DAM SAFETY GUIDELINES 2007

(2013 Edition)

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2013 Revision

Dam Safety Guidelines 2007 (2013 edition) results from a review and revision to Sections 6.1, 6.2 and 6.3 of the publication issued in 2007. The only changes from the 2007 edition are contained in this Preface and Sections 6.1, 6.2 and 6.3 and are marked in the right-hand margin. Other material in *Dam Safety Guidelines 2007* remains unchanged.

CDA members have requested additional guidance on Sections 6.2 and 6.3 of the CDA *Dam Safety Guidelines 2007*. The 2007 version referred to both Risk-Informed and Traditional Standards-Based Approaches to dam safety assessments, without comment on their relative merits. In this 2013 revision, the CDA clarifies its endorsement of the use of a risk-informed approach, which includes traditional deterministic standards-based analysis as one of many considerations. CDA accepts that there are fundamental weaknesses in both approaches. Issues with the risk-informed approach include current challenges in the characterization of the hazard, the dam system performance, and the consequences. The traditional standards-based approach not only shares these difficulties but has a number of additional significant limitations. Of particular concern are:

- Focus on extreme natural hazards in isolation, which can lead to preferentially implementing expensive solutions that may not necessarily improve the safety of the dam over that which could be achieved by other more economical means
- Inability to define standards for a number of dam failure modes, which may lead to inappropriate or misleading assessment of safety

There are also other recognized difficulties in the application of the 2007 version of Sections 6.2 and 6.3. For example, selection of the level for seismic annual exceedance probability "must be justified to demonstrate conformity to societal norms of acceptable risk." Resolution of this and other difficulties will require extensive discussions at a societal and governmental level, to answer the question of how safe new or existing dams should be. The CDA, as a non-governmental organization, does not in any way consider this question to be their responsibility; however, it recognizes that guidance is required in the interim until such larger issues are resolved.

There are many instances where the prevailing capability and resources of dam owners will preclude the use of a comprehensive risk-informed approach. Continued use of a standards-based approach is inevitable in these cases, with appropriate additional conservatisms. A standards-based approach may be appropriate for certain elements of dam design and assessment. The CDA has identified the need for continued development and acceptance of the risk-informed approach. The revised Sections 6.1, 6.2 and 6.3 should be considered interim guidance, to be used until the above difficulties are addressed over time.

PREFACE TO 2007 EDITION

Dams in Canada are owned by utilities, mining companies, pulp and paper companies, various levels of government, and private owners. Regulation of dam safety in Canada is primarily a provincial responsibility; some provinces have enacted specific dam safety regulations, while others use existing Acts or regulations to authorize the design, construction, inspection, operation, rehabilitation, alteration, or decommissioning of dams. Federal agencies have jurisdiction over some aspects of dam safety related to international boundary waters covered by treaty with the United States. The federal government also has some responsibility for security of critical infrastructure which includes many dams. In any case, legal regulations take precedence over guidelines produced by nongovernmental organizations.

In 1995, after three years of effort by working groups across the country, the Canadian Dam Safety Association published *Dam Safety Guidelines*. In 1999, the Canadian Dam Association (CDA) issued a revised version. In 2003, the CDA began soliciting input and suggestions for revisions and additions through the Internet and workshops across the country. *Dam Safety Guidelines* is a product of the CDA members, and a large number of individuals contributed to it.

Dam Safety Guidelines consists of

- *Section 1, principles that are applicable to all dams*—The principles should be understood by dam owners, regulators, managers, operators, and other interested parties. The brief explanatory text outlines, in general, how conformance with the principles could be demonstrated.
- *Sections 2–6, guidelines that outline processes and criteria for management of dam safety in accordance with the principles*—The guidelines are of interest to dam owners, regulators, managers, operators, and other decision-makers, as well as engineers and consultants.

The CDA also publishes a separate companion series of technical bulletins on dam safety. The technical bulletins suggest methodologies and procedures for use by qualified professionals as they carry out dam analyses and safety assessments. The technical bulletins are of particular interest to professional engineers involved in dam engineering.

The responsible dam safety engineer or decision-maker must assess and interpret the information provided in *Dam Safety Guidelines* and the technical bulletins, identify any considerations not addressed by those documents, and determine the appropriate dam safety requirements for a specific situation.

The CDA intends to review and update *Dam Safety Guidelines* and the technical bulletins as the need arises. While every reasonable effort has been made to ensure the validity and accuracy of the published information, the CDA and its membership disclaim any legal responsibility for use of *Dam Safety Guidelines*.

1. PRINCIPLES

1.1 Dam Safety Management

PRINCIPLE 1a

The public and the environment shall be protected from the effects of dam failure, as well as release of any or all of the retained fluids behind a dam, such that the risks are kept as low as reasonably practicable.

The **owner**[1] is responsible for the safe management of a **dam.** Dam safety management takes place within the context of public policy and the business objectives of the owner. The standard of care applied to the management of safety should reflect society's values and priorities in allocating and distributing resources to protect lives, the environment, and property. The absence of specific regulation does not negate the owner's responsibility for safe management.

Dam safety management is the management of **risks** associated with dams, including release of fluids as a result of structural failure, mis-operation, planned operation, or any other cause. For dams that retain contaminants of any sort, protection of the public and the environment should extend to seepage and pathways not necessarily associated with catastrophic failure of the retaining structures.

Established conservative practices may be assumed to provide protection that is **as low as reasonably practicable** (ALARP). The current, most widely applied approach to decision-making is based on **deterministic** principles, rules, and requirements aimed at ensuring a relatively high but unspecified level of safety. The rules and requirements are adjusted to provide proportionately higher safety levels when **hazards** or **consequences of failure** are greater. The decision process typically relies on **classification** of dams on the basis of the consequences of failure, as well as on engineering analysis and assessment and the application of engineering judgment.

An alternative approach, **risk assessment**, is emerging as a method for improving the way safety decisions are made, particularly as those decisions become more complex and society demands more transparency and accountability. If resources and knowledge are available, risk assessment can be considered an approach that incorporates more specific knowledge of the particular circumstances of the dam under consideration.

By definition, *risk* incorporates both the consequences of an adverse event and the probability of such an event occurring. However, it is recognized that determining the probability of failure is a complex task that is not readily accomplished, given the current state of knowledge.

The safety management framework should make transparent all factors considered, thus reassuring the public and the stakeholders that risks to people, property, and the environment are

[1] Terms in bold may be found in the glossary.

being properly addressed. At the same time, the framework should ensure that the dam owners, in responding to economic pressures, will not be imposing intolerable risks. The framework should address all ethical, social, and economic considerations of how to achieve the necessary trade-offs between benefits to society and adequate protection for individuals.

PRINCIPLE 1b

The standard of care to be exercised in the management of dam safety shall be commensurate with the consequences of dam failure.

The potential consequences of dam failure may include loss of life, injury, and general disruption of the lives of the population in the inundated area; environmental and cultural impacts; and damage to infrastructure and economic assets. To assess the potential consequences, the potential **failure modes** for the dam and the initial conditions downstream from the dam should be determined, the resulting discharge characteristics estimated, the impacted areas mapped, and the consequences quantified.

If dam failure is related to a natural event, the total consequences are generally above and beyond those that would have occurred had the dam not failed. These **incremental consequences of failure** are attributable to dam failure. In these guidelines, the term **consequences of failure** refers to the incremental consequences.

The estimate of consequences should cover both downstream and upstream damage, including

- Cascade effects where a given drainage basin has a series of dams
- Release of contaminants to the environment

Environmental, cultural, and third-party economic losses should be estimated separately and taken into account. The dam class should be determined by the highest potential consequences, whether human, environmental, cultural, or economic.

The class should be based on the failure scenario that would result in the worse consequences: either sunny day failure or flood failure. This classification should be used for purposes of general management oversight, as well as inspection, maintenance, and **surveillance** programs. For determining design criteria for specific components at a site, the consequences of failure of the components may be evaluated separately.

PRINCIPLE 1c

Due diligence shall be exercised at all stages of a dam's life cycle.

The principles of dam safety apply at all stages of the life cycle (design, construction, operation, decommissioning, and long-term closure).

During initial construction and (or) rehabilitation, the project specifications must be strictly followed; any deviation should be subject to an appropriate review and approval process. Quality control and documentation must be maintained throughout the construction period. Temporary construction facilities should be designed and constructed such that the risks to the safety of the dam, cofferdam, and appurtenant structures are appropriately managed.

During the operational stage, public safety should be an important element of the dam owner's due diligence.

Prior to decommissioning and closure, the dam owner should prepare a detailed plan for withdrawing the dam from service, indicating measures necessary for site safety. The possibility that any remaining structures might be exposed to loads or combinations of loads not foreseen in the original design or exposed to otherwise unacceptable conditions should be carefully addressed. Closure requirements for **tailings dams** should be considered at the initial design stage and at all subsequent design and construction phases.

PRINCIPLE 1d

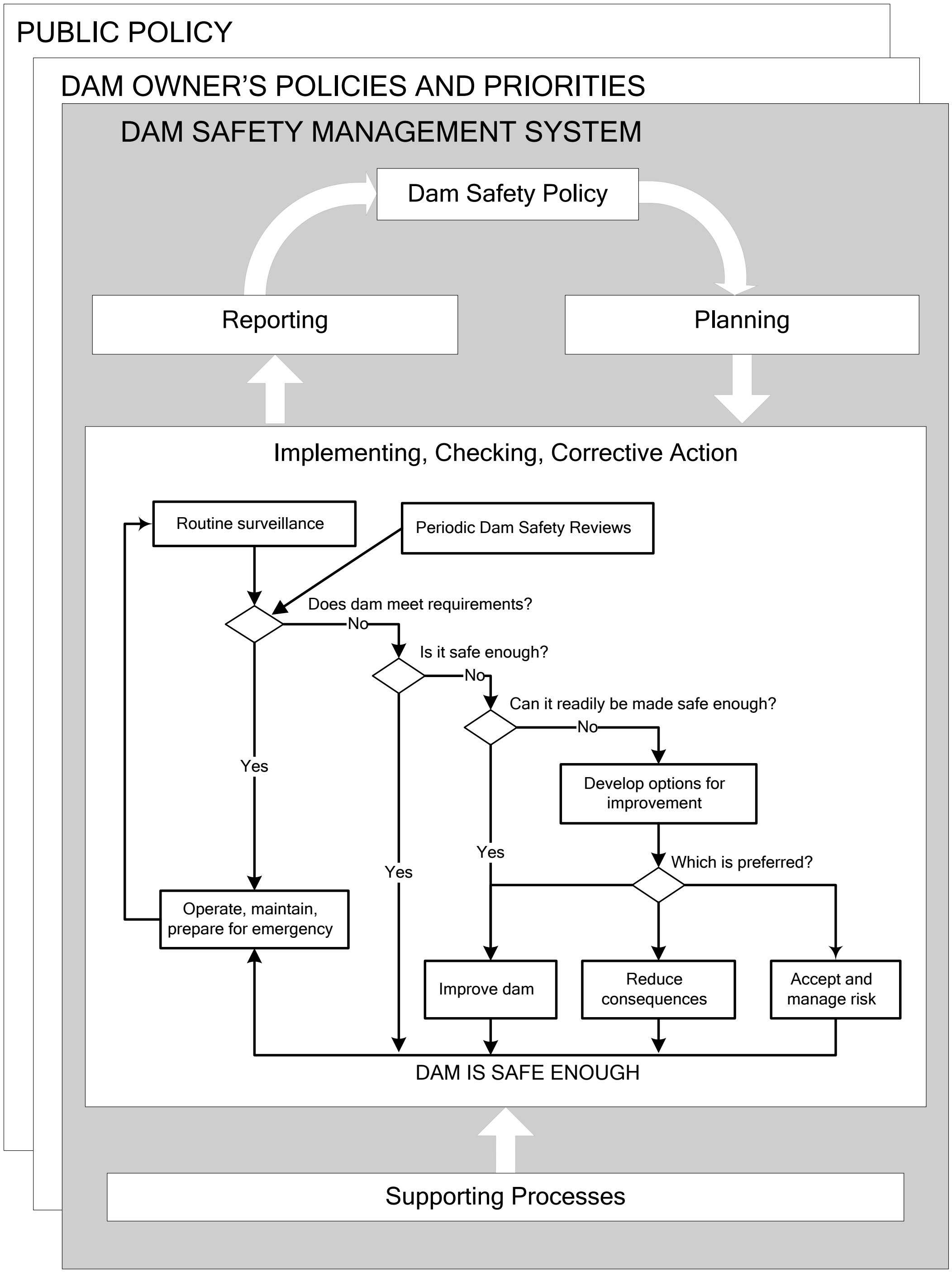
A dam safety management system, incorporating policies, responsibilities, plans and procedures, documentation, training, and review and correction of deficiencies and nonconformances, shall be in place.

The dam safety management system provides a framework for safety activities, decisions, and supporting processes within the context of public policies and the owner's business objectives. Figure 1-1 illustrates the typical activities and decision points in such a system.

The owner's policy should clearly demonstrate commitment to safety management throughout the complete life cycle of the dam. The policy should cover the following:

- *Level of safety that is to be provided*—Applicable regulations must be met, and industry practice and due diligence must be taken into account.
- *Ultimate accountability and authority in the organization for ensuring that the policy is implemented*—Responsibilities and authorities need to be delegated within the organization for all dam safety activities.
- *Decision-making process within the organization for decisions related to dam safety*—Critical safety decisions with significant societal or financial implications must be made or approved at the highest level.

Figure 1-1: Overview of a Dam Safety Management System



The safety management system should take the following into account:

- An inventory of dams and **appurtenance**s in the system
- Safe operation, maintenance, surveillance, emergency preparedness, public safety, and security
- Periodic **Dam Safety Reviews**
- Follow-up, prioritization, and correction of deficiencies in dam performance, supporting infrastructure, operation, maintenance, surveillance, security procedures, and the management system
- A permanent record of the design, construction, operation, and performance of the dam and the management of its safety (record should include design documents, instrumentation readings, inspection and testing reports, Dam Safety Review reports, operational records, investigation results, and current closure plans if applicable)
- Qualification and training of all individuals with responsibilities for dam safety activities (training records should be maintained)
- Regular review of the safety management system

1.2 Operation, Maintenance, and Surveillance

PRINCIPLE 2a

Requirements for the safe operation, maintenance, and surveillance of the dam shall be developed and documented with sufficient information in accordance with the impacts of operation and the consequences of dam failure.

A critical part of the dam safety management system is the development, implementation, and control of procedures for the operation, maintenance, and surveillance of the facility, taking into account public safety and security.

The presence of a dam, its special features, and its operation, coupled with the river morphology, can present safety hazards to the public while participating in activities at or around the dam site.

Operation, maintenance, and surveillance procedures should be initially developed for the particular site during the construction phase and then updated when there are major changes to the structures, flow control equipment, or operating conditions. These procedures should be documented in an Operation, Maintenance, and Surveillance Manual (**OMS Manual**) or equivalent. The procedures and practices should be reviewed regularly (as a minimum, during the periodic Dam Safety Reviews) to ensure that the information is up to date. This review is required for complete life-cycle management, from construction through major rehabilitation or replacement to closure or decommissioning of the dam.

Ongoing log books, records, or reports should be maintained to show that the specified activities and observations have been carried out and that the dam safety requirements are being met. The appropriate level of detail in the OMS Manual and corresponding records depends on the complexity of the site and the severity of the potential consequences of failure. A simple dam with minimal consequences of failure might have a brief OMS Manual that also includes the emergency plan and public safety documentation.

PRINCIPLE 2b

Documented operating procedures for the dam and flow control equipment under normal, unusual, and emergency conditions shall be followed.

Proper operation of a dam system is critical to safety and performance and thus to managing potential impacts on the public, the environment, and other stakeholders.

Development of operating procedures should take into account the complexity of the site and the consequences of mis-operation. The operating procedures should not violate dam safety design parameters. The availability of staff to respond to changing conditions, the type and size of flow control equipment, and other site-specific considerations should be taken into account.

Operating procedures should consider the availability of reliable data, including the following:

- **Headwater** and **tailwater** elevations
- Remote indicators of the operation of flow control equipment
- Flood-forecasting information
- Fluid balance requirements for tailings ponds and other industrial ponds
- Operations of other dam owners that affect inflows to the **reservoir** and the need for operations to discharge excess inflows

Operating procedures should address the following:

- Flood management, including clear operating procedures for local staff
- Public safety issues, including the use of recreational areas and restricted zones
- Notification plan for changing flows or conditions
- Prevention of unauthorized entry to the site or operation of equipment
- Compliance with regulatory or other established limits on reservoir levels, tailings beach length, and (or) **freeboard** for operating tailings dams under construction, rates of water rise or drawdown, and discharge rates in both the upstream and the downstream environs
- Ability of the flow control equipment, including backup power supplies, to operate under all expected conditions
- Management of debris and ice to ensure operability of discharge facilities
- Winter operations
- Tailings management issues

Dam operators need to be aware of situations in which operations may go from normal to abnormal or become an emergency. The authority of operating staff to initiate emergency procedures should be clearly defined and linked to the emergency plan.

PRINCIPLE 2c

Documented maintenance procedures shall be followed to ensure that the dam remains in a safe and operational condition.

Maintenance of equipment and systems is important to ensure operational availability, safe operations, and integrity of the dam. This is particularly true of mechanical and electrical systems used for flow control, where failure can be sudden. Maintenance needs also vary seasonally through different stages in the life cycle.

The particular maintenance needs of critical components or subsystems, such as flow control systems, power supply, backup power, civil structures, public safety and security measures, and communications and other infrastructure, should be identified.

Maintenance activities should be prioritized, carried out, and documented with due consideration of safety implications. Maintenance procedures for closed or **decommissioned dams** should take into account the availability of appropriate personnel to perform the maintenance activities.

PRINCIPLE 2d

Documented surveillance procedures shall be followed to provide early identification and to allow for timely mitigation of conditions that might affect dam safety.

Surveillance, including visual inspections and instrument monitoring, is a method for checking whether the dam is performing satisfactorily. Effective dam surveillance is based on an understanding of how the dam might fail (failure modes), what early signs of failure to look for, and what inspection or monitoring measures could be used to detect a developing failure.

The surveillance program should provide regular monitoring of dam performance, as follows:

- Compare actual and design performance to identify deviations.
- Detect changes in performance or the development of hazardous conditions.
- Confirm that reservoir operations are in compliance with dam safety requirements.
- Confirm that adequate maintenance is being carried out.

The frequency of inspection and monitoring activities should reflect the consequences of failure, dam condition and past performance, rapidity of development of potential failure modes, access constraints due to weather or the season, regulatory requirements, security needs, and other factors. In addition to scheduled and documented inspections, surveillance can take place each time staff visits a site for other routine activities. Special inspections should be undertaken following unusual events, such as earthquakes, floods, or rapid drawdown. Training should be provided so that inspectors understand the importance of their role, the value of good documentation, and the means to carry out their responsibilities effectively.

Instrumentation may be useful or necessary, depending on the consequences of dam failure and on the need to understand performance parameters that should be measured quantitatively. The installation of an automated instrumentation data system should not preclude the need for routine visual inspections. Procedures should document how often instruments are read and by whom; where instrument readings will be stored, how they will be processed, and how they will be analyzed; what threshold values or limits are acceptable for triggering follow-up actions; what the follow-up actions should be; and what instrument maintenance and calibration are necessary.

Follow-up actions might range from continued or enhanced inspection and monitoring, to remedial repairs, to upgrading of the dam system. The dam owner should establish procedures for appropriate follow-up of surveillance findings. In some situations, immediate action, such as reservoir lowering or emergency repairs, may be necessary to manage the risks.

PRINCIPLE 2e

Flow control equipment shall be tested and be capable of operating as required.

Testing of flow control equipment should be carried out to demonstrate that it will reliably handle the expected operating loads and site conditions, retaining or releasing water upon demand.

The operational capability of equipment should be assessed with consideration of both normal and unusual conditions and the consequences of equipment failure. Test procedures should take into consideration upstream and downstream effects, including impacts on public safety and environmental concerns. Normal and standby power sources, as well as local and remote controls, should be tested. Test results should be documented.

1.3 Emergency Preparedness

PRINCIPLE 3a

An effective emergency management process shall be in place for the dam.

All dams should have emergency response procedures and emergency preparedness plans in place if lives are at risk or if implementation of emergency procedures could reduce the potential consequences of failure. The emergency management process should be updated over the full life cycle of the dam, including the construction phase and whenever significant cofferdams are required. For a new dam, the plans should be established prior to first filling of the reservoir.

The level of detail in the procedures and plans should be commensurate with the consequences of failure. Evaluation of the consequences should generally be done by carrying out dam-breach analysis and preparing inundation maps, followed by consequence assessment. If the consequences are low, the plans can usually be very simple; with the approval of the **regulator**, plans may not be required in some cases.

The absence of government regulations does not negate the owner's responsibility for emergency preparedness planning.

PRINCIPLE 3b

The emergency management process shall include emergency response procedures to guide the dam operator and site staff through the process of responding to an emergency at a dam.

Emergency response procedures should outline the steps that the operations staff is to follow in the event of an emergency at the dam. Documentation should clearly state, in order of priority, the key roles and responsibilities, as well as the required notifications and contact information.

Natural floods can create urgent situations that must be managed. These situations may include the passage of floodwater through or over a dam. In most cases the floodwater is well below the level that would threaten the structural integrity of the dam. However, downstream stakeholders are interested in the effects of inundation, whether caused by a major flood, the passing of discharges through a **spillway**, or a dam breach. For this reason, the dam owner's procedures should cover the full range of flood management planning, and normal operating and surveillance procedures should be linked with the emergency response procedures.

The emergency response procedures should include the following:

- *Procedures for identification and evaluation of the emergency*—Potential dam safety hazards (whether natural, structural, or caused by human actions) should be addressed in a manner consistent with identified failure modes and consequences of failure.
- *Contact information and communication procedures*—Procedures should be documented for informing the authorities responsible for emergency response and evacuation, the dam owner's staff and people in the inundation zone who are in immediate danger, the upstream and downstream water-retention facilities, and regulators about the emergency.
- *Remedial and management actions*—Procedures should be documented for providing the emergency responders with communication systems, equipment, materials, site access, inundation maps, other resources, and data.

PRINCIPLE 3c

The emergency management process shall ensure that effective emergency preparedness procedures are in place for use by external response agencies with responsibilities for public safety within the floodplain.

The emergency management process should be documented, distributed, and clearly communicated, in advance, to all response agencies with responsibility for public safety within the floodplain.

Developing partnerships with key downstream stakeholders and other response agencies is a critical element in the owner's emergency planning. Local responders should ensure that their emergency plans include a section addressing potential dam safety hazards (whether natural, structural, or caused by human actions).

Roles and responsibilities of the dam owner and response agencies should be defined and accepted. Where no formal response agency exists downstream of a dam, the dam owner should have in place reasonable and practical measures to protect those at risk.

Inundation maps and critical flood information should be available to downstream response agencies to assist them in identification of critical infrastructure that may be affected by large releases or the failure of a dam.

PRINCIPLE 3d

The emergency management process shall ensure that adequate staff training, plan testing, and plan updating are carried out.

Exercises should be carried out regularly to test the emergency procedures. There are significant benefits to testing the procedures in cooperative exercises involving both the dam owner's staff and the external agencies with response roles.

Emergency plans should be updated regularly, and distribution should be controlled so that all copies are kept up to date.

1.4 Dam Safety Review

PRINCIPLE 4a

A safety review of the dam ("Dam Safety Review") shall be carried out periodically.

The Dam Safety Review is a systematic review and evaluation of all aspects of design, construction, operation, maintenance, processes, and other systems affecting a dam's safety, including the dam safety management system. The review defines and encompasses all components of the "dam system" under evaluation (dams, spillways, **foundations**, **abutments**, reservoir, tailraces, etc.)

The review should be based on current knowledge and methods, which may be different from the acceptable practices at the time of original construction or a prior Dam Safety Review.

The level of detail in the Dam Safety Review should be sufficient either to demonstrate that the dam meets dam safety requirements or to identify areas where conformance cannot be demonstrated and future investigation or action is needed. The level of detail may be modified on the basis of previous assessments, complexity of the dam, continuity of surveillance and records, external and internal hazards, operating history, dam performance and age, and the need for public protection during operation.

The Dam Safety Review should include visual inspection of the dam and a review of

- Consequences of dam failure
- Operation, maintenance, and surveillance documentation and practices
- Emergency preparedness plans and procedures
- Previous Dam Safety Reviews
- Up-to-date closure plan in the case of a tailings dam
- Analyses of failure modes, **inflow design flood**, seismic loads, other loads and load combinations, stability and performance, reliability and functionality of discharge facilities, and overall effectiveness of safety management at the dam

The frequency required for the Dam Safety Review should be based on the consequences of failure, external hazards, failure modes, the ongoing surveillance program, and demonstrated dam performance.

The Dam Safety Review should be documented in a formal report, with conclusions and recommendations, to enable the dam owner to conform to accepted practices in dam safety and to comply with regulations.

PRINCIPLE 4b

A qualified registered professional engineer shall be responsible for the technical content, findings, and recommendations of the Dam Safety Review and report.

The Dam Safety Review should be carried out by a registered professional engineer (or team of engineers) with a background in design, construction, operation, and performance analysis of dams. The terms of reference for the review should define who is accountable for the final report.

The findings and recommendations should be independent of conflict of interest.

1.5 Analysis and Assessment

The purpose of dam safety analysis is to determine the capability of the dam system to retain the stored volume under all conditions and to pass flows around and through the dam in a safe, controlled manner. An interdisciplinary approach is needed that encompasses aspects of hydrotechnical, seismic, geotechnical, structural, mechanical, electrical, and environmental engineering. Further discussion of technical issues is included in the technical bulletins published by the Canadian Dam Association.

PRINCIPLE 5a

The dam system and components under analysis shall be defined.

At the start of a dam safety analysis, bounds for the system and processes must be established. The system to be analyzed could range from a specific concern pertaining to one component of the dam to the entire safety management system that applies throughout the life cycle of the dam.

Components of dams include all fluid retaining and conveyance structures, the reservoir and downstream areas, the flow control equipment, and other subsystems supporting safety (access roads and notification systems, for example).

Data and information about the dam system must be adequate (sufficient quantity and quality) for reliable assessment of the safety status of the dam.

PRINCIPLE 5b

Hazards external and internal to the dam shall be defined.

Hazards may change in nature and significance at different stages of a dam's life.

External hazards originate outside the boundary of the dam and reservoir system and are beyond the control of the dam owner. External hazards include the following:

- Meteorological events, such as floods, intense rainstorms (causing local erosion or landslides), temperature extremes, ice, lightning strikes, and windstorms
- Seismic events, either natural, caused by economic activity such as mining, or even reservoir induced
- The reservoir environment, including rim features, such as upstream dams and slopes around the reservoir that pose a threat
- Vandalism and security threats

Internal hazards may arise from the ageing process or from errors and omissions in the design, construction, operation, and maintenance of the dam and water conveyance structures. Internal hazards can be subdivided by source:

- Components that retain or interface with the body of water
- Water conveyance structures required to direct water around or through the dam in a controlled way
- Mechanical, electrical, and control subsystems
- Infrastructure and plans, including instruments, operating orders, maintenance strategies and procedures, surveillance procedures, and emergency plans, as well as inflow forecasts

PRINCIPLE 5c

Failure modes, sequences, and combinations shall be identified for the dam.

A failure mode describes how a component failure occurs to cause loss of the system function. Failure modes may be interdependent and change in nature and significance at different stages of a dam's life. In any analysis, the failure characteristics, including extent and rate of development, should be determined to an appropriate level of detail. At a general level, there are three dam failure modes:

- *Overtopping*—Water flows over the crest of the dam, contrary to design intent.
- *Collapse*—Internal resistance to the applied forces is inadequate.

- *Contaminated seepage*—Contaminated fluid escapes to the natural environment.

Dam safety risk management is directed to (*i*) prevention of the initiation of a failure sequence; (*ii*) control of a deteriorating situation; and (*iii*) mitigation of situations where the failure sequence cannot be stopped.

PRINCIPLE 5d

The dam shall safely retain the reservoir and any stored solids, and it shall pass flows as required for all applicable loading conditions.

Dam safety analysis should consider the full range of applicable conditions in order to determine how the structures are expected to perform and what amount of deviation from the normal condition is tolerable. Design, construction, and operation should be integrated in the analysis to ensure that the design intent has been incorporated into the dam.

2. DAM SAFETY MANAGEMENT

2.1 Introduction

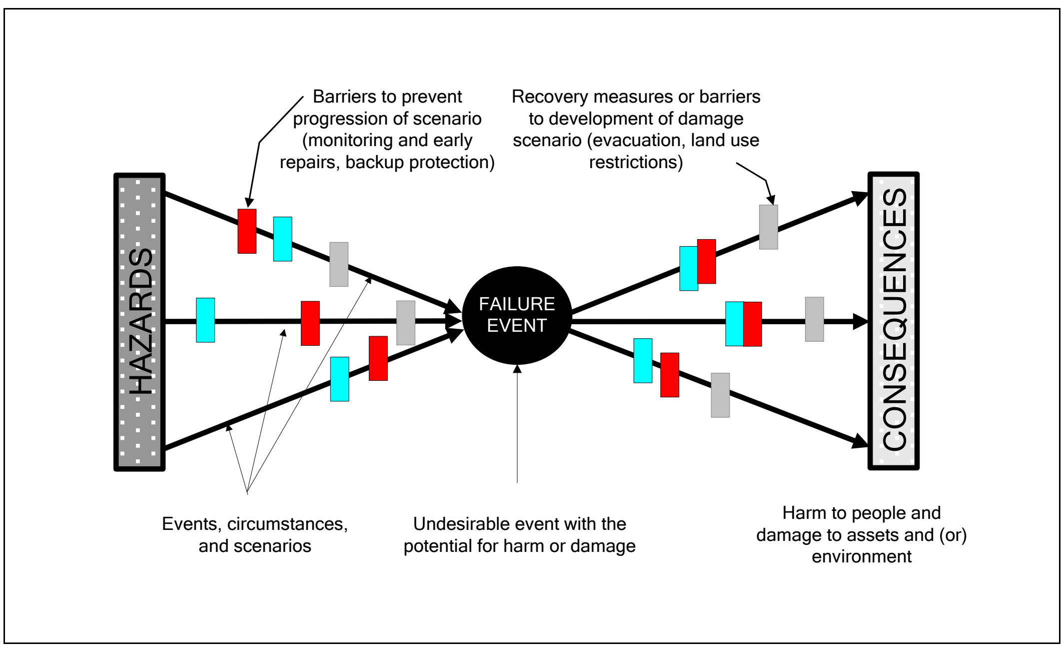
Management of dam safety has the primary objective of preventing dam failure, but it also involves preparing to respond to unusual conditions so that hazardous situations can be brought under control (Figure 2-1).

Dam safety activities are set in the context of the owner's business objectives and the public's interests, which may differ at times. In such cases, it is the role of governments to set public policies and regulations under which the dam owner must operate.

Managed systems for the safety of dam facilities, the public, workers, and the environment must be coordinated. The emphasis in these guidelines is on dam safety in terms of preventing adverse consequences from failure of the dam facilities.

This section describes the need for an overall management system to provide a framework for dam safety activities, decisions, and supporting processes. The key elements of a dam safety program are identified as they fit into the management system. Decision criteria and more detailed practices and procedures should be developed during the policy and planning stages in a functioning management system. The series of technical bulletins published by the Canadian Dam Association (CDA) contains technical information that provides guidance in this regard.

Figure 2-1: Prevention and Response in Dam Safety Management



The standard of care applied to management of safety at a dam should be commensurate with the consequences of failure of the dam and with the dam's condition. Accordingly, the extent of application of the management system as described in this document and the details and sophistication of such a system should also be commensurate with the dam's condition and the consequences of failure of the dam.

2.2 Overall Process

A dam safety management system must function within the context of public policies and the owner's business objectives. To properly support safety decisions, the safety management system should take an integrated view of dam safety that encompasses planning, implementation of procedures, review, and corrective action. Dam owners are accountable for the safe management of their dams throughout the dam's life cycle, from design to decommissioning or closure.

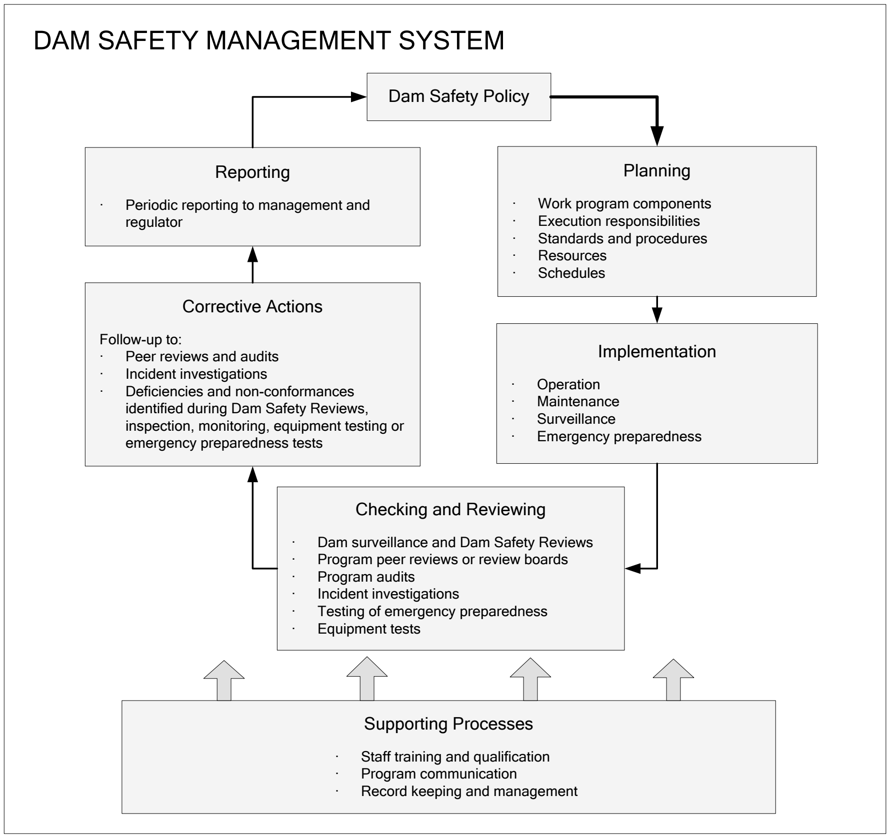
Typical functions of dams include water storage, mine tailings impoundment, power generation, flood control, recreation, and navigation. Thus, dam owners, while profiting from dam operations, also serve society by meeting important needs. The necessary time and costs of dam safety activities are sometimes considered to be in conflict with the primary business objectives. However, the cost of dam safety is small in comparison to the costs and damages that would follow a dam failure. Investments in dam safety should be accepted as an integral part of the business costs.

Dam design, construction, operation, maintenance, decommissioning, closure, and all associated activities engage a broad spectrum of human and engineering disciplines. To support these activities and ensure safety, the dam owner needs a good internal organizational structure, a clear decision-making process, competent staff, and key project data. To ensure and demonstrate due diligence, the owner's dam safety program should incorporate the essential activities of any effective management system, as shown in Figure 2-2 and described below.

- *Plan*—Develop policies and goals, and plan activities to meet these goals.
- *Do*—Implement the plan, according to documented procedures and clear accountabilities.
- *Check*—Review the implementation and results to assess the effectiveness of the program.
- *Correct*—Make the necessary improvements.
- *Report*—Report the status and issues to accountable management and (or) regulatory agencies.

These basic elements apply to the safety management of an individual dam, as well as to a situation where a dam owner is responsible for a portfolio of dams. Owners of multiple dams should maintain an inventory of dams in the system. Owners of dams in cascade must manage those dams in a coherent manner, ensuring that the impacts of each dam on the dams upstream or downstream are identified and managed appropriately. If dams in cascade have multiple owners, it is imperative that the owners cooperate with respect to operations, spill capacity, emergency response, and any other issues of mutual concern. Similarly, in situations where dams on parallel river systems might affect the same population, management of these dams should be coordinated, and the combined effect of the dams on the population should be identified and addressed. Public policies and regulations may apply.

Figure 2-2: Overview of an Owner's Dam Safety Management System



2.3 Elements of Management System

2.3.1 Policy

The owner's dam safety policy should clearly demonstrate the organization's commitment to safety management throughout the dam's life cycle. This policy should define the following:

- The safety practices and criteria to be used, taking into account any applicable regulations, industry practice (such as the CDA technical bulletins), and due diligence
- Ultimate accountability and authority for ensuring that the policy is implemented
- The delegation of responsibility and authority for all dam safety activities
- The process for making decisions related to dam safety

In large organizations, the dam safety functions within the overall structure of various organizational units should be identified, as well as interrelationships and responsibilities. Key individual positions accountable for dam safety, operation, **surveillance**, and maintenance should be identified, along with their responsibilities for internal and external reporting. It is particularly important that accountabilities for operational decision-making be highlighted so that staff members are aware of their responsibilities and know who has authority to make operational decisions during unusual situations or emergencies.

To ensure that safety objectives are not considered secondary to other business objectives, accountability for dam safety should be placed at the highest level of management. In large organizations, senior management should be periodically updated on the status of the safety of the dams and related **risk** and regulatory issues. The owner's staff and any consultants or contractors who carry out dam safety activities on behalf of the owner should be made aware of the decision-making process and who is accountable for what. Safety decisions with significant societal or financial implications should be made or approved at the highest level.

2.3.2 Planning

Planning involves identifying the components of the dam safety work program, assigning the responsibilities for executing each component, and ensuring that the resources are adequate to carry out the work. The plans should define the implementation methodologies, acceptable standards, and required frequencies for carrying out certain tasks.

It is often useful to consider three levels of planning: the strategic or long-range plan (5-10 years), the management plan (annual), and operational plans (specific to a project or task). The long-range plan and the annual plan for dam safety activities should be set by management at the highest level of the dam safety work program.

The annual dam safety plan should identify the program elements to be carried out, the budget allocated, the responsible organizational unit, priorities, and relationships to other tasks and organizational units. Each organizational unit should coordinate its assigned dam safety activities with its other tasks and priorities. For example, the overall plans would include the required frequency of certain activities, time of year (if the activity is affected by weather), priority for implementation, approval requirement, staff availability, and coordination with other work.

Task- or project-specific plans should take into consideration regulatory approvals, environmental or site-specific schedule constraints, and risks associated with execution of these tasks, as well as measures that should be in place to mitigate the risks.

2.3.3 Implementation

Implementation of a dam safety program is, by definition, implementing checks and reviews of dam performance and taking corrective action, as discussed in the following sections.

Ongoing activities associated with dam management include operation, maintenance, and surveillance, as well as emergency preparedness. These should be carried out according to a clear plan so that the intended function of the dam is achieved without compromising dam safety. Emergency preparedness plans and procedures should be integrated into the overall dam management plan.

2.3.4 Checking and Reviewing

Dam safety management should include processes for checking and reviewing dam performance, as well as the safety management system itself.

Routine and detailed inspections, monitoring and assessment of data, testing of equipment, and emergency exercises are processes to check and review the condition and performance of the dam and its components. Dam Safety Reviews should be performed periodically to provide independent assurance that the dam meets current safety requirements or to make recommendations for improvement.

The overall dam safety management system should also be reviewed regularly and the results reported to the owner's senior management. This review should cover policies, planning, the decision-making framework, and management commitment, as well as how well the routine dam safety activities are carried out. If the owner has only one dam, this could be covered in the Dam Safety Review. However, if the owner is responsible for many dams, an independent review of the safety management system for the complete portfolio is recommended. These reviews should be carried out by independent dam safety practitioners with broad and extensive experience in dam safety management.

It is also beneficial for an owner to audit specific aspects of the program to ensure that policies and procedures are being followed. For example, a procedure may call for all instruments at a dam to be read at a prescribed interval and for the data and data plots to be reviewed within a specified time frame. An audit would review the records to see whether this procedure is in fact being followed and whether there are any issues or problems that would necessitate staff training, resource adjustment, or revisions to the procedure.

After any significant dam safety incident, the owner should carry out an investigation to determine root causes, minimize the potential for such incidents to happen again, and ensure that lessons learned are incorporated into the system and communicated to staff.

2.3.5 Corrective Actions

Surveillance, maintenance, operating equipment tests, Dam Safety Reviews, emergency preparedness tests, incident investigations, management system reviews, and audits may identify or confirm safety deficiencies or non-conformance with standards, policies, or procedures. Therefore, the dam safety management system should include a process for timely follow-up and correction of potential deficiencies, confirmed deficiencies, and non-conformance.

Dam safety incidents and near misses may indicate deficiencies in the management system, processes, or equipment or in staff training and compliance with directives. A process for identifying and reporting incidents and for following up on these should be part of a dam safety management system. In addition, incidents or events at other dams or in other countries and jurisdictions can be instructive and may point to improvements that should be undertaken at similar dams to avoid similar situations. Lessons learned from such events should also be considered when corrective action is being undertaken.

In general, audits and investigations should be carried out in an open, transparent manner and in a spirit of continuous improvement. It should be made clear to all staff that the objective is not to lay blame but to address system weaknesses and ensure that lessons learned are incorporated appropriately in the safety management system. Promotion of a trusting environment will encourage staff to report all incidents and work cooperatively toward continual improvement.

Identified deficiencies or issues in dam design, performance, supporting infrastructure, operation, maintenance, surveillance, security, emergency preparedness, and the management system should be prioritized and addressed.

Prioritizing corrective actions and making decisions regarding their implementation should take the following into account:

- The consequences of dam failure
- The magnitude and significance of the deficiency or issue in question
- A **risk assessment** of the deficiency
- The level of risk tolerance within the organization
- Regulations, laws, and finances

A strategy for implementing corrective actions or safety improvements should be formulated. Such a strategy should include the following:

- *Priority*—the order in which corrective actions and improvements should be undertaken
- *Urgency*—how soon these activities should be undertaken
- *Progressive improvement*—whether these activities can be implemented in stages

2.3.6 Reporting

As a minimum, senior management and company officers should be updated annually on the status of the dam safety program. The update should cover these issues:

- Results of the various reviews
- Outstanding issues and deficiencies
- Incidents
- Corrective actions
- Adequacy of policies and procedures (or need for a change)
- Program objectives
- Adequacy of resources
- Any other concerns

Major decisions may need to be made at the highest level of management during this reporting process. Regulations may require that reports on specific activities or results be submitted to the regulator and that some major decisions be discussed with the regulator as well.

2.4 Supporting Processes

2.4.1 Training and Qualification

Supporting processes need to be in place for the effective implementation of a dam safety management system. These processes include adequate training and qualification of all individuals with responsibilities for dam safety activities. The training programs should be geared toward developing and maintaining the competency of these individuals and should take into account the required frequency of re-qualification, the complexity of operating systems, and any significant changes in the facilities or operating criteria. Training records should be maintained.

Individuals performing dam safety activities must be qualified and have a comprehensive understanding of the facility and its safe operation. This should include a basic understanding of the civil structures, flow control facilities, control systems, operating procedures, interaction of facility operations with other stakeholders, potential hazards and failure modes, and other relevant information. Typically, training should address site-specific issues and ensure that all failure modes, site intricacies, and interactions of site components are covered. Some type of competency check is also valuable to ensure that participants have understood the topics being delivered.

Staff training in emergency preparedness and response is addressed in section 4. This training should be given to all staff that may have a response role during an emergency. Testing of the emergency preparedness and response plans is an integral component of this training.

Staff should also be encouraged to become aware of new and updated technologies and maintain competency by becoming involved in industry and learned organizations. Owners should participate, and encourage their staff to participate, in the efforts of the dam industry to improve knowledge and update practices and technologies.

It is the owner's responsibility to determine that any consultant retained is appropriately qualified and experienced in dam design, construction, safety assessments, or any other activities to be carried out.

2.4.2 Program Communication

It is of utmost importance that the dam safety policy and management commitment be clearly communicated to staff involved in dam safety activities. Periodic reinforcement of the message should ensure that dam safety awareness and a culture of continuous improvement are supported within the organization. An open environment should also encourage upward communication to ensure that issues, concerns, or incidents are reported promptly.

Public consultations prior to construction of new dams and repair or upgrade of existing dams give the public an opportunity to provide input to the project and to express any concern. From the owner's perspective, it is important that the public understand the benefits and the risks associated with the project and be kept informed of progress or emerging issues.

Frequent contact, consultations, exchanges of information, and follow-up with emergency responders, stakeholders, and civic authorities are necessary during the development, maintenance, and testing of plans involving public safety and emergency preparedness. Clear, concise, and consistent communication is necessary to ensure that emergency preparedness and response plans are effective and that the public is aware of the hazards associated with the dams and their operation.

2.4.3 Record Keeping and Management

Documentation should be kept up to date so that there is a permanent record of (*i*) the design, construction, operation, and performance of the dam; and (*ii*) the management of its safety. Such documents typically include, but are not limited to,

- Permits and licences
- Design records
- Geotechnical investigation records
- As-built drawings
- Construction completion reports
- Photo and video records of construction activities at various stages
- Instrumentation readings and other technical data
- Inspection and testing reports
- Dam Safety Review reports
- Operational and maintenance records
- Investigation studies
- Closure plans if any
- Records of dam safety incidents, associated lessons learned, and follow-up actions
- Records of staff training
- Records of flow control equipment tests, emergency preparedness plans, drills and tests, and follow-up actions

Records and documents, including drawings, electronic documents, and databases, should be managed to ensure retention, availability, and retrievability during the entire life cycle of the dam. The records management process should specify which records must be kept permanently and the retention time for others.

Some documents, by their nature, need to be reviewed and updated frequently. Only the current version should be in use. Documents of that nature should be controlled, meaning that they are reviewed periodically, approved and issued by a designated authority, and distributed to registered copy holders. Measures should be in place to ensure that all copies are kept up to date and that recipients understand which information and responsibilities outlined in the documents pertain to them.

Dam safety documents that should be controlled include the Operation, Maintenance, and Surveillance Manual (OMS Manual) (or equivalent documents) and the emergency plan. Since operation and maintenance requirements may change throughout the life cycle of the dam, up-to-date instructions must be distributed and out-of-date information withdrawn from circulation. Similarly, the emergency preparedness and response requirements will change in response to changes in circumstances, in personnel, and in stakeholders' policies and mandates. In addition, any significant changes in operations, dam classification, regulatory requirements, or other critical information should trigger an update. Because OMS Manuals and emergency plans are controlled documents, any changes or updates to the documentation should be appropriately reviewed, approved, and circulated to the responsible personnel. Records should be kept of any changes or updates so that they can be checked during periodic reviews or audits.

2.5 Inundation, Consequences, and Dam Classification

2.5.1 Introduction

An understanding of the consequences of dam failure underlies several of the principles of these dam safety guidelines. A classification system based on consequences is presented herein. Consequences of dam failure may include loss of life, injury, property and environmental damage, and general disruption of the lives of the population in the inundated area. Release of the **reservoir** would also affect the upstream aquatic habitat, recreational property and activities, boating, water intakes, and other infrastructure.

The analyses leading to consequence assessment and classification of the dam should include characterization of a hypothetical dam breach, flood wave routing, inundation mapping, and evaluation of the impacts. A wide range of methods may be applied in each of these steps; the choice will depend on the extent of information needed. The level of effort and the resulting level of accuracy should be commensurate with the importance of the dam safety decisions that need to be made.

In general, a preliminary assessment using simple and conservative procedures should be done to obtain a first approximation of the level of consequences. Complexity and accuracy should be increased if there is a need for greater detail to confirm the dam classification, support a detailed emergency response plan, or inform risk management decisions. This approach allows for consequence classification to be used for small or obviously low-consequence structures where the cost and complexity of larger, more detailed studies may not be required.

2.5.2 Dam-Breach Analysis and Inundation Mapping

A dam-breach analysis is used to determine the ultimate discharge from a hypothetical breach of the dam. The outcome of the analysis is a flood peak or flood wave immediately downstream from the dam.

An evaluation is made of initial conditions, as well as the breach geometry and timing. The evaluation should address initial hydrologic conditions for the following:

- *Sunny-day failure*—This is a sudden dam failure that occurs during normal operations. It may be caused by internal erosion, piping, earthquakes, mis-operation leading to overtopping, or another event.
- *Flood-induced failure*—This is a dam failure resulting from a natural flood of a magnitude that is greater than what the dam can safely pass.

Reservoir levels and downstream tributary flow in the assessment should be those expected for a breach event of the particular type. For example, in the analysis for sunny-day failures, it is generally considered reasonable to use maximum normal reservoir levels combined with mean annual flow conditions in the upstream and downstream channels. For flood-induced failures, the reservoir levels used to estimate breach discharge should be appropriate for the failure mode threshold. Sensitivity analyses should be carried out to identify more critical situations for specific cases.

The breach location within the dam structure and other breach parameters, such as shape, width, depth, and rate of formation, should be determined for various initiating events and failure modes. Typically, for earthfill dams, both overtopping failure and piping failure are included in the analysis.

Most dam-breach analyses require the development of an outflow hydrograph to graph the changes in flow as the breach forms and the reservoir drains. Flood wave routing is conducted to follow the progress of the dam-breach wave from the dam to a location downstream where the effects would be negligible. If there are other dams or water-retaining structures downstream, the study must consider whether the flood wave would also cause breaching of those structures. If it turns out that downstream breaching is likely to occur, the consequence assessment for the failure of the upstream must include the damage caused by the downstream failures.

The simplest and most conservative procedures may be applied as a first approximation; more detailed analyses should be conducted if necessary. The method of analysis should reflect the required level of accuracy and the complexity of the downstream channel and infrastructure.

Mapping of inundation areas is used as the basis for estimating the potential consequences of a dam breach. Inundation maps are also used for emergency planning and should show (*i*) flood and flood peak arrival time; (*ii*) depth of flow; (*iii*) significant emergency infrastructure, such as roads and hospitals; and in some cases (*iv*) velocity of flow.

2.5.3 Dam Failure Consequences

Loss of Life

The consequences of dam failure should be evaluated in terms of life safety. The population at risk (PAR) in the inundated area provides an indication of the number of people exposed to the hazard. It accounts for demographic and land-use factors for the inundated area. Some classifications rely on estimates of PAR, defined as the number of people who would be exposed to floodwaters and would experience consequences that could range from inconvenience and economic losses to loss of life.

Consistent estimates of expected loss of life are very difficult to develop. The potential for loss of life depends on many highly uncertain and variable factors, such as depth of flow, velocity, time of day, advance warning, topography, distance from the dam, transportation routes, historical patterns of human activity, and mobility of the population.

No simple, reliable, or universally applicable methodology is available—different methods can produce very different estimates of loss of life. Estimates should take into consideration specific scenarios that account for a wide range of parameters. The assumptions, reasoning, and calculations should be clearly documented.

Economic Losses

The estimate of economic losses should include direct damage to third-party property, facilities, other utilities, and infrastructure. In most cases, the damage to the dam owner's property may be excluded from the estimate and left to the owner to consider separately. However, it should be recognized that in many cases the owner's losses would have significant impacts on society. Where appropriate, costs or values can be assigned to social and cultural impacts and included as economic consequences.

Environmental Losses

To some extent, environmental losses can be assigned a monetary value, but they should be evaluated separately. There may be cases, for example, where a dam retains a large reservoir and there is no permanent PAR, but the environmental consequences could be very serious. The significance of environmental losses should be assessed in terms of whether restoration of the environment is feasible and how long it would take. Since the nature of environmental loss is multifaceted it would be impractical, if not impossible, to arrive at a single numerical value characterizing the extent of the damage. For these reasons, a qualitative assessment may be more appropriate.

Cultural Losses

Social impacts, such as damage to irreplaceable historic and cultural features that cannot be evaluated in economic terms, should be considered on a site-specific basis. Separate assessments should be made of potential damage to sites of cultural and historic value, taking into account the feasibility and practicality of restoration or compensation.

Incremental and Total Consequences

These guidelines are based on the traditional assumption that due diligence and the standard of care expected of a dam owner relate to the potential damage above and beyond that caused by a natural event when the dam does not fail. The incremental consequences of failure are defined as the total damage from an event with dam failure minus the damage that would have resulted from the same event had the dam not failed.

2.5.4 Dam Classification

Table 2-1 presents a classification scheme that can be used to provide guidance on the standard of care expected of dam owners and designers. Estimates of potential consequences of dam failure are categorized to distinguish dams where the risk is much higher than others.

In some cases, a PAR assessment alone provides enough information to classify the dam and determine required safety levels and procedures. However, in areas with a permanent PAR, a more detailed classification can be determined on the basis of estimates of potential loss of life.

If the classification for a dam is based on loss of life in a natural flood, the flood and evacuation scenarios should be considered to ensure that the appropriate level of safety is provided.

Environmental, cultural, and third-party economic losses should be estimated separately and taken into account in assigning a dam to a class. The class should be determined by the highest potential consequences, whether loss of life or environmental, cultural, or economic losses. For the purposes of general management oversight, as well as inspection, maintenance, and surveillance programs, a single classification for the dam system should be based on the failure scenario that would result in worse consequences: either sunny-day failure or flood failure. For determining design criteria for specific components at a site, the consequences of failure of the components may be considered separately for the relevant individual failure modes and their combinations.

Table 2-1: Dam Classification

Dam class	Population at risk [note 1]	Incremental losses		
		Loss of life [note 2]	**Environmental and cultural values**	**Infrastructure and economics**
Low	None	0	Minimal short-term loss No long-term loss	Low economic losses; area contains limited infrastructure or services
Significant	Temporary only	Unspecified	No significant loss or deterioration of fish or wildlife habitat Loss of marginal habitat only Restoration or compensation in kind highly possible	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes
High	Permanent	10 or fewer	Significant loss or deterioration of *important* fish or wildlife habitat Restoration or compensation in kind highly possible	High economic losses affecting infrastructure, public transportation, and commercial facilities
Very high	Permanent	100 or fewer	Significant loss or deterioration of *critical* fish or wildlife habitat Restoration or compensation in kind possible but impractical	Very high economic losses affecting important infrastructure or services (e.g., highway, industrial facility, storage facilities for dangerous substances)
Extreme	Permanent	More than 100	Major loss of *critical* fish or wildlife habitat Restoration or compensation in kind impossible	Extreme losses affecting critical infrastructure or services (e.g., hospital, major industrial complex, major storage facilities for dangerous substances)

Note 1. Definitions for population at risk:

None—There is no identifiable population at risk, so there is no possibility of loss of life other than through unforeseeable misadventure.

Temporary—People are only temporarily in the dam-breach inundation zone (e.g., seasonal cottage use, passing through on transportation routes, participating in recreational activities).

Permanent—The population at risk is ordinarily located in the dam-breach inundation zone (e.g., as permanent residents); three consequence classes (high, very high, extreme) are proposed to allow for more detailed estimates of potential loss of life (to assist in decision-making if the appropriate analysis is carried out).

Note 2. Implications for loss of life:

Unspecified—The appropriate level of safety required at a dam where people are temporarily at risk depends on the number of people, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the design flood requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.

3. OPERATION, MAINTENANCE, AND SURVEILLANCE

3.1 Introduction

Dam operation, maintenance, and surveillance encompass a number of activities and constraints defined to ensure that the dam is managed with appropriate regard for safety. Documentation of procedures and practices is needed to ensure the safe operation of the dam under various conditions. This documentation should also cover the impacts of operations on the public, the environment, and other stakeholders. Maintenance activities should be prioritized, carried out, and documented with due consideration of dam safety and the implications of failure. Surveillance, including visual inspections and instrument monitoring, is the cornerstone of a dam safety management system, since it is the means for checking whether the dam is performing satisfactorily against criteria established during design or subsequent analysis.

3.2 OMS Manual

An Operation, Maintenance, and Surveillance Manual (OMS Manual) is a means to provide both experienced and new staff with the information they need to support the safe operation of the dam. For many dam owners, a single document may contain all the necessary elements. However, for some large dam owners or complex sites, the information may exist in a number of specialized, stand-alone operating, maintenance, and surveillance documents, and an OMS Manual may simply identify the overall organization and provide a listing of the documents or links to the appropriate information. Although the format may vary and the content should be specific to the site, a typical table of contents for an OMS Manual is shown in Table 3-1.

Documentation should be prepared during the construction phase and then updated at the time of major changes to the structures, equipment, or operating conditions. The practices and documentation should be reviewed regularly (as a minimum, during the periodic Dam Safety Review) to ensure information is not outdated.

Tailings dams frequently have unique operation and maintenance issues related to phased construction over a number of years of mine operation. The Mining Association of Canada has published guidelines on tailings management and on tailings dam operation, maintenance, and surveillance that outline important considerations for the mining industry.

Table 3-1: Typical Contents of OMS Manual

1 Project Description
- Overview
- Infrastructure
  - Communications
  - Access Routes
  - Public Safety
  - Site Security

2 Operation
- Roles and Responsibilities
- Water Management
- Operating Procedures
  - Normal Operations
  - Flood or Drought Operations
  - Unusual Operations
  - Emergency Operations
  - Records (Logs)
- Flow Control
  - Equipment and Facilities
  - Water Level Gauge Systems
  - Supervisory Control Systems
  - Emergency Systems

3 Maintenance
- Maintenance Programs
- Concrete Structures
- Embankment Structures
- Steel Structures
- Other Dam Structures
- Spillway Structures
- Penstocks, Tunnels, and Pressure Conduits
- Infrastructure (Access, Utilities)

4 Surveillance
- Visual Inspections
- Dam Instrumentation
- Response to Unusual Conditions
- Documentation and Follow-up

5 Maintenance and Testing of Flow Control Equipment

3.3 Project Description

The OMS Manual should include a brief summary of key project information, such as the purpose and history of the project development, the ownership, any significant site modifications, and the consequences of dam failure. The components of the dam system should be defined and documented to the extent that it would enable staff to understand their characteristics and interactions.

Infrastructure associated with the dam should be adequately documented. This would include an inventory of communications contacts and systems (land line, cellular, satellite, radio, etc.); road, rail, or other access routes; and both primary and secondary access routes, to ensure accessibility in an emergency. Legal agreements on ownership and usage by others should be identified.

Public safety systems and maintenance requirements should be documented, including procedures for seasonal installation and removal, if required, as well as the timing.

Maintenance requirements and security practices (including those for physical site, equipment, and cyber security) should be documented, but it may be advisable to keep the documentation confidential.

3.4 Operation

3.4.1 Operating Criteria and Constraints

The level of detail, accuracy, timeliness, sophistication, and extent of criteria, data, and systems for operations should take into account the complexity of the site, consequences of mis-operation, availability of staff to respond to changing conditions, the type and size of flow control equipment, and other site-specific considerations.

Operators require criteria that define operating limits and extensive reliable data to ensure safe operations within those limits. The purpose of defining operating constraints is to ensure the operation of the dam does not violate any design assumptions that could affect the safety of the dam.

Constraints on dam operations intended to maintain the integrity of the structures should be defined during dam design and reviewed periodically, for example during the Dam Safety Reviews. These constraints should be considered in the development of operating procedures and could include the following:

- Maximum safe discharge rates for all flow control equipment
- Highest safe reservoir level beyond which dam components or reservoir rim may start overtopping and become unstable or cause flow control equipment to be inoperable
- Reservoir levels at which overflow discharge structures, fuse gates, or fuse plugs are intended to operate, expected outflows, and post-activation follow-up requirements
- Physical restrictions on operations that may impact dam or reservoir rim stability; this should include precautions to be taken during drawdown events, first filling of the reservoir, or refilling of a reservoir after a period of low water level
- Legal constraints
- Seasonal constraints

3.4.2 Data Requirements

Dam operators require systems and data to support their operating decisions. The following data should be considered during the development of documentation:

- Timely headwater and tailwater elevations, needed for making operating decisions
- Ways to gauge flow volumes through generating units or flow control equipment operation; this could include rating curves showing the relationship between discharge and reservoir water level from the minimum to the highest safe reservoir elevation
- Reliable and accurate weather data and access to watershed flow data (river gauges, rain gauges, flood warning systems, etc.) to allow reservoir inflow forecasting
- Information on uncontrolled upstream inflows or flow data and travel times between dams on the same or interconnected watercourses
- Reservoir storage tables that go to the highest reservoir level the dam system is expected to be able to withstand without failure; this elevation may be above maximum operating or regulatory levels but can be critical for emergency operations

- Statistics for normal typical values of inflows, such as plots of minimum, maximum, and average inflows versus time, throughout a typical year, so that seasonal impacts can be identified and operators will know if inflows are within normal statistical ranges
- Expected inflow design flood (IDF) inflow values as well as the expected reservoir elevation to be reached during the IDF event

3.4.3 Operating Procedures

Operating procedures should be defined for all expected conditions. Typically, procedures should be in place for normal, unusual or flood, and emergency conditions (these terms relate to operating conditions and may not be directly comparable to the terms used for loading conditions in a dam safety assessment).

- *Normal conditions*—those that can be expected throughout much of the life of the facility and might also be defined as *routine conditions*
- *Unusual conditions*—deviations from routine, including changes in operations required because of flow control equipment failure, ice or debris blockages, seismic events, or large floods
- *Emergency conditions*—events that might lead to dam failure if action is not taken and could include extreme floods, seismic events, failure of a dam component, or equipment failure

It is important for operators to realize that even normal flood conditions could lead to emergency conditions if poorly managed. Procedures should be specific enough to define what actions are to be taken, by whom, and when.

Operating procedures should also include the requirement to document operating conditions and activities, such as reservoir water levels, inflows, discharge flows, equipment operations, unusual events, alarms and resulting actions, public activity, or any other incidents that were related to operations or could have affected operations. An operations log or record of actions should be maintained so that a periodic check of compliance with procedures and operating constraints can be made to help define potential omissions, procedural improvements, training requirements, or other overall operating enhancements.

Normal Operations

Normal operating procedures should be well defined and documented and should include safeguards and redundancies where necessary. Separate procedures might be developed for spring (freshet), summer, fall, and winter conditions.

Normal operating procedures should be a comprehensive set of documents outlining the following:

- Operating duties and authorities of staff involved in reservoir operations
- Procedures for flow control equipment operations outlining local flow control equipment operation versus remote or automatic operation, the use of alarms, staged gate opening or notifications or warnings for downstream stakeholders, remote cameras, and any other physical or procedural safeguards

- Identification of areas impacted by operations, including downstream communities, other dam owners, and industries, as well as any sensitive downstream areas that may be flooded for spillway discharge less than full capacity
- Staffing requirements and time required to complete system operations
- Communication protocols with other stakeholders
- Procedures to ensure that enough gates are operational during flood and winter conditions; this may include bubbler or heater system operations
- Procedures for ice or debris handling; this might include boom installation and routine debris removal, as well as contingency plans for alternate equipment for debris and ice handling

Unusual Operations

Flood operating rules should be predefined and specific enough that operating staff can follow them without seeking approval. This guidance is critical to ensure required operations are properly executed even if communications are lost under flood conditions.

Dam operators need to be aware of situations where operations could go from normal to unusual or emergency conditions. Procedures should include internal notifications, interim contingency plans for alternate discharge or reservoir manipulation, dispatch of maintenance staff, and criteria for return to service. In general, contingency plans should be in place for deviations from normal operating conditions, such as the following:

- Shutdown of flow control equipment for maintenance or other planned activity
- Flow control equipment inoperability due to power loss, failure to operate (opening or closing), unplanned event, or blockage due to ice or debris.
- Failure of an upstream dam or other water-retaining structure
- Rapid drawdown events that could threaten dam or reservoir rim stability
- Development of sinkholes, slumping, or sudden increase in seepage or turbid flow through embankment dam structures
- Loss of control system, water level gauging, or control of flow control equipment
- Inability of staff to access site for normal operations or during flood conditions

Early identification and mitigative actions are critical to prevent unusual conditions from becoming emergency conditions. Where possible, systems should be in place to identify and warn operators (through alarm systems) of the development of unusual conditions. This will then allow operators to take action to mitigate unusual conditions or to decide if the situation warrants implementation of the emergency plan.

Emergency Operations

Emergency operation procedures would typically be defined in the emergency plan. There may, however, be mitigative measures that operations staff can implement to avoid emergency situations. These mitigative measures may be outlined within either the OMS Manual or the emergency plan and might include the following:

- Seismic events that damage dam structures and require reservoir drawdown to prevent failure and (or) carry out emergency repairs
- Reservoir inflows that exceed those defined as inflow design flood values

- Loss of flow control equipment during flood events due to debris, ice, power failure, or loss of control system and rising reservoir levels projected to exceed maximum safe reservoir levels

It may be useful to include a table or description of scenarios that identify events that could lead to activation of the emergency plan. The authority of operating staff to initiate emergency procedures, along with possible triggers, should be defined.

3.4.4 Flow Control

Information related to flow control system operations should be identified and documented. This may include manufacturer's information, design reports, and other relevant information.

Procedures and supporting documentation should be in place for water level gauge installation, calibration, maintenance, and repair.

Supervisory control and data acquisition (SCADA), benchboard, or other control systems are important operational tools. Procedures should be in place to ensure these systems are adequately designed, sufficiently robust, and periodically checked to provide remote dam operators with suitable and timely data for dam operation. Where practical, alarms should be in place to warn operators of situations that could lead to problems.

In addition, some critical dam surveillance instrumentation may be linked into the control system to provide real-time indication of potential dam safety issues.

All emergency systems should be identified and documented. This could include dam-breach early warning systems, emergency power supplies, and other related equipment and systems. These systems should be included within the maintenance and surveillance program to ensure they are functional when needed. Staff familiarity with these systems will be beneficial for response in emergency situations.

3.5 Maintenance

3.5.1 Maintenance Programs

Maintenance of equipment and systems is important to ensure operational availability, safe operations, and integrity of the dam. This is particularly true of mechanical and electrical systems related to flow control equipment where failure due to lack of maintenance can be sudden and dramatic. Civil structures may also develop more maintenance issues as they age. Some dams may have maintenance needs that vary seasonally as well as throughout different stages in their life cycle.

Maintenance programs should identify the components of the dam requiring maintenance, define the schedule of those activities, and track which systems were maintained, what type of maintenance was performed, when it was done, and by whom. This type of information is valuable for identifying chronic problematic equipment issues or components of the system that might require replacement to ensure reliability.

"Routine" maintenance is that which can typically be scheduled or defined on the basis of time (weekly, monthly, etc.), usage (number of cycles, hours of operation, etc.), or observed condition from periodic visual inspection (excessive wear, corrosion, etc.). Routine maintenance may range from a simple change of lubricating fluids to a complete overhaul with replacement of major parts.

Even with an effective preventive maintenance program, dam owners need to be prepared for emergency maintenance. This might include having critical spare parts, tools, equipment, and trained, competent staff ready in the event of an emergency.

3.5.2 Concrete Structures

Maintenance needs for concrete dams, concrete-faced dams, and appurtenant structures should be identified and might include items such as the following:

- Regular cleaning of foundation and internal drainage systems
- Maintenance of surface and joint sealing systems
- Sealing of cracks

Some concrete materials are subject to alkali aggregate reaction (AAR), which causes expansion of concrete, pattern cracking, and ultimately loss of structural integrity. AAR can affect operations by causing closure of sluiceway openings, leading to binding and inoperability of logs or gates. AAR can also cause deck beams or slabs to shear at bearing points, and loss of strength can lead to load de-rating of sluiceway structures, causing the inability to move lifting equipment to pull logs. In some cases, special maintenance procedures may be needed to mitigate the effects of AAR.

Sluiceway gains need periodic maintenance, since deteriorated gains or roller paths for gated sluiceways could lead to binding of gates. Deterioration of gains in stoplog sluiceways can lead to logs jamming or turning over so they cannot be removed.

3.5.3 Embankment Structures

The maintenance required for embankment dams and appurtenant structures should be identified. Maintenance might include items such as the following tasks:

- Removing and mowing vegetation; establishing desirable vegetation cover
- Controlling burrowing animals
- Replacing deteriorated riprap
- Restoring settled crest and freeboard
- Repairing seepage-induced slumping
- Cleaning the drainage system
- Controlling surface erosion

3.5.4 Steel Structures

Maintenance requirements for steel structures should be identified. Maintenance may include the following:

- Corrosion protection (cleaning, priming, painting, replacing anodes or cathodes)
- Connector maintenance (torquing bolts, checking rivets and welds)

3.5.5 Spillway Structures

Some types of spillway structures and approach channels may require periodic maintenance to ensure their operability or integrity to safely discharge required flow. Maintenance requirements for these structures should be identified and may include the following:

- Clearing of debris; removal of vegetation from spillway approach and outlet channels and from the reservoir (where it may migrate and block discharge)
- Repair of cavitation damage or eroded aprons or unlined spillway channels after spill events
- Routine cleaning of debris from energy dissipaters, from joint repairs in concrete linings, and under drainage systems
- Removal of vegetation and repair of fuse plug initiation channels to ensure they will trigger as planned and not trigger prematurely

3.5.6 Penstocks, Tunnels, and Pressure Conduits

Well-designed penstocks, tunnels, and pressure conduits typically provide many years of service if appropriate inspection and maintenance programs are followed. Tunnels, pressure conduits, and penstocks may fail to perform as a result of a design deficiency, operator error, poor maintenance, unusual loading, and ageing. Consequences of failure of a tunnel, penstock, or pressure conduit through an embankment dam can be severe, including uncontrolled release of reservoir, dam breach, loss of life, environmental damage, structural damage, and loss of generation.

Effective maintenance includes the following tasks:

- Applying suitable internal or external coatings to extend the life of existing pipelines or penstocks
- Repairing concrete tunnels and conduit linings or removing rock falls in unlined tunnels

3.5.7 Other Dam Structures

Other types of materials have been used to construct dam structures, and the owners need to ensure proper maintenance of these structures. Timber cribs, gabions, rubber, geosynthetics, and other materials have been used for dam construction or rehabilitation. Maintenance requirements for these structures should be identified and may include the following:

- Application of wood preservative
- Replacement of missing connectors (nails, bolts)
- Replacement of deteriorated members or sheathing

3.5.8 Infrastructure

Necessary maintenance of infrastructure, including site access, may include the following:

- Grading and replenishment of granular surface roads
- Removal of snow on access road
- Maintenance of bridge structure and deck

- Cleaning of access road culverts and ditches and removal of beaver dams
- Maintenance of signage to ensure emergency responders can locate remote sites
- Clearing of roadside or access path vegetation

Maintenance requirements for public safety measures include issues such as the following:

- Regular inspections to ensure integrity of all system components (signs, fences, etc.)
- Protocol for timing of replacement of missing and (or) damaged components, depending on criticality of the item and redundancy
- Installation and removal of any seasonal structures, such as booms or buoys

3.6 Surveillance

3.6.1 General

Dam failures are often preceded by warning signs that may range from the appearance of cracks in earth or concrete dams to the discharge of turbid, sediment-laden water downstream of the dam. The warning time can range from days to months or even to years; however, in some cases warning time may be as little as hours or minutes. The goal of surveillance is to identify deviations in performance conditions so corrective or risk mitigation measures can be implemented before adverse consequences result.

In order to establish an effective dam safety surveillance program, surveillance engineers must understand the hazards that are present, how the dam might fail (failure modes), what early signs of failure to look for, and what inspection or monitoring measures could be used to detect a developing failure. This approach may be described as performance-based surveillance. In addition to monitoring dam performance, surveillance may be necessary for security reasons at a dam.

It is important for staff performing surveillance activities to understand the types of failure modes that apply to the dam structures under their care. Training should define procedures to be followed to document and report surveillance findings. Staff involved in surveillance activities and working at or near a dam should be trained in the proper protocol for reporting a potential dam deficiency and responding to an emergency.

All inspections should be documented to provide a continuous record of conditions so that comparisons can be made to identify changes and trends.

3.6.2 Visual Inspections

The observational approach has long been recognized as a key component of the performance monitoring process for earthworks and foundations. Visual observations can be used to accommodate the inevitable uncertainties associated with design assumptions in materials or construction techniques. A comprehensive visual inspection can identify most issues related to dam safety and provide the owner with the opportunity to perform mitigative measures. The level of detail needed depends upon the type of inspection being performed, complexity of the site, consequences of dam failure, past performance, and other relevant parameters. Therefore, routine inspections by trained on-site staff and visual inspections by qualified professional engineers are integral to an effective dam safety program.

The frequency of inspection and monitoring activities should take into account regulatory requirements, consequences of dam failure, dam condition and past performance, time of development of expected failure modes, seasonal or other access constraints due to weather, and other factors. Inspection during dam construction is critical to ensure conformance to design criteria and proper construction control.

Routine Inspections

Routine inspections are generally completed on a weekly or monthly frequency to identify any conditions that might indicate changes in dam performance and therefore require follow-up. These inspections may be carried out by engineers or other staff trained in dam surveillance. Of particular significance are new occurrences or noted changes in leakage, erosion, sinkholes, boils, seepage, slope slumping or sliding, settlement, displacements or cracking of structural components, clogging of drains and relief wells, etc.

Engineering Inspections

Engineering inspections are typically performed annually or semi-annually and include a detailed visual examination of the dam and the instrumentation used to monitor dam performance. This inspection should document observations regarding the condition of the dam, with any significant condition changes from previous inspections being highlighted. Some assessment of the severity of observed anomalies as well as recommendations for maintenance, repairs, investigation, or further monitoring should be completed. Because of this additional level of assessment, these inspections are generally performed by professional engineers.

Special Inspections

In addition to planned inspections, dams should be inspected during, if possible, and after unusual or extreme events, such as heavy rainfall, flooding, windstorms, severe icing, rapid snow melt, earthquakes, and exceedance of the absolute maximum operating water level (which could occur during an extreme flood or as the result of blocked discharge facilities or improper operation of the structure). Significant changes to normal operations, nearby construction activity, or other unusual events might also trigger special inspections.

3.6.3 Dam Instrumentation

Dam instrumentation should not be used as a replacement for regular visual inspections, but as an aid to augment ongoing assessment of dam performance. The need for instrumentation should be defined systematically on the basis of expected dam performance and identification of parameters that need to be measured quantitatively. The procedures, assumptions, failure modes identification, analysis, and other related information used to define the instrumentation program should be documented. Documentation should identify the parameters to be measured, how often and by whom, expected threshold values, and required instrument maintenance and calibration. In addition it is important for the dam owner to define where instrument readings will be stored, how they will be processed and analyzed, what are acceptable threshold values or limits that might trigger follow-up actions, what would be the required follow-up, and who has authority to initiate follow-up. The effectiveness of dam instrumentation should be reviewed periodically and updated as necessary to achieve the desired level of dam performance monitoring.

3.6.4 Documentation and Follow-Up

Data obtained from inspections and instrumentation must be documented, compiled, and analyzed in a timely manner for any indications of unusual dam performance. The dam owner should establish a procedure to document findings from the surveillance program that require follow-up action. In some instances findings may require immediate remedial actions, such as reservoir lowering or repair, to manage the risks. Some training and judgment are required on the part of the inspector to help define the urgency of follow-up actions. Observation of a hazardous condition at a dam may, in some cases, lead to activation of the emergency response plan.

3.7 Maintenance and Testing of Flow Control Equipment

Mechanical and electrical equipment associated with dams consists mainly of the flow control equipment (including gates, valves, stoplogs, flashboards, and inflatable dams), auxiliary equipment (such as heaters and de-icing equipment), power supplies, and control systems.

Inspection, maintenance, and performance testing are generally carried out as integrated activities. Operation and maintenance procedures should depend on the amount and complexity of equipment at the site. The equipment should be operated at least once each year. Maintenance procedures should include inspection, reporting, repair, and follow-up. Spare parts should be available for critical components.

All mechanical and electrical equipment that is required for the dam to pass the inflow design flood should be tested to demonstrate that the equipment is in good working order and the dam can pass the required flows. The appropriate inspection and maintenance intervals will vary depending on its condition, frequency of use, maintenance history, and criticality to dam safety, as well as the site climatic conditions.

An annual functional test should be conducted to verify that flow control equipment will operate under normal flows. The testing can be carried out at less than the full open flow, and for regularly used equipment, it could be a part of normal operation.

A full flow test should be carried out periodically (for example, as part of a Dam Safety Review) to verify the design capability of equipment. In a full flow test a gate, log sluice, or valve is fully opened so that the device and its auxiliary equipment operate close to their design loads. Contingency planning is needed to identify potential problems that could occur during the test and to develop procedures to deal with these risks.

4. EMERGENCY PREPAREDNESS

4.1 Introduction

Effective emergency management relies on establishment of a clear emergency response structure that is understood by all responders, supported by the following four components:

- An internal, dam-specific emergency response plan (ERP), including actions the dam owner will take in response to unusual or emergency conditions
- An emergency preparedness plan (EPP), developed by the dam owner for external use, defining the hazards posed by the dam, the roles and responsibilities of all parties, and notifications to be made
- Municipal, community, or regional emergency plans, developed by responding agencies for their own use to warn and evacuate residents within the floodplains
- A maintenance, testing, and training program to ensure that the processes are effectively integrated and kept up to date

Dam Safety Guidelines provides guidance on each of these components. References to the ERP or EPP are intended to indicate the internal and external documents prepared by a dam owner. Although these are discussed here as separate plans, they may be issued by the dam owner as a single document covering all the elements.

ERPs and EPPs should be in place for all dams where lives are at risk or if implementation of emergency procedures could significantly reduce the consequences of failure. Consequences are normally evaluated on the basis of dam-breach analysis and inundation mapping. The level of detail required in any ERP or EPP should be commensurate with the consequences of failure. If the consequences are low, the plans can usually be very simple. In some cases, with the approval of the regulator, plans may not be required. The absence of government regulations does not negate the owner's responsibility for emergency preparedness planning.

ERPs and EPPs should be controlled documents so that all copies are accounted for and designated individuals are responsible for keeping the copies up to date.

Emergency plans should be in place for the full life cycle of the dam, including the construction phase of a new dam, especially where significant cofferdams are required. For a new dam, the final plans should be in place prior to first filling of the reservoir.

During an emergency both the dam owner's staff and the community responders must understand the relationships between the different emergency operations centres (EOCs). Emergency plans should document the response structure, such as the widely used "incident command" model (Table 4-1).

Table 4-1: Incident Command Model

Type of EOC	Typical role
SCP	The SCP manages the emergency in the vicinity of the dam and reservoir. Dam staff attempt mitigation measures if required and also performs initial notifications as described in the fan-out procedures. The SCP coordinates broader response activities until regional EOC or corporate EOC is set up to assist
Dam owner EOC	In some cases an EOC is established by the dam owner upon notification of a major dam emergency. The centre normally provides comprehensive support for site activities by coordinating site security, logistical requirements, on-going communication with stakeholders and media, and technical and administrative support
Provincial government EOC	In a serious emergency, the provincial government may activate a government EOC to manage the emergency at the provincial level. The government EOC is staffed with the appropriate government officials and agency representatives as needed for emerging events, and normally activates a public media information room
Municipal EOC	Municipalities activate their municipal emergency plans and perform the required emergency response procedures outlined in their plans. These procedures are based on the information supplied by the dam owner. In most cases a municipal EOC is set up

Acronyms: EOC, emergency operations centre; SCP, site command post.

4.2 Emergency Response Plan

4.2.1 General

A dam owner should establish a formal internal ERP documenting the procedures that operations staff should follow in the event of an emergency at the dam. The ERP outlines the key emergency response roles and responsibilities, in order of priority, as well as the required notifications and contact information.

Natural floods can create an emergency that must be managed, including passage of the floods through or over a dam. In most cases, floods are well below the level that would threaten the safety of the dam. Dam owners may choose to incorporate all modes of downstream flooding in their emergency planning process, including flooding as a result of major storm events and structural emergencies.

Downstream stakeholders are interested in the effects of any emergency at the dam. In many cases, this will be a natural flood event. In any flood situation, the downstream stakeholders must put into action the same resources, but the level of resources will depend on the severity of the flood—whether a major flood, passing of discharges through a spillway, or a dam breach. The trend in practice is toward producing ERPs and EPPs that cover the full range of flood management planning, rather than focussing on dam-breach scenarios alone.

If the dam owner limits the ERP to structural modes of failure, a separate flood action plan or additional details in the OMS Manual may be required. Response procedures for security threats may also need to be documented separately and confidentially.

Developing partnerships between the dam owner, key downstream stakeholders, and response agencies is a critical element in emergency planning.

Normal operating and surveillance procedures should be linked with the emergency response procedures. Procedures addressing the transition from "normal" to "emergency" situations may be covered in the OMS Manual, the ERP, the flood action plan, or all three. Documents should be clearly cross-referenced, and the instructions should be consistent.

The use of check sheets in the ERP is encouraged. Individuals in key roles would use the check sheets to document their actions. Actions should be listed in order of priority.

4.2.2 Activation of Plan and Initial Response

Immediately upon discovery of a hazardous condition with the potential to cause downstream flooding, operations staff should verify and assess the level of emergency, using predefined criteria to trigger the appropriate emergency response. Typically, three levels of response are defined, with increasing levels of urgency:

- *Hazardous condition or incident*—The hazard or incident does not pose an immediate danger but could develop into one.
- *Potential dam emergency*—Downstream agencies or communities may need to take steps to mitigate damage or prepare for evacuation.
- *Imminent or actual dam emergency*—Widespread evacuation of the downstream population is appropriate.

For a dam emergency, site staff should activate the on-site ERP, which will, depending on the level of emergency, direct them to do the following:

- Activate the site command post (SCP) at or near the dam to manage the response at the dam site.
- If required, activate the EOC.
- Begin notifications as per the fan-out procedures.
- Notify any residents below the dam as per the ERP downstream notifications table (as identified in a mutual aid agreement).

4.2.3 Contents of Emergency Response Plan

Emergency Identification and Evaluation

The ERP should contain clear procedures for taking action when a potential emergency that may lead to downstream flooding is identified. Such situations include

- Forecast of a major storm event
- Failure of essential equipment, such as floodgates
- Slope failure having the potential to cause dam failure

- Complete failure of the dam caused by overtopping, earthquakes, internal erosion or piping, or other causes

By their nature, ERPs are site-specific.

The ERP should include procedures for timely and reliable identification, evaluation, and classification of existing or potential emergencies. Some of the procedures may be provided in separate documents, such as OMS Manuals, in which case a clear cross-reference should be made. The related documents must be readily available as well.

These procedures should cover the following major elements:

- *Conditions or events that indicate an existing or potential emergency*—Situations involving a breach or other structural failure, as well as a major flood without a breach, should be listed. Flooding conditions could occur as a result of piping, natural floods, earthquakes, sabotage, or landslide-induced waves.
- *Means of identifying an existing or potential emergency*—The data and information collection system, monitoring and surveillance arrangements, inspection procedures, and other provisions for indicating an existing or potential emergency should be briefly described.
- *Procedures for assessing the severity and magnitude of an existing or potential emergency*—The procedures, aids, instructions, and provisions for interpreting information and data for an assessment of severity should be clearly outlined.
- *Designation of the person(s) responsible for identifying and evaluating the emergency and activating the ERP*—The owner or owner's representative would normally be designated. However, if they do not have sufficient technical expertise, responsibility may be assigned to another individual. Appropriate alternates should also be designated, to ensure continuous coverage.

Preventive and Remedial Action

Any preventive or remedial actions that have been identified should be clearly described. Preventive and remedial actions may involve the installation of equipment or the establishment of procedures for one or more of the following purposes:

- Preventing emergency conditions from developing, if possible
- Warning of the development of an emergency
- Facilitating the operation of the dam in an emergency
- Minimizing the damage resulting from an emergency

Warning systems based on downstream water level or flow measurement are often available. Data can be collected remotely and automatically transmitted to the owner's head office or control centres where decisions related to the emergency process can be made. For unattended high-consequence dams, strict inspection and surveillance routines should be in place to detect and respond to potential problems at an early stage.

Notification Procedures

In a dam emergency, site staff should activate the on-site ERP, which will, depending on the level of emergency, direct them to do the following:

- Activate the site command post (SCP) at or near the dam to manage the response at the dam site.
- If required, activate the EOC.
- Begin notifications according to the fan-out procedures.
- Notify any residents below the dam, following the downstream notification procedures in the ERP (as identified in any mutual aid agreements).

Notification procedures must be clear and easy to follow. The ERP should contain a list of all persons and agencies to be notified when a potential or imminent flood emergency is declared. The list should have the names and positions (titles), locations, and 24-hour telephone numbers of the owner's personnel and public officials, as well as alternate contacts.

For each type of emergency, the ERP should clearly indicate the criteria or trigger points for notification, who is to be called (listed in order of priority), and who is to make each call.

The number of persons to be notified by each responsible individual should be kept to a minimum. Site personnel are generally few and should not be expected to make many calls. In some cases the number of calls will be governed by other responsibilities assigned to the caller.

The following individuals or agencies, where applicable, should be considered for inclusion in the notification procedures:

- All local authorities within the floodplain
- Any agency that has a significant role to play in any emergency response
- Residents and property owners located immediately downstream and adjacent to the dam where available warning time is very limited (where local authorities could not be expected to respond in time, in which case a mutual aid agreement should be in place)
- Dam owner's personnel
- Owners of upstream and downstream dams or water-retention facilities
- Federal, provincial, and local agencies
- Managers and operations staff of recreation facilities immediately downstream or adjacent to the dam

The ERP should clearly identify how information is to be disseminated from the dam owner to the responders, the general public, and the media. The media should be utilized to the extent available and appropriate. Use of the news media should be pre-planned to the extent possible.

The ERP should include a notification flowchart, which is a pictorial representation of the notification procedure showing the hierarchy of notifications. The chart should provide names and positions (titles), 24-hour telephone numbers, and alternative contacts and means of communication (e.g., radio call numbers), summarizing the notification procedure for each of the emergency conditions considered. The flowchart should be easy to follow in an emergency and should normally be limited to one page.

If the downstream response is complex, the notification flowchart may contain only the functional hierarchy of responding agencies, with reference to more detailed contact information in an attached communications directory.

Site Access

Information on access to the site should be provided. The focus should be on primary and secondary routes, including bridges, and means for reaching the site under various conditions (e.g., foot, boat, helicopter, snowmobile). The ERP should cover response during periods of darkness, including those caused by power failure; and in adverse weather conditions, including extremes of cold, snow, or storms.

Communication Systems, Equipment, and Materials

Full details of internal and external communications systems as they apply to an emergency response should be included in the ERP.

Location and availability should be included for equipment, emergency power sources, contractors, and stockpiled materials that are critical to the emergency response.

Inundation Maps

Where appropriate, the ERP should include inundation maps for the areas covered by the plan. Inundation maps are usually produced using available topographical maps. They should indicate flood stages, flood and flood peak arrival times, and inundated areas.

Flood routing shown on inundation maps should typically be carried to a point beyond which flooding would no longer constitute a hazard to downstream life and property.

Clarity and simplicity are important attributes of the inundation maps and tables. Therefore, the map scale should be such that all important features can be identified by operations staff or the local authority with responsibility for warning or evacuation.

The accuracy of inundation maps produced from the outputs of dam-breach analysis is limited by the accuracy of the data used as inputs in that analysis. Valley cross-sectional data may be scarce and are often limited to accurate sections at the dam, at bridge crossings, at Water Survey of Canada gauging stations, and within towns and villages. Where maps have been produced for different flood delineations, these may be included in the ERP.

The analysis requires many assumptions, so the resulting maps should not be viewed in absolute terms. Data on maps will give the estimated maximum extent of flooding, flood depths, and time to peak flow values for planning and evacuation purposes. However, the maps may be subject to considerable error due to model uncertainties and assumptions.

Warning Systems

If warning systems are to be used to warn nearby residents, campgrounds, and parks, full details on procedures for issuing the warnings should be included in the ERP.

Additional Information

General site plans may be useful additions to the ERP. Drawings showing the potential breach location used in the inundation study may be included. Tables showing the variation in flood stage with time at key locations in the flooded area should also be considered.

4.3 Emergency Preparedness Plan

4.3.1 General

In cases where dam failure or passage of a major flood could be expected to result in loss of life, the dam owner should prepare and maintain an EPP for use by external agencies. In the EPP, the dam owner describes the hazards, the associated notifications to be issued, and in general terms the actions expected of other responders. The EPP is not a response document, but it should contain essential information, such as inundation maps and flood arrival details, so that local authorities can develop their own response plans. In the event of an emergency at the dam, the local authorities and other downstream stakeholders would be contacted, as shown on a fan-out notification chart, and asked to initiate their community emergency plans accordingly.

The EPP should be clear and simple and contain information needed by the other responders. To facilitate maintenance and updating, distribution of the EPP should generally be limited to those who have a legal and defined emergency response role.

Typically, provincial or local governments have the responsibility to warn residents of a hazardous situation, but these warnings are based on information provided by the dam owner or operations staff. Normally, provincial or local governments have their own emergency procedures that should incorporate the information in the EPP prepared by the dam owner.

In conjunction with the local authority, the owner or operations staff should assess whether flood warnings should be issued directly to inhabitants in areas immediately downstream of a dam, in addition to emergency response agencies, in the short period before the anticipated arrival of a flood wave. These types of situations require a formal mutual aid agreement between the dam owner and the local authority responsible for warning and evacuation.

An EPP should provide the basic information that allows for (*i*) planning by municipalities, Royal Canadian Mounted Police, local police, provincial agencies, telephone and transportation companies, and other parties that would be affected by a major flood; and (*ii*) coordination of efforts by federal, provincial, and municipal levels of government.

Development of an EPP requires communication between the dam owner and operations staff and other agencies and affected parties. The dam owner is responsible for plan development, which generally involves the following steps:

1. Identify those situations or events that would require initiation of an emergency action, and specify the actions to be taken and by whom.
2. Identify all jurisdictions, agencies, and individuals who will be involved in responding to an emergency, and draft a notification flowchart that shows who should be notified, in what order, and in general terms what other actions are expected of downstream agencies.
3. Develop a draft of the EPP.

4. Hold coordination meeting(s) with all parties on the notification list so that they can review and comment on the draft EPP.
5. Carry out an appropriate exercise based on the draft EPP and then revise the EPP on the basis of the lessons learned. (The dam owner should also review the internal ERP to incorporate any relevant lessons learned.)
6. Make final revisions.
7. Obtain necessary regulatory approval and then finalize and distribute the EPP.

In the event of an emergency, an effective, comprehensive, well-tested emergency planning process will save lives and have the potential to reduce adverse effects.

4.3.2 Contents of Emergency Preparedness Plan

Project Description and Effects of Inundation

The dam owner should be clearly identified, and the on-site person directly responsible for safety of the dam should be identified by position. General contact information, such as 24-hour telephone numbers, should be included.

The EPP should include a brief description of the dam and a map or figure showing the general arrangement or location of the dam. There should be an overview of a general nature, covering the timing and hazardous conditions likely to develop at various downstream reaches in a major dam-related or flood-related emergency. Local authorities and other key responders can then ensure that their local emergency plans include (*i*) a current, all-inclusive inventory of potential impacts to people and property within the floodplain in their jurisdiction; and (*ii*) the appropriate corresponding response procedures.

The effects of inundation should be shown on inundation maps that are based on the best estimate of the areas that would be affected. The approximate travel times and the river stages for the flood wave should also be given, particularly at locations of critical infrastructure.

Overview of Emergency Response Structure

The EPP should outline the emergency response structure (e.g., incident command model) so that responders will understand how the emergency operations centres (EOCs) are organized and should interact during an emergency.

Notification Procedures

The EPP should outline the procedures that will be followed when an emergency situation is identified. These procedures include activation of the ERP and EOC, as appropriate, and notification of responders. The EPP should provide a notification chart showing how the dam owner will notify all responders. There may be different charts for a potential flood emergency and an imminent flood emergency. The charts should show who contacts whom, in order of priority, by organization and position, but it need not include actual phone numbers. To reduce the need for continuous updating, comprehensive contact lists can reside in the ERP and applicable community or municipal plans. Holders of the EPP should inform the dam owner of any changes in responsibility and contact information, and the dam owner is responsible for keeping the chart current in each EPP.

The following are typical contacts that would be included in the EPP:

- Dam manager and operations staff (general enquiry or 24-hour telephone number)
- Corporate or head office (general phone numbers)
- EPP inquiries (phone number of the plan administrator)
- Provincial emergency management organization (24-hour emergency number)

Comprehensive fan-out phone lists for the responders are not required in the EPP. Each responsible party should keep up-to-date contact lists in their own emergency procedures.

The number of persons to be notified by each individual in the notification procedure should be kept to a minimum. The number of calls that can be made will in some cases be governed by other responsibilities assigned to the caller. Site personnel are generally few and should not be expected to make many calls.

The news media, including radio, television, and newspapers, should be utilized to the extent available and appropriate. Use of news media should be pre-planned to the extent possible by the dam owner and (or) public officials.

Inundation Maps

Maps should be provided showing areas that would be inundated if the dam failed rapidly when the reservoir was at full supply level. Information about major assumptions and the accuracy of inundation maps should be included in the text.

Administration and Maintenance Procedures

The EPP is a controlled document. This means that all copies are accounted for, and designated individuals are responsible for keeping the copies up to date. It is useful to include a distribution list and a record of revisions in the EPP.

The EPP should outline the procedures for review, revision, testing, and training so that copy holders understand their roles in the administration and maintenance process.

4.4 Municipal or Local Emergency Plans

The care and control of citizens and property rest with the local authority in most jurisdictions. Local authorities are generally required to prepare municipal or regional emergency plans with procedures for warning and evacuating residents living within floodplains.

Local authorities and other key responders should ensure that their emergency plans include an annex for responding to flood emergencies. This annex should include (*i*) a current, comprehensive inventory of potential impacts to people and property within the floodplains of their jurisdiction; and (*ii*) the appropriate corresponding response procedures. These processes should be linked to the information provided by the dam owner in the EPP.

4.5 Training, Testing, and Updating

Training should be provided to ensure that dam personnel and external responders are thoroughly familiar with all elements of the ERPs and EPPs.

Technically qualified personnel should be trained in problem detection and evaluation and appropriate remedial (emergency and non-emergency) measures. This training is essential for proper evaluation of developing situations at all levels of responsibility (initial evaluation is usually based on on-site observations. A sufficient number of people, including staff that may have a response role, should be trained to ensure adequate coverage at all times.

The dam owner is responsible for ensuring that the SCP and the EOC are functional and that staff is adequately trained. Municipalities and other responders are responsible for their own emergency centres.

Testing is an integral part of emergency preparedness, to ensure that both the documents and the training of involved parties are adequate. Tests can range from a limited tabletop exercise to a full-scale simulation of an emergency and can include multiple failures. Dam operations staff should coordinate and participate in joint periodic testing of the emergency procedures with downstream agencies and stakeholders. It is incumbent upon each responding agency to have adequate plans and trained staff in place to deal with any emergency within their jurisdiction.

The EPP should be issued to those key response agencies affected, and all registered copies should be updated on a regular basis.

As updates or amendments to the plans are produced, they should be forwarded to each holder and acknowledged by the recipient. Telephone numbers and names of contact persons should be updated regularly, at least annually. A list of document holders should be included in the respective plans.

The dam owner is responsible for updating the EPP and ERP annually or as deemed practical and the phone lists as necessary. Revisions should be issued to all affected agencies identified as document holders.

5. DAM SAFETY REVIEW

5.1 Introduction

A Dam Safety Review is a systematic review and evaluation of all aspects of design, construction, maintenance, operation, processes, and systems affecting a dam's safety, including the dam safety management system. The review defines and encompasses all components of the dam system under evaluation (including dam, spillway, foundation, abutments, reservoir, and tailraces). The evaluation should be based on current knowledge and standards, which may be different from the acceptable standards at the time of original construction or a prior Dam Safety Review.

The following sections discuss the qualifications and independence of the review engineer; suggest the frequency, scope, and content for a Dam Safety Review; and stress the need for follow-up on the findings.

5.2 Review Engineer

The Dam Safety Review should be carried out by a registered professional engineer (review engineer) or a multidisciplinary team of engineers reporting to the review engineer. These engineers should have a background in design, construction, performance analysis, and operation of dams. The terms of reference for the Dam Safety Review should identify who is accountable for the final review report.

The dam owner is ultimately responsible for dam safety, so it is the owner's responsibility to ensure that the findings of the review engineer will not be influenced by his or her prior participation in the design, construction, operation, maintenance, or inspection of the dam under review. It is advisable that the same review engineer not carry out two consecutive safety reviews of the same dam. This is consistent with the principle of having the review findings be independent of any conflict of interest, and it also encourages dam owners to benefit from a range of perspectives, which can lead to identification of previously undetected performance issues.

5.3 Frequency of Review

The frequency of Dam Safety Reviews should depend on the consequences of failure, the presence of or changes in external hazards, the results of surveillance, and the demonstrated performance.

For new dams, it is important that all design and construction records be preserved and catalogued for easy retrieval at the time of the Dam Safety Review. It is suggested that documentation be compiled as the design proceeds, to ensure that all dam safety aspects have been addressed and all relevant design documents have been referenced. This process could be considered a "design phase Dam Safety Review," and the documentation would also serve as a starting point for the first post-commissioning Dam Safety Review. It is important that as-built drawings be produced to show any changes made from the original design drawings, the reasons for the change, and any unusual site conditions observed during construction.

During the dam's operational life, any significant change that might affect its safety should trigger a Dam Safety Review or appropriate investigation. Significant changes include, but are not limited to, the following:

- Construction modifications to the original dam design
- Discovery of unusual conditions
- New dams on the river system
- New developments downstream of the dam
- New knowledge of safety analysis
- New standards of safety
- Extreme hydrologic or seismic events

A study and assessment of all hydrologic, environmental, and physical impacts should be undertaken when a dam is being considered for closure or decommissioning.

Tailings dams and their facilities can be evolving structures. Their construction may continue over the entire active life of the facility. If the consequences of failure change during the life of a structure, so, too, will the safety, operation, maintenance, and surveillance requirements and the appropriate frequency of Dam Safety Reviews. For tailing dams, an inspection and monitoring program may be undertaken for many years after closure, along with periodic reviews and assessment of the post-closure performance.

For all dams, as soon as one review is completed the date for the next review should be set. Suggested review frequencies based on consequence classification are shown in Table 5-1. If surveillance or other observations indicate abnormal performance, a review should be initiated sooner than indicated.

For owners with a portfolio of many dams, if it is necessary to prioritize Dam Safety Reviews among dams with similar classifications, consideration should be given to the performance of the dams and to any problems or issues that have emerged since the prior Dam Safety Review.

Table 5-1: Suggested Frequency for Dam Safety Reviews

Dam class	Frequency
Extreme	Every 5 years
Very high	Every 5 years
High	Every 7 years
Significant	Every 10 years
Low	— [note 1]

Note 1. A Dam Safety Review is not required for low-consequence dams. However, the consequences of failure should be reviewed periodically, since they may change with downstream development. If the classification increases, a Dam Safety Review is required at that time.

5.4 Scope and Content of Review

5.4.1 General

The scope of a Dam Safety Review may vary from dam to dam, depending on the consequence class and other circumstances. However, it should cover all aspects required to demonstrate that (*i*) the dam is safe, operated safely, and maintained in a safe condition; and (*ii*) surveillance is adequate to detect any developing safety problem. If safety cannot be demonstrated, the review engineer should identify the deficiencies. The review generally includes site inspection, review of all relevant documentation, and interviews with operating and maintenance staff. Records of any dam safety incidents since the previous review and records of follow-up actions should be reviewed. The flow discharge equipment should be tested at this time as well, unless it has been operated fairly recently, in which case records of the last operation and the performance records for the equipment should be reviewed.

The level of detail in the Dam Safety Review should be sufficient to demonstrate that the dam structure and its operation, maintenance, and surveillance meet the principles of these guidelines. The level of detail may be modified on the basis of previous assessments, complexity of the dam, continuity of surveillance and records, external and internal hazards, operating history, dam performance and age, and the need for public protection during operation.

After the first Dam Safety Review for a particular dam, subsequent reviews are normally less costly and time-consuming. During the first review all available data should have been assembled and supplemented with investigation and data gathering. Design analysis should have been carried out, deficiencies identified, and recommendations made for improvements. For this reason, subsequent periodic Dam Safety Reviews can be structured more as an audit of the previous information, ensuring that it is complete and up to date with current standards and that the conclusions reached and recommendations made were appropriate and remain valid.

Changes in status or condition from those described in previous reports should be noted, and trends should be determined. The extent that recommendations from previous reports have been implemented should also be determined. The review should utilize information developed in previous reviews to the extent that its reliability and validity can be verified.

5.4.2 Site Inspection and Staff Interviews

All Dam Safety Reviews should include a site visit so that the review engineer or review team can observe the actual condition of the dam system. The site inspection should include the dam itself, dam instrumentation, discharge facilities, outlet works, downstream areas that could be inundated by a hypothetical dam breach, reservoir, reservoir slopes, and water instrumentation (upstream and downstream water level gauges). The review engineer should note any debris accumulation upstream of the dam and potential for debris accumulation under high inflow conditions. The general stability of reservoir slopes and evidence of slides or instabilities should be assessed and noted. Depending on the area's geology and topography, a study of recent aerial photographs and a comparison with historic photographs, as well as a fly-over inspection, may be necessary.

If the dam is exposed to conditions other than those on the day of the site inspection, the effects of these conditions should be investigated by other means. For example, in regions of extreme winters, the review engineer should examine records and (or) photographs of the dam in winter conditions and assess ice formation and loading and any associated problems. Similarly the effects of other extreme climatic conditions should be assessed as appropriate. Reservoirs subject to significant operational drawdowns should be inspected with the reservoir full as well as under drawdown conditions.

The extent of the area that should be inspected downstream of a tailings dam will depend on the nature of the impounded fluids, the reservoir and basin characteristics, and the foundation conditions.

A meeting or interview with site staff is required to provide the review engineer with further information and insight into (*i*) operating and maintenance issues or incidents; (*ii*) staff conformance to procedures; (*iii*) operating authority under unusual conditions; (*iv*) equipment or system issues; (*v*) dam performance; (*vi*) the general level of training and knowledge of the staff; (*vii*) staff familiarity with the river system; (*viii*) the presence of other dams on the system, the nature of their operations, and any coordination or integration issues; (*ix*) any public safety issues; and (*x*) other stakeholders' interests.

5.4.3 Data and Records

A Dam Safety Review requires an understanding of the construction methodology, conditions, and practices used for the construction of that dam. Ideally, a complete set of records would be available for every existing dam. Record keeping should start at the early planning stage and continue throughout all phases of the dam's service life. The records should include the following:

- Reports from previous Dam Safety Reviews
- Any relevant information on planning, field investigations, laboratory testing, design decisions, construction and quality control, first reservoir filling, operation, maintenance, repair, and modernization or enlargement
- Design calculations
- Equipment specifications
- As-built documents
- Updated drawings
- Data from hydrological, structural (including seismic), and operational monitoring
- All safety inspection reports

The availability of such records will facilitate the periodic Dam Safety Review. In the case of unacceptable performance, recommendations can be based on updated knowledge of the dam's actual state of structural integrity in comparison with its past operational behaviour. A continuous set of design and service records provides a reliable basis for making decisions on dam safety improvements.

Following the site visit and review of records, the review engineer should prepare a list of information gaps and advise the dam owner of the assumptions that must be made to fill the gaps or the additional data that are required in order to proceed.

Above all, careful judgment, based on sound theoretical knowledge and broad experience, must be used for the analysis and correct interpretation of both primary and secondary (indirectly obtained) data. The Dam Safety Review report should state the origin of data used in the analysis and the assumptions that have been made.

5.4.4 Consequences of Dam Failure

During the Dam Safety Review, the potential consequences of dam failure are to be reviewed. The primary reasons for a change in the consequences are (*i*) new development in the floodplain downstream of the dam, which would increase the damage from dam failure; or (*ii*) identification of environmental or socioeconomic consequences previously unaccounted for. If the classification has not previously been determined, this is the time to do so.

5.4.5 Dam Safety Analysis

Safety analysis of the dam system should include the internal and external hazards, failure modes and effects, operating reliability, dam response, and emergency scenarios. The interaction of human factors, organization, and equipment and the potential for errors, misunderstandings, or misinterpretations should be examined. The designs should be reviewed to determine whether the dam, discharge facilities, and reservoir slopes meet applicable safety requirements. Although various features are reviewed individually, their interaction and function as a system should also be considered. The review of design as it relates to the present condition of the as-constructed, as-operated dam should include but not be limited to the following, as applicable:

- Construction records, to determine how closely the as-constructed dam conforms to design assumptions and intent; and to establish the adequacy of dam and foundation materials
- Adequacy of the derived extreme events, floods, and earthquakes for which the dam was designed, taking into account any extreme events that may have occurred since the commissioning of the dam
- Structural stability and seepage and erosion resistance of all portions of the constructed water barriers, including their foundation, as well as any natural water barriers under normal and extreme loading, including the effects of permafrost
- Capacity of all waterways and conduits to discharge their design flows safely, and the adequacy of these waterways to pass the inflow design flood (IDF) and to draw down the reservoir in an emergency
- Adequacy of design for all gates, valves, intake flow control equipment, and hoists, including controls, power supply, and winter heating criteria, to ensure timely, safe, and reliable operation (level of reliability needed for the flood discharge facilities depends on the repair time available between the start of an extreme flood and overtopping of the dam should the gates become inoperable; discharge facilities must function after an earthquake to maintain safe reservoir levels)
- Operating rules under various conditions and their conformance with design intent and criteria
- Adequacy of as-constructed facilities to deal with special phenomena affecting safety (such as debris, ice conditions, and erosion) that may have been insufficiently

considered at the time of design and construction, as well as verification that they will function as and when required
- Adequacy of design, construction, and operational features to address potential failure modes and criticality
- For tailings dams, tailings and water chemistry, tailings characteristics, and water balance

For dams in a cascade, the impacts of upstream dams on the dam under review should be examined. Similarly, impacts of the dam under review on any downstream dams should be identified. Dams on parallel river systems that might affect a single population should be examined in the same manner. Cooperative agreements and agreed operational restrictions in place should be reviewed and assessed. Owners of dams in cascade or on parallel systems with common areas of impact should coordinate with respect to operations, spill capacities, emergency response, and any other issue of mutual concern. In practice, this may be difficult to achieve, particularly if there is no regulation requiring that these dams be managed and operated safely, with consideration of the entire river regime, the limitations and characteristics of each dam, and their areas of impacts.

5.4.6 Operation, Maintenance, and Surveillance

The documentation of operation, maintenance, and surveillance, along with compliance, should be reviewed. The following questions should be considered, for example:

- Have safe operating procedures been developed, documented, and followed? Are there contingency plans for dealing with the failure of components?
- Are all facilities needed for dam safety, including precipitation and water level gauges, snow survey stations, and dam monitoring instrumentation, maintained in satisfactory condition in accordance with established procedures?
- Are the methods and frequency of surveillance and monitoring adequate to detect any unsafe condition in a timely manner? Have monitoring data been analyzed regularly and used to ensure prompt detection of any potentially unsafe conditions in the dam, associated water containments, or reservoir slopes?
- Are there adequate debris management procedures to ensure that debris does not block spillways or reduce their discharge capacity?
- Are ice management procedures in cold regions adequate to ensure that the spillways are not blocked by ice when they are needed?
- Are maintenance procedures and their frequency adequate for the dam and its components, including gates and other discharge facilities, power supply, cranes, motors and hoists, and foundation drains?
- Are there adequate vegetation control procedures?
- Is the flow control equipment maintained in good working order and tested regularly to ensure it will function reliably when called on to operate?
- Are incidences of malfunction promptly reported, investigated, and addressed to prevent recurrence?
- Is the backup equipment (such as alternative power supplies) that is called for in the contingency plans available and readily accessible?

The review engineer can assess compliance with the documented procedures by auditing the operation, maintenance, and surveillance records, having discussions with site personnel, and judging the state of maintenance and site conditions during the site visit.

The Dam Safety Review should address the testing of equipment required to operate discharge facilities (including backup equipment and emergency power supply) needed for safe passage of the IDF and any other flood that could endanger the dam. If the discharge gates and equipment have been tested or operated within a year and adequate documentation is available, a review of such testing or operation records may be adequate. Otherwise, the testing can be carried out during the Dam Safety Review.

5.4.7 Emergency Preparedness

The emergency preparedness plans and emergency response procedures must be reviewed. The Dam Safety Review should determine answers to the following questions:

- Is emergency preparedness at an appropriate level and adequately documented?
- Are the warning systems, training, and emergency response plans adequate?
- Is the frequency of testing appropriate?
- Are there processes in place for document control?
- Are the notification lists maintained? Is there a robust process in place to keep them updated and communicated, especially for external contacts?
- Are findings and lessons learned from incidents or emergency drills properly documented and followed up within a reasonable time?

5.4.8 Public Safety and Security

The review engineer should verify that public safety hazards at the dam have been identified and addressed and that a management plan has been established to ensure the public safety measures are periodically reviewed, inspected, and maintained.

Some dams, in view of their size, location, and purpose, as well as the consequences of their failure, can be considered critical infrastructure that merits special security measures. In the Dam Safety Review of such dams, the review engineer should verify that such special measures are in place.

The review engineer should verify that operating equipment is secured against vandalism or operation by unauthorized individuals and that the dam management process ensures that any vandalism or breach of security is discovered and addressed promptly.

5.4.9 Dam Safety Management System

The effectiveness of the dam safety management system should be included in the review. Key elements of the management system are policy development, planning, implementation of procedures, checking, corrective action, and reporting. Indications of effectiveness include the following:

- Roles, responsibilities, and authorities are clearly assigned.
- Key activities are clearly assigned.
- Personnel understand their roles and responsibilities.

- Operation, maintenance, and surveillance activities are carried out and documented.
- Incidents are reported and addressed.
- Safety measures recommended in previous Dam Safety Review reports have been carried out.

5.5 Dam Safety Review Report

At the completion of the Dam Safety Review, the review engineer should present the dam owner with a formal report containing the conclusions of the review and recommendations that will help the owner fulfill the responsibility for dam safety and comply with regulations. This report should

- Document the review
- Quantify deficiencies in the structures
- Draw attention to any non-compliance with policies, guidelines, or standards and to any other issues requiring follow-up so that priorities can be readily established for safety improvement, remedial measures, or additional investigations
- Identify any additional steps needed for safe operation, proper maintenance, and adequate surveillance of the dam
- Report on information gaps in past documentation, identify potential deficiencies, and suggest further actions or investigations that may be needed to confirm conformance with dam safety requirements

The initial methods of analysis used in the review, or the data available, may be insufficient to clearly demonstrate an acceptable level of safety for the dam, discharge facilities, or reservoir slopes. If additional work is needed to evaluate and document dam safety, the Dam Safety Review report should include recommendations for more extensive analysis or investigations to provide adequate data for analysis.

Therefore, the essential output of the safety review is one or more of the following conclusions:

- The dam clearly meets all safety requirements.
- The dam clearly does not meet some safety requirements (list the deficiencies or non-conformances and recommended actions).
- It is uncertain whether or not some requirements are met (list the areas of doubt and the actions needed to reach a firm position).

It is the responsibility of the dam owner to review the Dam Safety Review report, forward it to the appropriate regulator, if required, and make management decisions on the follow-up actions to meet the owner's responsibility for dam safety.

6. ANALYSIS AND ASSESSMENT

6.1 Introduction

Dam safety calls for safe design, construction, operation, and maintenance that adhere to regulations and recognized practices. However, the *level of safety* cannot easily be measured using traditional methods. Specific methods, standards, and procedures have been adopted with the expectation that, in following the prescribed approach, the desired safety objective will be achieved although the level of protection is still not actually known.

Safety management is ultimately concerned with management of risk and should provide answers to the following questions:

1. What can go wrong?
2. What is the likelihood (probability) of it happening?
3. If it occurs, what are the possible consequences?

To understand how the structures are expected to perform and what level of deviation from the normal condition is tolerable, dam safety analyses should consider the full range of applicable conditions. Design, construction, and operation should all be considered in the analysis to ensure that the intent of the design has been achieved.

A formal risk assessment is a structured and systematic method for understanding possible outcomes, impacts of interactions, and areas of importance and uncertainty. In the traditional approach to dam safety management, regulations and standards are largely based on **deterministic** concepts of reliability. The likelihood of hazard occurrence is explicitly addressed only for floods and earthquakes, whereas other adverse events or elements of outside influence are introduced through selection of initiating events and consequence scenarios. *2013 Revision*

The traditional approach and the risk-informed approach complement each other to a degree, in that the overall objective in both cases is to ensure that the "dam is safe" to the extent reasonably and practicably achievable, given the limitations of each approach. In general, all dam safety assessment is carried out in the context of risk, with proven deterministic practices being used to varying degrees to reduce the analytical burden associated with **probabilistic** methods and to support decisions when quantifiable risk values are unattainable. The information required for a deterministic assessment is also used in a probabilistic assessment. In the latter, additional information and more complex analyses are introduced to simultaneously account for uncertainties in the models and in the physical processes affecting the dam. The probabilistic approach can be used to validate deterministic results and calculate more precise results where the data are available. Thus, within the constraints of practicality, a probabilistic assessment can provide an improved basis for decision-making that balances social and other benefits and the residual risks of an endeavour.

The two approaches to dam safety decision-making are outlined below. It should be noted that the setting of minimum safety levels should be a matter of public policy and regulation. Engineering analyses and assessments are used to confirm and demonstrate compliance or to develop alternative measures to meet the identified requirements.

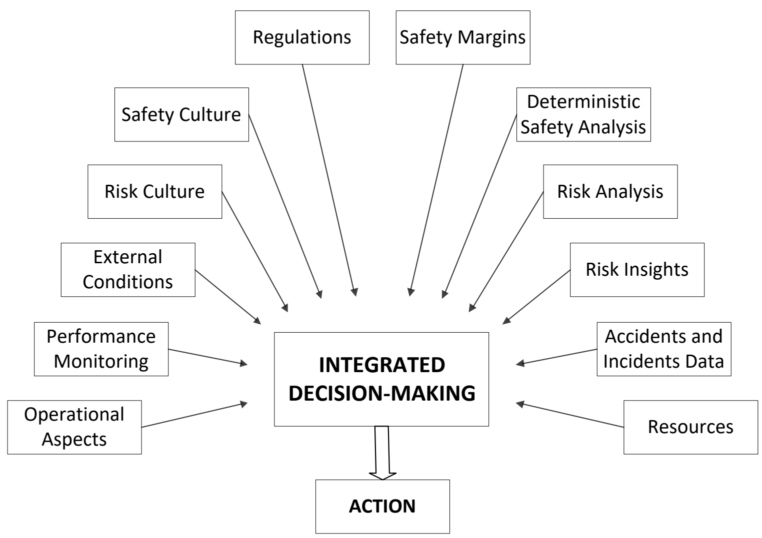
6.2 Risk-Informed Approach

Risk, understood as a measure characterizing both the likelihood of an undesired event and the consequences of such an event, can be used as a performance goal to demonstrate that required levels of safety are met. In the context of dam safety, the undesired events might include, for example, internal erosion; failure of the flow control equipment, remote controls, and monitoring; or human error.

In view of the large uncertainties involved with dam engineering, a risk-informed approach to dam safety assessments is encouraged. Such an approach includes traditional deterministic standards-based analysis as one of many considerations, as shown in Figure 6-1. *2013 Revision*

Figure 6-1: Integrated (Risk-Informed) Decision-Making

[Source: Bulletin 154, ICOLD 2011]



Quantitative risk assessment seeks to provide a complete mathematical description of the uncertainty in the calculated estimates of risk. The use of quantified risk methodologies is preferable for appropriate situations where the scientific techniques are available. However, determination of the probability of failure is a complex task that is not readily accomplished with the current state of knowledge.

Qualitative risk assessment characterizes uncertainty in non-mathematical form and uses schemes for indexing, scoring, and ranking risk factors.

The concept of tolerability of risk is fundamentally a matter of political choices, preferences and policies. The emerging view is that risk and uncertainty, as essential factors that have to be considered in the dam safety decision-making process, should be explicitly included and expressed. The decision-making processes should be logical, consistent, and capable of clearly identifying the trade-offs between economic efficiency and social equity.

The overall dam safety framework should ensure that no individuals or communities are unduly affected in the interest of the broader societal interests. On the other hand, society does not have infinite resources to spend on managing risks and often the resource spent inefficiently in one area is the same resource that is missing in another area where investment could be more beneficial. Effective application of the balanced equity-efficiency approach requires acknowledgment that both economic efficiency and social equity are legitimate goals that society wants to pursue.

One effective way to address individual and societal concerns about the hazards posed by dams is by characterization in terms of risk and derivation of tolerability criteria.

- *Individual risk* relates to concerns of how individuals see the risk from a particular hazard affecting them and their property. It is usually defined as the risk to a hypothetical member of the public living in the zone that can be affected in the event that a hazard occurs. The criteria for individual risk depend on such factors as whether or not the exposure is voluntary, whether the individual derives benefit from accepting the risk, whether the individual has some control over the risk, and whether the risk engenders particular dread.
- *Societal risk* generally refers to hazards that, if realized, could impact society and thus cause socio-political response. Societal risk may be seen as a relationship between the frequency of a particular hazard and the number of casualties if the hazard is realized. In applications dealing with hazards from engineered installations where the predominant issue is life safety, societal risk is characterized by graphs showing frequency of events that could cause multiple fatalities.

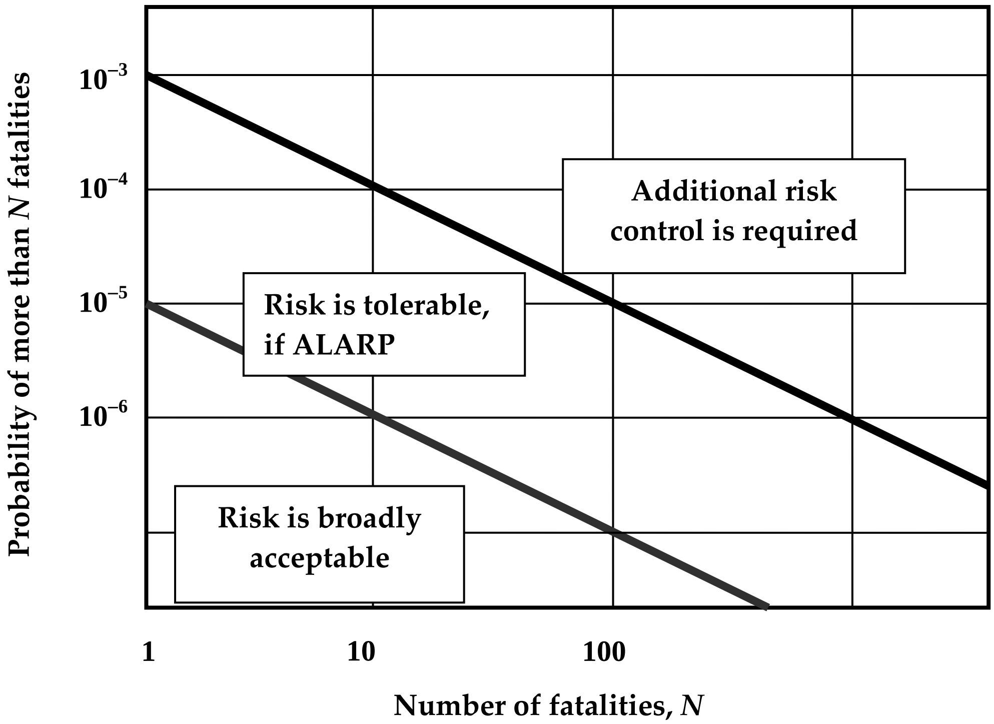
Risk assessment for dam safety should consider the approach as shown in Figure 6-2, which presents life safety risk guidelines that are consistent with values used in other hazardous industries and with the principle that risks should be made as low as reasonably practicable (ALARP). *2013 Revision*

Figure 6-2 is based on the premise that the maximum level of societal risk for life safety should be such that the annual probability of loss of N or more lives should be less than $\frac{1}{N}10^{-3}$ for loss of lives that were not explicitly foreseen and identified in advance of the failure; a higher risk is considered "unacceptable". The high societal aversion to catastrophic casualties should be reflected in setting the maximum performance goal in cases where more than 100 lives would be jeopardized. The risks should be made as low as reasonably practicable until they fall within a "broadly acceptable" region that is set 100 times lower.

An action to reduce the risk is clearly necessary if the risk is not acceptable. The ALARP principle is based on the duty to reduce risks to life to the point where further risk reduction is impracticable or requires action that is grossly disproportionate in time, trouble, and effort to the reduction of risk achieved.

2013 Revision

Figure 6-2: Example Societal Risk Levels for Dam Safety



In engineering applications, risk usually means a combination of the probability and the adverse consequences of an event. If this combination is expressed as the product of probability and consequences, it simply represents the probabilistic expectation (expected value) of the consequences.

Quantitative estimates of the risk (probabilities and consequences of possible adverse events) can be used as indicators of safety levels achieved and may be compared with specific safety goals also expressed in probabilistic terms. A probabilistic safety goal is usually expressed in terms of the annual probability of an adverse event and the associated consequences. A flood characterized by a peak daily inflow with a certain return period (frequency of occurrence, or probability of exceedance) is an example. Such defined safety goals can be subsequently used as a design or operational objective and interpreted as a desirable target for establishing reliable performance of safety. The selection of safety goals can either be based on arbitrary criteria or be established within the broader context of societal and individual tolerance/acceptance of risk.

In addition to accounting for societal risk in dam safety decisions, the individual risk should be considered in terms of the "maximally exposed individual" that is permanently resident downstream of the dam. Typically the maximally exposed individual is exposed to the hazard significantly more than 50% of the time. The maximum level of individual risk is generally given as less than 10^{-4}/year.

In order to calculate the risk to the individual, probabilistic methods must be available to quantify each factor in the following equation to calculate the probability of loss of life (P_{LOL}) for the maximally exposed individual.

$$P_{LOL} = P_{Event} \; x \; P_{Failure/Event} \; x \; P_{Fatality/Failure}$$

where	P_{LOL}	=	Unconditional probability of fatality for maximally exposed individual from a hazardous event
	P_{Event}	=	Unconditional probability that a hazardous event of specified type and magnitude range will occur
	$P_{Failure/Event}$	=	Conditional probability that the dam will actually fail, given the event
	$P_{Fatality/Failure}$	=	Conditional probability of loss of life, given dam failure

The risks calculated by the above formula need to be aggregated over all dam failure initiating events in order to obtain the total risk to the individual.

The conditional probabilities $P_{Failure/Event}$ that dams will fail, given an event, vary widely depending on the failure modes and the nature of the loadings. The actual value for a particular dam and event is often difficult to determine precisely. Hence, in some cases where no additional information is available, valid dam safety decisions can often be made on the basis of relatively simple analyses by making the very conservative assumptions that $P_{Failure/Event} = 1$ and $P_{Fatality/Failure} = 1$. For example, these conservative and necessary assumptions are applicable to flood events resulting in major overtopping of unprotected earth embankments.

The general risk analysis and assessment approach is an appropriate framework for dam safety management. Although our current ability to reliably quantify risk is limited, the approach has considerable benefits in providing well-defined and justifiable safety targets (performance goals).

In terms of the risk informed approach described here, the dam owner is expected to demonstrate that the resulting level of risk is justifiable and that the safety management of the dam conforms to the Principles of these Guidelines.

Table 6-1A presents minimum initial target frequency levels for the flood and earthquake hazards, for use in load-resistance performance analyses based on historic frequencies. The frequency levels given in the table are based on the expected loss of life and assume that the hazard would actually induce failure. The onus is on the owner to demonstrate that the assumption, that the fragility is 1, is overly conservative and suitable levels of societal risk will be achieved at a lesser hazard if the fragility is properly considered. A comprehensive risk analysis will address the uncertainties in the risk analyses. The maximum performance capacities to withstand flood and earthquake hazards, derived from a risk analysis, might be loosely compared to those achieved through the standards-based approach.

This table addresses only loss of life considerations. Similar targets should be developed for other consequences of dam failure, such as environmental, economic and cultural losses.

2013 Revision

Table 6-1A: Flood and Earthquake Hazards, Risk-Informed Approach

(Target Levels for Initial Consideration and Consultation between Owner and Regulator)

Dam Class [note 1]	**Minimum Annual Exceedance Probability (AEP) of the Natural Hazard** [note 2]	**Societal Risk Target**
Low	1/100	
Significant	1/1000	
High	1/2475	$(1/N)x10^{-3}$ [note 3]
Very High	1/10,000	$(1/N)x10^{-3}$ [note 3]
Extreme		$(1/N)x10^{-3}$ [note 3]

This table addresses two major natural hazards only, and does not consider the many other types of hazards that must be considered in dam safety assessments

Acronyms: AEP, annual exceedance probability; N, number of fatalities

Note 1. As defined in Dam Classification (Section 2.5.4).

Note 2. AEP levels for floods and earthquakes are the mean estimates of the hazard.

Note 3. Simple extrapolation of flood statistics beyond 10^{-3} AEP is not acceptable. The given AEP values should be based on detailed probabilistic assessments and definition of uncertainty bounds. Results should be compared against Probable Maximum Flood and Maximum Credible Earthquake values and their associated uncertainty (where available).

6.3 Traditional Standards-Based Approach

Established practice in safety assessment of dams relies mainly on a **standards-based approach**, a deterministic concept, largely because it is computationally straightforward; provides the reassurance of a well-known method; and uses numerical measures, such as safety factors. The deterministic approach requires the determination of stability or stress state for a critical region in the dam or its foundation. These states are typically analyzed for a set of usual, unusual, and extreme load combinations. The deterministic loads and resulting stresses are then related to the deterministic ultimate stability and failure criteria. The quantitative definitions of the factors of safety are determined primarily by empirical evidence, experience, and engineering judgment.

A deterministic design or assessment of unique structures is typically based on either (*i*) worst-case values for the input variables or (*ii*) nominal values with a safety factor applied to the result. Thus, the approach accounts for uncertainty by

- Assuming conservative (extreme) values for the loads
- Assuming conservative (safe) values for resistance variables
- Applying conservative safety factors

The usual (normal), unusual, and extreme cases can be considered from the perspective of exceedance probability. The most critical loads—seismic and hydrologic—are to some extent characterized on the basis of statistics, reliability theory, and probability. In this way, the *deterministic* approach has been gradually transformed to a *semi-probabilistic* concept. The calibration and numerous simplifications introduced in the final format of a standards-based procedure are often hidden in the background, and thus the deterministic method may be called prescriptive.

It should be noted that a particular factor of safety is physically meaningful only with respect to given design assumptions and equations. Engineering guidelines or regulations may provide precise instructions for calculation of the factor of safety. This ensures a certain uniformity of approach on the part of different designers. However, practising engineers must have a full understanding of the actual reliability assessment methods and meanings of factors used to express the safety, durability, and serviceability of structural components.

The actual probability of failure and the reserves in structural capacity cannot be explicitly evaluated by using a deterministic approach. The risks are managed implicitly, often by application of a classification scheme that reflects potential consequences of dam failure. Table 6-1B suggests values for the inflow design flood (IDF) and the design earthquake based on the traditional deterministic approach to dam safety assessment.

2013 Revision

Table 6-1B defines frequency-based target levels for some consequence categories, and deterministically derived target levels for other categories, similar to the corresponding table in the 2007 Dam Safety Guidelines. This table is based on the concept of assuring safety up to the physical limits of inflow or earthquake events (which the PMF and MCE attempt to approximate). As these events are considered to be at the maximum physical limits of nature, they approach a zero probability of occurrence and have undefined uncertainty with respect to their magnitude, resulting in their being of limited value in the assessment of dam safety risks. Further, their use may create a false sense that safety has been achieved under the ultimate natural loadings.

In essence, a deterministic approach does not account for the fact that there is considerable uncertainty regarding both the load intensities and the ability of the dam to resist given loads. The approach does take into account the probability of failure of a structural component exposed to variable load combinations in which one might consider the contributions of variable yield stress, variable geometrical properties, and random imperfections. However, this is carried out implicitly without any formal analysis or quantifiable information on probabilities involved. For these reasons, the **annual exceedance probability** (AEP) values for earthquakes in Table 6-1B applicable to the high, very high, and extreme classes have to be justified, to demonstrate that they conform to societal norms of acceptable risk. This justification can be provided with the help of failure modes analysis for the dam focused on the particular modes that can contribute to failure initiated by a seismic event.

Despite the shortcomings discussed above, the traditional deterministic methods have generally been very successful. They remain essential methods of dam design and dam safety management, even as emerging risk-informed approaches are introduced to provide insight into uncertainties and to improve interaction between engineers and decision-makers.

As with the risk-informed approach, when the standards-based approach is used, the dam owner is expected to demonstrate that the resulting level of risk is justifiable and that the safety management of the dam conforms to the Principles of these Guidelines.

2013 Revision

Table 6-1B: Flood and Earthquake Hazards, Standards-Based Assessments

(Target Levels for Initial Consideration and Consultation between Owner and Regulator)

Dam Class [note 1]	**Annual Exceedance Probability – Floods** [note 2]	**Annual Exceedance Probability - Earthquakes** [note 3]
Low	1/100	1/100
Significant	Between 1/100 and 1/1000 [note 4]	Between 1/100 and 1/1000
High	1/3 between 1/1000 and PMF [note 5]	1/2475 [note 6]
Very High	2/3 between 1/1000 and PMF [note 5]	1/2 between 1/2475 [note 6] and 1/10,000 or MCE [note 5]
Extreme	PMF [note 5]	1/10,000 or MCE [note 5]
This table addresses two major natural hazards only, and does not consider the many other types of hazard that must be considered in dam safety assessments.		

Acronyms: PMF, probable maximum flood; AEP, annual exceedance probability; MCE, maximum credible earthquake

Note 1. As defined in Table 2-1, Dam Classification (Section 2.5.4)

Note 2. Simple extrapolation of flood statistics beyond 10^{-3} AEP is not acceptable.

Note 3. Mean values of the estimated range in AEP levels for earthquakes should be used. The earthquake(s) with the AEP as defined in Table 6-1B is then input as the contributory earthquake(s) to develop the Earthquake Design Ground Motion (EDGM) parameters as described in Section 6.5 of these guidelines.

Note 4. Selected on basis of incremental flood analysis, exposure, and consequences of failure

Note 5. PMF and MCE have no associated AEP.

Note 6. This level has been selected for consistency with seismic design levels given in the National Building Code of Canada.

6.4 Hydrotechnical

Hydrological safety hazards include extreme rainfall and snowmelt events that can lead to natural floods of variable magnitude. The maximum flood for which the dam is to be designed or evaluated is termed the inflow design flood (IDF); the IDF should be selected on the basis of the potential consequences of failure. Table 6-1 suggests IDFs that could be used in dam design and assessment to provide appropriate levels of protection against dam-breach inundation downstream.

Statistical Flood Analysis

Statistical analysis is required for estimating the flood peaks and volumes associated with a range of **annual exceedance probabilities** (AEPs). In addition to the peaks, the volumes and the associated hydrographs for the floods of interest are usually required for reservoir routing or dam-breach and downstream channel routing. This analysis is done on a seasonal basis and is of greater significance for storage reservoirs that have large fluctuations in water levels and are designed to capture spring runoff. For run-of-the-river facilities, only the peak annual flood is usually required.

Flood statistics are subject to a wide margin of uncertainty, which should be taken into account in decision-making. In particular, the following should be noted:

- Results obtained may vary significantly from one statistical distribution to another, and no reliable method exists for the selection of the most appropriate distribution. This task relies entirely on the hydrologist's judgment.
- The evaluation of the highest floods on record often depends on the extrapolation of the rating curve at the station, which may be subject to a large degree of uncertainty.
- Beyond an AEP in the order of 1/500 year, statistics give only an "order of magnitude" estimate. For the purpose of flood evaluation in the dam safety process, extrapolation beyond the 1/1000 year flood is discouraged.
- Evaluation of the confidence limits on the statistical estimate is recommended.

Probable Maximum Flood

Extreme floods, including the **probable maximum flood** (PMF), are normally evaluated by deterministic methods that maximize the various factors contributing to the generation of a flood. The PMF is defined as the most severe flood that may reasonably be expected to occur at a particular location. The PMF is generated by the probable maximum precipitation (PMP), which is calculated in the following three steps:

1. Compile and analyze all major storms that have occurred over the basin under study or that could have occurred over it with a shift of storm track.
2. Determine the maximum air moisture that may be expected to prevail for the date of the occurrence of the storm.
3. Maximize the amount of precipitation from the storm by the ratio of the maximum air moisture (as derived above) to the moisture that prevailed when the storm occurred. For basins located in mountainous areas, it is necessary to distinguish between the amount of precipitation due to convergence (air mass effects) and the amount due to orography (topographical barriers).

The sequence of calculations leading to determination of the PMF is generally as follows:

1. Determine PMP on the basin.
2. Determine rainfall and snow accumulation statistics over the basin.
3. Establish a rainfall–runoff model of the basin based on historic rainfall and runoff data.
4. Define initial conditions on the basin that prevail when the PMP occurs. These conditions should be such that the soil moisture is at a maximum.
5. Compute PMF with the rainfall–runoff model, using established PMP and initial conditions.

Two PMFs are computed:

- The summer–autumn PMF, which is generated by the summer–autumn PMP
- The spring PMF, which is defined as the maximum of the following two cases:
  - PMF computed with spring PMP and snow accumulation with frequency of 1/100 year
  - PMF computed with probable maximum snow accumulation and rainstorm with frequency of 1/100 year

The reason for computing two separate PMFs for the spring season is that it would not be reasonable to assume that snow accumulation and a spring rainstorm, which are two independent phenomena, are simultaneously extreme.

Freeboard

The freeboard at all structures should be evaluated for normal and extreme conditions. It should exceed the minimum required freeboard established to minimize the probability of dam overtopping by waves. Additional freeboard or provision for overtopping may be required for dams with reservoirs subject to landslide-induced waves.

The minimum specified freeboard depends on the type of structure. Criteria are more stringent for embankment structures, which are more likely to fail from overtopping, than for concrete or other rigid structures that can withstand some overtopping without serious damage. For an embankment structure, the crest level should be set so that the structure is protected against the most critical of the following cases:

- No overtopping by 95% of the waves caused by the most critical wind with a frequency of 1/1000 year when the reservoir is at its maximum normal elevation
- No overtopping by 95% of the waves caused by the most critical wind when the reservoir is at its maximum extreme level during the passage of the IDF

The most critical wind for the latter case depends on the consequence class of the dam. Suggested AEP values of wind frequency used for calculation of freeboard during IDF are as follows:

Low consequence dam	AEP = 1/100
Significant consequence dam	AEP = 1/10
High, very high, or extreme consequence dam	AEP = 1/2

In addition, the maximum still-water level of the reservoir should be maintained at all times below the top of the impervious core, unless analysis can demonstrate that temporary exceedance of the top of the core does not endanger the dam. The thickness of the material covering the impervious core of the dam or dyke should be sufficient to prevent freezing of the core in winter. Some tailings dams that rely on an extended beach zone rather than an impervious core for seepage control are an exception to this guideline.

For concrete dams or other rigid structures with abutments that are resistant to erosion, the freeboard can be based on an economic analysis of damage, provided that safe access to the water control structures is maintained at all times.

Spillway and Other Flow Control Structures

The ability to safely route floods through a reservoir system is of paramount importance for dam safety. Flow control structures include the service and auxiliary spillways, low-level outlets, and other outflow structures. The following points should be considered:

- The design capacity of the structures, including resistance to uplift, cavitation, and erosion, should be correctly evaluated. Model testing may be appropriate.
- The channels leading to the flow control facilities should not be obstructed by floating debris, ice, or landslides during passage of the flood.
- Water conveyance structures downstream from the flow control sections, including energy dissipation structures, are integral parts of the flow control system. They should be designed to perform their function without being damaged, at least up to the IDF capacity.

- The flow control equipment must be operational at the most critical moment during a flood (or after an earthquake, if applicable).
- The discharge facilities should be capable of passing the IDF, taking into account the routing effect of the reservoir, without infringing on the minimum freeboard requirements.
- Proper operating rules should be available for all floods up to the IDF and should be well understood by the operating staff.
- Unless it can be clearly demonstrated that outlet works or hydropower stations can be operated reliably during flood events, the discharge capacity of these structures should not be included in calculations of the discharge capacity during floods.
- Safe access and a secure power supply to control structures should be maintained at all times.

Flood Operating Rules

Reservoir operating rules consist of a set of specified maximum and minimum levels to be maintained at specified dates in the year. If a large inflow (that is, flood) occurs, outflow structures need to be operated to maintain the reservoir level within the levels specified for that date by the operating rules. These rules should be defined in such a way that the operator increases and decreases the project outflows in response to observed monitoring data such as reservoir rise, climate data that correlates to near term reservoir inflow, or other relevant real-time observed data. The rule curves should not be prescribed in a manner that requires the operator to guess the magnitude of the incoming flood, because, unless sophisticated flood forecasting is available, there is no way to know in advance the exact magnitude of an incoming flood. The best that can be known about the incoming flood is that it will be a large one if observed rainfall and snow accumulation are greater than usual. When developing rule curves, the following flood operating rules should be observed:

- The minimum freeboard at the dam should be reached only if the incoming flood is the IDF.
- Whatever the magnitude of the flood that actually occurs, and regardless of what was forecasted or anticipated, the resulting reservoir level after the passage of the flood should be in the range of levels normally observed for that time of the year.

Reservoir management during emergencies should be documented in operations procedures and emergency plans, as appropriate.

Under some circumstances, it may be good practice to spill before the arrival of an anticipated large flood. However, such an operation should be based on inflow forecasting information and an understanding of the potential consequences.

Ice and Debris

Reservoir ice or ice and debris carried by the river to a run-of-the-river project could create a hazardous situation. The extent of the hazard would depend on the amount and thickness of ice and the characteristics of the dam and discharge facilities. Damage could be caused by the forces generated on concrete structures by thermal expansion of the ice cover or by the removal or modification of riprap protection of an embankment dam.

Ice can also interfere with the operation of gates or valves, and proper precautions must be taken to ensure sufficient spilling capacity is available during cold periods, either by heating some gates or by adequate design.

At breakup, reservoir ice floes may generate dynamic forces on concrete dams or spillway piers. Flowing ice may create jams at control structures and significantly reduce their capacity. Ice sticking on the crest of free overflow weirs may reduce the capacity of those weirs at breakup.

Debris may consist of various materials that can jam spillway bay openings and outlet structures. Debris may also significantly reduce or impede spillway and gate operation.

Log booms should be installed to keep the floating debris from reaching discharge facilities, or proper design should ensure that debris can be safely passed through the structures. Ideally, any significant amount of debris on a reservoir should be removed periodically.

6.5 Seismic

Safety analysis of existing dams and design of new dams for seismic (earthquake) loads is standard practice. Because of differences in methodology for seismic safety evaluation and differences in performance criteria, seismic loadings in local building codes do not apply to dams and associated appurtenant structures. The seismic zoning maps generated for the National Building Code of Canada are specifically provided for the seismic design of common buildings only, such as powerhouses.

Damage to dams and their appurtenant facilities can result from (*i*) shaking caused by an earthquake; (*ii*) liquefaction, settlement, cracking, or displacements induced by shaking; or in extreme cases (*iii*) surface rupture along the fault that caused the earthquake. Damage can result from ground motions induced at the dam site by an earthquake whose epicentre is located at some distance from the site. Hence, the seismic loading for designing new dams or evaluating existing ones is determined by the intensity of ground shaking expected at the dam site and is not strictly governed by the magnitude of the earthquake alone.

To fully characterize the required seismic design parameters, the level of earthquake ground motion at the location of the dam for which the dam or other structure is designed or evaluated is defined here as the **earthquake design ground motion** (EDGM).

The consequences associated with the partial damage or collapse of dams may increase as earthquake intensity increases. In principle, the design criteria must consider the desired level of safety and the nature of the design and evaluation procedures. Following a traditional standards-based approach to dam safety assessment, the EDGM should be selected on the basis of the consequences of dam failure; suggested values are provided in Table 6-1.

To arrive at the appropriate EDGM parameters for a specific site, a seismic hazard assessment must be conducted. Seismic hazard is to be evaluated on the basis of current knowledge and standards, which may often be different from the acceptable standards or practices at the time of original design. The seismic hazard assessment should be based on both (*i*) local and regional geotectonic information; and (*ii*) a statistical analysis of historical earthquakes experienced in the region, taking into account all potential seismic sources capable of contributing significantly to the seismic hazard at the site.

Surface fault displacement is not typically encountered in Canadian practice, as most of the seismically active areas in Canada lack direct correlations with well-defined active or likely active faults. Therefore, seismic hazard assessment in Canada is generally based on a probabilistic approach, although a deterministic approach is not precluded if sufficient seismotectonic information is available.

Ground motion attenuation relations appropriate to both the region and the types of seismic sources in the region should be evaluated and applied in the seismic hazard assessment. Sources of uncertainty, including seismic source models, magnitude recurrence rates, and attenuation relations, should be assessed to quantitatively evaluate their impact on estimated ground motions.

Effects of local subsurface conditions should also be taken into account, either in the seismic hazard assessment or in an analysis of the structure subjected to the ground motions.

It must be recognized that the national hazard results generated for the National Building Code are not site-specific, since little or no attention was paid to local factors or to uncertainty in the tectonic setting, except for major urban areas. As a result, the results may be unconservative for remote sites, where most dams are located. Furthermore, they represent only the median hazard value, whereas the mean (expected) hazard value is recommended for typical seismic hazard computations for dam design.

The parameters defining the seismic loading for dam safety analysis depend on the type of dam; the possible failure modes or performance requirements for the dam; and the selected analytical methods, such as time history, response spectrum, or pseudo-static.

Typically, the EDGM parameters are to be described in terms of acceleration response spectra, peak ground motion parameters, earthquake magnitude and distance, time histories, and foundation fault displacement (if applicable). The selected ground motions will represent the best estimate (the mean) of ground motions for the specified AEP.

The ground motion estimated by hazard analysis for a specific probability level fundamentally represents a composite of contributions to the hazard from earthquakes of all magnitudes at all distances (rather than a single design earthquake). For engineering application, input ground motions of one or more of the predominant and most likely "scenario earthquakes" that contribute strongly to the seismic hazard may be required. In this case, the seismic hazard should be disaggregated to identify the relative contributions of various magnitudes and distances to the hazard so that the most significant scenario events or time histories can be selected and used to check the engineering design.

Suites of time histories for input into time-domain linear or nonlinear analysis of a dam and (or) appurtenant structures should be selected to reflect the magnitude, distance, site condition, and other parameters that control the ground motion characteristics.

Depending on the type of dam and the analysis approach being applied, additional EDGM parameters could be required. These include the following:

- Duration of earthquake shaking
- Vertical ground motion
- Ground response spectra for a range of damping ratios
- Ground motion at the base of the analytical model
- Fault displacement

Seismic hazard characterization can also be undertaken by applying the general approach outlined above for dam safety risk assessment.

6.6 Geotechnical

For geotechnical consideration, the overall dam system includes the dam embankment and appurtenant structures, their foundations, abutments, and the reservoir rim.

The geotechnical assessment of any potential or existing system should begin with a geological interpretation of the area. This interpretation generally consists of a review of available geological maps, site reconnaissance, and possibly airphoto interpretation. A well-founded geological program provides a basic understanding of the foundation conditions and the basis for establishing an effective geotechnical site investigation program.

A geotechnical site investigation program helps determine the nature and variability of the foundation conditions and the potential borrow zones. The design of a new embankment dam is greatly influenced by the amount and quality of the borrow materials available at the project site. These investigations commonly consist of borehole drilling and sampling, *in situ* testing, and groundwater monitoring to identify the geological and hydrogeological sequences. When the near-surface materials are of primary importance, as in situations where the topsoil thickness needs to be established or impervious and granular borrow materials need to be identified, test pitting is often substituted for drilling. *In situ* testing methods most commonly used are the standard penetration test, cone penetration test, field vane test, pressuremeter test, flat dilatometer test, and permeability test. Surface or downhole seismic or resistivity measurements obtained by geophysical logging can also be used to supplement stratigraphic information obtained by the borehole drilling. The samples from these investigations are then tested in the laboratory to define the engineering properties of the material and to establish appropriate design parameters.

Foundation investigations and material testing should focus on establishing the engineering properties most relevant to the type of analyses to be undertaken. Typically, these properties include shear strength, gradation, compressibility, compactibility, and permeability. Of particular importance to most applications is the identification of discontinuities and anomalies such as jointing, fissures, and weak seams that, if present, will generally control foundation behaviour.

Engineering analyses need to be performed to demonstrate that the dam, foundation, and abutments will remain stable under all hazards and loading conditions. Geotechnical hazards include the following:

- Hydraulic fracturing
- Piping
- Internal erosion
- Surface erosion
- Slope instability
- Static and dynamic liquefaction
- Seepage
- Deformation

Loading conditions include the following:

- End of construction
- Rapid drawdown
- Reservoir surcharge
- Wind and wave action
- Steady-state seepage
- Earthquakes

Overtopping as a result of exceeding the reservoir capacity is the most common mode of failure for embankment dams. Although this is generally considered a hydrotechnical storage or discharge capacity issue, settlement of the dam crest can be a contributing factor. Once overtopping occurs, the uncontrolled flow may cause the dam to breach, depending on the erodibility of the materials exposed along the flow path. The rate of breaching is also dependent on this erodibility.

Loss of material due to internal erosion and piping is the second most common cause of embankment dam failure. Internal erosion and piping occur as a result of concentrated, excessive particle migration caused by seepage flow. Particle migration can occur when (*i*) seepage passes from a fine-grained material into an exceedingly coarser grained material; or (*ii*) perhaps more critically, material is carried into or through cracks or discontinuities in the dam, foundation, or abutments. Differential settlement and hydraulic fracturing are the most common causes of cracking in embankment dams. Hydraulic fracturing occurs when internal hydraulic pressures exceed the minor principal stresses inherent in the embankment material. Well-designed granular filters strategically placed within the embankment and between the embankment and the foundation have proven to be the best defence against internal erosion and piping failure.

The dam embankment and abutment slopes must be adequately stable to withstand all foreseeable loading conditions. In general, a limit equilibrium analysis should be sufficient to verify the stability of the slopes under normal operating conditions. Acceptance criteria are usually described in terms of factors of safety. A factor of safety in this case is defined as the ratio of available shear resistance along a potential plane of failure to the activating shear forces along the same plane. Accepted factors of safety (Tables 6-2 and 6-3) take into account the reliability of inputs to the stability analysis, the probability of the loading condition, and the consequences of potential failure.

The appropriateness of these calculated factors of safety depends on the conservatism of the assumptions made regarding stratigraphy, strength of materials, pore-water pressure, and loading. Lower calculated factors of safety for static assessment may be acceptable for existing structures with demonstrated performance supported by appropriate monitoring or more sophisticated analysis.

Table 6-2: Factors of Safety for Slope Stability—Static Assessment

Loading condition	**Minimum factor of safety** [note 1]	**Slope**
End of construction before reservoir filling	1.3	Upstream and downstream

Long term (steady-state seepage, normal reservoir level)	1.5	Downstream
Full or partial rapid drawdown	1.2–1.3 [note 2]	Upstream

Note 1. Factor of safety is the factor required to reduce operational shear strength parameters to bring a potential sliding mass into a state of limiting equilibrium (using generally accepted methods of analysis).

Note 2. Higher factors of safety may be required if drawdown occurs relatively frequently during normal operation.

Table 6-3: Factors of Safety for Slope Stability—Seismic Assessment

Loading condition	Minimum factor of safety
Pseudo-static	1.0
Post-earthquake	1.2–1.3

For large dams, dams with complex cross sections or foundation conditions, or dams subjected to seismic loading, it is usually appropriate to apply more sophisticated methods of analysis, such as numerical finite-element models. In these cases, other acceptance criteria, based on stress, strain, and displacements, should be set for elastic response under usual loads, quasi-inelastic response under unusual loads, and inelastic response under extreme loads. The stress–strain field, state of deformation, and distribution of pore-water pressures in the entire continuum of the dam system should be evaluated for different loading cases and stages, such as the following:

- During construction and immediately after construction
- During impoundment and transient seepage
- After full reservoir level has been reached and steady-state seepage has developed
- During long-term consolidation and creep
- Under transient loading, such as rapid or sudden reservoir drawdown, floods, and earthquakes

In general, for advanced numerical modeling, acceptance criteria for allowable maximum levels of stress, strain, and displacement are dependent on material strength and should be established for each project on a case-by-case basis. However, it is possible to set criteria based on a local factor of safety, for example ratio of shear strength to maximum shear stress at each point in the continuum of the dam and foundation. For slope stability concerns, such criteria could be established to provide a safety margin that is equivalent to the factors of safety shown in Tables 6-2 and 6-3.

The geotechnical assessment should also take the following into account:

- Seepage exit gradients should be within acceptable limits for the embankment and foundation materials. The usual techniques used to reduce seepage through the pervious units are impermeable upstream blankets, cutoff trenches, grout curtains, sheet pile walls, slurry trench cutoff walls, and other thin cutoffs. Strategically placed granular filter materials can also be used to provide an acceptable exit condition.

- The dam should be designed to retain the reservoir safely despite any cracking that may be induced by arching, settlement, or hydraulic fracturing.
- Freeboard should be sufficient to prevent heave of the crest due to frost action.
- Final freeboard, including camber, should be sufficient to accommodate expected settlement of the crest and cracks caused by frost action.
- For embankment dams, the maximum reservoir level, including the effects of wind, should be at or below the top of the impervious core, unless it can be demonstrated that for the duration of reservoir surcharge, no damage would be incurred.
- The following failure mechanisms should be assessed for seismic loading:
  - Slope instability leading to overtopping
  - Permanent deformation leading to overtopping
  - Fissuration or cracking leading to internal erosion failure
  - Liquefaction (both triggering and post-liquefaction stability conditions)
- The upstream slopes of the dam and its abutments should have adequate protection against erosion and possible breaching due to wave and ice action. The downstream slopes should be protected where necessary against the erosive action of runoff, seepage flows, traffic, frost, and burrowing animals.
- The stability of reservoir slopes should be evaluated under seismic loads, heavy rainfall, rapid drawdown, and any other loading conditions if slope failure could induce waves that would pose an unacceptable risk to public safety, the dam, or its appurtenant structures.

Monitoring instrumentation should be in place to provide the following:

- Data to validate design assumptions about settlement, pore pressures, stresses, displacements, deformation, and seepage
- Information on the ongoing performance of the dam, its abutments, and its foundations
- Observation of performance of critical areas

For concrete dams founded on bedrock, the geotechnical aspect of safety assessment should focus on the concrete–foundation interface, joints or discontinuities within the foundation that can result in differential movement of the dam, cracking, and potential failure.

For concrete dams and appurtenant structures founded on soil, consideration should be given to bearing capacity, settlement, differential settlement, swelling, uplift pressure, drainage, lateral earth and hydraulic pressure, and lateral displacements. Of particular importance in the design of concrete structures are possible long-term differential movements that could occur between components and excessive hydraulic uplift pressures that could lead to failure. Measures that may mitigate these conditions include the following:

- Minimizing excavation to reduce rebound
- Allowing rebound and swelling to occur between excavation and construction
- Sub-cutting and replacing soft or compressible foundation materials with granular materials
- Providing a sufficiently thick granular base beneath the structure to facilitate drainage and minimize frost heave

Even though these measures may be sufficient to reduce differential movements and uplift pressures, general practice is to introduce joints within the structure that can accommodate some differential movement, along with a well-designed under-slab drainage system to relieve hydraulic uplift pressures.

6.7 Structural

This section focuses on structural analysis of concrete gravity dams, but the principles can be applied to other water-retaining structures that rely on their own weight for stability. Discussion of geotechnical considerations for foundations and structure–foundation interfaces is provided in section 6.6. The design of new structures and the assessment of existing structures should be carried out using a full range of normal to extreme loads consistent with the site conditions, consequences of failure, applicable regulations, and current good practice in the industry.

The adequacy of structures and foundations to resist all specified loading conditions, including interactions with geotechnical interfaces, should be assessed on the basis of appropriate performance indicators. These include the position of the resultant force, normal and shear stresses, and calculated sliding factors.

Acceptance criteria for assessment of stability should reflect the degree of uncertainty associated with the analysis and an understanding of the imposed loads and material properties, as well as the consequence classification of the structure. Guidelines are shown in Table 6-4.

Table 6-4: Acceptance Criteria for Concrete Gravity Dams

Loading combination	Position of resultant force (percentage of base in compression)	Normal compression stress [note 1]	Sliding safety factor		
			Friction only	Friction and cohesion [note 2]	
				With tests	Without tests
Usual	Preferably within the kern (middle third of the base: 100% compression); however, for existing dams, it may be acceptable to allow a small percentage of the base to be under 0 compression if all other acceptance criteria are met [note 3]	$<0.3 \times f_c'$	≥1.5	≥2.0	≥3.0
Unusual	75% of the base in compression, and all other acceptance criteria must be met	$<0.5 \times f_c'$	≥1.3	≥1.5	≥2.0
Extreme flood	Within the base, and all other acceptance criteria must be met	$<0.5 \times f_c'$	≥1.1	≥1.1	≥1.3
Extreme earthquake	Within the base, except where an instantaneous occurrence of resultant outside the base may be acceptable	$<0.9 \times f_c'$	[note 4]		
Post-earthquake	Within the base	$<0.5 \times f_c'$	≥1.1 [note 5]	[note 6]	

Note 1. Where f_c' = compressive strength of concrete.

Note 2. Given the significant impact a very small amount of cohesion can have on shear resistance of small and medium-sized dams, the use of a cohesive bond in calculating the sliding safety factor should be done with extreme caution.

Note 3. It is very important to verify that all possible failure modes have been addressed under a potential cracked base scenario.

Note 4. The earthquake load case is used to establish post-earthquake condition of the dam.

Note 5. If post-earthquake analysis indicates a need for remedial action, this condition should not be allowed to remain for any length of time. Remedial action should be carried out as soon as possible such that factors of safety are increased to the level of the pre-earthquake conditions.

Note 6. Shear resistance based on friction and cohesion needs to be considered carefully, since the analysis surface may not remain in compression throughout the earthquake but may result in cracking, which will change the resistance parameters.

Identification of possible failure modes should be undertaken as part of any safety evaluation in order to identify the potential failure scenarios that may apply to the project. The emphasis in analysis should be on ensuring the safety of the structures against the identified failure scenarios.

Determination of the loads should take into account the actual field conditions for an existing dam. The consequence classification of the dam will determine the flood and earthquake loading. The following loads should be considered in the design and assessment of concrete structures:

- Dead loads of permanent structures and equipment

- Maximum normal headwater level, combined with the most critical concurrent tailwater level
- Maximum flood headwater level based on the IDF, with corresponding tailwater levels
- Internal water pressure and foundation uplift
- Static and dynamic thrust created by a sheet of ice, for reservoirs subject to freezing
- Vertical and horizontal loading due to rock or soil backfill, including potential effects of liquefaction, as well as loads from silt deposited against the structure
- EDGM
- Temperature-induced loads for stability and stress analysis of concrete structures with grouted contraction joints, especially buttress and arch dams
- Other loads, such as tensioned structural anchors, forces generated by the expansion of concrete caused by chemical reactions, and debris

Loads should be combined in accordance with the nature of their likelihood of occurrence into load combinations corresponding to the usual, unusual, and extreme load cases.

Concrete dams should be designed to resist and prevent the following:

- Sliding at the dam–foundation interface, within the dam, and at any plane in the foundation
- Overturning
- Overstressing of the concrete dam or foundation
- Excessive seepage through the foundation or through joints in the concrete

If the concrete appears to be damaged or weakened either (*i*) tests should be carried out to determine its strength parameters or (*ii*) suitably conservative assumptions should be made in the analysis. Shear should be assumed to be zero, unless tests prove the existence of cohesion.

The effects of static and dynamic (seismic) loadings on support structures for mechanical and electrical equipment used for dam safety should be examined to ensure that structural integrity and functionality are preserved.

The selection of the appropriate analytical method to evaluate the safety of a dam should take into account the type of structure, the characteristics of the loads and materials, the geological conditions, and the behaviour and condition of the structure. The analytical method should be selected for its ability to evaluate the safety of a dam against its principal failure modes. Extreme-consequence and very high consequence dams should generally be analyzed in more detail and by more sophisticated methods than lower consequence dams.

6.8 Mechanical and Electrical

Mechanical and electrical equipment at dams consists of the flow control equipment (including gates, valves, stoplogs, flashboards, and inflatable dams), auxiliary equipment (including heaters and de-icing equipment), power supplies, and control systems.

Spillway reliability relies on sound design, including appropriate redundancy and segregation, as well as a program of inspection, testing, and maintenance to ensure that the gate system remains reliable. The flow control equipment should be adequate for all anticipated conditions and meet present-day dam safety requirements. Over time, there may have been changes to the physical arrangement, corrosion damage, operating conditions, and applied loads.

The scope of analysis and assessment depends on a number of factors, including the following:

- Age of the equipment
- Condition of the equipment
- Operating history
- Anticipated operating requirements
- Potential failure modes and their consequences
- Criticality of the equipment to the safety of the dam

As a minimum, the design review should include an examination of available information on the equipment, especially the original design calculations, identification of appropriate loading conditions, and an analysis to determine the safety factors under these loading conditions.

The design review for a typical sluice gate would cover the superstructure, the gate hoist, and the gate itself. For the superstructure, the design loads include dead loads of the gates and the superstructure, snow and wind loads, maximum loads exerted by the gate hoist, and seismic loads.

The design loads that apply to the hoist include the gate weight, wheel or trunnion bearing loads, gate seal friction loads, gate cracking loads, hydraulic downpull and static friction loads, loads caused by the gate being frozen to the gains, and loads due to the gate jamming as it is raised. These loads can be exerted in various combinations.

The design loads on the gate itself include hydrostatic pressure loads on the skinplate and structural members, wheel and trunnion loads, and hoist attachment point loads. Impact loads on the skinplate from ice in the forebay may also be significant.

The preferred motors for flow control equipment are three-phase wound rotor or squirrel cage induction motors because of their inherently high starting torque and durability. These motors have proven to have very low failure rates, particularly if they are conservatively rated and well maintained.

Gate controls usually are a combination of local and remote control and water level and gate position instrumentation.

All mechanical and electrical equipment that is required to operate for the dam to pass the inflow design flood should be tested periodically. The testing program should demonstrate that the equipment is in good working order and confirm that the equipment can pass the required flows. It can also demonstrate that the operating loads are still within the expected and acceptable values. Two types of test are recommended:

- Annual functional test to verify that the gate, log sluice, or valve will operate under normal flows. This test can be carried out at less than the full flow, for instance to 10% of gate opening. For regularly used equipment this test could be a part of normal operation.
- Full flow test carried out periodically, for example as part of the Dam Safety Reviews. The test is intended to verify the design capability of equipment. It is recommended that the equipment be fully opened so that the device and its auxiliary equipment operate close to their design loads.

6.9 Other Considerations

During construction of new dams or improvements to existing dams, the project specifications should be strictly adhered to, and deviations should be allowed only after consultation with the design engineer. A rigorous quality control program must be maintained throughout the site preparation and construction period. The as-built conditions should be properly documented. Instrumentation data pertaining to the foundation, embankment, and appurtenant structures should be reviewed by appropriately qualified engineers. Temporary construction facilities should be constructed in such a way that the risks to the safety of the dam, cofferdam, and appurtenant structures are appropriately managed.

The potential environmental impacts of seepage and other releases from the facility should be evaluated for all stages of the life cycle. Evaluation of the environmental impacts must include chemical changes during operation and closure, such as oxidation of sulphides in impounded sediments or tailings. Acceptance criteria for environmental performance should be set by the appropriate compliance standards for the given facility.

The design and safety evaluation principles applied to tailings dams should be similar to those applied to conventional water retention dams. However, the production and operating phases of the tailings dam life cycle are somewhat different with respect to function (a high proportion of solids retained in the fluids) and dynamics (episodic raising of tailings dams concurrent with rising fluids and solids in the impoundment). These differences typically become less significant during the closure phase, when tailings are no longer being added to the impoundment.

Dam safety assessments must be multifaceted and recognize the complex interactions among all of the above-mentioned factors.

ACRONYMS

AAR	alkali–aggregate reaction
AEP	annual exceedance probability
ALARP	as low as reasonably practicable
CDA	Canadian Dam Association
EDGM	earthquake design ground motion
EPP	emergency preparedness plan
ERP	emergency response plan
IDF	inflow design flood
OMS (Manual)	Operation, Maintenance, and Surveillance (Manual)
PAR	population at risk
PMF	probable maximum flood
PMP	probable maximum precipitation
SCADA	supervisory control and data acquisition
SCP	site command post

GLOSSARY

Abutment	That part of the valley side or other supporting structure against which the dam is constructed
Annual exceedance probability	The probability that an event of specified magnitude will be equaled or exceeded in any year
Appurtenances	Structures and equipment on a site, other than the dam itself, including such facilities as intake towers, powerhouse structures, tunnels, canals, penstocks, low-level outlets, surge tanks and towers, gate hoist mechanisms and their supporting structures, and all critical water control and water release facilities. Also included is mechanical and electrical control and standby power supply equipment located in the powerhouse or in remote control centres
As low as reasonably practicable	The principle that the residual risk from a system should be "as low as reasonably practicable." For a risk to be ALARP it must be possible to demonstrate that the cost involved in reducing the risk further would be grossly disproportionate to the benefit gained
Classification	A system of assigning dams to categories, usually on the basis of the consequences of failure, so that appropriate dam safety standards can be applied. Some classification systems go beyond the consequences and consider other dam characteristics, such as vulnerability to various hazards
Consequences of failure	Impacts on the downstream or upstream area of a dam as a result of failure of the dam or its appurtenances. In these guidelines, the term *consequences* refers to the damage above and beyond the damage that would have occurred in the same event or conditions had the dam not failed. These may also be called incremental consequences of failure
Dam	A barrier constructed for the retention of water, water containing any other substance, fluid waste, or tailings, provided the barrier is capable of impounding at least 30,000 m^3 of liquid and is at least 2.5 m high. Height is measured vertically to the top of the barrier (*i*) from the natural bed of the stream or watercourse at the downstream toe of the barrier, in the case of a barrier across a stream or watercourse; or (*ii*) from the lowest elevation at the outside limit of the barrier, in the case of a barrier that is not across a stream or watercourse

	In these guidelines, the term *dam* includes *appurtenances* and systems incidental to, necessary for, or connected with the barrier. The definition may be expanded to include dams less than 2.5 m high or with an impoundment capacity of less than 30,000 m^3 if the consequences of dam operation or failure are likely to be unacceptable to the public, such as dams that create hydraulic conditions posing a danger to the public; dams with erodible foundations that, if breached, could lower the reservoir by more than 2.5 m; or dams retaining contaminated substances
Dam Safety Review	A comprehensive, formal review carried out at scheduled intervals to determine whether an existing dam is safe, and if it is not safe, to determine what improvements are required
Decommissioned dam	A dam that has reached the stage in its life cycle when both its construction and its intended use have been permanently terminated in accordance with a decommissioning plan
Deterministic	A term applied to a process whose outcome is always the same for a given set of inputs. Deterministic design is typically based on either (*i*) worst-case values of the input variables or (*ii*) nominal values with a safety factor applied to the result. Contrasts with *probabilistic*
Earthquake design ground motion	The level of earthquake ground motion at the location for which a dam structure is designed or evaluated
Failure (of a dam)	An uncontrolled release of the contents of the reservoir
Failure mode	The mode in which elements or components fail, causing a loss of the system function. At a general level, there are three dam failure modes: (*i*) overtopping, (*ii*) collapse, and (iii) contaminated seepage
Foundation	The rock and (or) soil mass that forms a base for the structure, including its abutments
Freeboard	The vertical distance between the still water surface elevation in the reservoir and the lowest elevation at the top of the containment structure
Hazard	A system state or set of conditions that together with other conditions in the system environment could lead to a partial or complete failure of the system. Hazards may be external (originating outside the system) or internal (errors and omissions or deterioration within the system)
Headwater	The water upstream from a structure or point on a stream

Incremental consequences of failure	The incremental losses or damage that a dam failure might inflict on upstream areas, on downstream areas, or at the dam itself, over and above any losses or damage that would have occurred in the same event or conditions had the dam not failed
Inflow design flood	The most severe inflow flood (peak, volume, shape, duration, timing) for which a dam and its associated facilities are designed
OMS Manual	A manual that documents the requirements and procedures for the safe operation, maintenance, and surveillance of a dam
Owner	The person or legal entity, including a company, organization, government department, public utility, or corporation, that is responsible for the safety of the dam. This person or legal entity may hold (*i*) a government licence to operate the dam; (*ii*) the legal title to the dam site, the dam, and (or) the reservoir; or *(iii)* both
Probabilistic	A term applied to procedures that are based on the application of the mathematics of probability and take explicit account of random variations in natural and other events and properties. Probabilistic design is based on an assessment of the probabilities of failure for specific design points
Probable maximum flood	An estimate of a hypothetical flood (peak flow, volume, and hydrograph shape) that is considered the most severe that is "reasonably possible" at a particular location and time of year. The estimate is based on a fairly comprehensive hydrometeorological analysis of critical runoff-producing precipitation (snowmelt if pertinent) and hydrologic factors favourable for maximum flood runoff
Regulator	A government ministry, department, office, or other unit of the national or provincial government entrusted by law or administrative Act with the responsibility for the general supervision of the safe design, construction, and operation of dams and reservoirs, as well as any entity to which all or some of the executive or operational tasks and functions have been delegated by legal power
Reservoir	The body of water, fluid waste, or tailings that is impounded by a dam, including its shores and banks and any facility or installation necessary for its operation
Risk	A measure of the probability and severity of an adverse effect on health, property, or the environment. Risk can be estimated by the mathematical expectation of the consequences of an adverse event occurring (that is, the product of the probability of occurrence and the consequence)

Risk assessment	The process of deciding whether existing risks are tolerable and present risk control measures are adequate, and if not, whether alternative risk control measures are justified or will be implemented. Risk assessment incorporates risk analysis and risk evaluation
Spillway	A weir, channel, conduit, tunnel, chute, gate, or other structure designed to permit discharges from the reservoir
Standards-based approach	The traditional approach to dam engineering, in which risks are controlled by following established rules for defining design events and loads, structural capacity, safety coefficients, and defensive design measures
Surveillance	The close monitoring of dam behaviour, including systematic collection, analysis, and interpretation of data through visual inspections and instrumentation
Tailings	Generally fine-grained, residual material remaining after the valuable resources have been extracted from the ore at a mineral processing plant
Tailings dam	A dam, including foundations, water control structures, and base of the impounding basin, that is constructed to retain tailings from mining or mineral processing operations
Tailwater	The water in the discharge channel immediately downstream of dam