NEW ZEALAND
Society on Large Dams

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New Zealand Dam Safety Guidelines 2024

MODULE 5
DAM SAFETY 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. Dam safety is assured through the implementation of sound dam safety management practices, including the resolution of any dam safety issues that may arise during the lifetime of a dam.

Dam Safety Management Systems detail procedures and activities for the management of dam safety and, importantly, provide an auditable record of dam performance and Owner commitment to dam safety. This module provides a framework for the development and implementation of a Dam Safety Management System (DSMS). It outlines the objectives of dam safety management and includes:

- A framework for the management of dam safety management activities, decision making, and supporting processes.
- Recommended competencies and training for personnel with responsibilities for dam safety management.
- Recommended practices for the development and implementation of an appropriate DSMS.
- Recommended practices for the ongoing review of a DSMS.

These Guidelines recommend all dams have a DSMS commensurate to the consequences of failure to support asset longevity, business risk management, license to operate, insurance and lending. The DSMS should contain the elements listed in Table 1 below. Note that seven of the DSMS elements align with the regulatory minimum Dam Safety Assurance Programme (DSAP) elements required by the Building (Dam Safety) Regulations (2022) (Regulations, 2022) for a Medium or High PIC dam (refer Module 1: Legal Requirements for more information on these requirements).

This module also includes a limited discussion on the role of regulators and Recognised Engineers in dam safety. Reference should be made to Module 1: Legal Requirements for a more complete description of their role 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.

Table 1: Elements of a Dam Safety Management System

Element	Reference section	Type of element	
		Recommended practice	Regulatory minimumDSAP 1
Governance	2.1	√	
People	2.2	√	
Dam and reservoir operation and management	4.1	√	√
Surveillance	4.2	√	√
Appurtenant structures and gate and valve systems	4.3	√	√
Intermediate dam safety reviews	4.4	√	√
Comprehensive dam safety reviews	4.5	√	√
Special inspections and dam safety reviews	4.6	√	
Emergency preparedness (refer Module 6)	4.7	√	√

Identifying and managing dam safety issues (refer Module 7)	4.8	√	√
Information management	4.9	√	
Audits and reviews	4.10	√	
Notes 1. Elements of a DSAP required by the Regulations (2022) (refer Module 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

The fundamental dam safety objective as discussed in the Parent Document is to protect people, property and the environment, present and future, from the harmful effects of a dam failure or an uncontrolled release of the reservoir contents. The Parent Document outlines principles that underpin and support the achievement of that objective. Principles 4, 5, and 6 relate to this module. Principle 4 in the Parent Document states that:

The responsibility for the safety of the dam rests with the dam Owner.

The dam Owner is directly responsible for the safe management of a dam. This is both a moral and legal obligation. The responsibility should include:

- Verifying that dams and appurtenant structures are designed, constructed, commissioned, and operated in a manner which ensures they meet appropriate performance criteria.
- Ensuring the safe containment of the reservoir and control of outflows.
- Establishing appropriate procedures and arrangements for dam safety to be maintained under all conditions.
- Establishing and maintaining personnel with appropriate experience and qualifications for ongoing dam safety management.
- Monitoring the performance of the dam and appurtenant structures.
- Maintaining and repairing or rehabilitating the dam and appurtenant structures as necessary to ensure ongoing safe performance.

Principle 5 in the Parent Document states that:

A Dam Safety Management System, commensurate with the consequences of dam failure and incorporating policies, procedures and responsibilities, should be in place for all dams.

Effective dam safety management is primarily achieved through the development and implementation of procedures, commensurate with the consequences of dam failure, which are incorporated within an overall DSMS. The DSMS should reflect the Owner's dam safety policy and provide a structured framework for the completion of dam safety activities, reaching appropriate dam safety decisions, and addressing identified dam safety issues. A DSMS should incorporate:

- A dam safety policy, dam safety statement, or dam safety standard.
- A description of the DSMS and its elements including dam safety management activities and resources for completing these activities.
- Responsibilities and procedures for implementing the DSMS.
- Procedures for checking and reviewing the performance of the dam and the DSMS.
- Procedures for identifying and addressing any dam safety issues, including deficiencies in the performance of the dam and the DSMS.
- Procedures for regular reporting on the performance of the dam and the adequacy of the DSMS to the Owner and, where appropriate, regulators.
- Appropriate supporting systems for management, staff training, communications, and information management.

This module is applicable to the safe management of dams, ranging from small Low PIC dams through to a portfolio of Medium or High PIC dams on a river system. The DSMS should include procedures for the operation, maintenance, and testing of mechanical and electrical equipment and systems that fulfil dam or reservoir safety functions (e.g. spillway gates, low level outlets, valves, power supplies, control and protection systems, communication systems). The procedures should cover normal, abnormal, and emergency operating conditions and include any procedures to lower the reservoir level in response to a dam safety emergency. In some cases, it may be appropriate to prepare a separate operations and maintenance (O&M) manual; however, it is important that the linkage to dam safety is not diluted.

These Guidelines recommend that where the consequences of dam failure would adversely affect people, property and the environment, Owners should consider developing and implementing a DSMS irrespective of the PIC of the dam. Recognising and acting on a potential dam safety related condition as early as possible is likely to result in the best chance of an economical resolution.

Principle 6 in the Parent Document states that:

All reasonable efforts should be made to prevent and mitigate accidental releases, dam safety incidents, and dam failures.

Dam safety incidents and dam failures do not necessarily correlate with complexity or improbable loadings. Technical issues or errors under normal operating conditions have been the cause of many dam incidents and dam failures, including combinations of small factors which together have resulted in dam safety incidents and dam failures.

To assure dam safety, appropriate measures should be taken to prevent:

- The occurrence of abnormal conditions or incidents that could lead to an uncontrolled release of part or all of the reservoir.
- The escalation of any such abnormal conditions or incidents to dam safety emergencies.

The primary means of preventing abnormal conditions or dam incidents is effective dam safety management (e.g. diligent visual inspection and monitoring, good communication practices, proper training, and regular maintenance and testing). The primary means of mitigating the consequences of incidents, should they arise, is resilience. This is achieved through an appropriate combination of effective management, operational processes, and robust engineering features that provide safety margins, diversity, and redundancy.

Resilient engineering maximises the ability of a structure or system to safely manage an abnormal, unexpected, or unpredictable condition (refer Module 3: Investigation, Design, and Analysis). Natural hazards impose loading conditions that can vary considerably from the idealised product of a hazard identification process. Resilient dam safety practices involve both smart engineering and redundancy. When properly implemented, these practices should ensure that no single technical, human, or organisational malfunction leads to a dam safety incident. Resilient dam safety practices should also ensure that the combination of malfunctions required to cause a dam safety incident has an acceptably low probability of occurrence.

The objective of this module is to provide Owners with a framework for the development and implementation of a DSMS.

1.2 Dam Safety Management System

An overall DSMS provides the dam Owner with a framework for dam safety management activities, decision making, and supporting processes. These Guidelines recommend that the Owner appoint an Accountable Executive (a named individual) who reports directly to the Owner. The Accountable Executive is accountable for and drives the organisation's commitment to meeting its dam safety objectives.

The DSMS should incorporate arrangements for governance including oversight, enabling, delegated authorities, and resourcing. An example DSMS is presented in Figure 1.1. Guidelines for establishing a DSMS are presented in sections 3 and 4 of this module. ICOLD Bulletin 154: Dam Safety Management – Operational Phase of Dam Lifecycle (ICOLD, 2010) and McGrath & Stewart (2013) provide further discussion on DSMSs and effective dam safety risk management.

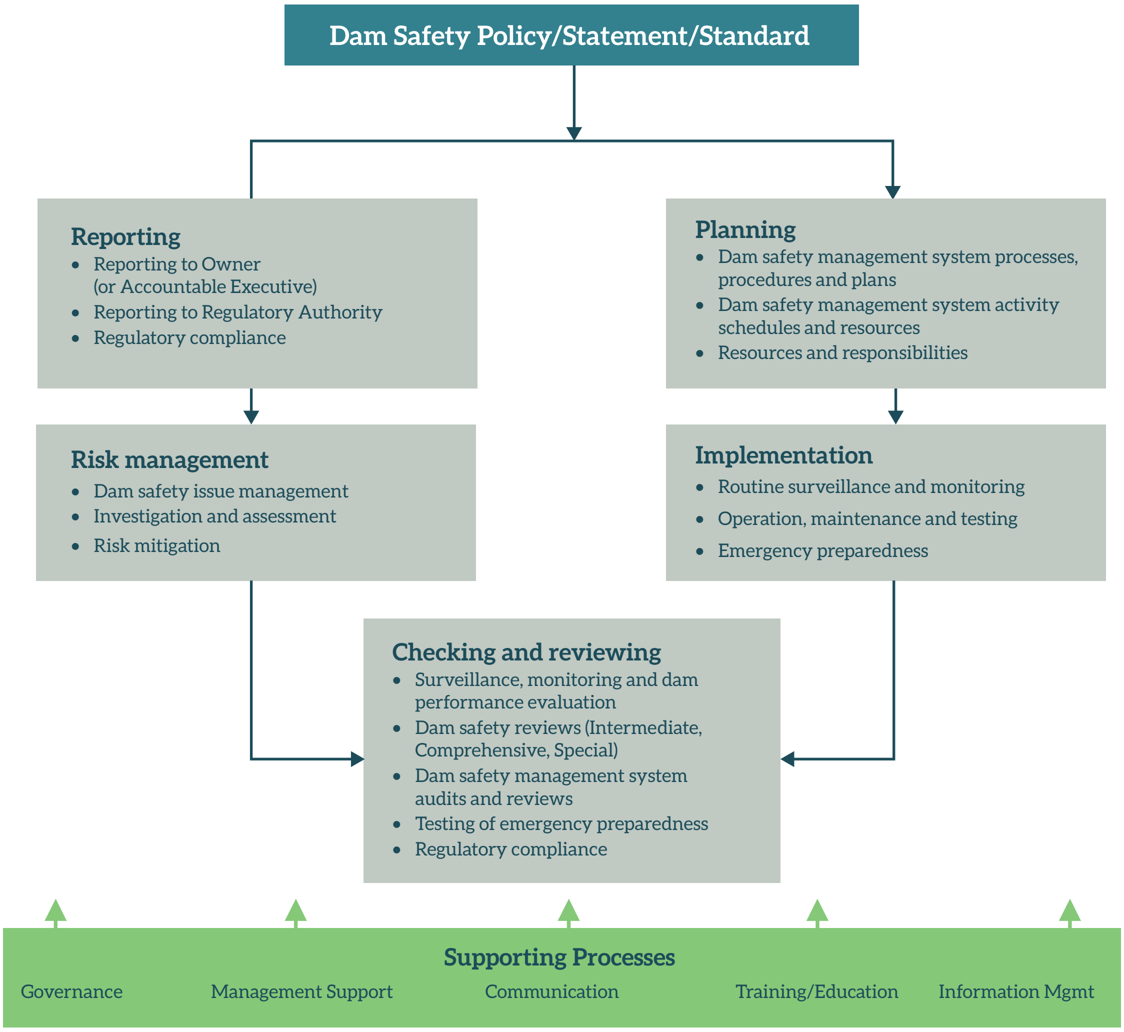

Figure 1.1: A Dam Safety Management System

A DSMS, such as that shown above, can be applied equally effectively to a small single dam, where one person fulfils the dam safety roles and responsibilities, and to a portfolio of dams where roles and responsibilities are distributed across a team of people internal to and external to an organisation. The key responsibility is with the dam Owner to ensure that an appropriate DSMS is in place to safeguard the public, property, and environment from a potential dam failure.

1.3 Scope of module

This module provides a framework for the development and implementation of a DSMS. It includes:

An outline of the importance of governance and people to an effective DSMS.

- An account of what should be considered in developing a DSMS.
- A description of the various elements that should be included in a DSMS.
- Recommendations for change management and continuous improvement.

This scope of this module is DSMSs (DSMS) for all dams. The regulatory minimum Dam Safety Assurance Programme (DSAP) requirements of the Regulations (2022) for a Medium or High PIC dam are outlined in Module 1: Legal Requirements. The required DSAP elements align with seven of the DSMS elements recommended in this module (Table 1). A list of reference documents is included at the end of the module to assist Owners in the development and implementation of DSMSs.

2. Governance and people

Numerous elements should be considered in the development and implementation of a DSMS. Governance and people are two elements that apply across all other elements of a DSMS.

2.1 Governance

2.1.1 Dam safety policy/statement/standard

Dam safety should be a primary consideration for any dam Owner, whether an individual, public authority, or private company. The overall responsibility for an effective DSMS remains with the Owner and its Accountable Executive, and these Guidelines recommend that any Owner of a Medium or High PIC dam should have a dam safety policy, statement, or standard.

A dam safety policy, statement, or standard articulates an Owner's commitment to dam safety management including the linkage of its dam safety objectives to:

- Applicable regulations.
- Industry practice.
- Public safety.
- The protection of third party property, public infrastructure, and the environment.
- The Owner's organisational goals and values.

Furthermore, a dam safety policy, statement, or standard provides the organisation's directive to personnel accountable for and responsible for implementing the DSMS.

2.1.2 Owner actions and priorities

An Owner's actions and priorities should promote the recognition of, and commitment to, the safe operation of its dams and reservoirs. Effective dam safety management requires responsibilities to be fulfilled at all levels in the Owner's organisation, from the Accountable Executive to field personnel. The Accountable Executive should take all steps to remain aware of the key activities and decisions relating to the safe management of their dams. Post-disaster enquiries following catastrophic dam failures and industrial accidents often identify shortcomings in this area as contributing factors to the disaster.

These Guidelines recommend that the implementation of a DSMS, including the resolution of dam safety issues that may arise during the lifetime of a dam, should be considered and prioritised appropriately in conjunction with wider business and organisation objectives.

However, 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 and, in the case of potential loss of life, it is considered morally unacceptable to assign a monetary value to the loss of a life. Furthermore, 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 risk-informed dam safety framework (refer Module 7: Lifecycle Management) will allow Owners to understand the nature and significance of the risks, prioritise the risks, target resources effectively, and demonstrate a prudent approach to reducing risks associated with their dams. Risk-informed decision making is an additional tool that can be utilised by Owners for the assessment of dam safety issues.

2.1.3 Delegated authority and enabling

A clear line of authority and accountability for dam safety in an Owner's organisation should be established and unambiguously stated. This should include the Accountable Executive (a named individual) with accountability for dam safety and reporting to the Owner.

Those persons responsible for implementation of a DSMS should have the appropriate resources (financial and personnel) and delegated authority to effectively fulfil their responsibilities. Levels of resourcing should allow for the timely completion of all dam safety management activities in accordance with organisational and regulatory requirements, including the investigation and resolution of any dam safety issues that may arise during the lifetime of the dam.

2.1.4 Communication

Owners should have effective communication processes in place that ensure important dam safety issues are promptly reported to the appropriate accountable and responsible personnel. These issues should be appropriately escalated to key decision makers and, where necessary, to external authorities. The organisational culture should promote upwards communication of dam safety information.

An Owner's dam safety policy, statement, or standard and its dam safety achievements should be communicated throughout the Owner's organisation. Effective communication and coordination will be achieved through integrating dam safety activities within the wider business.

Owners may be required to provide background data and information on potential dam safety issues to external parties such as regulators, emergency agencies and other stakeholders (e.g. affected property owners and recreational users). Legal requirements associated with demonstrating dam safety compliance are discussed in Module 1: Legal Requirements.

Finally, Owners may wish, for the benefit of their relationships with, and education of, other parties, to communicate information concerning their dam safety practices to stakeholder communities and interest groups.

2.1.5 Review

Internal and external reviews of the effectiveness and appropriateness of an Owner's DSMS is an important part of governance. Such reviews ensure that the stated dam safety objectives are appropriate and are being met, and that a pathway towards continuous improvement is being maintained. This is discussed further in section 4.10 of this module.

2.1.6 Additional governance for tailings dams

Owners of tailings dams should consider the additional governance recommendations provided by the Global Industry Standard on Tailings Management (GISTM) (Global Tailings Review, 2020) and ICOLD Bulletin 194 Tailings Dam Safety (ICOLD, 2022). They include appointment of an Accountable Executive (Owner team), Responsible Tailings Facility Engineer (Owner team) and Engineer of Record (EOR) and, for Very High or Extreme consequence dams, an Independent Tailings Review Board (ITRB).

2.2 People

2.2.1 Competence

The effective management of dam safety generally involves a wide range of skills. As this range of skills typically does not reside in a single person, an effective DSMS will usually involve a number of people from the Owner's organisation that includes managers, technical personnel, and operational personnel. The Owner is responsible for ensuring that appropriately competent personnel are engaged to oversee and implement all elements of the Dam Safety Management System, and that all involved parties understand and are competent to fulfil their roles and responsibilities. In some cases, Owners may not be fully conversant with the technical requirements for dam safety management and they will therefore be reliant on advice received from the Designer, in the case of a new dam, or Technical Advisor in the case of an existing dam.

It is important for the Owner to ensure that the technical advice is provided by competent and qualified personnel with appropriate backgrounds of experience in dam engineering and dam safety. Designers and Technical Advisors play key roles in ensuring dam safety and it is vitally important that Owners and their Designers and/or Technical Advisors understand the extents of their roles and the boundaries of their responsibilities.

On-the-ground routine surveillance and monitoring is commonly completed by the Owner's permanent staff or, in the case of a smaller dam, by the Owner personally. On-the-ground routine surveillance and monitoring is recognised as the first line of defence in dam safety and is one of the most important aspects of a DSMS. Evaluation of the surveillance and monitoring results, the assessment and reporting on dam performance, and the completion of intermediate dam safety reviews should be undertaken by people competent in the evaluation of surveillance and monitoring results. This is usually undertaken by the Owner's senior dam safety staff and Technical Advisors. All people with dam safety responsibilities should understand the conditions and hazards that can affect dam safety, the potential failure modes for the dam, the early signs for the development of each of the potential failure modes, and the surveillance and monitoring procedures relevant to each of the potential failure modes.

Typical competencies required for personnel involved in ongoing dam safety management are listed in Table 2.1.

Table 2.1: Competencies for People involved in Dam Safety Management

Role	Principal areas of competence
Dam Owner/Manager/ Accountable Executive	• Legal, regulatory and duty of care responsibilities relating to dam safety • Understanding of dams and reservoirs as systems, how they are designed to function, how they should operate, and how they may fail to function (potential failure modes) • Understanding of dam safety hazards and risks • Understanding of Dam Safety Management Systems, principles and practices, and emergency planning and response procedures • Understanding of quality assurance principles • Understanding of public safety around dams and reservoirs
Technical Advisor	• Understanding of dams and reservoirs as systems, how they are designed to function, how they should operate, and how they may fail to function (potential failure modes) • Understanding of dam safety hazards and risks • Structural, geotechnical, seismic, hydrologic and hydraulic design • Dam construction techniques • Understanding of Dam Safety Management Systems, principles and practices • Operation, maintenance and testing procedures • Surveillance and performance assessment • Response to dam safety issues • Emergency planning • Emergency response • Managing dam safety issues • Gates and valves including associated power supplies, control and protection systems, and communication systems
Operation and Maintenance Personnel[1]	• Safe operation of dams and reservoirs including recognition of departures from intended operation • Safe operation of gates and valves • Maintenance and testing practices • Dam safety and surveillance principles and practices • Emergency response procedures including escalation process for alerting others • Emergency response
Dam Safety Field Personnel (e.g. Surveillance Inspectors)[1]	• Dam safety and surveillance principles including visual recognition of departures from intended operation and the onset of potential failure modes and dam safety deficiencies • Potential failure modes • Understanding of dam safety hazards and risks • Emergency response procedures including escalation process for alerting others • Safe operation of gates and valves (if appropriate)

Role	Principal areas of competence
Key Emergency Personnel[2]/ Civil Defence	• Understanding of the potential effects of a dam system failure and uncontrolled releases • Emergency planning • Emergency response
Recognised Engineer (PIC, DSAP – for regulatory certification, audit and annual compliance)[3]	• Chartered Professional Engineer (CPEng) and Recognised Engineer qualification and competency requirements (refer Module 1: Legal Requirements)
Regulators	• Understanding of the implications of legislation relating to dam safety
Public at Risk	• Understanding of safety around dams and reservoirs • Emergency awareness and response

Notes:

1. Depending on the dam, Potential Impact Classification (PIC) and the Owner, these roles may be performed by the Owner in some cases and, in other cases, by a single person or team of people.
2. Depending on the dam, Potential Impact Classification (PIC), and the Owner, the Technical Advisor can be an external contractor or consultant, or the Owner's personnel.
3. Refer Module 1: Legal Requirements regarding who can fulfil the Recognised Engineer role and how to manage conflict of interest).

2.2.2 Training and education

A long-term perspective is required in the training of people for dam safety. Experienced technical expertise is scarce, and training is necessary to up-skill new entrants in the industry. Succession planning is vital to maintaining consistent dam safety expertise.

Training and education programmes for all personnel with responsibilities for dam safety should be geared towards developing and maintaining appropriate awareness and competencies, and should take into account:

- The organisational structure and governance arrangements.
- The characteristics of the dam, reservoir and appurtenant structures and surveillance procedures.
- The potential failure modes for the dam and appurtenant structures.
- The gate and valve systems that fulfil dam and reservoir safety functions.
- Site-specific issues including any potential or confirmed dam safety deficiencies.
- Changes in the facilities or operating procedures.

In some cases, it may be appropriate to prepare and issue a concise statement (e.g. 1-2 pages laminated) that outlines a dam's potential failure modes, things to watch out for, and response actions if unexpected changes are observed.

Training will depend on the nature and the PIC of the dam. It may range from the Designer or Technical Advisor training the Owner/Operator of a small Low PIC dam, to Operators of High PIC dams completing structured training courses, seminars, audits, and refresher courses. Training may include:

- Attendance at relevant courses and seminars (e.g. dam safety management courses, conferences and workshops).
- Attendance at technical workshops, seminars, symposia and conferences.
- In-house courses on the implementation of operational procedures.
- Interaction with other dam Owners to share and learn from their experiences.
- Keeping up to date with dam safety practice, through the acquisition and review of dam safety guidelines, technical papers, training materials, special interest journals, and participation in technical interest groups.

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- Involvement in dam safety management activities and processes.
- Review of and familiarisation with potential failure modes, intermediate dam safety reviews and comprehensive dam safety reviews.
- Participation in dam safety reviews.

Attendance at emergency management courses (e.g. Coordinated Incident Management System) and participation in emergency management exercises and simulations.

The personnel involved must understand what is required to fulfil their respective roles and be suitably trained in their areas of accountability and responsibility. This is particularly the case for managers, caretakers and operational staff who may be recruited into their positions without prior dam safety experience.

Training records should be maintained for all personnel with dam safety accountabilities and responsibilities.

3. Establishing a Dam Safety Management System

3.1 Form and content

As noted in section 1.1, these Guidelines recommend that, regardless of the PIC of the dam, Owners should consider developing and implementing a DSMS if the consequences of dam failure would adversely affect people, property, or the environment.

The form and content of a DSMS will vary to some extent depending on the Owner and the characteristics of the dam (or dams). However, a DSMS should:

- Be consistent with the dam safety principles given in the Parent Document of these Guidelines.
- Be appropriate to the type, size and PIC of the dam and its appurtenant structures.
- Contain dam and reservoir operation and maintenance procedures or, if appropriate, a reference to separate operation and maintenance procedures.
- Detail requirements and frequencies for routine surveillance and monitoring, data evaluation, and reporting to the dam Owner.
- Detail requirements and frequencies for the routine inspection and maintenance of appurtenant structures as well as inspections, maintenance, and testing of gate and valve systems that fulfil dam and reservoir safety functions.
- Assign competencies for the routine operation, surveillance, monitoring, inspection, testing, data evaluation, and reporting tasks to ensure they are carried out by appropriately qualified and experienced people.
- Contain requirements for intermediate dam safety reviews.
- Contain requirements for comprehensive dam safety reviews.
- Contain an emergency action plan or, if appropriate, a reference to a separate emergency action plan.
- Contain procedures for the identification, evaluation, and resolution of dam safety issues.
- Include appropriate governance, management, communication, training, and information management systems.
- Contain continuity and contingency planning to be prepared for disruptions and prolonged events (e.g. pandemics, widespread natural events)

Regulatory requirements for dam safety assurance are discussed in Module 1: Legal Requirements.

3.2 Dams systems

3.2.1 Defining and understanding the dam system

As stated in the Parent Document of these Guidelines, dam safety requires consideration of the total system surrounding the dam and should not be limited to the dam structure. It is important to consider the interaction between parts of the dam system, including both the technical and physical components (such as reservoir, dam, foundations, abutments, appurtenant structures) and the non-physical components. Non-physical components include human and organisational processes, procedures, and factors that the dam system depends on for safe function (such as inspections, monitoring, maintenance, operations, testing, emergency response, supervision, management, information flow, control decisions, and documentation). Effective information flow and communication is critical to the safe operation of dam systems, particularly at interfaces and boundaries, both internal and external to the system.

To support safe dam and reservoir operation and management, it is important for the dam Owner, Manager and Technical Advisor roles (refer Table 2.1) to have sound appreciation and documentation of:

- How the dam system is defined, including its reservoir and the boundaries where the total system is impacted by, and impacts on, the external domain.
- How the dam system is designed to function and how it should operate (operational states), including human and organisational factors.
- How the dam system was constructed and how it is functioning and operating (compared with how it was designed to function and operate).
- How the dam system's components are designed to function, including controls and interdependencies between components and human and organisational factors.
- How the components were constructed and how they are functioning (compared with how they were designed to function).
- External and internal hazards that threaten the dam system and its components, including human and organisational factors.
- How the dam system and its components may fail to function, i.e. potential failure modes including reservoir safety and operational failure modes.
- The consequences of dam system failure to function and component failure to function.
- Monitoring and change control process for changes to the dam system (e.g. physical, non-physical, hazards and threats).

Detailed discussion of dams as systems can be found in Operational Safety of Dams and Reservoirs (Hartford et al., 2016) and Canadian Dam Association (CDA) Technical Bulletin Failure Modes Analysis (Part 1: Identification of Failure Modes and Mechanisms) (CDA, 2023). The Oroville Dam Spillway Incident Independent Forensic Team Report, Appendix J (ASDSO & USSD, 2018), provides a useful Human Factors Framework and Methodology.

3.2.2 Reservoir considerations

The reservoir, or stored contents, is the fundamental hazard to people, property, and the environment created by the presence of a dam. It is therefore important to consider a dam's operation and safety in the wider context of the reservoir that it impounds, and thus the zone of awareness in the DSMS should address the total dam and reservoir system, including, and in some cases extending beyond, the impounded reservoir. The DSMS should consider other structures that retain the same reservoir (e.g. subsidiary dams, appurtenant structures, gates and valves), and the effects of upstream hazards that could affect the safety of the dam (e.g. erosion and sediment, upstream landslides). All issues and effects that could affect safe containment, conveyance, and control of the reservoir must be thoroughly considered.

When a dam is in a 'cascade' environment (refer Module 2: Consequence Assessment and Dam Classification), the outflow from a failure of an upstream dam can affect the safety of some or all of the downstream dams. In certain cases, an Owner may have little control over the potential adverse physical effects resulting from an upstream dam failure but, with an understanding of the characteristics of the upstream dam, an Owner of a downstream dam should be able to respond appropriately at their dam and provide any necessary warnings to the downstream population and affected agencies. A similar situation occurs where a natural dam forms upstream of an Owner's dam, as a result of a landslide or other accumulation of debris and impounds inflows forming a new reservoir whose failure may affect the safety of the Owner's dam and any downstream dams.

A dam Owner and/or Operator should have a wide appreciation of the dam system and public safety implications of inflows to, and outflows from, the dam's reservoir under all conditions.

Other issues which can affect reservoir safety and should be considered in the development and implementation of a DSMS include:

- Off-river storage dams, where the reservoir inflows and operation are predominantly controlled.
- Water transfers between catchments which can alter natural inflow regimes.
- Changes of land use around a reservoir which can affect inflow rates and may introduce debris and water quality issues that could affect dam safety.

3.3 Dam system considerations for developing a Dam Safety Management System

A dam system is unique with respect to its configuration, geologic setting, design, construction, hazards, threats, operational context, human and organisational factors, inherent condition, and historical performance. Therefore, each dam system has its own features, capabilities, operation, characteristic behaviours and potential failure modes.

Accordingly, the following questions should be considered when developing a DSMS to ensure that the content and activities are appropriate for the dam system:

- Are the dam system and its components well defined and documented, including functions, operation, controls, and interdependencies?
- What resilient features are built into the dam system that give it capacity to withstand changing conditions caused by sudden shocks, gradual stresses, and cumulative change (e.g. defensive design, fail to safe, redundancy, segregation, diversity, backup, access, training)?
- What are the dam type and features?
- What are the foundation type and features?
- What are the appurtenant structures, gate and valve systems, and their operational requirements?
- What are the reservoir and catchment features?
- What are the human and organisational factors required for the dam system to function and operate?
- How does the public interact with the dam system (e.g. public safety and security)?
- What physical security and cyber security aspects may threaten dam and reservoir safety?
- Are the external and internal hazards that threaten the dam system monitored and reviewed for change?
- What are the consequences of functional failure to third parties, their property and infrastructure, and the environment?
- What are the consequences of functional failure to the Owner and Owner's business?
- What are the primary and other purposes and functions of the dam and reservoir?
- What are the dam and reservoir's operational parameters (e.g. inflows, outflows, daily/seasonal/flood reservoir range)?
- What is the dam's design, construction, and performance history?
- What are the specific loading conditions for the dam?
- What are the performance expectations for the dam under all loading conditions?
- Is the characteristic behaviour well understood for all loading conditions?
- What is the dam's inherent condition?
- Is the instrumentation appropriate and does it work?
- What are the dam system's credible potential failure modes, what initiating conditions are required, and what would be the early indicators of the onset of the potential failure modes?
- How quickly could the potential failure modes develop?
- What timeframes are available to intervene should a potential failure mode develop?
- Is intervention possible if a potential failure mode is developing?

The DSMS should be fit for purpose and commensurate with the consequences of dam system failure (including component functional failures) and the required dam system performance under all loading conditions. The minimum legal requirements for dam safety assurance must be met (refer Module 1: Legal Requirements); however, these Guidelines recommend that additional elements and measures should be considered and incorporated into a DSMS appropriate to the particular dam system and its complexities. An effective DSMS supports asset longevity, business risk management, license to operate, insurance, and lending.

An effective DSMS should adapt dynamically to change and seek to continuously improve. Change management and improvement are discussed in section 5 of this module.

Knowledge management is a critical aspect of a DSMS that embodies a range of activities to support deep understanding of dam systems and their safe operation. Knowledge management activities include training, capability management (refer section 2.2 People), information management and information security (refer section 4.9 Information management).

For new dams the DSMS should reflect the results of the completed investigation, design, construction, and commissioning processes.

For existing dams, it may be necessary to compile data on the dam from a variety of sources, including existing documents and verbal reports from personnel involved in the dam's design, construction and/or operation, and develop a DSMS from the resulting information. Verbal reports from designers and constructors often provide valuable insights into matters not normally archived, so they should be transcribed into written reports.

3.4 Failure Modes and Effects Analysis (FMEA)

3.4.1 Uses and benefits

Failure Modes and Effects Analysis (FMEA) provides enhanced understanding of the key vulnerabilities of the dam system and enables surveillance, operation, maintenance, and emergency preparedness requirements in the DSMS to be targeted to the identified potential failure modes. The FMEA should identify surveillance requirements to provide early warnings of the development of the potential failure modes. FMEA provides valuable information for the safety evaluation of existing dams and minimises the potential for overlooking important issues relevant to the safe performance of dam systems. FMEA also assists in the prioritisation of future investigation and design activities and dam safety enhancement projects.

FMEA is most appropriate for Medium and High PIC dams, with the level of detail appropriate to the dam and its complexities. However, FMEA may also be applied to Low PIC dams where the operational value of a dam, or the business consequence of a dam failure, is significant.

Where an FMEA has not been completed for a Medium or High PIC dam it should be carried out prior to, or during the completion of, a Comprehensive Dam Safety Review (CDSR). After the completion of an initial FMEA for an existing dam, subsequent CDSRs should review the results of the FMEA and highlight any identified shortcomings in the FMEA report as well as any changes to the dam system that should be reflected in an FMEA update (refer section 4.5).

Refer to Module 3: Investigation, Design, and Analysis and Module 6: Emergency Preparedness for related detail on the development and use of potential failure modes.

3.4.2 Identification and assessment of potential failure modes

The identification and assessment of potential failure modes for a dam system (new or existing) can be achieved through the completion of an FMEA. In these Guidelines FMEA is defined as a systematic method for identifying and assessing dam system and component potential failure modes and effects based on a sound appreciation of:

- Dam system and component functions, operation, interdependencies, and controls.
- Hazards and threats.
- Human and organisational factors.
- Dam system and component failures to function.

A potential failure mode is a specific chain of events or set of circumstances that could result in the uncontrolled release of all or part of the contents of a reservoir. These guidelines recommend that potential failure modes include component level failures to function and their effects on the safe performance of the overall dam system.

An FMEA is best completed through considered preparation and review of relevant material, site visit (as needed), facilitated workshop, and reporting. Preparation and review of relevant material ahead of the workshop should include appropriate analyses to support effective identification and assessment of potential failure modes. The facilitated workshop should be attended by representatives of the dam Owner, Technical Advisors and others (such as designers, contractors, operators, maintainers, and surveillance staff) with relevant knowledge of the dam system's design functions, construction, hazards, threats, operation, and its historical performance. FMEA results inherently reflect the capability and knowledge of the people performing the FMEA based on the information available at the time. The facilitator has the important role of systematically asking structured, open questions that allow full and thorough consideration of the hazards and threats to the dam system and component functions. Experiences such as the Oroville Dam spillway failures have shown that reliance on free thought and an unstructured approach can be unsuccessful in identifying and understanding key dam system vulnerabilities. The Hazards and Failure Modes Matrix (HFMM) developed by BC Hydro, and adopted by Canadian Dam Association, is an example of a systematic and structured approach to screening and identifying dam system hazards and potential failure modes. Canadian Dam Association (CDA) Technical Bulletin Failure Modes Analysis (Part 1: Identification of Failure Modes and Mechanisms) (CDA, 2023) provides detailed guidance on such a systematic approach to identifying potential failure modes, including use of the HFMM and a supporting table of questions to ask contributing participants. The Oroville Dam Spillway Incident Independent Forensic Team Report, Appendix F3 (ASDSO & USSD, 2018), provides a useful commentary on Failure Modes Analysis. Failure Modes and Effects Criticality Analysis (FMECA), event tree analysis and fault tree analysis are further methods that can be used to analyse potential failure modes and identify system vulnerabilities. FMECA adds a step to FMEA to address the criticality of each failure mode. Failure modes are assessed for probability and consequence, and then ranked according to risk.

The FMEA should:

- Review the available design, construction and dam safety study documents, and operational and surveillance records for the dam.
- Review the dam system functional descriptions and diagrams to appreciate the dam system and component functions and operation, as well as controls and interdependencies, including human and organisational factors. Each dam system component's dam safety or reservoir safety function should be stated (e.g. containment, conveyance, control). Where dam system functional descriptions and diagrams don't yet exist, they may be developed ahead of, or as part of, the FMEA.
- Seek inputs from individuals and specialists with specific knowledge on the hazards and threats (both originating external to the dam system and internal to the dam system) and the performance of the dam system.
- Identify all potential failure modes related to the safe performance of the dam system's containment, conveyance, and control functions. Potential failure modes relating to reservoir safety (not dam safety) and operational events (load conditions smaller and more likely than unusual and extreme), may also be identified for public safety and business risk management reasons. Industry operational events and incidents continue to demonstrate that component-level functional failures can have significant to high consequences (e.g. unusual combinations of probable events).
- Categorise the potential failure modes as credible, not credible, or as having insufficient information (to categorise). Highlight those of greater significance. Credible means the potential failure mode is physically possible and not so remote a possibility as to be not reasonable to postulate. Several dam potential failure mode categorisation systems are available. For example the US Federal Energy Regulatory Commission Part 12D Refresher Training Potential Failure Modes Analysis (FERC, 2020) provides a four-category system that can be used to categorise and highlight potential failure modes based on physical possibility, significance, potential for occurrence, magnitude of consequence and likelihood of adverse response, and whether sufficient information is available.
- Assess (qualitatively or quantitatively) the likelihoods of the development of the credible potential failure modes.

- Identify the loading conditions, visual and instrumented performance indicators, and surveillance and emergency preparedness requirements for the potential failure modes. Where practicable, identify the rate that each potential failure mode could develop and what timeframes may be available to intervene should the potential failure mode develop.

The FMEA may also:

- Identify any potential or confirmed dam safety deficiencies relating to the potential failure modes.
- Identify knowledge gaps that require further investigation to obtain an improved understanding of the dam's potential failure modes.
- Assess the nature of the breach or uncontrolled release and the downstream consequences for selected credible potential failure modes (refer Module 2: Consequence Assessment and Dam Classification).

The process and outcomes of the FMEA should be fully documented, including: 1) a summary of other failure modes that were identified but considered not credible (with reasons for their rejection as credible failure modes); and 2) other failure modes where there was insufficient information to classify as credible or not credible.

3.5 Documentation

A DSMS, including all relevant operation, surveillance, maintenance, testing, and emergency procedures, should be well-documented and available at all times to those responsible for its implementation and review. The DSMS may be prepared as a stand-alone document, or as a 'core' explanatory document that is supported by other documents that detail specific elements of the DSMS. Nevertheless, the DSMS should be clear, user friendly and easy to implement.

All documentation relating to a DSMS should be controlled using appropriate document management processes. The documents should be stored securely, appropriately backed up and able to be accessed in normal and emergency conditions. While electronic formats provide significant technological and access advantages, hard copies may also be required for conditions where electronic access may become compromised.

4. Elements of a Dam Safety Management System

A DSMS includes elements that are minimum regulatory requirements (e.g. surveillance and dam safety reviews for Medium and High PIC dams) and recommended practice (e.g. governance and information management for all dams). Owners should include all elements in their DSMSs to ensure effective and appropriate dam safety management. The 12 elements that should be included in a DSMS are listed in Table 4.1. Seven of the elements are required by the Regulations (2022) to be included in a Dam Safety Assurance Programme (DSAP) for a Medium or High PIC dam (refer Module 1: Legal Requirements).

An effective DSMS will not only provide a framework for an Owner to assure safe dam and reservoir operation, for any dam irrespective of its PIC, but it will also support asset management practices and allow an Owner to maximise the value of their asset.

Two of the elements are addressed in sections 2.1 and 2.2, and the remaining 10 elements are addressed in sections 4.1 to 4.10 of this module.

Table 4.1: Elements of a Dam Safety Management System

Element	Referencesection	Type of element	
		Recommended practice	Regulatory minimum DSAP[1]
Governance	2.1	√	
People	2.2	√	
Dam and Reservoir Operation and Maintenance	4.1	√	√
Surveillance	4.2	√	√
Appurtenant Structures and Gate and Valve Systems	4.3	√	√
Intermediate Dam Safety Reviews	4.4	√	√
Comprehensive Dam Safety Reviews	4.5	√	√
Special Inspections and Dam Safety Reviews	4.6	√	
Emergency Preparedness (refer Module 6)	4.7	√	√
Identifying and Managing Dam Safety Issues (refer Module 7)	4.8	√	√
Information Management	4.9	√	
Audits and Reviews	4.10	√	
Notes: 1. Elements of a DSAP required by the Regulations (2022) (refer Module 1).			

4.1 Dam and reservoir operation and maintenance

4.1.1 Procedures and protocols

4.1.1.1 Dam and reservoir operation

The Owner should understand the dam system's design functions and operation, including the parameters within which their reservoir is to be operated for normal, unusual, and extreme loading and operating conditions. These parameters usually include measurable inflows, outflows, and reservoir level thresholds, and are typically embodied in protocols in consent conditions for a dam, reservoir, or scheme.

From a dam safety perspective, the operation of a reservoir and wider dam system should not present undue risk to people and property, the environment upstream and downstream of the dam, and downstream dams that form part of a cascade development on a river system. The Owner should also understand any operational conflicts that may exist in their dam system between dam safety, consent compliance, and public safety drivers.

Some dams may have a limited ability, or no ability, to operationally control inflows or outflows and therefore reservoir level. Moreover, the available storage in a reservoir will often not be sufficient to attenuate maximum outflows during large or extreme inflows. Procedures for the operation of reservoirs in a cascade development should be developed considering the safety of the whole cascade system.

Owners should ensure that their dam and reservoir operational plans and protocols are appropriate and provide sufficient margin to ensure the safety of the dam under all loading conditions and foreseeable operational scenarios. Sufficient freeboard should be available between the full supply level and the dam crest (refer Module 3), and neighbouring property and infrastructure, to prevent overtopping or flooding during unusual and extreme inflow scenarios. There may also be a need to limit the rate at which a reservoir level is lowered, via outflows, to ensure that the stability of the dam and reservoir shoreline is not adversely affected.

Dam and reservoir operation and maintenance procedures may be documented in an operation and maintenance manual or similar documented system. Where the operation and maintenance procedures are straightforward and simple, it may be appropriate to include them directly in the DSMS document.

If the operation and maintenance procedures and requirements are more complex, a summary of the procedures along with references to where the details can be found should be included in the DSMS document.

4.1.1.2 Dam and reservoir safety

A DSMS for High and Medium PIC dams should include the following operation and maintenance procedures:

- Reservoir operation procedures during normal, unusual, extreme, and emergency conditions (i.e. conditions that could result in dam failure if appropriate actions are not initiated).
- Operating procedures for gate and valve systems that fulfil dam and reservoir safety functions (e.g. reservoir level thresholds, gate/valve openings and discharge ramping rates).
- Maintenance procedures for gate and valve systems that fulfil dam and reservoir safety functions (e.g. visual inspections, battery/fuel checks, changes in lubricating fluids, major overhauls). Refer to section 4.3.4.
- Testing procedures for gate and valve systems that fulfil dam and reservoir safety functions, including power supplies, operating systems, and control and protection systems, to ensure ongoing functionality and reliability. Refer to section 4.3.4.
- Civil works maintenance procedures (e.g. internal drainage system cleaning, instrument repair, vegetation and debris clearing, upstream erosion protection reinforcement).
- Any procedures for the monitoring of upstream reservoir slopes and downstream banks (e.g. the stability of upstream landslides during high reservoir levels or rapid reservoir drawdown, and the stability of downstream river banks during high discharges).

Generally, the level of detail in operation and maintenance procedures related to dam safety should reflect the complexity of the dam system and its consequences of failure.

4.1.1.3 Review and test

The Owner, with support from appropriate technical and operations and maintenance personnel, should periodically review and test the dam's operation and maintenance procedures and protocols, particularly those where dam and reservoir safety is dependent on the correct operation of gates and valves.

4.1.2 Operator experience and training

Operating personnel should be competent, appropriately qualified, and trained to fulfil the requirements of the dam and reservoir operation and maintenance procedures. As well as fulfilling the functional requirements of the relevant procedures, operating personnel should be able to recognise significant threats to the safe performance of the dam and indicators for the development of its potential failure modes. They should also understand how to initiate appropriate response actions and when to seek specialist technical advice.

The level of experience, qualifications, and training of the operating personnel should be commensurate with the complexity of the dam and appurtenant structures. The nature of the dam's potential failure modes (especially those related to inappropriate operation or accidental mis-operation) and the consequences of dam failure (including unintentional flow releases) should be clearly understood by the operating personnel. The training process and operator competence certification should be documented in the Owner's quality assurance records.

4.1.3 Reservoir operation records

It is important that parameters associated with a reservoir's operation are consistently and accurately recorded and stored securely in a way that allows their consideration during routine dam safety monitoring, and annual and comprehensive dam safety reviews. Parameters that are important for the evaluation of dam safety include rainfall, reservoir inflows, reservoir lake levels, reservoir outflows, and all operations (including inspections, maintenance and testing) of gates and valves.

Incidents such as unusual loading conditions, operations, and occurrences, together with any evaluations and lessons learned, should also be recorded.

4.1.4 Dam and reservoir maintenance

There is a range of regular maintenance activities that contribute to the ongoing safety of dams and their reservoirs. These activities also maintain or enhance the value and lifespan of the asset, potentially minimising the need for more extensive maintenance and associated costs, or preventing the need for costly repairs or remedial works that could otherwise arise.

The following are common examples of maintenance activities, many of which will be required in some form for any dam. However, each dam and its setting is unique and will therefore have its own set of maintenance requirements. In recognition of this, maintenance requirements should be determined in consultation with appropriate Technical Advisors.

4.1.4.1 Reservoir shoreline and erosion

The reservoir shoreline can be susceptible to the effects of a dam's operation. The following maintenance activities, where necessary, should be completed:

- Repair rip-rap damage or surface erosion on the dam face.
- Repair excessive beaching or erosion of the reservoir shoreline.
- Maintain any facilities provided for the management of shoreline stability.

4.1.4.2 Concrete and embankment dams

Maintenance activities will be somewhat dependent on the dam type and its characteristics, and the actual loading and operating conditions. Any damage should be photographed and recorded. The following maintenance activities, where necessary, should be completed:

- Maintain and repair surface and joint sealing systems (including waterstops).
- Repair cracks and defects.
- Maintain or restore freeboard provisions.
- Repair wave-induced surface erosion.
- Repair concrete damage, and reinforcement or steelwork corrosion.
- Repair seepage-induced erosion and/or slumping.

4.1.4.3 Appurtenant structures and debris management

Spillway and intake facilities that fulfil dam safety functions should remain unobstructed to provide their full flow capacity on demand. In addition, appurtenant structures such as spillways, conduits and open channels (canals, flumes) may require periodic maintenance to ensure they remain capable of safely discharging their design flows.

The following maintenance activities, where necessary, should be completed:

- Repair damage such as scour, erosion, cracking, or waterstop failure in spillway chutes, stilling basins and outlet conduits.
- Maintain the functionality of drainage channels below spillways and of venting/air supply features included in discharge facilities to prevent cavitation.
- Maintain booms to prevent debris entry to spillway outlets and water intake facilities.
- Remove dead or unstable timber from the reservoir shoreline and the dam face.
- Manage and/or remove aquatic weed growth in the reservoir.
- Clean screens on intakes and outlet facilities.

4.1.4.4 Drainage systems

Dams, their abutments, appurtenant structures, and reservoir features (such as landslides or stabilisation works, where they exist) often rely on effective drainage of surface and sub-surface water for their ongoing stability and safe performance. Usually, effective drainage will also improve the ability to effectively monitor dam performance indicators such as seepage, leakage, and uplift.

To maintain the effectiveness of surface and sub-surface drainage systems the following maintenance activities, where necessary, should be completed:

- Maintain adequate surface drainage at dams, abutments and reservoir features, such that they are not unnecessarily saturated or eroded, and effective inspection and measurement of seepage/ leakage is possible.
- Maintain adequate sub-surface (internal) drainage systems at dams, foundations, abutments, reservoir features (where they exist) and structures such as spillway chutes, stilling basins and retaining walls to relieve piezometric pressures and/or foundation uplift, and allow effective inspection and measurement of uplift and seepage conditions.
- Periodically drain dam and abutment seepage areas and dam toes inundated by tailwater levels, where possible, to allow effective visual inspection and monitoring of seepage flows.

Dam and foundation internal drainage systems should be monitored for condition and performance with respect to their design assumptions and cleaned, if necessary and appropriate, to maintain their effectiveness. When choosing and implementing cleaning methods, extreme care should be taken to ensure the dam and foundation are not pressurised or eroded by the cleaning operation, and the drains are not damaged. Monitoring and recording of uplift pressures and drainage flows should be completed prior to, and following, cleaning (after conditions have stabilised) to verify the effect of the drain cleaning and the sensitivity of the drains to plugging, and to allow an appropriate drain cleaning frequency to be established.

4.1.4.5 Vegetation control

Vegetation on and adjacent to a dam and its abutments should be kept to a minimum. In particular, trees and large vegetation should not be allowed to establish on the dam or in the vicinity of its abutments and toe. Grass cover on embankment dams should be kept short.

The objectives of vegetation control are to:

- Prevent root penetration, which could affect the safety of a dam.
- Allow unimpeded observation of dam performance indicators such as seepage, leakage, slumps, instability and deterioration of materials.

Where vegetation has been allowed to establish on dam or abutment faces, the removal of the vegetation should be planned and executed with inputs from a Technical Advisor.

Dam and abutment slopes should also be kept clear of animal burrows, and activities that can result in rutting/tracking on dam faces (e.g. grazing and vehicle activities) should be minimised. Where it does occur, rutting and tracking should be repaired.

4.1.4.6 Infrastructure and services on dams

It is common for infrastructure and services (i.e. roads, power cables, communication cables, and water and gas pipelines), owned and operated by third parties, to be routed across dams and appurtenant structures. Dam Owners must ensure that they are informed and consulted about installation, operation and maintenance activities for the infrastructure and services, and that the safety of the dam and appurtenant structures is not compromised by the presence or maintenance of these items.

4.2 Surveillance

4.2.1 Philosophy

A robust and continuously improving surveillance process is the Owner's 'front line of defence' for the safe operation of their dams and reservoirs. Surveillance provides the cornerstone for effective management of dam safety and operational risks and includes routine visual inspections, instrument monitoring, data review and evaluation, and reporting on the safety of the dam.

Dam systems are inherently dynamic and therefore surveillance processes may need periodic review and adaptation to capture changing conditions and circumstances.

The United States Federal Guidelines for Dam Safety (FEMA 2004) includes the following statement:

> **Monitoring existing dams and reacting quickly to inadequate performance or to danger signals is a continuing critical aspect for dam safety. Careful monitoring and quick response can prevent failures, including those caused by poor construction.**

It is useful to define varying levels of surveillance for implementation as they are needed:

- **Routine surveillance** is undertaken during normal 'everyday' operating conditions.
- **Enhanced surveillance** is undertaken during, and/or for a period following, unusual or unprecedented loading conditions (e.g. floods and earthquakes), or when a potential dam safety deficiency exists. Additional and/or more frequent surveillance and monitoring is carried out to provide more detailed characterisation of the dam and/or foundation's behaviour and to assist with future actions should they be required.
- **Intensive surveillance** is required when there is a confirmed dam safety deficiency (when relevant load condition is occurring) or there is a developing dam safety threat. Intensive surveillance and monitoring can be round the clock, with experienced personnel and an enhanced means for reporting changes or anomalies to the Owner and their technical personnel or Technical Advisor. Intensive surveillance targets specific aspects of dam and/or foundation performance but should include broader observation of the dam system in the event there is an unusual response elsewhere. Emergency and regulatory authorities may be notified of the condition and put on alert.

4.2.2 Objectives

The level of surveillance should be appropriate to the individual dam considering its type, foundation, design, construction, operational context, consequences of failure, inherent condition, historical performance, characteristic behaviour, and potential failure modes. The objectives of surveillance are primarily to:

- Monitor dam and foundation performance, compare the performance with expected behaviours, and ensure that the characteristic behaviours are well understood for a range of loading conditions.
- Provide a baseline of performance information against which future changes in performance can be assessed.
- Be targeted to ensure that any changes in condition are noted to determine if they are possible early indications of the onset of a potential failure mode for the dam system. Such awareness may make it possible for intervention to occur (i.e. to prevent a potential failure mode from developing or to minimise the consequences of the occurrence of a potential failure mode).
- Identify and initiate the evaluation of dam safety issues arising from visual or measured/instrumented surveillance.
- Be dynamic and adaptive, such that the level of surveillance can be varied in a pre-determined manner in response to changing conditions and circumstances (e.g. loading, seasonal, operational, time or event based changes).
- Provide accurate and consistent data throughout the life of a dam.
- Be robust and auditable.

4.2.3 Process and procedure

An Owner's surveillance process and procedures should be well defined and functional. They should be established and documented in a way that clearly describes:

- What is to be done.
- Who is responsible for doing it.
- When and how often it is to be done (timing and frequency).
- How it is to be done.
- How it will be evaluated, documented, and quality assured.
- How any anomalies will be addressed.
- How issues will be escalated for consideration by Technical Advisors or other dam safety specialists.
- Events that could trigger the need for enhanced and intensive surveillance.
- Provisions for enhanced and intensive surveillance.

The documentation should be controlled and readily available to, and understood by, those responsible for the implementation of surveillance activities. It should also be regularly reviewed and updated to reflect changes in processes or requirements and allow improvements in the effectiveness of surveillance activities.

4.2.4 Quality

A high level of quality is required in the data and information that is gathered, stored and interpreted for monitoring and evaluating the safety of a dam throughout its lifetime. The surveillance process can be thought of as a 'quality chain' – a multi-linked chain where each step in the process forms a critical link. Without rigorous attention to assuring the quality at each step, links in the chain can become tenuous or broken, compromising the integrity of the whole chain, and hence the safety of the dam. The quality chain starts with the personnel undertaking surveillance activities in the field, continues with regular review of the information by appropriate Technical Specialists, and is completed with feedback to the field personnel (relative to the nature of continued surveillance) and reporting to the Owner on the safety of the dam and the need for specific responses or required actions.

4.2.5 Visual inspections

4.2.5.1 Philosophy

Visual inspection by competent and trained personnel is the most effective means of dam surveillance. There is no substitute for the observations and preliminary judgements of individuals who:

- Are familiar with the dam's layout and features.
- Are familiar with the objectives of instrument monitoring and measurement, and instrument monitoring and measurement procedures.
- Are aware of the characteristic behaviour of the dam and installed instruments.
- Can detect, record and report any change in condition.
- Understand the dam's potential failure modes and vulnerabilities.
- Are able to recognise indicators of adverse dam performance and the initiation of potential failure modes.

Visual inspections should follow a repeatable checklist of items that is appropriate to the dam (and foundation) type, characteristic behaviour, and potential failure modes. Inspection checklists should be developed and reviewed in conjunction with a Technical Advisor. An example checklist for an embankment dam is provided in Figure 4.1. Note that this example is provided to illustrate the nature of the checklist and, as such, items E1 to E10 are not all inclusive. The checklist developed for each dam should be geared to the specific nature, features, characteristics, identified credible potential failure modes and performance history of the dam.

An open ended question at the end of each section of the checklist should be included, such as, 'Are there any other conditions or observations of interest?'. It is very important that the checklist should not be so prescriptive that the inspector is not encouraged to look at other areas and features that may have a bearing on dam safety and this principle should be emphasised in the inspector's training.

Photographs of general and specific features, from repeatable locations provide an effective long-term record of inspection observations. Video recording of features or unusual events can also be particularly valuable. Unmanned Aerial Vehicles (UAVs, also referred to as drones) and underwater Remotely Operated Vehicles (ROV) fitted with video cameras or Light Detection and Ranging (LiDAR) are particularly useful for inspecting areas that are unsafe, difficult, or otherwise not possible to access, including during gate testing and emergency conditions. A competent and trained inspector should be part of the UAV/ROV inspection to witness the video footage, reference observations and support best understanding of key areas of interest at the time of inspection.

Figure 4.1: Example Routine Visual Inspection Checklist for an Embankment Dam

Routine Inspection List for Blue Dam

Inspected by:
Date and time:
Weather:

Potential Failure Modes and what to look for:

- PFM1: Embankment seepage and internal erosion leading to piping failure (e.g. unusual seepage, depressions)
- PFM2: Foundation seepage and internal erosion leading to piping failure (e.g. unusual seepage, depressions)
- PFM3: Flood-induced overtopping of embankment and erosion leading to failure (e.g. loss of freeboard, erosion)
- PFM4: Earthquake induced embankment cracking leading to seepage, internal erosion and piping failure (e.g. cracking, unusual seepage, depressions)
- PFM5: Earthquake induced embankment deformation leading to loss of freeboard and overtopping failure (e.g. loss of freeboard, deformation)
- PFM6: Operational flow imbalance induced overtopping of embankment and erosion leading to failure (e.g. loss of freeboard, erosion)

Item no.	Description	Observation/Comment
E1	Record reservoir level (e.g. metres above mean sea level)	
E2	Is there reservoir shoreline instability or erosion?	
E3	Is the upstream face showing any erosion, instability, depression or cracking?	
E4	Is the dam crest showing any deformation, misalignment, depressions or cracking?	
E5	Is the left abutment showing any instability or seepage, including where the dam embankment contacts with the abutment?	
E6	Is the right abutment showing any instability or seepage, including where the dam embankment contacts with the abutment?	
E7	Is the downstream face showing any instability, deformation, depression, cracking or seepage?	
E8	Is the dam toe showing any erosion or seepage?	
E9	Measure the total dam seepage (e.g. time to fill 1 litre container, or mm head over a 90 degree v-notch weir)	
E10	Is the spillway entrance obstructed? Is the spillway chute or plunge pool damaged or eroded?	

Other Comments/Observations (e.g. unusual events since last inspection, vegetation issues, operating issues):

4.2.5.2 Frequency

The frequency of routine visual inspections and the evaluation of collected data should be appropriate to the PIC of the dam, and the particular importance or vulnerability of the dam. Recommended frequencies for High, Medium and Low PIC dams, other than flood detention dams, are listed in Table 4.2. Flood detention dam should be inspected on an annual basis, and during and immediately following flood events.

Table 4.2: Suggested routine visual inspection frequencies (assuming no dam safety deficiencies)[1]

Type of Inspection	Potential Impact Classification (PIC)		
	Low	Medium	High
Routine	Monthly[2] to Quarterly	Monthly[2]	Weekly[3] to Monthly[2]

Notes
1. In some cases alternative inspection frequencies may be appropriate or required (for the reasons outlined in the paragraph below). If a potential or confirmed dam safety deficiency exists, the inspection frequency should be reviewed and if necessary amended.
2. Monthly inspections should include a minimum of 11 inspections each year with no more than 6 weeks between inspections.
3. Weekly inspections should include a minimum of 50 inspections each year with no more than 10 days between inspections.

In some cases, the dam Owner and Technical Advisor may select an alternative inspection frequency appropriate for the dam under consideration. The following characteristics should be evaluated when considering alternative inspection frequencies:

- The time required to detect and intervene if a potential failure mode is initiated.
- Potential or confirmed dam safety deficiencies or inherent vulnerabilities.
- The availability of 'other' observations of key dam/foundation features that would provide early indication of the initiation of potential failure modes (e.g. proximate Owner personnel or public, telemetered instrumentation).
- Unusual events (natural or operational) that could result in a change to the dam's loading condition (e.g. rapid drawdown/filling, historic low/high reservoir level), or that require additional surveillance (e.g. construction, rehabilitation or investigation activities).
- Practical considerations such as the dam's location and the ability to access and inspect the dam (e.g. remote locations, adverse weather conditions).

4.2.6 Performance monitoring instrumentation

4.2.6.1 Philosophy

There are many available options for the instrumented measurement of dams, reservoirs, and their features to monitor their performance. Where possible, when determining what instruments are required to monitor dam system performance throughout its operational lifetime, Owners and Technical Advisors should adopt a 'simple and targeted' instrumentation philosophy.

All instrumentation should have a clear purpose that is linked to one or all of the following objectives:

- Improving the understanding of a reservoir, dam or foundation's characteristic behaviour during normal operation, and during unusual and extreme events.
- Providing close monitoring of the reservoir and early indication of departure from normal operation.
- Providing early indication of the onset of potential failure modes for a dam.

Note that, in some cases, instrumentation may assist with the identification of features, trends or conditions that are indicative of a potential failure mode that was not identified during earlier studies. The information available during the completion of the earlier studies may not have allowed a particular potential failure mode to be identified or may have indicated that a particular potential failure mode was not credible.

Performance monitoring instruments should be robust, durable, require little maintenance and able to be read easily and consistently, often by non-specialist personnel. Most importantly, the instrument should be 'the right tool for the job'. That is, it should measure as directly as possible a parameter, condition or quantity that supports the aforementioned performance monitoring objectives. The operational lifetime of a dam system is typically tens of decades, and the surveillance instrumentation should be selected so that either it has a similar life span, or that components with a shorter life can be safely maintained and/or replaced.

The overall instrument array should be resilient and include redundancy where appropriate. Redundancy is specifically important for dams where piezometric (or uplift) information is measured using vibrating wire instruments, or where it is gathered and reported using telemetry or other means of electronic transmittal that can be affected by lightning strikes or power loss. In such cases, backup manual measurements of piezometers or uplift pressures should be provided at key locations.

Survey monuments installed to allow measurement of a dam's deformation or settlement (or the displacement of an appurtenant structures) are not typically considered to be 'instrumentation'; however, they do provide the same function in that they can yield important information relative to some potential failure modes and allow the behaviour of the dam to be monitored.

Dam performance monitoring instruments predominantly measure geotechnical, hydrologic, or structural parameters and, in their selection and maintenance, should not be confused with the types of instrument used to measure and monitor mechanical and electrical systems.

The need for and value of performance monitoring instrumentation will depend on the requirements for the particular dam system. Most instrumentation is selected during dam design and installed during construction and may have a primary purpose related to the monitoring of commissioning parameters rather than those parameters required for the long- term management of dam safety. Hence, it may be appropriate to consider additional instruments to ensure performance monitoring needs are met or, where instruments are found to be redundant, it may be appropriate to decommission instruments. Additional or different instrumentation may also be installed when a potential dam safety deficiency is being investigated and assessed.

Technological advances in instrumentation types and systems will occur over the life of any dam. It is therefore likely that the original instrumentation will be augmented or replaced by new systems over time. Where possible, a period of monitoring overlap should occur to ensure that historical data can be correlated to information obtained from new systems.

Module 3 (Investigation, Design, and Analysis) provides further detail on instrumentation for embankment dams, concrete dams, and tailings dams. In addition, relevant ICOLD bulletins that address dam instrumentation are referenced at the end of this module.

4.2.6.2 Key dam performance parameters and instrument types

Universal to all dams, the most important parameters to measure quantitatively and evaluate, where possible and appropriate, are:

- Reservoir level.
- Dam and foundation seepage and/or leakage rates.
- Dam/abutment internal water pressures and phreatic surfaces.
- Foundation uplift pressures.
- Dam deformation and displacement.

The above key parameters for embankment and concrete dams are shown diagrammatically in Figures 4.2 and 4.3 and are discussed in the sections that follow.

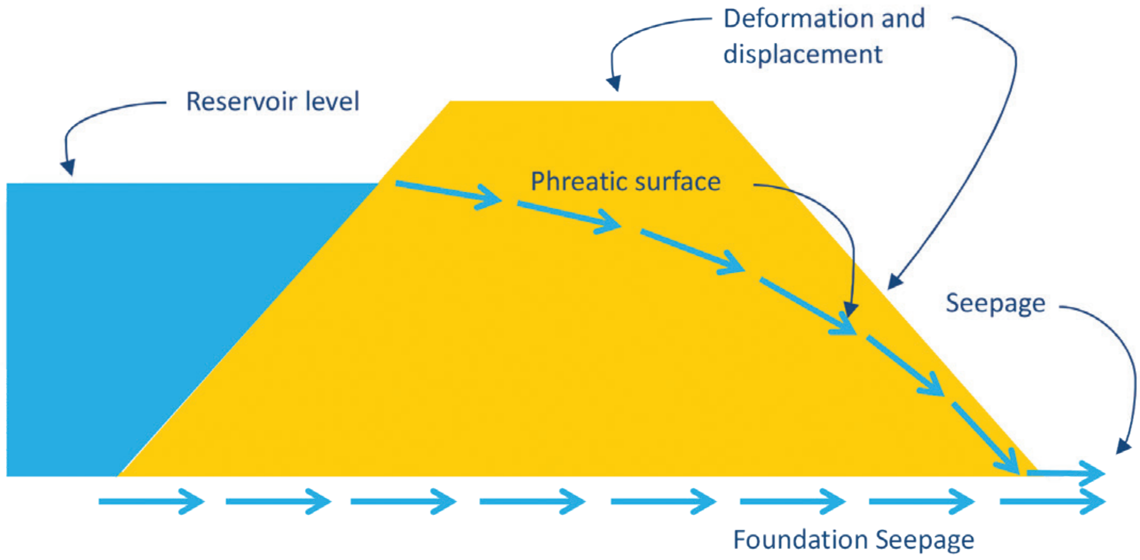

Figure 4.2: Embankment Dam Performance Parameters

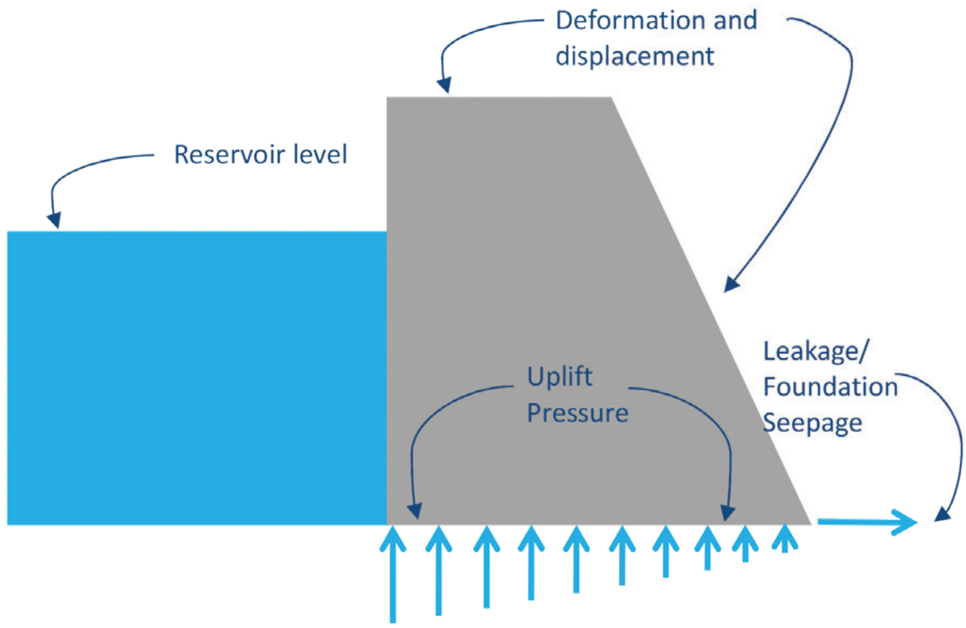

Figure 4.3: Concrete Dam Performance Parameters

4.2.6.3 Reservoir level, inflows, outflows and rainfall

Reservoir level is a fundamentally important measure of the loading condition, and therefore the driving head that the dam and its foundation are subject to, as well as the freeboard available to avoid overtopping. At a minimum, reservoir level should be recorded when visual inspections and instrumented measurements are completed to allow meaningful correlations of the effects of different loading conditions. Catchment rainfall, reservoir inflows and outflows, and reservoir level should also be monitored for operational purposes, with scope, reliability, and frequency commensurate to the dam safety, reservoir safety, and public safety consequences.

While water level sensor instruments are commonly employed for automated and frequent monitoring, a manually readable water level staff gauge should be installed in all reservoirs. Water level staff gauges are simple, effective, and reliable, as they do not need a power source or have electronic components. They also provide an important calibration check where water level sensors are installed. Water level staff gauges should be dimensioned to measure the full operational range of reservoir levels, including flood and dewatering conditions, and positioned so that they can be easily read in all loading and weather conditions. They should also be sited to allow reading without placing personnel at risk.

Reservoir level should optimally be measured in metres above mean sea level for ease of correlation with dam features and other measured performance parameters such as piezometric levels and foundation uplift.

4.2.6.4 Seepage and/or leakage rate

Seepage and/or leakage rate is an indicator of the performance of impermeable (or low permeability) elements installed in the dam and foundation, and the performance of the abutments and foundation where no impermeable elements are installed. The objective of measuring seepage flows is generally to identify seepage trends and understand the overall performance of the dam, rather than to record absolute values. Decreasing seepage flows may need to be scrutinised just as much as increasing seepage flows, as they may indicate a change relevant to dam performance.

The ability to measure rate of seepage and leakage through the dam, foundation, or abutment usually relies on directing the seepage or leakage through appropriate collection and drainage facilities to a measurement point close to the dam's toe or at the location where the seep or leak emerges from the dam, foundation, or abutment.

Seepage and leakage flow is best measured volumetrically, either by measuring the time to fill a container of known volume, or by installing a weir or flume with a theoretical (or calibrated) rating that allows the measured head to be converted to flow rate. For the purpose of ongoing monitoring and evaluation of a dam's performance, the most important aspect of seepage and leakage rate measurement is repeatability, rather than absolute precision. Weirs should be sized for the anticipated flows and weir boxes should be large enough to provide calm water surfaces behind the weir plates. In some cases, baffles may be needed to achieve this. V-notch weirs provide precision for the measurement of seepage flows; however, for large flows, broad crested weirs or flumes will be necessary. The observation of seepage and leakage flows via the use of weir boxes also allows the detection of any materials being transported by the seepage flows. The detection of turbid seepage or soil particles in seepage flows is important as they may be an indicator that internal erosion (backward erosion piping or seepage erosion) is taking place within the dam, in its abutments, or in the foundation. In order to detect whether or not soil particles in a weir box are the results of internal erosion, the weir box may have to be covered to protect it from windborne material and periodically cleaned to enable the captured material to be examined and weighed.

For dams built on permeable foundations (e.g. river gravels), or dams that have toes inundated by tailwater conditions, the collection and measurement of seepage or leakage can be difficult to achieve. In such cases the dam design may reflect the inability to monitor seepage or leakage at the dam toe. However, if seepage monitoring is required at a dam toe that is founded on permeable materials or inundated by tailwater, temperature sensing methods are available for the targeted detection of seepage within a dam or through its abutments or foundation. Also, as noted above, the toe may be able to be periodically dewatered (outflow shut off or diverted and standing water pumped out) to allow the measurement and observation of seepage outflows.

4.2.6.5 Internal water pressure and foundation uplift pressure

Internal water pressure and foundation uplift pressure are measured to allow the stability of the dam to be evaluated against performance expectations and design assumptions. The absolute measured values are therefore of prime importance; however, changes recorded over time also need to be examined and understood.

Water pressure is usually measured using a piezometer. Internal piezometric pressures are most relevant to embankment dams or tailings dams, and the foundations and abutments of all dams. The measurement of internal water pressure at a number of points in the body of the dam, or in its abutments or foundation, allows the phreatic surface (below which the materials are saturated) to be understood. Saturation of the downstream shoulder of an embankment dam is undesirable for dam stability.

Uplift pressures are most relevant to concrete dams and their foundations and allow their stability to be evaluated. Uplift pressures at or near the toe of embankment dams may also be relevant if a blowout condition or potential piping condition exists.

There are a number of piezometer types including open standpipes (observation wells), ported/slotted standpipes, and hydraulic, pneumatic, vibrating wire, and fibre optic piezometers. Piezometers are typically installed during the construction of a dam and built into the dam body or foundation. This makes the replacement of certain types of piezometers difficult and potentially risky. Therefore, the maintenance of installed piezometers, to preserve their accuracy and maximise their service lives, is very important and usually requires the input of an appropriately skilled and competent Technical Advisor (specifically a geotechnical instrumentation specialist). If piezometers cannot be replaced if they malfunction, the use of long-lasting and replaceable backup piezometers should be considered.

Where retrofit or replacement of piezometers is considered necessary (e.g. for replacing failed instruments, characterisation of a special feature or the monitoring of a potential failure mode), extreme care should be taken in planning and installing the instruments to avoid damage to the dam and its foundation. An appropriately experienced Technical Advisor or Technical Specialist should be consulted in such cases. In some cases, the dam safety risks associated with installing a new piezometer may outweigh the benefits of the instrument.

Foundation drains in concrete dams can be used as piezometers, either by measuring the depth to the water level (if the water level is below the top of the drain) or by installing a pressure gauge (if water is flowing from the drain). However, this approach may have limitations that include a slow response time and a general measurement of pressure as drains are usually not slotted or isolated to a particular zone. Furthermore, if an overflowing drain is capped with a gauge, or has an upstand pipe installed to elevate the water level, the resulting increase in foundation uplift may encourage the development of an adverse condition.

An appropriately experienced Technical Advisor or Technical Specialist should be consulted in such cases. For correct evaluations of dam performance, it is important that the locations of piezometers in the body of a dam or foundation are accurately known (position and level), that the instruments are correctly identified, that their precision and accuracy are regularly assessed, and that they are appropriately maintained.

4.2.6.6 Deformation and displacement

Deformation and displacement can be effective performance indicators for instability, settlement, and other potential failure modes. They are also useful to characterise the behaviour of dam and foundation components. They are most commonly observed by visual observation during routine surveillance and measured by traditional survey methods such as precise levelling and Electronic Distance Measurement (EDM) of targets installed at key locations on the dam and its foundation.

Visual observations can generally identify anomalous deformations, such as cracks, joint openings, depressions, bulges, tilting or out-of-line movements in a structure or abutment. However, instrumented measurement and surveying are the most effective methods for measuring and monitoring changes at specific locations and features, establishing movement trends, or verifying visual inferences of movement. A Technical Advisor with experience in the particular dam type should be consulted when designing a dam deformation survey layout to ensure that the dam's performance monitoring objectives are met.

As well as traditional survey methods, there are a number of alternative methods and technologies available for the measurement of deformations and displacements. Examples include pendulums, inclinometers, tilt meters, joint meters, Global Navigation Satellite Systems (GNSS), continuous survey monitoring (CSM), robotic total station and laser scanning (ground mounted or airborne). Fundamentally, the method and/or technology adopted should be selected such that it meets the dam performance monitoring objectives related to precision and accuracy, and can be readily calibrated.

For High and Medium PIC dams, deformation surveys should be conducted by specialist surveyors with equipment and methodologies that achieve the required precision and accuracy (within 1 to 2 mm vertically and 3 to 4 mm horizontally). For Low PIC dams, if deformation survey is necessary, the Designer or Technical Advisor may set the precision or accuracy required. However, it should be recognised that lower precision or accuracy will significantly reduce the value of the deformation monitoring. A survey control network on stable ground remote from the dam structure should be utilised to minimise survey errors and a specialist surveyor should be consulted in designing the control network. Generally, the size of the structure and its survey control network will influence the achievable precision and accuracy of the deformation survey. To be reproducible and detect changes, periodic surveys should generally be taken at the same time of year and where possible with similar reservoir level (especially important for concrete dams). To understand variation of deformation due to reservoir and temperature, surveys may be timed alternately to coincide with greatest upstream and downstream movements. Embankment dam moisture content, particularly where swelling clays exist, can also influence deformations. Also, when surveying methods or survey personnel change, a close examination of the results should be completed to establish the validity of the results and their correlation with past surveys. Vegetation management plays a significant part in the effectiveness of deformation monitoring. For visual observation, clear dam and abutment faces allow the identification of surface anomalies. For instrumented surveys, vegetation and man-made additions (e.g. handrails or fences) may block lines of sight between survey pillars and monitoring points.

4.2.6.7 Other available performance monitoring instruments and systems

There is a vast range of other instruments and systems available that can be used for repeated measurements/surveys for the monitoring of dam system performance and the monitoring of hazards. Some common examples include, but are not limited to:

The use of simple scribe marks across monoliths of concrete dams, on the crest or within galleries, to indicate relative movements of blocks. Two- or three- dimensional crack monitoring devices can also be attached to the concrete for greater accuracy.

- Chemical analysis tests for determining seepage and leakage origins.
- Turbidity meters (indicators of internal erosion).
- Video cameras for real-time visual observations, including the internal inspection of conduits (drains and outlet tunnels).
- Trip wire systems (e.g. displacement/rupture of an active fault, or a dam itself).
- Post-tensioned cable anchor load testing (to confirm anchor tensions).
- Temperature sensing systems for the identification of seepage in dams or foundations (e.g. distributed temperature sensing and resistance temperature devices). Temperature sensors can provide valuable data on the flow time and flow source of seepage water, particularly when complemented by other measured parameters such as piezometric pressure, seepage flow rate, and the temperature of the reservoir and other potential sources (such as ambient groundwater or tailwater).
- Early warning upstream rainfall collection and catchment modelling systems for predicting the size of incoming floods or extreme weather conditions (an important aspect for surveillance and emergency preparedness).
- Rainfall measurement to assist with the interpretation of seepage observations, and the evaluation or correlation of landslide and abutment slope movements.
- A seismic monitoring network for detecting and notifying the location and strength of earthquakes (an important aspect for emergency response). The GeoNet system detects, analyses, and reports on geological hazards in New Zealand. Geohazard data, including earthquake reports, is publicly available at **geonet.org.nz**.

- Strong motion seismic sensors for the measurement of ground motions. These may be helpful where the GeoNet network coverage is limited and/or where measurement of ground motions at the dam site is required. The locations for installation of strong motion recorders should reflect the site conditions and preferred locations, in order of usefulness, are:
  - the base of the dam to record the peak ground acceleration
  - the abutments to record topographic amplification of the peak ground acceleration
  - the dam crest to record the amplification of the peak ground acceleration.
- Remote sensing deformation monitoring systems, such as: Global Navigation Satellite Systems (GNSS), Interferometric Synthetic Aperture Radar (InSAR), Light Detection and Ranging (LiDAR), and photogrammetry.

Instruments and systems such as these may be built into or near a dam at the time of its construction, added during the life of a dam to supplement or enhance existing instrumented monitoring, used to address a specific potential failure mode, used to investigate a potential or confirmed dam safety deficiency, or used for periodic monitoring.

4.2.6.8 Instrument installation, calibration and maintenance

All instruments must be correctly installed (location, method), and calibrated and maintained at appropriate intervals to ensure the ongoing provision of reliable data. They must also be carefully installed to ensure their installation does not result in damage to the dam or its foundation. Documentation and drawings of instrument location, purpose, calibration and maintenance should be accurate, regularly reviewed, safely stored and available to operational staff, Technical Advisors, and reviewers. If instruments lack complete as-built information and calibration details, considerable time and effort may be spent attempting to interpret their data throughout the lifespan of the dam. In some situations, a meaningful or correct interpretation may not be possible.

4.2.6.9 Instrument monitoring frequency

The frequency of instrumentation monitoring should be initially set and periodically reviewed by the Designer or Technical Advisor. It should be appropriate to the particular dam, the consequences of its failure, and the dam performance monitoring objectives (such as understanding characteristic behaviour and as an indicator of a potential failure mode; refer section 4.2.6.1). The monitoring frequency should also appropriately reflect:

- The time required to detect and intervene if a potential failure mode is initiated.
- Potential or confirmed dam safety deficiencies or inherent vulnerabilities.
- The availability of 'other' observations of key dam/foundation features that would provide early indication of the initiation of potential failure modes (e.g. proximate Owner personnel or public, telemetered instrumentation).
- Unusual events (natural or operational) that result in a change to the dam's loading condition (e.g. rapid drawdown/filling, historic low/high reservoir level), or that require additional surveillance (e.g. construction, remediation or investigation activities).
- Practical considerations such as the dam's location and the ability to access and read the instrumentation (e.g. remote locations, adverse weather conditions).

The frequency should be dynamic and adaptive in response to changing observations and needs. As a general guide, Table 4.3 provides suggested routine monitoring frequencies for different instrumentation types.

Table 4.3: Suggested routine monitoring frequencies

Type of instrument	Potential Impact Classification (PIC)		
	Low	Medium	High
Reservoir level	At Routine Inspection	Continuously monitored[1]	Continuously monitored[1]
Seepage and/or leakage	At Routine Inspection[2]	Minimum at Routine Inspection[1]	Minimum at Routine Inspection[1]
Phreatic surface and/or uplift pressure	At Routine Inspection[2]	Minimum at Routine Inspection[1]	Minimum at Routine Inspection[1]
Deformation monitoring	Minimum 10-yearly[1]	Minimum 5-yearly[1]	Minimum 5-yearly[1]
Rainfall		Daily[3]	Daily to hourly[3]
Seismic event notification		Site-specific[4]	Site-specific[4]
Turbidity (of seepage)		As required	As required
Chemical analysis		As required	As required
Post-tensioned anchor cable loads		10-yearly	5-yearly

Notes

1. Determine frequency in consultation with appropriate experienced Technical Advisor considering reservoir operation regime, dam and foundation type, the specific dam performance monitoring needs (refer section 4.2.6), the consequences of failure, and the instrument monitoring frequency items listed above the table.
2. If instrumentation exists.
3. Rainfall measurement at, or near to, the dam site assists with seepage/leakage evaluation. Rainfall measured in or close to the dam's catchment (where available), assists with flood forecasting.
4. For dams located in close proximity to known active faults it is recommended to access a seismic monitoring network that provides timely notification of the locations and magnitudes of earthquakes relative to the dam site. A public notification service based on a national network of instruments is available (GNS Science's Geonet).

4.2.6.10 Manual reading and recording method

Where instruments are read manually, data should be recorded using systematic checklists that include alert levels. Alert levels should be set by a Technical Advisor familiar with the dam and instrument performance and should optimally provide both a 'data entry' check (e.g. whether the reading is within the instrument's range) and a check against performance expectation (refer section 4.2.8). Usually, instruments are read during the routine inspection and therefore alert levels can be included in the routine inspection checklists. This provides an important quality assurance check at the point of reading and provides the inspector with an indication of normal and/or expected instrument behaviour, and an alert in the event of an incorrect reading or change.

Owners may use paper-based or electronic field datalogger-based checklists. Electronic datalogging systems have the advantage of allowing direct transfer/upload to a monitoring system, therefore reducing the possibility of transcription error. Common data management errors include incorrect readings, incorrect data entries (numerical or data entered in wrong field), inconsistent data measurement methods, and incorrect data reductions/calculations. Alert levels can be built into electronic devices and may be supported by an on-demand display of previous readings for a given instrument. Whatever method is used to record observations and readings, all records must be carefully stored as part of the dam's long term surveillance record.

For those potential failure modes highlighted in the FMEA as most significant to the safety of the dam, the individual completing the monitoring (e.g. surveillance inspector, operator) should be aware of the relevant alert levels and be able to immediately alert the Owner or the Owner's Technical Advisor who routinely reviews the monitoring results.

4.2.6.11 Automated and remote data acquisition

Automated and remote acquisition of data from the dam site to the Owner's monitoring system can be beneficial in a number of applications. Generally, it is most useful for dams and reservoirs with significant consequences of failure, when there is a need to carry out enhanced or intensive data collection to gain an improved understanding of a dam's characteristic behaviour, to provide early indication of the onset of a particular potential failure mode, or to monitor a potential or developing dam safety threat. Remote acquisition of data provides frequent packets that enable a timely response, whereas data accumulated at the instrument over a number of weeks and intermittently downloaded may provide insufficient time for a rapid reaction to an undesirable trend.

Remote acquisition of data is particularly useful where access is limited or not possible. Examples include remote or hazardous locations (such as confined spaces or heights), or areas where access is blocked or dangerous (such as after an earthquake or during a flood or storm). The design of an acquisition system should consider the conditions that the system will be required to operate in (e.g. inclement or extreme weather) and should incorporate appropriate robustness and reliability.

The most common issues associated with acquisition systems are the provision of reliable power supplies and communication links. Where the consequences of dam failure are significant it is advisable to build redundancy into the system, such as a backup power supply and communication link. Where communication reliability is inadequate relevant to the importance of the measurement site, on-site data logging and storage should be included to allow manual download (transmittal of the information) in the event of communication failure.

4.2.7 Monitoring data management

4.2.7.1 Philosophy

The volume of data that is collected over a dam's lifetime can be very large, but it is essential to have an appropriate system in place for collecting, processing, storing and reviewing the data. For the simplest of dams this may be a paper-based system; however, for most dams, particularly more complex dams which have a greater number of visual and instrumented observation points, it is usual and convenient to use a computer-based system. The monitoring system should include alert thresholds set around performance expectations (refer section 4.2.8).

The monitoring data is part of the asset and its value and should be transferred with the asset should it change ownership.

Relevant ICOLD bulletins that address monitoring systems for dams are referenced at the end of this module.

4.2.7.2 Safe storage

Whether operating a paper-based or computer-based monitoring system, it is important to provide safe storage, including the frequent backup of data to an alternative location and an established plan for the continuity of dam surveillance under adverse conditions such as the loss of the primary dataset. Common data storage errors that may occur include the loss of data through adverse events such as deletion, overwriting, or electronic file corruption.

The data should be managed and stored in a system with an appropriate quality management process, in a way that both raw and transformed readings are kept (e.g. measured head at a v-notch weir and the calculated flow), and that accidental or inappropriate deletion or modification is not possible. Comments that relate to observations, interpretations or changes in operating condition/environment should be permanently 'tagged' to the relevant dataset.

The data should also be formatted and stored in such a way that long term records remain accessible and usable when an electronic system is changed or replaced.

Photographs and videos (and other media) used to record conditions of key observations should be appropriately referenced and easily retrieved to help answer current and future questions.

4.2.7.3 Presentation of time and spatially based data

It is essential to store and present surveillance data in a way that allows it is to be effectively evaluated, both in the immediate and full term history. This applies to both visually observed and instrumented data.

A unique identifier should be applied to each observation point (visual or instrumented), to serve as a reference in the paper or computer-based database. Data can then be presented in time-based lists and/or plots for review.

Quantitative data can readily be plotted in time-based charts. Qualitative data such as visual observations an also be plotted in this way by using a numerical recording system such as ‘0’ for ‘acceptable/normal’, and ‘1’ for ‘not acceptable or abnormal’ (i.e. something has changed), with relevant explanatory comments tagged to the data point (‘1’ should trigger an alert for follow-up). As another example, the visual assessment of a seep can be rated as ‘0 = dry’, ‘1 = drip’, ‘2 = trickle’, ‘3 = flow’, and ‘4 = alarming flow’ (‘4’ should trigger alert for follow-up).

Over time it is likely that sets or groups of instruments will respond in a correlated way to events such as lake level or rainfall changes. It is beneficial if the monitoring system adopted allows multiple instruments to be grouped and presented together. This can highlight when anomalous responses are occurring or if a particular instrument has stopped working.

A monitoring system should also have the ability to present spatially-variable data. For example, this may include surveyed deformations that vary with distance along a dam’s length, or piezometric pressures (or phreatic surface) that vary through a dam’s cross-section.

4.2.7.4 Quality assurance

A monitoring system should be designed and implemented with appropriate review, audit, escalation and sign-off processes to assure:

- The quality of the data collected.
- The correct data transformations are used.
- The data is evaluated and reviewed by competent Technical Advisors.
- Issues and anomalies are identified, resolved, or escalated as appropriate, and signed off by a competent Technical Advisor.

4.2.8 Dam performance evaluation

4.2.8.1 Philosophy

Competent Technical Advisors should be employed to establish performance expectations and evaluate dam performance appropriate to the consequences of failure and the complexity of the dam being evaluated. In some situations, Technical Specialists may be required (e.g. complex foundation and/or dam behaviour, complex structural or geotechnical analysis, high or extreme consequences of failure, or the management of a dam safety deficiency).

The evaluation of visual observations and instrumented data with respect to a dam’s safe performance is an essential part of a dam surveillance programme.

Performance evaluation should be undertaken following the completion of each routine surveillance inspection in a timeframe that reflects the dam condition and performance. During normal operating conditions the evaluation timeframe should reflect the PIC of the dam (e.g. within one inspection cycle for a High PIC dam, within one month for a Medium PIC dam and within 3 months for a Low PIC dam). Where there are unusual events or potential or confirmed dam safety deficiencies the evaluation timeframe should reflect the rate of event development and the level of risk.

The completion of an effective evaluation requires an understanding of the dam's behaviour under all loading conditions and the use of evaluation techniques that reflect the expected behaviour of the dam, the detail of the surveillance records, and the available information for the dam (e.g. design, construction, operation and maintenance records, rehabilitation records, and records of unusual events and incidents). Importantly, the evaluation must consider the dam's 'performance as a whole' in the context of the dam setting, design philosophy, construction features, condition, historical performance, and potential failure modes. Judgements should not be made based solely on isolated observations or instrument readings. Instead, the wider dam and foundation context should be considered, with conclusions drawn and supported by bringing together a range of relevant performance parameters and other information relevant to the safety of the dam.

4.2.8.2 Setting expectations

A Technical Advisor should approach an evaluation of a dam's performance with:

- An expectation of behaviour based on:
  - how the dam should behave in general terms based on its operational context, dam and foundation type, and design assumptions/limits
  - an understanding of the dam's characteristic behaviours – how the dam and foundation typically perform, including precedent loading conditions and observations.
- An understanding of the dam's potential failure modes and their key performance indicators.
- Established alert thresholds (acceptable performance limits) for key performance indicators.

While precedent observations or conditions are an important part of evaluating a dam's performance, it is not satisfactory to evaluate dam performance solely on the basis of deviations from previous performance.

4.2.8.3 Evaluation methods

As noted in section 4.2.7, there is a range of presentation methods that can be used by a Technical Advisor for the interpretation and evaluation of dam performance.

There is also a range of evaluation techniques that are applicable for interpreting complex conditions and observations. This module does not endeavour to present these in detail; however, reference can be made to the relevant ICOLD bulletins referenced at the end of this module.

4.2.8.4 Commentary on the use of Artificial Intelligence

The use of artificial intelligence (AI) to support dam performance evaluation has grown significantly and AI is being utilised for complex analysis on large datasets where the timeframe for analysis by a human may not be manageable. Several AI techniques have been used for the analysis of scientific and engineering data and include, for example, Mathematical Optimisation, Machine Learning, Fuzzy Logic, Artificial Neural Networks, Natural Language Processing, Deep Learning and many more.

There are specific requirements for data to be suitable as learning datasets for AI systems to be trained on and, as with all models, the quality and understanding of the output will be governed by the quality of the input and a comprehensive understanding of the system/technique used. The dam Owner should take necessary steps to ensure appropriate levels of quality assurance and factual reporting for all aspects of dam performance evaluation. Appropriate care and consideration should be given to data accuracy, size, data fit purpose, consistency, validity, uniqueness, completeness, and timeliness to minimise the potential for AI biases and other unreliable outputs, e.g. AI hallucinations.

AI systems/techniques are becoming increasingly accessible and available, and due to developments in computer resources and performance can be readily implemented. However, using and maintaining these systems requires a suitable level of expertise and resources which may not suit in-house operations. Where an external provider is engaged, the Owner should take the necessary steps to ensure the level of quality assurance set out in their DSMS is maintained.

There are many unknowns surrounding how effective and reliable output from an AI system is, especially where the input data, technique, and accuracy of the trained model may not be fully understood by the end users. If outputs are used to support dam safety decision-making they should always be ground-truthed and fact-checked.

If AI systems/techniques are to be incorporated into a long-term strategy for dam performance evaluation and decision-making the dam Owner should understand the longevity and dependability of the AI systems/techniques used and how they would:

- Perform consistently for the life span of the dam system.
- Be dependable and accessible (e.g. for emergency preparedness, changing conditions and circumstances of the dam Owner and/or service provider including succession planning).

4.2.9 Follow-up, escalation and reporting

As part of the surveillance process, an Owner should have an established procedure for the follow-up and resolution of untoward observations or situations, whether they are confirmed or unconfirmed. For example, this may include actions to be taken when alert thresholds are exceeded for monitoring data, or when an abnormal or unprecedented loading condition is experienced. The procedure must clearly identify the process for escalation of issues to those appropriately competent to deal with them. For Medium and High PIC dams (as a minimum) there should be an appropriate link that allows the Emergency Action Plan for the dam to be initiated (refer Module 6: Emergency Preparedness).

An important output of the surveillance programme is regular reporting to the Owner and relevant stakeholders on the performance of the dam, including any issues that arise and their resolution. These reports play an important role in the safety review of individual dams, and more broadly, the audit and review of the DSMS.

4.3 Appurtenant structures and gate and valve systems

4.3.1 Definitions

Appurtenant structures are structures other than the dam itself that are designed and are required for the safe containment and control of the reservoir contents and reservoir discharges under all loading conditions.

They may be at or near the dam or, in the case of a large reservoir, some distance from the dam; the key is that they impound and/or control the same reservoir. Pipelines and penstocks downstream of intake structures should be considered appurtenant structures if there are no gates or valves designed to isolate them from the reservoir contents.

Appurtenant structures frequently incorporate gates and/or valves (refer to Module 3 for how to identify appurtenant structures). Gates and/or valves that fulfil dam and reservoir safety functions are part of the total dam system and should not be considered in isolation, but rather as an integrated sub-system that includes the gates and/or valves, their lifting/operating systems, their associated power/energy supplies, and control, protection and communication systems. Such an integrated sub-system is implied when, for simplicity, these Guidelines refer to ‘gates and valves’ or ‘gate and valve systems’. Some owners designate these as ‘dam safety critical systems’ and ‘reservoir safety systems’. Identifying gate and valve systems should be completed in the context of the total dam system, components, design functions, operation, controls, and interdependencies (including human and organisational factors), how the dam system and components may fail to function (potential failure modes including reservoir safety and operational failure modes), and the consequences of failure to function. For further detail on dam systems, functions and failure modes refer to section 3.2 Dams systems and section 3.4 Failure Modes and Effects Analysis.

Inspection, maintenance and testing of gate and/or valve systems are carried out for the complete lifecycle including, but not limited to, routine inspection and maintenance, functional and performance testing, condition monitoring, testing for faults, testing for commissioning or recommissioning, comprehensive inspection, and performance assessment. The recommendations in this module are applicable to all of these aspects.

Because of their importance in fulfilling dam and reservoir safety functions, appurtenant structures and gate and valve systems need to be incorporated in a DSMS. Regulatory requirements for appurtenant structures and gates and valves are discussed in Module 1: Legal Requirements.

4.3.2 Dam and reservoir safety functions

For dam and reservoir systems and their components, dam safety functions support safe the dam's function to containment of the reservoir (e.g. safe dam performance). Reservoir safety functions support safe reservoir conveyance and control to prevent other uncontrolled reservoir releases (e.g. inappropriate gate operation, gate malfunction, gate failure, penstock or pipeline rupture).

Broadly, appurtenant structures fulfil or contribute to one or more of the following three dam and reservoir safety functions:

- Safe containment of the reservoir under all loading conditions.
- Safe conveyance and control of reservoir inflows and outflows (e.g. normal operation or flood discharges).
- Reservoir drawdown in response to a dam safety incident or emergency (conveyance and control).

Appurtenant structures that fulfil the above functions typically include or incorporate:

- Debris booms.
- Spillway control structures, chutes and stilling basins.
- Low level outlet structures.
- Penstock intake and canal inlet structures.
- Pipelines, penstocks, conduits and surge tanks with no means to immediately isolate them from the reservoir, and/or they are designed or intended for reservoir lowering.
- Gates and valves and their lifting/operating systems, including ancillary systems such as power supplies, and control, protection and communication systems.
- Pumps for the transfer of water into pumped storage reservoirs.

It should be noted that dams will often contain, or be adjacent to, a range of structures that may not have been designed or intended to have any role in dam or reservoir safety. While such structures are not appurtenant structures, changing circumstances over time (such as an increase in PIC) may require such structures to fulfil a dam or reservoir safety role.

If this occurs, the additional structures may require upgrading to address deficiencies that would otherwise prevent them from performing their dam or reservoir safety roles and would need to be incorporated in the DSMS.

An uncontrolled release of the reservoir is an event during which there is no control over the quantity of the stored contents released or the rate of discharge from the reservoir. Examples of conditions at appurtenant structures that could result in an uncontrolled release of the reservoir include:

- Inappropriate operation, malfunction or failure of gates and valves that fulfil a dam or reservoir safety function.
- Rupture of an appurtenant structure such as pipelines, penstocks, conduits, and surge tanks.
- Overtopping and subsequent erosion downstream of an appurtenant structure, or erosion of a dam or abutment adjacent to an appurtenant structure.
- Internal erosion in the foundation beneath an appurtenant structure, or in a dam or abutment adjacent to an appurtenant structure.
- Instability of an appurtenant structure.

4.3.3 Inspection, maintenance and testing

4.3.3.1 Civil appurtenant structures

Appurtenant structures are usually constructed from mass, reinforced, pre-stressed or post-tensioned concrete, or from steel (e.g. pipelines, penstocks), or from earth and/or rock materials.

Owners should inspect appurtenant structures at frequencies appropriate to the structures and their complexities to ensure that their condition and performance are well understood. The inspection and review of appurtenant structures should be appropriately included in routine dam surveillance, Intermediate Dam Safety Reviews (IDSRs) and Comprehensive Dam Safety Reviews (CDSRs). Special access may be required for the inspection of some areas (e.g. spillway chutes, dewatering tunnels).

The Owner should also maintain a regular programme of maintenance to ensure long term reliable performance of the structures. Examples include the repair of concrete and steel surfaces and joints, and the cleaning of drainage systems in spillway chutes and stilling basins.

Performance monitoring and surveillance of appurtenant structures usually involves measurements and observations similar to those for dams (e.g. seepage flow, water pressure and displacement).

4.3.3.2 Gate and valve systems

Gate and valve systems installed in appurtenant structures vary in complexity and the number of components, all of which must operate as intended to ensure that the dam or reservoir safety function is fulfilled. Some may be simple, such as hand operated valves, whereas others may have multiple modes of operation, power supply, and energy sources to provide appropriate levels of redundancy and diversity.

Gate and valve systems largely consist of mechanical and electrical components and equipment and, accordingly, have specific functional performance requirements. They require appropriate inspection, maintenance, and testing by competent operation and maintenance personnel (refer also section 2.2 and 4.1.2) to ensure they are in good working order and capable of performing normal and emergency operation under all conditions. Inspection, maintenance and testing competencies should be evaluated for each dam system, especially where personnel cover multiple dam systems and the gates and valves systems vary between dam systems. Moreover, the performance monitoring of gates and valves differs from that required for dams and appurtenant structures; it is dominated more by direct inspection and testing rather than by surveillance and monitoring. An additional difference is that gate and valve equipment and components can fail instantaneously, which is less likely to be the case with civil structures. Therefore, mechanical and electrical components and equipment require a different approach and design to ensure the risk of loss of function is minimised or avoided altogether. Dam system analysis, event tree analysis, fault tree analysis, Failure Modes and Effects Analysis (FMEA), and Failure Modes and Effects Criticality Analysis (FMECA) are examples of processes available to maximise the understanding of reliability and robustness of gate and valve systems. Robustness with respect to power sources, control methods, access, communication and mechanical equipment is typically provided by removing 'single points of failure' providing backup sources or methods, and maintaining a ready supply of critical spare parts (e.g. hydraulic pump, electric motor, winch brake). Regular inspection, maintenance, and testing also ensures that operational personnel are familiar with the equipment and its performance, particularly if the equipment is infrequently used or has been recently modified.

Inspection, maintenance and testing programmes, plans and procedures should be developed by the dam Owner in consultation with appropriately skilled and experienced Technical Advisors with consideration to each unique dam system and its gate and valve system. The programme and procedures should reflect a deep understanding of the system and component functions, operation, controls, interdependencies (including human and organisational factors), how the system and components may fail to function, and the consequences of failure to function. Such appropriately skilled and experienced Technical Advisors should also be part of gate and valve system performance reviews and assessments. For further detail on dam systems, functions, and failure modes refer to section 3.2 Dams systems and section 3.4 Failure Modes and Effects Analysis.

Inspection, maintenance and testing activities for gates and valves typically include but are not limited to:

- Lubricating moving parts and keeping oil levels topped up.
- Ensuring suitable fuel is available.
- Controlling or repairing corrosion.
- Operation of equipment that is infrequently used (e.g. standby generators).
- Ensuring batteries are charged.
- Repairing and replacing worn or damaged equipment.
- Condition monitoring (e.g. oil condition, motor currents, hydraulic pressures, gate speeds, operating temperatures and visual inspections).
- Testing of control, protection, and communication systems.
- Functional testing under a range of load conditions and all available control methods and power sources.

The scope, standard, and frequency of inspection, maintenance, and testing will vary according to the required function of the gate and valve system and the consequences of failure to function. Requirements for gates and valves that support normal facility operation, and fulfil no dam or reservoir safety function, may be determined by the Owner considering reliability targets and commercial considerations. Inspection, maintenance, and testing requirements for gates and valves that fulfil dam or reservoir safety function, on the other hand, should ensure very high levels of operational reliability under all foreseeable conditions commensurate to the consequences of failure to function.

If a gate and valve system has been repaired, modified, overhauled, or replaced then appropriate testing or commissioning should be performed to prove that the system functions correctly when reinstated. For works where plant performance data is collected during testing and commissioning, the commissioning test results can serve as a baseline reference for the long-term condition monitoring of the system.

4.3.3.3 Functional testing of gates and valves

Programmes and plans for the testing and commissioning of gates and valves should include functional testing to confirm that the system (including backup power supplies and controls) fulfils its dam or reservoir safety function reliably. With the exception of commissioning tests, gates and valves that are used regularly (as part of normal operations) can be tested as part of normal operations provided that appropriate test objectives are met, and that the tests are witnessed and documented by appropriate technical personnel or Technical Advisors. Gates and valves that are rarely used (not used in normal operations) should be tested at appropriate frequencies that reflect the importance of their function and the consequences of their failure to function. Again, appropriate test objectives should be met, and the tests should be witnessed and documented by appropriate technical personnel or Technical Advisors. Generally, for a given dam system, gates and valves that fulfil a flood management function should be tested more frequently than gates and valves that fulfil a reservoir dewatering function. However, for a dam system where the likelihood of a damaging earthquake or other failure mode that could require reservoir dewatering is comparable to that of a large flood, the testing frequencies should be similar.

Functional testing of gate and valve systems should include opening (e.g. spillway gates) or closing (e.g. penstock intake or canal inlet gates) using both normal and backup power supplies and all possible control modes (automatic, remote and local). Motor currents should be recorded for electric motor driven winch gear, mechanical screw drives, and electric motor driven hydraulic systems. Gate operating speeds can be a good performance indicator for some gate systems (e.g. fluid coupling). For all hydraulic systems (including diesel-hydraulic backup systems) hydraulic pressures should be recorded. Motor currents and hydraulic pressures are valuable condition monitoring parameters and should also be compared against settings of motor overload relays and pressure relief valves, respectively. The settings of pressure relief valves should also be confirmed. It is also important to record the reservoir level and tailwater level (if applicable) during the gate/valve tests. The repeatability of the above measurements by ensuring the same measurement setup, using calibrated instruments and measurement locations will provide a meaningful condition monitoring of the gate and valve system's performance. Inversely, if the repeatability of the measurements is not ensured, then the long-term monitoring and trending of the data collected can become incomparable. Similarly, significant changes to operating equipment should be documented to assist in interpreting the long-term condition monitoring and evaluating performance of the gate and valve system.

A backup power supply test should be performed for any new portable power supply on the gate and valve that is physically farthest away from the source, as it would experience the largest voltage drop. This test should be conducted for all gate and valve types serviced by the new portable power supply.

Owners should allow for adequate allocation of resources for the inspection, maintenance, testing, and commissioning of gate and valve systems.

Economic, environmental, and public safety considerations can affect the practicability of tests that result in large flows. In such cases Owners may choose to develop alternative test procedures that meet appropriate objectives and may include, for example:

- Performing the tests during scheduled spills or normal operations.
- Performing 'balanced' (no flow) tests in air or water with bulkheads in place. Gate/valve and bulkhead arrangements will vary and the limitations of these alternative tests need to be understood.
- Performing 'unbalanced' tests in water with upstream bulkheads in place (limited flow only). Again, gate/valve and bulkhead arrangements will vary, and the limitations of these alternative tests need to be understood.

In many cases, balanced testing is inadequate to fully verify the performance of a gate or valve system in comparison to unbalanced testing to verify gate lifting and closing margins. However, full range balanced testing is important to verify the gates' and valves' total movement range without resulting in a large discharge downstream.

The extent, standard, and frequency of the testing programmes, plans, and procedures should reflect:

- The PIC of the dam (or the gate's/valve's appurtenant structure, if it has a higher PIC than the dam).
- The complexity of the dam system
- The gate and valve system functions, performance requirements, and consequences of failure to function.
- The equipment available to perform the dam or reservoir safety function (e.g. numbers of gates, type of lifting equipment, backup power supplies, energy sources, and alternative means of operation).
- The age of the equipment.
- The condition of the equipment.
- For commissioning or testing after maintenance, the importance of the equipment or component being replaced, repaired, reprogrammed, or checked.
- The degree/extent of maintenance performed.

Testing programmes, plans, and procedures should be developed by the Owner in consultation with appropriate Technical Advisors and/or Technical Specialists (e.g. Gates Specialists, Mechanical Engineers, Electrical Engineers, Controls Engineers, and Communications Engineers). Dam system analysis, event tree analysis, fault tree analysis, Failure Modes and Effects Analysis (FMEA), Failure Modes and Effects Criticality Analysis (FMECA), and reliability assessments can allow gate and valve system testing to be targeted at vulnerabilities. Test and inspection scopes and frequencies should be commensurate to the consequences of failure to function. Reliability targets may also assist. Generally, in relative terms, for higher system reliability targets testing frequency should be higher, and similarly, if the system's reliability can be improved (e.g. through design improvements) then testing frequency may be lower.

As a general guide, not as a replacement for developing appropriate testing programmes, plans, and procedures for each unique dam system, Table 4.4 provides suggested testing frequencies for gate and valve systems installed in High and Medium PIC dams and appurtenant structures. Such approaches may also be appropriate for Low PIC dams and appurtenant structures where failure to function presents business risk, dam safety risk, or reservoir safety risk.

Some reservoir dewatering gates may also provide passage of flood function in some circumstances. The Owner, in consultation with appropriate Technical Advisors and/or Technical Specialists, should determine the degree of testing required for those gate or valve systems to achieve the required degree of reliability for all functions. This could be reviewed as part of the Comprehensive Dam Safety Reviews and adjusted where and when appropriate. The objective should be to maintain dam safety, reservoir safety and public safety while considering the risk of operating a gate or valve.

Table 4.4: suggested gate and valve testing frequencies for High and Medium PIC dams and appurtenant structures (may also be appropriate for Low PIC dams and appurtenant structures where failure to function presents business risk, dam safety risk or reservoir safety risk). This table does not replace testing programmes, plans and procedures developed by the Owner in consultation with appropriate Technical Advisors and/or Technical Specialists for each unique dam system.

Gate/valve dam or reservoir safety function	Backuppower/energy source test	Unbalanced head (flow) test	Balanced head (no flow) test
Passage of floods[1]	**Monthly** Minimum opening[2] Initiated by backup power source (i.e. battery and motor startup checks).	**Annual** 15% opening[3] Initiated by normal and backup power supplies and all control modes.	**5-yearly** Full range. Initiated by normal and backup power supplies and all control modes[7]
Reservoir dewatering[1,4]	**Six-monthly** Minimum opening[2,5] Initiated by backup power source (i.e. battery and motor startup checks).	**5-yearly** 15% opening[3,5] Initiated by normal and backup power supplies and all control modes.	**10-yearly** Full range[5] Initiated by normal and backup power supplies and all control modes[7]
Machine or water supply intake[6]	N/A	**5-yearly** Full-flow trip testing.	N/A

Notes

1. The risk of the gate or valve not returning to its pre-test position should be evaluated before the test.
2. The minimum opening to 'crack' the gate open (or open valve to minimum safe position), with sufficient movement to wet the downstream sill and demonstrate operation and loading of the backup power source.
3. The basis for a 15% gate opening, as an example, is based typically on a full rotation of a wheel on a vertical gate to free the bearings should there be any seizing, to lubricate the wheel bearings, and to dislodge any debris that may be caught. These reasons (and other relevant reasons) should be taken into consideration when selecting an appropriate gate opening for all gate and valve types. For large spillway gates or dewatering outlets this may result in very large discharges, in which case an appropriate alternative may be determined in consultation with a Technical Advisor or Technical Specialist.
4. Where the equipment is designed for reservoir dewatering or the Owner intends to use it for reservoir dewatering.
5. Where the likelihood of a damaging earthquake that could require reservoir dewatering is significant (e.g. dams with low seismic robustness in a moderate to high seismicity region, and with high consequences of failure), consider the necessity of a higher testing frequency in consultation with an appropriate Technical Advisor or Technical Specialist, taking into consideration the performance requirements of the gate/valve and the consequences if the gate/valve fails to operate.
6. Where intakes have automatic 'trip' closing, trip circuit testing (without gate closure) at a minimum annual frequency should be considered.
7. Due to the infrequent use of backup supplies and backup drives, the Owner should consider testing all backup supplies and backup drive systems through the full gate range.

4.3.3.4 Witnessing and record keeping

Record keeping is an important part of an inspection, maintenance, and testing programme. Owners should ensure that all activities are carried out under the supervision of suitably competent personnel and are properly planned and documented. The documentation should include the preparation of test plans, test procedures, and checklists (including specific inspection requirements, data to be obtained, and the normal or 'expected' values for critical data), and the recording of inspection observations and all test results. Any observed test failures or deficiencies should be documented, investigated, corrected, and communicated/reported to appropriate responsible personnel.

For events, failures to function, and potential or confirmed dam safety deficiencies observed between Dam Safety Reviews, e.g. through operational use and DSMS- implementation, the Owner should record the issue and follow the recommended process for managing dam safety issues, as appropriate (refer Module 7 for information on identifying and managing dam safety issues).

4.3.4 Inspection, maintenance and testing of other dam and reservoir safety systems

There is a range of other systems that may contribute to dam and reservoir safety and therefore should be inspected, maintained, and tested at frequencies appropriate to the consequences of their failure (non- operation or inappropriate operation).

Examples of other systems that fulfil dam and reservoir safety functions include:

- Pump systems – that remove foundation drainage water from a dam gallery. Pump systems should be sufficiently reliable to minimise the risk of pump failure and the consequent development of uplift pressures in a dam or its foundation.
- High or low water level detection systems – that indicate when reservoir levels are outside set limits (e.g. the maximum normal operation level). In some instances, these may be built into spillway watchdog/ failsafe systems as a method of automatic control. High water level detection systems are crucial for pumped storage reservoirs and usually have multiple levels of redundancy.
- Flood and earthquake alert systems – that provide alarms when floods or earthquakes exceed set trigger levels.

As outlined for gate and valve systems, dam system analysis, event tree analysis, fault tree analysis, Failure Modes and Effects Analysis (FMEA), Failure Modes and Effects Criticality Analysis (FMECA), and reliability assessments completed by suitably qualified and experienced engineers can assist Owners in developing testing programmes for other systems that contribute to dam and reservoir safety.

4.4 Intermediate Dam Safety Reviews

4.4.1 Objectives

An Intermediate Dam Safety Review (IDSR) is a dam performance review that is intermediate in the sense that it fits between Routine Surveillance and the Comprehensive Dam Safety Review in frequency and in its level of detail. The IDSR is largely based on a visual inspection by a Technical Advisor, in the company of the Owner's operational and surveillance staff, as well as a close examination of surveillance, operation, maintenance, and testing records. If concerns are raised, the review may require some additional analyses, tests or investigations.

The IDSR should identify any dam safety issues and categorise them into physical infrastructure issues, potential or confirmed dam safety deficiencies, and non-conformances (refer Module 7: Lifecycle Management). In some cases, the Owner may also require the IDSR to identify and/or recommend potential actions to resolve identified issues.

For High and Medium PIC dams IDSRs should be completed annually by a Technical Advisor external to the Owner's organisation. For Low PIC dams IDSRs should be completed every 1 to 2 years by an external Technical Advisor, or competent technical personnel within the Owner's organisation. The regulatory requirements for IDSRs are discussed in Module 1: Legal Requirements. The dam Owner and Technical Advisor should consider IDSR inspection timing with respect to reservoir level variation to support observation of the dam's condition and performance under a range of load conditions. High reservoir level is most beneficial due to the higher load condition; however, periodic low reservoir level inspection may support observation of features that would otherwise be under water.

4.4.2 Scope

The detail and scope of the IDSR should reflect the PIC of the dam and its complexities. Generally, the scope should include:

- An on-site inspection of the dam and appurtenant structures with the Owner and their operational and surveillance staff.
- A review of operation, surveillance, maintenance, and testing records.
- An evaluation of the performance of the dam as indicated by the on-site inspection and operation, surveillance, maintenance, and testing records for the period since the last IDSR.
- A report that identifies any dam safety issues, any changes to monitoring or visual inspection frequencies, or any additional items to be monitored.

On-site inspections should be systematically organised so that the status of all critical aspects of the dam can be accurately recorded and evaluated. Repeatable field inspection checklists should be used, and recent surveillance records and previous IDSR and Comprehensive Dam Safety Review (CDSR) reports should be reviewed in preparation for the site inspection.

Gates and valves that fulfil dam or reservoir safety functions are not necessarily tested; however, maintenance and testing records should be available for review.

4.4.3 Report

The findings of each IDSR should be recorded in a written report. The focus of the report should be on confirming safe dam performance and identifying dam safety issues.

Generally, IDSR reports for Medium and High PIC dams should include:

- Observations during the site inspection.
- Photographs taken during the site inspection.
- The identification of any significant events since the previous IDSR (e.g. floods, earthquakes), operational events (e.g. inappropriate operation, spill events, gate/valve testing), or dam safety incidents, and the responses and results of any such events or incidents.
- The identification of the completion of any maintenance and the resolution of previously identified dam safety issues, or the status of those issues.
- A review of surveillance data and other salient information.
- An evaluation of the performance of the dam and related structures/equipment, in the context of expected performance, characteristic behaviour and potential failure modes, using previous IDSRs and the previous CDSR as reference points.
- An outline of the status of instrumentation maintenance, including a comment on its adequacy.
- A summary of gates and valves that fulfil dam or reservoir safety functions, and an outline of their dam and reservoir safety functions.
- A comparison of planned and actual maintenance and testing activities for gates and valves that fulfil dam or reservoir safety functions (in the period since the previous IDSR), and comment on the adequacy of the completed maintenance and testing activities.
- The identification of any dam safety issues during the inspection and review, including any potential or confirmed dam safety deficiencies.
- The categorisation of any identified dam safety issues into physical infrastructure issues, potential or confirmed dam safety deficiencies, and non-conformances (refer Module 7: Lifecycle Management).
- A summary of the status of previously-identified dam safety issues.

As a minimum, IDSR reports for Low PIC dams should include:

- Observations during the site inspection.
- Photographs taken during the site inspection.

- The identification of any significant events since the previous IDSR (e.g. floods, earthquakes), operational events (e.g. inappropriate operation, spill events, gate/valve testing), or dam safety incidents, and the responses and results of any such events or incidents.
- The identification of the completion of any maintenance and the resolution of previously identified dam safety issues, or the status of those issues.
- A review of surveillance data and other salient information.
- A summary of gates and valves that fulfil dam or reservoir safety functions, and an outline of their dam and reservoir safety functions.
- The identification of any dam safety issues during the inspection and review, including any potential or confirmed dam safety deficiencies.
- The categorisation of any identified dam safety issues into physical infrastructure issues, potential or confirmed dam safety deficiencies, and non-conformances (refer Module 7: Lifecycle Management).
- A summary of the status of previously identified dam safety issues.

4.5 Comprehensive Dam Safety Reviews

4.5.1 Objectives

A Comprehensive Dam Safety Review (CDSR) is a comprehensive, periodic, independent review of the design, construction, operation, and performance of a dam, and all systems and procedures that affect dam and reservoir safety, against current dam safety guidelines, standards, and industry practice.

The CDSR should identify any dam safety issues and categorise them into physical infrastructure issues, potential or confirmed dam safety deficiencies, and non-conformances (refer Module 7: Lifecycle Management). In some cases, the Owner may also wish for the CDSR to identify and/or recommend potential actions to resolve identified issues.

CDSRs should be completed every 5 years for High and Medium PIC dams. Formal CDSRs are also recommended for Low PIC dams to preserve the asset value or earning potential of the dam. These Guidelines recommend that CDSRs should be completed for Low PIC dams on first filling and subsequently every 10 years. The regulatory requirements for CDSRs are discussed in Module 1: Legal Requirements.

If a dam enters a dam safety deficiency management phase and if the Owner is following a Special Dam Safety Review (SDSR) procedure (refer section 4.6), then the next regularly scheduled CDSR can be postponed until the dam is back in normal service.

The following sections provide guidance for the completion of CDSRs. The material focuses on key points but does not cover every detail.

4.5.2 General requirements

The CDSR scope should reflect the dam type, complexity, PIC, condition, and performance. It should also reflect whether the review is:

- An 'initial' review of an old dam for which there are poor records.
- A follow-up review after corrective action has been taken.
- A regularly scheduled review of a modern or modernised dam which has been well documented.

Records of the dam's history are important information sources for a CDSR, particularly if they contain details of the Designer's intentions, the characteristics of the materials used, construction records and the history of the dam's performance since commissioning. Data books for each dam, which should be kept by the owner, are a good way to compile and retain relevant information on the history of dams and are a valuable source of records on the dam for the CDSR. Key information typically includes:

- Investigation data and reports.
- Design reports and drawings.
- As-built drawings, construction photographs and construction reports.

- Commissioning reports.
- Operation, maintenance and surveillance procedures.
- Surveillance records and relevant operation and maintenance records.
- Event or incident reports and records of any changes to components or operations.
- Previous inspection and safety review reports.

In the case of older dams, much of this data is often almost non-existent. Therefore, either as a precursor to the first CDSR, or as part of it, considerable effort must be put into collating whatever data is available. Developing and maintaining these records is a key element of an effective DSMS. As stated previously in section 3.4, where an FMEA has not been completed for a Medium or High PIC dam it should be carried out prior to or during the completion of the CDSR. After the completion of the initial FMEA for an existing dam, subsequent CDSRs should review the results of the FMEA and highlight any identified shortcomings in the FMEA report as well as any changes to the dam system that should be reflected in an FMEA update. Refer to section 3.4 for further detail on completing FMEAs.

The independence, experience, and qualification of the CDSR reviewers is an important requirement. The reviewers for the first two CDSRs should not have had any direct prior design, construction or operations involvement in the dam and should be in a position to undertake the review independently and without prejudice. The Owner's technical personnel (internal or external) should not be reviewers, and a reviewer should not complete two consecutive CDSRs for the same dam. Most importantly, CDSR reviewers must apply their ethical judgement as professional engineers to determine their competence for the type, complexity, and PIC of the dam being reviewed.

In completing the CDSR, it is important that the Owner's dam safety, surveillance, operations, and maintenance personnel accompany the review team during the site inspection and provide or obtain answers to relevant questions from the review team.

4.5.3 Personnel requirements

The key personnel that should be involved in a CDSR are outlined below, along with their roles or responsibilities, and recommends skill or experience requirements:

Owner
The Owner should take all necessary steps to understand the requirements for CDSRs, plan and budget for their implementation, and ensure they take place. After taking any necessary advice, the Owner should draw up the brief for the CDSR, facilitate the CDSR, and consider and address any dam safety issues identified in the CDSR within an appropriate timeframe.

Owner's engineers, surveillance staff and operators:
On behalf of the Owner, these technical and operational personnel should provide all available data and relevant information to the CDSR review team, facilitating on-site inspections, providing safety briefings and inductions for on-site inspections, operating gates and valves that fulfil dam and reservoir safety functions, and responding to questions from the CDSR review team.

CDSR review team
The CDSR review team should complete the review and report in accordance with the Owner's brief and to a high standard of professional practice. Each member of the team should be appropriately experienced and senior in the area to be covered and, while past experience may be of considerable value, it is important that each person is also technically up to date, because a fundamental part of a CDSR is to assess the dam in the light of the current dam safety guidelines and current dam engineering practice. The Owner needs to appreciate that if the team is not appropriately qualified and experienced, the review may not identify important dam safety issues. Members of a dam's original design team may assist by clarifying matters but should not be included in the CDSR team for the first two reviews to ensure an independent review of dam safety is completed.

The composition of the team will vary depending on the situation; however, most dams will require an appropriately experienced and qualified civil engineer with specialist support for specific areas. Large and/or complex dams usually require:

- A specialist dam engineer able to evaluate the civil structures and components, and the overall safety of the dam and appurtenant structures.
- A specialist engineering geologist or geotechnical engineer to review the geology, foundation conditions and other geotechnical issues that could affect the safety of the dam or reservoir (e.g. existing landslides adjacent to the dam or reservoir).
- A specialist mechanical engineer able to evaluate relevant mechanical components that fulfil dam and reservoir safety functions, such as spillway and/or low level outlet gates and valves and their New Zealand operating systems, including documented procedures for their operation, maintenance and testing.
- A specialist electrical engineer to evaluate power supplies, communication systems, and control and protection systems that fulfil dam and reservoir safety functions.
- In some cases, where wider expertise may be necessary to evaluate aspects that are inadequately documented or understood, the CDSR team may be widened to include:
  - Seismologists.
  - Hydrologists and hydraulic engineers.
  - Dam structural analysts or designers.
  - Rock mechanics specialists.

Peer reviewers
While a CDSR is a form of peer review in itself, some Owners may require peer review of the CDSR team's work. This may apply particularly during initial CDSRs where there may be a lack of relevant information for the dam. The need for such a review depends on the particular circumstances of the dam, but peer review is recognised as a sound concept. Peer Reviewers need to have appropriately wide experience at least equal to that of the CDSR team members and generally will be drawn from the most senior practitioners available.

4.5.4 Scope and procedures for High and Medium PIC dams

CDSR requirements are similar for High and Medium PIC dams; however, the scope of the review and the specialist skills required will depend on the dam type and level of inherent risk.

Every dam is unique and as such it would be inappropriate for these Guidelines to prescribe exact procedures for individual reviews, and therefore the skills and experience of the dam industry should be drawn upon for specific advice. When preparing briefs for the completion of CDSRs, Owners who do not have sufficient expertise directly available should obtain advice from persons recognised in the industry as having appropriate expertise.

Following the selection and briefing of the CDSR team by the Owner, the completion of a CDSR for a Medium or High PIC dam usually involves:

- Review of all available relevant information including data books, reports and surveillance records.
- Review of known and potential hazards and dam safety threats.
- Review of the dam's PIC.
- Review of the outputs from the FMEA, the identified potential failure modes and their key performance indicators.
- Detailed on-site inspection of the dam and appurtenant structures.
- Site inspection and witnessing of testing of gates and valves that fulfil dam and reservoir safety functions (including their operating equipment, power supplies and control, protection and telecommunication systems). Testing may not be necessary if the Owner has completed and documented recent tests that adequately satisfy the test requirements; however, the operation and performance records for the tests should be reviewed in depth.

- Assessment of the adequacy of the dam and its appurtenant structures, including all gate and valve systems that fulfil dam and reservoir safety functions, to safely perform to current acceptability criteria for all loading conditions. The reviewers are unlikely to reanalyse the dam but may identify that there is a lack of analysis, design, or assessment for an element of the facility and identify this as a dam safety issue.
- Review of the DSMS, and operating, surveillance, maintenance and testing procedures and records, including clarifying matters of detail with operations, dam safety, and surveillance staff.
- Review of the organisation of operational resources and infrastructure.
- Review of emergency preparedness including procedures, training, exercises, facilities, and equipment.
- The completion of a report covering the review which includes:
  - comments on the appropriateness of the PIC,
  - comments on the outputs of the FMEA, the potential failure modes and their key performance indicators,
  - comments on dam performance,
  - a discussion of any issues related to monitoring and surveillance, and any changes that should be made to monitoring and surveillance processes,
  - an assessment of the safety of the dam with respect to current acceptability criteria,
  - comment on the appropriateness of the DSMS,
  - a discussion on any dam safety issues identified in the inspection, testing and review, including potential or confirmed dam safety deficiencies,
  - the categorisation of any identified dam safety issues into physical infrastructure issues, potential or confirmed dam safety deficiencies, and non-conformances (refer Module 7: Lifecycle Management),
  - comment on previously identified dam safety issues and either the adequacy of their resolution, or whether there are impediments that prevent their resolution.

4.5.5 Scope and procedures for Low PIC Dams

As discussed previously, CDSRs for Low PIC dams, while ostensibly not essential, are still important to any Owner from a dam safety perspective and are thus recommended in these Guidelines. In addition, an Owner may require a detailed safety review for asset management or reinsurance purposes, particularly where a dam failure could lead to a major loss of revenue.

If the recommended IDSRs are undertaken by appropriately skilled and experienced personnel, significant aspects related to dam safety should be identified as a matter of course. Where a CDSR is undertaken for a Low PIC dam, the procedures should be much the same as outlined above for Medium and High PIC dams, with the scope or level of detail set to reflect the Owner’s level of concern about asset protection and the potential effects of a dam failure.

4.6 Special inspections and dam safety reviews

4.6.1 Special inspections

Special dam safety inspections should be carried out following unusual events, observations, or emergencies. In the interests of time, these may be undertaken by the Owner or appropriate personnel with any anomalies referred to the Technical Advisor. Where practical, special dam safety inspections can be undertaken directly by the Technical Advisor. Unusual events and emergencies should be evaluated to determine whether they have resulted in any noticeable changes, damage that requires attention, whether any special safety measures or follow-up investigations need to be implemented, and whether the dam performance was in accordance with design expectations.

Unusual events, observations, and emergencies may include:

- Adverse surveillance observations or instrument readings.
- Large rainfalls or floods.
- Strong winds.
- Earthquakes.
- Landslides into the reservoir.
- Volcanic eruptions.
- Man-made damage.

In addition to unusual events and emergencies, special dam safety inspections may be necessary to examine a particular feature of a dam that has been identified as having a potential or confirmed dam safety deficiency (e.g. from surveillance evaluation and safety reviews), or which has been subjected to abnormal loading conditions or remedial works.

Special inspections should be well documented and archived as an important part of the dam's long term record.

4.6.2 Special Dam Safety Reviews

Special Dam Safety Reviews (SDSRs) may be required following an unusual event, observation, or emergency, or when a potential or confirmed dam safety deficiency has been identified. The management processes for SDSRs should follow those outlined in Module 7: Lifecycle Management for the management of dam safety issues.

The scope of an SDSR will be specific to the nature of the dam's condition and any potential or confirmed dam safety deficiency that has been identified, and may include:

- A review of records and reports from investigation, design, construction and surveillance.
- Site inspections and investigations (e.g. exploratory geotechnical or geophysical investigation by excavation, drilling, density testing, or shear wave testing).
- Natural hazard assessments (e.g. flood, seismic, geologic, reservoir landslides).
- Stability and performance assessments (e.g. structural, flood passage, rock mechanics, erosion, scour).
- New or updated Failure Modes and Effects Analysis (FMEA).
- Dam-break modelling and consequence assessment.
- The identification of preliminary remedial actions or mitigating measures (structural or non-structural).
- The completion of a report covering the review which includes:
  - any dam safety issues investigated and/or identified in the review, including potential or confirmed dam safety deficiencies,
  - possible interim risk reduction measures and long-term risk reduction options, and comments on time drivers for their implementation,
  - the categorisation of identified dam safety issues into physical infrastructure issues, potential or confirmed dam safety deficiencies, and non-conformances (refer Module 7),
  - comment on previously identified dam safety issues and either the adequacy of their resolution, or whether there are impediments that prevent their resolution.

When undertaking SDSRs the Owner should employ appropriate specialist expertise relevant to the dam and foundation type, natural hazards, any particular features, any potential or confirmed dam safety deficiencies, and the consequences of failure. These Guidelines recommend an appropriate level of peer review where the consequences of failure are high.

4.7 Emergency preparedness

Emergency preparedness, and its role as part of a DSMS, is mentioned for completeness in this module. However, it is of sufficient importance that it is covered separately and in full in Module 6: Emergency Preparedness.

4.8 Identifying and managing dam safety issues

Identifying and managing dam safety issues, and its role as part of a DSMS, is mentioned for completeness in this module. However, it is of sufficient importance that it is covered separately and in full in Module 7: Lifecycle Management.

4.9 Information management

4.9.1 Philosophy

In the context of a dam's lifetime, and the rigour that must be applied to its ongoing safe management, the importance of careful record-keeping and preservation of all dam information cannot be overstated.

Whether paper-based or computer-based, it is vitally important that all dam information is filed and managed in a way that it can be easily located by future users, including those that may not know it exists. Dam information should also be backed up and stored at an alternative location to the primary copy.

A robust and defensible information management system will safeguard an Owner against the risks of institutional knowledge being lost through staff turnover. Activities that are planned using reliable knowledge and good records will likely save the Owner considerable time and money. For example, when investigating a dam safety deficiency, historic records may avoid the need for intrusive (and unnecessarily risky) dam investigations.

4.10 Relevant information

The types of information that are important to a dam and its wider DSMS are many and varied. Material to be included in an information management system for the effective implementation of a DSMS should include:

- A dam inventory/register that captures the details of an Owner's dam portfolio including key dimensions and attributes such as (but not limited to) dam types, heights, appurtenant structures, PICs, surveillance frequencies, potential failure modes and key performance indicators.
- The DSMS and supporting documentation.
- Process and procedural documents relating to implementation of the DSMS (e.g. surveillance procedures, operation and maintenance procedures, gate/valve testing procedures, reservoir operating rules during normal and flood conditions).
- All historical documents and drawings relating to investigation, design and construction. These are sometimes compiled into a data book.
- All historical performance information including records of surveillance (including reservoir levels), maintenance, gate and valve operations and tests, significant events, and incidents.
- All dam related investigations, studies, reviews, upgrades (including new drawings) and changes to operating conditions or systems (e.g. a change to the reservoir operating rules and/or a change to the spillway gate control system).
- An instrumentation inventory and supporting information such as as-installed drawings, technical specifications, calibration certificates, operation and maintenance requirements, and records of maintenance.
- An auditable database of dam safety issues (e.g. those made during IDSRs and CDSRs) including tracking of their status and associated decisions.
- All dam safety governance, oversight, and status reporting prepared for the internal and external communication of issues (including communications with regulators and local authorities).
- Training schedules and records for all dam safety related staff including managers, engineers, operators, and surveillance inspectors.

4.11 Audits and reviews

Audits and reviews of a DSMS allow an Owner to maintain a pathway of continuous improvement and provide assurance that dam safety risk is being appropriately managed. Audits and reviews provide the best value when they are undertaken as a complementary mix of introspective self-assessment and external assessment.

4.11.1 Audits

Audits of DSMSs primarily ensure that defined processes and procedures are being followed. These audits do not necessarily need to be conducted by a Technical Advisor. Instead, they can be performed by someone capable of assessing governing processes and procedures and questioning them in sufficient detail when seeking supporting evidence. There is not a prescribed frequency for such audits; however, an Owner may choose to complete annual or two-yearly audits, depending on the nature of their organisation and dam portfolio. Internal audits may assist the Owner to identify preparedness for external audits such as the regulatory dam safety assurance programme (DSAP) certification and audit (by a Recognised Engineer) described in Module 1: Legal Requirements.

4.11.2 Reviews

Reviews of DSMSs are aimed at identifying opportunities for technical and strategic improvements based on recognised dam safety practice (e.g. is the existing DSMS appropriately and effectively managing dam safety risk?). Such reviews are usually performed by a highly experienced and external Technical Advisor (or Technical Specialist) in conjunction with the Owner and their key dam safety personnel. There is not a prescribed frequency for such reviews; however, an Owner may choose to complete 2-yearly to 5-yearly reviews, depending on the nature of their dam portfolio and organisational governance arrangements. As a minimum a DSMS review should be completed as part of a Comprehensive Dam Safety Review (CDSR) for High and Medium PIC dams. Regulatory requirements for the review of dam safety assurance arrangements for High and Medium PIC dams are provided in Module 1: Legal Requirements.

An Owner of a Low PIC dam, for which a DSMS exists, may choose to adopt seven- yearly to ten-yearly reviews.

Indicators of an effective DSMS include (but are not limited to):

- An Owner's dam safety policy/statement/standard exists and the objectives conform to relevant dam safety regulations, guidelines, dam safety practice, and the Owner's goals and values.
- Governance arrangements for the DSMS, including oversight and enabling, are in place and are effective. Dam safety issues and risks are well recognised by the Owner.
- Roles, accountabilities, responsibilities, and delegated authorities are clearly assigned.
- Personnel with dam safety accountabilities and responsibilities clearly understand their roles, accountabilities, and responsibilities.
- The DSMS is well resourced, implemented, and documented.
- Surveillance, operation, maintenance, and testing activities that affect dam and reservoir safety are carried out and documented with a high level of quality assurance.
- Dam safety issues and incidents are managed appropriately including escalation, reporting, investigation, and resolution.
- Potential and confirmed dam safety deficiencies are identified, investigated, and resolved in a timeframe and manner that is appropriate to the level of risk.
- Risks are well understood.
- The DSMS is responsive/adaptive to changing environment or operational conditions.
- Capability, knowledge, and succession requirements are planned for and implemented.

5. Change management and improvement

5.1 Philosophy

It is important for an Owner to stay abreast of developmental, environmental, and operational changes, both within and outside of their organisation, which may affect the operation of their dam systems. It is important to establish and maintain effective communications with key stakeholders. Stakeholders may include local and regional authorities, neighbouring industries and landowners, emergency authorities, and local communities.

An Owner should ensure that its mode of reservoir operation and the contents of its DSMS remain current and appropriate to their situation at any given time.

5.2 Common aspects that change

- The most common aspects that change with time and may require amendments to the mode of reservoir operation and/or the DSMS are:
- Changes in upstream reservoir/river/catchment use including the operation of other dams, de-forestation, recreational use, and development of the reservoir shoreline.
- Changes in downstream populations with development or increases in recreational use.
- Changes in climate and therefore inflows, reservoir levels, and flood management procedures.
- Seismic hazard changes.
- Bush fire hazard changes.
- Physical changes or threats that may be caused by geothermal activity, mining, or quarrying (including blasting).
- Environmental concerns (e.g. algal blooms or fish habitats).
- Physical security and cyber security threats.
- Public safety around dams and waterways.
- Owner organisational changes.
- Owner resource constraints during disruptions and prolonged events (e.g. pandemics, widespread natural events).
- Regulatory changes.

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