a result of the investigation and analysis it was concluded that the numbers of Inspecting Engineers will continue to decline. By 2022 it was expected that the number would have reduced to between 21 (most realistic case) and 30 (best case). It was estimated that the industry may require between 37 and 40 Inspecting Engineers to maintain delivery of the future workload. Clearly the current arrangements for securing an adequate supply of Inspecting Engineers in the future is unsustainable.

The ICE Reservoirs Committee has on a number of occasions considered the attributes required for reservoir inspection and whether different Panels might be recommended. So far they have resisted recommending a move from a “one size fits all” approach for Inspecting Engineers, and again for Supervising Engineers. It is questionable whether experience of construction should be required for all Inspecting Engineers, though this should be retained for Construction Engineers (those reservoir engineers competent to supervise and certify construction or alteration to a reservoir). As the risk posed by reservoirs varies considerably across the range of reservoirs, it is arguable whether the attributes needed for inspection or supervision of reservoirs should be the same across the whole of that range. Indeed, since many Supervising Engineers are very experienced, there is an argument for considering the progression through to Inspecting Engineer and then to Construction Engineer in a number of stages rather than the current leap.

Providing comprehensive quality training for prospective Supervising and Inspecting Engineers has the potential to improve both the quality of candidates and their future supply.

Maintaining competence

The collective knowledge of any professional area does not stand still. Knowledge grows through experience, advances in science and technology, research and development and most importantly, from incidents. It is important that reservoir engineers and other personnel continue to develop throughout their professional career by contributing to and learning from the growing body of knowledge in their field.

Professional development can take many forms, but principally it consists of:

- Sharing knowledge amongst practicing reservoir personnel through attending and contributing to meetings, seminars and conferences;
- Reading and learning from the latest guides and bulletins;
- Learning from day-to-day experience at work;
- Learning lessons from incidents;
- Learning from research and the development of science and technology;
- Training courses.

Knowledge sharing

The British Dam Society (BDS) – is a specialist knowledge society of the Institution of Civil Engineers (ICE). There are over 650 individual members and about 35 corporate members. The BDS is a charity and is run by a committee of volunteers. A peer reviewed journal of technical papers ‘Dams and Reservoirs’ is published four times per year by the ICE. There are normally six BDS lectures presented each year (physical and on-line), technical site visits, a young professionals group with a separate set of activities, a biennial Supervising Engineers’ Forum (a 1-day seminar tailored mostly around the role of the Supervising Engineer), and a biennial Conference (2.5 days) involving presentations, workshops and site visits. There is also a biennial 1 day Inspecting Engineers’ Forum which is just for the participation of Inspecting Engineers.

The International Commission on Large Dams (ICOLD) is the international body of which the BDS forms the UK ‘wing’. There are over 100 member countries. They collect and share knowledge between the various member countries and form policy. They organise various meetings, publish reports and guidance, and organise an annual meeting each year. Further information on the work of ICOLD is included in section 5.

The BDS is a good example of a knowledge community established and run by its members. In general it follows good practice and there is evidence to demonstrate the positive contribution it makes to keeping reservoir engineers abreast of the latest developments. It provides good two-way links with both ICOLD and ICE, though its activities on the international front could perhaps be strengthened.

Guidance

The BDS maintains a summary of key technical guides on its website. At the time of writing the list includes one item from ICOLD, four from the Environment Agency, four from the Institution of Civil Engineers, five from the Building Research Establishment, seven from the Construction Industry Research and Information Association (CIRIA) and two from HR Wallingford. Of the 23 guidance documents, 13 are more than 20 years old. The list illustrates the range of organisations that has evolved over the many years that this sector has been in existence. Whilst such divergence is not of itself an issue, it makes it harder for the user to discern from where the authority for such guidance comes. This is very different from other infrastructure sectors where much of the guidance is provided by the industry regulator and/or the Health and Safety Executive (HSE).

Defra and the Environment Agency have commissioned two comprehensive reviews of industry needs, the most recent in 2016 which identified and prioritised the research and guidance requirements of the reservoir industry, informed by a workshop with owners/practitioners and an academic engagement workshop with universities.

Currently, guidance is largely aimed at the engineering roles, more notable that of the Supervising and Inspecting Engineer. Some more recent material is aimed specifically at owners. Specific guidance for owners is challenging because of their considerable diversity, as explained earlier. Most of the larger reservoirs are operated by knowledgeable organisations such as water companies and hydropower operators. These organisations employ professional reservoir teams with experienced engineers who will typically be members of the BDS and have familiarity with standard industry guides, and the role of the different organisations involved. Approximately a third of regulated reservoirs are owned by private individuals, farmers, fishing clubs etc with typically no specialist engineering knowledge. This group will increase significantly in number if high risk small raised reservoirs are regulated in England in the future. They rely greatly on their Supervising Engineers, who would often be contracted in to provide their services, to advise them on all or most reservoir safety matters. These owners do not usually involve themselves with the BDS.

Outside of the large reservoir owners there appears to be very little guidance available for staff who undertake surveillance or operational and maintenance activities at a reservoir. These staff do not normally take part in the knowledge sharing activities of reservoir engineers and there is no equivalent forum for them. This is a significant omission which needs to be addressed.

Lessons learnt from incidents

International experience across all infrastructure sectors shows that much can be learnt from incidents and near misses. As part of their duties, the Environment Agency collects and records information from reservoir owners on incidents that have occurred in England. They started doing this in 2007, building on earlier work undertaken by the Building Research Establishment (BRE). The objective of collecting incident information is to improve safety by:

- investigating incidents where appropriate
- informing the reservoir industry of any trends and key lessons identified
- contributing to research into reservoir safety and incident analysis

Figure 2 shows the number of incidents reported between 2004 and 2017, by incident level. Incidents are classified as follows:

Level 1: Failure (uncontrolled sudden large release of retained water)

Level 2: Serious incident involving any of the following:

- emergency drawdown
- emergency works

- serious operational failure in an emergency

Level 3: Any incident involving:

- a precautionary drawdown
- unplanned physical works
- human error leading to a major (adverse) change in operating procedures

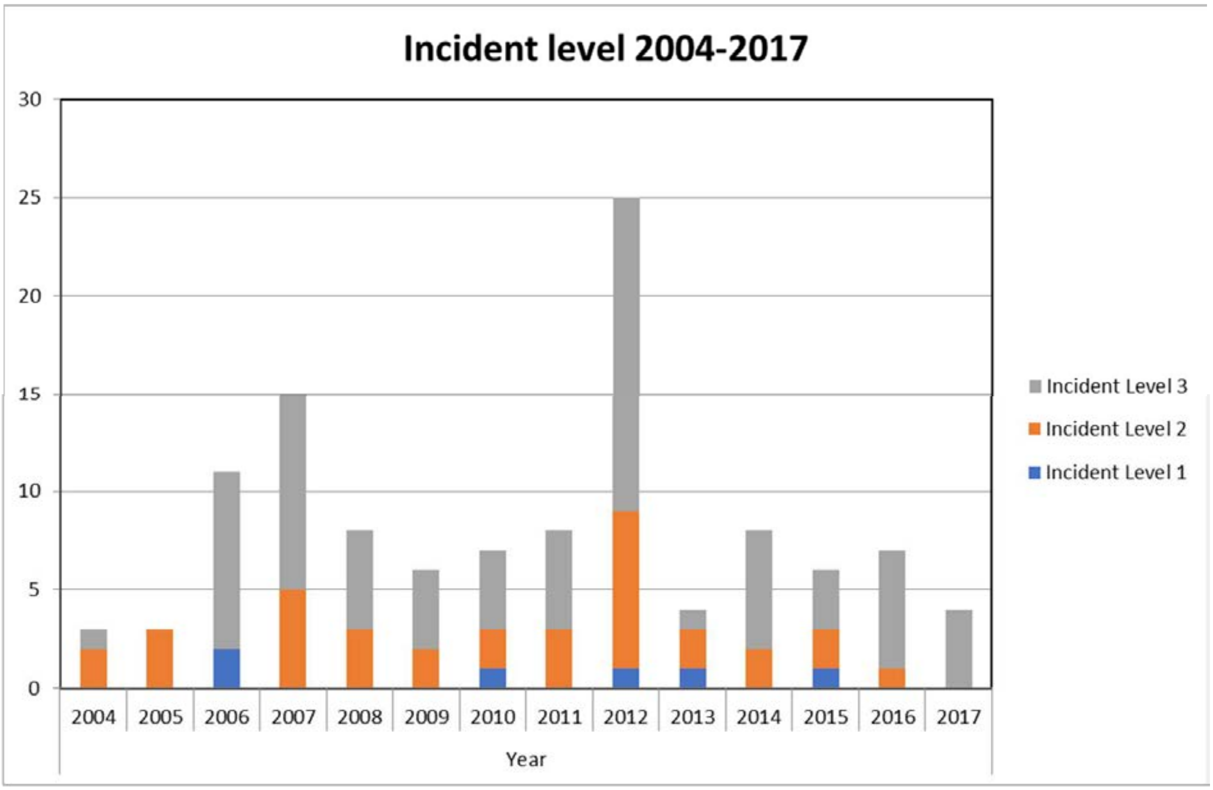

Figure 2. Reported Incidents 2004 to 2017 (after Warren and Patten[9])

The increase in incidents in 2007 and 2012 are attributed to flooding in those years, whereas 2013 was a relatively dry year. In 2013 incident reporting became compulsory. It cannot be concluded either way if this influenced the proportion of incidents that have been reported since. Since 2013, incidents occurring in Wales are not included in the Environment Agency's publications.

9. Warren AL and Patten B, "*Learning from reservoir incidents – a summary of the causes and management of incidents in the UK*", Smart Dams and Reservoirs, Proceedings of the 20th biennial conference of the British Dam Society, Swansea.

The Environment Agency publishes annual reports summarising reported English reservoir incidents. Reports for 2014 to 2018 (the latest) are available on the Government web site https://www.gov.uk/government/publications/reservoir-safety-post-incident-annual-report-2014. Within these published reports the Environment Agency have identified any lessons that it believes reservoir owners and wider 'communities' need to be aware of, in the interest of safety

As incidents are reported to the Environment Agency they are logged and given an incident number. The Environment Agency then sends them in batches to a consultant where they are reviewed. The level of detail provided by owners in many instances is poor. The legislation only states that an owner's report has to be provided but there is nothing to specify the level/quality/completeness of owner reporting.

Between 2016 and 2018 reports on some 11 incidents have not been published because they fell short of the incident classification criteria. This is why there are gaps in the sequence of reference numbers of the published incidents. It is intended that only significant incidents, where the causes have been properly understood and the appropriate lessons learnt, are published. However this can often be drawn-out and lead to a delay in publication – the 2018 report, for example, being the latest publication available at the time of writing. Also, the 2017 publication includes lessons learnt from incidents that occurred as far back as 2012. The Environment Agency explains this at the start of their publication with the following statement "*It is not unusual for reports to include information from previous years. This is because reservoir undertakers have 12 months to provide a full and comprehensive post incident report. They provide a preliminary report immediately when the incident is under control. Every year there is also the opportunity for these reports to include information on incidents that happened before or around the time that reporting became mandatory in 2013*".

Every five years a summary of incidents is included over the previous five years. Where there are urgent lessons to be learnt from a particularly serious incident, or where common lessons have been learnt from a number of similar incidents, the Environment Agency issues a Technical Bulletin. Eight such bulletins have been issued to date, the latest one in 2020 as a result of the Toddbrook incident. This was issued about 6 months after the incident so that lessons could be learnt from the formal review of the incident. These bulletins are important because they provide more information on the incidents and the lessons learnt. The bulletins have 'only 'guidance' status and owners and reservoir engineers can choose whether or not to act upon them. Details of the bulletins published are shown in table 2 below.

No bulletins were published between 2010 and 2017 despite the relatively large number of level 2 incidents reported. The Environment Agency concluded that there was no new learning to justify the publication of a Technical Bulletin in this period.

The Environment Agency, Supervising and Inspecting Engineers also contribute to papers on incidents published in Dams and Reservoirs. It is Environment Agency policy to support the work of the BDS. However, it is unclear how a decision is made to share learning through an article in Dams and Reservoirs rather than publish a Technical Bulletin. Table 2. Summary of published bulletins since 2007

Number	Year	Title
1	2008	Vulnerability of masonry spillways
2	2008	Reservoir flood safety in groundwater dominated catchments
3	2008	Overtopping of embankments raised with sheet piles
4	2009	Animal damage to embankments (unpublished)
5	2009	Tree damage to dam embankments (unpublished)
6	2017	Over-pumping of service reservoirs
7	2017	The reporting of incidents at reservoirs (England)
8	2020	Advice note following the Toddbrook reservoir incident, August 2019

Overall the concerns are that not all important incidents are being reported to the Environment Agency, those that are reported are not supported with sufficient information to allow appropriate lessons to be learnt, and that where lessons are learnt it is some time before they are communicated across the reservoir sector. There is no one place for a reservoir engineer to go to in order to keep abreast of learning from incidents so it is possible that individual engineers might miss something important.

Anyone can report any incident to the Environment Agency and they review every report raised. Given this, and the fact that owners have a legal obligation to report incidents defined as reportable, a more consistent and prompt means of sharing lessons and giving warnings should be possible. It would be worth considering the process used by the Rail Accident Investigation Branch (RAIB) which issues incident reports promptly and then follows this with a further report once lessons have been learnt. Like the Environment Agency, incidents are reported in the public domain, but with RAIB they are not done so anonymously.

Research and development

The Environment Agency/Defra-sponsored Reservoir Safety Research Advisory Group (ReSRAG) was established in 2001 to coordinate research strategy across the reservoir sector. It is responsible for linking the research needs of the reservoirs community in the UK with the capability of academia and the effective dissemination capability of the BDS, and this appears to be working well. The objectives of ReSRAG are to:

- Advise on and review R&D strategies
- Assist in the identification of funding
- Encourage wider input of interested parties
- Agree and advise on R&D priorities
- Support in the defining and drafting of R&D proposals
- Promote completed R&D, providing advice and guidance
- Support publicising widely to improve awareness.

The ReSRAG committee generally meets four times a year. The committee is made up of the Chair (usually the Chair of the BDS), two reservoir owners, two academics and two Panel Engineers along with representatives from the Scottish Government, Welsh Government, Northern Ireland Government, the Environment Agency and Defra.

ReSRAG sets out its research programme under the following eight themes.

- Hydrology and Hydraulics
- Geotechnics
- Structures (including concrete/masonry dams)
- Operations, monitoring and surveillance
- Risk and hazard assessment
- Environment, social, safety and welfare
- Dam breach, emergency planning & incident response
- Miscellaneous (seismicity, hydro-mechanical etc)

Details of each theme can be easily accessed on the BDS web site https://britishdams.org/reservoir-safety/reservoir-research/ and includes information on current UK research, recent and current international research, key international publications, and UK and international guidance, including a full list of guides from the International Commission on Large Dams (ICOLD), and key UK guidance.

Training and learning by experience

The BDS runs a biennial Supervising Engineers' Forum (a 1-day seminar tailored mostly around the role of the Supervising Engineer), and a biennial Conference (2.5 days) involving presentations, workshops and site visits. There is also a biennial 1-day Inspecting Engineers' Forum which is just for the participation of inspecting engineers. In addition to this there are four training courses run for reservoir engineers.

There are many ways in which those working in the reservoir sector can gain the necessary competence to do their work effectively. This can be through experience, coaching and mentoring, self-learning, attending meetings and seminars, and training. Each has its particular strength and a mix of measures is often found to be the best approach. It would appear that most of these activities are available to a varying degree for different groups of reservoir personnel. However, there does appear to be a notable gap in the availability of formal training. This is particularly so for aspiring inspecting engineers, operatives and surveillance personnel, and reservoir owners.

As with the other sections above, there are examples of good practice amongst the larger reservoir owners. It is with the smaller owners and the small engineering practices where the greater challenges lie. Here there is often not the resource available to meet the need. In other infrastructure sectors the Regulator appears to adopt and support formal training to a greater extent to that which currently exists in the reservoir sector. This appears in part to be due to a greater capacity to resource that training, and in part due to the duties and powers of the Environment Agency being rather more limited than other Regulators. There is a significant opportunity to improve both capacity and capability in the reservoir sector through targeted training.

For those employed in large owner organisations or in the larger consultancy practices, there should be ample opportunity to learn from experience. However, with the smaller owner or small engineering consultant, these opportunities can be limited. It would be useful to explore the extent to which secondments might be more effectively used to build competence. Whilst there will be certain issues of commercial confidentiality to overcome, reservoir personnel could greatly benefit from such an opportunity, particular for those Supervising Engineers who aspire to become Inspecting Engineers.

Summary

Overall, the process for supporting the ongoing competence of reservoir engineers is fragmented and there is no single lead organisation. In some cases this results in duplication of effort, as in the case of learning lessons from incidents, which may appear in bulletins from the Environment Agency, papers in Dams and Reservoirs, or presentations at BDS meetings. Equally there are some important gaps, for example the lack of regular review of the work of reservoir engineers once they are appointed to a Reservoirs Panel.

The future supply of Inspecting Engineers is worrying and must be urgently addressed. Previous attempts have proved unsuccessful so a different approach will now be needed. An earlier and more certain progression from Supervising Engineer to Inspecting Engineer could help with this. ICE could, for example, revisit the opportunities that might be afforded from a review of the necessary competences of Panel Engineers, in particular the need for construction experience for all Inspecting Engineers. In addition, a transitional grade of Inspecting Engineer where responsibilities were limited whilst experience was gained might prove fruitful.

It should be remembered that much of the time spent on assessing the competence of reservoir engineers, writing guidance and producing articles and papers is done on a pro bono basis, perhaps more than in other sectors. This may prove to be unsustainable in the future at current levels.

The lack of formal training is a missed opportunity. Whilst there is no substitute for experience, much can be gained from appropriately targeted training. There is an opportunity for the Environment Agency, BDS and ICE to work together to address this, and in doing so not limit their thinking just to reservoir engineers, but all those engaged in the reservoir safety process.

4. The safety management of UK infrastructure

The purpose of this section is to review the wider aspects of safety management in UK infrastructure and its implications for the reservoirs sector.

The development of infrastructure safety legislation

Each infrastructure sector developed its own approach to safety management through the 19^{th} and 20^{th} centuries. In parallel with the growing threat from infrastructure was the threat from the work place, accelerated by the rapid industrial growth. To counter this threat HM Factory Inspectorate was formed to regulate conditions in the workplace. This progressively expanded to cover mines, agriculture, and quarries. In 1974 the Health and Safety Executive was formed by the Health and Safety at Work Act. Although still focussed on safety in the workplace, section 3 of the Act imposed requirements for the management of safety in society at large.

Health and safety legislation

The Health and Safety at Work Act 1974 was developed from the recommendations of the Robens Committee[10]. The Act also established the Health and Safety Commission and its Executive (HSE). Both the Act and the Commission are aimed at the safety of people at work, but they also apply to the safety of society outside of the workplace. The principles established by Robens essentially moved thinking away from a rule-based approach towards a risk-based approach to managing safety. These principles are worth repeating here:

- Health, safety and welfare (at work) could not be assured by an ever expanding body of legal regulations enforced by an ever increasing army of inspectors;
- Primary responsibility for ensuring health and safety should lie with those who create the risks and those who work with them;
- The law should provide a statement of principles and definitions of duties of general application, with regulations setting more specific goals and standards.

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10. *Safety and health at work: Report of the Committee*, (Robens Report), H.M. Stationery Office, P.O. Box 569, London SE1 9NH, United Kingdom, July 1972, 2 vols. 218 pp. and 718 pp.

Section 3 of the Health and Safety at Work Act 1974 places general duties on employers and the self-employed to conduct their undertakings in such a way as to ensure, so far as is reasonably practicable, that persons other than themselves or their employees are not exposed to risks to their health or safety.

For section 3 to apply:

- there must be a duty-holder - either an employer or a self-employed person, and
- there must be a risk to the health or safety of a person who is not the employee of the duty holder or the self-employed duty holder themselves, and
- that risk must arise from the conduct of the duty holder's undertaking. An 'undertaking' means 'enterprise' or 'business'. Note that whether a particular activity is part of the conduct of the undertaking is determined by the facts of each case (*R v Associated Octel Co Ltd (1996) 4 All E R 846)*. Although not decisive in every case, whether the duty-holder can exercise control over both the conditions of work and where the activity takes place is very important.

This section has important implications for those who operate infrastructure, since they must comply with this legislation. They have a legal duty to manage the risk to a person and to society that arises from their activities as the operator of that infrastructure. HSE have set out the principles that underpin the Act in their seminal work *Reducing Risks: Protecting People* (R2P2)[11]. This addresses the fundamental principles of how we ensure the safety of society, recognising that there is no such thing as absolute safety. The methodology set out in R2P2 arises largely from experience in the nuclear sector. It starts with identifying hazards, assessing the risks that those hazards pose and then determining what controls are necessary to manage those risks. In considering risk it accounts not only for the actual danger but the possibility of danger. It recognises that people's expectations include that "*the State should be proactive in ensuring that its arrangements for securing the protection of people from risk are adequate and up to date as distinct from reacting to events, and that those arrangements should address, as necessary, the concerns the hazards give rise to"*.

As well as the risk to an individual, high consequence risk (for example that arising from nuclear installations or reservoirs) gives rise to societal concerns since an accident or failure might result in significant damage and/or loss of life. Safety assurance is therefore based on achieving a level of risk that is reasonable for the individual (individual risk) and acceptable to society (societal risk).

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11. *Reducing Risks, Protecting People, HSE's decision making process,* Her Majesty's Stationery Office, St Clements House, 2-16 Colegate, Norwich NR3 1BQ, 2001

As stated in R2P2, how people view risks and apply value judgements is perhaps the most challenging factor to take into account when developing an approach to regulating risk. In developing their approach HSE considered the risks that both the individual and society typically faces, and what is generally considered to be acceptable. For example, an individual will normally accept the increased risk arising from driving for the convenience and freedom that driving affords. For society as a whole, risks tend to be viewed differently from individual risk. For example, society would be more likely to accept ten incidents of the death of a single person than one incident involving the death of ten people. HSE also identifies different degrees of risk: those that might be considered as *broadly acceptable*, those that would be clearly *unacceptable*, and in between a range where risk would be *tolerable* (figure 3). The legislation requires risk to be lowered So Far As Is Reasonably Practicable (SFAIRP). This is interpreted as a requirement that in the range of tolerable risk, the risk is managed to be "As Low As Reasonably Practicable" or ALARP.

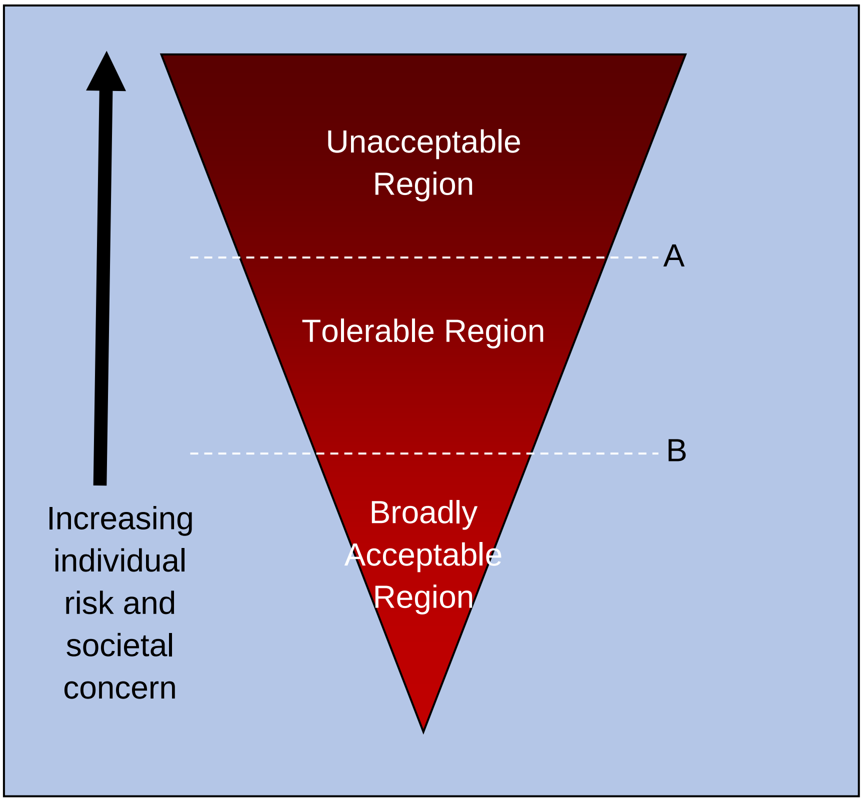


Figure 3. HSE Framework for the Tolerability of Risk

Tolerability limits for risks entailing fatalities

The HSE framework sets the limit of tolerability at 1 in 1000 per annum for those in the workplace and 1 in 10000 per annum for an individual member of the public who has a risk imposed on them. These correspond to level A in figure 3 above. In practice the actual fatality rates are often much lower than these. A useful comparison with fatalities from other causes is given in table 3 below. Tolerable risk to an individual becomes broadly acceptable for risks below 1 in 1000000, represented by level B in figure 3.

Table 3: Annual risk of death for various causes averaged over the entire UK population (from R2P2[11])

Type of Accident	Annual Risk
Injury and poisoning	1 in 3137
All types of accidents and other external causes	1 in 4064
All forms of road accident	1 in 16800
Gas incident (fire, explosion or carbon monoxide poisoning)	1 in 1510000
Lightning	1 in 18700000

When considering societal risk, the number of people affected becomes important. For fatalities this is usually expressed as the annual Likely Loss of Life (LLOL). As a general rule, the greater the LLOL, the less acceptable the risk. HSE proposes that the risk of an accident causing the death of 50 people or more in a single event should be regarded as intolerable if the annual frequency is estimated to be more than I in 5000. This provides an "anchor point" for societal risk across the range of risks, and enables a risk diagram to be drawn out for different levels of societal risk (figure 4). This is often referred to as the ALARP diagram, and is widely used to justify appropriate levels of risk in the safety management of infrastructure.

In practice the responsibility for the asset operator is to manage the risk of their operation within the boundaries set out in figures 3 and 4. Where risk lies within the unacceptable region, then measures should be taken to appropriately reduce that risk to at least a tolerable level. Within the tolerable range there is then the requirement to demonstrate that risk is being reduced to ALARP.

In applying the ALARP principle the benefits of reducing the risk are weighed against the associated costs. The test of "reasonably practicable" is that the consequential cost to the asset operator should be significantly greater than the commensurate benefit of reducing the risk, but not grossly disproportionate. A gross disproportionate factor of 10 is often used in such circumstances such that a cost of up to 10 x the associated benefit of reduced risk would not be unreasonable.

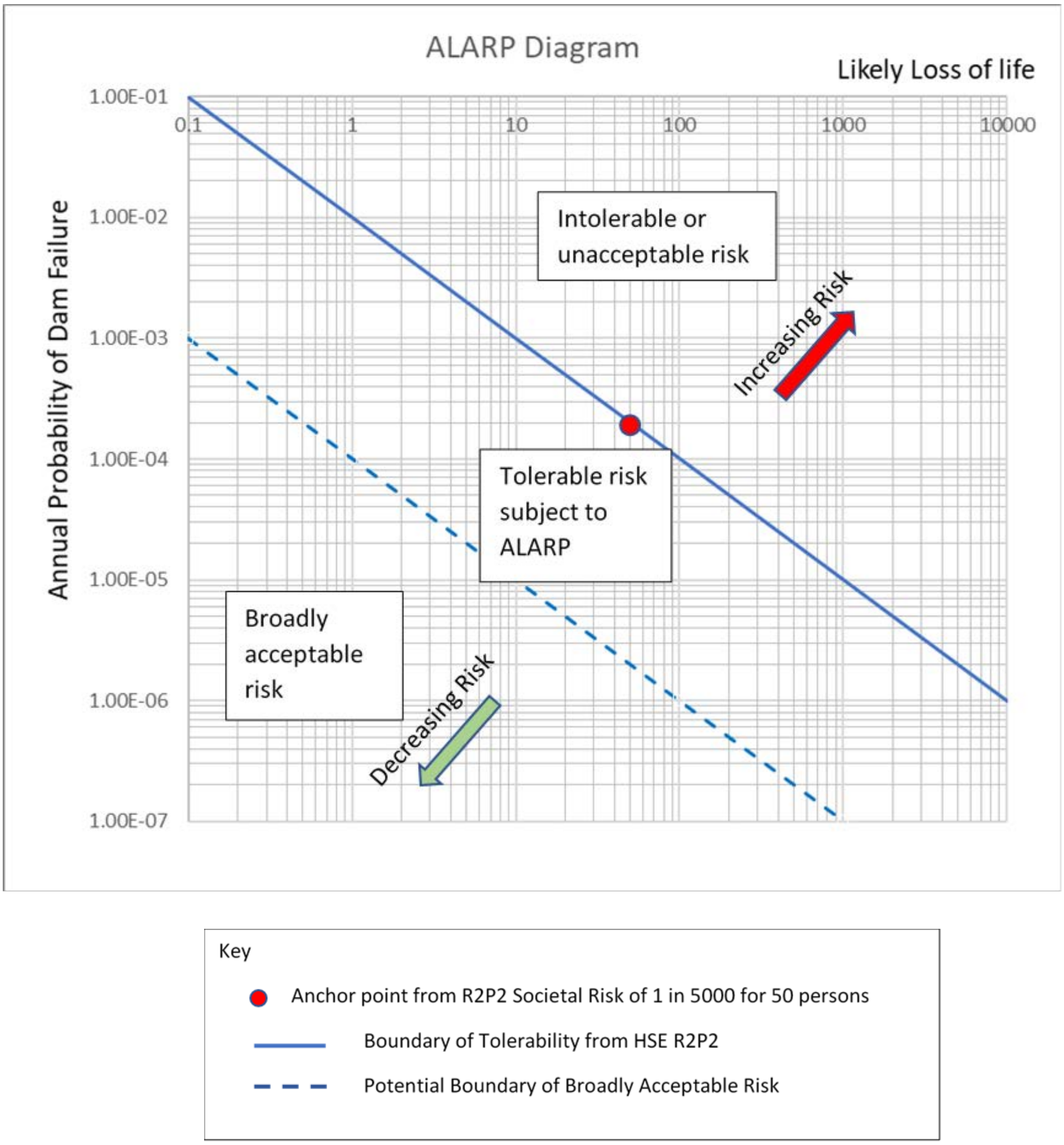


Figure 4. Diagram of societal risk (the ALARP Diagram)

The Health and Safety Legislation described above applies to all infrastructure sectors, including the reservoirs sector. For it to be effective, Government needs to be sure that the various asset operators to whom the legislation applies are exercising due diligence and complying with the legislation. To achieve this the Government establishes Regulators. Regulators are given duties and powers in associated regulations to monitor, review and enforce the legislation. The following sections review the role of Regulators in the nuclear and rail infrastructure sectors, sectors that are comparable in overall risk to the reservoirs sector.

The nuclear industry

The nuclear industry covers operating reactors, fuel cycle facilities and nuclear waste management and decommissioning sites across the UK. These are operated by a range of organisations including EDF Energy Nuclear Generation Ltd, URENCO UK Ltd, Springfields Fuels Limited, Sellafield Ltd, LLW Repository Limited, Magnox Limited, Rolls-Royce Submarines Ltd, Devonport Royal Dockyard Ltd and the Atomic Weapons Establishment plc. Nuclear sites pose a significant risk to individuals and society due to the potential release of radioactive material.

The legal and regulatory framework for nuclear sector is established by the Health and Safety at Work Act 1974 (HASWA), The Nuclear Installations Act 1965, the Nuclear Industry Security Regulations 2003, The Nuclear Safeguards (EU Exit) Regulations 2019 (NSR19) and the Energy Act 2013 (TEA13). The industry is regulated by the Office for Nuclear Regulation (ONR), across 5 purposes: nuclear safety, nuclear security, radioactive material transport, conventional health and safety and safeguards.

ONR operates in accordance with the Regulators Code[12] and the Legislative and Regulatory Reform Act 2006. Regulation is conducted on the basis that responsibility for safety lies with the industry itself by ensuring that there is, at each site, effective arrangements in place to maintain nuclear and radiological safety, preventing inadvertent exposure to workers and the public. This is achieved at reactors, for example, by effective containment, cooling, shielding and control. There is a well-defined approach to safety in the industry which ensures, so far as is reasonably, practicable that:

- Faults do not occur (through conservative design, good operating practices and proper maintenance);
- If faults occur, they are controlled (through providing appropriate control and protection systems);
- If the protection fails, alternative systems are in place to mitigate the consequences.

The nuclear industry follows the standard hierarchical approach to the control of risk: elimination, substitution, engineering controls, administrative controls and use of personal protective equipment.

12. The Regulator’s Code, HM Government, April 2014

ONR works on a system of regulatory control based on a formal licensing process. ONR issues licences under The Nuclear Installations Act 1965, to a corporate body, to use a defined site, for specified activities. The nuclear site licence granted by ONR is a legal document, issued for the full life cycle of the facility. Currently, there are 36 licensed sites regulated by ONR and it is an offence to operate a nuclear installation without a licence. The work of ONR is targeted and proportionate to the hazards and risks presented, with 98% of its costs recovered from the industry.

A standard set of 36 Standard Conditions, covering design, construction, operation and decommissioning, is attached to each licence. These conditions require licensees to make and implement adequate arrangements in the interests of safety. Alongside the HASWA, the licence conditions provide ONR with legal powers to enforce compliance where serious shortfalls occur.

ONR defines factors that govern a safe nuclear site including:

- A capable, suitably resourced licensee able to maintain control and oversight of safety at all times;
- A strong, embedded safety culture within the licensee and the supply chain;
- Robust, substantiated design with appropriate limits and conditions of operation;
- A rigorous operating regime with peer checking, self-assessment, training, accreditation and oversight;
- An experienced internal assurance function within the licensee's organisation;
- Effective use of external peer review by the licensee;
- A strong independent external regulator staffed by highly trained, qualified professionals undertaking site inspection and technical assessment work.

ONR uses a goal-setting regime rather than a prescriptive approach, where licensees determine and justify how best to achieve safety goals. The approach is risk-based and embeds the same principles of effective risk management set out by HSE discussed in the previous section. Safety is the responsibility of the licensee (duty holder) who must produce a written demonstration of safety in the form of a Safety Case, which demonstrates the safety of its installation and that the associated risks to workers and the public are ALARP.

Numerical targets are used as an aid to judgement when considering whether radiological hazards are being adequately controlled and risks reduced to ALARP. A limit of a risk of death to an individual member of the public of 1 in 10^4 per annum is the maximum that will be tolerated, with 1 in 10^5 per annum applied to new nuclear installations. Generally, the risk of death associated with nuclear plants does not exceed 1 in 10^6 per annum, and in most cases is much lower. These targets align with those adopted by HSE from its tolerable risk framework, reflected in its R2P2[10] document.

ONR defines a Safety Case as "*a logical and hierarchical set of documents that describes risk in terms of hazards presented by the facility, site and the modes of operation, including potential faults and accidents, and those reasonable practicable measures that need to be implemented to prevent or minimise harm*." The Safety Case takes account of experience from the past, is written in the present, and sets expectations and guidance for the processes that should operate in the future, if the hazards are to be controlled successfully. It clearly articulates the safety claims, arguments and evidence, defining the limits and conditions for plant operation in the interests of safety.

The licence conditions mentioned earlier, require the licensee to establish and implement a management system that gives due priority to safety, which is subject to review by ONR. They require the licensee to ensure adequate records are made of operation, inspection and maintenance of all plant that affects safety, and require the licensee to report and investigate incidents.

Licensees are required to undertake periodic reviews of safety, completing a systematic and comprehensive reassessment of safety every 10 years. The review includes a re-assessment of the plant against modern standards, consideration of operating experience, maintenance and learning from incidents. The result is a schedule of reasonably practicable safety improvements that must be implemented and an updated Safety Case.

Anything that has a major impact on the ongoing safety of a facility must be appropriately justified, for example, physical changes to plant or modes of operation. The more safety significant changes need to be formally approved by ONR.

ONRs own technical specialists assess and determine the acceptability of Safety Cases and the adequacy of the periodic review. To fulfil its functions effectively and give confidence to stakeholders that it is a capable and appropriately resourced organisation, ONR has developed robust internal processes that govern regulatory training, knowledge management, technical standards and regulatory research. It also has a comprehensive tiered approach to internal assurance that reports to the ONR Board, providing oversight of its own compliance and effectiveness.

To ensure licensees comply with the conditions of their licence and other legal requirements, ONR inspectors, warranted under the HASWA and TEA13, undertake regular site inspections. Typically, ONR site inspectors will spend 25% of their time on site, inspecting a wide range of areas including operations, plant and system conditions, records, training etc.

Following the defence in depth principle, licensees have their own internal compliance function that undertake similar reviews of its safety cases and complete plant inspections to provide assurance to its Safety Director on the adequacy of safety on the site.

ONR is the enforcement authority for the associated legislation and regulations. It has the powers to prosecute for non-compliance when it is considered to be in the public interest and has done this successfully where there has been evidence of a significant breach of law giving rise to harm, or a serious risk of harm. ONR also has the power to prosecute where there has been a failure to comply with an enforcement notice or direction. Manslaughter charges will also be considered following a death.

To support its activities and provide industry with clarity on regulatory standards and expectations, ONR produces a range of guidance and procedural documents that are readily available on its website. ONR also works closely with fellow national regulators in other countries and international agencies to ensure that its regulatory practices align with international standards and relevant good practice for safety, security and safeguards.

The rail industry

The rail industry consists of the mainline railway, High-Speed 1, light rail, heritage railways, tram networks and metro systems. This system is operated by a wide range of organisations including at one end, Network Rail, the mainline train operating companies and Transport for London, and at the other small heritage railways and tramways. The Office for Road and Rail (ORR) is the safety regulator for all these different organisations and also the economic regulator for Network Rail. Its safety powers arise from the Health and Safety at Work Act 1974, the European Railway Safety Directive 2004/09, and the Railways and Other Guided Transport Systems (Safety) Regulations 2006 (ROGS).

In broad terms ORR operates in a similar way to ONR. It grants permission to Network Rail, train operating companies and other organisations to operate on the basis that they will apply their own management system to effectively control the risks they create when running their business. This is achieved through a system of formal certification and authorisation that places certain duties upon those organisations as duty holders. Authorisation is reviewed at least every five years. It is an offence to operate a public railway without authorisation from ORR. As with the nuclear sector, it is the duty holder or licensee that drives the safety management process in the rail sector.

ORR has two key aims: to achieve compliance with legislation and regulation across the rail industry and at the same time to drive a culture of continuous improvement in health and safety management, risk control and asset management to achieve its vision of "*zero industry caused fatalities and major injuries to passengers, the public, and the workforce*."

ORR implements compliance strategies in order to:

- ensure that duty holders comply with relevant health and safety legislation, or if they fail to comply, ensure they are held to account;
- ensure duty holders eliminate or properly control risks;

- take action to deal immediately with serious risks;
- promote and achieve sustained compliance with the law; and
- deter non-compliance and prevent work-related ill health and injury to workers, passengers and other members of the public who may be affected by the operation of Britain's railways.

ORR operates in accordance with the Regulators Code[11] and the Legislative and Regulatory Reform Act 2006 in order to ensure firm but fair regulation based on proportionality, targeting, consistency, transparency and accountability. It has to have regard to economic growth when making decisions, and achieves this through:

- Sensible risk management – not gold plating;
- Engaging with the business;
- Fostering the sharing of good practice;
- Allowing time to improve on non-compliance;
- Minimising the administrative burden.

Duty holders in the rail sector have to submit details of their Safety Management Systems, which is similar to the Safety Case in the nuclear sector. These are assessed and approved by ORR. Duty holders therefore have to engage professional staff including their own inspectors in order to fulfil this function. This will be in proportion to the scale of their individual operations. ORR has the technical capacity and capability to review and approve Safety Management Systems. It does not duplicate the inspection process, but has the powers and capability to make spot checks and undertake spot inspections.

ORR uses industry information about actual harm (caused to individuals) and modelled risk (using historic mainline data) to measure health and safety performance.

A key element of safety management is ORR's Risk Management Maturity Model which is now in its third generation (RM3). It measures an operator's ability to manage risk maturely and achieve excellence in risk control (figure 5), and is used to foster continuous improvement. According to ORR's 2019 Annual Report the industry has engaged with RM3 2019 and in particular has welcomed the changed approach to assessing organisational culture, now embedded in all criteria.

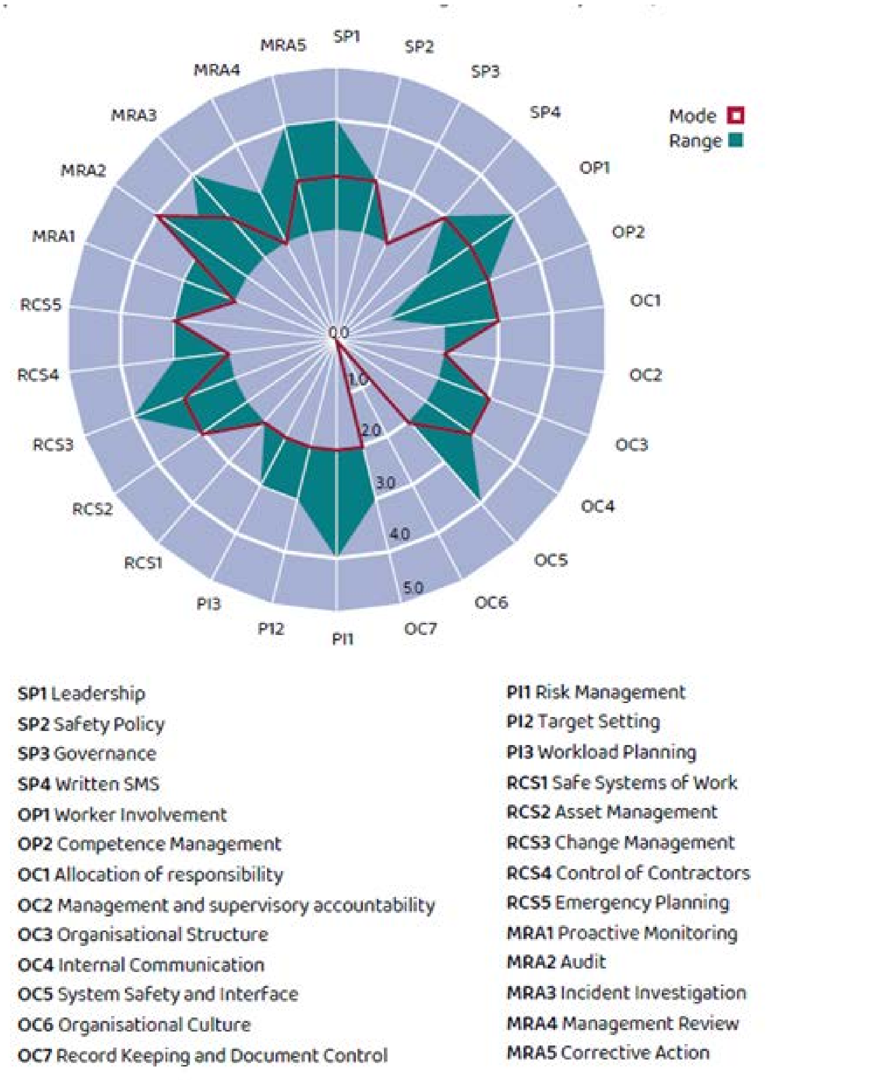


Figure 5. Example of ORR's risk management maturity model (RM3)

ORR is also the enforcement authority. In most cases it achieves compliance without formal action. It has powers to issue improvement notices, prohibition notices and to revoke operating certificates. In 2019/20 it issued 20 improvement notices, 4 prohibition notices and completed 3 prosecutions resulting in fines of over £1.5m.

There is an obligation on duty holders to report accidents, incidents and near misses. These may be investigated by both the duty holder and ORR. Rail accidents and near misses are also investigated by the independent Rail Accident Investigation Branch (RAIB). It issues reports and makes recommendations to avoid recurrence, conducting around 20 investigations a year. It does not apportion blame or liability and has no enforcement powers. As well as full investigation reports, RAIB also publishes Safety Digests. Safety Digests are a useful alternative to full RAIB reports as they are produced more quickly after an incident and are focused on identifying safety learning rather than making recommendations.

Rail safety standards are managed separately from ORR by the Rail Safety and Standards Board (RSSB) – set up by a public inquiry in 1990. It manages and develops railway standards by gathering performance data and reviewing risk. It manages industry research, development, and innovation programmes.

ORR supports its work through published guidance and also produces a very detailed and open annual health and safety report, in which it sets out its progress year on year against key performance indicators. In particular it highlights the current challenges it faces. For example, the 2019/20 report highlights pressure on the system, supporting people, technology and managing change as its key areas of concern. Where it has a specific concern regarding a duty holder’s safety management record, this is explicitly stated in the report, for example “*although we found some examples of good practice on the network, we continue to find too many examples of inconsistency and variation in the application of rules, standards, processes and procedures*”.

Summary

The Health and Safety at Work Act 1974 provides comprehensive legislation covering the safe operation of infrastructure assets. The 1975 Reservoirs Act as subsequently amended is not entirely compatible with this. As mentioned previously, this may mean that in certain circumstances a reservoir owner can be compliant with the reservoir legislation but not with Health and Safety legislation.

Regulation and enforcement in the nuclear and rail sectors differs significantly from the reservoir sector in the UK. Both ONR and ORR are underpinned by legislation that gives them duties and powers to thoroughly review the safety processes of their asset owners/operators and where necessary undertake their own inspections. Safety is assured through identifying and evaluating risk and then reducing it so far as is reasonably practicable.

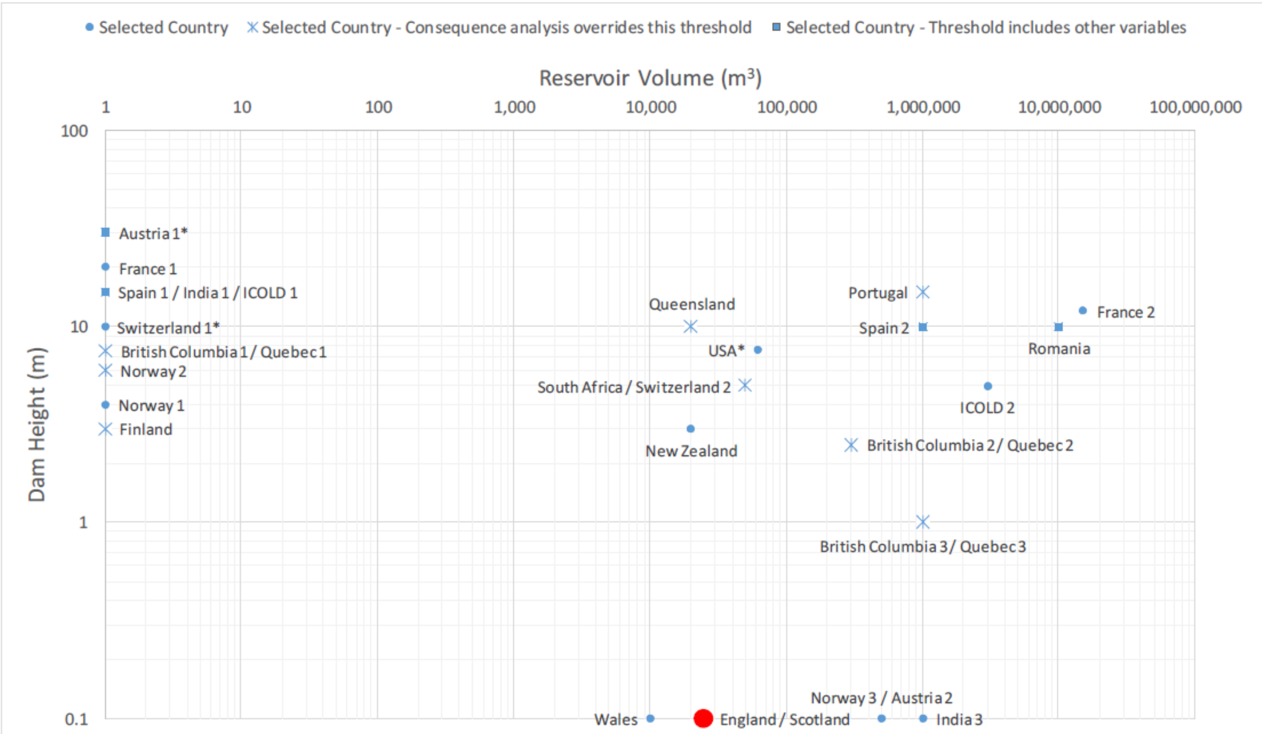
Unlike the Environment Agency, most of ONR and ORR’s operating costs are largely recovered from their owners and operators and this ensures that they have the capacity and capability to deliver their obligations. They are responsible for developing appropriate guidance and standards and for ensuring that all personnel are appropriately qualified.

Of particular note is the process ORR uses to engage its owners and operators in a dialogue over competence. This has helped to develop a culture of continuous improvement.

5. International practice of reservoir safety management

By international standards, large reservoirs in England would not be considered to be particularly large. Only about 20% of them would meet the International Commission on Large Dams' definition of a large dam*: a dam with a height of 15 metres or greater from lowest foundation to crest or a dam between 5 metres and 15 metres impounding more than 3 million cubic metres*.

Figure 6 gives a comparison of the threshold for the regulation of dams in different countries of the world in comparison with the UK.



Notes: * indicates countries where it is specified that smaller dams are regulated by provincial authorities
Source: Analysis by Mott MacDonald (2019) using data from Reservoirs Act 1975 - Guidance for a new risk-based approach (Halcrow, 2008)

Figure 6. Thresholds for the regulation of reservoirs in different parts of the world[13]

13. Review of the Existing Risk Methodology, Report No FD2701, Environment Agency, March 2020

Practices for the management of safety of reservoirs and dams vary between different countries according to their state of development and their different regulatory instruments. As well as different legal structures, countries also have different approaches to funding and standards. Most countries that maintain reservoirs with large dams collaborate with the International Commission on Large Dams (ICOLD), which provides leadership on reservoir safety management, produces guides, and supports learning through meetings, conventions and by sharing lessons learnt from incidents. Many large reservoir projects are funded by the World Bank, and it too plays a role in informing standards and good practice, particularly in governance and regulation.

The World Bank

In 2002 the World Bank undertook a comparative study of the regulatory framework for dam safety in different countries[14]. The aim was to go beyond compliance with legislation and make development objectives the goal of safeguarding policies. It considered the regulatory arrangements in 22 countries in term of the legal form of the regulations, the institutional arrangements for regulating dam safety, the powers of the regulating entity and the contents of the regulatory scheme

The report identified the essential elements of regulation as follows.

- The owner of the dam is responsible for making the dam safe and for operating and maintaining it in a safe condition;
- The Regulator is responsible for protecting the safety of the public by establishing dam safety standards with which the dam owner must comply and by monitoring compliance with these standards;
- Good regulatory control should clarify the dam owner's responsible for the safety of the dam and for operation and maintenance, and the ways in which the Regulator can perform its monitoring functions and its own inspections.

However, the main findings of the 2002 report have now been superseded in a more comprehensive review of reservoir safety management practice in the world, in the World Bank's 2020 publication "*Laying the Foundations*"[15]. Whilst covering a broader spectrum of reservoir safety topics, much of its content focusses on reservoir regulation.

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14. Bradlow D D, Palmieri A and Salmon M A, "*Regulatory Frameworks for Dam Safety – A Comparative Study*", World Bank, Washington DC, USA, 2002

15. Wishart MJ et al, "*Laying the Foundations: a global analysis of regulatory frameworks for the safety of dams and downstream communities*", World Bank Group, Washington DC, USA, 2020

From the 51 countries surveyed the 2020 report concludes that whilst the questions surrounding the institutional arrangements governing dam safety have become increasingly complex, the three essential elements listed above continue to apply. A complete spectrum of regulation exists across the countries surveyed, ranging from entirely self-regulation at one end to full central control and command at the other (fig. 7). Most countries operate somewhere in between these extremes. Where the 2020 report differs from the 2002 report is in respect of the recommendations given in respect of the independence of the Regulator.

In the earlier report the advice given is that the Regulator should be entirely independent from the owner, whereas the later report recognises that in certain circumstances it is acceptable for the regulator and the owner to be part of the same organisation. An example would be where the government is the regulator of a set of largely private sector reservoir owners but also owns reservoirs itself. In such cases the branch of government that owns and operates its reservoirs should be separate from that which provides the regulatory function, and there should be internal systems in place to assure that separation. This is similar to the system that currently exists in England. However, the 2020 report also states that the fully independent system provides the highest assurance of safety.

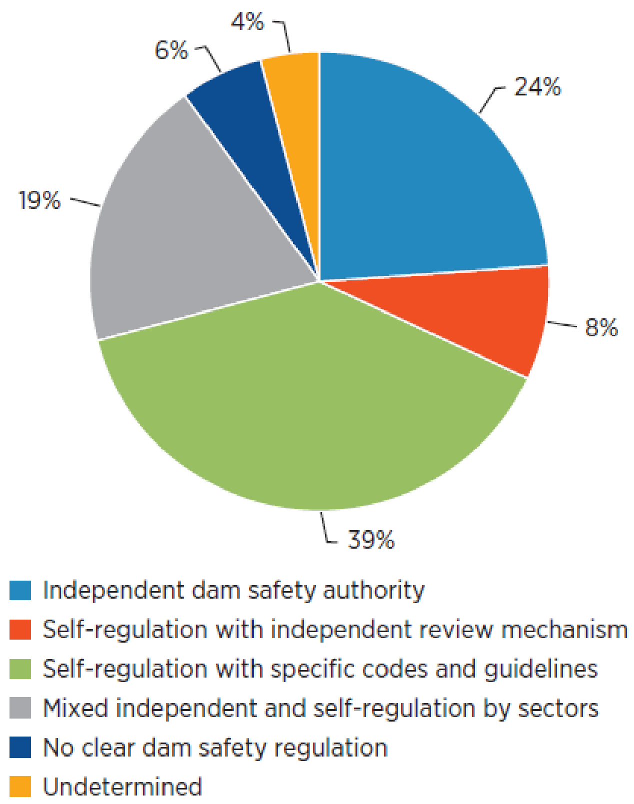


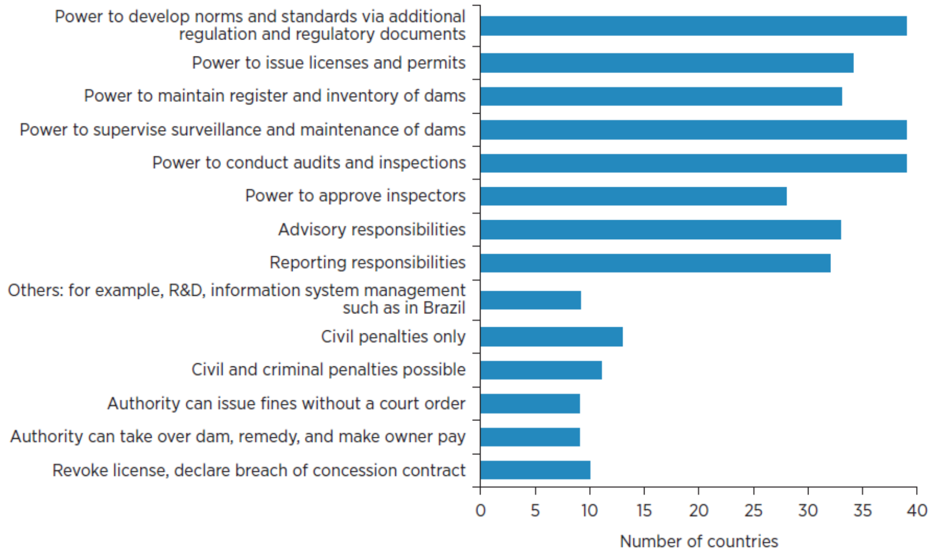
Figure 7. Independence of dam safety assurance authorities among the World Bank case study countries and jurisdictions[15]

The World Bank report sets out the primary roles of the Regulator as:

- Compliance audit
- Checking of reports and certificates
- Direct inspection function

Currently the Environment Agency undertakes the first two of these but not the third. The more a regulator is involved with the process of safety assurance the more liability it carries and the more resources are needed to undertake its function.

A Regulator must have the necessary duties and powers to undertake its stated function and this should be underpinned by legislation. The range of powers that Regulators possess was found to differ widely between countries, as illustrated in figure 8 below.



Source: Original figure for this publication.
Note: R&D = research and development.

Figure 8. Specific roles and powers of dam safety assurance regulators among the World Bank case study countries and jurisdictions[15]

Dam safety regulatory frameworks will need to consider suitable mechanisms for holding the regulatory authorities accountable and for resolving disputes between the authorities and dam owners.

International commission on large dams (ICOLD)

ICOLD was formed in 1928 to provide an international focus and platform for reservoir engineers. It has since driven the development of good practice in dam engineering, safety management, and more recently risk assessment and management. In 2019 it revisited its objectives and brought its member organisations together to make a world declaration on dam safety (see Appendix E). This was stimulated by a need to address constant evolution and many changing conditions, including ageing infrastructure, retirement of experienced personnel, increased participation of the private sector, climate change, lack of available sites for new dams and changing local, regional and national governance. The aim of the declaration was to restate its pillars of dam safety, namely:

- The structural integrity of dams is the keystone to dam safety;
- A routine surveillance and maintenance programme is necessary for early detection of potential issues;
- An instrumentation and monitoring programme is essential throughout the life of a dam;
- Design-intrinsic risks need to be adequately addressed;
- Natural hazard risks change with time, thus should be regularly reviewed and updated;
- Emergency planning is of the upmost importance for all dams;
- Adequate training of operators is part of a comprehensive dam safety programme;
- Sharing lessons learned benefits the entire industry, making all dams safer;
- A comprehensive dam safety approach will allow minimisation of risks;
- A dam owner has the ultimate responsibility for its dam;
- The role of regulatory authorities is paramount for safety;
- An international perspective to dam safety can be enlightening.

ICOLD promotes good practice largely through the many guides and technical bulletins that it publishes. In 1969 it undertook a survey to determine the extent to which different countries had adopted a risk-based approach to managing safety[16]. This gives useful information country by country but there is no analysis of the data and no overall conclusions are drawn. What it showed was that different countries were at different stages of development of their approach to reservoir safety management, with some adopting risk-based methods at that time.

In 1987 ICOLD published its Dam Safety Guidelines[17]. It set out the most likely causes of dam failure and explained why the inspection and monitoring of dams was important. At that time the process adopted for the inspection of dams in the UK followed many of the principles and practices set out by ICOLD. ICOLD envisaged regular inspections every 5 years with a more detailed review (including a review of the design) every 10 to 20 years, compared with a 10 year interval overall in UK practice. There are some key statements regarding reservoir safety that are worth repeating here.

- Standards, regulations, design and maintenance methods, and operating rules can in no way replace the exercise of competent experience and judgement;
- The fact that no problems have been detected over a long period of time does not necessarily give proof of safety;
- The regulatory agency should be structured so as not to relieve an owner or operator of a dam or reservoir of the legal duties, obligations, liabilities and/or responsibilities inherent in ownership;
- The regulatory agency should plan for periodic review of legislation and regulations.

By 2005 ICOLD had updated it guidance to include risk assessment[18], driven by a change in public attitudes to risk and the need for transparency. This aimed to define a common safety policy based on risk, and built on a process that had been developing over the previous 10 years (though the identification of risk assessment in reservoir safety management can be traced back in ICOLD documentation as far as 1969). The approach in the 1987 bulletin remained valid, but for very high risk dams an approach similar to the principles of HSE's publication R2P2[11], including the concept of tolerability of risk and ALARP, was adopted. It included the identification and assessment of failure mechanisms.

Typically there will be a range of dam owners in any country. For many, managing their safety is part of wider socio-economic activity. For smaller owners resourcing can be a challenge. However, for high hazard dams, the ICOLD guidance notes that a lack of resources cannot be used as a justification of inaction due to unaffordability.

ICOLD guidance covers all aspects of safety management including design, operation and maintenance, surveillance and inspections. It notes that the modern view of safety governance includes the establishment of an independent regulatory body to assure the safety of dams, with adequate legal authority, technical and management competence and human and financial resources to fulfil its responsibilities.

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16. Current State of Practice in Risk- informed Decision-making for the Safety of Dams and Levees, International Commission on Large Dams, Paris, France, 1969
17. Dam Safety Guidelines, Bulletin 59, International Commission on Large Dams, Paris, France, 1987
18. Risk Assessment in Dam Safety Management, Bulletin 130, International Commission on Large Dams, Paris, France, 2005

Reservoir safety management in other countries

In 2008, ICOLD undertook a comprehensive review of reservoir practices in different countries[19]. The goal was to make basic information available about existing practices in dam safety management. The study resulted in an overview of the main arrangements for dam safety frameworks. The participating countries were distributed geographically as follows: Europe 25, Asia 8, North America 3, South America 3, Africa 3, and the South Pacific 2.

In almost all cases the reservoir owner was responsible for safety, and undertook regular surveillance. This was supported by periodic inspections. The most common way to assure reservoir safety was found to be a regulation or other agreement for a reservoir owner to use “best available technology” and/or “generally recognised rules of technology”. Such universally valid rules were referred to as the technical framework, and typically included national standards or norms, guidelines, instructions, and ICOLD Bulletins. Almost all countries had a legal framework where reservoir safety requirements were included either in laws specifically dealing with reservoir safety or an overarching legal framework with a water law and a public protection act. In addition there were normally lower level reservoir safety regulations and supporting technical guidance.

ICOLD found that the general view of safety governance was that governments typically set in place a regulatory framework for reservoir safety and assignment of responsibilities that included the establishment of an independent regulatory body to assure the safety of reservoirs. The regulatory body should be independent from the reservoir owner and other interested parties so that it was free from any undue pressure from them. If the owner of the reservoir was a branch of government, this branch should be clearly separated from and effectively independent of the branches of government with responsibilities for regulatory functions. The Regulator should have adequate legal authority, technical and managerial competence, and human and financial resources to fulfil its responsibilities.

Like the UK, many countries started with a standards-based approach to reservoir safety management supported by legislation which specified the standards, and then progressively moved to a more risk-based approach, supported by objective orientated legislation. The differences from country to country may be due more to the fact that different countries are at different stages of that development rather than fundamental differences in the philosophy of risk management. The following sections give examples of where countries are more advanced in that process.

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19. Regulation of Dam Safety: An overview of current practice world-wide, Bulletin 167, International Commission on Large Dams, Paris, France, Jan 2021

The Netherlands

The Netherlands have few reservoirs but have substantial sea and river flood defences which require an effective system for managing their safety. Because of the large potential impact of inundation from rivers and the sea, the Netherlands has strong legislation, strong governance and a large budget to manage this. Defences consist of barrages, dunes and embankments along the coast, and embankments for river defence.

The principles for managing flood risk are set out in the National Water Plan 2016-2021[20] and the standards enshrined within the Water Act. Following the 1953 coastal flooding, the Netherlands universally adopted a minimum standard for primary coastal defences of 1 in 10^4, based on the annual probability of overtopping of a defence. Lower standards were applied inland, or where the consequences of flooding was small. The current Water Act, in place since 2017, changed the standard to a maximum acceptable probability of flooding. The standards vary between 1:100 and 1:100000 per year. They include the potential structural failure of the defence as well as overtopping. The standards are such that the probability of dying due to a flood may not be higher than 1:100000 per year, taking into account the possibility of evacuation and flight.

Higher standards are adopted where societal impacts are high, for example where

- there are potentially large groups of victims;
- and/or major economic damage;
- and/or serious damage as a result of the failure of vital and vulnerable infrastructure of national importance.

A risk-based approach has been used to arrive at the standards for the probability of overtopping or structural failure of a defence, based on the consequences in either case. Assessments of the probability of overtopping requires periodic reassessment of extreme sea and river levels. The probability of structural failure is determined through periodic inspection of embankments and structures, and faces the same challenges as assessing the probability of failure of reservoir structures.

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20. National Water Plan 2016-21, Ministry of Infrastructure and the Environment, Ministry of Economic Affairs, The Netherlands, 2015

21. Fundamentals of Flood Protection, Ministry of Infrastructure and the Environment, The Netherlands, 2016 (2017 in English)

All primary defences have to be inspected regularly. The detailed approach to safety assessment and management is set out in the Fundamentals of Flood Protection[21]. This explains the approach to determining probability for natural occurrences such as high sea level or river flows, and the probability of structural failure of flood defence infrastructure. As part of this it identifies issues of uncertainty, distinguishing between inherent uncertainty and uncertainty arising from lack of knowledge, and how this is managed in assessing risk. Most notable is that an evolving part of managing the risk of inundation from flooding is the potential to manage the consequences.

Responsibility for flood protection in the Netherlands is shared by three levels of administration: central government, the provincial authorities and the water authorities, and is particularly complex. It is managed strategically by the Floods Commissioner who reports directly to the Dutch Government. The National Water Plan includes a map of the Netherlands indicating all national flood defences, unique reference numbers, and their respective flood protection standard. This information is readily available to the Dutch public through their government web site.

The USA

There are about 90,000 dams in the United States (US) according to data provided in the US National Inventory of Dams, held at the federal level by the US Army Corps of Engineers. According to the data, about 65% of these dams are privately owned and the rest are owned by federal, state or local government agencies.

In the US, state governments are responsible for safety regulation and inspection of the vast majority of dams – about 70%. Each state has its own set of laws, rules and policies that guide regulation. All states, except Alabama, have similar laws although some are less stringent in that they exempt some dams for specific purposes or hazard category. Each state legislature provides budgets for these offices – some more than others. On the federal side, there are several agencies that are involved with dam safety. Some agencies own and self-regulate, such as the US Army Corps of Engineers and the US Department of Interior (there are several sub-agencies or bureaus under this department including the large US Bureau of Reclamation).

Some agencies just regulate dams that are owned by others, like the Federal Energy Regulatory Commission (they regulate non-federal dams that produce power) or the US Mine Safety and Health Administration (they regulate some mine tailings/waste dams). The US Department of Agriculture built many dams in the mid-20th century and handed them to local catchment districts – they remain involved by offering technical support.

There is, therefore, no single entity in the US that oversees reservoir or dam safety. The United States Society on Dams (USSD), the Association of Dam Safety Officers (ASDSO) and the National Dam Safety Program, operated under the Federal Emergency Management Agency (FEMA), assist the industry in coordinating and transferring knowledge and best practice. The National Dam Safety Program provides some federal funding to states to assist them with their regulatory programs and produces national guidelines.

The US Bureau of Reclamation (USBR) is one of the largest dam owners in the USA. It is responsible for managing and funding all activities necessary to ensure the safety of 243 high risk reservoirs in the 17 western states of the USA. Their Dam Safety Program is centrally managed through their Dam Safety Office in Denver, Colorado. This is a risk-informed programme, utilising risk analysis and risk assessment to guide decisions on investment priorities. Its risk informed process is built on principles similar to the HSE in R2P2[11] and uses the concepts of broadly acceptable risk, unacceptable risk and tolerable risk with ALARP. The USBR program is authorised by the Reclamation Dam Safety Act[22], as amended. Policies and guidelines are established in the Reclamation Manual[23]. Technical practices and methodologies are documented in a series of technical manuals and design standards. USBR also manages its own research programme on dam safety. The most relevant Policies, Directives and Standards are available on the USBR website https://www.usbr.gov/ for reference. These are widely used by other organisations around the world.

As part of the National Dam Safety Programme, FEMA issued Federal Guidelines for Reservoir Safety Risk Management in 2015[24]. It is aimed at US federal agencies that own and regulate dams. Its recommendations are largely based on USBR's risk approach with thresholds on the ALARP diagram similar to those used in the UK, but with a different limit of tolerability, see figure 9. It recommends that inspections should be done through a small team of inspectors rather than a single inspector and that owners should prepare a safety case for each of their reservoirs.

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22. Reclamation Safety of Dams Act, Senate and the House of Representatives of the United States of America in Congress, USA, 1978-2004.

23. Reclamation Manual, United States Bureau of Reclamation, Washington DC, USA, 2020

24. Federal Guidelines for Reservoir Safety Risk Management, FEMA – P1025, US Department of Homeland Security, 2015.

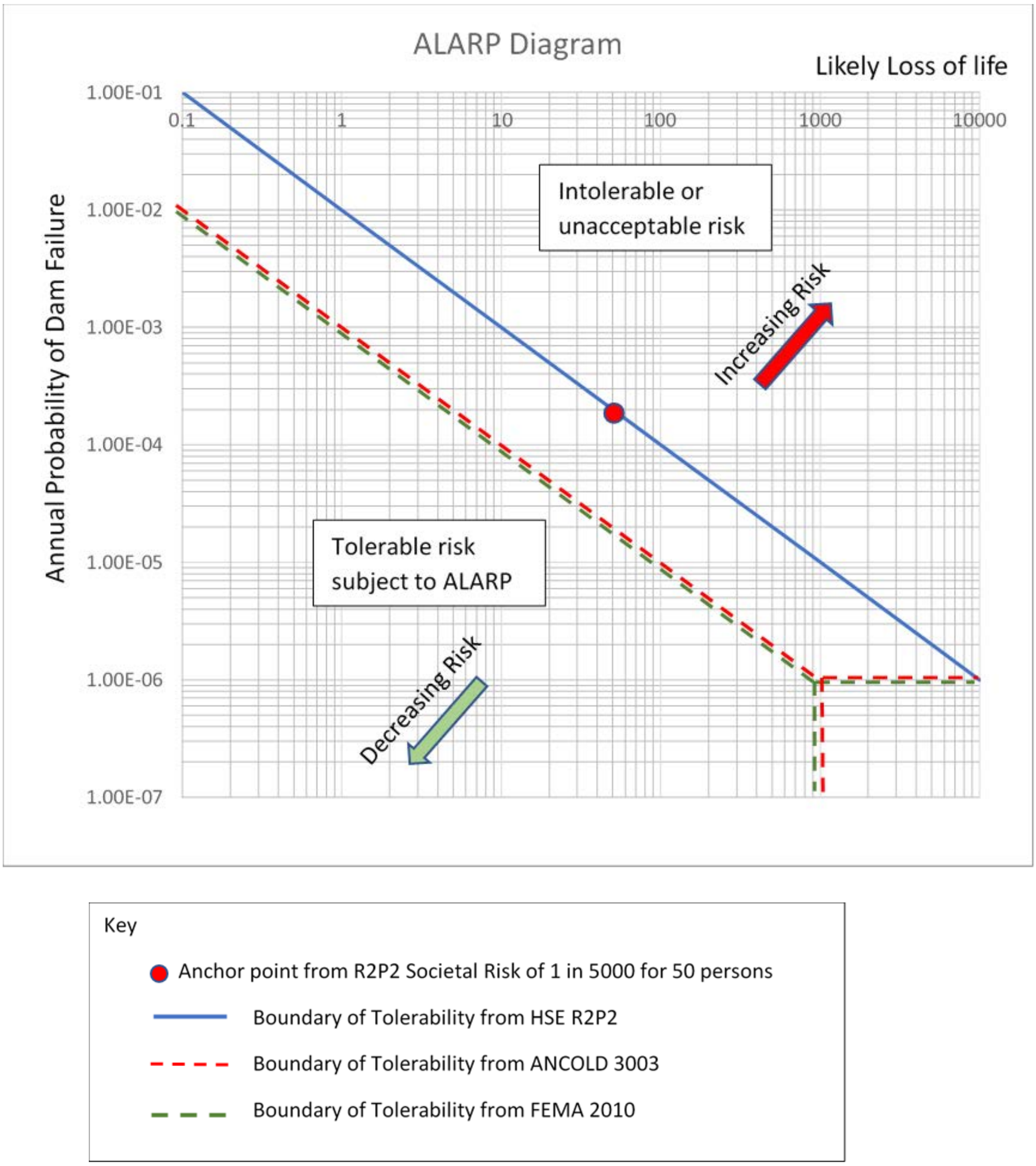


Figure 9. Limits of Tolerability for Societal Risk Adopted in Guidance in Other Countries. Note that ICOLD, ANCOLD and FEMA have adopted a more stringent boundary to the zone of tolerability (blue and red broken lines) than the EA's risk guidance[4] and HSE[11] (blue line).

Australia

In Australia, dam safety legislation varies between the states and territories. Of the six states and two territories, four states and one territory have regulations covering the operation of reservoirs and three authorities do not. To coordinate and lead the development of reservoir safety the Australian National Committee on Large Dams (ANCOLD) was formed, and this has been one of the principal sources of guidance for reservoir owners in Australia.

Like ICOLD, FEMA and the USBR, ANCOLD bases its approach to managing risk on the basis of tolerability (see figure 9). In 2003 it published Guidelines for Dam Safety Management[25]. It sets what dam owners and regulatory authorities should do and lists the essential elements of a dam safety programme. It adopts the principle of proportionality such that the amount of effort and resources put into a dam are determined by each dam's hazard and risk. To achieve this it separates reservoirs into five categories according to hazard (based on the population at risk) and the severity of damage and loss.

The guidelines set out the information that an owner should provide in their dam safety programme and includes:

- The dam safety emergency plan;
- Details of operating procedures;
- The operations and maintenance manual;
- Inspection and evaluation reports, including surveillance data;
- As-built drawings;
- Information on the history of the dam's development;
- Design report, construction report and details of safety reviews.

The requirements for dam safety inspections are similar to the UK's except that the frequency varies depending on the consequence of failure, the level of risk and the type and size of the dam. This typically results in an inspection frequency of every 5 years, compared with 10 years in the UK. Inspections by Inspecting and Supervising Engineers tend to be more detailed and fees substantially greater than in the UK to accommodate this.

Further guidance has been developed over the years including guidelines on risk assessment in 2003[26], currently being updated, and guidelines on the consequence categories of dams in 2012[27].

25. Guidelines on Dam Safety Management, Australian Committee on Large Dams inc, Hobart, 2003

26. Guidelines on Dam Risk Assessment, Australian Committee on Large Dams inc, Hobart, 2003

27. Guidelines on the Consequence Categories for Dams, Australian Committee on Large Dams inc, Hobart, 2012

28. Dam Safety Management Guideline, Department of Natural Resources, Mines and Energy, Queensland Government, Australia, Oct 2020.

In addition to the periodic dam safety inspections discussed above, ANCOLD recommends that there should be a more detailed Dam Safety Review every 10 to 20 years, depending on the level of risk. This includes a detailed review of the structural, hydraulic, hydrological and geotechnical design aspects and of the records of surveillance activities. It assesses the integrity of the dam for known failure modes against acceptance criteria such as engineering standards or risk management criteria. The review would normally be undertaken by a small panel to include specialists as necessary, and may require further investigations, surveys, sampling, testing and calculations/modelling. This may take up to several hundred hours of engineering input and is significantly more substantive and costly than current practice in the UK.

The periodic inspections and design safety reviews inform the investment programme to manage risk at a dam. Risk must be managed so that it is at least tolerable and reduced to a level that is ALARP.

Independent audits are undertaken as an additional good practice activity in Australia[25]. A panel of technical reviewers is formed to review designs of any significant remedial works, which may impact on dam safety, and for any new builds. Additionally, technical review panels (TRP) review Dam Safety Reviews and Comprehensive Risk Assessments, as well as entire Dam Safety Management Programs[28].

Reservoir Safety Management in Northern Ireland, Scotland and Wales

The devolved administrations are responsible for the oversight of reservoir safety in their respective jurisdictions and for enforcing reservoir legislation. Wales has the same legislation as England but makes its own regulations. In practice these are not significantly different from those in England with the exception that a lower regulatory threshold of $10000m^3$ applies to the definition of a large raised reservoir. Scotland has enacted and implemented its own legislation, whilst Northern Ireland has its own legislation in place but has yet to implement it. The key features of the different administrations in Northern Ireland, Scotland and Wales are set out below.

Northern Ireland

The Reservoirs Act (Northern Ireland) 2015 provides for the regulation of reservoir safety in Northern Ireland. The Act, when commenced, will introduce a proportionate regulatory framework for the management and maintenance of reservoirs capable of holding $10000m^3$, or more, of water above the natural level of the surrounding land. These are defined as *controlled reservoirs*. Subject to statutory responsibility for the Act being transferred to the Department for Infrastructure, and the Minister's agreement, the necessary secondary legislation required to commence the Act and introduce the management regime will be made in due course.

The Act places a requirement on the Department to give each controlled reservoir a designation that will inform the level of regulation and maintenance for the reservoir. Each reservoir will receive a designation of High Consequence, Medium Consequence or Low Consequence, depending on the impact that flood water resulting from a catastrophic failure of the dam would have on human life or health, economic activity, the environment and cultural heritage. High Consequence reservoirs will require the greatest degree of regulation and maintenance while Low Consequence reservoirs will require minimal regulation. The criteria for each of the reservoir designation categories is currently being developed, and is likely to be structured in a similar way to that adopted in Scotland, as set out below.

Scotland

Reservoir safety management in Scotland is governed by the Reservoirs (Scotland) Act 2011 which retains many of the features of the Reservoirs Act 1975, but applies it to reservoirs above 10000m^3 capacity. The Act is being implemented in a phased approach. Currently the regulatory regime only applies to reservoirs with a capacity over 25000m^3. Smaller reservoirs with capacity between 10000 m^3 and 25000m^3 will be brought under the new regime at a later date. The Scottish Environmental Protection Agency (SEPA) is the enforcement authority for the Act. The Act requires reservoirs to be designated on the basis of risk. Section 22 of the Act states that SEPA must consider the potential adverse consequences of an uncontrolled release of water and the probability of such a release when carrying out the risk designation process. However, as it is considered that there is, currently, no agreed industry standard for assessing the probability of an uncontrolled release that can be applied consistently at a national scale, SEPA bases the risk designation on the consequence aspect alone.

The reservoir risk designation process utilises available and readily derivable information that is considered reliable, including national datasets held by SEPA, the Scottish Government or associated organisations to provide information on the potential adverse consequences of flooding from an uncontrolled release of water. To enable SEPA to assess the potential impacts on receptors a reservoir inundation map will be produced for each of the registered controlled reservoirs.

The methodology for categorising reservoirs as High, Medium and Low risk subsequently adopted in Scotland is described below. SEPA has placed receptors into seven high level categories (shown in Table 4 below). Within the categories there are a suite of indicators (shown in Table 5) that will be assessed for potential impacts, which enables SEPA to assign a risk designation. A weighting has been applied to some categories in terms of the influence the receptor may have on the designated risk. This weighting has been applied by restricting which receptors can be assessed at each risk level. For example, it is not possible for the ‘Agriculture’ or ‘Environment’ receptor groups to achieve a score of high.

Table 4. High Level Categories for Assessing Consequence: Scotland

1	**Human health – People**	Potential risk to life attributed directly to an uncontrolled release of water. This will **not** include potential injuries, illness or risk to life resulting from secondary issues
2	**Human health - Community**	Important facilities that could cause community disruption if affected e.g. schools
3	**Economic activity - Businesses**	No. of business properties and the estimated weighted annual average damage of property
4	**Economic activity - Transport**	Roads, railways and airports
5	**Economic activity - Agriculture**	Agricultural land and forestry areas
6	**The environment**	Designated areas and their vulnerability to flooding
7	**Cultural heritage**	Cultural sites such as UNESCO World Heritage Sites

Where a reservoir has a number of dams that are each capable of holding 25000m^3 of water or more, an inundation map must be produced for each dam. Subsequently an assessment of risk will be undertaken for each of these dams, using inundation maps to assess the consequences of an uncontrolled release of water. Once an assessment has been completed for each dam associated with the reservoir, the reservoir will be given a single provisional risk designation. This designation will be equal to the highest risk level of any of the assessed dams, not an average of the risk designations. It is important to note that for a reservoir to be assigned a high-risk designation it will only be necessary for one of the seven receptor groups to have been impacted at high.

Table 5. Designation of Risk based on Consequence: Scotland

	Risk Designation		
	Low	**Medium**	**High**
Human health (A) - People	No risk to life identified within the reservoir inundation area.		Risk to life for one or more persons within the reservoir inundated area.
Human health (B) - Community	GPs and dentists □ Pharmacies □ Post offices	All residential care homes in urban location □ Health centres and clinics in urban areas □ Police or fire station in urban areas. □ Water pumping and waste water treatment sites.	All hospitals and ambulance depots □ Residential care homes in remote/rural locations. □ Health centres & clinics in remote/rural locations □ Police or fire stations in remote/rural locations □ Education facilities □ Prisons □ Power supply/production □ Water for consumption
Economic activity (A) - Businesses	Non residential property (NRP) score of 0	(NRP score of 1-70) □ 1-12 retail properties or □ 1-4 factories or □ 1-3 warehouses or □ 1-11 offices	(NRP score of 70+) □ 13+ retail properties or □ 5+ factories or □ 4+ warehouses or □ 12 +offices
Economic activity (B) - Transport	All 'B' roads unless in remote and very remote areas. □ All minor roads unless in very remote areas.	'B' roads in remote and very remote areas. □ All 'A' roads unless in remote and very remote areas □ Minor roads in very remote areas	Airports □ Motorways □ 'A' roads in remote and very remote areas □ Railways
Economic activity (C) - Agriculture	□ Agricultural land class 1 <136 ha □ Agricultural land class 2 <193 ha □ Agricultural land class 3a <377 ha □ Agricultural land class 3b <755 ha □ Agricultural land class 4 <1,038 ha □ Agricultural land class 5 <2,076 ha.	Agricultural land class 1 >136 ha □ Agricultural land class 2 >193 ha □ Agricultural land class 3a >377 ha □ Agricultural land class 3b >755 ha □ Agricultural land class 4 >1,038 ha □ Agricultural land class 5 >2,076 ha.	
Environment	Designated areas containing species/habitats deemed to be 'VL' vulnerability □ Designated areas containing species/habitats deemed to be 'L' vulnerability.	Designated areas containing species/habitats deemed to be 'M' vulnerability □ Designated areas containing species/habitats deemed to be 'H' vulnerability	
Cultural heritage	Category C listed buildings	Category B listed buildings, gardens and designed landscapes	UNESCO World Heritage Sites, scheduled monuments, Grade A listed buildings

The primary purpose of the risk designation is to drive that statutory level of engineering over-sight that the reservoir must receive. Table 6 indicates the consequence of each of the three risk designation levels regarding the inspection and supervision that the reservoir will receive.

Table 6. Supervision and Inspection Requirements for Different Reservoir Designations: Scotland

High Risk	Required to appoint a Supervising Engineer at all times. Required to appoint an Inspecting Engineer at least once every 10 years (or when recommended by Supervising Engineer).
Medium Risk	Required to appoint a Supervising Engineer at all times. Only required to appoint an Inspecting Engineer when recommended by Supervising Engineer
Low Risk	No statutory requirement to appoint either a Supervising or Inspecting Engineer

Wales

The responsibility for the regulation of reservoirs in Wales lies with Natural Resources Wales (NRW). Although the legislation and much of the Regulations are the same as in England, NRW is currently exploring different approaches to managing reservoir safety to help focus regulatory effort in light of the smaller reservoirs (10000m^3 – 25000m^3) registered since 2016 and now subject to regulation.

NRW has been looking at:

1. Establishing what thresholds within the high-risk reservoir designation could better inform its regulatory approach, with a view to agreeing these with the Local Resilience Forum (LRF) to reflect the resource it has to respond to different scale incidents
2. Once these thresholds are established, NRW in its regulatory capacity, will seek to identify and measure the extent to which all recommendations are being implemented for the highest risk reservoirs; this would likely be two-fold:
    a. Deep Dive audit to focus on a particular issue
    b. Longitudinal audit to pick up on recurring themes

Where recommendations may not be enforceable by statutory notice NRW will seek ways to influence change through other means and better public reporting. NRW anticipates that its revised charging scheme will reflect the cost of regulatory work needed to ensure safety, not just compliance. For example, where a lack of maintenance is apparent NRW may place that reservoir in a higher tier for enhanced scrutiny, for which a higher fee applies. Good operators benefit from reduced fees therefore. NRW has trialled internally the use of incident information notices – basic details provided soon after event. It plans to circulate these to all undertakers soon after an incident occurs.

Summary

ICOLD is a useful source of collective knowledge and opinion on reservoir safety management, whereas the World Bank is concerned rather more with reservoir regulation and governance. Both are clear that the owner is responsible for the safety of the reservoir, and must lead the reservoir safety management process. The Regulator is responsible for protecting the safety of the public. Since these two tasks are independent, both ICOLD and the World Bank state that the Regulator should preferably be independent from the owner, but recognise that it may be acceptable for a government to establish a regulator and own its own reservoirs provided that these two functions are separated.

ICOLD produces guidance based on good practice collected from the different countries with modern dam safety processes. It forms its opinion through consulting reservoir experts from around the world and it is this that gives it its credibility. Equally, the World Bank is an internationally respected financial organisation that funds many reservoir projects. Both advocate a risk-based approach to managing reservoir safety. They emphasise the importance of appropriately qualified personal acting in a professional capacity and the need for competent owners that have the capacity to fulfil their obligations. As mentioned by ICOLD, a lack of resources cannot be used as a justification of inaction due to unaffordability.

Most countries operate a safety management framework that includes surveillance, operation and maintenance, and periodic inspections, and is supported by comprehensive legislation and regulations that are enforced by a regulator. These processes are similar overall to those in England, but the detail varies. All the UK administrations are moving to a system for regulating reservoirs that designates reservoirs into different categories. Although the term risk is used in most cases it is the consequence that currently determines the designation, at least in the first instance. England is different from Scotland, Northern Ireland and many other countries that use a risk-based designation of reservoirs only to use two designation categories – high risk and not high risk. This is worth further consideration. All jurisdictions seem to place a great emphasis on the role of the owner as the entity responsible for reservoir safety. It is interesting, therefore, to see the thinking in NRW as to how owners might be better incentivised to focus more on those responsibilities and to drive continuous improvement.

6. Compliance and safety

My previous report showed that, based on the experience of Toddbrook, a reservoir could be compliant with reservoir legislation yet may not be safe. This review of the wider reservoir sector indicates that overall compliance with reservoir legislation is good, with the Environment Agency reporting 95% compliance for the period 2017 to 2019. There also appears to be a good understanding amongst many reservoir owners of their responsibilities towards reservoir safety, though some may be unaware of their duties under Health and Safety Legislation. There is a comprehensive approach to assuring the competence of Supervising and Inspecting Engineers when they are recommended for appointment to the various reservoir Panels and in general their reports and certificates are completed and issued promptly. Yet my Review clearly shows variability in the quality and content of inspection reports, and a lack of attention to maintenance indicated in Supervising Engineers' reports.

Dams are relatively benign structures under normal conditions. Experience shows that it is under infrequent extreme loading conditions that failures are more likely to occur, principally at times of flood or earthquake. The fact that there has been no loss of life since reservoir legislation was introduced is no indicator in itself that our reservoirs are safe. This is why there has to be a robust process for assuring the safety of reservoirs, underpinned by appropriate legislation.

Current reservoir legislation is based on the concept of the original Reservoir (Safety Provisions) Act 1930. Although this has been substantially updated with subsequent legislation, the original intent to prevent an uncontrolled release of water from a reservoir remains. Clearly this was to protect any downstream community or land from adverse impact, in other words, to keep it safe from the hazard created by the reservoir. There is therefore an implied link between the intent of the legislation and the need for assuring safety. The legislation does not require a reservoir or its dam to be kept in perfect condition. What is important is to avoid an uncontrolled release of water. However, this cannot be guaranteed. There will always be a probability, however small, that some event or mishap will occur. The same is true with the concept of safety. There is no such thing as being absolutely safe – but this then gives rise to the question of how safe does safe need to be?

Surveillance, monitoring, operation and maintenance

Surveillance

The importance of regular surveillance of a reservoir has been mentioned earlier. It is particularly relevant given the age of many of the reservoirs in England. The early detection of defects in reservoir infrastructure, especially the dam, can avoid sudden catastrophic failure. Surveillance can take many forms, but it typically includes:

- **Regular surveillance carried out by the operational staff of the owner, for example, to read reservoir level gauges or any instrumentation installed at the reservoir, to check for seepages or deformations and to keep waterways clear of obstruction**. Such staff will be employed by the owner and typically attend once a week but sometimes as much as two or three times a week. It will generally include observations of the condition of the reservoir, and especially of the dam, noting in particular any movement, deformation and the occurrence and progression of any defects in the fabric of the dam.

- **Routine visits by the Supervising Engineer under the Act**. The focus here will be on ensuring that aspects related to reservoir safety are being properly addressed, that nothing untoward is occurring or has occurred and that the hazard associated with the reservoir is unchanged. Visits will typically be once or twice a year, though more would be appropriate for very high-risk reservoirs. During these visits the Supervising Engineer will review the results of day to day surveillance with surveillance personnel, together with records of any survey or instrumentation data. They will typically check that all monitoring equipment and other reservoir apparatus such as valves and gates are operating correctly. They also need to ensure that all the required records for the reservoir are up to date. Supervising Engineers produce a report of each visit. They are also required to produce an annual statement for the owner on the safety of the reservoir. A copy of this is delivered to the Environment Agency. It will note, amongst other things, how the requirements of the last Inspecting Engineer are being complied with.

- **Periodic inspections take place at least every 10 years where an inspecting engineer assesses the condition of the reservoir.** They typically involve a detailed visual inspection and a review of the records of the reservoir. In doing so they will consider all relevant material available for the reservoir including design and construction documentation, previous inspection reports, surveillance reports, monitoring data, reports from Supervising Engineers and any risk assessments, as well as their own observations. During their visit, the Inspecting Engineer normally consults the Supervising Engineer and personnel engaged in routine surveillance, operation and maintenance at the reservoir. The extent and detail of the assessment will be in proportion to the hazard posed by the dam. Normally Inspecting Engineers will share their findings and requirements for measures in the interests of safety or maintenance with the owner as soon as possible after the inspection, and then issue a detailed report later (but within 6 months of the inspection). In some cases the Inspecting Engineer may require further investigations into the condition of the reservoir to be undertaken.

Surveillance by personnel is often supplemented by measurement and monitoring using specialist equipment designed for that purpose. Monitoring is most useful when it is linked to the potential failure modes of a dam, is undertaken at frequent intervals, and has a suitable warning system that links to remedial action and/or emergency response. Good monitoring can reduce the probability of failure of a dam by detecting early defects, and should be specifically allowed for in any risk assessment. However, one of the limitations of monitoring is trying to predict what the initial symptom of a structural problem would be, and what type of instrument would best detect this. In its most basic form, monitoring typically consists of:

- Reservoir water level recordings
- Deformation monitoring such as settlement surveys of the dam crest
- Flow recording of seepages from drains, and observations of turbidity
- Porewater pressure measurements by piezometers in earth embankment dams

Monitoring techniques are advancing all the time and some of the more modern methods are now being utilised in the sector. These can help to reduce reservoir risk further and can be especially valuable at high hazard reservoirs. They are discussed in more detail below.

Modern methods of monitoring

In recent years there has been a surge in the development of sensor technology, remote recording, data communication systems and data analysis techniques, including artificial intelligence. Whilst such techniques are not prevalent across all reservoir sites it would be wrong to think that the reservoir sector was particularly backward in adopting such measures. Modern methods of monitoring can provide several advantages such as:

- More efficient use of personnel
- Prediction of loss of dam integrity
- Greatly improved warnings if there is a rapid deterioration/problem
- Reduced number of reservoir drawdowns
- Proactive input to risk reduction which in turn can lead to an improved understanding of risks and therefore more targeted investment

Such methods may be at different stages of development, for example, industry ready, emerging (currently being trialled) or "blue skies" (still undergoing research and development). Whilst some techniques offer the benefits of continuous monitoring and remote sensing this may be at the loss of accuracy and/or reliability. Questionable data can be worse than no data at all. Traditional monitoring techniques may offer better accuracy and reliability than more modern techniques in some cases. Some techniques lend themselves better than others to retro-fitting and some are more appropriate for new construction. Whilst remote sensing offers the opportunity for early indication of anomalies, it will rarely be an adequate substitute for proper visual surveillance through visiting the dam site.

Dams can fail in various ways and depending on dam type. They and/or their foundations can erode due to over-topping. They can suffer sliding or stability failures. Internal over-stressing or dislocations can occur, and internal drainage or seepage flows can increase. This last aspect is a key indicator as it may forewarn of internal erosion, increased hydraulic pressures or some form of internal dislocation. Spillways can also fail for various reasons including hydro-dynamic imbalance. Monitoring methods should therefore be aligned to potential failure mechanisms:

Dam movement and deformation to detect sliding, settlement and stability issues: levelling, alignment and deformation monitoring using robotic total survey stations, automated tilt measurement, inclinometers, extensometers and embedded pressure cells. Many dam owners now use such techniques and may not, therefore, consider them to be "modern methods". Drone-based and handheld LIDAR methods are becoming more common as costs reduce. Satellite imagery is also proving effective though it is essential here to interpret data correctly to avoid misidentifying anomalies. Further information about how this technology is developing can be found from the Damsat Project https://damsat.org/ currently being led by HR Wallingford on behalf of the UK Space Agency.

Leakage and seepage detection: fibre-optic sensing cables, electromagnetic techniques, infrared imagery as well as direct measurements at flow measuring gauges. All can be automated, including turbidity measurement to determine material loss and automated piezometers to detect changes to the piezometric head.

Spillway investigation/monitoring: topographic surveys using robotic total stations, photogrammetry, LIDAR and satellite imagery, ground penetrating radar and pull-out tests.

An important part of modern monitoring technology is its ability to operate remotely and provide continuous data for real time analysis. This can be very valuable for implementing warning systems. Remote power supply has been a problem but this is being overcome through the use of solar panels. Costs, however, can be high, and some techniques may only be justifiable at high hazard reservoirs. In general, the promise of short term savings may be a minor advantage compared with longer term gains and reduction of risks.

Operation and maintenance

Regular and appropriate maintenance and proper operation of a reservoir are essential to safety. Maintenance may include:

- Management of vegetation, animal incursion and mowing of grass;
- Repair of access paths and roads;
- Removal of corrosion from metal parts and their repainting and repair;
- Repairs and sealing to brickwork, blockwork and concrete;
- Maintenance of monitoring equipment;
- Repairs to railings, gates and other safety features.

Operation may include the exercising of gates and valves, the intermittent flushing of sediment from the reservoirs, and general control of flows. Precautions need to be taken to protect the public and the environment from harm during operational activities.

Routine surveillance and maintenance may at times be outsourced to third party contractors. This can inevitably lead to a disconnect between the third party contractor, the Supervising Engineer and the owner. Particular vigilance is needed in managing such contracts to guard against this compromising their effectiveness.

Reservoir safety management plan

All high risk reservoirs should have a reservoir safety management plan (RSMP) in place. This should set out what surveillance, monitoring and maintenance is required at a reservoir and how it is to be operated, together with the frequency of each element, how it is to be delivered and by whom. It would be in addition to and sit alongside an on-site emergency plan, and be appended with a record of all surveillance, operational and maintenance activities together with associated data, measurements and other information, which should be kept up to date. Currently there is a requirement in Section 11 of the Reservoirs Act 1975 as amended for maintaining records of all monitoring as stated within the Prescribed Form of Record for the reservoir. It would seem sensible to merge and expand this to require the full content of the RSMP to be lodged in the Prescribed Form of Record.

Those undertaking surveillance, monitoring, operation and maintenance should be appropriately trained. There are good examples of training of operatives amongst the large reservoir owners and there would be benefits if these could be shared across the sector. Many reservoir owners have already prepared such plans and maintain associated records. However, this is by no means universal nor uniform in its use.

Standardising the approach to RSMPs would promote consistency and facilitate scrutiny by the Regulator. It would also allow an appropriate level of effort to be determined according to the reservoir hazard (see the later section on reservoir classification). The level and frequency of surveillance, monitoring, operation and maintenance at a reservoir should be in proportion to the hazard posed by the reservoir and the condition of reservoir structures. RSMPs should be prepared in consultation with the Supervising Engineer who should formally review and approve them annually and certify that in that year the owner has been compliant with the requirements of the RSMP. The format of the annual statement should be modified to accommodate this.

Development of a risk based reservoir safety management approach

Over the years the public have become more aware of the risks that they face in day to day life and there is now an expectation that these should be appropriately and transparently managed by those who cause the risk in the first place. They do not expect the risks they face each day to be removed, but they do require the risk to be reduced as far as is reasonably practicable. This principle is enshrined in Health and Safety legislation and is widely adopted in infrastructure management around the world, as explained in the earlier sections of this report. The concepts of placing limits of tolerability to risk and a requirement to reduce risks as low as is reasonably practicable (ALARP) form a sound basis for assuring the safety of any infrastructure. When supported by appropriate legislation it can give assurance to the public that when infrastructure is compliant with that legislation it is also reasonably safe.

In 2007, the near failure of Ulley Reservoir at Rotherham led to the closure of the M1 motorway and 1000 people were notified of possible evacuation. The subsequent Pitt Review of the 2007 floods made several recommendations relating to reservoirs, including the provision of new legislation. Subsequently, new legislation was drafted for England and Wales in the Floods and Water Management Act, and this was passed into legislation in 2010. In their 2007 biennial report the Environment Agency set out their agenda for legislative change in preparation for the new Act. This included a proposal to introduce a risk-based approach with proportionate levels of engineering input and a legal obligation on undertakers to register with the Environment Agency all bodies of water retaining 5000m^3 above the natural level. Risk levels were to include:

- High hazard – probable loss of life and/or major property/infrastructure damage;
- Significant hazard – possible loss of life and/or major property/infrastructure damage;
- Low hazard – very low probability of loss of life. Minor property/infrastructure damage.

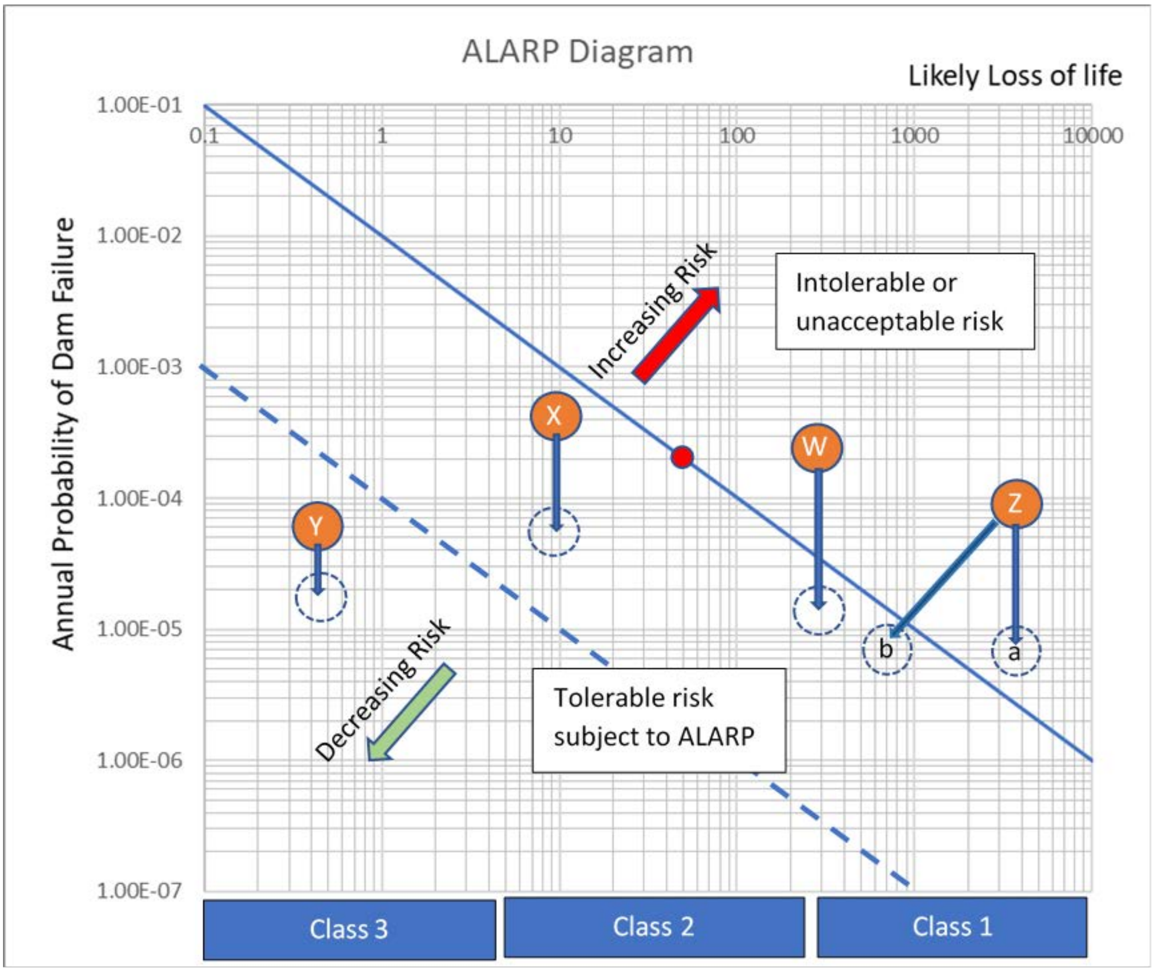
At the time, risk was not a new concept in reservoir safety management, and as explained in the preceding section, many countries, including England, had started to use risk informed approaches in managing the safety of their reservoirs. The Environment Agency had also issued guidance on risk management methods. In the end, the Pitt Review recommendation for a new reservoirs act was not progressed, and the existing legislation was amended instead. The Environment Agency's concept of a risk based approach was diluted to a binary categorisation of reservoirs into high risk and not high risk, and the threshold for small raised reservoirs increased from $5000m^3$ to $10000m^3$.

No further aspects of risk were pursued, such as the opportunity to work within tolerable limits of risk or to implement measures in the interest of safety to reduce risk to as low as reasonably practicable (ALARP). Thus the opportunity to modernise the legislation and bring it more into line with the Health and Safety at Work Act 1974 was missed. Moreover, some 11 years after the legislation was enacted, the requirements for the regulation of small raised reservoirs (reservoirs of raised volume between 10000 and $25000m^3$), and a requirement for the production of emergency plans has yet to be implemented in England. It is interesting to note that although the Environment Agency sought some additional powers in the new Act, there appears to have been no aspiration to modernise their role much beyond that of an enforcement authority (for example to give it powers to review or challenge the reports of supervising and inspecting engineers or to carry out its own inspections).

There is ample evidence of the benefits that a risk based approach can bring to the safety management of infrastructure, and that it can be successfully applied to the reservoir sector. A number of large reservoir owners in the UK have adopted a risk based approach to managing their portfolios of reservoirs. The concepts of broadly acceptable risk, unacceptable risk, and tolerable risk reduced to as low as is reasonably practicable (ALARP) have been shown to be workable and valuable in assuring that infrastructure is reasonably safe. It can also assist reservoir owners in complying with their obligations under health and safety legislation[11].

In this approach, risk is typically based on the risk to the individual (individual risk) and to society (societal risk). Individual risk is the increase in the chance of death per year of a person downstream of a reservoir. It is calculated as the product of the individual vulnerability (percentage of time an individual is present in the location x the fatality rate if the dam failed) and the overall probability of failure. For individual risk, HSE[11] defines the point at which risk becomes unacceptable as 1×10^{-4} and where tolerable risk becomes broadly acceptable risk as 1×10^{-6}.

Societal risk varies depending on the total likely loss of life (LLOL) amongst those living downstream and the probability of failure of the dam, as illustrated in figure 10. Note that in the figure the boundary between the zone of tolerable risk and the unacceptable risk zone is defined by the blue line which passes through the anchor point defined by HSE[11] of an annual risk of 1 in 5000 for 50 persons. In other countries this line is set differently (see figure 9).



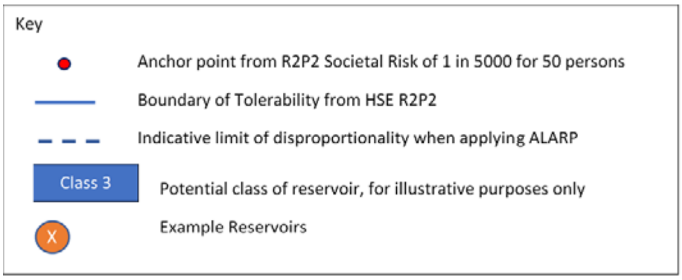


Figure 10. Potential ALARP Societal Risk Diagram for Use in Reservoir Safety Management in England (note that this figure is for illustrative purposes only and the values and thresholds included should not be interpreted as a recommendation).

Figure 10 shows how the societal risk of reservoirs in England might be managed. For example, reservoir W lies in the unacceptable risk zone and would require measures in the interests of safety to bring it below the boundary of tolerable risk and to be as low as reasonably practicable, as indicated by the dashed circle, say, directly below. Reservoir X lies in the zone of tolerable risk, but also would require its risk to be reduced to as low as is reasonably practicable. The test of reasonably practicable is explained in R2P2[11]. In essence, in achieving ALARP, everything should be done to reduce the risk, but not be so much as to be disproportionate. This can be interpreted for reservoirs just within the boundary of tolerability, as a cost (including other negative effects such as a reduction in service from the reservoir) of up to 10 x the benefit that the measures would deliver (e.g. reduction in loss of life). This is explained in more detail in a review of the existing risk methodology published by the Environment Agency in 2020[13]. The proportionality factor of 10 could then be reduced progressively depending on how low the reservoir risk is within the tolerability zone, possibly to 2 or 3 when the blue broken line in figure 10 is reached. The degree to which the cost should outweigh the benefit would therefore be less for reservoir Y than it would for reservoir X.

In some ALARP diagrams the zone below the blue broken line is shown as "broadly acceptable risk" (figure 4). However, HSE legislation, in common with other safety legislation around the world, requires risk to be reduced So Far As Is Reasonably Practicable (SFAIRP) without any limit. ALARP needs to be consistent with SFAIRP so there is a requirement to continue to reduce the risk in the broadly acceptable zone as well as in the tolerable risk zone.

Reservoir Z is a particular case of a reservoir in the Unacceptable Risk Zone. Here the risk may be high because of a large community close to the reservoir rather than the condition of the dam. In practice it may be difficult or extremely costly to reduce the annual probability of failure of a dam much below 1×10^{-5} (point a). A solution to managing safety here might be to decommission the reservoir. However, such reservoirs often provide an essential service to society, for example providing a drinking water supply. If an alternative supply is not available and cannot reasonably be created, the loss of this service could have a greater impact on society than the risk of the reservoir. In these cases a more creative approach to managing the safety of the reservoir may be needed, such as increased monitoring and surveillance linked to a warning system that may enable the risk to be reduced by active management of the consequence in the downstream community. The risk of reservoir Z would then be moved to point b in figure 10.

In some cases a high consequence may be attributed to development that has taken place since the reservoir was built. It is important that processes are in place to ensure that local planning authorities consider all the risks that reservoir flooding poses to new development; and how new development may impact reservoir owners and the reservoirs they own and operate.

In the preceding paragraphs the consequence of a breach of a dam has been expressed in terms of the loss of life (individual or societal). For many reservoirs the threshold for individual risk (1×10^{-4}) will be the determining factor, rather than societal risk. Also, loss of life may not be the only appropriate means of quantifying consequence. Other factors such as the impact on critical infrastructure, local economy, the environment or cultural heritage might be important (see tables 4 and 5 for example).

When adopting a risk based approach it is important to understand that the probability of failure of a reservoir cannot be determined precisely and in most cases there will be significant uncertainty in its quantification. In the same way there will be uncertainty in determining ASLL. Thus assigning where a reservoir should be placed on the ALARP diagram (figure 10) cannot be precise. Equally, the reduction in risk due to measures implemented in the interests of safety cannot be precisely defined. There will, therefore, always be an element of professional judgement in interpreting the diagram and in demonstrating ALARP.

A qualitative approach to risk assessment will in general produce results in terms of high, medium or low risk for example, or as a score rather than a numerical value. In such cases an ALARP diagram will be needed that is also expressed in these terms. An example is given in figure 11 below.

Likelihood of downstream flooding	Potential magnitude of consequences given downstream flooding (ASLL)				
	Level 0	Level 1	Level 2	Level 3	Level 4
Extreme	ALARP	ALARP	ALARP	Unacceptable	Unacceptable
Very high	Tolerable	ALARP	ALARP	ALARP	Unacceptable
High	Tolerable	Tolerable	ALARP	ALARP	ALARP
Moderate	Tolerable	Tolerable	Tolerable	ALARP	ALARP
Low	Tolerable	Tolerable	Tolerable	Tolerable	ALARP
Very low	Tolerable	Tolerable	Tolerable	Tolerable	Tolerable

Figure 11. Variation on ALARP Societal Risk Diagram for Use with Qualitative Risk Assessment[4]

The key features and benefits of adopting a risk based approach to managing reservoir safety are summarised in table 7. What table 7 shows is that a risk-based approach can provide substantial benefits. A more systematic, detailed evaluation of potential failure modes will have a greater chance of successfully identifying weaknesses in a dam, allowing early intervention and reducing the likelihood of sudden and catastrophic failure. Potential drawbacks are minimal and are, in any case, to be found with the current approach. However, it should be recognised that, because of the additional effort needed, the full benefits of a move to a risk-based approach are unlikely to be realised within the time constraints currently imposed on reservoir inspections by some forms of contract.

Table 7. Key Features and Benefits of a Risk-Based Approach to Reservoir Safety Management

Features of risk-based approach	**Benefits of risk-based approach**
A systematic evaluation of all potential failure modes	Ensures a systematic evaluation of all potential failure modes. This contrasts with the current approach which applies existing guidance documents and thus analyses in detail floods, with an assessment of seismic loading and drawdown. Currently there may be insufficient consideration of stability and internal erosion.
A better understanding of dam detailing, material properties and gaps in knowledge.	Ensures that time is spent on understanding the details of a dam, its material properties and important gaps in knowledge.
Assessment of uncertainty and the impact that this may have on the output.	Moves assessment away from total reliance on visual assessment under normal loading conditions to include consideration of the potential impact of extreme loading conditions.
An objective estimate of the probability of failure	Enables investment to be spent on the elements (investigation and works) which will provide the greatest reduction in risk rather than on elements for which there are well-established criteria and methodology but may only result in a small reduction in risk.
Evaluation of the potential consequences of failure, in terms of potential loss of life and damage caused.	Allows the amount and detail of assessment to be balanced against the consequences (the principle of proportionality)
Assessment of the probability of failure and consequences against measures of tolerability.	Gives assurance that the level of risk is reduced to an appropriate level, justifies future investment and assures the owner of being duly diligent in managing the reservoir. Provides transparency of the process. Allows relative priorities for investment in reservoirs to be compared with other infrastructure or assets that the owner may be responsible for

Classification of Reservoirs

Only Large Raised Reservoirs (those with a capacity > 25000m^3) are currently regulated in England and of these, only those designated as high risk are subject to regular inspection and supervision under the Reservoirs Act 1975 as amended. The current legislation requires that a reservoir be designated as high risk unless it can be shown that it does not endanger life. This is a very precautionary approach and results in a wide range of risk across the large number of reservoirs designated as high risk. The additional expense of risk assessment may not be justified for a reservoir at the lower end of this range where the risk to life is small. Equally, a more thorough risk assessment can be justified for reservoirs towards the upper end. There is an argument, therefore, for categorising high risk reservoirs into classes for the purposes of safety management. In theory this should be based on the level of risk. An evaluation of the potential of a risk score for use in classifying reservoirs has been investigated by the Environment Agency[13] and it was concluded that a robust process could not be developed on the basis of the information that was readily available for a reservoir. Instead it was recommended that for the purpose of safety management it would be better to classify reservoirs by hazard (quantified by the consequence of an uncontrolled release of water).

This is not a new concept. At present, regulated reservoirs are divided into categories for the assessment of spillway capacity[1] and different categories for evaluating the potential effects of earthquakes. Other countries use their own categories for managing reservoir risk. For example, ANCOLD[25] categorises reservoirs on the basis of the population at risk from the reservoir (PAR) and the severity and damage or loss. It is important to note that, because of the variation in layout and topography of developed areas, there is not a strong correlation between PAR and LLOL as illustrated in figure 12.

Increasingly the likely loss of life (LLOL) informs categorisation, although other factors may also be considered, as explained previously. Possible endangerment of life has been used by the Environment Agency in determining the threshold for high risk reservoirs. In this case LLOL is defined by the Average Societal Loss of Life (ASLL). ASLL is the summation of the peak Fatality Rate multiplied by the Maximum Population at Risk (MPAR)[13] at each individual property and is usually expressed for one reservoir as the maximum of all tested breach locations. Since it is a statistical concept, it can be non-integer.

Categorising reservoirs by class based on LLOL (or ASLL) can be a useful way of accounting for the wide range of risk presented by high risk reservoirs in England. This is shown in figure 10 (for illustration only). Other factors such as the volume of water retained in the reservoir, or the height of the dam, have been proposed as a means of categorising reservoirs. However, these do not correlate well with ASLL as shown in figure 13. Loss of life based on ASLL is, therefore, likely to prove the most appropriate approach and should be the primary consideration when selecting the threshold between different classes of reservoir. Other factors such as the impact on the local economy, important infrastructure, the environment and cultural heritage should also be considered.

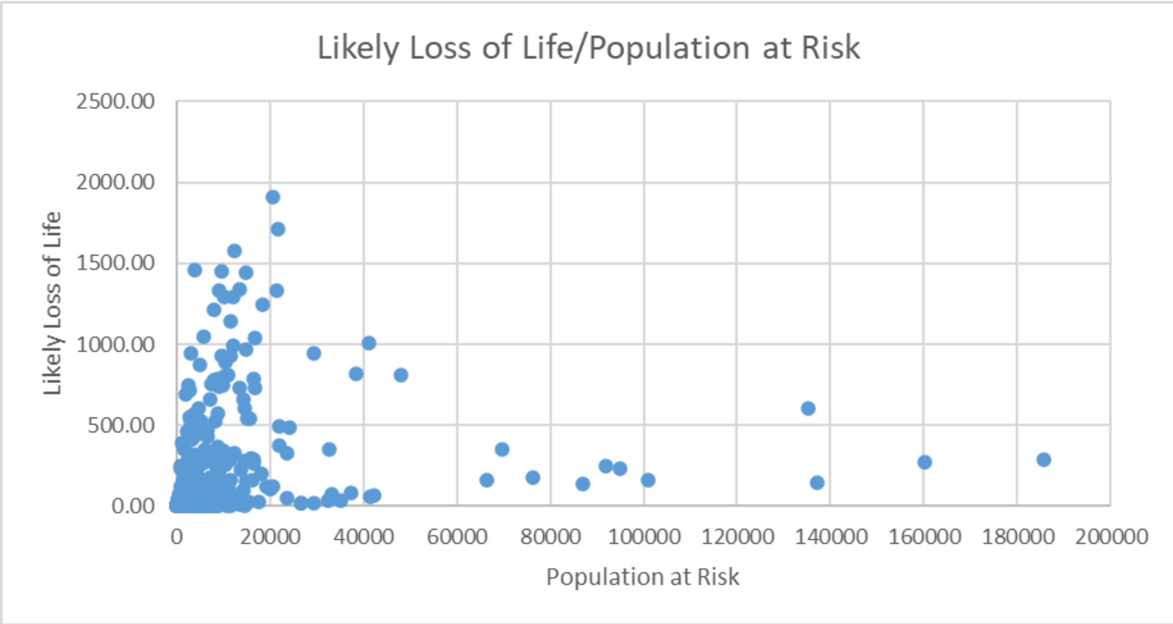
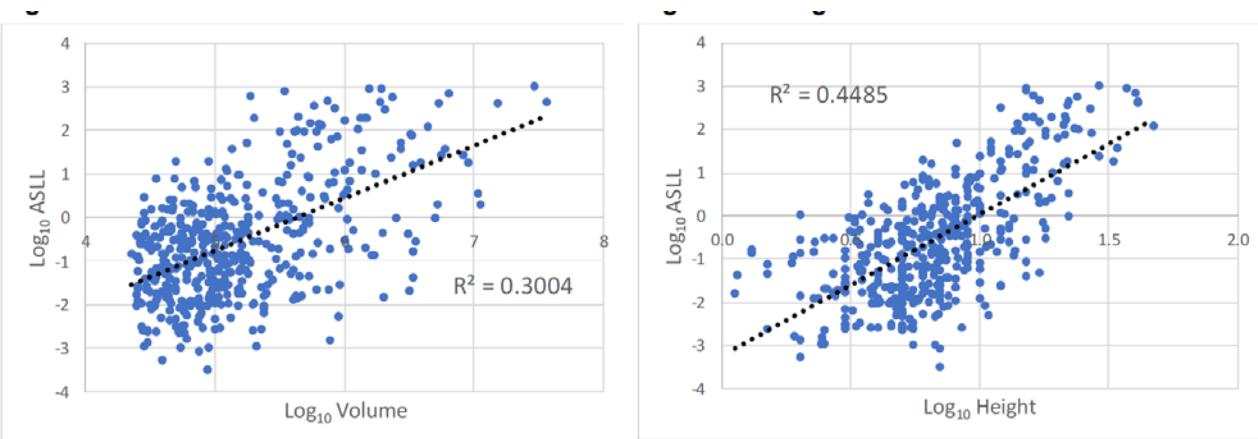


Figure 12. Variation of Likely Loss of Life with Population at Risk[13]



Source: Analysis by Mott MacDonald (2019) using RFM data provided by the EA (Environment Agency, 2019)

Source: Analysis by Mott MacDonald (2019) using RFM data provided by the EA (Environment Agency, 2019)

(a) (b)

Figure 13. Variation of ASLL with Reservoir Volume and Height of Dam[13]

It is therefore proposed that reservoir safety management of high risk reservoirs is based on three classes (the term “class” is used here to avoid confusion with the current categorisation of reservoirs which would now be superseded).

Class 3: Reservoirs at the lower end of the range of risk which, following an uncontrolled release of water, would be likely to result in a very low loss of life. These would require a level of supervision and inspection similar to that which exists at present.

Class 2: Reservoirs where the loss of life following an uncontrolled release of water would be significant but not large. In addition to current arrangements for supervision and inspection, a qualitative risk assessment would be required as a minimum along with the inspection.

Class 1: Reservoirs with a potential high loss of life following an uncontrolled release of water. Visits to the reservoir for supervision would be increased from the current minimum of 1 per annum to a minimum of 3 per annum, say, and the interval for periodic inspection would be set at a maximum of 5 years. A quantitative risk assessment would be required along with the inspection. In addition to the periodic inspection, a design safety review would be required every 20 years, involving one or more specialists in addition to the inspecting engineer.

The thresholds dividing one class from another should be based on the hazard posed by the reservoir as determined by the consequence of a breach of the dam. This also presents an opportunity for reviewing the base threshold that categorises a reservoir as high risk. The current criteria can result in some reservoirs that present an insignificant level of risk being included. It might be better to shift the effort in reservoir safety management and the regulatory burden more towards the reservoirs that create the greatest hazard. This could be even more relevant should Government decide to include raised reservoirs with a capacity between 10000m^3 and 25000m^3 within the regulations. The choice of thresholds will significantly affect how many reservoirs are categorised as high risk and then how many are placed in each of the three classes. Figure 14 illustrates the distribution of reservoir numbers by ASLL, and this can be used to assess the numbers of reservoirs in each class determined by different thresholds. Some examples are given in table 8.

Referring to table 8, an ASLL of 0.001, where only one person is involved, is a 0.1% chance of that person being killed in the event of a catastrophic failure. When this is combined with a probability of failure of 1 in 1000, say, it gives the probability of loss of life to an individual of 1 in 10^6. This is the threshold for broadly acceptable individual risk quoted in R2P2[11], and a threshold for designating high risk less than this could be considered to be over conservative in risk terms.

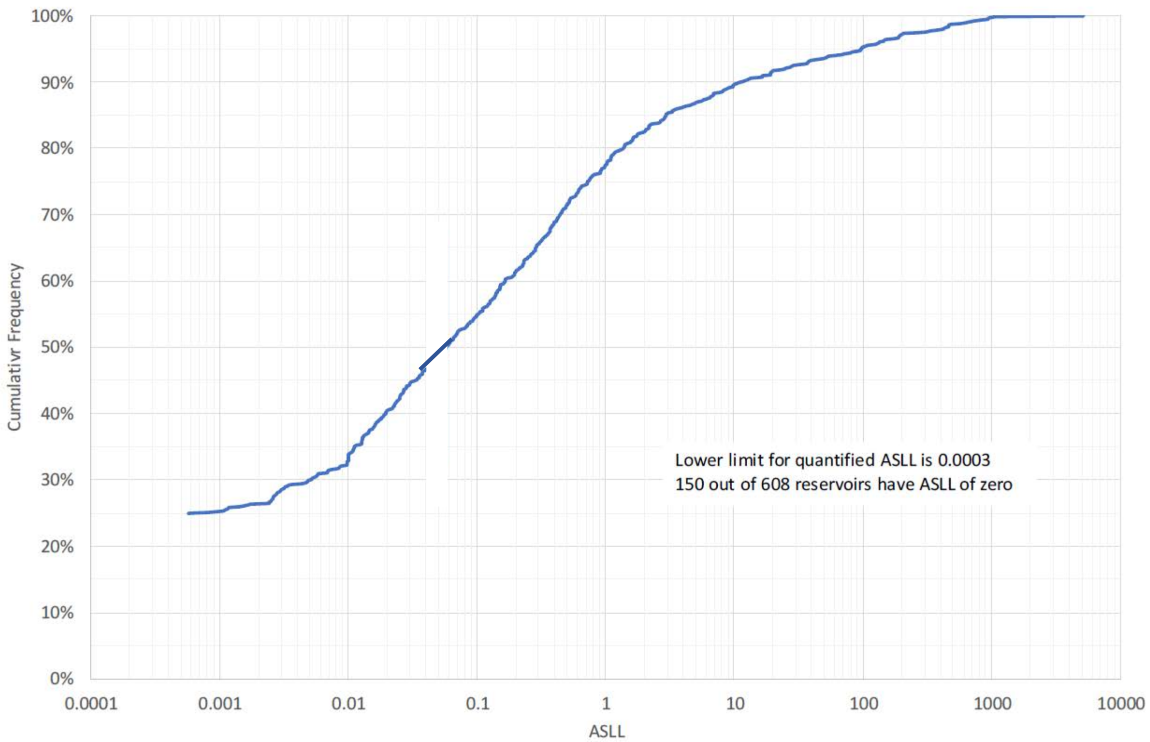


Figure 14. Variation of ASLL across the population of high-risk reservoirs in England[13].

Table 8. Examples of the Effect of Different ASLL Thresholds on the Number of Reservoirs in Each Class in England. Percentages refer to the reservoirs currently designated as high risk

ASLL Threshold for High Risk	% removed from high risk designation	ASLL Threshold Class 3 to Class 2	ASLL Threshold Class 2 to Class 1	% and approx. number in Class 3	% and approx. number in Class 2	% and approx. number in Class 1
Current	n/a	0.1	10	55%/1153	35%/733	10%/210
Current	n/a	1	100	77%/1613	18%/377	5%/105
0.001	25%	0.1	10	30%/629	35%/733	10%/210
0.001	25%	1	100	52%/1089	18%/377	5%/105
0.01	32%	0.1	10	23%/481	35%/733	10%/210
0.01	32%	1	100	45%/942	18%/377	5%/105

Should high risk small raised reservoirs (capacity between 10000m^3 and 25000m^3) be brought into regulation in England, the effect of different thresholds would be even more marked.

Regulation and legislation

At present the Environment Agency only has powers to monitor the completion of tasks and the issuing of reports and certificates and to intervene in the event of non-compliance or an emergency. The Regulator's powers fall short of those available to other infrastructure regulators in the UK. They would need additional duties and powers to intervene should surveillance or monitoring not be properly specified or implemented or a risk assessment not completed to the necessary quality and detail for example. They would also need additional duties and powers to technically review engineer's reports and to spot check or undertake their own inspections or supervisory tasks. Such powers are needed in the reservoir sector if the changes set out above are to be successfully and consistently implemented.

Summary

The current system for managing reservoir safety has become over reliant on compliance at the expense of ensuring due diligence in managing safety. A different emphasis is now needed to adequately protect the public. In this section three specific proposals are made to bring about this change:

- To improve and extend the statutory requirements for surveillance, monitoring, operation and maintenance through the development and execution of Reservoir Safety Management Plans (RSMPs) approved annually by the Supervising Engineer and reviewed by the Regulator,

- To enhance the inspection process and, for higher risk reservoirs, to require a risk assessment such that measures required in the interest of safety can be shown to reduce risk to as low as reasonably practicable (ALARP). The risk assessment would take into account the level and frequency of surveillance, monitoring, operation and maintenance certified in the RSMP.

- To amend the legislation to give additional duties and powers to the Regulator to enable them to review and if necessary intervene to ensure that the improved approach set out above is properly and consistently implemented.

A risk based approach of the type set out above deals explicitly with the basic question of how safe is safe. It sets out a structured and transparent process for ensuring that owners fulfil their obligation to manage the risks that their reservoirs pose to be a low as is reasonably practicable. Some reservoir owners have already implemented such a regime.

If the threshold for designating high risk reservoirs remains unchanged, the effect of classifying high risk reservoirs is minimal for class 3 reservoirs, which are likely to be a significant proportion of the current high risk reservoirs (see table 8). For class 1 and 2 reservoirs, there will be an increase in effort and cost needed for the risk assessment process. Research has showed that the costs of this are likely to be offset by the benefits realised[13]. However, if the threshold for designating reservoirs as high risk is changed to better reflect risk, then the regulatory burden will remain similar to the current situation overall (because some reservoirs previously designated as high risk would cease to be regulated) but rebalanced towards reservoirs presenting higher risk. Should Small Raised Reservoirs (10000m^3 to 25000m^3) be brought into regulation it is likely that fewer would be classified as high risk, thus avoiding an additional regulatory burden with little resulting benefit.

In my previous report I recommended that, as part of the periodic inspection process, the potential of issuing a certificate of safe to operate should be explored. I do not consider this to be appropriate. The concept does not adequately deal with the question of how safe is safe. Nor does a certificate issued once every ten years, say, deal with the essential safety elements of surveillance, monitoring, maintenance and operation. The process set out above provides a much more robust approach to managing the safety of our reservoirs.

Without the changes set out above the gap between compliance and safety is unlikely to be reduced to a level that will reassure the public about the safety of our reservoirs. Closing the gap between compliance and safety would justify a modest increase in the regulatory burden if necessary. At the same time it would bring reservoir safety management more in line with Health and Safety legislation, and comparable with other high risk infrastructure sectors.

7. Potential impact of climate change

Increased precipitation and floods

High precipitation and the consequential floods are a major threat to reservoirs as the overtopping of a dam can lead to a breach and an uncontrolled release of water. Dams are protected from this by their spillways, and it is important that these are designed to both convey flood flows and withstand the structural load under flood conditions. For the highest hazard reservoirs the spillway must currently pass the Probable Maximum Flood (PMF) without causing a breach of the dam, and for other lower hazard reservoirs lesser floods are adopted as the standard.

Faulkner and Benn identified several issues with the current methods of estimating flood flows for the design and management of reservoir spillways[29]. Estimates of probable maximum precipitation (PMP) on which the values of PMF are currently based use rather dated methods and data sets such that the values produced may not be representative of the current climate. The PMF has been exceeded on several occasions by as much as 19%[30].

The statistical methods used to extrapolate extreme values assume a stationary climate when the evidence of the increasing occurrence of widespread heavy daily rainfall across the UK in the last few decades (Figure 15, left panel) indicates that the climate is not stationary. Similarly, the statistics on local extreme daily rainfall (Figure 15, right panel) also suggest an increasing occurrence, although the gauge network used here is not ideally suited to detect localised events.

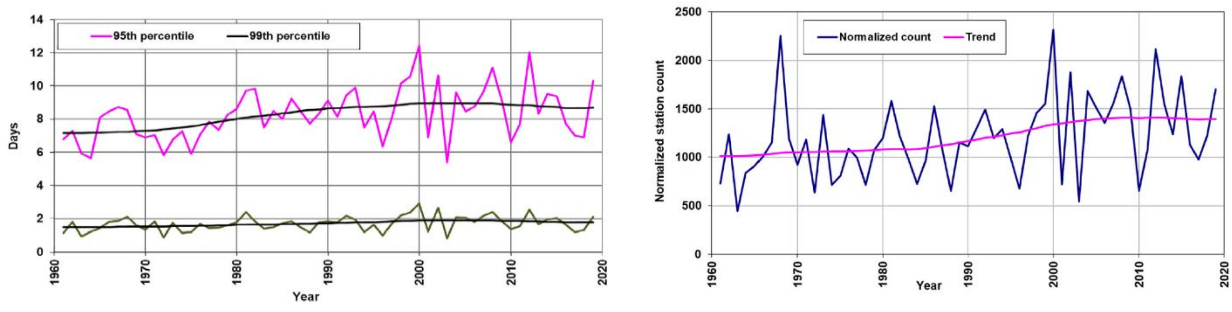


Figure 15: Two metrics for detecting changes in extreme rainfall over the UK. Left panel: Number of days per year where UK area-averaged rainfall exceeds the 95th (9.5mm) and 99th (13.9mm) percentile, where the percentiles represent the 50-year period, 1961-2010. By definition the 95th and 99th percentiles should be exceeded on 18 and 3-4 days respectively each year. This metric focuses on widespread heavy rainfall typically associated with major autumn and winter storms. Right panel: Annual count of the number of station-days which have recorded daily rainfall totals greater than or equal to 50mm. As well as major storms this metric also picks up localised extreme events that lead to flash flooding[31].

Moreover, current methods do not allow assessment for future climate change over the projected life of a spillway.

In 2016, the National Flood Resilience Review[32] asked the Met Office to develop new plausible extreme rainfall scenarios. Rather than relying solely on observed rainfall they applied a new methodology known as UNSEEN (UNprecedented Simulation of Extremes with Ensembles). UNSEEN used multiple scenarios of computer-generated weather to provide the base data for estimating extremes. Because it can generate a much larger data set, and also because it allows for climate change experienced so far in the UK, it does not have the limitations of earlier methods. It provides better estimates of the tails of the observed events for the current climate and the bounds on what is meteorologically plausible in terms of extreme events. When compared with recent observed extreme events it showed that there is a 1% risk every year of regional, monthly rainfall in winter being 20% to 30% above previously observed values, due just to the natural variability of the UK's climate. The use of synthetic event sets based on simulation has the potential to provide more robust estimates of tail-end risks, although estimating 1 in 10000 (or 0.01%) probabilities will still be out of reach. It also enables correlated and clustered events to be studied. These can be used in conjunction with observation-based estimates of PMP to stress test reservoir design.

In the autumn of 2020 the Environment Agency commissioned a new project which aims to assess the suitability of existing methods for estimating PMP and PMF, and develop new methods and guidelines to ensure that we understand the risk posed to our highest hazard reservoirs from extreme flood events[33]. The project has two phases. The first phase aims to review options for alternative approaches to PMP and PMF estimation and recommend a way forward for development and implementation in phase 2. Phase 1 is currently ongoing and will take around 12 months to complete. This project provides an important opportunity to address the current deficiencies of estimating extreme event flood values for use in spillway design and operation.

It is important that this research addresses the deficiencies of the current methods of estimating extreme flood events at reservoirs and builds on the recent developments from the new methodologies developed by the Met Office and the latest UKCP18 projections.

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1. Faulkner D and Benn J, "*Reservoir Flood Estimation. The Way Ahead*", Dams and Reservoirs, ICE, Nov 2019.

2. Stewart EJ, Jones DA, Svensson C, et al. " *Reservoir Safety – Long Return Period Rainfall*", Report WS 194/2/39/TR, Defra, London, 2013

3. Kendon M et al, "*State of the Climate 2019*", Met Office, 2019

4. National Flood Resilience Review, HM Government, Sept 2016

5. Improving Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF) estimation for reservoir safety, Environment Agency, 2020

These include information at the kilometre scale and hence the catchment scale of the reservoir (the CCRA3 which will be published shortly provides new evidence of more extreme changes in rainfall, especially in winter). In particular it needs to provide robust estimates of the frequency of different flood events for current and future climates in a form that can be used in reservoir risk assessment.

It cannot be said with any degree of certainty what the impact of climate change might be until this work is completed. An uplift in PMF may not necessarily result in a need to increase spillway capacity provided that at a particular reservoir it can be shown that the risk is both tolerable and as low as reasonably practicable (ALARP). However, it is possible that if there is a significant uplift to the PMF and/or the 1 in 10000 year flood then additional investment will be needed to improve the spillway capacity at a number of reservoirs.

Storminess and wind speeds

Storms are an important climate impact driver for the UK and there has been considerable debate on whether storminess is increasing. A comprehensive review of the evidence[32] concluded that there is, as yet, no clear evidence for increased storminess. Wind gusts over 40 knots in the latter part of the 20th century have been noted but with a decline thereafter. Nevertheless, more research is needed to address this important question for the UK since increased wind speed could cause overtopping of existing wave walls at dams. There appears to be no need, therefore, to amend current guidelines for estimating wind speeds at reservoirs at this time, but this should be kept under review.

Slope stability

Increased wet weather leads to increased ground wetness and this, in turn, can affect the stability of embankments. This is important for earth embankment dams and is a reason why routine surveillance and maintenance is so important in ensuring their safety. Recommendations are made elsewhere in this report on these matters. In addition, increased ground wetness can affect the stability of slopes around the perimeter of a reservoir, and whilst this is likely to pose less of a risk it should nevertheless be something that reservoir engineers are aware of.

Drought

Current assessments of the likely effects of climate change on periods of drought indicate a future increase in duration and occurrence, largely during the summer months. The rate of change is still uncertain, but we will likely see a growing need for reservoir storage to supplement existing supplies for domestic and industrial water use and irrigation. The number of reservoirs is likely to increase, and existing reservoirs may remain drawn down for longer periods and/or be subject to more frequent filling and emptying cycles. This may affect the integrity or stability of some reservoir structures, and reservoir engineers and surveillance personal will need to be vigilant in identifying and evaluating these effects. As frequent droughts may lead to the construction of more reservoirs, there could be additional demands on Supervising and Inspecting Engineers, and on the Regulator.

Flood storage

A further impact of increased extreme precipitation will be the increased frequency of extreme river flows leading potentially to an increased demand for flood risk management measures. Thus, an increase in the number of flood storage reservoirs can be anticipated.

It has been suggested that some of that storage could be provided by lowering water levels in existing water resource reservoirs. This could create problems similar to the effects described in the preceding section on drought. It would need to be carefully evaluated and supported by appropriate surveillance and monitoring should it be implemented at any reservoir. Its benefit would also have to be assessed against the penalty of losing water resource capacity.

Summary

It appears that adequate research is in hand to re-evaluate flood estimates for reservoir safety evaluation taking account of climate change. It will be important for future research and guidance to also consider the wider impacts of climate change such as the impact of hotter summers on structures and embankment fill materials. Climate change will also impact reservoir operation and it is important that the reservoir industry adapts not only to increasing demands for water but also to an increasing frequency in surplus/deficit in raw water supply.

It has been suggested that water supply reservoirs might be adapted for flood storage in the future. Assessing the practicalities of this is not part of this Review. However, should this progress, any safety issues would have to be properly evaluated and a suitable process developed for their management.

8. Summary of findings and recommendations

The Environment Agency estimates that over 2.4m people in England are at risk from 2095 large raised reservoirs, most of which are currently designated as high risk. They present one of the largest threats to human life and property of any infrastructure sector in the UK. The failure of a dam can lead to a sudden and large release of water which would be difficulty for the population affected to envisage. The Toddbrook Reservoir incident in 2019 could have ended in disaster. Had the dam breached, and had this occurred at night and without warning, there would likely have been a significant loss of life.

Dams are quite benign structures. However, they can come under stress as a result of extreme events such as floods and earthquakes. Their safety is assured through effective design and construction in the first place. Following that, good surveillance, monitoring, operation, maintenance and periodic inspection is what assures ongoing safety. This helps to manage the inevitable deterioration with age and identify any potential defects early. Since the introduction of reservoir legislation there has been no loss of life as a result of an uncontrolled release of water from a reservoir. However, to rely on that on its own as a measure of the safety of our reservoir stock would be unwise.

Given the hazard posed by our reservoirs, it might reasonably be assumed that the process used to assure their safety, and the legislation that underpins it, is regularly reviewed. That is not the case. Over history, the development of reservoir safety in the UK has been driven by reservoir incidents, Dolgarrog and Skelmorlie in 1925, Ulley in 2007 and Toddbrook in 2019. Relying on incidents to drive change is also unwise. In Part A of my Review I recommended that the Secretary of State undertakes a regular periodic review of reservoir safety, as allowed for in current legislation. This report provides the latest of these, but it should not be the last.

The key findings of my Review are:

- The evidence collected reinforces the findings set out in my earlier report on the Toddbrook Reservoir incident.
- At present reservoir safety management in the UK does not sufficiently account for the wide variation in the hazards that reservoirs create.
- Many owners fully understand their responsibility for the safety of their reservoir and are proactive in safety management. Others take a more reactive approach in response to periodic inspections of their reservoir but do little else beyond that.
- The current process of assuring reservoir safety is well understood by the various parties and there is high compliance with current reservoir legislation and the associated regulations. However, Health and Safety legislation also applies to reservoirs and whilst some reservoir owners understand this and manage their reservoirs accordingly, there will be many others that do not.

- At too many reservoirs there are examples of incomplete maintenance and inadequate surveillance which are essential elements of reservoir safety.
- The process for assuring the safety of reservoirs relies heavily on qualified reservoir engineers. At present there is too much variability in the quality and content of their reports which reduces confidence in the inspection and supervision process. The process of ensuring the competence of reservoir engineers at the time of their appointment to Panels is well established but there are important areas that need improvement.
- The current supply of reservoir engineers, especially of Inspecting Engineers, is insufficient to meet likely future demand. This has been a long standing problem. There is a real danger that the current system for managing reservoir safety could break down in the future if a sufficient supply of reservoir engineers cannot be maintained.
- Unlike other infrastructure sectors, reservoir safety is not always managed on the basis of risk. Unacceptable, tolerable and broadly acceptable risk, along with reducing risk so far as is reasonably practicable, are important principles in ensuring the public are adequately protected. They are not universally or systematically applied to reservoirs in the UK, though there are good examples amongst the UK owners of portfolios of reservoirs where they are used to manage reservoir safety and prioritise investment.
- An effective Regulator is essential for any high risk infrastructure sector. Appropriate legislation and regulations are needed if a Regulator is to give the necessary assurance that the procedures and practices that assure safety are properly implemented. The last major revision of UK reservoir legislation was in 1975 (subsequent amendments being made in 2003 and 2010). Updating and implementing reservoir legislation to align it with good practice in other sectors is now well overdue.
- Climate change is likely to have a significant impact on reservoir safety, in particular regarding the capacity of reservoir spillways and the stability of earth embankment dams.

These findings are covered in more detail in the following sections, and appropriate recommendations are made to address the issues identified.

The principle of proportionality

All reservoirs currently designated as “high risk" are subject to the same periodic supervision and inspection by qualified reservoir engineers. The current threshold that is used to designate “high risk” is set relatively low and results in a considerable range of hazard posed by high risk reservoirs. It is not appropriate for the safety at all high risk reservoirs to be managed in the same way. The principle of proportionality should apply, with greater effort (and investment) in reservoirs at the higher end of the hazard range and less at the lower end.

Dividing high risk reservoirs into different classes of hazard would be an appropriate way of achieving this. At the same time Government should review the current threshold for designating high risk reservoirs to determine if a threshold based on risk (as determined by the hazard) would be more appropriate (see section 6).

RECOMMENDATION 1. High risk reservoirs should be divided into three classes depending on the hazard created by the reservoir.

a) **The degree of effort and detail required in reservoir safety management should depend on the Class.** Reservoirs in the lowest of the classes of hazard (3) should be subjected to the same regime of inspection and supervision by qualified reservoir engineers that exists at present. Higher hazard reservoirs should be progressively subject to a more detailed approach. For reservoirs in the highest hazard class (1), the maximum period between inspections should be reduced to 5 years and a detailed Design Review undertaken every 20 years.

b) **The threshold between classes should be determined by the Environment Agency, in consultation with Defra, the ICE and the BDS**. As hazard changes over time, the thresholds that determine the different classes should be kept under review.

c) **Government should review the current threshold for designating high risk reservoirs.** They should determine if a threshold based on risk (hazard) would be more appropriate in the light of other recommendations in this report that recommend a risk based approach for managing reservoir safety.

The owner

There are excellent examples where owners take a proactive approach to reservoir safety management. However, there are too many cases where owners are not proactive, relying largely on statutory requirements from inspecting engineers at their ten yearly inspections, or a specific direction from their Supervising Engineers. Some reservoir owners appear not to allocate sufficient resources to the safety management of their reservoirs. Some may be unable or unwilling to do so. Maintenance often does not get completed and in some cases not done at all.

In other infrastructure sectors an owner's duties are formally set out and include a requirement to have approved plans in place covering surveillance, monitoring, operation, maintenance, periodic inspections and condition assessment of their assets. Evidence has to be provided to the Regulator that the various requirements of these plans are duly completed by the owner in a timely manner. As this requirement is normally covered by legislation, failure to comply is a criminal offence and can lead to penalties or prosecution. Owners also have to demonstrate that they are competent to operate their assets, have appropriately trained staff in place to deliver their obligations and have the capacity and capability to fulfil their duties. There are no such requirements within current reservoir legislation in the UK.

The Office of Road and Rail have developed a useful framework for working in partnership with their permit holders (operators) to evaluate and develop their competence, and lessons can be learnt from this for the reservoir sector. Also, a number of large owners of reservoirs have developed internal training and development programmes for their operational staff and these should form a suitable model for wider application in the sector. Natural Resources Wales are currently identifying ways of incentivising owners through a variable system of charging.

RECOMMENDATION 2:

a) **The Environment Agency should make owners fully aware of their duties and responsibilities.** This should include the need to exercise due diligence and to respond to the directions of reservoir engineers in a comprehensive and timely manner

b) **The Environment Agency should work with the owner to help develop their capability and that of their operational staff and to foster continuous improvement to their reservoir(s).** The expected capability should depend on the reservoir hazard (class).

c) **The Environment Agency should have the powers to charge owners for their regulatory services and to do this in a way that incentivises responsible behaviour.** Charges should reflect the amount of effort that is needed to regulate the reservoir(s). See also recommendation 11.

d) **The Environment Agency should establish a procedure for managing and adjudicating any disputes with an owner and resolving them.** This should replace the current system that allows owners to appeal inspection reports.

Good and regular maintenance is essential to preserve the safety of reservoirs. Yet there is ample evidence to demonstrate that this is not always completed in a timely manner. Equally, good surveillance and monitoring can detect early deterioration of dams and other reservoir structures so that remedial measures can be implemented before a failure occurs. It is a key duty for owners to undertake effective surveillance, monitoring, operation and maintenance of their reservoirs.

RECOMMENDATION 3. Owners should adopt a systematic and well documented approach to reservoir safety management and this should be approved annually:

a) **The reservoir owner (undertaker) should prepare and implement a Reservoir Safety Management Plan (RSMP). The extent of the plan should reflect the classification of the reservoir.** The plan should detail all the necessary surveillance, monitoring, operation, maintenance and periodic inspections required at the reservoir, as set out in section 6 of this report, and include a log of all activities to demonstrate that the plan is being effectively delivered. The RSMP should also include, in an appendix, all available details of construction and alteration of the reservoir, copies of reports of periodic inspections by Supervising and Inspecting Engineers, and certificates to demonstrate that the requirements of Supervising and Inspecting Engineers have been complied with.

b) **The RSMP should be kept as part of the Prescribed Form of Record and the requirements of that Record should be amended to accommodate this and avoid duplication.**

c) **The Supervising Engineer should review and approve the RSMP annually and certify that the owner's actions have been carried out in accordance with the Plan**. Approved and certified RSMPs should be submitted annually by the owner to the Regulator.

d) **The Owner should ensure that all personnel with responsibility for delivering the RSMP are appropriately competent to do so**. For reservoirs in classes 1 and 2 this should include an appropriate means of certifying their competence.

e) **The Environment Agency should produce guidance for owners for the production and delivery of RSMPs, including exemplars for the different classes of reservoir.** Implementation of these recommendations should recognise that a number of owners already meet many of the requirements of RSMPs and this should not, therefore, impose an undue burden on them.

Reservoir engineers

Appropriately qualified engineers are central to the safety management of reservoirs. Whilst legislation, rules and regulations can provide a suitable framework, and instrumentation and data can provide a useful evidence base, there is no substitute for the analytical ability and professional judgement of an experienced engineer[13]. Even though reservoir engineers may be employed or appointed by a particular body or organisation, their work should always be objective and delivered in an impartial manner in the wider interests of society. They should be appropriately qualified in the first place but keep their knowledge up to date by continued learning. Periodic assessment should assure their ongoing competence.

The owner's primary source of professional advice is from their Supervising Engineer. The Supervising Engineer is required to provide a statement each year to the owner on the safety of the reservoir. They are also required to visit the reservoir at least once a year and review its condition. Supervising Engineers have to be available at any time to support the responsibilities of the owner. However, it is clear from this Review that the effectiveness of this process is variable, and in too many cases essential maintenance and surveillance is not being completed in a timely manner. It is also not clear if Supervising Engineers always engage fully with operational and surveillance personnel or adequately review records and data. There is a good case, therefore, to reinforce the whole process of day to day surveillance, monitoring, operation and maintenance of reservoirs and how this is reviewed and reported.

RECOMMENDATION 4. Supervising Engineers should be fully engaged in assuring the day to day surveillance, operation and maintenance of the reservoirs that they supervise:

a) **As part of their routine visits to a reservoir, Supervising Engineers should fully engage with surveillance and operational staff, review the records demonstrating tasks completed and verify that the RSMP is being delivered as planned. These are in addition to their existing duties.** Where instrumentation records are being taken, the Supervising Engineer's reports should include a copy of the results, ideally in graphical form, together with a commentary explaining how they demonstrate that the reservoir's behavior is remaining within safe limits. They should discuss any recommendations with the reservoir owner and where necessary give directions for improvement.

b) **Each year the Supervising Engineer should formally certify compliance with the RSMP as part of the annual statement and approve the RSMP for the following year**. The Environment Agency should be able to review the annual statements of Supervising Engineers and RSMPs and to challenge them (see recommendation 11).

There is evidence from this Review to demonstrate that the work of many Inspecting Engineers is of high quality but that in some cases the standard of reporting falls below the level that should be expected. Some reservoir owners find inspection reports impenetrable. At times they find it difficult to understand the reasons behind the remedial measures required or the evidence that supports them. Not all reports cover the items required by legislation or recommended by industry guidance. Where requirements are made, they are sometimes not underpinned by evidence or analysis. This makes it difficult for an owner to understand the benefits the requirements will bring or how effective they will be when implemented.

RECOMMENDATION 5. The Periodic Inspection of Reservoirs by Inspecting Engineers should be systematic, detailed and impartial, and their findings and requirements communicated in a clear and evidence-based manner:

a) **As part of their inspection of a reservoir, Inspecting Engineers should identify all the potential failure modes of the dam and other reservoir structures.** They should determine the significance and credibility of each of these and then evaluate each to understand the overall likelihood of failure. On the basis of this they should require any measures in the interest of safety (MIOS) or amendments to the RSMP.

b) **Where an Inspecting Engineer considers that further investigations are needed, an interim report should be issued together with any associated MIOS or precautionary measures pending the completion of the investigation and the issuing of a final report and requirements for further measures, where required.**

c) **For class 1 and 2 reservoirs, Inspecting Engineers should undertake or update, as necessary, a risk assessment for the reservoir (see recommendations 1 and 10).** Where MIOS are required as a result of a risk assessment, these should be specified so as to reduce risk to ALARP, and evidence should be provided to demonstrate that.

d) **Appropriate and clearly defined timescales should be attached to each MIOS depending on the urgency of implementation.** In assessing the condition of the reservoir, the Inspecting Engineer should not rely on visual observations alone, but should make use of the data and information collected during routine surveillance activities, previous reports from Inspecting and Supervising Engineers and records of the reservoir's design and construction. In any report they should express their findings, recommendations and requirements in a clear and evidence-based manner.

e) **Where precautionary measures may compromise the beneficial use of a reservoir, their implementation should be determined on the basis of managing the risk to be ALARP.**

The Regulator should review inspection reports and be able to challenge them (see recommendation 13).

In the interests of independence, Inspecting Engineers should not undertake inspections at reservoirs where they are the Supervising Engineer.

Not all MIOS may have the same degree of urgency. As recommended in my earlier report, Inspecting Engineers should be clear on which MIOS may be urgent and which may be delivered later. It has been suggested that when the MIOS are required then as well as completion dates, start dates should also be of MIOS. In practice that would require a definition of what is meant by “start”. It might be better to seek an early appointment of a Qualified Civil Engineer (QCE) to oversee the works to assist the owner in the timely delivery. In any case all dates should be qualified as the last date with an additional requirement to complete as soon as reasonably practicable. Amendments to the RSMP should also specify the implementation date with the additional requirement of as soon as is reasonably practicable.

RECOMMENDATION 6.

a) **Any MIOS that is urgent should be clearly and unambiguously indicated as such in the Inspecting Engineers Report and an appropriate completion date specified.**

b) **For urgent MIOS the Owner should ensure that a Qualified Civil Engineer (Construction Engineer) is appointed to oversee their implementation as soon as practicable but no later than 14 days from the issue of the IE’s report.**

c) **Urgent MIOS should be completed as soon as practicable and a certificate issued by the QCE not later than the specified completion date.**

d) **The certificate issued on completion of MIOS should provide details of the measures certified.**

e) **Required amendments to the RSMP should include dates by which each amendment should be implemented. The RSMP should be updated with the amendments within 14 days of issue of the IE’s report and their implementation reviewed by the SE immediately as soon as practicable after the specified date of implementation and thereafter during their regular visits.**

The number of qualified reservoir engineers has been dropping in recent years whilst the number of regulated reservoirs is growing. This is especially a problem with the number of Inspecting Engineers. The current trend is likely to result in the assurance of reservoir safety becoming unsustainable in the long term. This has been recognised for some time but action taken to date has made no substantial difference. A new and perhaps more radical approach is urgently needed. In progressing this it might be useful to note that whilst measures to address the gender balance and ethnic mix in other branches of engineering are bearing fruit, no appreciable progress seems to have been made in the reservoir sector.

RECOMMENDATION 7. Defra and the Environment Agency, working with their counterparts in the other administrations of the UK, owners and employers should commission the ICE to undertake a thorough review of the supply and development of supervising and inspecting engineers to ensure future supply. This should include the technical and professional requirements, the value of the sector to the employers' business, and the commercial models and practices for procurement. In particular the attractiveness of this branch of the profession should be compared with other sectors where recruitment is not so much of a challenge.

Part of the challenge of ensuring a sufficient supply of reservoir engineers in the future is to ensure effective career progression between Supervising and Inspecting Engineer. The progression here is seen by many as too much of a hurdle, and for those who do decide to progress, the process can be uncertain, often requiring several applications to be successful. This is defended by some as being a necessary means of protecting standards. Yet there is no logical reason why progression should not be smoother. A more staged form of progression, properly supported with mentoring and effective training, is likely to make the process far less daunting for the candidates without any impact on standards.

RECOMMENDATION 8. The ICE Reservoirs Committee should review the attributes of reservoir engineers to ensure that they appropriately match the role that they play and foster smoother career progression without dropping standards.

a) **The Reservoirs Committee should review the designation of Reservoir Panels to ensure that they are appropriate for future needs**. **In particular they should consider if a single set of attributes is appropriate for the inspection of reservoirs with different levels of hazard.** For example, it may be appropriate for engineers qualified to inspect lower hazard reservoirs of certain types of construction to have less experience and attributes compared with those qualified to inspect higher hazard reservoirs or reservoirs of more complex construction. Likewise, the inspection of extremely high hazard reservoirs may require greater experience/attributes. There may also be an argument for not requiring construction experience for all Inspecting Engineers, though this should be retained for engineers qualified to oversee and certify construction or alteration of a reservoir and other changes to reservoir structures, or measures in the interests of safety requiring construction works.

b) **The ICE should review the process for supporting prospective candidates for Supervising and Inspecting Engineers through comprehensive training, mentoring and guidance.** The potential to introduce probationary periods for newly qualified Inspecting and Supervising Engineers should also be considered.

The failure of the spillway at Ulley Reservoir, Sheffield, in 2007 demonstrates the vulnerability of dams during extreme events. A similar failure occurred to the spillway at Oroville Reservoir in the USA in 2017. In both cases this impacted on large numbers of people in the downstream area. An understandable question during my Review has been whether the lessons from these events had been sufficiently well learnt and why the incident at Toddbrook was not avoided. Any effective profession relies on the continued learning and development of its members. This is a responsibility of both the individual and the profession as a whole. There are some examples of good practice of knowledge sharing across the reservoirs profession largely driven by the Environment Agency as Regulator, the BDS and the ICE. However, at times this can be rather fragmented and there are some notable gaps. One area where professional practice should improve is through learning lessons from incidents and near misses. Whilst there is a statutory system for reporting reservoir incidents in the UK, appropriate lessons are not always learnt from this. There are examples of better practices in other infrastructure sectors from which the reservoir sector should learn. Also, reservoir engineers are not always able to learn from international incidents and there is an opportunity for BDS to increase its efforts here. Overall stronger leadership in this area from the Environment Agency would help coordinate efforts and reduce fragmentation.

RECOMMENDATION 9. The Environment Agency, working with Defra and their respective counterparts in Wales, Scotland and Northern Ireland, should work with the ICE and others to improve the capacity and capability of reservoir engineers through better knowledge sharing, better incident reporting and improved guidance:

a) **The Environment Agency should work with the ICE, BDS, CIRIA, ICOLD and others to ensure that all reservoir engineers have better access to national and international learning as it develops.** This should be achieved through promoting conferences, seminars and meetings which can be attended by all reservoir engineers in a convenient and affordable way. More attention should be placed on the continued learning and development of reservoir engineers and their personal contribution to knowledge before their initial application and at the time they apply for reappointment.

b) **The Environment Agency, in consultation with Defra, should review the incident reporting framework and report content, and work with owners to draw out more comprehensive lessons in a timely manner.** This will ensure that incidents are brought to the attention of reservoir engineers without delay and that lessons learnt from any subsequent investigations are shared in a timely and comprehensive manner.

c) **The Environment Agency should review the definitions in the reporting framework to allow for the reporting of near misses and for anonymous reporting**. In doing this they should review how this is done in other infrastructure sectors.

d) **The Environment Agency should work with the ICE to comprehensively update guidance on reservoir supervision, reservoir inspections and risk assessments.** Appropriate, pro-formas should be produced as part of the guidance with the aim of assuring that reports are consistent and complete. However, pro-formas should avoid being over prescriptive so as not to encourage a ‘tick box’ approach. Ultimately the safety of reservoirs is best assured by the expert judgement of the professionals involved.

e) In the event of new legislation or regulations, Defra should commission the ICE to update its guidance to the Reservoirs Acts.

Risk

Whilst there are good examples of risk-based approaches to the management of safety in the reservoir sector, they are not universally adopted. Risk based approaches to safety management are common in other UK infrastructure, based around the Health and Safety at Work Act 1974, and supported by appropriate legislation and regulations. Despite the Floods and Water Management Act 2010, reservoir legislation and the associated regulations in England and Wales have not kept pace with this change. Current reservoir legislation does not require a risk-based approach to reservoir safety management and as a result the public cannot be assured that the risk that reservoirs present is being appropriately managed, either collectively or individually. Current reservoir legislation does not encourage reservoir owners to be proactive in managing risk or reservoir engineers to adopt a risk based approach to their work. As demonstrated earlier in this report, the result is that a reservoir can be compliant with reservoir legislation without necessarily being safe.

Measures implemented as a result of a risk assessment should be such as to ensure that reservoir risk is reduced to at least a tolerable level and to be as low as is reasonably practicable. Occasionally the consequence of a breach of a dam may be so great, for example where a reservoir is situated upstream of a large urban area, that it proves impracticable to reduce the probability of failure to a level where the risk is tolerable. In such cases it may be possible to actively manage the consequence in the event of an incident through a well implemented and rehearsed warning system and evacuation strategy, so that the risk becomes tolerable. This would require the owner to work with other authorities, and in particular the Local Resilience Forum, to achieve this end. Warning and evacuation protocols have been successfully implemented in other industries and at reservoirs in other parts of the world. Alternatively, it may be possible to reduce the risk to a tolerable level by reducing the volume retained in the reservoir. If neither proves possible the reservoir should be decommissioned.

RECOMMENDATION 10. Class 1 and 2 high risk reservoirs should be managed and operated on the basis of risk, to ensure their ongoing safety.

a) **Reservoir owners should manage the safety of these reservoir(s) by ensuring the risks that they pose are managed to be as low as is reasonably practicable (ALARP).** The assessment of risk should include a quantification of the probability of failure of the dam and other significant reservoir structures, based on an appropriate assessment of potential failure mechanisms, the consequences arising from an uncontrolled release of water on the area downstream of the reservoir, and the effectiveness of the RSMP. It should also take the owners competence into account.

b) **The risk assessment should be based on recognised good practice.** The Environment Agency should give guidance to owners on the appropriate approach to risk assessment, which should include an assessment of uncertainty. However, it should recognise that some owners already have robust risk assessment methods in place. Owners should not be unduly constrained in the methods that they use.

c) **MIOS implemented as a result of the risk assessment should be such as to reduce the risk to be both tolerable and ALARP.**

d) **Where the probability and/or consequence of failure of a reservoir cannot be practicably reduced to a level where the risk becomes tolerable the reservoir should be decommissioned.**

The regulator

The Environment Agency currently acts to enforce the legislation and to take action in the event of an emergency. It does not have all the wider ranging duties and powers of regulators in other infrastructure sectors. Nor has its role to date been to act as a champion of reservoir safety or to foster continuous improvement amongst the different stakeholders. It does not have all the powers or the resources to undertake this wider regulatory role, or, in its present form, to fulfil its role in implementing all the recommendations of this Review.

In other infrastructure sectors the regulator is independent from the reservoir owner, has the necessary competence to fulfill its duties and is adequately resourced. As the Environment Agency is also a reservoir owner and operator, it cannot be said to be fully independent. It currently has systems in place to separate these two functions and there is no evidence to suggest that it acts inappropriately in this respect. Such an arrangement is not unusual in other countries[15]. However, it would benefit from being more autonomous within the management structure of the Environment Agency, and from having periodic external scrutiny to ensure it continues to act in an independent manner.

At present its reservoir regulatory work focusses on ensuring compliance and responding to emergencies. Whilst it has the competence to do this, it would have to build additional technical competence and capacity to undertake the new duties recommended in this report. As the proposed regulatory role is significantly wider than its current enforcement role, the Environment Agency's reservoir regulatory team would also need to change culturally to effectively implement such additional duties.

Code of practice

A key role of the Environment Agency in fostering continuous improvement is to establish what good looks like. A Code of Practice could prove invaluable in support of this. It would act as a benchmark in establishing what is expected from all the different parties engaged in reservoir safety management. Although there is extensive good quality guidance available it is rather fragmented, and a Code could link this all together. It would also be useful in identifying gaps in guidance and in knowledge, thus informing future research needs. Such codes of practice are used effectively in other sectors. A Code of Practice should provide a basic framework, setting out standards and ways of working. It should allow for periodic updates as the sector develops, for example, as technology and professional practice develops. Secondary legislation could refer to the need for owners, engineers and the Regulator to exercise their functions on the basis of the good practice set out in the Code.

Much of what might be needed will already be available in some form within owners, the Environment Agency and the ICE. The Code of Practice should also be informed from practices in other countries and other infrastructure sectors.

RECOMMENDATION 11. The Environment Agency should promote and champion good practice. It should provide guidance to owners and engineers, and have the duties and powers commensurate with regulators in other infrastructure sectors.

a) **The Environment Agency and Defra should work with the ICE and BDS, to produce a Code of Practice in Reservoir Safety Management**. This should set out clearly the roles and responsibilities of all the parties to reservoir safety management, in particular owners, surveillance, monitoring, operational and maintenance personnel, reservoir engineers, the Regulator and the ICE Reservoirs Committee. The Code should not only reflect legislation but include wider good practice. In due course Government should consider if such a Code should become statutory.

b) **The Environment Agency should have a duty of assuring the necessary systems and procedures are in place and applied by all to ensure all parties engaged in reservoir safety management fulfil their duties and responsibilities.** The Environment Agency should promote reservoir safety (with others as necessary) through promoting the Code of Practice and by fostering good practice through timely reports, guidance and training, to ensure that the measures recommended in this Review are properly implemented in a consistent manner.

c) **The Environment Agency should have a duty to review a sample of Supervising Engineers' reports and annual statements, inspection reports, risk assessments and RSMPs each year.** This duty will ensure an on-going national assessment of the quality of inspections and reporting which should be used to update guidance and training where necessary. The Environment Agency should also have the duty and powers to review specific reports and/or RSMPs beyond the annual sample where it finds this appropriate.

d) **The Environment Agency should have powers to question or challenge Supervising Engineer's annual statements and reports, inspection reports, risk assessments and RSMPs**. Where there are concerns over the appropriateness of a statement, report, risk assessment or RSMP or its delivery or requirements, which cannot be resolved with the owner and their engineer(s), the Regulator should have the powers to appoint their own reservoir engineer(s) to undertake an inspection and/or risk assessment, and require MIOS and/or amendments to the RSMP and enforce their implementation.

e) **The Environment Agency should have the duty to spot check the surveillance, operation, maintenance, and the condition of a sample of regulated reservoirs each year. They should have the powers to do this at any reasonable time and without warning and to issue improvement, stop and other notices to owners as a result of such checks or for any other reason**. These powers should be in addition to any current powers. The Environment Agency should also have powers to spot check the surveillance, monitoring, operation maintenance and condition of reservoirs beyond the annual sample.

To fulfil the additional duties set out in this report the Environment Agency would have to substantially invest in both technical capability and capacity. That additional capacity should largely be created in house to aid the necessary cultural change

It would not be reasonable to expect the additional costs of providing further regulatory resources to fall entirely on the public purse. Other UK regulators have the powers to recover all reasonable costs from their asset operators. A similar system should be explored for the reservoir sector with owners contributing to the costs of licensing and regulation in proportion to the hazard and the amount of effort needed to regulate their reservoir(s).

RECOMMENDATION 12. The Reservoir Regulatory and Enforcement Function within the Environment Agency should be properly resourced and its independence fully protected.

a) **Routine costs for regulation and enforcement should be fully recovered from reservoir owners in a fair and equitable manner (for example according to reservoir hazard and the amount of regulatory effort required).** This includes additional costs associated with specific enforcement measures, intervening and taking over the duties of a reservoir owner, and all costs associated with emergency action in the interests of safety. Government should meet any further reasonable costs that cannot be recovered, for example costs relating to emergency intervention where a reservoir owner becomes insolvent.

b) **The Environment Agency should have the powers to make charges to Owners and to issue fines and other penalties as a result of a lack of compliance.** Such powers should allow the Environment Agency to use charges and fines as a means of fostering good practice amongst owners.

c) **The independence of the reservoir regulatory section of the Environment Agency should be strengthened.** The Environment Agency should ensure that it has reporting and resourcing procedures in place that protect its independence, and periodic scrutiny of its independence using external assessors should be established.

Climate change

The current methods for estimating probable maximum precipitation and probable maximum flood should be updated to allow for the non-stationarity of climate and to allow for climate change over the future life of the reservoir. It is also possible that more prolonged periods of wet weather and the increase in rainfall intensity may affect the stability of earth embankment dams. The more rigorous approach to surveillance, monitoring and maintenance, recommended elsewhere in this report, will be particularly important in helping to address this.

RECOMMENDATION 13:

a) **The current research project commissioned by the Environment Agency into PMP and PMF should allow for the non-stationarity of climate. It should give guidance on estimating the frequency of present day and future extreme flood events suitable for use in reservoir risk assessment.** This should be based on data from multiple scenarios of computer generated weather using the best available tools and incorporating the latest rainfall climatologies.

b) **The Environment Agency should review recent and ongoing research on the impact of climate change on constructed embankments and determine if further research is needed to better understand the implications for earth embankment dams and other reservoir structures.** If necessary further research should be commissioned.

The public

From a public perspective, the current process of managing reservoir safety could be clearer and more transparent. Whilst the Regulator's reports are available in the public domain and the public can freely access details of legislation and regulations from the Government web site, little information is available relating to safety management at individual reservoirs. This does not provide the public with the assurance they need to understand how reservoir risk is being effectively managed and mitigated.

RECOMMENDATION 14:

a) **The Environment Agency should produce an annual report of its activities and an objective assessment of the overall state of the nation' reservoir stock. The report should be public facing and explain the role that the Environment Agency plays in reservoir safety and its objectives.** The Environment Agency should establish key performance indicators so that it can demonstrate the continued improvement in reservoir safety year on year**.** The public should be able to readily understand how reservoir risk is managed and be assured of its effectiveness and independence.

b) **Owners should publish key information about each of their regulated reservoir(s), to an agreed format, such that the public can be assured that safety is being appropriately managed.** The public should be able to access appropriate information at individual reservoirs without compromising security needs. The Environment Agency should produce a pro-forma to assist with this.

Legislation

The last reservoir act was the Reservoirs Act 1975. Although a new act, it largely built on the structure and intent of the 1930 legislation. Subsequent development has been via amendments to the 1975 Act. The current legislation is dated and very different from the more objective based legislation in other infrastructure sectors. Standards and detailed requirements should preferably not be embedded in primary legislation but delivered through regulations. More weight should be placed on guidance and in allowing the Environment Agency greater flexibility in fulfilling its duties as a result, thus obviating the need for frequent updating of primary and secondary legislation. A particular feature of current reservoirs legislation is that it is not entirely compatible with the Health and Safety at Work Act 1974. The consequence of this is that a reservoir owner may be entirely complaint with reservoir legislation but not meet other legislative requirements. It is possible that many reservoir owners may not realise this. At times reservoir legislation conflicts with other environmental legislation and this also needs to be resolved. The high compliance figures reported by the Environment Agency may not, therefore, reflect the full picture of legislative compliance (they are not designed to do so).

Given the dated nature of current reservoir legislation, there is a good argument for a new Reservoirs Act, However, this would take time to pass into legislation. Government must ultimately decide on the best way to move forward on the basis of what it might achieve more urgently without changes to the current regulations. Then it should consider what could be achieved through new regulations, what amendments to the current primary legislation might be made as part of other legislation passing through Parliament and then, in the longer term, whether to develop a new Reservoirs Act.

RECOMMENDATION 15. The recommendations made in this Review should be supported by the development of appropriate legislation and regulations.

a) **Government should consider how they might best implement the recommendations made in this Review and determine what changes are needed to legislation and regulations in order to gain the full benefits to reservoir safety in the long term**.
b) **In considering future reservoir safety legislation and associated regulations, Government should take into account the more recent wider developments in safety management and technology, and ensure it reflects the broad principles of safety management as embedded in Health and Safety legislation and practice.** It may, for example, be appropriate for the Secretary of State to determine suitable standards and thresholds from time to time through regulations and/or statutory guidance rather than embedding these in primary legislation. This would allow maximum flexibility for change as knowledge and practice on reservoir safety develops.
c) **When amending current legislation and drafting new legislation the enforcement policy should recognise that it is not always appropriate to take formal enforcement action in every case.** This will avoid parties who make every effort to comply but marginally miss compliance on occasion being recorded as being non-compliant.
d) **Government should consider whether these changes are substantial enough to propose a new Reservoirs Act, rather than continuous amendments to current legislation, to ensure our approach to reservoir safety remains fit for purpose in the future**. In the intervening time Government, in consultation with the reservoir profession, should consider how many of the recommendations in this review might be sensibly delivered in the short term through secondary legislation and improved guidance.

9. Appendices

Appendix A: Glossary of terms of definitions

ASLL	Average Societal Loss of Life
ALARP	As Low as Reasonably Practicable
ANCOLD	Australian National Committee on Large dams
ASDO	Association of Dam Safety Officers, USA
BDS	British Dam Society
BRE	Building Research Establishment
CCRA3	Third Climate Change Risk Assessment 2022
CIRIA	Construction Industry Research and Information Association
Construction Engineer	An engineer qualified to supervise and certify works involving construction work at a reservoir
Defra	Department of Environment, Food and Rural Affairs
Environment Agency	Government Regulator for Reservoirs in England
FCRM	Floods and Coastal Risk Management
FEMA	Federal Emergency Management Agency
HASWA	Health and Safety at Work Act, 1974
Hazard	The ability to do harm

HSE	Health and Safety Executive
ICE	Institution of Civil Engineers
ICOLD	International Commission on Large Dams
Inspecting Engineer	An engineer qualified to inspect the condition of a reservoir including the dam and other structures and require measures in the interests of safety to be implemented.
LIDAR	Laser Imaging, Detection, and Ranging
LLOL	Likely Loss of Life
LRF	Local Resilience Forum: multi-agency partnerships made up of representatives from local public services, including the emergency services, local authorities, the NHS, the Environment Agency and others. These agencies are known as Category 1 Responders, as defined by the Civil Contingencies Act
MIOS	Measures in the Interests of Safety
MPAR	Maximum Population at Risk
NRW	Natural Resources Wales
NSR19	The Nuclear Safeguards (EU Exit) Regulations 2019
ONR	Office of the Nuclear Inspectorate
ORR	Office of Road and Rail
Owner	In the context of this report the Owner is the entity that undertakes the operation of the reservoir and is legally known as the Undertaker. In most cases the Undertaker will also be the Owner.

Panel	Reservoirs Panel. A panel of engineers qualified under the Reservoirs act 1975 as amended and held by the Secretary of State for the Environment. The Secretary of State appoints an engineer to a Panel on recommendation from the ICE Reservoirs Committee.
PAR	Population at Risk
PFR	Prescribed Form of Record. A formal record of he key characteristics and data for a reservoir, kept by the owner as prescribed by the Reservoirs Act 1975 as amended.
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
Probability	Quantification of likelihood, normally expressed as an annual probability of occurrence
Qualified Engineer	An engineer qualified under the Reservoirs act 1975 as amended
R2P2	“Reducing Risks and Protecting People – R2P2”, HSE 2001
RAIB	Rail Accident Investigation Branch
Regulator	The organisation that assures that the regulations are comprehensively and appropriately followed. Usually the Regulator is also the Enforcement Authority. The Regulator in England is the Environment Agency.
ReSRAG	Reservoir Safety Research and Advisory Group
Risk	The likelihood that a hazard will be realised. Normally quantified by multiplying the probability of occurrence with the consequence.
RSMP	Reservoir Safety Management Plan.

RSSB	Rail Safety Structure Board
SEPA	Scottish Environmental Protection Agency
SFAIRP	So Far as is Reasonably Practicable
Supervising Engineer	An engineer qualified to supervise a reservoir. Normally appointed by the Owner
TEA13	The Energy Act 2013
UKCP18	UK Climate Programme 2018
UNSEEN	UN precedented Simulation of Extremes with Ensembles
Undertaker	See Owner
USBR	United States Bureau of Reclamation
USDD	United States Society on Dams

Appendix B: References and footnotes

1. Legally, the responsibility for the safety of a reservoir lies with the undertaker, the entity who undertakes to operate the reservoir. In most cases the undertaker is the owner. In this report the term “owner” is exclusively used to mean the “undertaker”.

2. The Reservoir Regulator for England is the Environment Agency. It is also the body responsible for enforcing the reservoir legislation. Similar bodies exist in Wales and Scotland. There are differences between the legislation that applies in England and Wales compared with Scotland and Northern Ireland.

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9. Warren AL and Patten B, “*Learning from reservoir incidents – a summary of the causes and management of incidents in the UK*”, Smart Dams and Reservoirs, Proceedings of the 20th biennial conference of the British Dam Society, Swansea.

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11. Reducing Risks, Protecting People, HSE’s decision making process, Her Majesty’s Stationery Office, St Clements House, 2-16 Colegate, Norwich NR3 1BQ, 2001

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13. Review of the Existing Risk Methodology, Report No FD2701, Objective 3, Environment Agency, March 2020

14. Bradlow D D, Palmieri A and Salmon M A, "*Regulatory Frameworks for Dam Safety – A Comparative Study*", World Bank, Washington DC, USA, 2002

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23. Reclamation Manual, United States Bureau of Reclamation, Washington DC, USA, 2020

24. Federal Guidelines for Reservoir Safety Risk Management, FEMA – P1025, US Department of Homeland Security, 2015.

25. Guidelines on Dam Safety Management, Australian Committee on Large Dams inc, Hobart, 2003

26. Guidelines on Dam Risk Assessment, Australian Committee on Large Dams inc, Hobart, 2003

27. Guidelines on the Consequence Categories for Dams, Australian Committee on Large Dams inc, Hobart, 2012

28. Dam Safety Management Guideline, Department of Natural Resources, Mines and Energy, Queensland Government, Australia, Oct 2020.

29. Faulkner D and Benn J, "*Reservoir Flood Estimation. The Way Ahead*", Dams and Reservoirs, ICE, Nov 2019.

30. Stewart EJ, Jones DA, Svensson C, et al. " *Reservoir Safety – Long Return Period Rainfall*", Report WS 194/2/39/TR, Defra, London, 2013

31. Kendon M et al, "*State of the Climate 2019*", Met Office, 2019

32. National Flood Resilience Review, HM Government, Sept 2016

33. Improving Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF) estimation for reservoir safety, Environment Agency, 2020

Appendix C: Organisations consulted as part of this review

I am grateful to the following organisations that assisted in this Review.

The Association of Dam Safety Officers, USA

The Angling Trust

The British Dam Society

The Canal and River Trust

Damsafety

Defra

The Devolved Administrations of the UK

The Environment Agency

GHD Brisbane

The Health and Safety Executive

The Institution of Civil Engineers Reservoirs Committee

The International Commission on Large Dams

Jacobs

Ministry of Transport and Water Management/Rijkswaterstaat, the Netherlands

Mott MacDonald

The National Farmers Union

The National Trust

Natural Resources Wales

Northumbrian Water

The Office of Road and Rail

The Office for Nuclear Regulation

Severn Trent Water

Stantec

The Scottish Environmental Protection Agency

The United States Bureau of Reclamation

United Utilities

Yorkshire Water

Appendix D: Task and Finish Group

The following Task and Finish Group was established to support the Review and advise on the findings and recommendations.

Name	Position
Richard Coackley	Chair, Institution of Civil Engineers Reservoirs Committee
Alan Warren	Chair, British Dam Society and Head of Reservoirs Team at Mott Macdonald
Jo Harrison	Director of Assets, United Utilities
Ian Hodge	Deputy Director of FCERM, Environment Agency
Ian Shearing	Senior Policy Advisor, Health and Safety Executive
Mark Foy	Chief Nuclear Inspector, Office of Nuclear Regulation
Ian Prosser	Director of Rail Safety, Office of Road and Rail
Hazel Durant	Defra

Appendix E: ICOLD world declaration on dam safety

International Commission on Large Dams

The construction, operation and maintenance of dams and their storage **reservoirs have provided significant benefits to humankind** throughout history. Storage of water behind dams regulates natural streamflow provides for benefits resulting from increased water availability, renewable energy production and reduction of adverse impacts caused by nature's extremes of flooding and drought. This document addresses the importance of dam safety, which is encompassing of water dams, mining tailings dams and levees.

A growing population in our fragile world is causing steady increases in demand for water, food, energy, minerals and flood control. Dams are critical infrastructure to meet these basic human needs as well as rising standards of living. At the same time, however **dams create new hazards involving potential risks to downstream communities, including potential adverse impacts to life, property and the environment. The potential for** dam safety incidents, possibly resulting in an uncontrolled or catastrophic release of stored water is of the highest concern.

The profession of dam engineering has a **profound ethical responsibility** to carry out its professional duties so that dams and reservoirs are designed, constructed and operated in the most effective and sustainable way, while also ensuring that both new and existing dams are safe during their entire lifespan from construction to decommissioning.

ICOLD and Dam Safety

For almost a century, the International Commission on Large Dams (ICOLD) has made dam safety one of its highest organizational commitments, as stated in the ICOLD Mission statement:

"ICOLD leads the profession in setting standards and establishing guidelines to ensure that dams are built and operated safely, efficiently, economically, and are environmentally sustainable and socially equitable."

Before the creation of ICOLD in 1928, knowledge on dam safety was disparate while the need for building water storage infrastructure was very high and growing. It therefore became a priority of ICOLD to disseminate the understanding of the design and operation of dams based on experience within the global dam engineering community. And, along with this dissemination came a strong focus on dam safety that has permeated up to the modern era.

ICOLD has played a key role in improving dam safety through its work in collecting and analysing information on the lessons learned from past successes and failures. Since the very beginning, ICOLD and its thousands of professionals within the member countries have continuously contributed to the improvement of dam safety through publication of technical papers and exchange of experience during Annual Meetings and Congresses. ICOLD's Technical Committees develop Bulletins for publication that summarize the current state of the practice.

Since the creation of ICOLD, the number of failures compared to the total number of dams in operation has been reduced significantly, which is a positive achievement that reflects the worldwide influence of ICOLD in raising dam design and management standards. **Nonetheless, constant vigilance and commitment to dam safety is still required in order to continue the global trend towards safer dams**. Any dam incident is a matter of the gravest concern for dam professionals. ***It is our ICOLD Declaration that Dam Safety is our highest priority.***

Changing Conditions of Dam Safety

Due to the vital need for water, food, energy, minerals and flood control, the total number of dams worldwide continues to grow. Maintaining the present trend of a decreasing incidents of dam failure rate is a never-ending challenge for the profession. ICOLD's role in knowledge transfer and capacity building through the dissemination of the best practices is as pertinent as ever. The science technology and human roles on dam safety are in constant evolution with many changing conditions:

- **Ageing of existing infrastructure,** creating new concerns related to the longevity of construction material and equipment, including infilling of reservoirs with sedimentation.
- **Lack of experience in dam safety management and operations** in some countries engaged in building dams, requiring the need for capacity building.
- **Retirement of experienced personnel** in all countries, leading to a deficiency in qualified engineers trained in dam design.
- **Increasing participation of the private sector** in the development of dams **as well as increasing cost and time pressure on developers, designers, contractors and operators,** creating a need for new governance conditions for dam safety.
- **Climate change** causes changes in extreme precipitation and drought events, resulting in increased hydrological risks. It is critical to consider changes in climate during planning and management, including resilient design and adaptive reservoir operation of dams. In some regions, this results in a need to increase the height of dams, expand spillway capacity, modify reservoir operating procedures, and/or construct new dams. There may also be a need to assess and address other hazards created by climate change as part of the planning, design and operational phases.
- **The most suitable sites for dams** have largely been utilized, thus new dams must be built in more and more challenging locations, especially regarding geological conditions.
- **Changing local, regional and national governance** can have a significant impact in regulatory authority for dams.

As a recognized international organization of experts in dam engineering, ICOLD calls upon governmental authorities and financing institutions to promote an awareness of the subject of Dam Safety. The goal of this ***ICOLD World Declaration on Dam Safety*** is to restate the fundamentals dam safety that have been learned over time. Furthermore, all involved entities should be reminded to ensure, through the fulfilment of their responsibilities, that these fundamentals are respected in order to minimize risks associated with dams and reservoirs.

Pillars of Dam Safety

With almost a century of commitment to dam safety, and knowing that the zero risk does not exist, ICOLD recognizes several overarching pillars of dam safety:

- **Structural integrity of dams is the keystone to dam safety**. Best current practices of dam design and performance during the occurrence of hazardous events such as extreme floods and earthquakes have been largely documented by ICOLD bulletins in order to create a sound basis on which existing and future dam structures should be designed, built and operated in safe conditions.

- **A routine surveillance and maintenance programme is necessary for early detection.** Inspection and upkeep are of high importance to minimize the risk and to ensure dam safety in the long term. Periodic safety review by qualified engineers that are highly experienced in dam safety assessment is mandatory. Supervision of dams should be based on both the operator´s self-supervision and periodic external safety reviews by an independent and competent authority or institution.

- **An instrumentation and monitoring programme is essential throughout the life of a dam.** A comprehensive dam monitoring programme is necessary to: a) determine behaviour during construction; b) assess performance during first reservoir filling; c) compare actual performance with design; d) characterise long-term behaviour; e) provide early warning of abnormal conditions; f) capture & analyse response to events, such as large floods, earthquakes, etc.; g) predict future performance of the dam; and h) demonstrate safe management of the dam to regulatory authorities.

- **Design intrinsic risks need to be adequately addressed**. These risks are based on dam type, materials, ageing, foundations, hydraulic structures, etc., in which good practices and surveillance are the keys for safety.

- **Natural hazard risks change with time, thus should be regularly reviewed and updated.** These hazard risks like floods and earthquakes are external threats, for which risks are accepted based on known science and likelihood of occurrence.

- **Emergency planning is of utmost importance for all dams**. Emergency plans should be developed with the objective of avoiding loss of life and reducing damage to property, infrastructure and the environment resulting from a dam failure. The first filling of the reservoir being a critical period during which the emergency plan must be ready for implementation in a timely manner. Periodic review, updates and practice of the emergency plan is mandatory.

- **Adequate training of operators is part of a comprehensive dam safety programme**. Those placed in charge of dams carry an important responsibility to maintain their training and understanding of their dam. Mis-operation of a dam, especially of spillway gates, can lead to accidents, downstream flooding or potential overtopping of the dam.

- **Sharing lessons learned benefits the entire industry, making all dams safer.** The experience of ICOLD has shown that sharing lessons from dam incidents and failures is crucial to improve state-of-the-art practices. For all involved parties, it is thus imperative to make any documentation on dam incidents, including independent expert reports on the root causes of such incidents freely accessible to the international community.

- **A comprehensive dam safety approach will allow minimization of risks**. This is done through collaboration of national organizations to support dam safety: structural measures for strengthening the structure's integrity and stability; measures to minimize the consequences of failures as well as education and public awareness about dams. A comprehensive dam safety approach should also consider the fact that river basins, many of which are transboundary basins, often include several dams, or systems of dams and levees.

- **A dam owner has the ultimate responsibility for its dam.** ICOLD recognizes that the safety of all dams is primarily the responsibility and liability of owners and operators. Adequate personnel and financial resources as well as relevant know-how are essential conditions to meet this responsibility.

- **The role of regulatory authorities is paramount to safety.** Regulatory authorities should take a strong role in ensuring adequate site investigation, best practice design standards, quality construction, contractual frameworks, emergency preparedness and operational compliance within accepted guidelines and standards. Developing norms, standards and safeguards is a key factor to proper dam safety surveillance.

- **An international perspective to dam safety can be enlightening.** International organizations such as ICOLD, which provide guidelines based on worldwide experience, can provide important guidance to designers, owners and government authorities to better understand the current state of best practices for design and safety of dams.

Summary Declaration

With the aspirational goal of working towards continuous reduction of dam safety incidents, ICOLD, as the leading international organization committed to dam safety, calls upon all involved professionals and companies to make a firm commitment to safety improvements and risk reductions at all dams.

Furthermore, Governments, Financial Institutions and other Developers in their contribution to the development and regulation of dam infrastructure, are called upon to make a similar political and financial commitment so that the all-important safety recommendations for dams outlined in ICOLD Bulletins, will be disseminated to the relevant entities and followed to completion.

This common effort will contribute immeasurably to the overarching ICOLD vision:

"Better Dams for a Better World."