NEW ZEALAND
Society on Large Dams

ISBN: 978-1-0670518-7-7

New Zealand Dam Safety Guidelines 2024

MODULE 7
LIFE CYCLE MANAGEMENT

Abstract

Dam safety objectives and principles that are applicable to the investigation, design, construction, commissioning, operation, assessment, rehabilitation, and decommissioning of dams in New Zealand are included in the Parent Document. The Parent Document also includes a glossary of terms used in these Guidelines.

This module discusses dam life cycle management issues beyond design and construction, and provides guidance for managing dam safety issues and deficiencies, the rehabilitation of dams, sediment management, change of dam use, and the decommissioning of dams. The focus of the module is primarily related to issues that can directly affect the safety of dams (i.e. the uncontrolled release of reservoir contents). However, the module also provides guidance on the management of public safety around dams which is an important component of dam safety management.

This module includes limited discussion on the role of regulators in dam safety. The reader should refer to Module 1 (Legal Requirements) for a more complete description of legislative roles and responsibilities.

Notice to reader

Although this module is configured to be as self-contained as practicable from a technical standpoint, readers should familiarise themselves with the principles, objectives, and limitations outlined in the Parent Document and Module 1: Legal Requirements before considering the information in this or any other module.

1.1 Document history

Release	Date	Released with
Original	May 2015	Parent and all modules
2023	December 2023	Updates to Parent and Modules 1, 2 and 5
2024	December 2024	Updates to Parent and all Modules

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1. Introduction

1.1 Principles and objectives

Dam safety is important through all stages of a dam's life cycle including initial design and construction, operation, rehabilitation, decommissioning and, in the case of tailings dams, long-term closure.

Principle 8 in the Parent Document states that:

Due diligence should be exercised during all stages of a dam's life cycle.

The focus of this module is on 'lifetime' issues that Owners may encounter with existing and new dams beyond design and construction. The module provides guidance for Owners and, if appropriate, regulators in managing and addressing issues associated with public safety around dams, lifetime changes, dam safety issues and deficiencies, dam rehabilitation, sediment management, change in use, and dam decommissioning.

Public safety around dams is an important component of dam safety management. Besides the risk of an uncontrolled release from the reservoir, dams, their reservoirs, and associated hydraulic structures can present various other hazards that may impact public safety. Some controls considered necessary for the mitigation of public safety hazards may place constraints on dam operation which, in turn, may influence dam safety.

Dams typically have life expectancies that span several generations. It is almost inconceivable therefore that the environment within which a dam is situated, its use, and societal priorities, will remain unchanged over the life of a dam. Irrespective of normal wear and tear processes, Owners must be cognisant of such changes over time and how these may influence the safety of their dams. Even where little change has occurred over time that may influence dam safety, different operational requirements, technology advances and changes in performance expectations may necessitate the completion of significant modifications or upgrade works to a dam and/or its appurtenant structures. This includes changes to our understanding of the natural environment, such as climate change and seismology.

Many aspects of life cycle management need to involve interaction with the public and stakeholders. It is therefore important for Owners to consider how stakeholder engagement and participation can be incorporated within their projects. Ultimately the management of dam safety deficiencies, modified operating procedures, and potential decommissioning projects will involve the consideration of short and long-term risks and, as such, there will be a range of stakeholders who will be interested in both the manner in which risks are considered and the ensuing decision.

Owners may need to consider the necessity for risk reduction measures, potentially including rehabilitation works, to ensure or restore appropriate levels of dam safety where:

- The Potential Impact Classification (PIC) of a dam has changed as a result of downstream land use change.
- The understanding of issues such as climate change, flood and seismic hazards, and dam performance change with time.
- Materials have deteriorated over time (e.g. contamination of filter and drainage systems in an embankment dam or alkali-aggregate reaction damage in a concrete dam).
- The dam's use or operational regime changes.
- The public's dam safety expectations change.

In addition, if the costs of rehabilitation works are high or if a dam reaches the end of its economic life, Owners and regulators will need to consider whether the dam should be decommissioned and removed or modified for an alternative use or mode of operation.

1.2 Scope of module

There are many changes that can occur over a dam's lifespan that may require dam safety management. It is not the intent of this module to exhaustively explore the dam safety implications of all potential lifetime changes and how they might be addressed. This module provides a broad overview to highlight some issues of which Owners should be aware, along with the processes that might be adopted for their management.

This module addresses the management of issues associated with identified deficiencies, rehabilitation, sediment management, decommissioning, change of use, and public safety around dams. In particular, this module addresses:

- Lifetime changes that may necessitate dam safety management.
- The identification and management of dam safety issues.
- The investigation, assessment and treatment of identified dam safety deficiencies.
- Rehabilitation of dams.
- Sediment accumulation in reservoirs and its effects on dam safety.
- Changes in use, where the function of a dam is required to be different from its original function.
- The identification, assessment, and management of public safety risks due to public interactions with dams, reservoirs, and waterways.
- Decommissioning of a dam and decommissioning procedures.

A list of reference documents is included at the end of the module to provide further assistance to Owners and their Technical Advisors.

2. Public safety around dams

2.1 Introduction

Irrespective of dam safety related incidents or failures, the simple existence of dam systems and their associated operation poses risks to the public. The public interact with each unique dam system and its components in many different ways, for a range of reasons (e.g. recreation, sport, adventure, tourism, social influence, vandalism). While the consequence associated with a public safety incident may be much smaller when compared to a major dam safety incident, the exposure is often much greater or potentially continuous. This is observed in the statistics of countries with well-established dam safety regimes where fatalities during normal operations are far more frequent that dam safety related fatalities. This pattern is also evident in New Zealand where several examples of public injuries and fatalities have occurred during normal dam system operation (e.g. 2017 Aratiatia Dam spillway gate operation and swimmer drowning).

The risk to the public during normal operation of dams is also potentially growing as people increasingly utilise and enjoy the recreational and social benefits associated with waterbodies and rivers. Most dams in New Zealand facilitate increased access for the public, often driven by requirements associated with authorisations (e.g. resource consents). Dams also often provide enhanced access to water bodies for members of the public less experienced in wilderness locations. These factors make public safety relevant to dam owners and operators, but also to regulators and those with a role in the management of safety around waterbodies (e.g. government, parks and recreation agencies, councils, emergency agencies, navigation, boat safety, water safety, private landowners).

Owners are obligated under the Health and Safety at Work Act 2015 to ensure that dam workplaces are safe for operational employees, persons who enter the site, and others put at risk by the Owner's work (e.g. dam operation). Refer to Module 1 Legal Requirements for more information.

2.2 Dam safety versus public safety

There are many similarities between dam safety and public safety. However, there are some very important differences that should be considered when operating a dam system and developing a Dam Safety Management System (DSMS) (also refer Module 5 Dam Safety Management).

- **Exposure.** The hazard posed to the public may be continuous, occur at regular timing, or even be totally random. Regular operational processes such as base flows, releases, and lake level changes all influence the nature and level of risk posed to the public. Similarly, less routine operational processes such as flushing flows or recreational releases can produce sudden changes to public risk.
- **Dam size.** The Potential Impact Classification (PIC) of the dam has no relevance to public safety around dams, reservoirs and waterways. Small dams and weirs (sometimes named 'drowning machines') are disproportionately represented in public safety related incidents. Small structures are often perceived by the public as being less threatening and hence they may take greater risks around these structures. Many urban settings include numerous small dam structures around which the public interact.
- **Ability to directly control.** The Owner may have little or no control over the public's ability to access portions of the water body influenced by dam operations. Dam systems, associated reservoirs and waterways may extend a large distance upstream and downstream of the dam structure. Beyond the intake and tailrace, access to much of the upstream and downstream waterways is likely to be beyond the dam operator's control yet will be influenced by dam operation.
- **Shared responsibility.** Public safety is a shared responsibility. Many control measures adopted to mitigate risk to the public require the public to abide by that control. In a dam safety context, the Owner is the expert and is responsible for both assessment and managing the risks posed by the dam system. In a public safety context, while the Owner is responsible for assessing the risks, in many locations the responsibility for mitigation is shared. If the public seeks to ignore or circumvent the mitigation provided, they are adopting responsibility for the associated change in risk. Recreational groups or businesses also potentially share in this responsibility.

- **Risk changes**. The level of risk can change very rapidly. Public forums such as social media platforms can rapidly change the number of public visiting a site. This can increase the consequence should an incident occur, and may also result in further changes to the risk, e.g. increased crowding may push public into higher risk areas.

2.3 The managed system

Comparable to dam safety and a Dam Safety Management System, public safety is best approached as a total managed system (Figure 2.1).

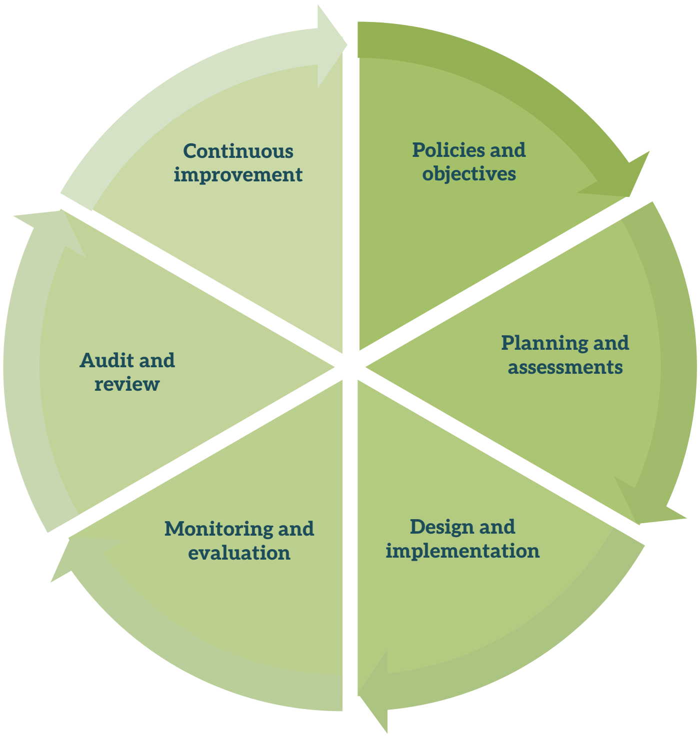

Figure 2.1: Public safety as a managed system showing six components

To be effective, each component of the managed system needs to exist and operate at a similar level of maturity. There is little value in having one component operating at a very high level if others are significantly more basic. This can lead to increased risk through a misplaced perception of excellence.

The following sections briefly discuss each of the components. Discussion on more specific aspects of public safety are provided in section 2.4.

2.3.1 Policies and objectives

Policies and objectives define the framework for action. They will also define roles and responsibilities. The full scope of public safety related issues can never be codified, so the policies and objectives provide the ambition against which approaches and decisions can be tested; allowing those responsible for decisions to ask "in making this decision, is it consistent with our policies and objectives?".

When derived to inform an Owner's approach to public safety, policies and objectives will inevitably have, and require, close association with other policies and objectives (e.g. health, safety, and wellbeing; dam safety, and risk policies and objectives).

2.3.2 Planning and assessments

The intent of the planning and assessments component is to define how the public interacts with the dam system and associated waterways and, through the presence and operation of the dam system, what risks are induced. This will likely include consideration of:

- Operational procedures and practices during normal conditions (including during minor floods).
- Consideration of 'zones of influence' upstream, close to, and downstream of the dam.
- Past public safety incidents, near misses and observed public practices.
- Potential rescue processes, including self-rescue.
- Consultation with relevant recreational groups and water users.
- Potential changes over time (e.g., public use patterns, operational changes).
- Effectiveness of existing control measures and any record of failure of these controls.

The planning and assessment component typically encompasses an internal loop of **'Plan – Assess – Plan'.** Formulating a **Plan** to undertake the assessment (who, what, when, how to assess), is critical to the completion of an effective **Assessment**, from which a **Plan** for potential mitigation measures can be formed.

2.3.3 Design and implementation

The overall purpose of undertaking the design implementation of any control measure is to reduce the risk to the public. Implementation of risk management and mitigation measures should demonstrate that the policies and objectives of the organisation have been met. It is important to consider how the public might respond to the measure and this information needs to be fed back into the managed system. For example, if a fence simply means the public moves to the next open portion of the riverbank, then the fence may have achieved little risk reduction or even increased risk if rescue processes are more challenging in this new location.

Many potential mitigation measures interact directly with the public and hence can provide an opportunity for the wider benefits of knowledge transfer (between the Owner and public) and broader public awareness of public safety around dams.

Measures that incorporate increased public understanding and awareness can have greater and wider positive impact than localised targeted measures such as a fence, as they should reduce the potential for the public to place themselves at risk in the first place. However, it may be more challenging to demonstrate that such measures are effective compared to a physical barrier.

2.3.4 Monitoring and evaluation

A core objective of any monitoring and evaluation process is to determine effectiveness of control measures. If the intent of the measure is not fully met, then the remaining risk may exceed acceptable levels and not meet the organisation's policies and objectives.

Further, if not effective, the control measures might be a waste of time and financial resources. In the worst case, the control measure may even increase risk by giving the public, or organisation, an incorrect perception of safety.

The effectiveness of any control measure will likely change over time, potentially rapidly. Signs may need to be refreshed regularly to counteract 'familiarity blindness' where people simply stop noticing details they have seen many times.

To be effective, monitoring and evaluation therefore needs to occur at a frequency and depth that allows consideration of trends, and captures anomalies and near misses.

2.3.5 Audit and review

Audits primarily focus on ensuring that defined objectives, processes, and procedures are being followed. Reviews are aimed at identifying deficiencies and opportunities for improvements both in the system and the practices being undertaken. The purpose of audit and review is therefore to feed into continuous improvement of the managed system.

Consistent with dam safety processes, audits and reviews need to be undertaken at frequency that is meaningful to test system functionality and inform system improvements. Public safety audits are recommended annually, and reviews are recommended five yearly. Their effectiveness will also be a function of the scope developed for the audit or review, and the experience of those undertaking the audit or review.

2.3.6 Continuous improvement

A core tenet of a managed system is seeking to continuously improve. A perfect solution, derived though a single application of a process, is both unachievable and conceptually flawed.

Lessons will be identified within each of the other components of the system. Lessons identified are not lessons learnt. The continuous improvement component therefore aims to translate lessons and issues identified in to improved ways of doing things in the future.

It should be recognised that, unlike the field of dam safety, which has matured over decades of applied practice, public safety is globally still in its infancy. This increases the comparative value of continuous improvement within the system, as greater potential risk reduction is available by applying enhanced understanding when the system maturity is emerging.

2.4 Public safety considerations

The following provides more detail on relevant public safety considerations, in particular guidance on undertaking assessment, design and implementation, and incident management.

2.4.1 Planning and assessments

The following process for undertaking public safety planning and risk assessment are provided in a broad sequence. Depending on each dam system's specific details and context the order may change or some aspects may not be relevant. The process should include the following areas of assessment:

Dam system boundaries

A clear understanding of the dam system's boundaries of influence should be established. These are not physical or property boundaries but rather extend to the limits (upstream and downstream) of where the presence and operation of the dam system may represent a threat to the public.

Within these boundaries there will likely be differing zones of influence representing how proactively or directly the Owner might exercise control and mitigate impacts. An example may be to separate the area within the dam system boundary into the following zones:

- **Zone A: Monitoring only.** Likely to be quite remote from the dam, such as appurtenant structures and waterway hazards.
- **Zone B: Monitoring and information.** Areas where risks are present and the Owner may inform the public about dam hazards, but beyond where the Owner can exert any direct control.
- **Zone C: Monitoring and warning.** Approaching areas of specific risk but where the public should be able to respond to avoid the hazard.
- **Zone D: Monitoring and exclusion**. Likely to be in the immediate vicinity of specific structures and hazards.

Nature of public interaction
Review how the public use the various aspects of the dam system (including structures, reservoirs and waterways), and in what locations. Information should be gathered from a range of sources including operational staff, recreational groups, public forums (websites, social media), local authorities, and site surveys. It should include the following:

- Frequency of use including temporal or seasonal aspects.
- Nature of use.
- User demographics including group sizes.
- Access methods.
- Use trends over time.
- Past public safety incidents and near misses.

Public safety hazard posed by the dam system and its operation
Review how the dam system operations may present a threat to the public given the ways they use the different parts of the dam system. Typically, this would be sub-divided by the reservoir or waterway's hydraulic component and/or reach (distance segment). Consideration should be given to different modes of operation as well as time of day/week and seasonal factors. Past public safety incidents and near misses should be considered when identifying hazard posed by the dam system. Changes to the dam system, its operation, and public use should also be considered.

Public safety hazards typically encountered in and around a dam system's structures, reservoirs, and waterways include:

- **Reservoir operation** induces water level changes and alters threats from submerged structures and floating debris. These can change the conditions that the public will experience (e.g., boats, swimming).
- **Intakes and discharges** induce hydraulic conditions, including currents and turbulence, that may be dynamic over short periods of time.
- **Highly aerated water and/or under currents** can trap people and make rescue difficult.
- **Dams and appurtenant structures can be invisible** to upstream users (particularly weirs that may not have visible crest) and boat users may be unable to respond quickly enough to avoid the threat.
- **Falls from climbing on or traversing dam system structures** can amplify risks associated with other threats such as intake and discharge hydraulics if a person falls into these areas.
- **Slips at reservoir, canal, and river margins** can result from site conditions including slippery moss or algae and soft sediments that directly pose a threat and may also hamper rescue attempts (including self-rescue).
- **Changing river hydraulic conditions** can trap and surprise users, particularly those who may be used to the apparent steady conditions induced by the presence of the dam.
- **Water conditions** including low clarity and low temperature that can induce disorientation and/or hypothermia.

Hydraulic assessment
This may not be required for all dam system components or modes of operation. A hydraulic assessment may be required to provide detail of how water levels and flows may respond in reaches between and beyond known points. This will be particularly relevant if a new or changed mode of operation is envisaged.

Different levels of hydraulic assessment complexity and maturity are possible. The selection of approach should be commensurate with the risk being managed. The simplest assessments may consist of site observations and measurements during different modes of operation, through to complex hydraulic models.

Existing public safety controls
Incorporate the nature and effectiveness of any existing public safety control measures in the public safety risk assessment. Any evidence of the control measure being compromised (e.g. control breach, control failure, near miss) should be considered. It may be possible to draw on experience from other dam systems' control measures to help inform the performance of control measures.

Interaction with dam safety requirements
Consider whether potential controls to mitigate public safety hazards may place constraints on dam system operation and have dam safety implications. For example, constraining the rate of spillway gate opening to reduce the risk to downstream river users could impact the ability to safely manage a large flood event.

Tabletop review
Bring together the Owner's relevant technical, operational, and management staff, along with relevant technical advisors, to review and consider the completeness and quality of available information (dam system, nature of public interaction, public safety hazard review, hydraulic assessment, public safety controls, past incidents and near misses, dam safety interactions). This should include considering relativity between information such as accuracy and number of observations. Understanding the limits of the information available is a fundamental input to developing mitigation strategies.

Site inspection
Verify and ground-truth the outcomes of the previous steps on site and check for any gaps or new evidence. Interaction with local operational staff (if not included in the desk top study) is important to get their knowledge of issues, changing uses and past incidents. Because the nature of public use and dam system operation is often seasonal, consideration should be given to repeating the site inspections under different conditions to obtain a sound representation of the hazard posed by public interaction with the dam system.

Public safety risk assessment
Carefully examine and assess the risk of each type of harm to public around the dam system structures, reservoirs and waterways. The risk assessment should draw on the information and understanding developed from all the previous steps. After completing the assessment, the Owner can weigh up whether it has taken enough precautions or should do more to prevent incidents or accidents. The Owner's policies and objectives (e.g. public safety, dam safety, health safety and wellbeing, risk) will support this step. Across an Owner's portfolio the public safety risk assessments also help ensure effort is targeted at achieving the greatest overall risk reduction, given the mitigations that can be undertaken.

Record and document
Carefully document the data, results and outcomes. The outcome from the process is unlikely to be absolute but rather present a range of risk vs. mitigation options. It is important to capture this to help inform future reviews and assessments. Further guidance on information management is provided in Module 5, section 4.9.

2.4.2 Hazard mitigation and management

A wide variety of potential control measures (physical, operational, and educational) are available to mitigate hazards to the public. As noted in section 2.2, many control and risk mitigation measures require a shared responsibility with the public to be effective. Therefore, as part of the control measure, the public needs to be informed about why the control is in place and how to respond.

There are a limited number of cases where it may be practicable to eliminate the hazard (e.g. a stilling basin could be designed or modified to eliminate back eddies that could trap swimmers). In some cases, hazards may be mitigated by the adoption of alternative dam system and reservoir operating procedures while, in other cases, hazards may be best controlled by the installation of barriers, warning signs, rescue equipment, or alarms.

Further detail on mitigation options is contained in section 2.5. Key elements of the hazard mitigation and management processes include:

Integration of assessment findings into asset management
Integrate the findings from the assessment phase into the organisation's implementation planning framework, e.g. using an asset management platform or risk management system.

Planning and selection
Use the risk assessment process to prioritise hazard mitigations. The planning and selection process for control measures may influence their delivery sequence. At some locations, more than one mitigation measure may be required to achieve adequate risk management. These may be progressively installed to achieve optimal ongoing risk reduction at both a location and portfolio level.

Solutions should be customised to the specific risk, not taking a 'one-size-fits-all' approach. However, a level of standardisation within types of solutions (e.g. symbols on signs, siren type) is needed to ensure that the public, first responders and authorities are not confused by conflicting messages and inconsistent systems.

The planning and selection phase should also consider maintenance requirements and how control measure performance might be monitored and effectiveness reviewed.

Mitigation, training, and notification
Depending on the broad nature of solutions adopted to reduce a risk, there is a need to define how they might be implemented. This may be more than simply a physical action as it may require consultation with stakeholders or rely on increasing the public's awareness and understanding of the hazard and associated risks.

Some measures may focus on enhancing the ability for rescue. These may need to involve coordination with, and training of, local operators and/or emergency response personal. Where self-rescue is intended then public education may be needed.

Other measures may involve altering dam system and reservoir operation, for example, to reduce the rate of change in river flows. These will typically require careful testing and commissioning processes as they may induce new hazards in other areas of the dam system. For example, a slower rate of change in discharge may increase risk due to lake level change.

Implementation
Depending on the solution, implementation may range from a single action such as installing a sign, to a sustained program of effort and public education. There may be multiple stages, effectiveness review points, and potential modifications.

Consideration may also be given to interim risk reduction measures while permanent solutions are enacted.

2.4.3 Public safety incidents

Identifying and recording public safety incidents is important for improving control measures and reducing risks. Incidents should include near misses and failure of control measures to function as intended. The frequency of interaction between the public and the dam system (and associated reservoirs and waterways) can be very high and hence provide information on many potential incidents and near misses. As for health and safety practice, recording and evaluating events provides valuable data on trends, the effectiveness (or ineffectiveness) of control measures, and the state of understanding within the public. The communication of incidents within the Owner's organisation also grows public safety awareness.

Classification of incidents is helpful to inform both public safety risk assessment and potential mitigation measures, if required. An example of a classification system is:

Category 1 – Major public safety incident. Would include one or more of:

- Fatality.
- Critical injury requiring a hospital stay.
- Rescue by first responders (e.g. Emergency management service, police, fire services).

Category 2 – Significant public safety incident. Would include one or more of:

- An injury requiring medical attention beyond First Aid.
- Unauthorized access by the public to a hazardous area where no further effective control measures exist between the public and the hazard.
- Self-rescue required.
- Failure of a public safety operational control measure to perform its intended function.

Category 3 – Minor public safety incident. Would include one or more of:

- A minor injury requiring First Aid.
- Unauthorized access by the public to a hazardous area where there remains further effective control measure(s) to prevent exposure to a hazard.
- Failure of a public safety physical control measure in performing its intended function.

Category 3 would include near-miss events. Alternatively, near-miss events could be captured as a fourth category. The classification system should also link to the Owner's internal response and reporting systems.

2.4.4 Public safety management plan

Where identified hazards exist, and these are assessed to pose a risk to the public, a site-specific public safety plan should be prepared. This will contain the hazards, nature and performance expectation of control measures, as well as monitoring and effectiveness evaluation requirements. It will also contain, or provide linkages to, relevant emergency management procedures.

A public safety plan should outline:

- The objectives of the plan including the dam system structures, reservoirs, and waterways to which the plan applies.
- Definition of roles and responsibilities including those responsible for
  - plan review and update,
  - implementation,
  - training requirements,
  - performance monitoring,
  - control measure effectiveness evaluation,
  - incident categorisation, reporting, and evaluation.
- A summary of
  - the public's interaction with the dam system structures, reservoirs and waterways,
  - past incidents, near misses, and control measure failures,
  - the identified hazards and the results of the risk assessment.
- A description of
  - control measures in place for the dam system and a plan showing their locations,
  - any rescue equipment and key access locations for rescuers,
  - training requirements to maintain public safety competencies and risk mitigation.
- Inclusion or reference to relevant operational procedures such as
  - notification lists and protocols,
  - operation of intake and discharge facilities,
  - reservoir and waterway management,
  - surge and automatic trip operations,
  - inspection of hazards locations and the maintenance of physical control measures,
  - performance monitoring and effectiveness evaluation of control measures,
  - categorisation, reporting, and evaluation of public safety incidents.

2.5 Control and mitigation options

There are a wide variety of public safety control and mitigation options. In many situations, a combination of control measures will be required to provide adequate risk mitigation and provide a level of redundancy, recognising that the effectiveness of some controls may change under different conditions. Table 2.1 briefly outlines some control and mitigation options.

Table 2.1: Control and mitigation options

Class	Control	Comments
Physical, Exclusion	Security fences and gates Barriers Personnel booms	Seeks to achieve full exclusion. May still require the public to acknowledge and abide by the control.
Physical, Warning	Sirens Flashing lights Signs, buoys	Provides a warning of a potential change. Often work as combinations, e.g., Siren and sign.
Operational	Controls on rates of change Limits on range Managed variability (e.g. small warning discharges) Pre-discharge inspections (in-person, camera, drone)	Often in conjunction with signs and may have temporal/seasonal aspects. Provide variability to trigger the public's awareness of change.
Knowledge & Education	Public education programmes Use of media Specific Event Ambassadors Stakeholder relations & collaboration	Seek to raise awareness including direct interaction with the public at high use times/ events. Interaction with schools and recreational groups to raise awareness.
Alternative	Specified recreational areas/times Public open days	Seek to locate public activities away from hazardous areas and/or at low risk times.
Rescue	Egress and self-rescue systems Safe entry/exit points	Seeks to maximise the chance that the public can be safely rescued.

3. Operational floods

Module 3 discusses the topic of flood hazards and appropriate Inflow Design Floods for dams. This is in the context of dam safety with associated links to emergency preparedness as discussed in Module 6.

Particularly for Medium and High PIC dams, more frequent but smaller floods should be comfortably passed by the available spill capacity with minimal dam safety risk. This section briefly discusses some of the considerations relevant to smaller operational floods. While these may not be significant to dam safety, they may be relevant to individual dams, and hence Owners, in terms of flood management.

3.1 Consequence of floods

While smaller, more frequent flood events may present minimal dam safety concerns, these same events may be significant or even catastrophic for business continuity, stakeholders, communities and other infrastructure.

There will be, in many cases, a range of design standards applied to infrastructure, unrelated to the dam, which could be impacted by a flood event. Typical flood standards are in the range 1 in 50 AEP to 1 in 200 AEP for structures such as stopbanks, bridges, roads and industrial infrastructure. It is therefore highly probable that, during flood events that are moderate from a dam design viewpoint, significant damage and associated consequences can arise elsewhere in the catchment.

For example, stopbanks protect property and people from flood hazards. Their design capacity means that, at a particular scale of flood, there is a relatively rapid increase in the probability of stopbank failure with associated consequences. Similarly at some design flood level a bridge may be destroyed or be unserviceable. The consequence of floods, and hence risk, does not therefore follow some progressive relationship as flood magnitude increases. Rather there is almost always a sequence of steps in consequence. This is demonstrated in Figure 3.1.

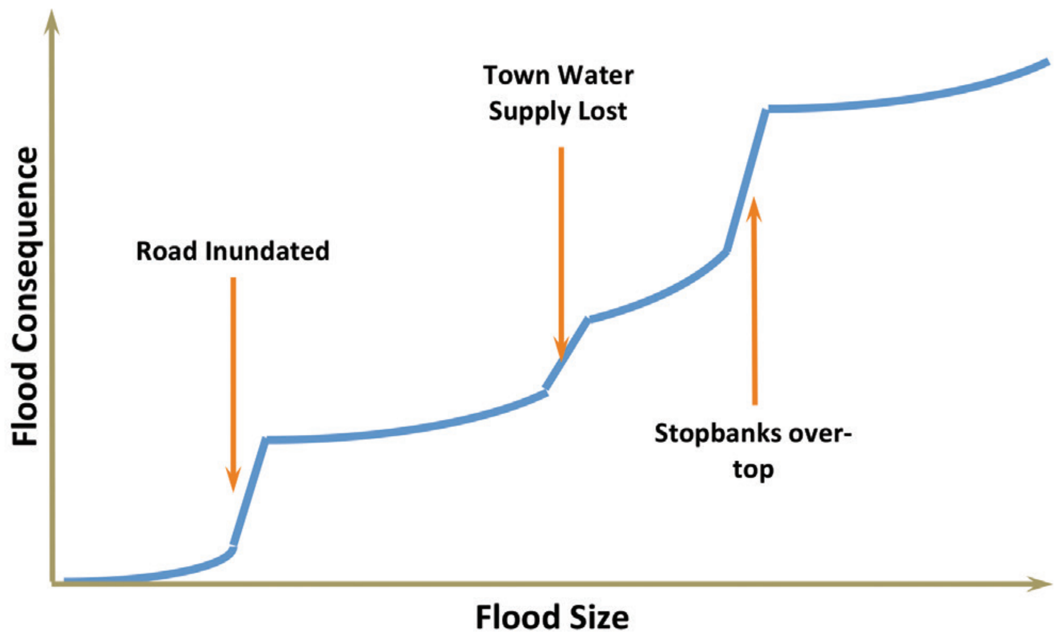

Figure 3.1: Flood consequence vs size

3.2 Flood management

Communities typically desire and expect dams to actively reduce the impact of flood events. The ability for a given dam to influence flood events is a function of a range of considerations dominated by the:

- Availability of forewarning of a flood.
- Volume of the reservoir in comparison to flood volume.
- Physical constraints associated with discharge.
- Operational constraints such as resource consents.

As flood magnitudes increase a given dam will therefore have less ability to reduce the impact of the flood. This issue is often difficult for communities to comprehend as they may have experienced the dam providing significant benefit during small flood events. Therefore, the expectation is that it should have a similar or even greater beneficial impact on larger events. Clearly the opposite is true.

Flood management, and the ability to partially mitigate flood risks, is unique to each dam and catchment, and as such there is no single methodology. Further, given changes to the dam, its operation, catchment properties, and hazards over time, it is likely that flood management options will also change with time.

It is also not simply a case of seeking to reduce the maximum flood flow, although this may be a desirable outcome. Depending on a range of interrelated sensitivities, the timing, duration, and rate of change in flow may also need consideration when managing flood events. Considerations when assessing flood management options may include:

- **Flood magnitudes and levels critical to other infrastructure or communities.** These will induce the steps in consequence compared to flood magnitude (see Figure 3.1).
- **Potential tidal or storm surge influence.** Tides and storm surges will impact downstream water levels and as such may change the rate of flow that the river can cope with before a given consequence is likely to arise.
- **Timing of release** (e.g. day vs night) and any change in vulnerability that may arise. It may be important to attempt to reduce flood releases during the hours of darkness when communities are more vulnerable.
- **Environmental impacts of releases.** Issues such as erosion and sediment movement may have environmental consequences.
- **Debris management.** Reservoir debris can block spillway discharge. Debris released downstream during floods can damage infrastructure and land use.
- **Financial consequence of draining reservoirs.** If a reservoir is lowered to facilitate greater flood storage this will have a financial and potentially societal impact; for example, reduced water supply security, reduced recreational benefits and reduced energy supply.
- **Public safety.** Considerations such as spilling water in advance of a flood to gain reservoir storage can have public safety implications. Particularly in larger catchments, there may be little indication lower in a catchment that a flood is pending. Early spill releases may induce greater public safety risk than the flood itself.
- **Time available to adjust reservoir level prior to a flood event.** If greater time is available, actions, and hence possible impacts, can be more subtle. Improved warning times are a valuable tool in improving flood management options.
- **Precedent flood events.** Past flood events are useful in verifying dam flood performance and the response of downstream river systems. Dam flood capacity cannot be commissioned at the end of construction like other dam components. Performance during actual flood events provides partial verification and the ability to learn how larger events may be handled. Precedent flood events can also be useful in defining when flood management should be escalated. If it is known that minimal risks arise from up to certain magnitude events, then these can be considered normal operation.

Many of the points above conflict with each other. In optimising dam operation for a given consideration there will almost always be compromises to others. Flood management and associated procedures need to consider these trade-offs and should never result in a compromise in dam safety.

4. Lifetime changes

There are many changes that can occur over a dam system's lifespan that may influence dam safety management. These may include changes and modifications initiated by the Owner, as well as external influences beyond the Owner's control but of which they need to be aware. Change in dam use is discussed separately in section 4.

Some potential lifetime changes that may influence dam safety management are (also refer Module 5 Dam Safety Management):

- **Upstream catchment changes** – land use changes upstream can result in changes in flood risk, sediment and debris inflows and changes in water quality. All these can influence the ability of the dam system to function as intended and meet performance requirements. Additional dams built upstream may also represent a change in risk for the existing dam.
- **Reservoir changes** – sedimentation, land use changes along reservoir boundaries, recreation, and the potential instability of reservoir slopes due to erosion or drawdown operations all require dam safety management.
- **Dam use and operation** – this will almost certainly change over time in response to changes in use or demand. This could mean an existing use is discontinued and replaced by a new use, or the addition of multiple uses (e.g. recreation) over time. Constraints may also be imposed though resource consent conditions that may influence operational flexibility and how the dam can respond to extreme events.
- **Progressive deterioration** – despite regular prescribed maintenance, some dam components will deteriorate. This will lead to the need for periodic replacement, upgrades or rehabilitation to maintain an acceptable level of dam safety.
- **Sudden deterioration** – this may occur following a major event, during which the dam may perform as intended but not without incurring damage that requires repair (e.g. spillway channel or stilling basin erosion) or operational modifications to maintain an acceptable level of dam safety. In an extreme case decommissioning may be necessary.
- **Legislative changes** – these may result in changes to acceptable dam safety practices and thresholds. As legislation can be considered to represent the expectations of society, these changes reflect the evolving acceptance of risks by communities.
- **Health and safety considerations** – dam safety management typically incorporates a range of physical inspections and measurements to verify performance. Where these rely on personnel accessing structures, future health and safety requirements may limit access and necessitate the introduction of alternative measurements or systems to verify dam performance.
- **Downstream changes** – the population and/or value of the culture, heritage, environment, and infrastructure located within the potential dam-break flood inundation area will almost certainly change with time. While this is likely to be a progressive evolution it may manifest itself in a series of step changes in dam safety requirements appropriate to the PIC of the dam.
- **Technological advances and standards of practice** – technological improvements and an improved understanding of dam performance may result in a corresponding shift in dam safety requirements, even if the dam, its use, and the environment in which it is located, remain constant.
- **Understanding of threats and hazards** – knowledge and understanding of external hazards and threats such as flood, earthquake, landslide and other natural hazards can change over time. For example, longer historical records, paleo hydrology and climate change can lead to updated flood estimates for unusual and extreme events. Seismology and earthquake engineering are evolving practices that can change earthquake prediction and/or expected dam performance. Changes to internal and non-natural hazards, such as operations, plans and vandalism, can also affect dam safety.

- **Physical security and cyber security threats** – dam system functions may be threatened by breaches of dam system property, operating technology, and information technology. Security threats and vulnerabilities that impact dam safety and reservoir safety should be assessed, and appropriate plans and control measures implemented.
- **Acceptability of risk to society** – dam operations during normal, unusual, and extreme loading conditions often pose societal risks. Future changes in societal acceptance of dam-related risks could significantly impact dam safety.

5. Identifying and managing dam safety issues

5.1 Philosophy

it is essential to identify and manage dam safety issues. These issues should be addressed with established processes and procedures as part of the Dam Safety Management System (DSMS) (refer Module 5, Section 3).

Dam safety issues are defined as a broad set of issues that arise in a DSMS and affect dam safety including physical infrastructure issues, dam safety deficiencies (potential or confirmed) and non-conformances (refer section 5.2 for detailed definitions). Dam safety issues should be identified by the dam Owner and/or their Technical Advisor through the following dam safety management activities (refer Module 5: Dam Safety Management):

- Surveillance and monitoring.
- Inspections.
- Gate and valve system testing.
- Dam safety reviews.
- Failure Modes and Effects Analysis (FMEA).
- Investigations and studies.
- Risk assessments.
- Emergency Action Plan testing.
- DSMS audits and reviews.

5.2 Dam safety issue categories

When managing dam safety issues, it is helpful to place them in categories so that:

- Clarity of the different issues and their relative importance can be achieved.
- The significance of issues can be better understood.
- An appropriate response to the issues can be identified.

These Guidelines recommend the following dam safety categories, as shown in Figure 5.1 and described in sections 5.2.1, 5.2.2 and 5.2.3.

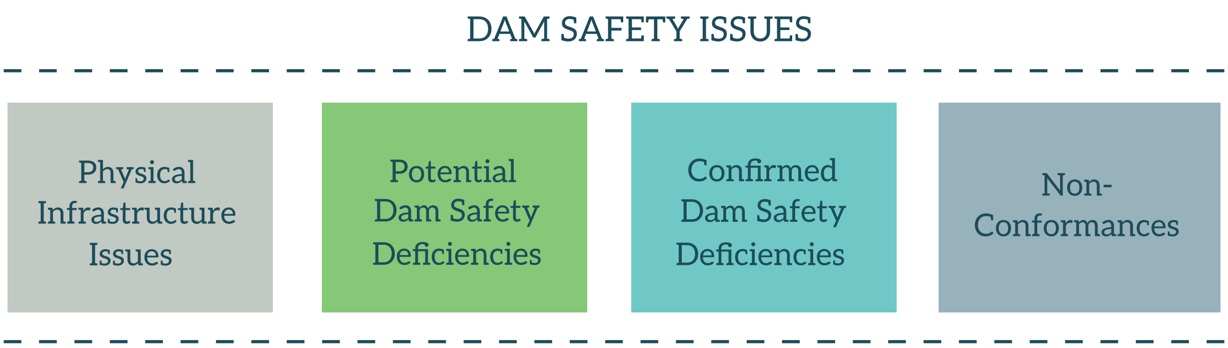

Figure 5.1: Dam safety issue categories

5.2.1 Physical infrastructure issues

Physical infrastructure issues are where equipment, access, instrumentation, communications, or maintenance is insufficient to verify satisfactory dam performance. The following examples are provided:

- Inadequate or unsafe access preventing surveillance and monitoring observations at the dam system.
- Vegetation on a dam embankment or abutments preventing visual observation.
- Dam performance monitoring instrumentation is inadequate, out of calibration, or requires maintenance.
- Instrument telemetry links or other data automation equipment are not functional.
- Surface or internal relief drain maintenance is required.
- Wave or surface runoff erosion requires repair.
- Concrete requires surficial repair.
- Spillway walls, chute joints, or waterstops require maintenance.
- Gate and valve equipment maintenance is required (e.g. paintwork, grease winch ropes, change oil, check batteries, check limit switches).

Physical infrastructure issues are usually considered as part of normal asset management, making them potentially suitable for prioritising and planning responses based on their anticipated impact on normal business operations.

However, in some cases this approach may be inappropriate as certain physical infrastructure issues must be addressed immediately and there may not be a clear distinction between some physical infrastructure issues and dam safety deficiencies.

5.2.2 Potential or confirmed dam safety deficiencies

Dam safety deficiencies include potential dam safety deficiencies, where particular dam system functions (e.g. containment, conveyance, control) or performance requirements may not be met (unknowns exist and further investigation and/or assessment is required), and confirmed dam safety deficiencies where adverse function or performance has already been observed or will definitely come to pass under realistically expected loading conditions. They are usually where a fundamental flaw (design, construction, mis-operation, or previously unrecognised condition) or vulnerability exists that may develop, under certain circumstances or loading conditions, into an identifiable (and credible) potential failure mode. The following examples are provided:

- Embankment dam material compatibility and filter criteria are not met.
- Foundation or abutment defects were not treated during dam construction.
- The capacity of the spillway is less than the recommended performance criterion.
- The dam does not meet structural performance criteria.
- High foundation uplift pressures beneath a concrete dam, or high internal piezometric pressures in an embankment dam or its abutment.
- Internal erosion has initiated or is in progress.
- The gate or valve system does not meet functional performance requirements.
- The gate or valve systems are inappropriately operated.
- The gate or valve system operators are not adequately qualified and trained.
- Reservoir shoreline instability exists and could initiate dam overtopping.

Dam safety deficiencies can be very complex and take time to investigate, assess, and resolve effectively and safely. Through appropriate investigation and/or assessment, potential dam safety deficiencies may be resolved as either not a dam safety deficiency or a confirmed dam safety deficiency. This process should be completed in conjunction with appropriately experienced Technical Advisors and thoroughly documented. Dam safety deficiency and risk management is discussed in detail in section 5.4. Risk-informed decision making, discussed in section 5.4.2, is a valuable tool that can assist in the prioritisation and management of dam safety deficiencies.

5.2.3 Non-conformances

Non-conformances are where DSMS processes and procedures have not been followed, or established dam safety practices have not been implemented. The following are example non-conformances:

- The DSMS does not exist or is inadequate.
- The DSMS is not adequately documented.
- The DSMS processes, procedures, or plans are not followed.
- Appropriate dam safety governance, oversight, and enabling arrangements do not exist.
- DSMS roles and responsibilities are not adequately defined and understood.
- The DSMS is not implemented by appropriately experienced and qualified personnel.
- Dam system functions, failure modes and consequences of failure are not adequately defined or understood.
- The surveillance inspectors are not adequately qualified and trained.
- Dam safety issues are not escalated, recorded, and tracked appropriately.
- Dam safety issues are not resolved in a timeframe appropriate to the level of risk.
- DSMS record-keeping or information management is inadequate (e.g. design, construction, operation, maintenance, surveillance, or testing records are limited or unavailable).
- An Emergency Action Plan does not exist, is inadequate, or is not tested.
- Operating procedures or instructions are not provided at the local gate control facility.
- Dam safety regulatory requirements are not met.

Non-conformances are addressed by taking appropriate corrective actions to achieve conformance with the Owner's procedures and processes, relevant legislation, and established dam safety practice.

5.3 Dam safety issue recording, prioritising and tracking

An Owner should have a systematic and auditable approach to recording, updating and tracking their dam safety issues. The following should be clearly identified for each issue and available for update and review:

- The nature of the issue.
- When the issue was identified.
- Supporting references and information.
- The verified category of the issue (physical infrastructure issue, potential dam safety deficiency, confirmed dam safety deficiency, or non-conformance).
- Who is responsible for addressing the issue.
- The priority of the issue (updated as the understanding of the issue has developed).
- The planned investigation, assessment, and resolution process.
- Progress and decisions in the investigation, assessment, and resolution process.
- Overall tracking and reporting on the status of the issue.

The importance of the above as an effective recording and tracking tool, and as evidence of prudent dam safety issue management, cannot be overstated.

5.4 Dam safety deficiency and risk management

5.4.1 Philosophy

Dam safety deficiencies, potential or confirmed, can arise from internal influences, such as physical changes or processes that can affect dam safety, or external influences such as changes in hazards, land use and consent requirements that can affect dam safety. A dam safety deficiency can therefore be associated with:

- Inadequate design and construction, where the performance of the dam is inconsistent with the design assumptions and/or modern assessment criteria (e.g. stability, flood passage, seismic loads). Such deficiencies may be identified within one to two years of commissioning, but this is not always the case as some deficiencies may take many tens of years to materialise.
- Deterioration in the performance of a dam, or appurtenant structure, which cannot be addressed through normal maintenance. Deterioration is typically associated with gradual changes that occur over time. But deterioration can also include sudden changes that result from equipment failures, major floods or large earthquake events.
- The development of engineering practice and design criteria. This might include advances in techniques for assessing natural hazards and advances in the understanding of phenomena relating to dams, such as internal erosion processes.
- A change in the physical and social environment in which the dam operates. Environmental changes can include development in downstream flood plains, increases in downstream populations, and operational constraints imposed though the renewal of resource consents.

The Building (Dam Safety) Regulations (2022) require a Dam Safety Assurance Plan (DSAP) for Medium and High PIC dams. Management of dam safety issues, including deficiencies, is part of the Owner's DSAP requirements. Further guidance on regulatory DSAP requirements is provided in Module 1 (Legal Requirements) and Module 5 (Dam Safety Management).

Guidance for the investigation, assessment, and resolution of dam safety deficiencies, including the use of risk-informed decision making (RIDM), is provided in the following sections. Where a confirmed deficiency indicates an elevated likelihood of dam incident or failure, interim risk reduction measures (such as reservoir level restrictions and additional surveillance) and Emergency Action Plans (EAPs) may need to be initiated. Interim risk reduction is discussed later in this module. Guidance for the preparation and maintenance of EAPs is included in Module 6 (Emergency Preparedness).

5.4.2 Dam safety deficiency management process

A safe dam does not impose an unacceptable risk to people, property and environment, and meets safety criteria that are acceptable to the government, the engineering profession, and the public. Dam safety deficiencies represent unrealised potential for the uncontrolled release of the reservoir contents, dam failure, or functional failure of one or more dam system components that reduce the safety of the dam. Dam safety deficiencies represent a dam safety risk to the Owner, the public, downstream property, the environment, and cultural sites.

Risk is the product of the likelihood of an adverse event (that results from the dam safety deficiency) and the consequences of that event. These Guidelines recommend that Owners manage their dam safety deficiencies using a risk management process that includes the steps discussed in the following sections and illustrated in Figure 5.2.

These Guidelines recommend using a risk-informed decision making (RIDM) framework to manage dam safety deficiencies. 'Risk-informed' implies using risk assessment and risk understanding as inputs to decision making. RIDM can account for a wider range of parameters and utilise risk assessment in its broadest sense as an input to determine the benefits from risk reduction. Expressing deficiencies in risk terms allows the comparison of risks posed by deficiencies at one dam or the comparison of risks across a portfolio of dams. Therein a reasoned approach to prioritising deficiencies can be developed and the basis for risk reduction communicated to stakeholders. Risk estimation carries inherent uncertainty and care should be taken not to present risk estimates as an absolute or certain measure.

Dam safety risks do not often align with normal business risk management models because of the sometimes very low probability of the consequences, which may be extreme compared to normal business risks. Furthermore, a dam failure resulting in the loss of a life could have criminal consequences for the Owner that cannot be captured in a business risk model. While these differences need to be recognised by Owners, a RIDM dam safety framework allows Owners to understand the nature and levels of risks, prioritise risks, target resources effectively, and demonstrate a prudent approach to reducing risks associated with their dams.

Owners should have clear and defined procedures in their DSMS for the investigation, assessment, management and resolution of dam safety deficiencies. All Owners should be able to demonstrate that their dam safety deficiencies, whether they are potential or confirmed, are being addressed in a prudent manner.

Deficiency management procedures may involve selection of a team to investigate and assess deficiencies, estimate risk levels, develop risk reduction options, complete independent reviews, and provide feedback to stakeholders. ALARP is a principle established in Common Law that risks should be reduced to the point where the cost of reducing the risk is grossly disproportionate to the improvements gained. It is also important that deficiency management procedures are sufficiently flexible to allow for a timeframe appropriate to the level of the risk, and to adapt to changes that may result from new information.

Note that these Guidelines do not provide risk criteria to determine whether or not risk reduction should be undertaken. Owners should consider their organisational risk management objectives and consult with stakeholders and Technical Advisors to determine if risk reduction measures are warranted and what risk reduction measures should be implemented.

RIDM is an essential tool for the management of dam safety deficiencies. It is not, however, a means for Owners to avoid mitigation measures that should be completed at their dams. Risk concepts are outlined further in the following subsections.

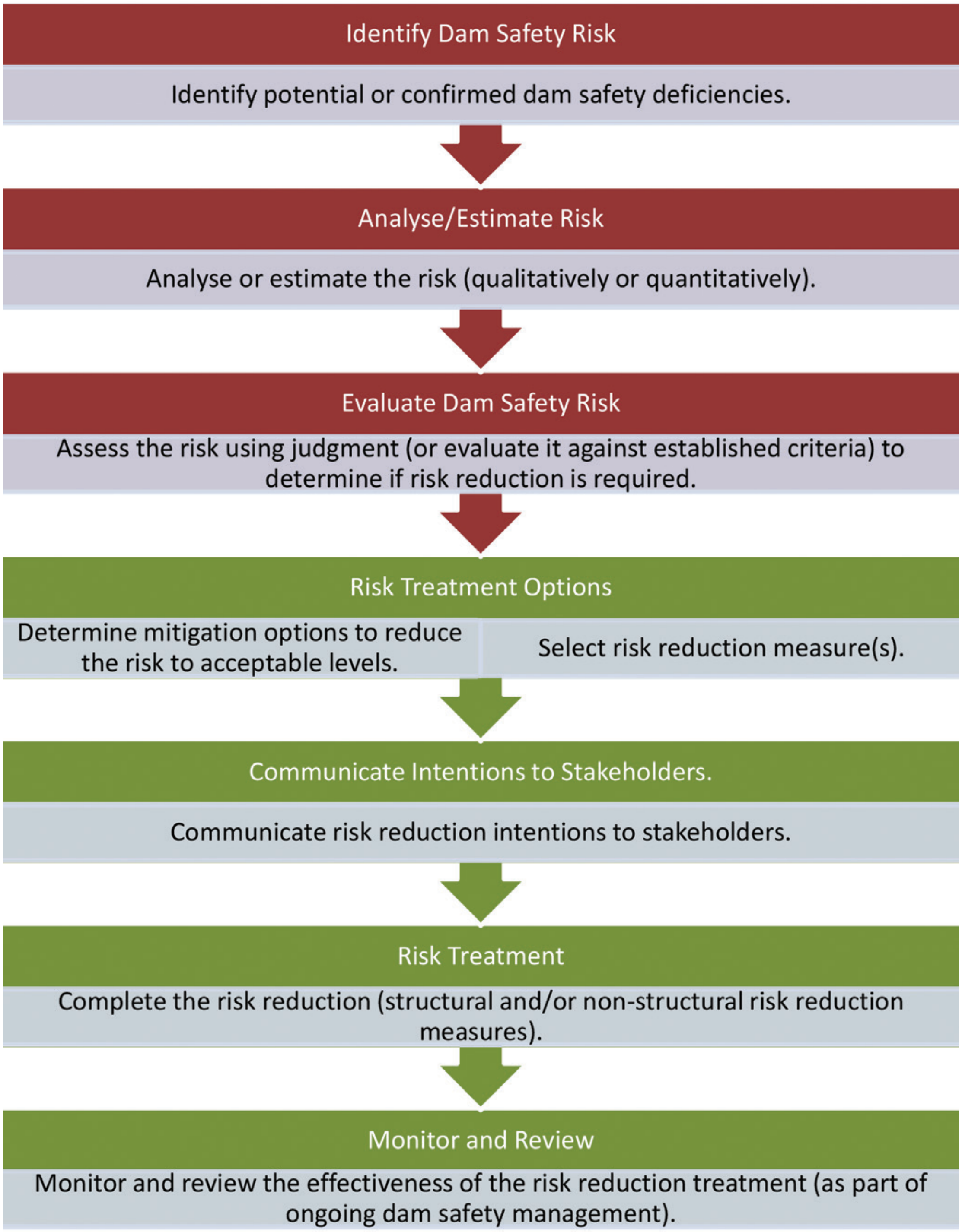

Figure 5.2: Dam safety risk management process

5.4.3 Risk definitions

Definitions of risk terminology are contained in NZS ISO 31000:2009 (Standards New Zealand, 2009) and ICOLD Bulletin 130 (ICOLD, 2005). They are included in the Glossary in the Parent Document and are repeated here for convenience:

- **As Low As Reasonably Practicable (ALARP)** - a principle established in Common Law that risks should be reduced to the point where the cost of reducing the risk is grossly disproportionate to the improvements gained.
- **Consequence** – the outcome or impact of an event.
- **Residual risk** – the remaining level of risk at any time before, during and after a programme of risk mitigation measures has been taken.
- **Probability** – a measure of the degree of confidence in a prediction, as dictated by the evidence, concerning the nature of an uncertain quantity or the occurrence of an uncertain future event. It is an estimate of the likelihood of the magnitude of the uncertain quantity, or the likelihood of the occurrence of the uncertain future event. This measure has a value between zero (impossibility) and 1.0 (certainty)
- **Risk** – a measure of probability and severity of an adverse effect to life, health, property or the environment. In the general case, risk is estimated by the combined impact of all triplets of scenario, probability of occurrence and the associated consequence. In the special case, average risk is estimated by the mathematical expectation of the consequences of an adverse event occurring (that is, the product of the probability of occurrence and the consequence, combined over all scenarios).
  Risk requires an understanding of:
  - the probability of the scenario (e.g. the failure mode),
  - the probability of an adverse response to the scenario (e.g. the probability of an uncontrolled release of water due to the scenario),
  - the consequences given that the adverse event occurs.
- **Risk analysis (risk estimation)** – the use of available information to estimate the risk to individuals or populations, property, or the environment from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification, consequence estimation, probability estimation, and risk estimation.
- **Risk assessment** – the process of evaluating risk and potential related risk reduction requirements. Risk assessment incorporates the risk analysis and risk evaluation phases.
- **Risk criteria** – the terms of reference against which the significance of a risk is assessed.
- **Risk reduction** – actions taken to lessen the likelihood of an occurrence or its adverse consequences, or both.
- **Uncertainty** – result of imperfect knowledge concerning the present or future state of a system, event, situation or population under consideration. The level of uncertainty governs the confidence in predictions, inferences or conclusions. In the context of dam safety, uncertainty can be attributed to (i) inherent variability in natural properties and events, and (ii) incomplete knowledge of parameters and the relationships between input and output values.

Because of the unique nature of every dam system, its setting and the hazards faced, uncertainty exists in most dam safety assessments. Uncertainty is present in all three of the above risk parameters (see Risk).

5.4.4 Procedures for identifying, estimating and evaluating dam safety deficiencies

Owners should have clear and defined procedures in their DSMS for identifying, estimating, and evaluating dam safety deficiencies. Where an Owner has a number of dams, deficiency management may be undertaken on a portfolio-wide basis to prioritise risk reduction.

Dam safety deficiencies may be identified in conjunction with any dam safety management or operational activity. However, they are most often identified in conjunction with dam safety reviews and Failure Modes and Effects Analysis (FMEA). The initial identification of a deficiency might be tentative until further information and/or expertise more thoroughly assesses the issue and makes a more definitive determination.

Identifying dam safety deficiencies requires a comprehensive understanding of the dam system, hazards, and failure modes, along with dam safety engineering knowledge and experience. Dam safety specialists are often involved in identifying dam safety deficiencies. The level to which dam safety deficiencies are considered and assessed should be commensurate with the consequences of failure of the dam.

Risk estimation or analysis of dam safety deficiencies typically involves estimating the risk level of each dam safety deficiency. Risk estimates of dam safety deficiencies may be made qualitatively or quantitatively. Guidance on risk estimation methods for dams is provided in Fell et al., (2015) and ICOLD Bulletins (e.g. ICOLD, 2005; ICOLD, 2021b). Qualitative risk level categories ranging from very low to very high are commonly used in New Zealand. One reason to estimate the risk levels of dam safety deficiencies is to help prioritise them. It is essential to prioritise multiple dam safety deficiencies of a dam system or dam portfolio to effectively use limited resources for risk reduction.

Figure 5.3 Tolerable Risk Framework below is taken from the Natural Hazard Commission Toka Tū Ake (formerly EQC) Natural Hazard Risk Tolerance Literature Review (EQC, 2023a). This is based on the UK Health and Safety Executive's risk framework (HSE, 2001). Figure 5.3 illustrates the concepts of unacceptable, tolerable and broadly acceptable risks. Characteristics of unacceptable, tolerable, and broadly acceptable risks applicable to dam safety are outlined below.

1. Unacceptable (also referred to as Intolerable)
   a. Risk cannot be justified except in extraordinary circumstances.
   b. High risk level.
   c. Reflects poor or outdated practice / conditions.
2. Tolerable if ALARP (As Low As Reasonably Practicable)
   a. Tolerable only if risk reduction is impracticable or if its cost is grossly disproportionate to the improvement gained.
   b. Medium risk level.
   c. Partially reflects recommended practice / conditions.
   d. Note: Figure 5.3 includes a note in the lower portion of the 'Tolerable if ALARP region' – 'Tolerable if cost of reduction would exceed improvement'. This note defines the boundary between the 'Tolerable if ALARP region' and 'Broadly acceptable region' for the purposes of these Guidelines. Any risk categorised in the 'Tolerable if ALARP region' is subject to ALARP. If a risk is reduced such that it becomes 'Broadly acceptable', no further risk reduction is required.
3. Broadly acceptable
   a. Necessary to maintain assurance that risk remains at this level.
   b. Low risk level.
   c. Fully reflects recommended practice / uncompromised conditions.
   d. Meets current standards, codes and guidelines, including these Guidelines.

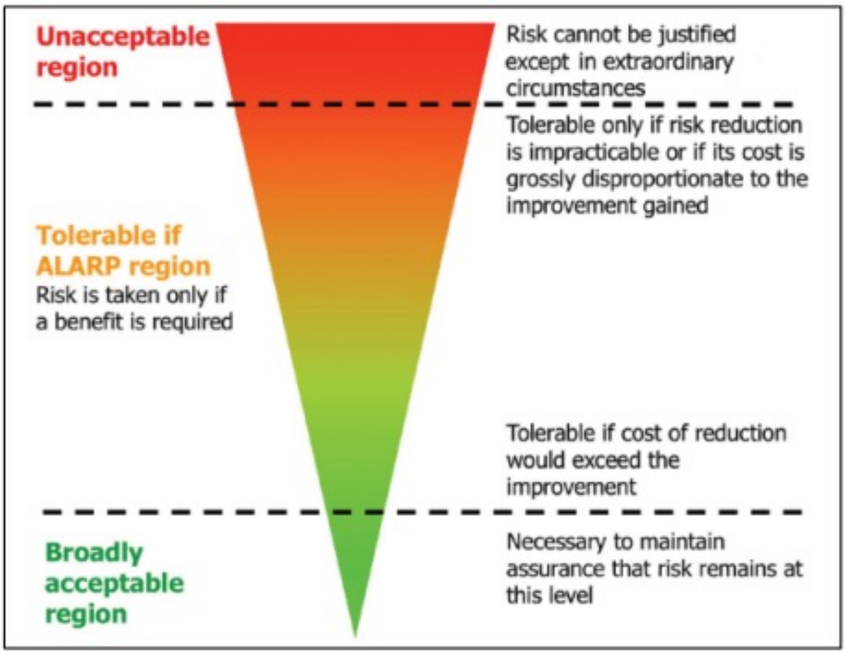

Figure 5.3: Tolerable risk framework – (EQC, 2023a)

The Natural Hazard Commission Toka Tū Ake (formerly EQC) Risk Tolerance Methodology (EQC, 2023b) provides additional discussion about assessing risk tolerance.

Two fundamental tenets that drive acceptance of risk are described in ICOLD Bulletin 130 (ICOLD, 2005):

- Equity: The right of individuals and society to be protected, and the right that the interests of all are treated fairly. In the case of dams this is especially true with respect to those individuals not receiving the benefit from the presence of the dam.
- Efficiency: The need for society to distribute and use available resources so as to achieve the greatest benefit.

These tenets are often competing but demonstrate that, in matters of life safety, the public have a say in risk-based decision making that affects their safety. Owners should note that affordability in implementing risk reduction measures is unlikely to be considered as a factor when the risks are deemed unacceptable.

5.4.5 Risk treatment options

Unacceptable deficiency risks require risk mitigation. Deficiency risks considered 'Tolerable if ALARP' require assessment of risk mitigation.

Risk mitigation options may include administrative, operational change, maintenance, surveillance, and structural improvement measures. As examples, an administrative risk reduction could include improving downstream emergency preparedness; operational change could include reducing reservoir level; maintenance risk reduction could include improving spillway and low level outlet gate reliability; surveillance risk reduction could include increased surveillance frequency; and structural improvement risk reduction could include spillway repair. Risk mitigation options need to be deficiency specific but developed in conjunction with other risk mitigations in the dam system to account for interdependencies.

The amount of risk reduction provided by various risk mitigation options will vary.

5.4.6 Time frame for risk mitigation

Timeframes for addressing dam safety deficiencies, following their identification, are typically not prescribed in standards or regulations. The unique nature of each situation requires evaluation. Nevertheless, the dam Owner has a duty of care to act in a timely manner if downstream consequences, especially public safety risks, increase. A timely response to a dam safety deficiency may also minimise any adverse effects on a dam Owner's business that could result from a reduction in asset availability.

An appropriate timeframe for action to be taken for an identified and confirmed dam safety deficiency could be immediate or could range from months to years, depending on the nature and significance of the deficiency. Both components of the risk equation (likelihood and consequences) need to be assessed. Consequences can include life safety, third party damages, loss of service provided by the dam, or financial losses to the Owner.

When dealing with a portfolio of dams, where an Owner has conducted a dam safety evaluation across the entire portfolio, it is recognised and generally accepted that it is not possible for an Owner to address all identified dam safety deficiencies at one time.

The Owner should follow a two-step process to demonstrate defensible diligence in dam safety risk management:

- Implement an interim risk management plan that will effectively provide protection through elevated management actions (e.g. reservoir restrictions, intensive monitoring, warning systems, etc). This includes taking immediate action on any dams where the identified dam safety risk is recognised as imminent or extremely serious.
- Once the interim risk management plan is in place, develop a deficiency investigation and risk reduction plan based on a risk-informed prioritisation timeframe. Such a plan should be set in the context of the wider constraints on the dam safety effort as dictated by regulation and economic pressures. The risk reduction plan (priorities and schedule) must address all of the deficiencies in a way that takes account of the various risks and constraints.

Partial risk reduction, rather than ideal risk reduction, may be an economic and timely risk reduction approach. Some deficiencies present opportunity for staged risk reduction. Significant improvement in the risk position should be achieved when risk reduction to a broadly acceptable level is impracticable.

5.4.7 Interim risk mitigation

Where potential dam safety deficiencies relate to rare events, such as extreme earthquakes or floods, detailed and systematic studies may be required to confirm the extent of the potential deficiency and whether a confirmed deficiency exists. Such studies can take time (in some instances several years). In these cases, a preliminary estimate of risk should be completed to determine what, if any, interim risk reduction measures are necessary. Appropriate interim risk reduction measures could include:

- Increasing surveillance and monitoring.
- Changing operational procedures (including lowering the reservoir level).
- Improving warning systems.
- Improving emergency planning and preparedness.
- Stockpiling materials.
- Constructing temporary buttresses.

There may also be situations where the above risk reduction measures achieve acceptable longer term risk reduction and remove the need to undertake structural works to address the dam safety deficiency. However, this will depend on the nature of the deficiency and the ability to demonstrate how the risk will be reduced. Owners should consult appropriate Technical Advisors and stakeholders in making such decisions.

6. Dam rehabilitation

6.1 Introduction

Dam rehabilitation is synonymous with remedial work considered necessary to restore a dam system to an appropriate level of function and performance. It may become necessary for a wide variety of reasons that include design and/or construction deficiencies, material degradation, wear of equipment critical to dam safety (e.g. lifting gear for a spillway gate), damage from flood or earthquake events, damage from vandalism, changes in operating conditions, changes in flood and earthquake loadings, changes in the PIC of a dam, and legislative requirements.

The following subsections discuss the management of rehabilitation works and outline conditions that can necessitate the completion of rehabilitation works at concrete dams, embankment dams, and appurtenant structures. ICOLD Bulletin 119 (ICOLD, 2000) outlines possible remedial measures to address identified dam safety deficiencies and includes many examples of rehabilitation works that have been completed.

6.2 Rehabilitation considerations

6.2.1 Dam safety

Dam safety considerations which must be addressed during the completion of any dam rehabilitation project include:

- The safety of the dam in its existing condition.
- The safety of the dam during the completion of the rehabilitation works.
- The safe passage of flood events during the completion of the rehabilitation works.

The urgency with which rehabilitation works should be completed should reflect the nature of the identified dam safety deficiency and the level of risk it presents. For example, for a Medium PIC embankment dam, an inability to safely pass a 1 in 100 AEP flood event should be urgently addressed but an inability to safely withstand the effects of a 1 in 2,500 AEP earthquake event could be addressed over a longer timeframe.

In many cases, the safety of a dam prior to the completion of rehabilitation works can be increased by enhanced surveillance and monitoring of the identified deficiency or by lowering the reservoir to reduce the loads on the dam. Increased warning systems for at-risk downstream areas may also be suitable as an interim measure. In some cases, the best solution may be to stage the rehabilitation project so that the risk is reduced progressively through the completion of initial temporary works, that are quickly undertaken to address a particular deficiency, and the completion of the full permanent solution at a later date.

The safety of a dam should not be adversely affected during the completion of a rehabilitation project. The Designer and Owner must be satisfied that the proposed methodology for the construction of the rehabilitation project does not result in unacceptable dam safety margins and that appropriate management systems are in place for monitoring the performance of the dam throughout the construction process.

The safe passage of flood events during the construction of rehabilitation works requires careful consideration. For example, a requirement to rehabilitate a spillway gate or a spillway facility must be carefully planned to minimise the potential for incoming flood events to exceed the available spillway capacity. Planning must consider operational constraints, the flood event to adopt for the design of the rehabilitation works, and how the flood event will be safely managed during the construction of the rehabilitation works. It may be necessary to complete the rehabilitation works at a time of the year when high flood events are less likely to occur, to lower the reservoir to provide flood storage, and/or to complete the rehabilitation works in a way which minimises the reduction in spillway capacity during the construction of the rehabilitation works.

A dam may fulfil an important public safety function, such as bulk water supply or flood management, and the rehabilitation project will need to consider how the function can be practically managed through construction. Such matters can often influence or even dominate the final design solution. In some cases, it may be necessary to adopt a more expensive solution, such as a complete replacement structure, to effectively manage the risks during the implementation of the rehabilitation works.

6.2.2 Design, construction, commissioning and handover

The completion of dam rehabilitation projects, particularly significant projects, requires processes not dissimilar to those for new dams. In fact, rehabilitation projects can be more complex as the existing and potential flood loadings on the dam, and the operations associated with the dam and reservoir, need to be managed throughout the rehabilitation work.

The design, construction, commissioning, and handover of any dam rehabilitation works should be completed in accordance with the procedures outlined in Modules 3 and 4. However, special attention should be paid to the following:

- The principle of 'do no harm' should be present throughout the risk reduction process including the selection of the preferred rehabilitation solution, and the design and construction of the preferred solution. A significant number of well-intended dam rehabilitation projects have resulted in dam failures or serious dam incidents. Paradoxically, a number of these projects were rehabilitation projects directed toward addressing very unlikely events.
- The original design and construction records that relate to the proposed rehabilitation works. The records should be carefully reviewed to obtain a clear understanding of the original design assumptions and the structural integrity of the existing works. Where these are unavailable, or are considered to be unreliable, extensive investigation or testing may be required in order to establish existing details.
- The methodology for constructing the rehabilitation works and its effects on the safety of the dam. Construction methods can have significant effects on dam safety. For example, the removal of a portion of the downstream shoulder of an embankment dam to install filter and drainage facilities could result in a significant short-term reduction in embankment stability.
- The consequences of the rehabilitation works on the overall safety of the dam. For example, a raising of the dam crest to obtain additional freeboard could lead to an increase in hydraulic load and a reduction in dam stability.
- The need for re-analysis of the complete structure. If the rehabilitation works incorporate substantial modifications, or if the design assumptions are significantly different from the original design assumptions, the complete structure should be reanalysed.
- The revision of operating procedures and Dam Safety Management Systems, and the training of personnel with operation and dam safety management responsibilities. Rehabilitated dams and appurtenant structures may have different operational requirements, particularly during extreme events, than the original structures. In addition, different surveillance and monitoring procedures may be necessary for monitoring the performance of rehabilitated structures.
- The need for instrumentation to monitor the performance of the completed rehabilitation works. Rehabilitation works often provide good opportunities to upgrade existing instrumentation or install new instrumentation for the monitoring of dam performance.

Many of the items listed above can benefit from the use of risk-informed decision making (RIDM) techniques as discussed above. The dam Owner and their Technical Advisors should assess risks covering the above matters to demonstrate adequate consideration of the risks relating to the rehabilitation itself, as well as the original dam safety deficiency. This should include aspects covering safety in design.

6.3 Rehabilitation work on concrete dams

Conditions that can necessitate the completion of rehabilitation works on concrete dams include ageing processes associated with the foundation and the body of the dam, the adoption of different design criteria arising from a change in the PIC of the dam, an improved understanding of flood or earthquake hazards, and damage incurred during extreme flood or earthquake events.

Such conditions can include:

- A loss of foundation strength or stability, resulting from reservoir saturation and the change to the foundation's hydraulic regime, changes in the groundwater regime adjacent to the foundation, or chemical and physical alteration of the foundation rock.
- Foundation erosion, resulting from the erosion of rock joint materials by high hydraulic gradients or solution processes where dams are founded on soluble rocks (e.g. limestone).
- Degradation of grout curtains, resulting from inadequate design or construction, deformation during or following lake filling, or erosion of the foundation leading to increased hydraulic gradients.
- Degradation of drainage facilities, resulting from inadequate design or construction, or insufficient or inappropriate maintenance.
- Degradation of concrete, resulting from alkali-aggregate reaction or the action of sulphates on concrete and mortar.
- Cracking of concrete, resulting from shrinkage and creep.
- Cracking of concrete, resulting from an inability of the structure to withstand actual loadings.
- Degradation of dam faces, resulting from chemical reactions between the concrete and the reservoir, and from freeze and thaw effects.
- Deterioration of structural joints, resulting from inadequate design and construction, deformation, or waterstop damage.
- Loss of post-tensioned force in cable anchors, resulting from corrosion.
- Insufficient flood passage capacity.
- Inadequate structural stability under normal, flood, or earthquake load conditions.

6.3.1 Rehabilitation measures

Inadequate performance or factors of safety under all loading conditions, or the adoption of different design criteria, may necessitate rehabilitation works to improve dam performance or stability. Dam performance and stability can be improved by:

- Increasing the vertical force by enlarging the profile of the dam, adding ballast, or installing post-tensioned cable anchors.
- Increasing the resisting horizontal force by the construction of a downstream buttress.
- Draining the dam and its foundation to reduce uplift.
- Grouting or the construction of shear keys to provide additional friction along sliding surfaces.
- Installing an upstream waterproof membrane to reduce dam leakage.
- Installing an upstream seepage blanket to reduce foundation seepage pressures.
- Installing a crest wall and/or raising the spillway chute walls and/or providing additional spill measures to increase flood capacity.
- Toe protection works to prevent erosion of the foundation.

6.4 Rehabilitation work on embankment dams

As for concrete dams, conditions that can necessitate the completion of rehabilitation works on embankment dams include ageing processes associated with the foundation and the body of the dam, the adoption of different design criteria arising from a change in the PIC of the dam, an improved understanding of flood or earthquake hazards, and damage incurred during extreme flood or earthquake events.

Such conditions can include:

- Observation of material transport through the dam, along conduits, or through the foundation related to internal erosion (e.g., piping).
- The potential for internal erosion.
- Observation of slumps, depressions, or deformation of the dam or the abutments.
- Identification of potentially liquefiable materials in the dam or its foundation.
- Identification of a low permeability core (or similar element) not constructed high enough to assure dam safety during normal or flood operating conditions.
- The lack of filter protection for the full height of the core, where a filter is necessary for the prevention of internal erosion or piping.
- An improved understanding of material performance under normal, flood or earthquake loading conditions (e.g. erodibility, permeability, liquefaction).
- Insufficient flood passage capacity.
- Inadequate structural stability under normal, flood, or earthquake load conditions.

6.4.1 Erosion effects

Erosion effects can include internal erosion of the embankment, its abutments, or its foundation initiated by inadequate material compatibility and seepage control. Additionally, external erosion can be initiated by wave action on the upstream face or overtopping of the embankment. While external erosion of the upstream face can threaten the safety of an embankment dam, it can be readily identified through visual surveillance. If external erosion is repaired within an appropriate time frame it should not become a dam safety deficiency. In contrast, internal erosion may not be observed for a long time. If it is not addressed promptly, internal erosion can quickly become a significant dam safety deficiency. Internal erosion or an unacceptable risk of internal erosion can occur in the embankment, in the foundation, or from the embankment into the foundation, and can be initiated by:

- A lack of filter and drainage protection, or inadequate filter and drainage protection, for seepage control.
- Internal instability of broadly graded embankment materials (e.g. glacial till).
- Hydraulic fractures in areas of low stress (e.g. through core trenches and adjacent to conduits).
- The presence of preferential seepage paths along conduits or in the foundation, or the development of preferential seepage paths over time in the dam or through infilled joints in the foundation.
- Dispersive clays.

6.4.2 Deformation effects

Deformation effects that can seriously threaten dam safety include differential settlements, slope instability initiated by inadequate shear strengths, and liquefaction of the embankment or its foundation during a large earthquake. Differential settlements can encourage the development of hydraulic fracturing, cracking, and low confinement pressures at interfaces between embankment dams and hydraulic structures, with subsequent increased seepage and internal erosion. The loss of shear resistance in the embankment dam or foundation materials due to saturation, creep, or liquefaction could cause slope instability, leading to sufficient crest deformation to initiate an overtopping failure. Compression of dam fill materials and foundations, particularly soil foundations, can reduce crest levels and freeboard to varying significance to dam safety. Other deformation effects resulting from variations in the reservoir level are usually less significant to dam safety.

6.4.3 Rehabilitation measures

Inadequate performance or factors of safety under all loading conditions, or the adoption of different design criteria, can necessitate the completion of rehabilitation works to improve embankment stability or performance, or increase freeboard provisions during a large flood event. Embankment dam performance can often be improved by:

The placement of toe buttresses and/or the provision of additional drainage facilities to reduce piezometric pressures in the downstream shoulder.

The installation of filter and drainage zones, that meet modern criteria, to provide protection against internal erosion and piping. This might involve temporarily removing the downstream shoulder, if possible, and installing replacement filter and drainage materials against the core. Additional weight may also be added to the replaced shoulder (sometimes termed filter-buttress upgrades). If the replacement of filter and drainage materials against the core is prohibitively expensive or impractical, then new filter and drainage materials placed downstream of the core and supported by a buttress may be a viable alternative.

Increasing the freeboard to safely accommodate an extreme flood event by raising the dam crest, by constructing a concrete wave wall along the dam crest, and/or by increasing the existing spillway capacity.

6.5 Rehabilitation work on appurtenant structures

Appurtenant structures are structures at the dam site, other than the dam itself, that are designed and are required for the safe containment and control of the reservoir contents and reservoir discharges. They are part of the total dam system and frequently incorporate gate and/or valve systems (with their associated power supplies, and control and communication systems) that fulfil dam and reservoir safety functions. These are termed 'gate and valve systems' in Module 5.

A primary driver for the rehabilitation of appurtenant structures, which include spillway and outlet facilities together with their gate and/or valve systems, is the effects of ageing and deterioration of mechanical and electrical equipment. Other primary drivers include a requirement for additional capacity (e.g. spillway capacity, generation capacity), additional diversity and redundancy in power supply and/or control systems, and damage to the civil works by appurtenant structure discharges (e.g. cavitation damage in surface spillways, abrasion damage in low level outlet structures, scour immediately downstream of discharge facilities).

The reliability of mechanical and electrical equipment and components installed in appurtenant structures that fulfil a dam and reservoir safety function is critical to overall dam safety. The installed equipment usually has a significantly shorter life than the associated civil works and replacement may be necessary within 30 to 40 years of installation. Shorter lifespans can result from the combined effects of corrosion, erosion, excessive vibration and poor maintenance. Additionally, communication and control systems can become outdated and unsupported within a few years. Regular inspection, maintenance and testing, as recommended in Module 5, are essential for the identification of poor performance, failure to function, and the programming of rehabilitation works.

6.5.1 Rehabilitation measures

Sufficient spillway capacity and reliable spillway performance are essential for the safe passage of extreme flood events. Any increase in flood estimates for the dam or the PIC of the dam since its original design and construction could necessitate the provision of additional spillway capacity. This could be by either enhancing the performance of the existing spillway or by providing an auxiliary spillway, or a reduction in the normal operating level of the reservoir to provide additional flood storage. Higher spillway discharges and higher reservoir levels can also sometimes necessitate additional downstream works to ensure safe discharge of extreme flood events (e.g. increased wall heights to ensure the spillway chute walls are not overtopped, improvements to address an increased likelihood of abrasion damage at energy dissipating structures).

The scope of the downstream works should reflect the characteristics of the spillway and its operational requirements during an extreme flood event. For example, some damage to the downstream facilities may be acceptable during an extreme flood event in a small catchment when the duration of the event is short and the resulting damage would not affect the safety of the dam. Alternatively, damage to the downstream facilities may be unacceptable during an extreme flood event in a large catchment when the duration of the event is long and the resulting damage would affect the safety of the dam.

The rehabilitation of low-level outlet facilities is often difficult. In some cases, dewatering of the reservoir may be possible and the rehabilitation works may be able to be completed in dry conditions. In other cases, dewatering of the reservoir may not be possible and completion of the rehabilitation works may necessitate a programme of underwater construction to provide a means of dewatering the outlet facility. Clearly, low level outlet facilities should be regularly tested, as recommended in Module 5, to ensure they are not affected by debris blockages, component deterioration or failure, and to identify unacceptable performance.

7. Sediment management

Sediment accumulation in reservoirs is usually considered to be an environmental effect that should be addressed in the resource consent application lodged for a dam. However, sediment accumulation in reservoirs can also have dam safety implications which include the potential for:

- Overloading of concrete dams, due to the increased loading from saturated fine sediment adjacent to the upstream face of the dam.
- Blocking of spillway or sluice gates.
- Abrasion damage in appurtenant structures.
- Depletion of live storage volumes and the consequential reduction in flood attenuation by reservoirs.
- Increased flood levels towards the upstream ends of reservoirs.

Sediment accumulation in reservoirs can also result in reduced sediment loads in river systems downstream of dams, degradation in downstream river systems, reduced groundwater levels adjacent to downstream river systems, and river channel instability.

While such factors may have been addressed during the investigation and design of a dam, they should also be assessed during the life of a dam to ensure that the effects of sediment accumulation remain within the design assumptions. Such assessments should be incorporated within Dam Safety Management Systems (DSMSs) but, where there is the potential for significant effects on dam safety, Owners should consider the development of a separate sediment management plan.

For many dams, measures to mitigate the effects of sediment accumulation on dam safety may not be required until some decades after commissioning. However, it may take considerable time and expense to implement mitigation measures, particularly if they require variations to operational consents (e.g. reservoir lowering for sediment flushing). In some cases, it may be appropriate to develop sediment management plans well before sedimentation begins to affect dam safety. Typically, where required for dam safety, sediment management plans should include:

- Monitoring requirements to establish the characteristics of sediment accumulation in the reservoir (e.g. locations, deposition rates).
- Regular assessments of the potential effects of sediment accumulation on dam safety.
- Mitigation measures to ensure sediment accumulation does not adversely affect dam safety.
- Appropriate timelines for obtaining any necessary variations to operational consents and implementing the mitigation measures.

Further guidance and case studies for sediment management are provided in ICOLD Bulletins 115 (ICOLD, 1999), 140 (ICOLD, 2021a), 147 (ICOLD, 2009), 182 (ICOLD, 2019), USACE (2016) and USBR (2017).

8. Change in use

A change in use is where the function (purpose or mode of operation) of a dam system is different from its original function. For example, a dam constructed primarily for hydropower generation or primarily for water supply could, if it was no longer required for its original function, be modified for use as a recreational asset. Such a change in use would likely result in a change in reservoir operation.

Many dams offer a level of flood control, and infrastructure and communities may have developed downstream of a dam partially in response to the level of flood protection provided by the dam. In such cases, maintaining and changing the use of the dam would be unlikely to change the level of flood protection provided by the dam. The alternative of decommissioning and removing the dam could result in an inadequate level of flood protection for the infrastructure and communities downstream of the dam.

The Resource Management Act 1991 includes no requirements relating to change of use. However, resource consents for the storage and use of the stored contents would be required, and any consents would be required to be renewed at the frequency required by the Act. Given that the purpose of the Act is to "promote the sustainable management of natural and physical resources", consents under the Act would probably be necessary for any change of use that would result in adverse effects on the environment.

The Building Act 2004 and the Building (Specified Systems, Change the Use, and Earthquake-Prone Buildings) Regulations 2005 include specific requirements relating to change of use. The requirements included in the legislation relate to the use of spaces or dwellings for crowd activities (e.g. cinemas, grandstands), sleeping activities (e.g. hospitals, hotels, houses), working, business or storage activities (e.g. factories, business premises, warehouses), and intermittent occupation or providing intermittently used support functions (e.g. car parks, locker rooms). While no requirements are included in the current legislation that relate to a change in use for dams, any demolition activities or modifications to an existing dam necessary for a change in use would require a building consent and potentially resource consent. Investigation, design, and change of use procedures should generally follow those outlined in Modules 3, 4, 5, and 6, with a focus on controlling the risks during the change process and leaving them acceptably low on completion.

A change in use may also necessitate the identification of an alternative Owner with an interest in maintaining the dam for the alternative use. In assessing whether a change in use is a viable option, Owners will need to consider:

- Who will be legally liable for the ongoing safety of the dam.
- Future ownership options.
- Whether an alternative Owner can be identified with an interest in maintaining the dam for an alternative use.
- Who will be responsible for the ongoing surveillance, operation and maintenance of the dam.

From a dam safety perspective, it is important that any change in use incorporates an appropriate Dam Safety Management System. The recommendations included in Modules 5 and 6 should be followed.

9. Dam decommissioning

9.1 Introduction

Decommissioning of a dam may become necessary because the dam has outlived its usefulness, or it requires rehabilitation works which the Owner cannot afford or which render the operation of the dam uneconomic. Unless emergency action is agreed by the regional authority as being necessary, the decommissioning of large structures will typically require consents under the Resource Management Act 1991 and Building Act 2004. Investigation, design and decommissioning procedures should generally follow those outlined in Modules 3, 4 and 6, with a focus on controlling the risks during the decommissioning process and leaving them acceptably low on completion.

A decision to decommission a dam should be based on the careful evaluation of a wide range of alternatives to resolve issues associated with dam safety, high rehabilitation costs, high operation and maintenance costs, environmental effects, sedimentation issues, and long-term function and ownership. Such evaluations need to consider issues arising from either retention or decommissioning of the dam as there will be effects and consequences with either approach. In some cases, full removal may be necessary to resolve critical issues, while in other cases partial removal may provide a satisfactory long-term solution. The following subsections provide guidelines regarding dam decommissioning as a project alternative. These guidelines are restricted to the consideration of issues related to dam safety – they do not address environmental, legal, social, economic, ownership and political issues, all of which could have significant effects on the identification of a preferred decommissioning option. These guidelines do not apply to tailings dams.

9.2 Decommissioning process

An overview of a typical dam decommissioning process is shown in Figure 9.1.

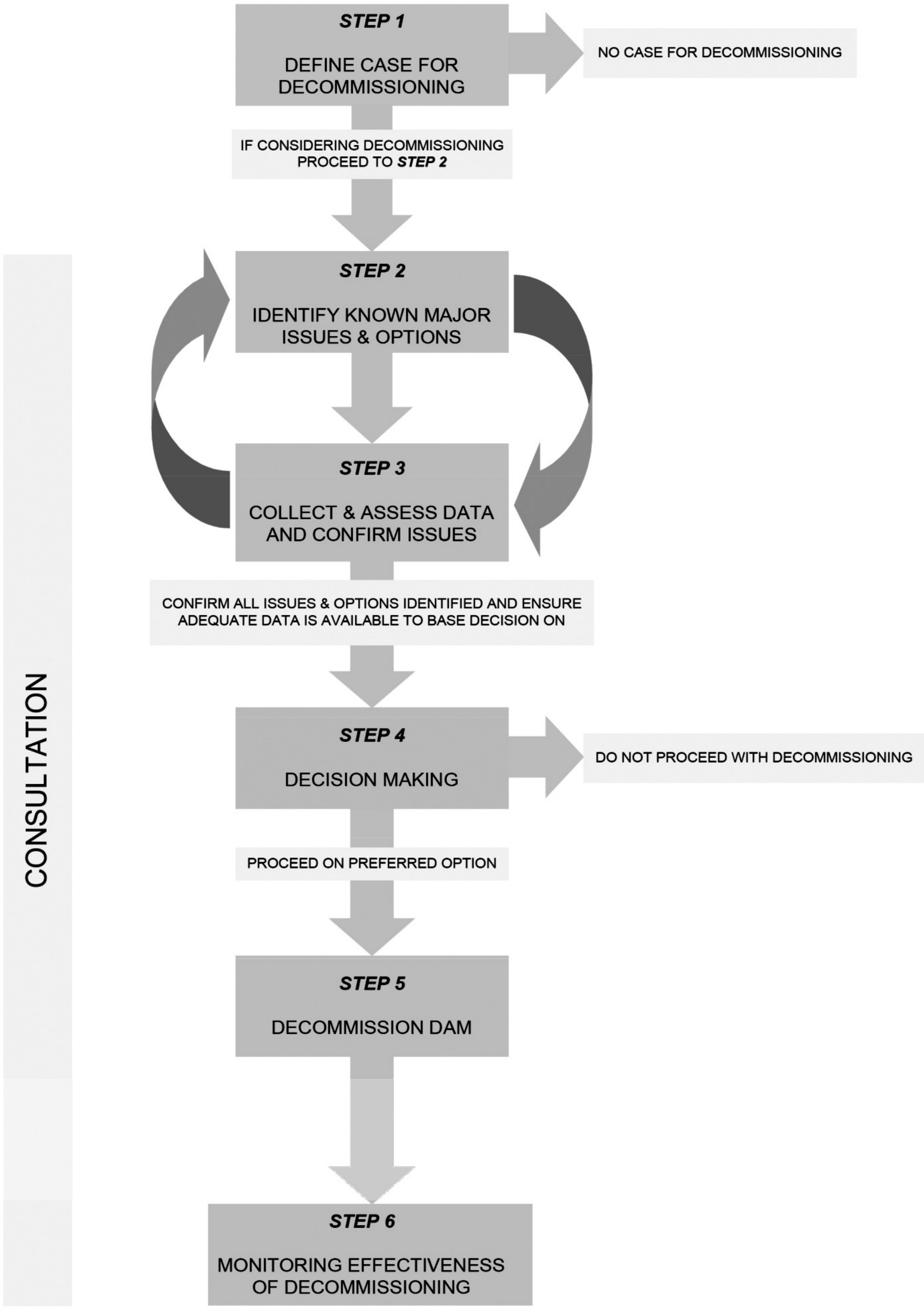

Figure 9.1: Dam decommissioning process (source: ICOLD Bulletin 160, ICOLD, 2018)

The process should include the careful evaluation of a wide range of decommissioning options that include complete removal and partial removal. A wide range of issues will be associated with each decommissioning option. Some will be common to many of the options, while others will be specific to a single option. The use of independent advice from technical specialists and stakeholders is essential in the identification of a preferred decommissioning option.

Stakeholder participation in the decision-making process and stakeholder support of a preferred decommissioning option will usually be essential for a successful project outcome. Obtaining consents for a preferred decommissioning option will likely require engagement with stakeholders.

9.3 Define the case for decommissioning

9.3.1 Overview

Step 1 of the process (Figure 9.1), defining the case for decommissioning, requires that all drivers are identified. The drivers for dam decommissioning may include some or all of the following:

- The financial viability of continued operation (with or without rehabilitation).
- Dam safety requirements.
- Ongoing or potential ecological effects.
- River restoration or enhancement projects.
- Regulatory/compliance issues (e.g. Building Act 2004, Resource Management Act 1991, refer Module 1).
- Other Owner or public issues or benefits.

A decision to decommission a dam should be based on an evaluation of a range of alternatives to resolve issues associated with dam safety; rehabilitation or change in use costs; ongoing operation and maintenance costs; environmental effects; sedimentation issues; and long-term function and ownership. Such evaluations need to consider issues arising from options for rehabilitation, change in use, and removal of the dam as there will be effects and consequences with each approach. In some cases, full removal may be necessary to resolve critical issues, while in other cases partial removal may provide a satisfactory long-term solution.

9.3.2 Dam safety

The Building Act 2004 and Building (Dam Safety) Regulations 2022 require dams to meet current dam safety requirements. If the dam safety requirements are not met, Owners should consider related questions including:

- Is the dam meeting its original purpose or need?
- Have additional issues or needs arisen?
- What rehabilitation works are necessary to address the identified dam safety deficiencies?
- What is the estimated cost and time for the completion of the rehabilitation works?
- How would the completion of the rehabilitation works affect my commercial operation?
- Is it economically viable for me to complete the rehabilitation works?
- What alternatives are available if it is uneconomic for me to complete the rehabilitation works? e.g. change in use or dam removal options.
- What is the estimated cost and time for the completion of the decommissioning options?
- What are the issues associated with the alternatives and what alternatives would likely be acceptable to the consent authorities?

Complete removal of a dam may not be necessary to satisfy current dam safety criteria and, in many cases, a change in use with appropriate rehabilitation or partial removal could be sufficient. Partial removal could include lowering some or all of the dam crest to permanently reduce the loads on the structure. Removing some or all ancillary structures (e.g. gates, pipelines, pump stations, powerhouses) may also be warranted if such removal addresses the dam safety deficiency.

9.4 Decommissioning design and implementation

9.4.1 Overview

Decommissioning Steps 2 through 5 (Figure 9.1) are used to collate and assess relevant information, develop options, make decisions and ultimately implement the selected decommissioning approach. Careful design and a comprehensive understanding of the existing structures are essential to the success of a dam decommissioning project. In some cases, there will be sufficient documentation available to confidently establish the characteristics of the existing structures. In other cases, where documentation is scarce, a programme of investigation and testing may be necessary to confirm site conditions.

The design process and subsequent construction work for the removal works should generally follow the recommendations included in Modules 3 and 4. Guidance on Dam Safety Management Systems and Emergency Preparedness (Modules 5 and 6 respectively) should also be followed as there is a need to amend operationally focused documentation to address the temporary and changing nature of dam safety risks during the dam decommissioning phase. Depending on the scale of the decommissioning project, specialist design and contractor support may be necessary to achieve a successful outcome. Important engineering issues that will require careful consideration during the design and decommissioning processes include:

- The structural limits necessary to achieve an appropriate level of dam safety.
- The long-term management of accumulated reservoir sediment; e.g., removal and disposal, removal by the river, flushing and release into the downstream river, re-contouring and re-vegetation, and other environmental issues.
- Reservoir drawdown capabilities and limitations on drawdown rates.
- Flood management during decommissioning.
- The methodology for decommissioning the dam; e.g. sequence, demolition, and removal methods; disposal and site restoration.
- The long-term safe passage of flood events.
- The long-term surveillance, operation, and maintenance requirements for ongoing dam safety where the dam remains afterwards.
- Long-term public safety considerations where partial structures remain and can be accessed and used by the public.
- The time required to make decisions and implement solutions, and their effect on risk. Guidance on time frames for risk mitigation is provided in section 5.4.6.

International guidelines such as ICOLD Bulletin 160 (ICOLD, 2018), USBR (2021) and DELWP (2022) cover dam decommissioning and associated case studies. Managing accumulated sediment in a reservoir during a decommissioning project is an important aspect. Section 7 outlines guidance and useful references on sediment management.

9.4.2 Resource consents

Regional and district council consents related to the dam must be reviewed in the context of the specific decommissioning approaches being considered. In some cases, a change or cancellation of the existing resource consent conditions may be appropriate, while in other cases, new consents may need to be sought and existing consents surrendered.

9.4.3 Building consents

The building consent process for dam removal is noteworthy and requires some special discussions with the relevant Building Consent Authority as to its approach. The New Zealand Building Act 2004 requires a building consent for significant modifications or demolition to a Large Dam (as defined in the Act) but allows for an exemption in some cases. In the case of partial removal, building consents will generally be required but exemptions may still be relevant.

In the case of a full removal, after the proposed work is complete, there will be no building or structure that could endanger people so compliance with the Building Act 2004 is not possible; i.e. the proposed work 'does not comply with the building code' in as much as the code cannot not apply to things that do not exist. In this case, it may be more appropriate for an exemption to be sought.

9.4.4 Dam removal

Removal of Large Dams should generally follow design and decommissioning procedures outlined in Modules 3, 4, 5, and 6, with a focus on controlling dam safety risks during the removal process and leaving them acceptably low on completion.

In undertaking dam removal design and risk assessments, it may be helpful to identify critical stages during the works. Examples of such critical stages include step change points from High to Medium or Medium to Low PIC, with associated articulation of dam safety performance criteria for each stage. It is plausible that decommissioning-specific FMEA, public safety plans, construction safety plans, DSMSs, and EAPs will differ at each stage. It is likely that the design and/or Contractor's methodology will shape the risk profile as the project evolves.

9.4.5 Decommissioning performance monitoring

Step 6 of the process (Figure 9.1) is the development of a programme of performance monitoring, normally implemented to quantify and evaluate effects that accompany the decommissioning of a dam, and to monitor the ongoing safety and public safety of the completed project.

A performance monitoring programme during dam decommissioning should address the dam safety objectives of the programme, monitoring requirements and frequencies, acceptable performance criteria for the elements being monitored and reporting and evaluation requirements. Mitigation measures and an Emergency Action Plan (refer Module 6) should also be in place to address any dam safety concerns that could arise during decommissioning works.

If partial removal is adopted and the completed project incorporates a permanent reservoir that meets 'large' or 'classifiable' dam regulatory thresholds, an updated Dam Safety Management System including an Emergency Action Plan may be required. Ongoing dam safety performance monitoring is needed to verify the completed works are performing as intended, and to identify developing or changing conditions that could affect the safety of the altered dam. Post-decommissioning performance monitoring programmes should reflect the PIC of the changed dam and the procedures recommended in Module 5 should be followed.

In the case of a partial dam removal where the completed project incorporates a permanent reservoir that does not meet the large or classifiable dam regulatory thresholds, there may still be some residual dam safety risks. How a dam Owner addresses and manages the risks of small remnant dams or weirs and associated reservoirs should be assessed on a case-by-case basis. The recommendations included in Modules 5 and 6 can still be followed.

In the case of full dam removal, or partial dam removal where the completed project does not incorporate a permanent reservoir or result in temporary impoundment during flood events, dam safety risks are not relevant but the designer and/or residual asset owner should consider the public safety risks associated with the final project works.

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