DRAFT/PROPOSED

ICOLD BULLETIN

GENERAL PRINCIPLES AND FRAMEWORK FOR DAM SAFETY

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FOREWORD

To be written by Committee Chair

Note: To be determined if a Preface by the principal authors is needed e.g. if objectives and audience are not sufficiently covered in the Foreword and Introduction.

1. INTRODUCTION

ICOLD supports the dam engineering profession worldwide in setting standards and guidelines with the objective of ensuring that dams are built and operated safely, efficiently and economically, and that they are environmentally sustainable and socially equitable.

This overarching Bulletin provides a summary of the general concepts and principles of dam safety, as well as the activities involved in safe management of dams to meet the changing needs of dam safety. The Bulletin establishes a framework for a set of ICOLD Bulletins and other documents that address the needs of government, regulators, national associations and owners.

This guidance is applicable in all countries, including those where well developed dam safety programs and capacity already exist as well as countries that are establishing new programs but have limited resources and technical and management capacity. Continuing program development, capacity building and development of information sources are essential components of all dam safety programs.

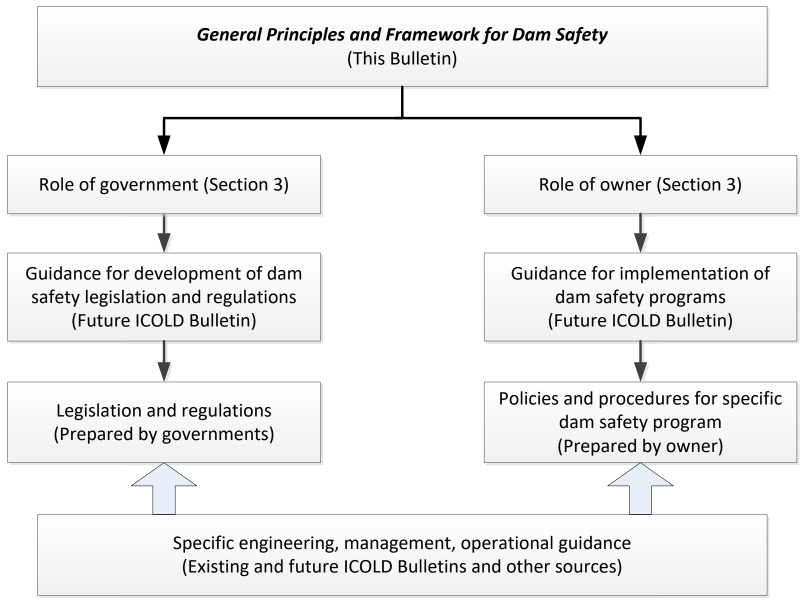
ICOLD guidance on dam safety has evolved over decades. A Technical Committee on Dam Safety was established in 1982 to facilitate an integrated approach to safety issues among all ICOLD Technical Committees. The Committee was assigned to guide definition of a common safety philosophy and prepare general guidelines on dam safety consistent with this philosophy. ICOLD places high emphasis on ensuring safety through all life phases of dams. The Committee on Dam Safety has prepared several bulletins with a focus on specific life phases, and many other bulletins include safety as an essential component and objective.

ICOLD recognizes that the science, technology and human roles in dam safety are in continuing evolution with many changing conditions. These include ageing of existing infrastructure, retirement of experienced personnel, lack of experience in many countries, climate change effects on extreme conditions, recognition that site selection options are increasingly limited, and changes in local and regional governance.

This Bulletin presents an overall framework for management of dam safety during all phases of a dam's life. As illustrated in, the Bulletin provides a starting point for development of more detailed ICOLD guidance to assist government authorities, dam owners, designers, constructors, and operators as they develop their own specific regulations, guidelines and operating manuals.

This Bulletin applies to dams at all life phases – from concept and design, through construction and operation, to decommissioning and disposal. It can be used in conjunction with other ICOLD Bulletins that apply to specific phases and circumstances. While the Bulletin applies to dams on trans-boundary rivers, in such cases the safety management system and enabling mechanisms should be set in the context of the international arrangements between the countries for the use of shared water resources.

Figure 1. ICOLD Dam Safety Guidance Documents



Dams are unique structures in unique natural locations, and they are designed and constructed to meet unique social and policy needs and expectations. Consequently, differences in design and safety management practices must and will continue to exist between individual dams and countries. How a dam development project proceeds, how it is operated and how decisions are made concerning its monitoring, surveillance, maintenance, refurbishment or retirement, can differ from one dam to another and from one country to another as reflected in relevant laws, societal norms, expectations, traditions and experiences.

In recognition of the uniqueness of each dam and differences in approaches, the general principles and processes that are outlined in this Bulletin can be adapted for the specific situations that exist. The level of effort involved in adapting this general guidance will vary according to each situation

In addressing the safety of dams, it is essential to consider the uncertainties that prevail in many aspects of development and operation of dams, with the view to controlling the associated safety risk. While it is not possible to eliminate uncertainty in nature and in real world decision-making, appropriate consideration of risk can lead to the means of understanding and minimizing the effects of these uncertainties. Considering all factors together - risks, costs and benefits in the context of the governing laws and regulations, overall design philosophy, performance of the dam, and prevailing safety objectives - provides the basis for an integrated approach to maintaining adequate safety over the life phases of a dam, while securing the overall benefits of the dam at an affordable cost.

2. CONCEPTS AND PRINCIPLES

2.1 General

The overall goal of dam safety programs is for dams to be constructed safely, operated safely, and ultimately decommissioned safely, such that the dam developments can be financially viable, deliver the expected net benefits, and be environmentally and socially sustainable in the long term.

Dam safety is the product of an integrated arrangement of appropriate governance, licensing and regulatory arrangements, responsible ownership, diligent application of best available engineering design and maintenance, and robust management and operational practices within the context of the river basin including any transboundary issues.

The management arrangements for dam safety must be sustainable over the life of the dam requiring an adequate supply of financial resources, and continuous streams of well trained managers, engineers, operators and inspectors, who have the equipment and capabilities that they need to perform their duties.

The prevailing legal and government authorities and the regulatory regime set the overall governance structures, parameters and boundaries within which the development of the dam proceeds. These parameters and boundaries may vary over time during the operation of the dam in alignment with changing societal needs and expectations and the dam Owner will be required to respond accordingly.

A safe dam is not simply an assembly of well-engineered parts, although sound engineering of the parts is a pre-requisite for a safe dam. The safety of a dam depends on effective design, construction and operation of the overall project, considered within their river basin contexts as integrated systems. The river basin context may involve transboundary issues that will influence the operation and the safety management of dams on the river system.

The principal roles in achieving the safety objectives are those of the Owner, the Designer, the Constructor and the Operator (who may or may not be the Owner), as follows:

1. The Owner is responsible for safety, in addition to being responsible for all of the enabling arrangements for the development and operation of the dam.
2. The Designer transforms qualitative and sometimes quantitative attributes and performance objectives into directions that are actionable by the Constructor and the Operator.
3. The Constructor produces the tangible safety and performance attributes and features which become the realised outcomes of the design intent.
4. The Operator then operates the as-constructed system within the boundaries specified in the design.

Thus, while the Owner is ultimately accountable for safety, in practice the safety of the dam is controlled by the thoughts and actions of the Designer who should be involved in all phases of the dam development up to and including the early years of operation of the dam. Comprehensive documentation of all aspects of the design and expected performance of the dam is essential for quality assurance during design, construction, and commissioning, and for long term operation. In the modern context, the Designer must create a structural form that can be safely built, operated reliably over many years, and ultimately safely decommissioned and removed from service. The design documentation also serves as a basis for demonstrating that the dam complies with all relevant laws, regulations and administrative requirements, and will meet all performance expectations over the life of the dam while ensuring that all associated risks can be maintained at a broadly acceptable level.

Due to the uniqueness of their locations, it is appropriate to consider each dam as a one-of-a-kind *prototype* addressing its particular natural setting and purpose. In this way, dam development is different from most other industrial structures or products which are typically standardized. Most issues at dams are site-dependent and must be resolved by application of state-of-the-art and state-of-the-practice norms underpinned by fundamental engineering principles.

Safety requirements and objectives often change across the different project stages from the very first studies to the construction stage and commissioning. An overarching regulatory, management and accountability framework serves as a basis for assessing, demonstrating and assuring dam safety over all life phases in a transparent and publicly accessible way.

2.2 Overarching ICOLD Principles of Dam Safety

In developing dam safety guidance documents, ICOLD has defined nine overarching principles on dam safety, which apply to all life phases for all types of dams.

(a) Justification of Dams: Dams should be constructed and operated only if they yield an overall benefit to society.

(b) Fundamental Dam Safety Objective: The fundamental dam safety objective is to protect people, property and the environment from the harmful effects of misoperation or failure of dams and reservoirs.

(c) Responsibility for Integrity and Safety of Dams: The prime responsibility for the overall integrity and safety of dams over all life phases rests with the dam owner.

(d) Role of Governments: The legal and regulatory frameworks for all industrial activities, including dams, provide the overarching structures for the construction, operation, renewal, and retirement of dams in a country or region.

(e) Leadership and Management for Safety: Effective leadership and management of the integrity and safety of dams should be established and sustained over all life phases of dams.

(f) Balancing Protection Across Competing Objectives: Protection against misoperation and failure of dams and reservoirs should seek to achieve a balance across competing objectives to provide the highest level of integrity and safety that can reasonably be achieved.

(g) Limitation of Risks to Individuals and Society: Measures for controlling risk from dams should ensure that no individual bears an unacceptable risk of harm, and that risks to society and the environment do not exceed the risk tolerance of society.

(h) Sustainability of Dams and Reservoirs: In order to secure societal value, dams and reservoirs must be sustained in the long term and, where applicable, transboundary issues should be addressed. To ensure sustainability of dams, all practicable efforts should be made to prevent and mitigate failures and accidents.

(i) Emergency Preparedness and Response: Appropriate arrangements should be made for emergency preparedness and response for dam failures and accidents.

2.3 Engineering Principles

Fundamental engineering principles for the design of safe systems, developed and documented across many industries, also apply to the design of all dams.

The fundamental engineering principles for safety in design are:

- Redundancy - More than one way to achieve the system output
- Diversity - Different ways to achieve the same function
- Segregation - Output served from different directions
- Defensive design - Large margin of capacity over demand, in all systems including redundant systems
- Fault tolerant (including human factors) – A single fault will not cause loss of system function
- Fail to a safe condition - If the system does fail, it will be rendered to a harmless condition

Owing to the uniqueness of dams, a particular dam and reservoir system as a whole would not be expected to display all of these features, but sufficient features should be provided for various sub-systems within the dam-reservoir system to meet the safety goals. In general, the fewer the principles that are achieved, the greater the dependence on the margin of capacity over demand of the project components and on the quality and robustness of the engineering and system management.

2.4 Natural Variability and Uncertainty

Variability and uncertainty are important factors that must be considered in dam engineering and dam safety assessment, in large part due to the natural settings of dams and their long service lives.

Factors contributing to the variability and uncertainty include:

- Construction with locally available materials which are inherently variable and not always optimal
- Climatic effects during multiple construction seasons
- Uncertain events and conditions due to natural hazards
- Variability of inflows
- Variable construction quality

- Ageing and deterioration
- Effects of climate change on conditions over the project life
- Incomplete design records and as-built records

In the vast majority of cases over the millennia, dam engineers have dealt with these variabilities and uncertainties by using a conservative engineering philosophy in design of key components that errs on the side of safety by a considerable margin. However, on rare occasions, dam failures and incidents occur because the influences of one or more uncertain phenomena have been underestimated, not properly accounted for, or even not recognized. In recent years, there has been increased awareness that failures occur from a wider range of causes including human, management and operational factors. Consideration of risk, which involves explicit treatment of variability and uncertainty, has emerged as a means of better understanding, characterizing and controlling the effects of variability and uncertainty in a broader range of phenomena.

However, there is a limit to the extent to which conservative preventive measures can be introduced in the design phase. There will always be some residual uncertainty and associated risk, including that which appears during construction, that must be managed in a reactive way. To this end, dam safety management places considerable emphasis on continuous monitoring and surveillance of dams during both construction and in operation.

In addition, in the safety management of existing dams, and particularly older dams, there will be considerable uncertainty in the as-built and existing condition, frequently due to limited information. Such deficiencies need to be addressed by additional investigations and studies.

Corrective measures such as maintenance, and physical and operational improvements provide additional means of controlling uncertainty by preventing the actual performance of the dam from deviating from the intended performance.

2.5 Dam, Reservoir and River Systems

A dam, reservoir and river system is a complex of interacting parts, subject to a variety of natural and operational disturbances, and operated by people and organisations. These form an engineered system that is set in a natural environment.

A dam system comprising the dam and appurtenant structures, reservoir, foundations, abutments and other components, is a natural system that has been altered by human interventions using engineering means. This results in a dam system being different from other engineered systems such as aircraft or nuclear power stations which are completely engineered, to the extent that they operate as distinct separable entities within the natural environment. In contrast, dams function contiguously within the natural and social environments.

While the systems nature of dams has always been understood to some degree, much engineering design has focused on the structural and hydraulic performance of individual components. In recent years, the capability has been developed to look at all of the components and their interactions in a holistic way, making an integrated approach to design, performance operation and safety possible.

From an engineering perspective, the key considerations in a systems approach are:

- Understanding and management of system requirements
- Functional arrangements and capabilities of the system
- Understanding and explaining how these capabilities are achieved
- Appropriate consideration of the environment in which the system functions

The objectives and capabilities of the system - specifically addressing the products and services that the system produces, for example, water for irrigation, hydropower, or navigation - set the context for all of the design, operational and safety considerations, and performance objectives. The question of how the capabilities are achieved is equivalent in operational terms to the question of how the whole process works. The environment in which the system functions is that domain, physical, social, and organizational, within which the system's products and services are produced.

The systems approach to assessing the performance and safety of dams is familiar from the perspective of dam design, as designers consider the complete system and not just individual aspects in isolation. The challenge to the designer is to balance the many aspects of dam operation and performance into an integrated whole. That integrated whole comprises the natural siting of the dam in its hydrology and geology, the physics of water containment and the control of discharges and production, and the monitoring and control of operations. The interdependencies of these many facets of the dam are never far from the mind of the chief designer. The safety assessment of existing dams continues to evolve to embrace a similar holistic view of performance. This evolution towards the systems approach will envelop the well tested and established dam safety assessment practices as set out in ICOLD Bulletins and supporting documents and practices.

The advances towards the systems approach to management of the safety of existing dams have brought opportunities to realise the benefits of the methods of systems reliability and systems safety as developed in the aerospace, automotive, nuclear and petrochemical industries in dam safety assessment. The approaches to risk analysis in dam safety assessment (ref. B130) rely on these methods of systems analysis.

When combined with established engineering principles and practices, these recent advances provide a sound basis for dam safety assurance in the modern context.

3. ROLE OF GOVERNMENT IN DAM SAFETY

The arrangements established by governments set the legal, regulatory, operational and administrative contexts that frame dam safety decision-making in all phases of the dam's life.

How governments discharge their responsibilities with respect to dam safety can vary considerably, even across a single country, depending on the applicable governing arrangements. The government must decide what regulatory framework, distribution of responsibilities for implementation of activities and assurance of dam safety, is in the best interests of its constituency and constituents.

Governments play a pivotal role in determining the safety of dams - whether as pro-active participants, passive observers, arms-length administrators, or as detached reactive entities. Depending on the role, it is essential that governments maintain appropriate policy and technical capacity.

In general, dam construction involves fundamental alteration of the natural flows of water, a precious natural resource that is shared among individuals, regions or nations. The availability and utilization of water is a political matter within and between nations.

While dams provide numerous benefits, their construction also brings detriments and risks that are not uniformly distributed between people and regions or across generations. Minimization of the detriments and risks is central to the role of dams in ensuring sustainability of the water resources, the economy, and the affected populations. Achievement of these objectives requires some involvement of governments, which have a general duty to protect the interests of their constituent peoples.

Governance refers to the high level processes by which political decision-makers are held to account and through which the broadest strategic decisions are taken at international, national, regional or local levels in society. Governance encompasses the actions, processes, traditions and institutions by which authority is exercised and collective decisions are taken and implemented.

The spectrum of dam safety governance ranges from comprehensive prescriptive rules set down by central governments or international agreements, to self-governance by dam owners and self-regulatory arrangements whereby the dam operators manage dam safety as they see appropriate. On the one hand, the dam owner may be strictly held to account for adherence to prescribed rules and procedures on an ongoing basis, while at the other extreme, the owner is held to account only after a dam failure.

Licencing, regulation and enforcement of activities form a commonly utilised approach that governments use to discharge their responsibilities to control activities and protect their citizens with respect to the use of the nation's water resources.

A licence is an official permit to partake in a particular activity. Diversion and storage of water are activities that are often subject to licensing. Regulation represents the controls that ensure that the terms of the licence are met. Enforcement refers to the statutory powers that governments or their appointed regulatory authorities use to impose conditions and corrective actions on licensees and, where necessary, to impose fines for failure to comply with the regulations and licence.

Licensing and regulation are carried out with consideration of the objectives for which the licence has been granted. The authority takes account of:

- Need to protect consumers and the wider public
- Need to maintain public confidence in the industry and the institutions of government
- Importance of declaring and upholding standards of conduct and competence by licence holders
- Benefits of the activity
- External obligations as required

These fundamental aspects of licensing, regulation and enforcement are controlling factors in dam safety assurance. The term “regulatory regime” has emerged to describe the suite or arrangements that must be in place for a type or approach of regulation to be effective. What is meant by a regulatory regime must collectively consider the elements that interact to regulate activities, including: the organisations that implement regulation, of which there may be several; the frameworks used to set expected behaviours and outcomes; and the systems in place to measure and enforce compliance. Regulation is fundamentally a political matter that is fashioned by prevailing political forces.

There is a broad spectrum of approaches to regulation. At one end, the approach to regulation emphasizes enforcement of rules by governmental agencies and penalties for noncompliance with the rules. This approach remains widespread in many industries, particularly those that create societal concerns and where governments are expected to intervene and control the activities of industries. The degree of control can vary in accordance with government policies and prevailing societal concerns. On the other end, governments may decide that apart from specific licencing arrangements for the use of water, no additional regulatory mechanisms are required for compliance purposes, and they rely on the relevant overarching laws as well as national and local customs and traditions as the basis for achieving the regulatory objectives.

Between the extremes of relying solely on licencing, general legal duties, and customs and traditions, and prescriptive rules and regulations, there is a range of approaches for governments to choose from. These include:

- Performance-based approaches that emphasize outcomes rather than specification of specific actions or technologies
- Approaches based on management systems that involve specific responsibilities for adhering to plans and procedures that control hazards and limit the occurrence of harm
- Self-auditing against a specified compliance framework established by the responsible authority
- Voluntary approaches whereby industry and regulatory authorities develop industry standards and codes of practice

Ensuring effective compliance with rules and regulations is an important aspect of governance. As is the case with regulatory approaches, there is a broad spectrum of possible enforcement arrangements.

The challenge for governments is to achieve a high level of compliance and achievement of the objectives, while keeping the burden of compliance as low as possible. The enforcement arrangements are typically tied to the regulatory approach through the regulatory regime.

The enforcement of prescriptive regulation can entail government-appointed inspectors inspecting dams and operational records, and directing that certain activities be implemented to improve dam safety through corrective measures. The inspectors may be provided with the powers to impose fines, restrict licences or even take control of the facility. At the other end of the spectrum, there may not be any form of enforcement until after an incident or failure that triggers application of the overarching laws. How such situations might progress depends on the particulars of the laws and the regulatory regime, but it could range from fines for non-compliance to punitive damage awards to those adversely affected. A diverse range of enforcement alternatives and outcomes exists between these extremes.

This Bulletin presents general concepts and principles of dam safety that should be considered within the overall governing and regulatory arrangements for dam safety.

4. ROLE OF THE OWNER IN DAM SAFETY

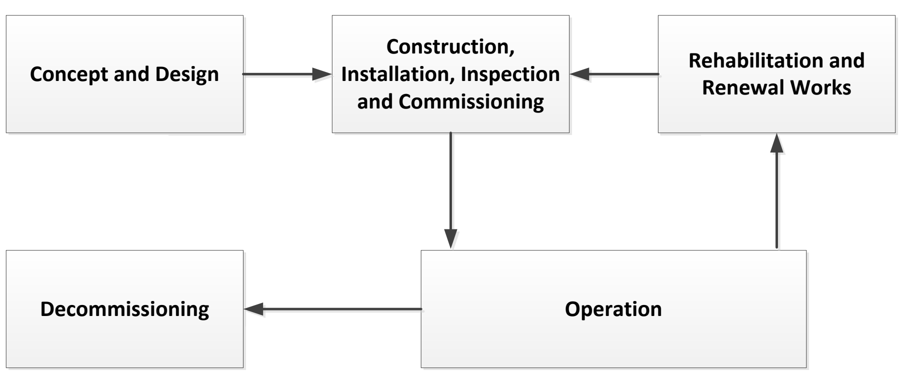
The Owner typically bears the ultimate responsibility for the safety of the dam through all phases of the life of the dam.

In all phases, the Owner is responsible for providing clear authority and the necessary resources and capacity for dam safety management, including the following essential activities:

- **Policy and management system**
- **Safety in design and construction**
- **Independent reviews**
- **Adequacy of structural and hydraulic capacity**
- **Safe operation and maintenance**
- **Surveillance and monitoring of performance**
- **Emergency preparedness**
- **Periodic safety assessment and decision-making**
- **Remedial measures**
- **Continuing training of operators and capacity building**

The responsibilities of ownership of dams begin during the preliminary planning of a dam development and end when the dam is decommissioned or removed, and they change over the life phases of the dam development. The life phases are illustrated in Figure 2.

Figure 2. Life Phases of a Dam



Successful establishment and operation of a dam development by the Owner go beyond management of the engineering and technical aspects and include the broader aspects of managing the entire development according to principles for safety management, environmental protection and social performance over the life of the dam. This is most effectively and efficiently done within an overall management system established by the Owner and, depending on the particular governmental framework, approved by the regulator. The management system is a set of structured policies and processes used in a systematic way by the dam Owner and responsible organizations engaged by the Owner, to ensure that they can carry out the functions necessary to achieve the safety and other objectives efficiently and effectively.

While responsibility for meeting safety objectives of the design should rest with the Designer, the Owner has to fully understand and accept the project design. The Owner is responsible for implementing an adequate quality control system during design, construction, operation and ultimately decommissioning. Responsibility for safety of the works during construction and commissioning should rest with the Construction Supervising Engineer as determined by contractual arrangements of the Owner.

Once they are constructed, dams are not readily modified or improved to increase either efficiency or safety. Uncertainty pervades all phases of the life of a dam, and adoption of a systems approach, as discussed in section 2 above, with conservative design assumptions is often the only means available to deal with this uncertainty. The uncertainty is greatest in the design and construction phases and the Owner must have the resources to manage the changes in conditions that arise during design and construction, usually by adopting a conservative position.

The residual uncertainties at the end of the construction stage may be reduced after commissioning and during the early years of operation. However, dams can never be fully commissioned in the way that other engineered artifacts can be commissioned by testing up to the limits of the design. The residual uncertainty, which can never be eliminated, must be managed by the Owner over the remaining life of the dam. This residual uncertainty and attendant risk is best managed by designing and constructing the dam to be very robust in comparison with the best practices of the day and then to carry out sufficient surveillance, monitoring and maintenance to prevent the risk position from deteriorating over the life of the dam. The Owner will typically be held accountable for demonstrating that adequate resources are being applied over the life of the dam to prevent erosion of the original safety margins.

A full understanding of the design and the expected performance of the dam is central to all follow-up monitoring and assessment of the dam performance over the remaining life phases. Consequently, management of the documentation and records of design, construction, commissioning, operational monitoring and performance assessments should be begin at the concept and design phase and be carried by the Owner through all life phases of the dam to decommissioning.

Advances in science and technology, ever increasing societal expectations concerning the safety and social performance of dams, the emergence of new natural threats, and the unavoidable effects of deterioration of structures and equipment over time must be taken into account at the design stage and throughout dam operation to renewal and even decommissioning.

The Owner’s dam safety management arrangements are expected to account for all of these factors to ensure that the condition and performance of dams is kept under constant review, that emergent threats are identified and characterized, and that any necessary improvements are made as soon as is practicable. The dam safety management arrangements of the Owner should be designed and implemented to ensure that these essential elements are provided with continuity.

The functions or activities necessary for safe management of a dam – mainly the dam Owner's responsibility - are outlined in Section 5 and described in other ICOLD Bulletins. The results of these activities must be integrated and assessed to provide assurance, as described in Section 6.

5. DAM SAFETY MANAGEMENT ACTIVITIES

5.1 Overall Framework

Dam safety is founded on appropriate regulation, responsible ownership and diligent engineering. This is best achieved, with public acceptance, if the overall process is transparent and open to independent scrutiny.

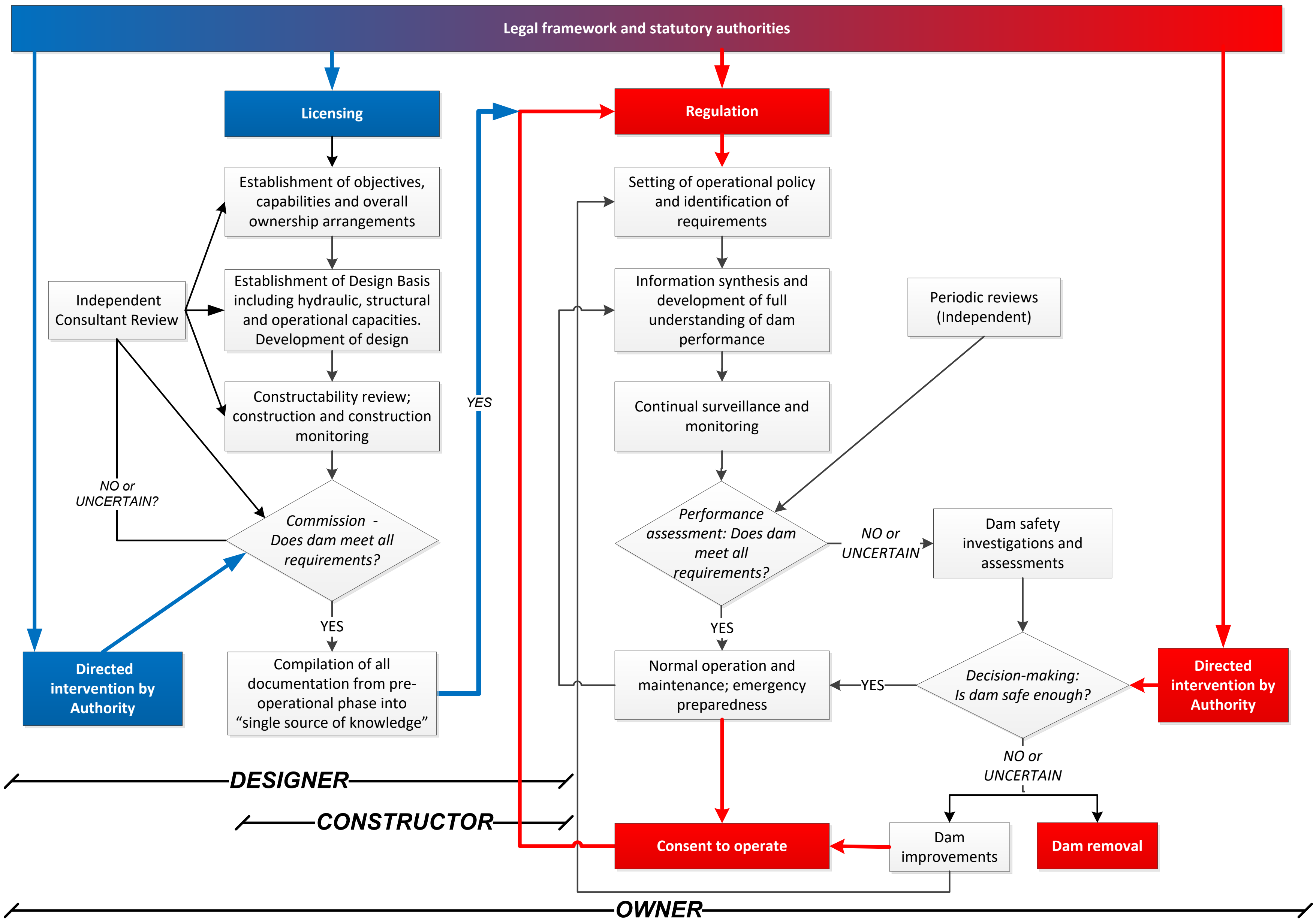
Efficient and effective safety management of dams requires that all relevant considerations be brought together in an organised framework that identifies the roles of all parties, government, regulators and owners, over all phases of the life of a dam.

Figure 3. Overall Framework for Management of Dam Safety presents a framework that provides a consolidated and condensed outline of dam safety management over all phases of a dam's life, including the decommissioning phase. The legal framework and statutory authorities are overarching to the process, while legal requirements and regulatory objectives specific to dam safety are embedded within the process.

The activities of the development phase, where the designer and the constructor have central roles, are indicated on the left of Figure 3. Overall Framework for Management of Dam Safety. The dam owner retains responsibilities for all other activities including meeting the requirements and expectations of the governing or regulating authority and the public, and exercising appropriate controls over the activities of the designer and the constructor. The Owner's responsibilities continue through the entire life of the dam.

Each step in the process can be expected to have several sub-steps that might involve multiple layers of activities and different players. The specific activities set out in Figure 3. Overall Framework for Management of Dam Safety are addressed in existing ICOLD Bulletins and will be further addressed in two future ICOLD publications that will be a companion to this Bulletin and will expand upon the roles of both government authorities and Owners in dam safety management. While the responsibilities and duties of the government authority must be independent of the responsibilities and functions of the Owner, the two sets of arrangements must work together as a coherent "system" of arrangements such as those shown in Figure 3.

Figure 3. Overall Framework for Management of Dam Safety



5.2 Policy and Management System

The organized and systematic management of dam safety in the pre-operational phases of the dam involves integration of the management arrangements of the Owner/Developer, the Designer and the Constructor, within a socio-economic environment that is enabled and overseen by the licensing authority.

The management arrangements during the operational phase are generally under the control of one entity, although in some cases there might be two - the Owner and the Operator. The operating environment is permitted by the licensing and regulatory authority. The management system for the operational phase should include details of:

- **Organizational governance and policies**
- **Safety management implementation arrangements including compliance requirements, financial arrangements and resourcing procedures**
- **Engineering standards, surveillance and monitoring requirements and operational and maintenance procedures**

The Owner/Developer, Designer and Constructor can be autonomous groups as is the traditional case, or they can be a single entity as is the case of design-build-operate development arrangements, or some combination of these entities. They all share the common objective of a safe, financially viable and environmentally sustainable project in the long term while avoiding losses and accidents during the construction phase. Each entity can have its own management arrangements that are internally independent, but they should be unified at their interfaces, such that safety is addressed in terms of common values and principles, with complimentary internal processes.

Arrangements should be in place to ensure that the factors that influence operation are understood and incorporated in the design stage. Arrangements should also be in place to ensure that there is full transfer of all design knowledge and performance expectations through the commissioning phase into the operational phase.

Since dams typically have several operating objectives, some of which sometimes are in conflict with each other, the management system should set out how competing and conflicting objectives are balanced while always erring well on the side of safety. The management system should be designed and applied to transparently demonstrate that:

- All identifiable threats to the safety of the dam have been assessed and either eliminated or effectively controlled.
- The process for identifying and controlling dam safety threats is subject to regular reviews.
- Adequate technical, engineering, financial and personnel management arrangements are in place and are being maintained to ensure that dam safety is achieved at all times and that specific safety performance targets are met.

The Owner of the dam must have the financial capacity to deal with the eventuality that the dam does not meet all requirements, a situation that may occur at some stage in the life of the dam, sometimes more than once. Since dams are fixed infrastructure and not readily modified at a nominal or modest cost, it is normally most economical to target a very low level of broadly acceptable residual risk at the design stage, when added risk controls can usually be incorporated at reasonable marginal cost. Then this level of broadly acceptable residual risk is maintained throughout the life of the dam.

The question "Does dam meet all requirements?" is central in Figure 3. Overall Framework for Management of Dam Safety, both before dam operation begins and again to indicate periodic assessments during the operational life. The level of effort involved in reaching such a conclusion can be extensive and take several years. Interim measures such as reservoir elevation restrictions and enhanced surveillance may be appropriate when there is concern about a level of risk that is higher than broadly acceptable.

5.3 Design, Engineering and Technical Information

Adequate engineering and technical information must be available at all phases, to provide an understanding of the dam, its functions and its failure modes.

The safety of a dam over all life phases is strongly influenced by the safety considerations that are embodied in the initial concept and design phase. The design also has a controlling influence over all other development, operation, maintenance and repair activities that arise over time, including how the dam might be rehabilitated or decommissioned.

Three vitally important aspects of design that feature in all aspects of the construction, commissioning and operation of a dam are:

- **Expected deformations**
- **Expected leakages**
- **Hydraulic outlet functions**

To be safe, a new dam must have appropriate reserves of strength and hydraulic control capacity, taking into account all reasonably imaginable scenarios of normal utilization and exceptional hazards which it may have to withstand during its life, including the effects of climate change and any applicable transboundary issues. During dam operation, the design information must be known and the reserves of strength maintained to assure safety.

Safety Considerations in Design

The philosophy of dam design has evolved over many years. In the past, the emphasis was on creating a structure which would, together with the foundation and environment, satisfactorily perform its function without appreciable deterioration during the conditions expected normally to occur in the life of the structure, and which would not fail catastrophically during the most unlikely but possible conditions which may be imposed.

It is now recognized that dam design, while mainly based on the above philosophy, should include greater consideration of safety over all life phases in structural and operational terms, addressing:

- Unusually high structural demands that can arise from relatively common combinations of natural and operational conditions
- Need for design-based long term performance prediction and monitoring capabilities
- Long term maintenance needs in the design
- Additional or multi-functional hydraulic control arrangements that permit safe rehabilitation or retirement of dams
- Measures to maximise human performance in all aspects of dam operation.

These considerations are aimed at ensuring that dams are as structurally and operationally robust and as safe as it is practicable to make them, while providing flexibility to respond to:

- New threats as they emerge
- Effects of ageing and deterioration
- Changes in the operational regime due to climate change
- Changing service requirements
- Demographic changes
- Changes in societal safety expectations
- Transboundary issues

The designer should address these conditions in accordance with the available physical evidence, local traditions or values, and any prevailing legal requirements. However, considerable judgment is required on the part of the designer to select and balance appropriate design parameters so that the dam development conforms to the constraints while also meeting its objectives in an economic way. The chosen parameters should meet or exceed legal requirements and generally conform to locally applicable guidelines and practices. The designer then designs a project that addresses these considerations in an appropriate way.

The natural conditions of a dam site have a major influence over the dam design and safety. The process of design necessarily involves optimization among all of the objectives and competing demands of the dam development, safety and the whole-life-cycle cost. While it is recognized that dams cannot be absolutely safe, dam safety should be held to be of paramount importance in this optimization process.

The primary means of preventing and mitigating the consequences of accidents is ‘defense in depth’. This approach is implemented primarily through combining consecutive and independent levels of protection that would all have to fail before harmful effects could be caused to people, property or to the environment. If one level of protection or barrier fails, the subsequent level or barrier is available.

When properly implemented, defense in depth ensures that no single technical, human or organizational failure could lead to harmful effects, and that the combinations of failures of sub-systems that could give rise to overall system failure and significant harmful effects are very rare. The independent effectiveness of the different levels of defense is a necessary element of defense in depth.

Adequate Hydraulic and Structural Capacity

To this end, the design of a dam involves providing adequate structural capacity to withstand the forces of extremely large floods and earthquakes, and adequate hydraulic capacity to safely pass extremely large flows around the dam in a controlled way. The design must also involve arrangements to ensure that the dam can be operated safely under all conditions for which it has been designed. Safe operation includes achieving a balance between the hydraulic forces acting on a dam and the control of downstream effects of releases from the dam. In this context, safety of dams always involves some residual uncertainty. However, there are established minimal norms of dam safety that should be respected under all circumstances – for instance, a dam should not simply collapse on a sunny day.

The provision of adequate reserves includes consideration of the fact that the "as built" condition is not always the "as designed" condition and that, once constructed, dams are not readily modified except at considerable expense and with attendant construction risk. The safety and performance of the hydraulic and structural features are interdependent in themselves as well as being dependent to varying degrees on other factors including the site topography, natural hazards, the type of dam, the purpose of the dam and the economics of construction and operation.

In some countries, minimum requirements for hydraulic and structural capacity are specified separately, whereas in others there is reliance on industry accepted national guidelines or established good practices of design. However, achievement of the minimum specified requirement might not be sufficient protection depending on the importance of the dam, the potential causes and consequences of dam failure and the overall degree of risk.

With respect to hydraulic capacity, the main characteristics of inflows to reservoirs to be accommodated are the inflows at any point in time and the volume of the flood over time. How the reservoir is to be operated in response to floods must be specified at the design stage and documented as operational requirements. With respect to structural capacity, the dam and its appurtenant structures must be both strong and durable. In many cases it is necessary to consider balancing flood retention capacity (height of dam) with flood discharge capacity (size of spillway), project economics and the effects of releases from the dam.

5.4 Surveillance and Monitoring of Dam Performance and Operation

Surveillance and monitoring provide the basis for ongoing checking and analysis of the performance and operation of a dam, reservoir and river system, and thus provide fundamentally important risk control measures during the operational phase.

Surveillance and monitoring activities are focused on providing early detection of deteriorating performance by establishing performance criteria and threshold limits and confirming that:

- **Deformations of the dam structure are limited to those that are expected to occur during normal conditions, and those that are due to variations in ambient temperature and very high reservoir elevations.**

- **Leakage should be small and well within expected limits.**
- **Hydraulic outlets are maintained in a fully functional condition**

In the case of a well designed and constructed dam, deviations from the expected performance will be rare. However, ongoing good performance as determined from monitoring and surveillance activities does not provide a justification for relaxation of the arrangements.

The surveillance and monitoring arrangements are established at the design stage as are the expected performance characteristics that provide a reference against which any deviations are measured. Surveillance and monitoring parameters and locations are strategically placed to provide the optimal means of monitoring the performance of the dam. These arrangements include regular visual inspections, types and locations of instruments, types of inspections, and frequencies for data collection and interpretation and threshold values. In the case of existing dams where the performance characteristics expected at the design stage are not available, appropriate performance expectations are created by review of performance data and back analysis of the features and characteristics of the dam.

Surveillance and monitoring is carried out over all stages of the life of the dam: construction, impoundment and operation. However, there are important differences between the monitoring activities for the different phases. The phenomena to be measured and the modalities of the monitoring vary during these different phases. Secure data management and archiving are essential components of the programs.

The design of a monitoring device - which includes determination of phenomenon to be measured and choice of location - must be made to achieve two objectives: understanding of dam behaviour and detection of abnormal behaviour. An understanding of the operational modes of the components of the dam and analysis of their associated failure modes is required to achieve this latter objective: the sensors must then be arranged so as to detect the measurable and precursory signs of a failure mode. Analysis of the failure modes may also be required to set the frequency of measurements: the anticipated failure rate is the main parameter so that the readings frequency must be scheduled in such a way that a significant physical occurrence is not missed between two measurements.

5.5 Safe Operation and Maintenance

Safe operation and maintenance of dam and reservoir systems involves ensuring that:

- **Impounded water is retained within limits specified in the design or as subsequently modified**
- **Outflows are released in accordance with established procedures that control the flows, such that they are safely passed at the dam, and outflows can be safely accommodated downstream**
- **The dam, appurtenant structures, equipment, monitoring arrangements and devices required to achieve the safe containment and safe conveyance objectives, are maintained in good condition, are tested regularly, and any functional deficiencies are corrected**

The achievement of these objectives requires that the reservoir operating personnel are properly trained and supported by appropriate resources, and that the information and models that they base their operating decisions on are current and adequate for the situations that they have to deal with.

Achievement of these objectives also requires that a suitable maintenance management regime is established, staffed by appropriately trained personnel, provided with the necessary resources, and having the authority to maintain the dam, appurtenant structures, equipment, monitoring arrangements and devices as necessary. Many defects, usually caused by ageing and operational wear and tear, can be treated and eliminated during normal maintenance.

Debris and or sediment management may form a significant part of the maintenance effort as may the control of ice in cold climates. Safe operation and maintenance of dams usually includes maintaining safe access to the dam site for operational, maintenance, surveillance and monitoring activities.

5.6 Emergency Preparedness

While dam failures are rare, all dams require adequate and appropriate emergency preparedness and response arrangements.

The primary goals of preparedness and response to a dam breach emergency are to ensure that for reasonably foreseeable incidents, inundation consequences would be minor, and for any incidents or failures that do occur, practical measures are taken to mitigate consequences for human life and health, property, infrastructure, and the environment. The development of emergency response arrangements should include consideration of all reasonably foreseeable events. Emergency plans should be exercised periodically to ensure the preparedness of the organizations having responsibilities in emergency response.

Accident and incident management procedures should be developed in advance to provide the means for responding to deviations in dam performance and for regaining control of the reservoir or implementing a controlled spill in the event of a loss of control of the reservoir, and for mitigating any destructive consequences

5.7 Safety Assessment and Decision-Making Process

To be demonstrably safe, a dam should be managed within a structured, transparent process that includes periodic independent safety reviews, assessments and decision-making, so that any deficiencies can be corrected or mitigated by remedial measures.

The framework for dam safety management (Figure 2) includes decision-making after the question “Does the dam meet all requirements?” The Owner is responsible for ensuring that there is a robust process for making decisions when it is found that a dam does not meet the requirements.

Dams that are considered to be "satisfactory" in that they meet all requirements and performance expectations, typically continue in the normal cycle of operation, maintenance and emergency preparedness. The Owner is responsible for management oversight and providing periodic dam safety reviews to confirm this status.

If the dam is not found to meet all requirements and performance expectations, further investigations and assessments leading to remedial measures may be necessary. The decision process must also address the potential need for interim risk reduction measures before the necessary improvements are completed (Figure 3).

Establishing and managing the process is the responsibility of the Owner, but government and other stakeholders may be involved in the decisions. Inputs and considerations for the assessment and decisions are discussed in Section 6.

5.8 Independent Reviews

An independent peer review of the design and construction is essential before a new dam is commissioned and put into service.

Periodic and comprehensive independent dam safety reviews should be carried out throughout the operational life of a dam.

For new dams, particularly for large projects or smaller ones with complex conditions, it is advisable for the owner to appoint a board of consultants for "Peer Review" with the authority to guarantee that all appropriate technical and construction measures have been taken to ensure the operational and structural safety of the project.

For existing dams, safety reviews or assessments should be clearly and completely documented in formal engineering reports prepared to the same standard and quality assurance process as design reports. The report typically forms part of the permanent record of the condition, performance and safety status of the dam. In general, it can be expected that the safety assessment report will form the basis for renewal of any license or permit to operate. Independent review of existing dams by suitably qualified engineers enhances the strength of periodic dam safety reviews and overall safety assessment processes.

For existing dams, the report may include recommendations for dam safety improvements that the dam Owner should address.

6. ASSURANCE OF DAM SAFETY – AN INTEGRATED RESULT

6.1 Safety Goals

Owners of dams should provide authoritative and transparent demonstrations that their dams are safe, in that they are free of any conditions, deterioration or developments that could lead to their failure to safely pass floods or retain the reservoir.

The safety goals – performance requirements and expectations - should be built into the overall objectives of the dam development at the design stage, as are the means of achieving them over the whole life of the dam development. There are typically various objectives, which may be stated in terms of the performance of the dam development, including the following:

- **Water management**
- **Power generation**
- **Performance during and after severe natural events**
- **Operational performance, reliability and safety**
- **Environmental performance**
- **Community contributions**

Determination of the safety of a dam takes all of these matters into account with particular emphasis on confirmation that there are appropriate reserves of strength and hydraulic control, taking into account all reasonably imaginable scenarios of normal utilization and exceptional hazard which it may have to withstand at any time during its life. For existing dams, the determination of safety involves investigating whether or not the reserves of strength and hydraulic capacity that were provided at the design stage are adequate in the modern context, and whether or not the reserves have been maintained over the operational life to date.

6.2 Design Basis

The design basis and supporting considerations provide the primary framework for design and construction of dams and subsequent determination of the safety of existing dams. Clear and comprehensive documentation of the constraints and the considerations by which the designer and constructor have arrived at the as-built project is necessary for the efficient determination of the safety of the dam over its life.

A first order or initial determination of the safety of a dam can be made on the basis of the question "Does the dam meet the parameters of the design?" A second order determination of the safety of a dam can be made in terms of whether the measured performance of the dam is well within the expected performance limits as determined in the design. What constitutes “sufficiently large” is determined by local traditions and generally accepted norms as set out in locally applicable regulations, relevant national guidelines and ICOLD bulletins. In some cases for new dams, and in most cases for existing dams, it is appropriate to consider whether or not the original design basis is current and adequate for the modern context, as a precursory question.

In recent years, it has become clear that considering individual physical demands on dams in isolation is not sufficient to characterise the totality of the demands that might arise. Indeed, a dam might be subjected to more severe demands from a combination of structural and operational factors, all considerably less than the reasonably foreseeable extremes of each condition considered in isolation. In addition, transboundary issues may need to be addressed. Emergency conditions can arise during dam operation due to the combination of a number of conditions, none of which in themselves are particularly serious. It also may be necessary to operate a dam that has been damaged during a severe event such as an earthquake or a debris-laden flood, before or while it is being restored.

6.3 Pre-Operational Phases

Dam engineering requires the designer to balance a diverse range of complex and competing factors – both technical and non-technical - that are inherently uncertain, for reasons of nature. The majority of design considerations are very much site-dependent and can be approached only by using general technical principles, state-of-the-art and state-of-the-practice guidance. Safety considerations are spread across different project stages from the very first studies to the construction stage and commissioning.

The natural conditions that are encountered during construction may differ from those considered in the design, necessitating design changes which may have safety implications. These implications must be carefully considered by the designer and the design modified as necessary to ensure that the safety objectives will be met.

The owner/investor should establish rules for the designer in terms of reporting of all activities, explicitly including safety issues. Identification and control of human and organizational (non-technical) factors that influence safety are the responsibility of all the leaders of the entities involved in the development of a dam. The engineering quality controls provide the means to capture and correct omissions, misunderstandings, computational errors or other defects that might arise due to human and organisational factors.

Technical factors that can influence safety are usually linked to uncertainties in the determination of external loads acting on the structure or of the strength of the dam itself, its appurtenant structures and their foundations. In this regard, technical factors can be considered in terms of those that are external to the development process (e.g. weather conditions during construction) and those that are internal to the development that arise within the project arrangements (e.g. unanticipated characteristics of the materials incorporated in the works).

Uncertainty in the development phase of a dam is normally accommodated in terms of conservative assumptions about the controlling physical parameters in the design and construction, with the expectation that any residual risk will not be of significance. However, overly conservative assumptions can lead to excessive cost with little incremental safety benefit over less conservative assumptions. Ultimately, the determination of the balance between cost and conservativism in safety assessment is a matter of the owner, taking account of all legal regulatory expectations and the professional opinion of the designer and an independent board of consultants.

Surveillance and monitoring must be designed from the start of the project, since they are fundamental to safety through all life phases. Visual inspections by well informed staff are a key component. In general, more parameters are measured during construction and filling, and at a higher frequency, than during operation. It is extremely important to have continuity of the measurements between the construction phase and the operation phase. This enables better understanding of the behaviour of the dam and, in particular, ensures that its behaviour is consistent with the expectations of the project.

6.4 Operational Phase

Determination of the safety of existing dams requires investigations, analysis and assessment. At a minimum, the investigations involve site visits, interviews with operations staff, desk studies of design reports and monitoring data, surveillance interpretations, and synthesis of all this information. There are situations where field investigations are necessary to verify that the available information is current and adequate in the modern context.

Analysis and assessment of the safety of existing dams depends on:

- **Comprehensive records of the design and construction**
- **Data and measurements of performance since construction**
- **Observations of changes around the reservoir and its environs**
- **Maintenance records**
- **Records of unexpected events or conditions**
- **Operating procedures and operational records**
- **Range of suitable analytical methods**

If the necessary data and records are available, and if the dam is relatively new, safety analysis is largely a comparative exercise where the observed behaviour over time is compared with the predicted behaviour. Minor repetitive deviations that can be explained in terms of normal natural processes such as thermal expansion and contraction and which were considered in the design typically do not raise safety concerns. Under such circumstances, the level of safety can be deduced by comparison with the design parameters.

The operational procedures should be carefully examined and the prevailing operating rules and procedures should be compared with the design intent for currency and adequacy. Current operational records should be examined for consistency with past operations and any changes in demand for spillway discharges should be assessed for their effects on the performance and maintenance of the discharge outlets.

Safety demonstrations are often required for older dams that may have deteriorated to some degree due to the inevitable effects of normal ageing and wear and tear or other deterioration mechanisms, and where the records range from imperfect to almost non-existent. Inadequacies in such records means that the process of dam safety analysis relies heavily on inferences from whatever data is available, together with knowledge of the causes of poor performance of broadly similar dams in the past. Thus, those involved in analysing the safety of dams must be skilled in inferential reasoning and in comparative analysis against case histories and established experiences. It is inevitable that safety analyses of existing dams with limited records will be more uncertain than would be the case for new dams that are well monitored and documented. Further, performance demands may have changed since the dam was designed due to advances in the underlying science or because of increased societal expectations, or a new operational regime has been introduced.

The effective synthesis of all the information pertaining to the safety of dams requires considerable engineering expertise that transcends the multiple professional disciplines involved in the engineering of dams. As is the case with the teams involved in the design of dams, those involved in the safety assessment of existing dams should include experts in the various technical domains, as well as at least one individual with broad and deep expertise in the holistic analysis of the performance of dams. Effective synthesis of the information pertinent to safety involves utilisation of design techniques, models of how the dam and its appurtenant structures perform the water containment and conveyance functions, and various methods of reliability and risk analysis.

6.5 Decommissioning

Decommissioning of dams is a complex process requiring the full range of specialist capabilities that are required in design and construction.

The management of dam safety during the decommissioning process has many parallels with dam safety management during the construction stage.

Full control of inflows and the stored volume is required during the decommissioning process which inevitably erodes safety margins. Augmentation of the existing discharge capacity is usually an early stage activity during decommissioning, even for those dams with bottom outlets, as large floods are always possible during the decommissioning process which may take several years.

6.6 Measuring Dam Safety

In terms of structural and hydraulic considerations, a measure of a dam's safety is provided by the margin of the capacity of the dam over the structural and hydraulic performance demands that might be made over its life.

For a new dam, a measure of its safety is the margin which separates the conditions it is designed and constructed for, from those leading to its failure to safely pass floods or retain the reservoir.

For existing dams, the effects of aging and deterioration from years of operation in the natural environment should be accounted for and the safety determined by considering the actual state and performance capacity of a dam relative to those conditions leading to its failure to safely pass floods or retain the reservoir.

In cases where adequate documentation of the design and construction is not available, steps should be taken to provide sufficient information to assess the safety of the dam. This may require field investigations, re-analysis of structures and hydraulics etc.

To be minimally safe, the capacity must exceed the demand. The extent to which the capacity should exceed the demand is in part an engineering matter, in part an economic one, and ultimately it is a policy matter that is typically embodied in local practices and guidelines. However, large margins between capacity and demand are usually provided, with a common minimum being 50% more available capacity than expected demand. Much larger margins are common and are usually sought to accommodate the inevitable uncertainties that prevail in the engineering and operation of dams.

In recent years, probability of failure and levels of risk have emerged as additional measures of dam safety, to a limited extent. The use of probability brings the potential to establish a quantitative measure of the value of any safety improvements that might be made, with the view to optimising cost and safety. The probabilistic calculation is based on the same physical parameters as the traditional capacity-demand approach but also involves addressing the variability in these parameters to allow representation of the margin between capacity and demand in probabilistic terms. A decision to adopt a process that optimises the cost of dam safety is fundamentally a political one which includes moral and ethical considerations, as in general the public interest is at risk.

The recommended process for characterising the level of safety of a dam is as follows:

- [1] Systematically identify all the features of the dam
- [2] Determine the magnitude of the margin between the available structural and hydraulic capacities and the associated demands
- [3] Identify any features where the margin between capacity and demand falls short of generally accepted practice
- [4] Make a determination as to the safety of the dam in terms of a scale that covers the range of safety conditions from satisfactory to unsatisfactory.

In terms of established practice, a dam can be considered to be safe if all of the features meet or exceed established design and performance norms. On the other hand, a dam that does not meet all established norms can be considered to be potentially or actually deficient, in terms of safety. All contemporary methods of characterising the safety of dams, including probabilistic methods, are variations of this basic concept.

Quantification of the safety of dams, as in other domains, continues to evolve as new knowledge develops and as computing power increases. Methods of structural reliability analysis are now used in certain cases to calculate the reliability index of the structure, from which the chance of failure can be determined. Other established methods of quantifying the safety of dams include Fault Tree Analysis (FTA) and Event Tree Analysis (ETA). One emergent area of analysis involves considering the dam and reservoir as a dynamic system such that the possibility of combinations of adverse conditions arising can be considered explicitly and their influence quantified.

It must be recognised that the uncertainties that prevail in design and construction continue into the operational phase, and may even increase as a result of the normal effects of ageing, the way the dam is operated and maintained, or loss of records. Quantified estimates of the safety of dams inevitably involve large margins of uncertainty and even error that must be taken into account in dam safety decision-making that is based on numerical statements of the level of safety.

6.7 Audit and Safety Management Review

Dam safety assessments, reviews and audits should be carried out periodically, so that all parties - government, owner, and public - can be assured that dam safety is being managed appropriately.

Independent audit of the Owner's management processes and controls forms an important overarching safety assurance process. Such audits typically focus on the Owner's governance arrangements, adherence to policy commitments, conformance to the procedures in the management system, decisions made since the last audit including actions and inactions, resourcing levels in terms of financial resources and personnel, and the overall financial capacity of the dam owner to manage the risk associated with the Owner's dams

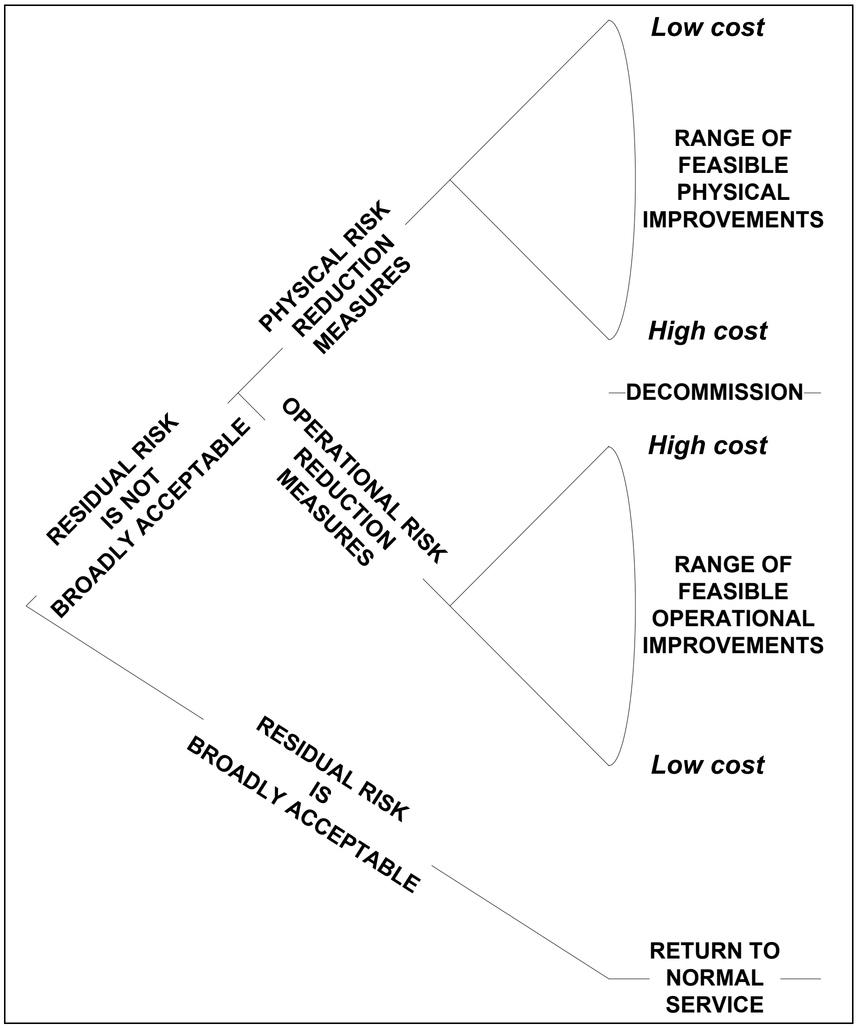
6.8 Risk Reduction, Rehabilitation and Operational Improvements

If a dam is found to be deficient or potentially deficient in terms of safety, the Owner is responsible for implementing appropriate safety control improvements in both the short term and the long term.

The responsible government authority or regulator should be kept appraised of the dam safety improvements as the dam will require re-certification (relicensing) when the safety improvements have been completed

Once dam safety investigations and assessments have been completed, if the dam does not meet all requirements and expectations, the Owner is responsible for implementing a follow-up action plan to control the risks. The contents of such a plan can range from "operate with enhanced monitoring and surveillance until next scheduled assessment," to a multi-year program of remedial works. In extreme cases, a retirement plan might be established for the dam. The decision process for risk reduction options is illustrated in Figure 3.

Figure 4. Decision Framework for Risk Reduction Options
(Applicable after question "Does dam meet all requirements?" in Figure 3



Rehabilitation of dams to account for all manner of changes since construction, as well as projects to enhance the original design capacity (e.g. reservoir raising to increase storage capacity), is increasingly common. Enhancement of original capacity could become more common in response to climate change either to permit safe handling of increased design floods or to improve the storage capacity. These projects can be exceptionally challenging and since they are carried out while the dam remains operational, great care is required in their design and implementation to ensure safety and the long term viability of the dam development under a different operational regime.

The situation of the safety of the system during the rehabilitation and enhancement works is potentially more complicated than in the case of the construction of a new dam, as frequently the dam must remain operational to some degree during the rehabilitation process. The design of the proposed works must be readily constructible given the constraints of the operation of the dam and construction capabilities. Throughout the whole process, effective control of the stored volume, inflows and outflows is of paramount importance. It may be appropriate to construct a temporary upstream cofferdam to perform the water retention function while the works are carried out.

6.9 Building and Maintaining Capability to Manage Dam Safety

Dam Owners should ensure that they have a safety culture and organisational arrangements to develop and maintain the capability needed to manage the safety of their dams.

Building and maintaining the organizational capacity and human capability to design, operate and maintain dams over the long term should be a major goal of a modern dam safety program. Important dimensions of building self-sustaining engineering and technical capacity and capability for dam safety include:

- Building and strengthening the dam engineering profession in developing countries
- Renewing and developing the profession in developed countries
- Dissemination of knowledge through training
- Succession planning and attracting young professionals to the dam engineering profession
- Research and development

Building and maintaining technical capacity to manage the safety of dams require sustainable funding mechanisms and co-operative arrangements between dam owners and other industry entities including local, regional, national and international professional groups.

ICOLD recognises that the acceptability of dams and their safety involves a dynamic process that is at the interface of social and environmental policy, national and international political agreements and positions, science and engineering. ICOLD and its Technical Committees continue to develop knowledge and understanding in these areas of sustainable human development, with the view to ensuring that the technical aspects of dams and their safety are presented and understood in transparent, publicly accessible and socially acceptable ways.