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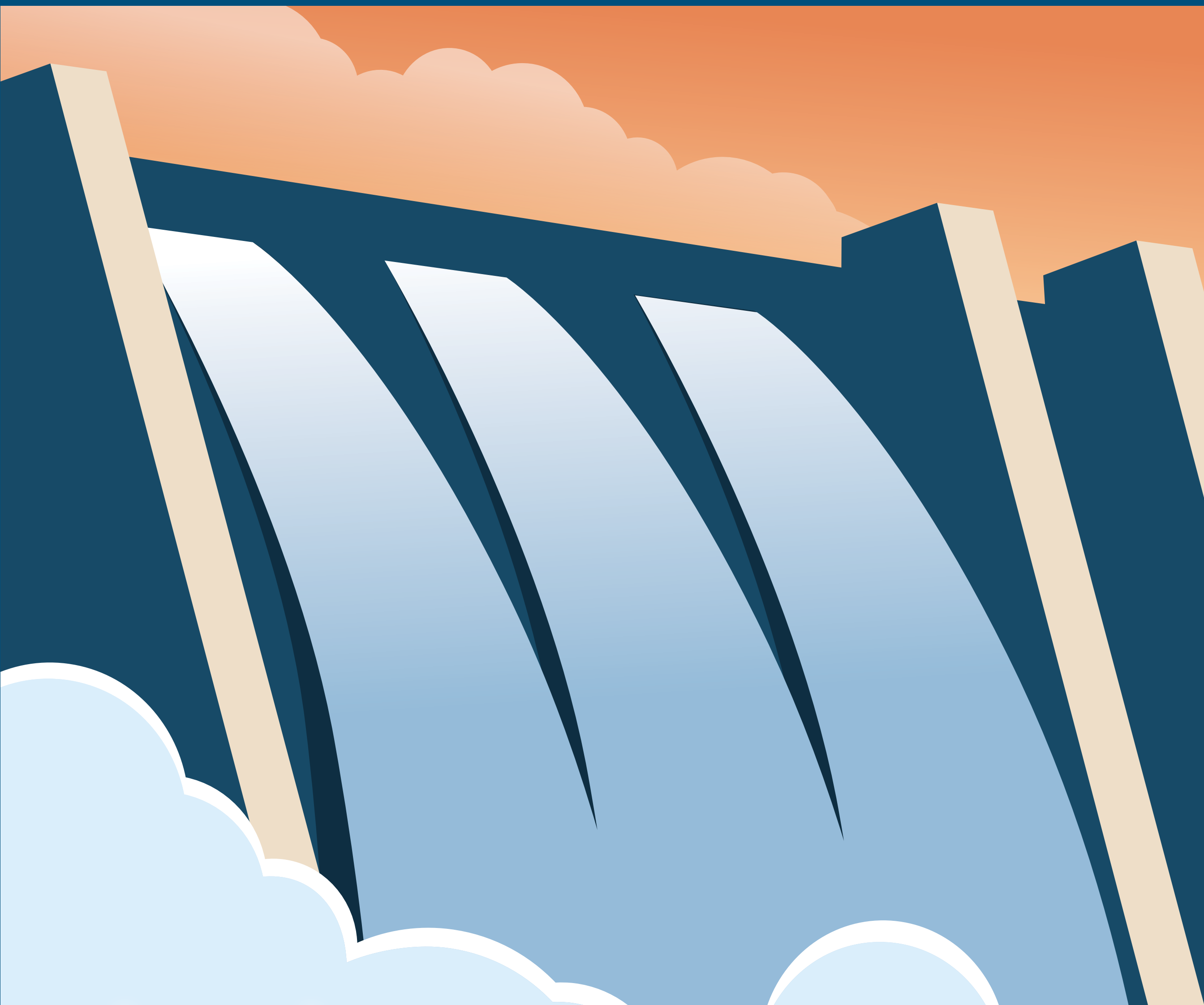

Laying *the* Foundations

A Global Analysis of Regulatory Frameworks for the Safety of Dams and Downstream Communities

WORLD BANK GROUP

Marcus J. Wishart, Satoru Ueda,
John D. Pisaniello, Joanne L. Tingey-Holyoak,
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Foreword

Achieving a water-secure world for all requires significant investments in sustaining water resources, delivering services, and building resilience. As the world faces an increasing gap between the forecasted demand for water and the available supply, water is at the center of economic and social development: it is vital to sustaining the environment, maintaining health, growing food, generating energy, and creating jobs. Water also encompasses some of the greatest threats to economic progress, poverty eradication, and sustainable development due to chronic water scarcity, hydrological uncertainty, extreme weather events, and the water-related impacts associated with climate change.

Sustainable infrastructure is, therefore, key to enabling a water-secure world for all. For thousands of years, societies have strived to manage the temporal and spatial variability of water to satisfy human needs and serve productive purposes. However, the challenge of delivering sustainable infrastructure is an increasingly complex one. The world's hydraulic infrastructure is aging, returns on new investments are diminishing, downstream populations are increasing, and changes in climate and weather patterns are creating greater uncertainty. The response requires measures that go beyond design and construction to encompass sound policies, smart regulation, strong institutions, and an increasing focus on risk-informed decision-making.

As the world's largest multilateral source of financing for water in developing countries, the World Bank supports a diverse portfolio of projects related to hydraulic infrastructure. These include new dam construction and rehabilitation programs, technical assistance, and sector reforms. While dams embrace complex social, environmental, and political choices, they also make important contributions to economic prosperity, improved resilience, and poverty reduction. Ensuring sound construction, safe operation, and sustained services from such infrastructure requires a sound regulatory framework that is durable and equitable and can safeguard downstream communities while enabling economic development. Establishing and maintaining an effective regulatory framework requires due consideration of the legal, institutional, technical, and financial elements within the reality of a country's context.

Recognizing the importance of assuring the safety of dams, safeguarding downstream communities, and sustaining productive assets, the World Bank has adopted a series of operational policies over the years. These include the Operational Manual Statement 3.80 "Safety of Dams" issued in 1977, Operational Policy 4.37 governing the safety of dams in 2001, and the inclusion of specific provisions in the Environmental and Social Framework that came into effect in 2018. These policies outline specific requirements of the borrower relating to investment projects. Where appropriate, and as part of the policy dialogue with the country, the World Bank also supports measures necessary to strengthen the regulatory frameworks for assuring the safety of dams.

Laying the Foundations provides a timely contribution to sharing approaches that promote the safety of dams and resilience of downstream communities. The objective is to provide guidance to policy makers and practitioners on good global practices for establishing regulatory regimes for dam safety. By reflecting on country case studies that represent a broad range of economic, political, and cultural circumstances, the report provides a valuable framework to inform policy decisions on dam safety that are tailored to the local context.

Jennifer Sara
Director
Water Global Practice
The World Bank

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Laying the Foundations: A Global Analysis of Regulatory Frameworks for the Safety of Dams and Downstream Communities is based on a comparative analysis of information derived from 51 country case studies. The study was led by a World Bank team with the generous support of many individual experts and partner organizations without whom this work would not have been possible. The team gratefully acknowledges their contributions to this immense body of global knowledge. However, the opinions expressed in this report and any errors herein are the sole responsibility of the authors and should not be attributed to the individuals or institutions acknowledged herein.

The World Bank team was led by Marcus J. Wishart (Lead Water Resource Specialist) and Satoru Ueda (Lead Dam Specialist) and included Kimberly N. Lyon (Water Resources Management Specialist), Esteban Boj García (Water Analyst), Naho Shibuya (Disaster Risk Management Specialist), Priyali Sur (Communications Specialist), and Yue Chen (Analyst). The technical and comparative analyses and the compilation of case studies were carried out by the Sustainable Engineering, Accounting and Law Group in the Division of Business and Law at the University of South Australia, led by John D. Pisaniello (Associate Research Professor) and Joanne L. Tingey-Holyoak (Senior Lecturer). The country case studies for Japan, the Lao People's Democratic Republic, and Myanmar were prepared by a team from Nippon Koei: Tomonori Abe (Managing Director), Ichiro Araki (Chief Dam and Hydropower Engineer), Junichi Fukuwatari (Acting General Manager, Water Resources and Energy Department), Takuji Kataoka (Chief Engineer), Shintaro Suzuki (Consultant), and Naoki Yamashita (Consultant).

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Abbreviations

ALARP	As Low As Reasonably Practicable
ANA	Agência Nacional de Águas (National Water Agency, Brazil); Autoridad Nacional del Agua (National Water Authority, Peru)
ANCOLD	Australian National Committee on Large Dams
ANEEL	Agência Nacional de Energia Elétrica (Brazilian Electricity Regulatory Agency)
APP	approved professional person
ASDSO	Association of State Dam Safety Officials (US)
BCU	basin country unit
BPA	Burnie Port Authority (Australia)
BPBD	Badan Penanggulangan Bencana Daerah (Regional Disaster Management Agency, Indonesia)
CAP	Common Alerting Protocol
CBA	cost-benefit analysis
CDA	Canadian Dam Association
CIRIA	Construction Industry Research and Information Association (UK)
CNRH	Conselho Nacional de Recursos Hídricos (National Water Resources Council, Brazil)
CSLS	cost per statistical life saved
DEFRA	Department for Environment, Food and Rural Affairs (UK)
DSC	Dam Safety Committee (NSW, Australia)

DSHA	Deterministic Seismic Hazard Assessment
DWS	Department of Water and Sanitation (South Africa)
EAP	Emergency Action Plan
EDF	Électricité de France (Electricity of France)
EPP	Emergency Preparedness Plan
ESF	Environmental and Social Framework
ESS	Environmental and Social Standard
EU	European Union
FEMA	Federal Emergency Management Agency (US)
FERC	Federal Energy Regulatory Commission (US)
FMEA	failure modes and effects analysis
FMECA	failure modes, effects, and criticality analysis
GDP	gross domestic product
GIIP	Good International Industry Practice
GRanD	Global Reservoir and Dam Database
GWP	Global Water Partnership
HPC	Hazard Potential Classification
HSE	Health and Safety Executive (UK)
IAEA	International Atomic Energy Agency
ICOLD	International Commission on Large Dams
IDF	inflow design flood
IE	initiating event
IRL	individual risk limit
JOTC	Joint Operations Technical Committee
LSM	Life Safety Model
MLIT	Kokudo-kōtsū-shō (Ministry of Land, Infrastructure, Transportation, and Tourism, Japan)
MPWH	Kementerian Pekerjaan Umum dan Perumahan Rakyat (Ministry of Public Works and Housing, Indonesia)
NASA	National Aeronautics and Space Administration (US)
NDSP	National Dam Safety Program (US)
NFIP	National Flood Insurance Program
NSW	New South Wales (Australia)
O&M	operation and maintenance
OASIS	Organization for the Advancement of Structured Information Standards
OBE	operating basis earthquake
ODSP	Owner's Dam Safety Program
OECD	Organisation for Economic Co-operation and Development
OMNR	Ontario Ministry of Natural Resources (Canada)
OP/BP	operational policy/Bank procedure
OPG	Ontario Power Generation (Canada)
PAIRQ	potential adverse impact on resource quality
PAR	population at risk
PEL	potential economic loss

PFMA	potential failure mode analysis
PHA	potential hazard associated
PLL	potential loss of life
PMF	probable maximum flood
PRA	portfolio risk assessment
PRM	portfolio risk management
PSHA	Probabilistic Seismic Hazard Assessment
R&D	research and development
RA	risk analysis
RC	risk category
SEE	safety evaluation earthquake
SFAIRP	So Far As Is Reasonably Practicable
SoO	Statement of Obligation (Victoria, Australia)
SPANCOLD	Comité Nacional Español de Grandes Presas (Spanish National Committee on Large Dams)
SPM	Safety Plan Matrix
TCM	Technical Characteristics Matrix
UCE	undesired central event
UK	United Kingdom
US	United States
USACE	US Army Corps of Engineers
USBR	US Bureau of Reclamation

Executive Summary

CONTEXT

Assuring the safety of dams is central to protecting downstream communities, infrastructure, and the environment. Dam safety is also important for securing water for productive purposes and sustaining economic development. With a global portfolio of more than 58,000 large dams, issues associated with the safety of dams and downstream communities are becoming increasingly important, particularly given aging infrastructure, increasing downstream populations, shifting demographics, and changes in climate and weather patterns.

While dam failures are typically low-probability, unpredictable events, they often have dramatic consequences. Catastrophic dam failures are characterized by the sudden uncontrolled release of water. Such failures can result in extremely adverse consequences, including large-scale loss of human life and significant economic and environmental impacts. Lesser degrees of failure can progressively lead to or heighten the risk of a catastrophic failure. As such, it is essential to establish a dam safety system that can ensure the safety of dams and downstream communities.

The foundation for effective dam safety assurance is an appropriate and well-designed regulatory framework that captures the legal, institutional, technical, and financial elements in the reality of a particular jurisdiction. Establishing and maintaining a regulatory framework that is fit for purpose is, therefore, necessary for ensuring the quality of dam design, construction, and operation and maintenance. The framework also ensures that safety measures are reflective of the risks inherent in managing these structures and the context in which they are developed. Such frameworks need to be developed as part of a holistic strategy for water management that is integrated in basin and regional planning processes.

OBJECTIVE

The objective of this global study was to lay the foundations for dam safety assurance by providing a comparative analysis of regulatory frameworks and assessing the range of legal, institutional, technical, and financial options that can be used by countries to inform the development of appropriate frameworks for sustainable assurance. The analysis was intended to (1) inform the establishment of regulatory regimes and institutional arrangements for dam safety assurance, (2) provide a framework for gap analyses aimed at enhancing existing legal regimes and institutional arrangements for dam safety assurance, and (3) guide the design of projects aimed at supporting the establishment or strengthening of regulatory frameworks for dam safety assurance.

These objectives are achieved by (1) providing a comprehensive set of country case studies with a balanced representation among a diverse set of countries with varying economic, political, and cultural circumstances; (2) carrying out a comparative analysis of the legal, institutional, and technical metrics along with financial and operating model analysis to identify a continuum of practice and precedents; and (3) recommending a set of legal, institutional, technical, and financial elements suitable for different country circumstances supported by a menu of options for consideration by policy makers.

COUNTRY CASE STUDIES

The analysis is informed by an assessment of 51 country case studies that are estimated to account for more than 95 percent of the world's dams registered with the International Commission on Large Dams (ICOLD) and 85 percent of total storage capacity. These countries cover nearly 70 percent of the world's total land area and include 80 percent of the world's population. They represent a range of economic circumstances: 18 high-income countries, 16 upper-middle-income countries, 14 lower-middle-income countries, and 3 low-income countries. All but one of the 51 country case studies are members of ICOLD, representing about half of the 101 ICOLD members.

ANALYTICAL APPROACH

The country case studies and the comparative analysis were carried out through an iterative process involving a series of consultations with more than 300 stakeholders over a number of years. A pro forma template was developed to provide a consistent structure with which to systematically identify and assess key elements of dam safety assurance along regulatory, legal, institutional, technical, and financial metrics. The analysis was guided by an international advisory panel and involved consultations with World Bank specialists as well as national experts. The process also included a series of regional workshops to facilitate the compilation of data, review information, and verify and validate the findings. A "regulatory mix pyramid approach" was adopted to identify a range of legal, institutional, technical, and financial options along a continuum that can be tailored to varying jurisdictional circumstances and country characteristics.

TOWARD A DECISION FRAMEWORK

This continuum is intended to inform a Decision Support Tool describing the key legal, institutional, technical, and financial elements and various options that should be considered when designing a regulatory framework for dam safety assurance. While the type of legal system and the constitutional basis for law making and administration will define how the regulatory environment can be implemented, the size of a country's portfolio of dams, their geometric dimensions, and their hazard potential and vulnerability will guide the main features of a suitable regime. Policy makers are confronted by widely varying characteristics, financial situations, and institutional arrangements. The Decision Support Tool is intended to help countries choose the most appropriate solution for their needs and context by leaning on a baseline theoretical framework through regulatory mix theory. The various considerations along this continuum enable the development of elements and models that can be considered along a spectrum for varying circumstances and in the systematic development of the most suitable approaches to dam safety assurance and the protection of downstream communities.

LEGAL FRAMEWORKS FOR DAM SAFETY

The enabling legal framework for dam safety assurance serves to establish the minimum standards, along with duties, roles, and responsibilities, for assuring the safe development and operation of dams. The legal foundations for dam safety assurance can come in various forms, depending on the type of legal system and the constitutional basis for law making and administration. A number of regulatory options exist along a continuum, ranging from highly prescriptive measures to broader framework legislation to self-regulating mechanisms. These are all informed by the legal traditions and specific geopolitical history of a country. Such provisions should also reflect the technical characteristics of the portfolio of dams, including the number and type of dams, the nature of ownership and financing arrangements, their sectoral distribution, as well as the potential hazard or consequence profile of the portfolio. It is important that the legal framework evolves with changes in the portfolio, demographic trends, and country conditions.

The type of legal system in a country will influence the agility of the dam safety legal framework to respond to changing circumstances and can have important implications for equivalence between jurisdictions. The primary responsibility for dam safety rests with the dam owner, and this should be clearly stipulated in the specific legislative provisions. Integrating dam safety provisions within broader framework legislation, such as for water or environmental legislation, is generally considered a practical first step in developing the initial regulatory provisions for dam safety. The legal framework for dam safety assurance should include specific, yet proportional, provisions for the following: (1) definition of dams subject to regulations; (2) roles and responsibilities of the dam owners and regulators; (3) dam safety standards and requirements commensurate with the potential hazard or consequence, typically through a dam classification system; (4) disaster risk management and emergency preparedness, especially in light of climate change, increasing population, and demographic changes; (5) required financial resources and human capital for dam safety; and, where necessary, (6) the identification and capture of dam-safety-related risks that are specific to transboundary settings.

INSTITUTIONAL FRAMEWORKS FOR DAM SAFETY

The institutions responsible for ownership, operation, and oversight of dam safety assurance are informed through the enabling legal framework. The nature of the institutional arrangements will reflect the composition and structure of the national portfolio, and there are several institutional options that infer different degrees of responsibility. The independence of institutions responsible for dam safety assurance can have significant implications for implementation and enforcement of the regulatory regime, and there is no single solution. The context prescribes the utility of the different options along a continuum, and where oversight mechanisms do exist, these can be implemented through centralized apex institutions, stand-alone sectoral entities, or subnational organizations that are fully independent, rely on a degree of self-regulation, or include a mixed approach. Central to any successful dam safety assurance system is ensuring that the institutional capacity is sufficient to meet the expected duty of care. This includes sufficient financial resources, human capital, and technical capacity to respond to the challenges of the portfolio under management and regulation.

A clear statement of primary responsibility for the safety of the dam is a key element of any regulatory framework for dam safety. This clear definition is a prerequisite for ensuring accountability in the case of personal or property damage due to a dam failure or during the operation of the dam.

While some responsibility can be shared, delegated, or contracted to others, the dam owner is universally recognized as the primarily responsible entity for the safety of the dam and appurtenant structures, and is further responsible for ensuring that the dam is operated safely. Maximum assurance is usually realized through an independent regulatory authority and uniform regulations that apply across sectors and integrate transboundary considerations. The powers and functions of the regulating authority can exist along a continuum of compliance audit, quality assurance, or direct inspection. These should be determined by the portfolio characteristics and distributed with due consideration of issues associated with potential liability and the capacity of the regulatory system to address these. It is important to allow for a continuous process of improvement that can ensure that the institutional arrangements adapt to the changing nature of the portfolio and downstream demographics.

CONTENTS OF THE REGULATORY REGIME

The contents of the regulatory regime reflect its specific mandates and technical requirements pertaining to dam safety assurance. These include the specific roles, powers, and responsibilities of the regulator and the specific duties and responsibilties of the dam owner, operator, and any other parties involved. The key elements and provisions of any dam safety regulation include the following: (1) capture of regulated dams, (2) proportioning mandates according to classification, (3) dam safety design standards and criteria, (4) requirements for surveillance and inspection, (5) requirements for operation and maintenance, (6) record-keeping requirements, (7) education and training, (8) legal status of guidelines and standards, and (9) enforcement and arbitration.

Dam classification systems are particularly useful in proportioning dam safety requirements, such as design standards and duties of care, depending on potential hazard. This allows for optimization in the allocation of financial and human resources. Different countries have developed different systems, such as size-based or hazard-based classification or a combined approach, considering the socioeconomic conditions and resources available to the owners and regulators. Provisions for owner education and guidance are also important for continuous improvement in assuring the safety of dams and downstream communities. Country-specific guidelines are essential to act as guidance for dam owners and their engineers and/or to set minimum dam safety management and design standards that are appropriate to the circumstances of each country. Further, provision for compliance monitoring and enforcement is essential to realizing the objectives and intentions of the regulatory regime and its contents. This requires sufficient financial resources, human capital, and technical capacity for the regulator to police and enforce compliance and can be enhanced through a range of mechanisms.

RISK-INFORMED DECISION-MAKING

Risk-informed approaches are increasingly being used to inform dam safety assurance. This reflects growing recognition that there are a number of dam safety incidents caused by nonstructural elements that are not well captured by the traditional standards-based approach. The changing nature of portfolios at the country level coupled with the evolution of societal values and stakeholder expectations advocate for the application of more risk-informed approaches. Such approaches are also introduced under the World Bank's Environmental and Social Framework that became effective in October 2018, recognizing that the risks associated with a dam are design and situation specific and will vary depending on the structural components, socioeconomic factors, and the environment within which the dam is being constructed and will operate. The provisions of any approach, therefore, need to be proportionate to the size, complexity, and potential risk associated with the dam.

There is a wide range of tools for risk assessment, from relatively simple, qualitative analysis to semiquantitative assessments such as risk indices to more complex and rigorous quantitative methodologies using failure probability. The selection of a suitable technique should depend on the complexity of a particular dam safety condition, required remedies and/or potential hazard, and the specific country context. Such approaches can lead to more efficient allocation of resources, prioritized remedial measures, and monitoring activities.

While there are clear benefits to risk-informed approaches, it is important to recognize that they can be complex and require considerable resources. Careful consideration needs to be given to the legal foundations and requirements for introducing portfolio risk assessment and management if it comes with the notion of an acceptable or tolerable risk. Such a specific threshold is country specific and not applicable in most civil law countries. It will invariably reflect broader societal and cultural values and, importantly, will change over time as society's values and expectations change. The risk-informed framework needs to be reviewed, revised, and subjected to a process of continuous improvement to ensure the continued safety of dams and downstream communities. While the importance of risk-informed approaches is expected to increase, such approaches should be used as a complement to the standards-based approach and not as the only decision basis used in the management of dam safety risks. Other elements should include consideration of engineering principles, standards, and current good practice; owner or wider societal values; and stakeholder expectations and perceptions. Properly structured risk-informed approaches can contribute to effective resource mobilization to enhance overall dam safety at various levels to assist countries in developing practical and effective risk management systems suited for the country-specific contexts.

EMERGENCY PREPAREDNESS AND PUBLIC SAFETY

Emergency preparedness is a critical element to assuring the safety of dams and downstream communities. While dams are, in principle, designed and constructed to ensure their safety against foreseeable extreme events and maximum loads, they can face additional threats. These can include extraordinary events beyond the design criteria, structural deficiencies, equipment malfunctions, deterioration of structures or equipment due to aging, human errors, and deliberate destructive actions, such as terrorism and cyberattacks. Public safety should also be covered as part of any effective dam safety assurance program, including safety from operations resulting in sudden or unsafe releases of water, failure of the electro-mechanical system, and unrestricted public access to hazardous areas around dams and reservoirs.

Emergency Preparedness Plans (EPPs) are increasingly mandated and are essential in providing a predetermined plan of action that a dam owner should implement if a dam safety emergency develops. Clear technical guidelines should be established for the scope and preparation of EPPs, using potential failure mode analyses where appropriate. Essential elements include the identification and evaluation of potential threats, procedures for warning downstream areas at risk, and emergency actions. These plans allow dam owners, operators, local governments, and emergency agencies to undertake their respective roles and actions, including emergency notification and evacuation, in a coordinated and timely manner to minimize damage in areas affected by a potential dam failure or mis-operation.

FUNDING DAM SAFETY

The financial framework for ensuring sufficient funding to sustain dam operations and the regulatory assurance scheme is critical to dam safety and to maximizing the productive asset value and life of dams. Funding is needed to sustain evolution of the policy environment and the underlying understanding of the sector context, including hydrometeorological conditions, increases in downstream populations, and changing land use associated with individual catchments. Funding is also needed to address deterioration due to aging infrastructure, changing technical standards, and improved techniques. The resource requirements for dam safety and potential revenue mechanisms are determined by the ownership structure (public or private), the type of services provided (hydropower, water supply, irrigation, flood protection, and so forth), and the nature of the oversight mechanisms (self-regulation or autonomous regulators). These can significantly impact the quality of dam safety management and the level of assurance.

The financial resources required to sustain the regulatory regime and oversight mechanisms can be derived from two basic sources of sustainable revenues: taxes through budgetary allocations from government, tariffs through user-pay systems and service fees, or a combination. Distinct differences are observed in funding mechanisms for both dam safety assurance and dam safety management when considering the sector and ownership models. Regulatory frameworks for dam safety assurance are more commonly funded by a mixture of government tax-based revenues and payments generated from users. However, the ability to fully meet the expected requirements in many parts of the world is undermined by user fees and tariffs that continue to be below full cost recovery and by competing financial demands on limited government budgets. Strategic financial planning coupled with tools to facilitate the prioritization of dam safety measures and resources within a portfolio can be useful in constrained budget environments. Balancing these considerations should be positioned within a multicriteria framework that can match the resources with the requirements to address the broad range of needs in assuring the safety of dams and downstream communities.

TRANSBOUNDARY DAM SAFETY

Assuring the safety of dams and downstream communities within the context of internationally shared or subnational transboundary river basins presents a unique set of challenges that have largely been underestimated. Limiting the definition of dams with international character to those where the abutments lie in different countries captures only a very small number of such dams. Extending the definition to include dams located in a transboundary basin whose failure or mis-operation could cause a potential impact considerably increases the number.

While dam safety is typically administered at the national and/or state level, there are important public safety and economic security considerations associated with dams in transboundary rivers that are shared between different countries or subnational jurisdictions within a country. These include different, and sometimes conflicting, legal, cultural, and political regimes; enabling institutional arrangements; and historical considerations informed by socioeconomic and biogeographical features. The coexistence of different legal and institutional regimes within transboundary river basins can create the potential for different standards and duties of care.

Given the potential disparity of dam safety legal regimes within a transboundary basin, a minimum level of coordination among riparian or subnational states is required to ensure the safety of dams and downstream communities. Dams attributed with international character need to be properly captured by the dam safety assurance regime. Provisions within the basin and among the riparian states, or subnational jurisdictions, should be evaluated to determine the degree of equivalence among the legal regimes and ensure a minimum level of assurance across the basin. In certain instances, it may be necessary to address inconsistencies between the legal frameworks by subjecting transboundary infrastructure to a unique set of dam safety requirements. Measures should also be introduced or enhanced to facilitate the exchange of information relating to operations, improve coordination around emergency preparedness, and advance internationally recognized principles, such as the obligation to do no harm and ensure equitable and reasonable use.

A DECISION SUPPORT TOOL

Assuring the safety of dams and downstream communities requires considering a range of options appropriate to various jurisdictional circumstances with different portfolio characteristics, human and financial resources, and population locations and growth. The desired regulatory framework for assuring the safety of dams and downstream communities is one that affords the maximum level of assurance. However, this level will depend not only on the structural elements and the prevailing policy environment but also on the ability to realize the intentions of the regulatory framework. The framework for assuring the safety of dams and downstream communities, therefore, needs to be part of an integrated strategy for water resource management that is positioned within regional planning and basin management processes.

A Decision Support Tool has been developed that aggregates the information derived from the global analysis to inform the design of a regulatory environment for assuring the safety of dams and downstream communities. A series of regulatory design principles has been identified in regulatory mix theory that emphasizes the importance of choosing complementary instrument combinations that can be mixed to enable movement from minimum assurance to maximum assurance. These combine to identify a series of options from which policy makers can decide on the appropriate mix for country-specific considerations. These are not mutually exclusive, and decisions on an optimal level of assurance will be informed by the country's characteristics, such as the constitutional basis for law making and administration, and those of the portfolio of dams, such as the size of the portfolio, the type of dams, and the assessed risks and hazards.

The global analysis of regulatory frameworks for the safety of dams and downstream communities demonstrates that single-instrument approaches are unlikely to be successful for regulating dam safety assurance in any setting and that in order to avoid the consequences of dam failures, minimum and maximum assurance elements need to be positioned in such a way as to provide a continuum of options with various models of enforcement available. When combined with the comparative analysis of the country case studies, this continuum lays the foundation for the development of a consolidated regulatory framework for dam safety assurance and a Decision Support Tool that can be applied to country-specific settings. The Decision Support Tool enables various alternatives to be explored, ranging from minimum dam safety requirements that a regulatory framework for assuring the safety of dams and downstream communities should aim to achieve to more complex features suited to accommodate portfolios with different characteristics.

1

Dams and Development: An Introduction

DEVELOPMENT CONTEXT

Dam safety is central to public protection and economic security. For thousands of years, societies have developed hydraulic infrastructure to manage temporal and spatial hydrological variability and ensure that water is available to satisfy human needs and to serve productive purposes. This infrastructure has been used to make water available at the right time, in the right place, and in the right quantities to deliver a range of services. During this time, the development and operation of dams have made important contributions to economic prosperity and poverty reduction.

Dams and reservoirs provide water to generate power and to improve food security through irrigation. They supply drinking water and sustain other domestic and industrial demands, they enable the inland transportation of goods and people between economic centers, and they improve resilience by providing protection from floods and droughts. Due to their versatility in use, dams and their respective reservoirs are not only important for economic activity but often become scenic landscapes with recreational value.

As climate variability increases and the number of people living in urban centers grows, the value of water storage will increase. Dams and reservoirs can provide economic empowerment and security to the poor and other vulnerable groups by improving resilience, controlling flood waters, and minimizing the impacts associated with droughts. Not only do floods and droughts force millions of people into poverty each year, but they disproportionately affect the poor. Many of the effects extend beyond material asset loss, sometimes resulting in permanent impacts on livelihoods, health, and education (Hallegatte et al. 2017).

Dams also embrace a broad range of complex social, environmental, and political choices on which the human aspiration to development and improved well-being depend (WCD 2000). While dams have been important contributors to the development of many countries, they fundamentally alter the rivers along which they are developed and the use and distribution of the natural resource, posing risks to aquatic life, the surrounding environment, and the downstream communities that depend on them. The development of dams and the management of reservoirs, therefore, need to be part of an overall water management system that is integrated within basin and regional planning; their development should also engage a diverse group of stakeholders to consider the range of development options and alternatives that may be available.

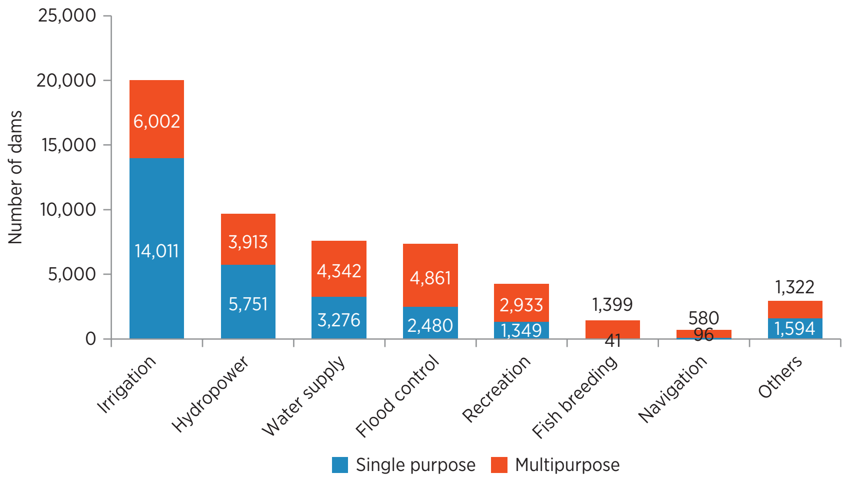
Given the social and economic dependence on these structures, dams must be maintained in good operating condition and reservoirs managed safely. Keeping dams safe and in good operating condition is paramount to the economic security and public safety of surrounding areas and downstream communities. It is also the only way to extract the full economic and financial value of the services provided by these long-lived investments. In order to promote a culture of enhanced dam safety and better risk management, dam owners need to be held responsible for implementing safety measures within a clearly prescribed legal and institutional regime. Equally as important as the reduction of possible accidents arising from dam failures is the enforcement of safety standards by regulatory entities in charge of promoting good practices.

DAMS AND RESERVOIRS: A GLOBAL PICTURE

The world has a large stock of large dams (figure 1.1). The World Register of Dams maintained by the International Commission on Large Dams (ICOLD)[1] includes approximately 60,000 large dams and their corresponding attributes among its 101 member countries. Large dams are defined by ICOLD as those with a height of 15 meters or more from the lowest foundation to the crest, or a dam between 5 meters and 15 meters impounding more than 3 million cubic meters of water.[2] The East Asia and Pacific region accounts for half of all dams registered with ICOLD, while Latin America and the Caribbean, Middle East and North Africa, and Sub-Saharan Africa each account for less than 5 percent of ICOLD-registered dams.

Roughly half of the world's large dams are multipurpose (figure 1.1), although the majority are developed with irrigation as the primary purpose. Most of these are located in East Asia and the Pacific, although it should be noted that 65 percent of all dams registered with ICOLD from East Asia and the Pacific do not include any data on how they are used. Irrigation dams also account for the vast majority of dams registered with ICOLD from

FIGURE 1.1 Number of dams worldwide, by primary purpose



Source: Based on ICOLD, "General Synthesis," Paris (accessed December 2017), http://www.icold-cigb.org/GB/world_register/general_synthesis.asp.

TABLE 1.1 The distribution of dams, by region and primary purpose

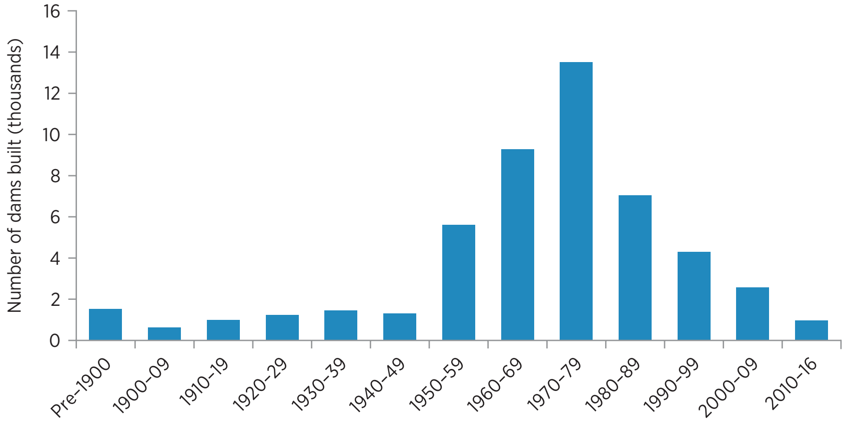
Primary purpose	East Asia and Pacific	Europe and Central Asia	Latin America and the Caribbean	Middle East and North Africa	North America	South Asia	Sub-Saharan Africa	Total
Irrigation	7,104	2,192	769	1,032	1,118	4,921	1,133	18,269
Hydropower	1,496	2,447	1,048	51	1,893	170	131	7,236
Water supply	720	1,532	265	138	1,657	65	344	4,721
Flood control	1,023	448	74	135	2,770	4	7	4,461
Other	50	351	336	119	2,951	—	50	3,857
No data	19,198	140	141	32	46	221	196	19,974
Total	**29,591**	**7,110**	**2,633**	**1,507**	**10,435**	**5,381**	**1,861**	**58,518**

Source: Original table for this publication based on ICOLD, "World Register of Dams," Paris (accessed July 2017), https://www.icold-cigb.org/GB/world_register/data_search.asp.
Note: — = not available.

South Asia (91.5 percent), Middle East and North Africa (68.5 percent), and Sub-Saharan Africa (60.9 percent).

The primary purpose most cited after irrigation is power generation. Hydropower remains the world's largest source of renewable electricity generation, representing more than 15.7 percent of global generation from any source and 61.8 percent of generation from renewable sources of energy (IEA 2019). The majority of registered hydropower facilities are located in Europe and Central Asia (table 1.1), with North America and East Asia and Pacific closely following. Flood control is the primary registered purpose in less than 10 percent of the large dams registered with ICOLD in all regions, with the exception of North America, where flood control accounts for 26.1 percent of the portfolio.

FIGURE 1.2 The development of dams over time



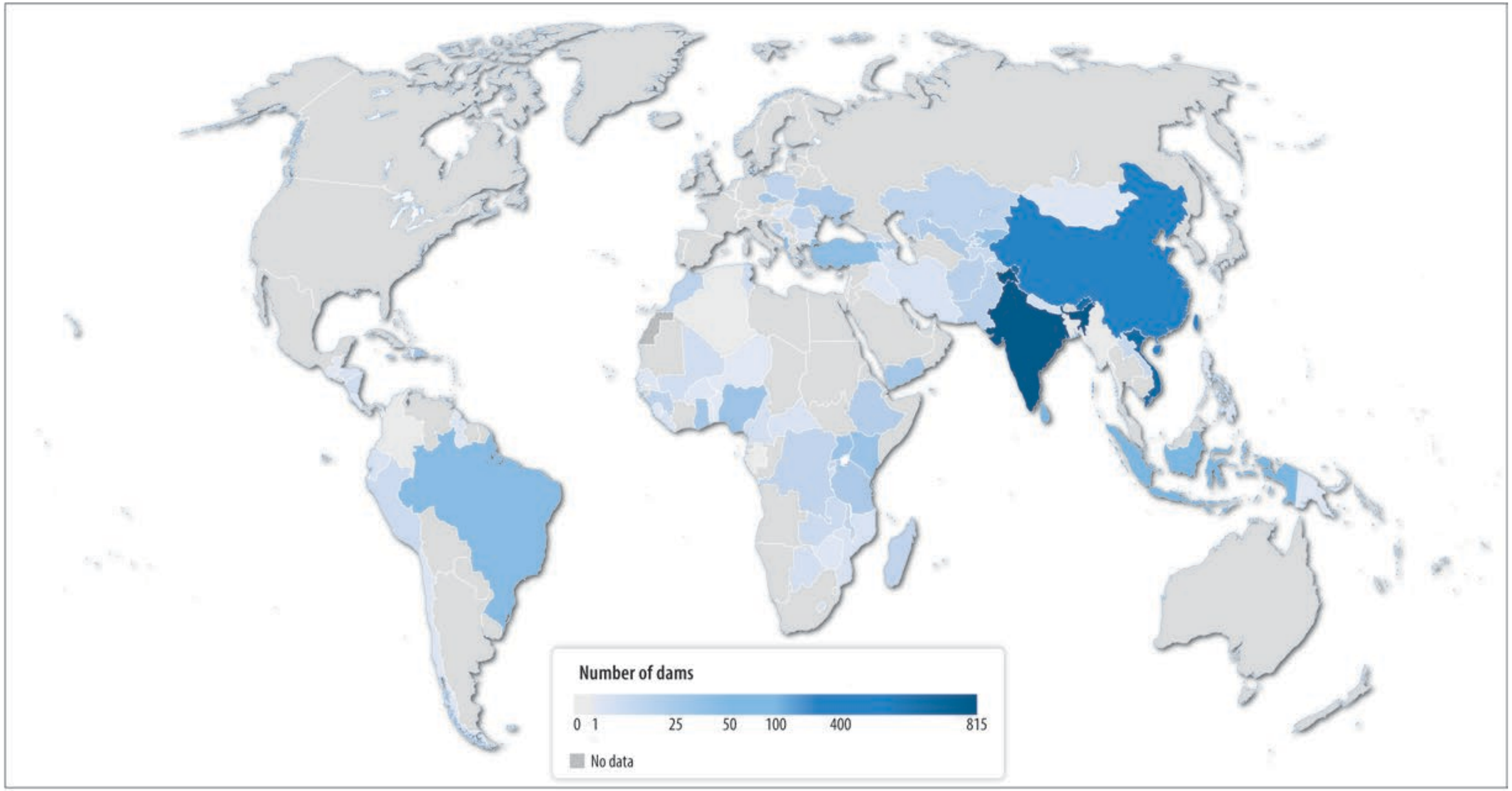
Source: Original figure for this publication based on ICOLD, "World Register of Dams," Paris (accessed July 2017), https://www.icold-cigb.org/GB/world_register/data_search.asp.

The world's dams are aging as populations are increasing. A large share of dams registered with ICOLD were built between 1950 and 1989, with more than 19,000 dams in operation for 50 years or more (figure 1.2). The world's large dams make a significant contribution to the efficient management of water resources that are unevenly distributed and subject to large seasonal fluctuations. However, with age comes deterioration, and the increasing number and ages of large dams, coupled with changes in downstream demographics and economic asset value, requires increasingly sophisticated tools and management approaches capable of identifying and managing associated risks.

WORLD BANK ENGAGEMENT WITH DAMS

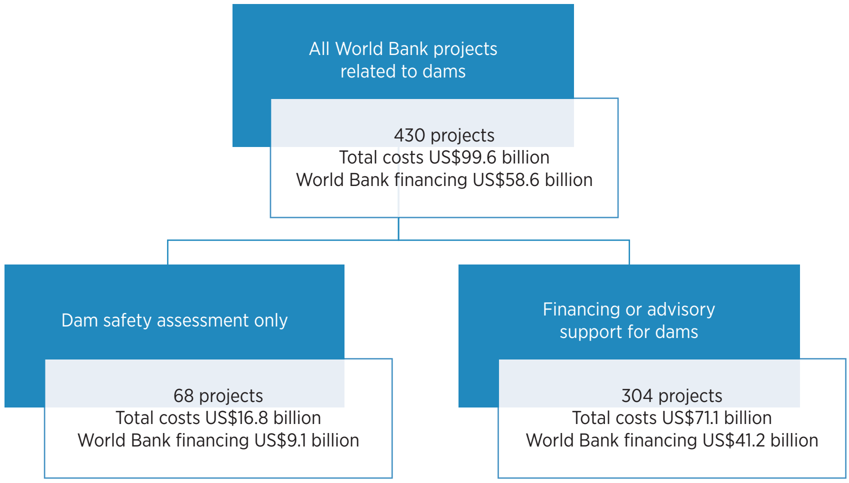
The World Bank Group supports a diverse portfolio of projects related to dams in more than 90 of its 189 member countries (map 1.1).[3] This includes small and large dams and covers interventions ranging from new dam construction and rehabilitation programs to technical assistance and sector reforms. The World Bank supported the preparation and implementation of 430 projects in over 90 countries between fiscal years 2002 and 2019 (figure 1.3).[4] This includes support to the construction of new dams, such as those in Cameroon, Kenya, Lebanon, Lesotho, Pakistan, and Vietnam, among others, as well as stand-alone rehabilitation projects for individual large dams, such as the Kariba Dam in the Zambezi River Basin, the Corumana Dam in Mozambique, and a cascade of hydropower dams in Albania and Ukraine. It also includes support to major dam safety programs, such as those in Armenia, India, Indonesia, Sri Lanka, and Vietnam, among others. The total project costs, including dams and associated downstream water supply and

MAP 1.1 **Distribution of World Bank–financed projects involving dams**



Source: Original map for this publication.
Note: Based on data as of 2019.

FIGURE 1.3 World Bank–financed projects involving dams, FY02–FY19



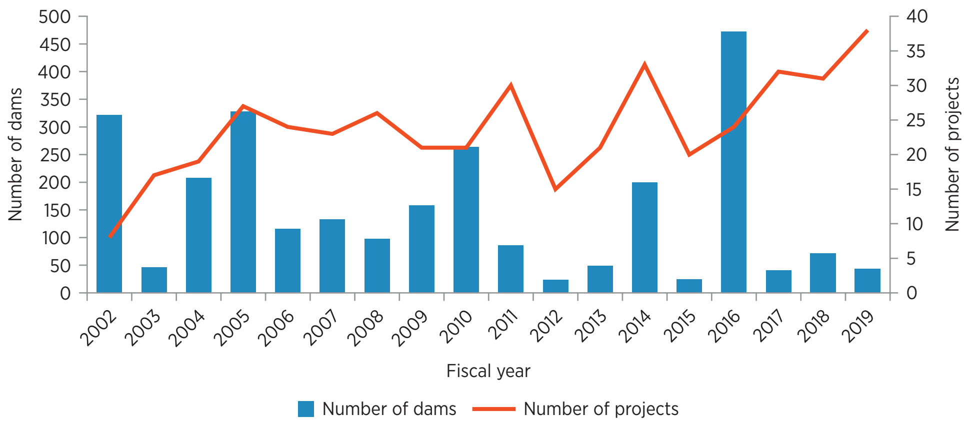
Source: Original figure for this publication.
Note: For this analysis, there were 56 projects that had triggered the World Bank policy on the safety of dams either as a precautionary measure or as part of a framework project approach. For these, the exact scope related to dams is to be determined.

hydropower generation facilities, are estimated at nearly US$100 billion, with World Bank commitments of more than US$58 billion. The World Bank is also supporting major technical assistance programs relating to dam safety, including in Brazil, the Lao People's Democratic Republic, and Nepal.

The portfolio of projects supported by the World Bank that involves dams has been relatively steady over the past 15 years, with 15 to 25 new projects approved on average each year (figure 1.4). From 1970 to 1985, it was estimated that World Bank financing was involved in about 3 percent of the world's new dam projects. Over the following 10 years, the World Bank's rate of involvement fell to about 2 percent. In 2001, World Bank loans for dams were estimated to have fallen and accounted for approximately 0.6 percent of the world's financing for new dams in low- and middle-income countries (World Bank 2001). The magnitude of the World Bank's support to dam programs has varied substantially from year to year. This is due, in part, to the lengthy preparation required for dam projects, the changing nature of the international market, and the fact that there are few large, national-scale dam programs.

There has been an upward trend in new dam construction in recent years, reflecting a consolidated response across sectors to help address energy, water, and food security. However, in many countries this increase in new dam construction has often moved at a faster pace than the evolution of legal, institutional, and regulatory frameworks; as a result, governments may not have sufficient capacity to ensure dam safety management. Additional challenges for these countries include enhancing dam safety through quality assurance measures during design and construction, establishing secure financing mechanisms that provide sustainable revenue streams, and enabling objective and transparent risk-based portfolio approaches.

FIGURE 1.4 Number of World Bank–financed projects and associated dams approved in FY02–FY19



Source: Original figure for this publication.

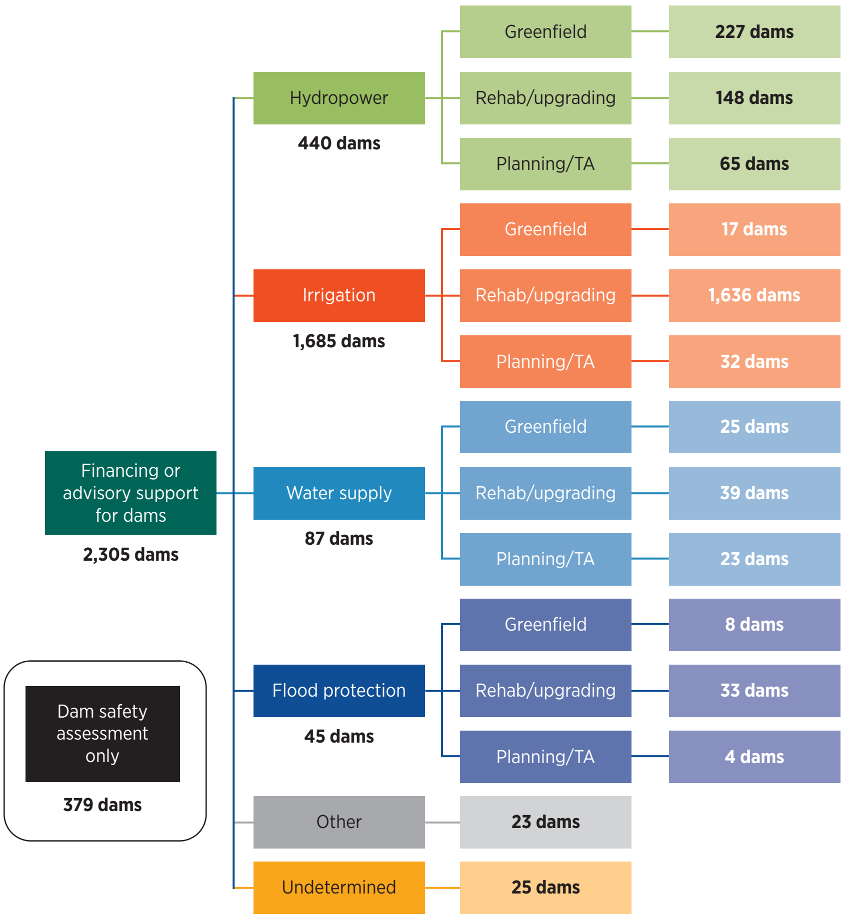
An increasing number of member countries have called on the World Bank to take a lead role in advising on the frameworks and capacity development required to ensure an acceptable level of dam safety. This complements a growing World Bank portfolio of dam safety and rehabilitation projects and the mobilization of investment funds for new dam developments.

The majority of World Bank financing in support of dams is directed toward the rehabilitation and upgrading of existing facilities (figure 1.5). The majority of these dams are irrigation dams that suffer from the absence of irrigation services fees, which would normally provide the revenue needed to support regular operation, maintenance, and rehabilitation. The high demand for World Bank financing for irrigation facilities also reflects the active role of governments in the provision of irrigation services in many countries.

The role of dams in improving and expanding power generation, irrigation, and domestic and industrial water supplies, in addition to mitigating the impacts of floods, has been an important contributor to the economic development of many countries. Given the consequences should a dam not function properly or fail altogether, the World Bank is concerned about the safety of both the new dams it is financing and existing dams on which any World Bank–financed project is directly dependent.

While the owner of a dam is typically responsible for ensuring that appropriate measures are taken and sufficient resources are provided for its safety, projects supported by the World Bank require a number of specific measures, irrespective of the funding sources or construction status (box 1.1). These requirements are outlined in Operational Policy 4.37 governing the safety of dams and Environmental and Social Standard 4 on Community Health and Safety under the Environmental and Social Framework that came into effect on October 1, 2018. Where appropriate, as part of policy dialogue with the country, the World Bank also supports measures necessary to strengthen the institutional, legislative, and regulatory frameworks for dam safety programs.

FIGURE 1.5 Small and large dams supported under World Bank–financed projects approved in FY02–FY19, by primary purpose



Source: Original figure for this publication.
Note: Figures do not include small water-retention or water-diversion structures, including tanks, levees, check dams, and so forth. TA = technical assistance.

BOX 1.1

WORLD BANK OPERATIONAL POLICIES ON THE SAFETY OF DAMS

The importance and relevance of ensuring dam safety has long been recognized by the World Bank. The Operational Manual Statement (OMS) 3.80 "Safety of Dams," issued in 1977, made it clear that dam failure due to natural phenomena or inadequate design can have disastrous consequences, underscoring the importance of dam safety. This OMS was revised and reissued twice to reflect evolving thinking on dam safety issues before being

(continued)

BOX 1.1 *(continued)*

replaced by Operational Policy and Bank Procedure 4.37 in October 2001. This extended the application of the policy's provisions beyond water storage dams to include tailings, slimes, and ash impoundment dams.

Operational Policy 4.37, on the safety of dams, is 1 of 10 World Bank "safeguard policies." These policies require that potentially adverse environmental and selected social impacts of World Bank–financed projects be identified, and avoided or minimized to the extent feasible, or mitigated and monitored. The principal objective of the safeguard policies is thus that of "doing no harm," and specific provisions require that the dam be designed and its construction supervised by experienced and competent professionals. It also requires that the borrower adopt and implement certain dam safety measures for the design, bid tendering, construction, operation, and maintenance of the dam and associated works.

Application of, and compliance with, the safeguard policies has demonstrated that their use can achieve much more than just avoiding harm. Going beyond compliance, and making development objectives the goal of the safeguard policies, is the World Bank's current endeavor. In this context, Operational Policy 4.37 recommends, where appropriate, as part of the policy dialogue with the borrowing countries, that World Bank staff discuss any measures necessary to strengthen the institutional, legislative, and regulatory frameworks for dam safety programs in those countries.

In August 2016 the World Bank adopted the Environmental and Social Framework (ESF). The ESF is intended to protect people and the environment from potential adverse impacts that could arise from World Bank–financed projects, and promotes sustainable development. The framework provides broad coverage, including important advances on transparency, nondiscrimination, social inclusion, public participation, and accountability. It offers a broader and more systematic coverage of environmental and social risks that also places more emphasis on building borrower governments' own capacity. The ESF applies to all projects whose concept notes are approved on or after October 1, 2018. Projects with concept notes approved before October 1, 2018, are still subject to Operational Policy 4.37.

The ESF sets out a risk management approach for projects built on the World Bank's risk classification system, coupled with the concept of proportionality. The risk classification system is based on the probability of a certain hazard occurrence combined with the severity of impacts resulting from such occurrence. The risks associated with a dam are design and situation specific, and will vary depending on the structural components, socioeconomic factors, and the environment in which the dam is being constructed and will operate. Application of the requirements under the ESF will need to reflect

(continued)

BOX 1.1 *(continued)*

these considerations and be proportionate to the size, complexity, and potential risk posed by the dam. Guidance on application of the requirements relating to the safety of dams under the ESF is provided to World Bank staff and borrowers through a Good Practice Note and a series of Technical Notes.

Specific provisions relating to the safety of dams are outlined in Environmental and Social Standard (ESS) 4: Community Health and Safety. Paragraph 4 notes, "Where the project involves a new or existing dam, the borrower will provide sufficient resources to apply the requirements on safety of dams, as set out in Appendix 1." Appendix 1 subsequently provides the detailed requirements for ensuring dam safety.

The ESF defines large dams as dams with a height of 15 meters or greater from the lowest foundation to the crest, or those between 5 and 15 meters impounding more than 3 million cubic meters. The ESF extends the prescriptions for ensuring dam safety to include all other dams regardless of size or retention capacity (referred to as "small dams") that could cause safety risks.

Where a dam does not fall into the above categories, dam safety measures designed by qualified engineers in accordance with Good International Industry Practice (GIIP) are to be adopted and implemented. GIIP is defined as the exercise of professional skill, diligence, prudence, and foresight that would reasonably be expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally or regionally.

In such circumstances, the borrower is required to confirm, through the environmental and social assessment, that there will be no or negligible risk of significant adverse impacts due to potential failure of the dam structure to local communities and assets, including assets to be financed as part of the proposed project. Where appropriate, the World Bank may also discuss and support the borrower with measures necessary to strengthen the institutional, legislative, and regulatory frameworks for dam safety programs in the country.

DEFINING DAM SAFETY ASSURANCE

Dam safety is defined in various ways, often depending on the country context, but it can be considered "the art and science of ensuring the integrity and viability of dams such that they do not present unacceptable risks to the public, property, and the environment" (FEMA 2004, 7). The safety of a dam manifests itself in being free of any conditions or developments that could lead to its deterioration or destruction. The margin that separates the actual conditions of a dam, or the conditions it is designed for, from those leading to its damage or destruction is a measure of its safety (ICOLD 1987).

Assuring dam safety requires the collective application of engineering principles and experience, and a philosophy of risk management that recognizes that a dam is a structure whose safe function is not explicitly determined by its original design and construction. It also includes all actions taken to identify or predict deficiencies and consequences related to failure, and to document, publicize, and reduce, eliminate, or remediate to the extent reasonably possible any unacceptable risks (FEMA 2004, 7). The objective of any dam safety assurance program is to protect people, property, and the environment from the detrimental effects of mis-operation or failure of dams and reservoirs (ICOLD 2017).

The safe operation of dams has significant social, economic, and environmental relevance. Failures are typically low-probability, sudden events that often have significant consequences. Catastrophic dam failures are characterized by the sudden, rapid, and uncontrolled release of water or the likelihood of such an uncontrolled release. Such catastrophic failures can result in extremely adverse impacts, including the large-scale loss of human life. There are lesser degrees of failure, and any malfunction or abnormality outside the design assumptions and parameters that adversely affect a dam's primary function can be considered a failure. These lesser degrees of failure can progressively lead to or heighten the risk of a catastrophic failure. As such, it is critical to detect any abnormal behavior at an early stage through regular surveillance and monitoring, and to undertake timely corrective actions. Dams can fail for one or a combination of the following reasons:[5]

- Overtopping caused by insufficient installed or available flow discharge capacity of the dam, mis-operation, or flawed operating strategies and plans
- Structural failure of materials used in dam construction
- Movement and/or failure of the foundation supporting the dam
- Settlement and cracking of concrete or embankment dams
- Internal erosion of soil in embankment dams
- Inadequate maintenance and upkeep
- Deliberate acts of sabotage

The number of dam failures has been decreasing over time. The failure ratio of dams[6] is estimated to have decreased from 1.42 percent between 1900 and 1925 to 0.12 percent since 2000 (ICOLD 1995, draft Bulletin 99 update, April 2019). This improvement in dam safety is considered to be the result of improvements in technical investigations, design, and construction techniques, along with advances in oversight mechanisms and the dissemination of knowledge through organizations such as ICOLD. However, considering the ratio of dam failures relative to the number of dams built[7] shows an increase from 0.29 percent between 1975 and 1999 to 0.38 percent from 2000 to 2018. Nearly 50 percent of dam failures are observed within the first year after commissioning.

Dam safety is an important part of public safety. However, public safety considerations include a range of other issues. Sometimes these elements come into direct conflict. For example, dam safety measures may advocate for a reservoir drawdown to protect the dam in case of floods, while reservoir operations may advocate for a more controlled and reduced release to protect populations downstream. While dam failures are low-probability events, they can have severe consequences. For example, the failure of the Xe-Pian Xe-Namnoy saddle dam in Lao PDR in 2018 resulted in an estimated 140 casualties, while the failure of the Córrego do Feijão tailings facility in Brumadinho, Brazil, in 2019 led to more than 230 casualties.

In resource-constrained environments, those responsible for assuring dam safety need to make a judgment on an appropriate response, proportional to the risk, and allocate scarce financial and human resources accordingly. These response mechanisms need to be balanced against other, competing demands related to public goods, services, and protection measures. The low probability of dam failures can mean that scarce resources in resource-constrained environments are often allocated to more visible, competing demands, such as the provision of basic services. This leads to inadequate maintenance or the deferment of required rehabilitation of dams.

In recognition of these challenges and the associated trade-offs, a number of tools have been developed within the policy continuum to facilitate better-informed decision-making. For example, the Health and Safety Executive of the United Kingdom (HSE 2001) set out an overall framework to ensure consistency and coherence across the full range of risks for all hazardous installations, regardless of the sector. The framework includes arrangements to secure the health, safety, and welfare of people at work, and the health and safety of the public, in the way undertakings are conducted. Specific measures in the framework include proposing new laws and standards, conducting research, and providing information and advice. Building on this evolving body of knowledge, many jurisdictions are exploring the tolerable allowable risk related to potential dam failures and using this process to inform decision-making about dam safety measures.

Dam failures often trigger specific legislative responses to improve regulation and oversight (box 1.2), and many countries have developed regulatory frameworks to ensure dam safety. Regulatory mix theory proposes an optimal mix of command-and-control regulation, market-driven or enforced self-regulation, and voluntary mechanisms for any area in need of protective regulation to facilitate sustainable economic activity while protecting environmental and social interests (Gunningham 1993; Gunningham and Grabosky 1998; Gunningham and Sinclair 1999a, 1999b, 2006). Traditionally, command-and-control measures have been the favored policy mechanism of governments for regulation to control hazardous activities.

BOX 1.2

DAM FAILURES OFTEN INFORM LEGISLATIVE RESPONSES

Dam failures are unpredictable, sudden, and dramatic events that often trigger legislative responses to improve regulation and oversight. For example, a series of dam failures in the United States during the 1970s resulted in a national focus on inspecting and regulating dams.

On February 26, 1972, a tailings dam owned by the Buffalo Mining Company in Buffalo Creek, West Virginia, failed. Within minutes, 125 people were killed, 1,100 people were injured, and over 3,000 were left homeless.

On June 5, 1976, Teton Dam, a 123-meter-high dam on the Teton River in Idaho, failed, causing US$1 billion in damage and leaving 11 dead. Over 4,000 homes and 4,000 farm buildings were destroyed as a result of the Teton Dam failure.

Following these dam failures, congressional and federal agency investigations were made into both the disasters and the entire question of dam safety, and new federal legislation for dam safety was initiated by Congress. A Presidential Decree was issued in 1977 directing all federal agencies to review their dam safety practices, addressing many elements of dam safety. Major elements included internal and external review, qualifications of personnel, integration of new technology, Emergency Preparedness Plans, and review of existing dams. The agencies' reviews and the assessment of the reviews by a federal ad hoc interagency committee and by an independent review panel showed that sound practices are generally being used but concluded that improvement is needed in some management practices for dam safety (FEMA 2004).

More recently, the spillway failure of the Oroville Dam that triggered the evacuation of around 200,000 people in February 2017 resulted in the state of California amending its water code. Changes introduced in February 2018 include enhancing dam safety requirements through amendments to those provisions relating to inspections and reporting, a reassessment protocol including risk management approaches, and independent expert inspection for high-hazard dams, among others.

Similarly, the 2002 dam safety legislation and regulations in Quebec, Canada, were the direct result of the 1996 Saguenay flood that caused several dam failures resulting in three fatalities. Brazil went through similar experiences relating to major dam failures before enacting the National Dam Safety Policy, Law 12.334, in September 2010.

Some important dam failures in Brazil include the Camara Dam in Paraiba that resulted in the death of 5 people and left 800 people homeless in June 2004; the 200-meter-high Campos Novos hydropower dam that experienced a failure of the diversion tunnel in June 2006, causing an uncontrolled release of water from the reservoir; and the flooding downstream of the Algodoes Dam

(continued)

BOX 1.2 *(continued)*

in May 2009 that affected 30,000 inhabitants of the city in Piaui. Following the January 2019 failure of the Córrego do Feijão tailings facility in Minas Gerais that resulted in the deaths of an estimated 270 people, the Brazilian Senate passed a bill similar to that which it had failed to pass three years earlier aimed at tightening the regulation of tailings facilities.

However, the enactment of regulations by legislators to prescribe behavior and set up agencies to monitor compliance has often been ineffective, particularly where there are a number of institutional actors within the policy setting (Gunningham 1993; Gunningham and Sinclair 2006) or resource and capacity constraints.

Dam safety assurance can be achieved through a range of interventions (regulatory, technical, institutional, and so on), and the regulatory framework should include pluralistic approaches across the entire life cycle of a dam. This includes planning, design, and construction, as well as surveillance, operation and maintenance, rehabilitation and refurbishments, and eventually decommissioning. Policy mixes need to incorporate instrumental and institutional combinations that will not only save resources but avoid regulatory overload (Gunningham and Grabosky 1998; Krysiak 2009). Single-instrument prescriptions are typically not effective across a wide range of jurisdictions where the characteristics of the country and the nature of the portfolio of dams vary. The most effective regime is therefore one in which the various legal, regulatory, institutional, technical, and financial mechanisms are appropriate to the specific economic, political, and cultural circumstances of the portfolio, country, and/or region.

NOTES

1. ICOLD is a nongovernmental organization founded in 1928. It has national committees from 101 countries with approximately 10,000 individual members. ICOLD members are practicing engineers, geologists, and scientists from governmental or private organizations, consulting firms, universities, laboratories, and construction companies.
2. The World Bank defines large dams in its Operational Policy 4.37 on Safety of Dams as follows: “Large dams are 15 meters or more in height. Dams that are between 10 and 15 meters in height are treated as large dams if they present special design complexities—for example, an unusually large flood-handling requirement, location in a zone of high seismicity, foundations that are complex and difficult to prepare, or retention of toxic materials. Dams under 10 meters in height are treated as large dams if they are expected to become large dams during the operation of the facility.” In the Environmental and Social

Framework that came into effect on October 1, 2018, the World Bank definition of large dams is consistent with the definition used by ICOLD. However, the dam safety requirements for large dams are also applied to smaller dams regardless of size or retention capacity if they could cause safety risks or are expected to become large dams during their operating life.

3. The World Bank Group consists of five organizations. The first two make up the World Bank: (1) The International Bank for Reconstruction and Development (IBRD) lends to governments of middle-income and creditworthy low-income countries, and (2) the International Development Association (IDA) provides interest-free loans and grants to governments of the poorest countries. Joining these in the World Bank Group are (3) the International Finance Corporation (IFC), focused exclusively on the private sector and helping developing countries achieve sustainable growth by financing investment, mobilizing capital in international financial markets, and providing advisory services to businesses and governments; (4) the Multilateral Investment Guarantee Agency (MIGA), promoting foreign direct investment in developing countries by offering political risk insurance (guarantees) to investors and lenders; and (5) the International Centre for Settlement of Investment Disputes (ICSID), providing international facilities for conciliation and arbitration of investment disputes.
4. The portfolio figures—of the 430 projects in over 90 countries—refer to investment projects financed by IBRD and IDA, including grant-financed activities through Recipient-Executed Trust Funds. These figures do not include nonlending advisory services and analytical work, or IFC and MIGA operations.
5. Modified after the FEMA (2004) guidelines.
6. Calculated by ICOLD as the number of failures divided by the total number of existing dams.
7. Calculated by ICOLD as the number of failures divided by the total number of existing dams.

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2

Objectives and Analytical Approach

OBJECTIVES

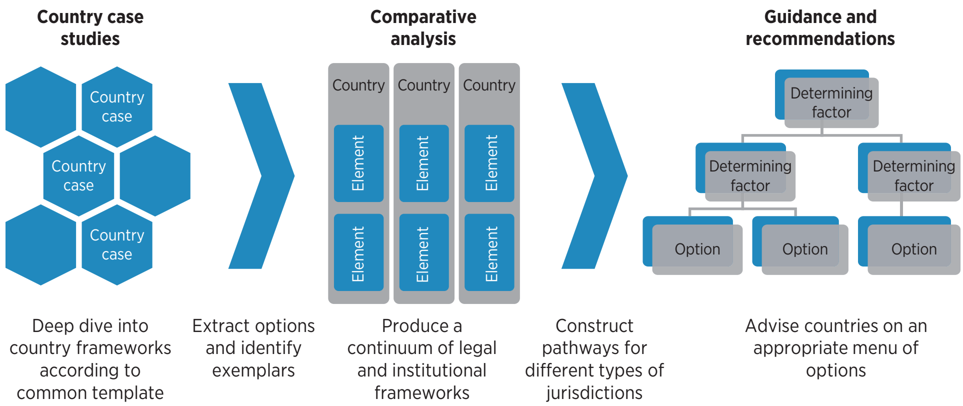
The objective of this global comparative analysis is to characterize a range of existing legal, institutional, technical, and financial options to inform the development of appropriate regulatory frameworks for sustainable dam safety assurance. The analysis is intended to accomplish the following three objectives:

1. Inform the establishment of regulatory regimes and institutional arrangements for dam safety assurance
2. Provide a framework for gap analyses aimed at enhancing existing legal regimes and institutional arrangements for dam safety assurance
3. Guide the design of projects aimed at supporting the establishment or strengthening of legal regimes and institutional arrangements for dam safety assurance

These three objectives are achieved by the following:

- Providing a comprehensive set of country case studies with a balanced representation among a diverse set of countries with varying economic, political, and cultural circumstances
- Carrying out a comparative analysis of the legal, regulatory, and institutional metrics along with financial and operating model analysis to identify a continuum of elements of exemplary practice and precedents

FIGURE 2.1 Concept process flow for the global comparative assessment



Source: Original figure for this publication.

- Recommending a set of regulatory frameworks suitable for different country circumstances supported by a menu of different options (figure 2.1)

The comparative analysis builds on a number of earlier efforts to provide a broad, representative overview of the various legal, regulatory, and institutional mechanisms among a diverse set of countries with varying economic, political, and cultural circumstances. These earlier efforts include the World Bank's 2002 comparative study of regulatory frameworks for dam safety (Bradlow, Palmieri, and Salman 2002). This provided a benchmark for dialogue with client countries and informed the foundations for a number of dam safety programs. It also acknowledged that "dam safety is a dynamic, evolving concept" (p. 94). As this valuable resource has been in use for nearly two decades, there is a need to reflect on the latest Good International Industry Practices and the accumulated experience from World Bank support in the implementation of legislative frameworks for dam safety.

The framework for this comparative analysis is further informed by a series of technical bulletins published by the International Commission on Large Dams (ICOLD). Most notably, these include ICOLD's (2014) "Regulation of Dam Safety: An Overview of Current Practice Worldwide," which provides a useful update on the evolving legal frameworks for dam safety.[1] It notes that after many years of considering the benefits and shortcomings of formal dam safety assessments, there are a number of emerging issues. These include the evolution and integration of risk-based approaches into the regulation of dam safety in a number of countries and the importance of financial mechanisms for ensuring sufficient revenue to sustain the operation and management of dams, along with the human resources required to meet the obligations provided for under the various legal regimes.

COUNTRY SELECTION

Fifty-one country case studies were selected for analysis (map 2.1). Country selection was based on a number of considerations, including characteristics of the country's portfolio of dams and the existence of a legal regime. Selection aimed to include as many countries as possible from the 2002 World Bank study as well as the ICOLD (2014) "Regulation of Dam Safety" bulletin. Consideration was also given to those countries where the World Bank is engaged and to ensuring that the list represents a diverse set of countries with varying economic, political, and cultural circumstances (see appendix A). This results in a set of case study countries that cover a range of economic circumstances:

- 18 high-income countries
- 16 upper-middle-income countries[2]
- 14 lower-middle-income countries
- 3 low-income countries

The country case studies were first selected on the basis of the portfolio of large dams. These countries are estimated to account for more than 95 percent of the world's dams registered with ICOLD and 85 percent of total storage capacity. The 51 countries cover nearly 70 percent of the world's total land area (and 20 percent of the earth's total surface area) and 80 percent of the world's population. All but one of the countries included in the case studies are ICOLD members, and they represent about half of the 101 ICOLD members (table 2.1).

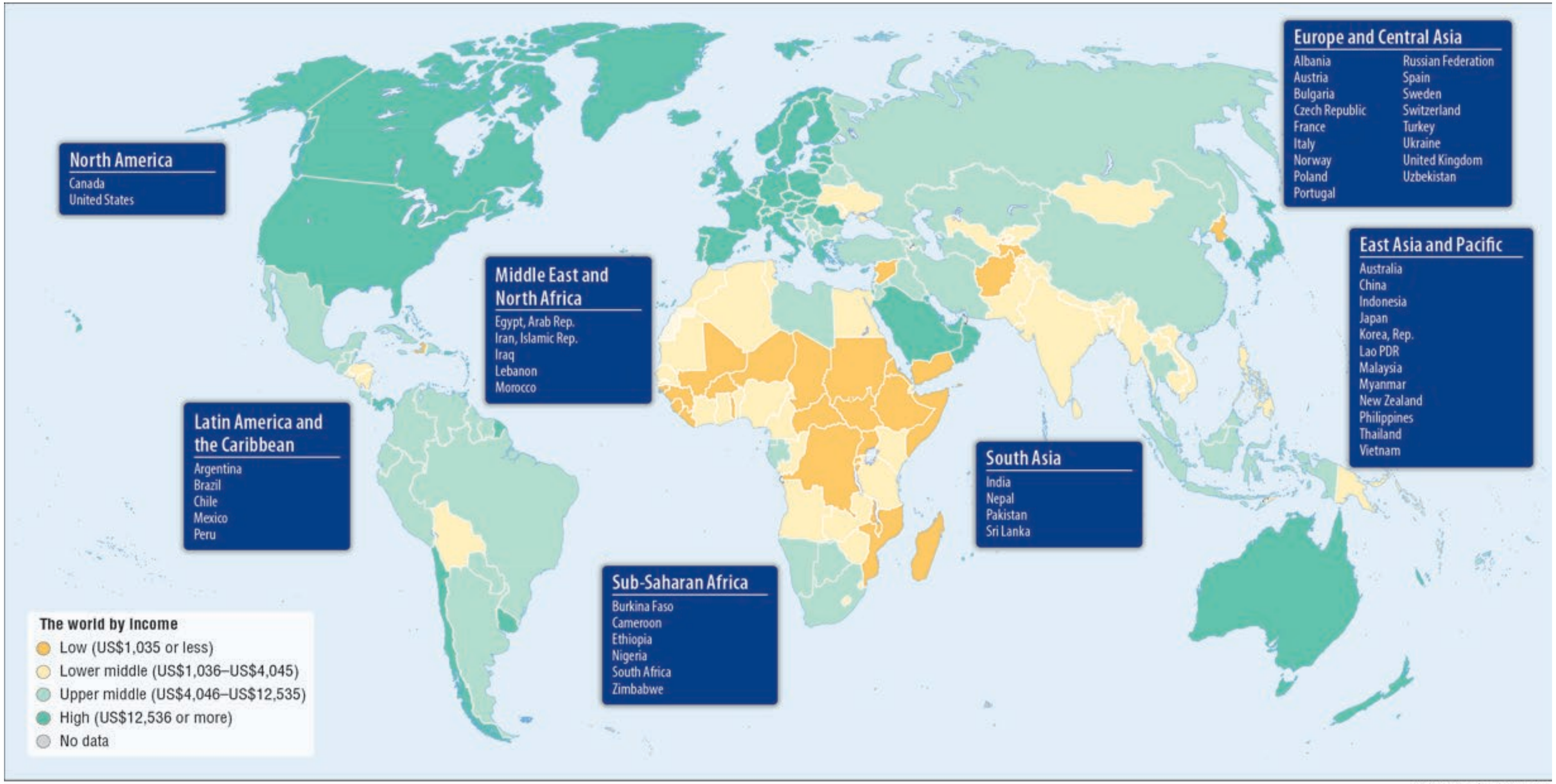
ANALYTICAL FRAMEWORK

The comparative analysis was an iterative and consultative process that engaged more than 300 specialists. It was carried out in three phases and drew on global data sets, publicly available information, the input of World Bank specialists and other international and national experts, formal peer review, and consultations with professional bodies.

Phase 1 included development of a pro forma template and deep dive into the dam safety framework for the 51 country case studies (see appendix B). This was intended to provide a consistent structure and format across all of the case studies, ensure a targeted and efficient use of time in collecting information that was both publicly and not publicly available, and reduce the time required for additional verifications or corrections.

Elements analyzed included a review of each country's legal and statutory framework, identification of underlying principles and priorities, dam safety regulations, institutional and financial arrangements, and the enforcement

MAP 2.1 Country case studies included in the comparative analysis, by region



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Source: Original map for this publication.
Note: Income levels are gross national income per capita for 2019 and are defined using the World Bank Atlas method. See https://datahelpdesk.worldbank.org/knowledgebase/articles/906519/.

TABLE 2.1 International Commission on Large Dams (ICOLD) member countries

Albania	Morocco	Afghanistan	Ivory Coast
Argentina	Myanmar	Algeria	Kenya
Australia	Nepal	Angola	Latvia
Austria	New Zealand	Armenia	Lesotho
Brazil	Nigeria	Belgium	Libya
Bulgaria	Norway	Bhutan	Luxemburg
Burkina Faso	Pakistan	Bolivia	Madagascar
Cameroon	Peru	Bosnia-Herz.	Mali
Canada	Philippines	Colombia	Mozambique
Chile	Poland	Congo (Dem. Rep.)	Netherlands
China	Portugal	Costa Rica	Niger
Czech Republic	Russia	Croatia	North Macedonia
Egypt	South Africa	Cyprus	Panama
Ethiopia	Spain	Denmark	Paraguay
France	Sri Lanka	Dominican Rep.	Romania
India	Sweden	Finland	Serbia
Indonesia	Switzerland	Georgia	Slovakia
Iran	Thailand	Germany	Slovenia
Iraq	Turkey	Ghana	Sudan
Italy	Ukraine	Greece	Syria
Japan	United Kingdom	Guatemala	Tajikistan
Korea (Rep. of)	United States	Guinea-Bissau	Tunisia
Lebanon	Uzbekistan	Honduras	Uruguay
Malaysia	Vietnam	Iceland	Venezuela
Mexico	Zimbabwe	Ireland	Zambia

Source: ICOLD, "Member Countries," as of 2018, http://www.icold-cigb.net/GB/icold/member_countries.asp. Used with permission; further permission required for reuse.
Note: Shaded cells = case study countries. Country names are given per ICOLD source, not World Bank convention. At the time of the analysis, the Lao People's Democratic Republic was the only case study country that was not an ICOLD member.

of regulations and dispute-resolution mechanisms. Metrics included the number and characteristics of dams in the national portfolio (small and large, private and public), the number of hazardous dams, and the level of funding available for dam safety management. The analysis also considered the context of the country's economic, political, and cultural circumstances.

The analysis did not include mining and tailings facilities, which are often regulated under separate legislative provisions. The pro forma template was populated using publicly available information and then subjected to expert review through targeted questionnaires. The expert peer review questionnaire also included a specific request to identify Good International Industry Practice and exemplars in specific areas.

The template was developed around the following heads of analysis:

- Legal foundations and regulatory arrangements for dam safety
- Institutional arrangements for dam safety
- Contents of the regulatory regime
- Risk-informed dam safety approach
- Emergency preparedness and security
- Funding of the regulatory regime
- Dam safety in transboundary settings

Phase 2 involved a systematic comparative assessment of the regulatory frameworks for sustainable dam safety among the 51 country case studies. The comparative analysis involved identifying and comparatively assessing all key elements of dam safety assurance from the case studies along legal, institutional, technical, and financial metrics. It also included a financial and operating model analysis to identify the merits of different approaches, elements of exemplary practice, and precedents for appropriate practice for varying jurisdictional circumstances. Multiple jurisdictions were included for some country examples, with not all elements being mutually exclusive, resulting in the total number of case study countries and jurisdictions greater than 51 in some instances.

Each key element was first assessed and compared qualitatively to identify any merits and exemplary practice. Each element was then considered quantitatively among the different countries. For example, this considered whether the element is used, the number of any requisite subelements included, and how effective implementation is for each element, where such performance information was available. Each element was also considered in the context of country circumstances. For example, the number of dams, population density, and per capita gross domestic product were assessed to determine precedents for appropriate practice.

Given challenges in the availability, quality, and comparability of quantitative data, qualitative information also became an important part of the analysis. These data have been presented in a clear and objective way. The study assesses and describes the manner in which case study countries and jurisdictions have dealt with their dam safety challenges, and provides an evaluative account of the merits of the various approaches. The study aimed to identify approaches that are meritorious and thus suitable for translating to other similar jurisdictions in need of policy or institutional reforms. Both quantitative and qualitative elements of the analysis were combined to generate a continuum of options for different jurisdictional circumstances in phase 3.

Phase 3 used a "regulatory mix pyramid approach" to identify a continuum of regulatory frameworks for sustainable dam safety that can inform a menu of options and be tailored to varying jurisdictional circumstances and country characteristics. Drawing on the feasible alternatives from phase 2, this continuum is intended to inform decision-makers about the merits of different options, enabling the most suitable menu of options to be developed systematically.

In addition to identifying a range of options for policy makers, the analysis examines the typical classification of dams (risk, hazard, and required safety level), the application of risk-informed approaches, the key elements for sustainable operation and maintenance and funding mechanisms for different types of dams, the key elements for effective emergency management and innovative tools for effective dam safety management and reservoir operation (information network, database, and so on), and transboundary considerations for dam safety management, among others. It also considers an introductory program for countries to establish a national dam safety framework that includes portfolio risk management.

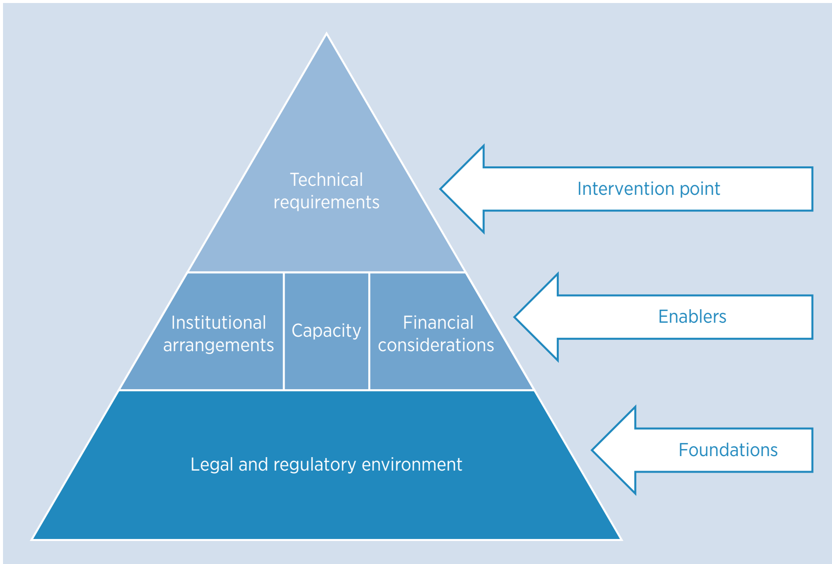
A series of consultations and workshops were held to facilitate the compilation of data, review information, and verify and validate the preliminary findings. These included initial consultations with an expert panel and World Bank specialists who have experience in dam safety and in each of the case study countries. A series of national consultations were held with country representatives along with national and international experts in dam safety. These included a consultation workshop in Tokyo, jointly organized with the Global Facility for Disaster Reduction and Recovery, which involved representatives from East Asia and the Pacific and South Asia. They also included consultations at the International Hydropower Association meeting in Addis Ababa with representatives from Africa and the Middle East; a workshop in Montevideo held by the International Center for Hydropower for Latin American countries; a regional dam safety meeting for Central Asia held in Almaty, Kazakhstan; and a series of presentations and consultations at the ICOLD meetings in Johannesburg (2016), Prague (2017), Vienna (2018), and Ottawa (2019).

A CONTINUUM OF OPTIONS FOR DAM SAFETY ASSURANCE

The continuum of regulatory frameworks for dam safety presents options for policy makers ranging from basic, minimum requirements to more comprehensive models; they are meant to be proportional to the specific needs of a jurisdiction based on key determining characteristics of its portfolio of dams. The options along the continuum are built on critical elements for effective dam safety regulation, specifically the legal foundations, institutional arrangements, financial considerations, and technical requirements contained in the regulatory regime (figure 2.2).

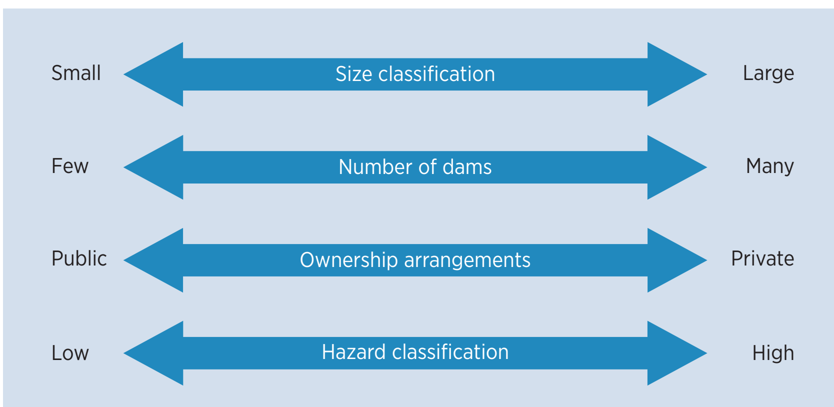
The appropriate form of regulation and oversight in a given jurisdiction depends on the country characteristics, including the prevailing legal system, institutional capacity, and socioeconomic context. It should be informed by

FIGURE 2.2 Elements of a dam safety assurance system



Source: Original figure for this publication.

FIGURE 2.3 Portfolio determinants that should shape the dam safety system



Source: Original figure for this publication.

the characteristics of the portfolio of dams, including the number and type of dams, the nature of ownership and financing arrangements, along with the sectoral distribution and hazard profile of the portfolio (figure 2.3). It is also important that the legal and institutional framework evolves with changes in the portfolio and country conditions. It is therefore necessary to provide a continuum of legal and institutional options against which countries can assess their specific needs and requirements.

Compliance enforcement that maximizes assurance must also be available to policy makers in a dam safety system. Cooperative measures may form the base of enforcement options, escalating to coercive instruments as a last resort. The regulatory nature of coercive sanctions often means that they are expensive to administer. In addition, they may be met with resistance by dam owners in some settings, but there will be dam owners and operators who do not respond to other, less intrusive policy instruments, and compliance enforcement may be the only way to control their behavior.

The continuum of options and key determining characteristics are combined in a Decision Support Tool in chapter 10 and further detailed in appendix E to guide users in assessing their needs and identifying dam safety regulation options appropriate to their circumstances.

NOTES

1. Other key references include "Dam Safety Management: Operation Phase of Dam Life Cycle" (ICOLD 2011) and "Risk Assessment in Dam Safety Management: A Reconnaissance of Benefits, Methods, and Current Applications" (ICOLD 2005), along with the ICOLD (2012, 2017) *European Club Report on Dam Legislation* and various national guidelines.
2. Of these, Mexico and Turkey are members of the Organisation for Economic Co-operation and Development.

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3

Legal Foundations for Dam Safety Assurance

CONTEXT AND RATIONALE

The enabling legal framework for dam safety assurance establishes the minimum standards, along with the duties, roles, and responsibilities, for ensuring the safe development and operation of dams. The legal system of a country (common law or civil law) and its constitutional basis for law making and administration[1] (unitary and central or federal and decentralized) provide the definitive precursors within which the enabling legislative environment for dam safety is formulated.

The level of government at which law making and administration occur in relation to dam safety also affects who is and who could be made responsible for dam safety assurance. Responsibility could range from the central government in national systems to state or provincial governments in federal systems. Furthermore, the degree of decentralization will determine many of the challenges that a country may have to overcome to ensure uniform dam safety standards across the entire territory. The legal framework will also enable collaboration mechanisms to be established among the competent authorities at different levels of a country's administration to ensure integrated application of dam safety assurance and disaster risk management laws.

The formulation of this legal framework subsequently provides the basis for differentiation of attributes important in defining the regulatory regime for dam safety assurance. These can include the degree of independence (from fully autonomous, independent regulation to self-regulation), the nature of the ownership (such as private versus public), and differing sectoral requirements based on the dam's purpose, whether for hydropower, irrigation, water supply, or flood protection.

The legal framework will either enable the establishment of an oversight institution to provide dam safety assurance via command and control or, when appropriate, designate dam owners, either private or public, to oversee the safety of the dams themselves without the intervention of any oversight authority (self-regulation). This legal framework for assuring the safety of dams and downstream communities can be *specific* (contained in a dedicated dam safety law), or it can be integrated into other *enabling legislation*, such as water, environmental, or other related laws, with the corresponding legal and functional implications.

The legal framework also establishes the applicable regime across different dam owners, sectors, and types of dams. To meet the needs of a country's dam portfolio, the government may choose to provide the same level of dam safety assurance uniformly to all dams or apply different dam safety standards and practices to different types of dams, different sectors, or to dams of a particular size and hazard via dam classification systems, risk assessments, portfolio risk management tools, or sector-specific tools.

The existence of a clear definition of dam failure liability and how liability is determined is another important consideration within the legal framework for dam safety. This defines the standard of care that dam owners, managers, and operators must meet to reduce the probability of dam failure and avoid mis-operation of dams. While the standard of care in civil law countries can be found in detail under the law, common law countries may choose to refer to national dam safety committee guidelines. These guidelines are often prepared by national committees representing their countries at the International Commission on Large Dams (ICOLD) and sit outside the law.[2] They are not subject to the typical restrictions of a provision contained within a legal instrument.

The legal framework will determine the grounds for dam failure tort-based liability and whether any criminal liability may result. Tort-based liability can be strict liability, whereby the dam owner is liable for all damages caused by the failure of the dam regardless of whether any negligence is involved, or negligence-based, whereby the dam owner is liable only if found to be negligent in not meeting the acceptable standard of care associated with dam management. Criminal liability following a dam failure can also apply if there are grounds for it under the applicable criminal laws of the country (for example, criminal negligence). For this to apply, acts of gross negligence or recklessness usually have to be proven beyond reasonable doubt. The legal framework can also inform the role of dam safety insurance for the dam owner, operator, or downstream community. These instruments are, for the most part, just emerging, and if they do exist, there are often challenges in transforming (that is, monetizing) dam safety risk into economic and financial risk. Excessively high premiums are also not affordable for many dam owners, particularly for private, small-dam owners.

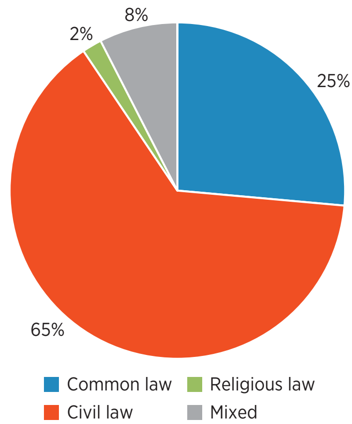
TYPE OF LEGAL SYSTEM

The legal system of any country is shaped by its legal traditions and incorporates specific variations based on the country's particular geopolitical history. Notwithstanding this variation, most contemporary legal systems are generally based on one of four basic systems: civil law, common law, customary law, or religious law. Some jurisdictions have legal systems that combine aspects of these four systems.

The various legal systems are differentiated in part by the varying importance given to the case law. Common law is generally uncodified with no comprehensive compilation of legal rules and statutes. The body of law is based on custom and general principles and embodied in case law, whereby judicial precedent is the norm applied to situations not covered by statute. Judicial precedent–based case law can be overridden only by statute law, which is then also subject to judicial interpretation. In contrast, civil law is codified, and the statute or code law is the primary source of legal rights and obligations. Under civil law, all laws can be strictly and thoroughly prescribed in legislation or codes with no judicial precedent applying, even for legislative interpretation (see box 3.1).

Of the 51 case study countries included in the analysis, 65 percent are governed under a civil law system, 25 percent are governed under a common law system, 8 percent have a mixed legal system, and only one country, the Islamic Republic of Iran, has a full prescribed religious law system (see figure 3.1, map 3.1, table 3.1, and appendix A for individual country system designations).

FIGURE 3.1 Distribution of the type of legal systems among the 51 case study countries



Source: Original figure for this publication.

BOX 3.1

THE TWO MAIN TYPES OF LEGAL SYSTEM

Civil law: All laws are strictly and thoroughly prescribed in legislation and/or codes with no judicial precedent set, even for legislative interpretation. Regulating dam safety must be done in a more prescriptive manner. Updating the dam safety framework can take a great deal of time and resources, as civil law requires new dam safety laws and regulations superseding previous ones.

Common law: In this system, judicial precedent–based case law can be overridden only by statute law, which is then also subject to judicial interpretation. There is the option of making laws more generic (in contrast to prescriptive), allowing for a general reference to dam safety guidelines to set requisite standards.

TABLE 3.1 Legal systems among the 51 case study countries

Region	Common law	Civil law	Other (customary or religious law only)	Mixed
East Asia and Pacific	4	7	0	1
Europe and Central Asia	1	16	0	0
Latin America and the Caribbean	0	5	0	0
Middle East and North Africa	0	3	1	1
North America	2[a]	0	0	0
South Asia	4	0	0	0
Sub-Saharan Africa	2	2	0	2
Total	**13**	**33**	**1**	**4**

Source: Original table for this publication.
a. Although Canada can be considered a mixed legal system, it has been counted here as a common law system because the majority of its provinces are independent common law systems; see also appendix A.

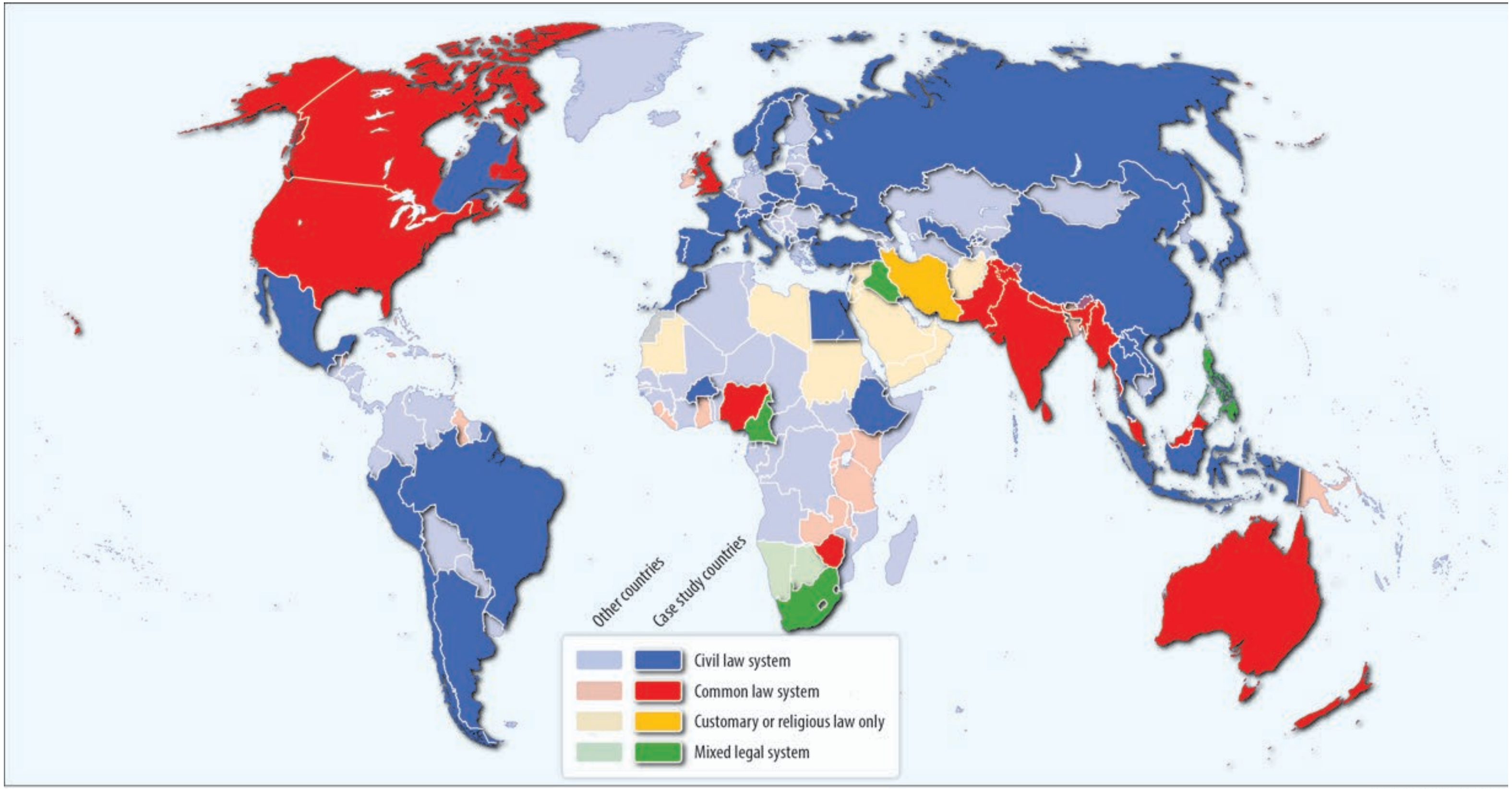
The legal regime typically reflects the country's geopolitical history (map 3.1). The common law tradition developed in England during the Middle Ages and was applied across the British colonies, while the civil law tradition developed across continental Europe around the same time and was applied in the colonies of the imperial powers from Europe. Civil law was also adopted in the nineteenth and twentieth centuries by a number of countries formerly possessing distinctive legal traditions, such as Japan and the Russian Federation, that sought to reform their legal systems in order to gain economic and political power comparable to that of Western European nation-states.

Many former European colonies have mixed legal systems. These can involve the following:

- A mix of common law and civil law operating together in the same country, as in, for example, the Philippines
- A mix of common law and civil law operating independently in different jurisdictions of the same country, as in, for example, Cameroon and Canada
- A mix[3] of common law and/or civil law with religious and/or customary law, as in the case of South Africa, where the legal tradition is reflected in its historical Roman Dutch system, in which statutes do not reach the point of codification, and judicial interpretation is allowed—and English common law is used to determine grounds for liability, and some elements of customary and indigenous law can also be found

The historical distinctions between common law and civil law systems are becoming less significant. Statutes are becoming increasingly relevant in common law countries and case law increasingly relevant in civil law countries. Notwithstanding this trend, there are distinct differences between the two that have significant implications for how countries approach dam safety assurance (table 3.2).

MAP 3.1 **Distribution of the type of legal systems among the 51 case study countries**



Source: Original map for this publication.
Note: Canada's shading indicates that it has both civil law and common law jurisdictions.

TABLE 3.2 Characteristic features of the common and civil law systems as they might relate to dam safety

Feature	Common law	Civil law
Written constitution	Not always	Always
Judicial decisions	Binding	Not binding on third parties; however, administrative and constitutional court decisions on laws and regulations binding on all
Writings of legal scholars	Little influence	Significant influence in some civil law jurisdictions
Freedom of contract	Extensive—only a few provisions implied by law into contractual relationship	More limited—a number of provisions implied by law into contractual relationship

Source: World Bank, "Key Features of Common Law or Civil Law Systems," last updated September 6, 2016, https://ppp.worldbank.org/public-private-partnership/legislation-regulation/framework-assessment/legal-systems/common-vs-civil-law.

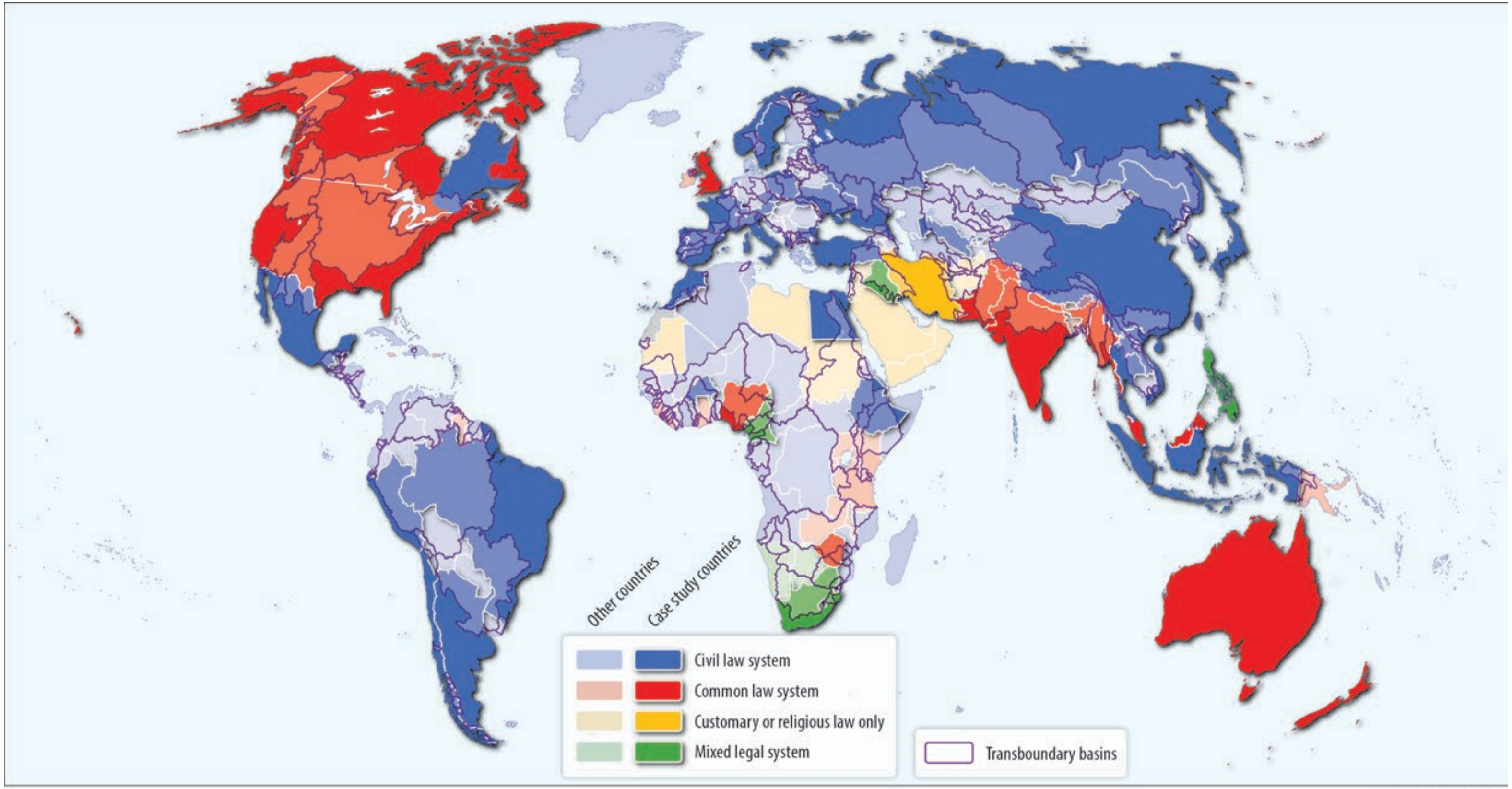
Under civil law, the dam owner's obligations and the required standard of care are detailed and prescribed in the law. Any modification to this regime must be done through another legal instrument of at least equal status. A dam owner under the civil law system will be held liable only if such liability is established under the law and the damages suffered by the plaintiff have been set forth in a statute as damages that are eligible for compensation. Sometimes, certain legal provisions are generic and their applicability depends on a lower-ranking piece of legislation that develops them into more specific terms.

Under common law, the dam owner's obligations and required standard of care are developed through case law, which is derived from court rulings. As such, the law may not be detailed, or may not even be regulated under statute, because the standards of care owed by the dam owner to the community are developed through case law. The standard of care could be defined in a set of guidelines that are referenced by the law and sit outside of any specific legal instrument. This allows for an agile evolution of the applicable guidelines without the need for legislative action.

The type of legal system can have important implications for the degree of equivalence between jurisdictions. This has direct implications on how the standard of care for a dam owner is determined, the means through which the regulatory framework can be amended, and the agility with which it can adapt to changing circumstances within a national or basin portfolio. This can also have important implications for transboundary basins where different legal and institutional frameworks for dam safety may need to coexist.

There are a number of international river basins that are shared by riparian states with different legal systems (map 3.2), notably the Nile River Basin, the Mekong River Basin, the Ganga River Basin, the Rio Grande River

MAP 3.2 **International transboundary river basins shared by riparian states with different legal systems**



Source: Original map for this publication.
Note: Canada's shading indicates that it has both civil law and common law jurisdictions.

Basin, and the Niger River Basin. In each of those jurisdictions, dam safety assurance standards may be defined at different levels, and different safety criteria may be applied to dams that regulate the flow of the same water resource. Recognizing the benefits of dams to human development and the differences among legal systems could be a first step for the riparian states in these river basins to assess the degree of equivalence among the different obligations and standards of care established under the national regulatory regime and ensure minimum acceptable thresholds for assuring the safety of dams and downstream communities within the basin.

GOVERNMENT LAW MAKING AND ADMINISTRATION

The constitutional basis for law making and the prevailing legal regime determine the level at which dam safety assurance is administered by the competent authorities. In a unitary system of government, the power and administration are held by one central authority. In a federal system of government, the power and administration are divided between the national or federal government and lower, subnational levels of government, such as provinces or states.

The form of government law making and administration can impact the degree of equivalence and applicability of any dam safety legislation that is enacted within a country. Different standards enacted and enforced by subnational entities, such as states or provinces in a federal system, can result in different levels of assurance compared to uniform standards provided through a central authority in a unitary national government.

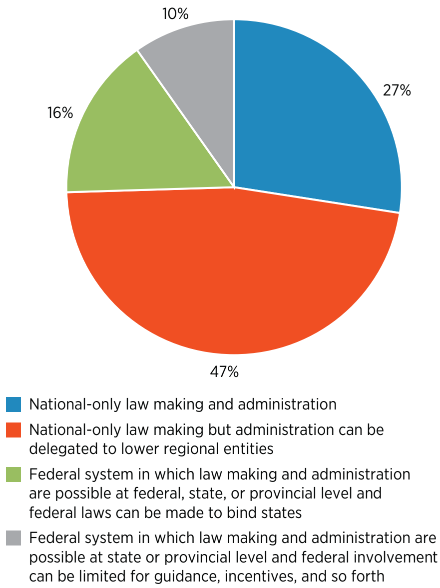
There are four administrative categories of government law making:

1. National-only law making and administration
2. National-only law making with the possibility for administration at subnational regional levels
3. A federal system in which law making and administration are possible at either the national or subnational level, and national laws can be made to bind state laws
4. A federal system in which law making and administration are possible only at the subnational level, and national involvement can be only in the form of encouragement or incentives to the states to develop uniform laws

Dam safety legislation in 90 percent of the case study countries is prescribed at the national level (corresponding to the first three categories), with the administration of the law possible at either national or subnational levels (corresponding to the third category) (figure 3.2 and table 3.3). More important, these laws can bind states or provincial authorities and so allow for uniformity in dam safety standards and assurance across the country. This is in contrast to federal systems where state or provincial authorities are not bound by laws made at the national level. Federal jurisdictions may therefore encounter challenges in ensuring a minimum degree of equivalence among dam safety provisions across different states or provinces unless other mechanisms are employed.

Nonlegislative measures can be used to encourage equivalent approaches to dam safety assurance. The fact that there are countries where national governments are unable to direct state and/or provincial authorities to regulate dam safety in a specific manner does not mean that those national governments cannot achieve an equivalent dam safety assurance regime across all states and/or provinces. For example, incentive schemes implemented through the federal government can provide for improved dam safety assurance at the subnational level. The evolution of the National Dam Safety Program in the United States builds on the Model State Dam

FIGURE 3.2 Law making and administration of dam safety assurance among the 51 case study countries



Source: Original figure for this publication.

TABLE 3.3 Summary of law-making and administration characteristics among the 51 case study countries

Income level/region	National-only law making and administration	National-only law making but administration can occur at lower regional levels	Federal system in which law making and administration are possible at federal, state, or provisional level and federal laws can be made to bind state laws	Federal system in which law making and administration are possible for dams and safety only at state or provincial level and federal involvement can be only in the form of encouragement or incentives to the states to develop uniform dam safety laws
Total	**14**	**24**	**8**	**5**
Income level				
High income	2	11	2	3
Upper middle Income	6	4	4	1
Lower middle income	6	5	2	1
Low income	0	4	0	0

(*continued*)

TABLE 3.3 *(continued)*

Income level/region	National-only law making and administration	National-only law making but administration can occur at lower regional levels	Federal system in which law making and administration are possible at federal, state, or provisional level and federal laws can be made to bind state laws	Federal system in which law making and administration are possible for dams and safety only at state or provincial level and federal involvement can be only in the form of encouragement or incentives to the states to develop uniform dam safety laws
Region				
East Asia and Pacific	3	7	0	2
Europe and Central Asia	4	11	2	0
Latin America and the Caribbean	1	0	4	0
Middle East and North Africa	5	0	0	0
North America	0	0	0	2
South Asia	0	2	1	1
Sub-Saharan Africa	1	4	1	0

Source: Original table for this publication.

Safety Program (FEMA 1998, 2007) to include fiscal incentives aimed at encouraging more responsible dam safety policies to be enacted. These are aimed at ensuring more efficient and effective administration of the policies and moving toward a more uniform dam safety assurance policy across the states (see box 3.2). While these efforts are aimed at trying to improve the degree of equivalence, other federal jurisdictions such as Australia and Canada have not adopted such nationally administered incentive mechanisms to actively encourage the states and/or provincial authorities to regulate dam safety in a specific manner in order to achieve equivalency in the subnational dam safety regimes. The inevitable result of this has been differences in the evolution of the prevailing legal regime and nonuniform approaches to dam safety assurance.

TYPES OF LEGISLATION FOR DAM SAFETY ASSURANCE

The legislative options for dam safety assurance can come in various forms and be presented along a continuum of options. Specific provisions may stipulate how a country ensures the integrity and viability of its dams in such a

BOX 3.2

ACHIEVING UNIFORM, EFFICIENT, AND EFFECTIVE STATE-LEVEL DAM SAFETY ASSURANCE IN THE UNITED STATES

In November 1977, President Jimmy Carter expressed concern over the level of safety of nonfederal dams following the failure of a privately owned dam in his home state of Georgia, the Kelly Barnes Dam located upstream of Toccoa Falls. Although this dam was relatively small (8 meters high), 38 lives were lost. Subsequently, the US Army Corps of Engineers was directed to conduct a more detailed national inspection of dams.

An initial report revealed that 31 states had adequate laws to control dam safety, while the remaining 19 had either no laws or laws considered inadequate. In the final report presented to Congress in May 1982, some 68,000 dams were identified (64,000 being nonfederal dams). Of these, 8,800 were deemed to be "high-hazard" dams. Following the inspection of all the high-hazard dams, 2,900 were rated as unsafe, the majority (2,370) because of inadequate spillway capacity. Following this, the federal government recognized the need to encourage the states to initiate effective dam safety programs (Danilevsky 1993; US Department of Interior 1980; Bossman-Aggrey, Green, and Parker 1987).

The US Federal Emergency Management Agency (FEMA) was subsequently assigned the responsibility of coordinating and promoting dam safety in order to encourage the establishment and maintenance of effective dam safety programs at the state level. Since then, FEMA has published a number of guidelines and has established relationships with the states, including the Model State Dam Safety Program, aimed at helping the states establish effective and efficient programs.

A review of the state dam safety programs conducted by FEMA in 1992 found that 41 states had programs that met the minimum guidelines of the model program and only two lacked a dam safety policy. However, the review also discovered that many states were unable to effectively implement the programs because of a lack of funding and insufficient staff. Less than 20 percent of the states showed a ratio of fewer than 100 dams per full-time equivalent staff member. This ratio was significantly higher for many of the other states, with some having over 1,000 dams per staff member.

In response, the federal government established the National Dam Safety Program (NDSP). Initially authorized under the Water Resources and Development Act of 1996, and reauthorized under the Dam Safety Act of 2006 and again under the Water Resources Reform and Development Act, the NDSP includes grants to the states to help with the improvement of state dam safety programs. These are provided to those states that successfully establish dam safety programs approved under the terms of the act and in line with the model program.

(continued)

BOX 3.2 *(continued)*

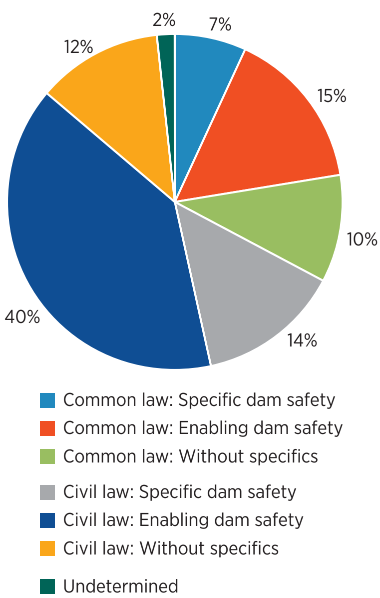
As a result of the work of FEMA and the NDSP, 49 states, with Alabama as the exception, now have regulatory programs in place for dam safety and participate in the NDSP. FEMA reports that "[s]ince the National Dam Safety Program was first authorized more than 10 years ago, there have been significant improvements in the safety of many of our Nation's dams that are a direct result of National Dam Safety Program funding for state assistance, training, and research" (FEMA 2009, 11; see also FEMA 2016).

For more information, see FEMA, "National Dam Safety Program," https://www.fema.gov/national-dam-safety-program.

way that it protects its people, property, and the environment from the detrimental effects of mis-operation or failure of dams and reservoirs. It may also be the case that the country has no specific provisions pertaining to dams. Legislative options along this continuum include the following:

- A dedicated act or statute pertaining solely to dam safety, in which case mandates are mostly prescribed
- Provisions in enabling legislation that empower an entity to control dam safety management and ensure compliance without any further specificity, in which case such entity is given a regulatory function to further develop more specific dam safety regulations or rules[4]
- Self-regulation mechanisms that do not necessarily have specific enabling legislative provisions

FIGURE 3.3 Legal basis for dam safety responsibility among the case study countries and jurisdictions



Source: Original figure for this publication.

Dedicated legislative provisions relating specifically to dam safety are observed in 12 of the case study countries and jurisdictions examined (figure 3.3 and table 3.4). These cover both common law and civil law countries, as well as countries of all income levels, including but not limited to Albania, Brazil, the Republic of Korea, Portugal, Switzerland, the United Kingdom, and Uzbekistan. In such instances of dedicated legislative provisions, most mandates are prescribed, or include provisions empowering a dam safety authority to further develop more prescribed dam safety regulations or rules. This is the case, for example, in the Australian state of New South Wales.

TABLE 3.4 Types of legislative provisions for dam safety assurance among the case study countries and jurisdictions, by income level

	Common law			Civil law			
Income level	Dedicated specific dam safety law	Enabling law with dam safety specifics	General without dam safety specifics	Dedicated specific dam safety law	Enabling law with dam safety specifics	General without dam safety specifics	Undetermined
High income	3	4	0	4	9	0	1
Upper middle income	0	1	1	4	7	4	0
Lower middle income	1	3	4	0	6	2	0
Low income	0	1	1	0	1	1	0
Total	**4**	**9**	**6**	**8**	**23**	**7**	**1**

Source: Original table for this publication.

Dam safety provisions are observed within broader enabling legislative provisions in more than half of all the case study countries and jurisdictions examined (56 percent). Such enabling legislation is observed in China, France, Japan, Mexico, Spain, Turkey, and Vietnam and typically relies on legal provisions within an existing water resources or environmental law or other type of legislation to empower an entity to control dam safety. (See table 3.5 for legislation by world region.)

There are no specific dam safety regulations in 22 percent of the case study countries and jurisdictions. This category of general law without specifics on dam safety under both common and civil law captures two kinds of country contexts: those that have no statute laws that could cover dam safety even in a generic manner, and those countries that have general statute laws (for example, for water or energy facility management) that could be used to cover dam safety in a generic manner. The absence of specific dam safety provisions creates a number of risks and should be seen as an interim step while a specific dam safety legal framework is being put in place. The absence of any specific provisions is particularly problematic for countries with a large portfolio of dams and significant private sector participation.

All of the high-income countries in both civil law and common law systems have prescribed provisions for dam safety assurance. In contrast, none of the low-income countries included among the case studies have dedicated dam-safety-specific legislation, relying on enabling legislation with specific dam safety provisions or having only general provisions without any dam safety language. The fact that lower-income countries account for the majority of countries that do not have any specific dam safety legislation providing for independent supervision raises a number of important considerations. These countries either do not have the capacity or means to develop dam safety legislation or undertake nominal self-regulation without specific dam safety provisions. However, provisions should be made to secure the

TABLE 3.5 Types of legislative provisions for dam safety assurance among the case study countries and jurisdictions, by region

	Common law			Civil law			
Region	Dedicated specific dam safety law	Enabling law with dam safety specifics	General without dam safety specifics	Dedicated specific dam safety law	Enabling law with dam safety specifics	General without dam safety specifics	Undetermined
East Asia and Pacific	1	3	2	1	5	1	0
Europe and Central Asia	1	0	0	4	12	0	0
Latin America and the Caribbean	0	0	0	2	3	1	1
Middle East and North Africa	0	0	0	0	2	3	0
North America	1	2	0	1	0	0	0
South Asia	1	1	3	0	0	0	0
Sub-Saharan Africa	0	3	1	0	1	2	0
Total	**4**	**9**	**6**	**8**	**23**	**7**	**1**

Source: Original table for this publication.

necessary technical and financial support for developing suitable regulations and addressing the long-term capacity gaps for ensuring the safety of dams and downstream communities.

Some countries have different legal systems across their states or provinces, governing different sectors, or differentiated systems for national and subnational regulation (table 3.6). These have been included in the analysis, so the total number of examples is greater than the 51 case study countries, and a number of different jurisdictions are sometimes referenced to capture specific subnational provisions and experiences. For example, in Australia, the state of New South Wales has a dedicated dam safety law, while in the states of Queensland, Tasmania, and Victoria the dam safety provisions are found within enabling water laws. Similarly, Canada's Quebec Province has a dedicated civil law addressing dam safety, while the provinces of Alberta and British Columbia rely on common law systems, with dam safety provisions found in the enabling water law; in Ontario, such provisions are found in the enabling legislation for lakes and rivers. The United States also has multiple systems, including the Dam Safety Act under FEMA; dam safety regulations under state water-related laws (California and Washington) and state natural resources or environment laws (Michigan and Utah); and the US Federal Energy Regulatory Commission's (FERC's) hydropower dam regulations that apply for the

TABLE 3.6 Examples of dedicated and enabling sector legislation

Country	Dedicated dam safety legislation	Enabling sector legislation
Australia	New South Wales	Queensland (water) Tasmania (water) Victoria (water)
Brazil	National Dam Safety Law (through the National Water Agency, ANA)	States (for water) and various sectors, such as Electricity Regulatory Agency (ANEEL)
Canada	Quebec	Alberta (water) British Columbia (water) Ontario (lakes and rivers)
United States	National Dam Safety Program (through FEMA)	National (nonfederal hydropower dams, through FERC) Federal agencies (US Army Corps of Engineers, US Bureau of Reclamation, etc.) California (water) Michigan (natural resources, environment) Utah (natural resources, water rights) Washington (water)

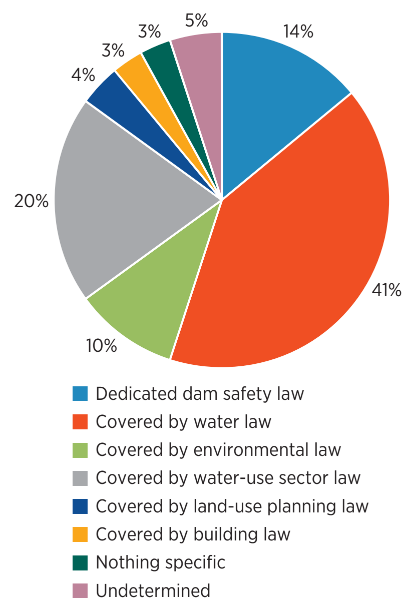
Source: Original table for this publication.
Note: FEMA = Federal Emergency Management Agency; FERC = Federal Energy Regulatory Commission.

most part to nonfederal dams, among others. Brazil legislated a National Dam Safety Law in 2010 but maintains sector-level regulations for their specific safety provisions.

DAM SAFETY REGULATION UNDER ENABLING AND DEDICATED LEGISLATION

Enabling legislation can take a range of different forms (figure 3.4). While many countries have developed sector-based regulations to address specific sectoral needs, including irrigation, water supply, and hydropower generation, other countries have developed uniform regulations across sectors, as in Brazil and the United States. Dam safety provisions are also observed in other legislation, such as for land-use planning in Burkina Faso and the building code in New Zealand. The suitability of such laws depends on the characteristics of the dam portfolio within the country. Water-related laws may be the most suitable if most dams are multipurpose dams. If most dams are for energy generation, then hydropower or broader energy regulation laws may be more appropriate.

FIGURE 3.4 Legal basis for sectoral dam safety responsibility among the case study countries and jurisdictions



Source: Original figure for this publication.

Dam safety provisions are found within the scope of dedicated water or water-related legislation in 41 percent of the case studies. Dedicated water-related legislation includes law for water resources, flood management, or the management of hydraulic structures. Given the close links between dam safety and the development and management of water resources, this usually provides for a comprehensive sectoral approach. It also integrates related provisions, including the provision of water rights, licensing for the construction of new facilities in the basin, and required reservoir operations linked with other hydraulic facilities along the river courses. A uniform or equivalent regulatory framework for dam safety should be preferred for larger portfolios to ensure the consistency of safety regulations and reservoir operations across different dam owners and sectors.

Dam safety provisions are found within the scope of water service–related sectors, such as irrigation, water supply, and hydropower, in 21 percent of the studied cases. This typically reflects the evolution of the dam portfolio within a country where there is a strong focus and concentration of expertise and resources within a particular sector or a differentiated development of sectors at different times. For example, if most of the dams within a country are for irrigation, or dams for irrigation were developed before dams for other purposes, the irrigation sector may be best placed to lead in dam safety management systems or may have done so out of necessity. Similarly, if a country has placed a strong emphasis on hydropower development, or if hydropower makes up the majority of a portfolio, then the energy sector typically takes a lead in the development of the overall dam safety framework, such as FERC in the United States and Organismo Regulador de Seguridad de Presas in Argentina. This is particularly important when there is a strong focus on facilitating private hydropower development, and tailored regulatory mechanisms may be required.

Changing the legislative provisions for dam safety assurance is a long and complex process. While it is often difficult to determine accurately when a legislative process starts, the review of the legal frameworks from the case studies suggests that more than half of the legal frameworks for dam safety are currently in transition (table 3.7). The experience of the case studies suggests that this process can take close to a decade, with a number of countries having been engaged in a legislative reform process for more than 10 years. The time taken to revise the legal framework for dam safety assurance typically increases the legal uncertainty, particularly around the obligations that dam owners have to comply with. It can be the case that the legislator (parliament or government) has not developed the dam safety law with the necessary supporting regulations or decrees and the law remains inapplicable or its applicability is unsatisfactory.

The importance of differentiating the legal provisions for dam safety in specific legislation is highlighted by the case of Indonesia. The country has a well-developed, national legal framework for dam safety based on three main tenets: (1) structural safety, (2) surveillance, and (3) emergency preparedness. This has evolved over four decades and is currently governed through

TABLE 3.7 Examples of legislative provisions relating to dam safety assurance in transition

Region	Country	Dam safety assurance and regulation in transition: Needs and motivations	Approximate time in transition (years, as of 2018)
East Asia and Pacific	Australia	New South Wales: Need for a more risk-based approach, less hands-on regulator, stronger compliance and enforcement, and some user-pay provisions for increased capture	5
	Indonesia	Not integrated enough with water resources law	8
	Malaysia	Need for independent regulation	6
	New Zealand	Review whether to use building or environmental laws; debate on regulatory capture of too many small dams	14
	Philippines	Need for regulation	7
	Vietnam	Better-defined institutional roles and size classes needed	8
Europe and Central Asia	Italy	General revision to be determined; need to update large dam criterion	11
	Portugal	Need to make mandates for small dams more proportionate	4
	Spain	Moving toward risk-based in principle to practice	10
	Sweden	Consequence classification—updating of guidelines	4
	Switzerland	Better-defined responsibilities and liabilities and insurance mandate	8
	United Kingdom	Unified system resulted in inconsistent application of Reservoirs Act by county councils; also need to capture more dams—smaller but high hazard	8
Latin America and the Caribbean	Argentina	Covers only large hydropower dams; needs to cover all large dams	3
	Brazil	Need for national uniform state laws and database	10
	Peru	Specific dam safety regulations needed with a multisector committee and a technical committee to support the enabling legislation	10
Middle East and North Africa	Egypt, Arab Rep.	Need for more specific regulation	5
	Iran, Islamic Rep.	Need for better, more prescribed mandates	5
	Morocco	More use of a concession system with institutional roles better defined	6
North America	Canada	Alberta: Need to add option to judge safety using risk-informed framework Quebec: Need for independence between dam safety regulatory function and dam safety ownership and management function	3
South Asia	India	More uniform central approach needed but proportionate to irrigation dam numbers	8
	Nepal	Need for regulation	3
	Pakistan	Strengthen role and effectiveness of regulator	10
Sub-Saharan Africa	Burkina Faso	Need to strengthen the regulatory framework with guides	4
	Ethiopia	Need for dam safety assurance	17
	Nigeria	Initiated following a dam failure in 2002, with draft in 2007 and another in 2016	15
	South Africa	Challenges with compliance	2
	Zimbabwe	More independent regulator to be established	4
Total: 27 of 51 case studies (53%)			**Average = 7.3 years**

Source: Original table for this publication.

the Ministry of Public Works and Housing (MPWH) Ministerial Regulation No. 27/PRT/M/2015 specifically on dams. The Water Resources Law No. 7 of 2004 was repealed in 2015 by the Constitutional Court on the basis that the 2004 law encouraged privatization and commercialization of water resources at the expense of people's rights to water. As a result, the legal basis for dam safety reverted to operating under Water Law No. 11 of 1974 and MPWH Ministerial Regulation No. 72/PRT/1997 on Dam Safety. This regulation was subsequently repealed and replaced by Ministerial Regulation No. 27/2015 on Dams and MPWH Ministerial Regulation No. 03/KPTS/M/2016. Notwithstanding changes in the legal regime, the regulations were able to provide a continuing, comprehensive framework for dam safety assurance.

It is important to maintain a continuous process of vigilance, review, and amendment to the legal framework to ensure that it reflects the risks within the portfolio. For example, while none of the legislative frameworks in the Europe and Central Asian case studies were considered to be under review, the United Nations Economic Commission for Europe, in conjunction with a number of partners, have been supporting a regional program to improve the development of institutions, legislation, capacity building, and subregional cooperation relating to dam safety. This initiative was launched in response to increasing concerns in Central Asia over the safety of dams and other water-control facilities located mostly on transboundary rivers. Over the course of a decade, the regional program tackled the issue of ageing infrastructure and inadequate maintenance, accentuated by a growth in downstream populations, increasing risks to life, infrastructure, and the environment. This process helped develop a regional legal framework for dam safety; influence national legislation, standards, and institutional responsibilities for dam safety; and build capacity and expertise across the region relating to dam safety.

Embedding dam safety provisions within enabling legislation can increase the risk of legal uncertainty. When provisions relating to a subject as specific as dam safety share the same legal instrument with provisions that regulate other areas such as water resources, the environment, land-use planning, or disaster risk management, the potential for legal uncertainty increases, particularly if the enabling legislation is repealed or subject to revision. This can have implications for all of the provisions contained therein, including those for dam safety, even though they may not be the subject of the revisions. For example, in Indonesia the provisions for dam safety were included as part of the enabling water resources legislation. When this law was repealed in 2015 due to issues unrelated to dam safety, the specific dam safety provisions were also annulled because the legal instrument in which these provisions were contained was constitutionally revoked. While separate ministerial regulations were subsequently issued as an interim measure, these do not necessarily have the same authority in the legal hierarchy as the national act.

DEFINING LEGAL LIABILITY FOR DAM SAFETY ASSURANCE

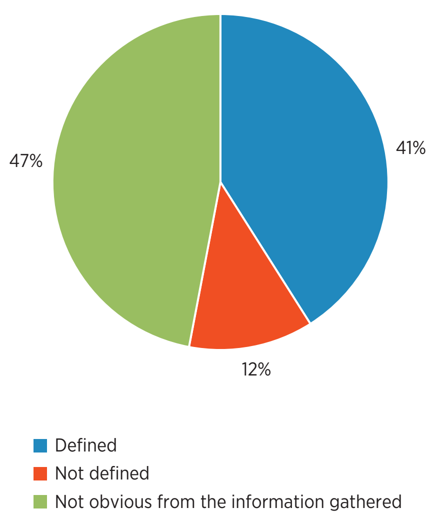
Responsibility and liability for dam safety are two distinct but strongly related elements within the legal framework. *Responsibility* for dam safety refers to the actions taken by the dam owner toward the care and consideration of the safety of the dam. *Liability* for dam safety refers to the legal obligation of the dam owner to compensate the victims for the personal and property damage caused by mis-operation of a dam or dam failure. This is also known as *tort-based liability*.[5] While the responsibility for dam safety exists throughout the life of the dam, from the design stage until the decommissioning, the liability for dam safety arises only in the case of dam failure or mis-operation and provided the person that suffers personal or property damage from those events seeks compensation from the entities responsible for the safety of the dam.

Dam safety liability means converting dam safety responsibility into an actual legal obligation that compels the wrongdoer (typically the dam owner) to compensate in case of damage caused due to dam failure or mis-operation. The person who sustains injury or suffers pecuniary damage as the result of the dam failure is known as the plaintiff, and the person who is responsible for inflicting the injury and thus incurs liability for the damage is known as the defendant.

Deciding who can be held liable in the case of a dam failure or mis-operation requires a clear definition of responsibility. Responsibility lies primarily with the owner but can also involve the regulator as well as other actors, such as the designer, contractor, or operator. Having a proper register of dams can assist in providing transparency in this process. However, although clear responsibility for dam safety may be determined in each jurisdiction, the analysis of the legal provisions among the case studies suggests that a clear definition of liability for dam failure may not follow (figure 3.5). Therefore, in those jurisdictions where dam failure liability is not defined, it may be difficult to translate a failure to comply with dam safety responsibility obligations into an actual legal obligation for compensation to a victim.

In those jurisdictions where the regulator has a more hands-on role and direct surveillance overseeing and ensuring dam safety, the regulator may assume more responsibility for the safety of the dam. If the dam safety regulator's relevant function provided

FIGURE 3.5 Extent of definition of liability for dam failure among the case studies



Source: Original figure for this publication.

by the legal framework extends beyond a compliance audit or quality assurance role, it could be held liable along with the dam owner. This is the case of the dam safety regulator in the state of Washington in the United States, which, by assuming responsibility for design review and approval and surveillance, also assumes some associated liability. It is most likely that, for this reason, Washington state law does not specifically address owner or departmental liabilities. In this case, while an agency might be ensured legal immunity through legislation, as is apparent under a similar system adopted in the US state of California, individual liability could still prevail under the law of ordinary negligence. Even though the law provides for immunity, there is generally nothing that will prohibit an injured citizen from suing a second citizen if that second citizen has been negligent (Sowers 1974, 92). Therefore, it may be possible for a person who is injured by the failure of a dam to sue the individuals employed by the state agency even though the agency itself may be legally immune.

Liability in the case of dam failure is typically not clearly defined. Of the case studies, only 41 percent have a clear definition of liability associated with dam failures or mis-operations. Among these are Italy, Korea, Malaysia, Norway, and the United Kingdom. Liability is not defined or there is no obvious definition evident from the information collected in nearly 60 percent of the case studies (table 3.8). This lack of legal clarity around the liability places the burden on the victim to demonstrate who is supposed to compensate them for the damages incurred.

Common law definitions of liability relating to dam failure are more frequent (over 60 percent of the cases). More than half of the civil law case studies either do not define dam failure liability, or its definition is not obvious from the available information. This could be a reflection of the fact that action of the legislative power is required under a civil law to define dam failure liability as it is always defined through statutory measures.[6] A breach of the statutory duty is therefore required to prove liability for dam failure. If this duty is not defined under the law, for instance by describing the obligations of the dam owner, then proving a breach of the statutory duty by the defendant (for example, under a generic liability principle) can be more difficult for the plaintiff. In common law countries, statutory provisions may exist but are not necessary, because liability can be defined through the body

TABLE 3.8 Definitions of liability among the case study countries and jurisdictions, by legal system

Legal system	Defined	Not defined	Undetermined
Common law	7	0	4
Civil law	10	3	16
Religious law	0	0	1
Mixed	3	3	2
Common and civil law	1	0	1
Total	**21**	**6**	**24**

Source: Original table for this publication.

of case law built by the courts over time. None of the common law countries included in the assessment have enacted statutory provisions to define dam failure liability and, therefore, have opted to rely entirely on common law to define liability in the case of dam failure.

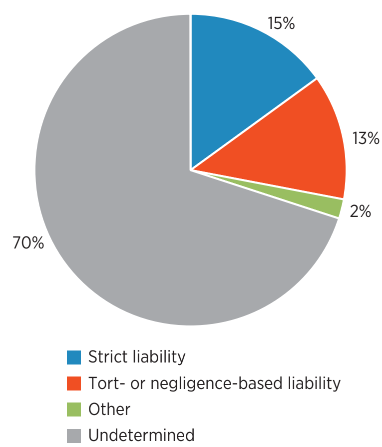
Tort-based dam failure liability can be strict or negligence-based. Strict dam failure liability means that the person responsible for the safety of the dam is always legally responsible for any injury or damage caused by the dam failure.[7] This legal responsibility is regardless of culpability as there is no requirement for the plaintiff to prove fault, negligence, or intention on the part of the defendant. In such instances the plaintiff needs only to prove injury and loss due to dam failure. In contrast, negligence-based liability requires the plaintiff to prove fault or negligence on the part of the defendant. Thus, the responsible person(s) becomes liable only if they have not maintained an acceptable standard of care. Standard of care encompasses all practicable measures that the dam owner or contractor is required to exercise to ensure the safety of the dam and the communities downstream of it.

Determining the grounds for either strict or negligence-based potential liability is typically not clearly defined, and it was not possible to determine the grounds for liability in the majority of the case studies. Only 15 percent of the case studies define strict liability, including Italy, Norway, and the United Kingdom, with 13 percent of the case studies having a clearly defined negligence-based liability, such as Korea and Malaysia (figure 3.6).

Strict liability is more commonly adopted by civil law countries (table 3.9) and seems more prevalent among high-income countries (table 3.10). In the civil law countries and jurisdictions that adopt strict liability, the liability provisions are expressly defined under the dam safety statute law, including the parties that are strictly liable and what exceptions may apply. For example, in Switzerland the strict liability applies to the dam owner and/or operator where both parties are joint and severally liable and the exceptions that apply include act of God, war, terrorism, and contributory gross negligence on the part of the victim. Strict liability is present in some common law jurisdictions such as Sri Lanka and the United Kingdom. For example, the United Kingdom defines strict liability for dam failure only through its common law (per *Rylands v Fletcher*, 1868), and there is no need to define it under statute because all damages historically recognized may be sued for, whether there is mention of those damages in the current statutory law or not.

Negligence-based liability is observed in both common law and civil law countries. In civil law countries the plaintiff needs to prove that the dam owner or contractor was in breach of the statutory

FIGURE 3.6 Types of liability among the case study countries and jurisdictions



Source: Original figure for this publication.

TABLE 3.9 Types of liability among the case study countries and jurisdictions, by legal system

Legal system	Strict liability (dam owner is liable for all damages regardless of fault)	Tort- or negligence-based liability (dam owner and contractors liable only if they have not maintained an acceptable standard of care)	Other	Undetermined
Common law	2	3	0	6
Civil law	5	3	1	18
Religious law	0	0	0	1
Mixed	0	0	0	5
Common and civil law	0	0	0	2
Total	**7**	**6**	**1**	**32**

Source: Original table for this publication.

TABLE 3.10 Types of liability among the case study countries and jurisdictions, by income level

Income level	Strict liability (dam owner is liable for all damages regardless of fault)	Tort- or negligence-based liability (dam owner and contractors liable only if they have not maintained an acceptable standard of care)	Other	Undetermined
High income	6	4	1	9
Upper middle income	0	1	0	11
Lower middle income	1	1	0	9
Low income	0	0	0	3
Total	**7**	**6**	**1**	**32**

Source: Original table for this publication.

duty, which is defined by the law. In common law countries the plaintiff needs to prove that the dam owner or contractor was in breach of the currently accepted standard of care. This standard of care should be balanced against the dam's potential hazard and required safety level and the required time, human capital, and financial resources of undertaking measures to control the safety of the dam. In many countries, these measures and, hence, the standard of care, are set by regulations, with further detailed requirements established through guidelines that sit outside the law. This approach gives regulatory authorities flexibility to modify the requirements in a practical manner. For example, Malaysia refers to the Malaysian National Committee on Large Dams to set the acceptable standard of care. In Australia, the federal system and its delegation of responsibilities to the states means that some have deferred generally to the national committee (ANCOLD) guidelines, others follow guidelines from the state regulator, and the state of Tasmania defers to specific ANCOLD guidelines expressly within its regulation without providing detailed dam safety requirements or defining the standard of care.

Most jurisdictions implicitly assign primary liability for dam failure to the dam owner. This is due to the owner being primarily responsible for dam safety. For example, in Australia this primary responsibility or liability on the dam owner arises from a duty of care owed to a downstream plaintiff. This is "nondelegable," as the dam owner is considered to have the "central element of control" of the risk, as the occupier of the land, and so cannot delegate that duty to a contractor (per *Burnie Port Authority v General Jones*, 1994, box 3.3). This verdict applies to many owners of dams with potential risks to exercise the duty of care when there is proximity between the dam and the assets of the plaintiff that could be damaged by failure. Hence, dam owners are obligated by law to take reasonable care of their dams according to current prevailing standards (Pisaniello 1997, 2011, 2014). Furthermore, the only way a dam owner can share liability with a contracted party in Australia is to personally sue the party for breach of contract and/or professional negligence

BOX 3.3

BURNIE PORT AUTHORITY V GENERAL JONES (AUSTRALIA HIGH COURT, 1994): NEGLIGENCE VERSUS STRICT LIABILITY

Per common law in Australia up to March 1994, an owner was liable for losses downstream in the event of dam failure, irrespective of whether negligence on the owner's part to appropriately construct, maintain, or operate the dam could be proven. This was based on the Common Law Doctrine of Strict Liability, which was, in fact, first put forward in 1868, in the case of *Rylands v Fletcher*, concerning the collapse of a dam.

In this case, although the dam owner was excused of any negligence, he was held to be liable by Blackburn J on the following basis:

> [A] person who for his own purposes brings on his lands and collects and keeps there anything liable to do mischief if it escapes, must keep it in at his peril, and, if he does not do so, is prima facie answerable for all the damage which is the natural consequence of its escape. (*Rylands v Fletcher*, 1868)

But the Law of Strict Liability came under the consideration of the High Court of Australia in the case of *Burnie Port Authority v General Jones Pty Ltd* (March 1994) with a significant result. In that case, Burnie Port Authority (BPA) occupied a warehouse and allowed welding to happen near some cardboard. This caused a fire that caused $A 2.5 million of damages to the

(continued)

BOX 3.3 *(continued)*

neighbors' goods. The case held that even though the welders were contractors, the BPA owed a nondelegable duty of care, and because there was a dangerous substance it should have taken greater care, especially when it was obvious welding could cause this harm. But most significantly, the court decided by a majority that the rule in *Rylands v Fletcher* was not the law in Australia, for the following reason:

> [T]he strict liability rule had all but been obliterated by subsequent judicial explanations and qualifications and . . . should be seen as absorbed by the principles of ordinary negligence. Under those negligence principles, a person taking advantage of the control of premises to introduce a dangerous substance, to carry on a dangerous activity, or to allow another to do one of those things, owes a duty of reasonable care to avoid a reasonably foreseeable risk of injury or damage to the person or property of another.

While removing the common law duty of strict liability in Australia in favor of the current negligence (fault-based) duty, the court indicated that the higher the magnitude of danger, "the standard of reasonable care may involve a degree of diligence so stringent as to amount practically to a guarantee of safety." Hence the duty can arise out of acts or omissions, such as failure to maintain a dam, and varies according to the magnitude of risk. But when strong terms such as "guarantee of safety" are used by judges in landmark cases, this suggests that if the highest possible industry standard has not been met, then liability certainly may apply. Such a high common law duty or standard of care—essentially applying when people's lives are at risk—means that strict liability may practically still apply in Australia at least for the more highly hazardous dams.

that may have contributed to causing the dam failure, in which case multiple parties would be joined in the one action.

The test of negligence is to ask whether the defendant behaved unreasonably toward the plaintiff in circumstances where a duty of care was owed. This duty of care is owed when there is a reasonably foreseeable risk to the plaintiff involved that was not too remote. The duty involves reducing the risk to an acceptable standard as set by case law and/or statute law in common law systems or statute law in civil law systems. Therefore, the plaintiff must prove on the balance of probability that the following held true:

- The defendant owed a legal duty of care.
- The defendant has a standard of care expected.
- The defendant was in breach of that standard of care, such as not reducing the foreseeable risk, so far as is reasonably practicable in common law

countries (see box 3.4), or as required under the statutory duty in civil law countries.

- The plaintiff's injury and loss arose from that breach.

BOX 3.4

IMPLICATIONS OF CASE LAW ON REASONABLE PRACTICABILITY IN COMMON LAW COUNTRIES

The approach of public safety regulators to risk management appears to be founded in the common law legal tests for "negligence" and in the term "reasonable practicability." In common law countries, duty holders must look to both their statutory and common law obligations unless statutory obligations expressly override common law ones.

The UK Health and Safety Executive (HSE 2001) explained the implications of case law on "reasonable practicability." Given that it is ultimately a matter for the courts to decide whether or not duty holders have complied with such duties, considerable attention must be paid to how the courts have interpreted the above qualification.

Case law on duties qualified by the concept of reasonable practicality makes it clear that the courts will look at all relevant circumstances, on a case-by-case basis, when reaching decisions on the appropriateness of action taken by duty holders in meeting this qualification. Of particular importance in the interpretation of "reasonable practicability" is *Edwards v National Coal Board* (UK 1949).

This case established that a computation must be made in which the quantum of risk is placed on one scale and the sacrifice, whether in money, time, or trouble involved in the measures necessary to avert the risk, is placed in the other; and that, if it be shown that there is a gross disproportion between them, the risk being insignificant in relation to the sacrifice, the person upon whom the duty is laid discharges the burden of proving that compliance was not reasonably practicable.

If not defined under statute, it can be inferred from relevant common law on negligence regarding duty or standard of "reasonable care." This will vary depending on the level of the risk balanced against the expense, difficulty, and inconvenience to alleviate it in a justifiable way. For example, as per the *Wyong Shire Council v Shirt* 1980 Australian High Court case, the judge stated that for the "risk calculus": that when deciding on a breach of duty of care, the court must not only determine a foreseeable risk but it must also determine a reasonable person's response by "consideration of the magnitude of the risk and the degree of probability of its occurrence, along with the expense, difficulty and inconvenience of taking alleviating action and any other conflicting responsibilities which the defendant may have."

In addition to pecuniary damages or penalties, criminal liability and sanctions may also be imposed on the dam owner or contractor in the event of dam failure or mis-operation of a dam. These sorts of criminal penalties typically have a statutory character, because they are contained in the law. However, there are some jurisdictions, such as the United Kingdom, where the area of criminal law remains largely governed by the common law. Criminal liability following a dam failure can apply if there are grounds for it under the applicable criminal laws of the country (for example, criminal negligence). This usually requires acts of gross negligence or recklessness to be proven beyond reasonable doubt.

INSURING AGAINST LIABILITY

Dam safety insurance does not exist in most of the case study countries or jurisdictions (table 3.11). Where it does exist, it is usually voluntary (25 percent), with a few countries adopting mandatory insurance (6 percent), and in one instance in the US this is subsidized, albeit indirectly.[8] Further, the analysis shows that dam safety insurance typically becomes an element of the dam safety legal framework in countries with higher income levels. For example, in Sweden dam safety insurance is mandatory for all members in the power industry association (Energiföretagen), and all regulated or classified dams must be insured for third-party liability. This is facilitated through a branch insurance based on an annual fee levied on every dam facility (Bartsch 2017). Dam safety insurance is also mandatory in Portugal, where owners of dams located downstream of the border with Spain are seeing their insurance premiums increase. According to the insurance companies, this increase is reportedly because the dams located upstream within Spanish territory do not meet the required safety standards to keep insurance premiums stable.

Requiring by law that dam owners or individuals downstream of a dam who could be potentially impacted by floods resulting from a dam failure obtain insurance to cover them for all consequences in such event can be a method for dam safety assurance (Pisaniello, Tingey-Holyoak, and Burritt 2012). While insurance fundamentally provides more of a remedy once dam

TABLE 3.11 Insuring against liability among the case study countries and jurisdictions

Income level	Does not exist	Mandatory	Voluntary	Subsidized	Undetermined
High income	3	2	9	1	5
Upper middle income	8	1	4	0	1
Lower middle income	11	0	0	0	3
Low income	4	0	0	0	0
Total	**26**	**3**	**13**	**1**	**9**

Source: Original table for this publication.

failure has occurred, rather than assurance that dams are being managed properly, this method can provide a quasi-regulatory form of supervision of dam safety management if insurance premiums are linked to the level of dam safety management. If dams are not managed to an acceptable standard by owners, insurance premiums will be significantly higher. Hence owners have an incentive to manage dams properly and in line with acceptable standards. However, they are not mandated to guarantee that they will do so. This can only be provided through "command-and-control" dam safety legislation. The main challenge with an insurance-based approach is that the premiums set by the insurance industry are usually excessive and not affordable for most dam owners. For the approach to work, some government intervention in the form of a government-run, subsidized, or underwritten scheme would typically be required (Pisaniello, Tingey-Holyoak, and Burritt 2012).

KEY MESSAGES AND CONCLUSIONS

There are a number of key factors that determine the legal foundations for dam safety assurance. These include the type of legal system, the constitutional basis for law making and administration, and a continuum of legislative options that include prescriptive legislation, enabling legislation, or self-regulation mechanisms.

The type of legal system in a country will determine to a certain extent the agility of the dam safety legal framework. Common law provides a less prescriptive mechanism than civil law, in which dam safety assurance standards can be contained within a set of guidelines existing outside the legal regime. As a result, dam safety assurance standards can practically evolve without requiring any action from the legislative power. In contrast, civil law is more prescriptive and requires dam safety assurance standards to be contained within legislation or codes. This type of legal system requires legislative action by a parliament, government, or other regulatory authority relevant to dam safety in order to update evolving standards.

The constitutional basis for government law making and administration for dam safety raises important considerations for securing uniformity in dam safety assurance. If a country's constitution recognizes multiple authorities with responsibilities for establishing dam safety frameworks and standards (for example, state or provincial-level governments), then the federal government may consider establishing a common dam safety framework building on multiple regulations by federal governments and subnational authorities, as well as sectoral regulations. Brazil introduced such an approach through its 2010 Dam Safety Act. The government may also need supplementary mechanisms other than the law to encourage uniformity. Uniformity means that the same legal framework for dam safety management and assurance applies to all dams within a country, regardless of their geographic location or ownership.

Some countries operate their portfolio of dams without any specific provisions for dam safety assurance in either dedicated or enabling legislation. The absence of specific dam safety provisions creates a number of risks and should be seen as an interim step toward the establishment of a specific legal framework for dam safety. This absence of any specific provisions is particularly problematic for countries with a large portfolio and significant private sector participation. If the country's portfolio of dams is very small and without any major hazards, it may be possible to manage the dam safety elements on a project-by-project basis. However, provisions should be made to secure the necessary technical and financial support for developing suitable regulations and addressing the long-term capacity gaps for ensuring the safety of dams and downstream communities.

Legislative provisions for dam safety assurance are typically static and rarely account for changing circumstances. For this reason, many of the case studies have legal frameworks in transition, and contradictions between different pieces of legislation can exist. During these transitional periods, it is important to ensure vigilance and a continuous process of review to ensure regulatory enforcement. This should be supported through capacity building to allow for the human capital and financial requirements to accommodate the new legislative provisions for dam safety. Such transitions are often prompted by specific events that increase the awareness around dam safety, such as the enhanced legislation one year after the Oroville Dam incident in California (see box 1.2 in chapter 1).

Integrating dam safety provisions within enabling legislation, such as water or environmental law, is generally considered a practical first step in developing the first regulatory provisions for dam safety. Many countries with diverse portfolios have successfully established the foundations for dam safety through such approaches and continued to amend them as needed. Establishing the foundations and then building along a continuum that evolves in response to the changing circumstances within the country, and in response to the characteristics of the portfolio, allow these to be applied to the institutional arrangements. Project-specific arrangements in the case of single dams or small portfolios can give rise to dedicated dam safety units within existing regulatory authorities. These can evolve into stand-alone regulatory authorities at either the national or state and provincial levels according to changes in the portfolio and the availability of sufficient human capital and financial capacity. However, possible risks should be carefully assessed at each stage and specific measures incorporated to manage these, particularly during transition periods.

The primary responsibility for dam safety rests with the dam owner, and this should be clearly stipulated in the specific legislative provisions. The legal framework should clearly stipulate the required design standards, safety requirements, and standard of care, including reporting procedures. These should be informed by a dam classification system that enables regulatory authorities to assess the owner's compliance in a clear and transparent manner.

The roles and responsibilities of the regulatory authority should also be clearly stipulated with provisions to ensure that their activities are reported and disclosed in the public domain.

In the case of damage due to failure or mis-operation of a dam, it should be possible to hold the dam owner liable. However, to do so requires a clear definition of dam failure liability, as well as how such liability is determined (strict or negligence-based) and allocated. Proper registration of dams clearly assists in distributing responsibility and improving transparency among the different stakeholders involved, such as the government, dam owners, dam operators and managers, water-user associations, the regulatory authority, engineers, and the community. An unclear demarcation of roles and responsibilities makes it difficult to hold any one of them accountable for any property or personal damage downstream caused by a failure or unsafe operation of a dam.

Dam safety guidelines that have a legal basis and set the acceptable standard of practice help in determining if a dam owner has breached the standard of care that is owed to the community. When establishing the standard of care in such standards, the potential hazard and required safety level should be carefully considered. Care should also be taken to consider the financial, human, and institutional capacity available to dam owners, operators, managers, and the regulator to meet the established standard of care. Rarely do dam owners and operators insure against all the consequences in the event of dam failure. These instruments are still underdeveloped, and if they do exist, there are often challenges in monetizing dam safety risk into economic and financial risk, as well as excessively high premiums that are not affordable for most dam owners. As such, intervention in the form of a government-run, -subsidized, or -underwritten scheme is typically required. Careful consideration must also be given to potential perverse incentives in insuring against the duty of care.

In developing the legal framework for dam safety assurance, it is advisable to include specific provisions for the following issues: (1) definition of dams subject to regulations; (2) the roles and responsibilities of the dam owners and regulators; (3) dam safety standards and requirements commensurate with the potential hazard, typically through a dam classification system; (4) disaster risk management and emergency preparedness measures, especially in light of climate change, increasing population, and demographic changes; and (5) financial resources and human capital necessary for ensuring dam safety. Given that small dams often sit outside of the regulatory provisions and can present a different set of risks, it is recommended that authorities specify practical requirements for ensuring the safe operation, maintenance, and monitoring of small dams, particularly when there is a large portfolio of hazardous small dams. The definition and classification of dams subject to regulations should be reviewed, assessed, and updated regularly in response to the evolving nature of the hazards due to changes in the portfolio or the demographic profile downstream.

NOTES

1. *Law administration* refers to both the implementation and enforcement of laws.
2. All countries belonging to ICOLD have established their national committees on large dams or equivalent under similar but different names covering various sectors related to dams. Some of the national committees have developed national dam safety guidelines, albeit outside of formal regulations.
3. This mix can involve several subvariations. For example, customary norms are accepted in many jurisdictions that belong to a civil law tradition or even to common law systems that do not accept religious systems (for example, certain principles of international law are given explicit recognition as custom either in their constitution or case law). The reference to customary law and religious law within the one mix here is intended to acknowledge these and simplify the analysis, given that customary and religious law, wherever applied, does not have much relevance to dam safety assurance and regulation.
4. *Enabling legislation* refers to provisions incorporated within an existing or new broader framework law (such as that for water, environmental, or other related laws) to enable the control or regulation of dam safety management. The incorporated provisions look to define and distribute the different roles and responsibilities needed to assure the safety of dams.
5. This is in contrast to criminal-based dam failure liability, which usually involves intent or recklessness in wrongdoing and is captured under the criminal law jurisdiction of a country.
6. It should be noted that in civil law systems the relevant general civil liability code (if one exists) and associated generic liability principles may be used as grounds for liability in the absence of any dedicated dam failure liability provision. This study simply looked for any specific provision of liability within the dam safety laws and codes themselves, such as in Norway, Sweden, and Switzerland, and in the majority of cases this was absent or relied on peer reviewers' feedback, some of which simply indicated being dealt with under general civil liability code.
7. With some extreme exceptions often applying, such as force majeure (act of God), war, and acts of terrorism.
8. Per Pisaniello, Tingey-Holyoak, and Burritt (2012), "Under the USA's National Flood Insurance Program (NFIP), the risk is underwritten by the US government and the premiums are subsidized by the taxpayer while the insurance companies get income from writing the policies. The purchase of flood insurance is mandatory for all federally related financial assistance for the acquisition and/or construction of buildings in high-risk flood areas (Special Flood Hazard Areas) and the amount to be covered is the maximum amount of coverage available for the particular property type, or the outstanding principal balance of the loan, or the insurable value of the structure. If the property is not in a high-risk area, but instead in a moderate-to-low risk area, federal law does not require flood insurance; however, a lender or bank can still require it. The NFIP is then also linked to dam safety through the Community Rating System scheme which awards credits on insurance premiums to flood-risk communities for the dam safety assurance programs operated by their states—more credits are awarded when a state adopts more elements of the [Association of State Dam Safety Officials'] model state dam safety program."

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4

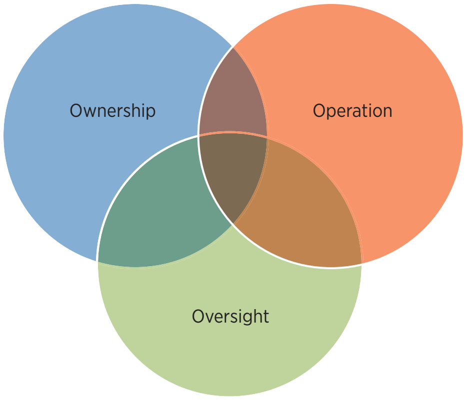
Institutional and Governance Arrangements for Dam Safety Assurance

CONTEXT AND RATIONALE

The institutions responsible for ownership, operation, and oversight of dam safety assurance are informed through the enabling legal framework (figure 4.1). The nature of the institutional arrangements will reflect the composition and structure of the national portfolio. These will be determined by the prevalence of public or private owners and operators, their sectoral purpose, and financial architecture and will be informed by the size distribution and type of dams. As a result, there is a range of institutional forms that exist along a continuum with different degrees of independence.

Ownership can be distinct and separate from the responsibility for management, operation, maintenance, and rehabilitation. There are a number of different institutional options that infer different degrees of responsibility among owners, operators, and oversight institutions. While the responsibility for dam safety assurance can be wholly assigned to the owner, some of these responsibilities may be contracted out (for example, to the engineer, builder, manager, operator, or lessee) or split between the owner and the regulator. If the regulator assumes more of a hands-on role in dam safety inspection, assessments, and approvals, then it may also assume some of the responsibilities for dam safety and therefore be subject to potential liability. The responsibility can also sit solely with the government through self-regulation of the dams that it owns, in which it assumes a hands-on approach, although actual execution varies depending on the level of capacity.

FIGURE 4.1 Institutional involvement in dam safety assurance



Source: Original figure for this publication.

The independence of institutions responsible for dam safety assurance can have significant implications for dam owners and operators. There is no single solution, and the context prescribes the utility of the different options along a continuum. Where oversight mechanisms do exist, these can be implemented through centralized apex institutions, stand-alone sectoral entities, or subnational organizations. These can be fully independent, rely on a degree of self-regulation, or include a mixed approach.

Central to any successful dam safety assurance system is ensuring that the institutional capacity is sufficient to meet the expected duty of care. This includes sufficient financial resources, human capital, and technical capacity to respond to the challenges of the portfolio under management and regulation. This capacity needs to be able to respond to changes in the portfolio characteristics to ensure the standard of care is maintained and adequate.

There are increasingly complex questions surrounding the institutional arrangements governing dam safety. One of the most significant challenges facing many countries is ensuring the continuous evolution of the overall institutional framework for dam safety to address changes in the nature of the portfolio, while having the political, societal, and environmental climate to balance water storage safety in all aspects of design, operations, and maintenance. While the complexity of dam safety requires formal governance models for risk management, a contextual and practice-based approach is required to better understand the historical, social, spatial, and institutional dynamics of dam safety risk governance (Boholm, Corvellec, and Karlsson 2012).

ROLES AND RESPONSIBILITIES FOR DAM SAFETY ASSURANCE

Responsibility for dam safety refers to the care and consideration that needs to be given to ensure that a dam is kept in safe condition. This includes the accountability of the person or group of persons that are responsible for the safety of the dam throughout its life and, most important, for maintaining it in proper condition during the operation phase to meet the needs that fit its purpose, whether it is water supply, irrigation, energy production, flood protection, or a combination of these.

A clear statement of primary responsibility for the safety of the dam is a key element of any legal framework for dam safety. This clear definition is a prerequisite for ensuring accountability in the case of personal or property damage due to a dam failure or events during the operation of the dam.

Roles and responsibilities need to be assigned in relation to the ownership, operations, and oversight or regulatory functions. These exist along a continuum and are informed by the degree of separation among the owner, operator, and regulatory authorities responsible for oversight. In some instances, such as government self-regulation of publicly owned dams, these are all situated within the same organization. These roles and responsibilities can include the following:

- The dam owner is fully responsible for all elements of dam safety assurance.
- The dam owner is responsible, but some responsibility can be contracted out for operations, maintenance, and/or development to an engineer, contractor, manager, operator, or lessee.
- The regulator is responsible for some elements of dam safety with a corresponding degree of liability depending on the level of involvement in dam safety inspection, assessments, and approvals.
- The allocation of responsibilities varies among different entities depending on ownership, classification, sector, and purpose, among other criteria.

The dam owner is the primary responsible entity for the safety of the dam in almost all instances examined among the case study countries and jurisdictions. In the case of damage to assets or to people downstream of the dam due to dam failure or unsafe operation, the dam owner would be the first entity from whom to seek compensation. Where the government is the sole owner of all dams and assumes full responsibility, which may be the case in those countries where the government self-regulates the dams that it owns, it naturally has a more hands-on approach, although the actual execution level varies depending on their capacity.

The dam owner is not necessarily the only entity responsible for the damage caused in the event of a dam failure or mis-operation. While the dam owner is primarily responsible for the safety of the dam, responsibilities may be shared by the dam owner along with other persons: for example, when responsibilities are delegated to dam managers or operators. The regulator can also assume different degrees of responsibility with associated degrees of potential liability depending on the extent to which it assumes responsibility for dam safety inspection, assessment, and review. However, in almost a quarter of the case studies, the legal framework refers only to dam owners, meaning the distribution of responsibility may not be as clear in the event of a dam failure or damage caused through operations.

Shared responsibility for dam safety is possible but requires a clear separation and definition of the roles and responsibilities of the owner and those of the dam manager or other entities involved. These should be defined through legislation to ensure a proper legal foundation for compliance, with minimum provisions and clear recourse in the event of dam failure or mis-operations. Often the legislative foundations allow adjustments to those provisions of the law through formal agreements between the dam owner and the other parties. In other instances, the legal provisions do not make specific reference to such possibilities, so that the distribution of roles and responsibilities is entirely under the control of the parties via agreement, such as in Australia, Burkina Faso, Malaysia, and Morocco. Notwithstanding the contract law, the dam owner is primarily responsible for ensuring the safety of the dam and liable in the event of any dam failure or mis-operation.

Where there is a clear delineation of shared responsibility for dam safety, legislation should specifically mention the ways in which the dam owner can contract such responsibility to a different party, such as a concessionaire, for a fixed period. In this way, the entity that is granted the concession is the primary responsible party for the financing and maintenance of the dam, essentially becoming the dam owner for the agreed period. However, even though the concessionaire may be designated as the primary responsible party for the safety of the dam, the dam owner is not free from all responsibility. As a form of contract agreement, the concession provides the dam owner only with avenues to share the responsibility for dam safety assurance with the concessionaire. In those jurisdictions where such means to share responsibility are not as clear or explicit, the dam owner would have a greater probability of bearing the entire responsibility for dam safety on its own. In jurisdictions such as Albania, Brazil, and the Czech Republic, the dam safety legislation clearly states the possibility of contracting such dam safety responsibility to concessionaires and the possibility of allocating the responsibility through contract law in the form of an agreement.

Oversight institutions can assume some responsibility and liability for dam safety assurance when the scope of the oversight moves from quality assurance to periodic direct inspection. In the United States, some responsibility for dam safety in the jurisdiction of Washington State lies with the state's Department of Ecology, which is an independent regulator. This oversight authority carries out periodic direct inspection and is responsible for implementing appropriate inspection and review programs for all dams, as well as for checking and supervising the design and construction of new dams in the state. Accordingly, an appropriate fee is charged to the dam owner for this service. Such "direct inspection" contrasts with the typical "quality assurance" dam safety assurance policy, which usually places the responsibility for surveillance on the dam owner, and the government merely assures itself, in the interest of public safety, that dam owners are taking responsible steps to achieve adequate quality at all the necessary phases associated with dam safety.

OVERSIGHT OF DAM SAFETY ASSURANCE

Providing a mechanism for the oversight of dam safety is essential for ensuring public protection, economic security, and environmental sustainability. Such mechanisms provide for the independent assessment of matters governing public safety, are used to establish technical standards and safety requirements, monitor compliance with dam safety requirements, enforce license conditions, regulate tariffs, handle disputes and redress grievances, and ensure emergency preparedness. Establishing appropriate oversight mechanisms can be achieved through a range of options. These options exist along a continuum that extends from minimum levels of dam safety assurance via pure self-regulation in the absence of any formal oversight mechanisms for any dams (either privately or publicly owned), through self-regulation of public dams with dedicated sectoral entities, to fully integrated, independent oversight mechanisms that provide for full command and control of all dams (figure 4.2).

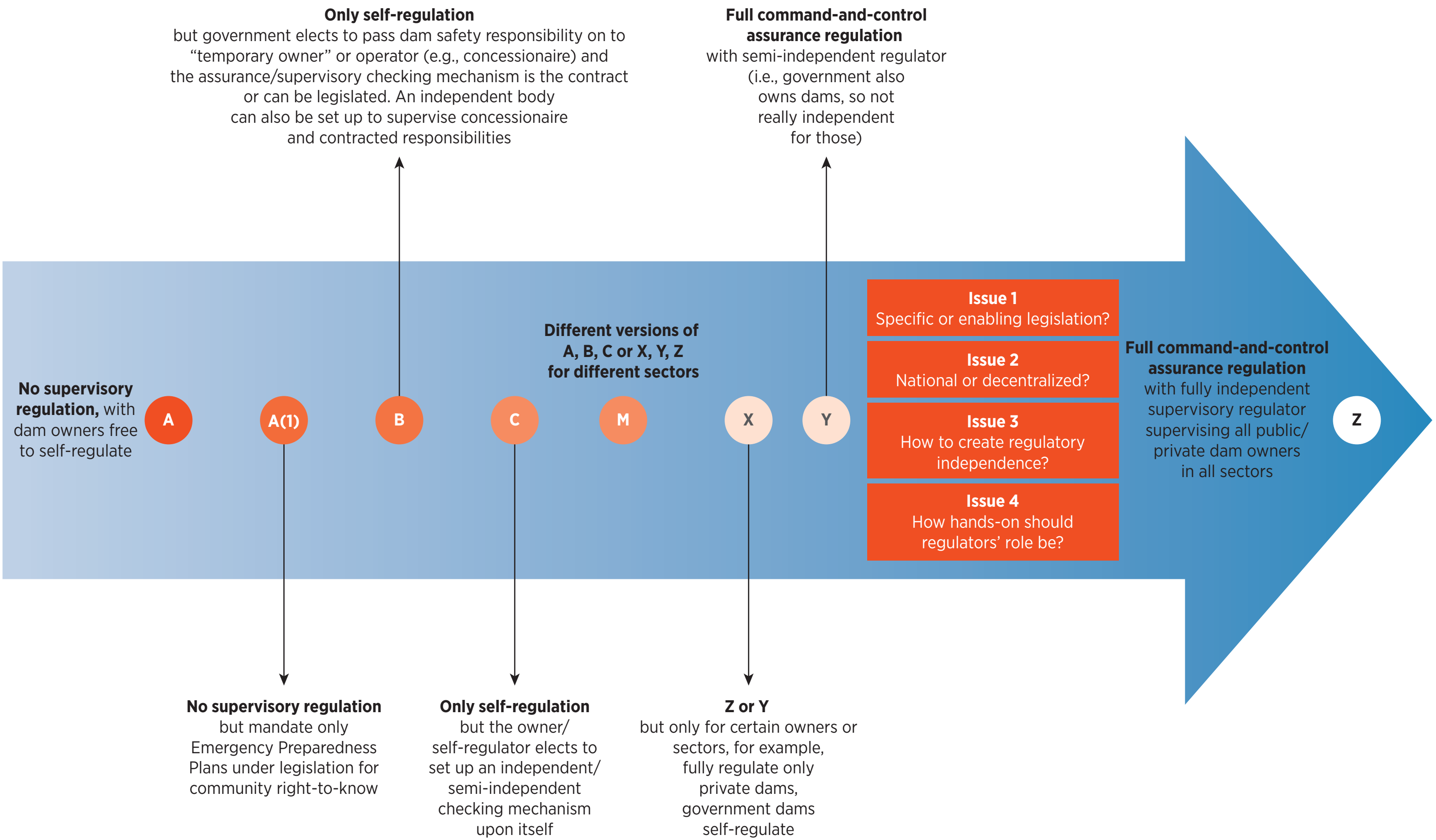
Variations can be adopted along the continuum through a range of options. What is appropriate for a jurisdiction will depend on its circumstances, and there are a number of considerations when moving dam safety along this continuum toward increased assurance. These include (1) whether to adopt specific or enabling legislation, and whether such legislation needs to be uniform or sector-based; (2) whether to implement national or decentralized regulations; (3) how best to create independence; and (4) what will be the extent and characteristics of the oversight role. The legal empowerment of oversight mechanisms for dam safety assurance can be achieved through two options.

The first option is to refrain from creating an oversight authority that supervises dam owners and instead trust that they will actively engage in continuous efforts that will work toward ensuring the safety of the dams under their responsibility. This can be encouraged by following dam safety guidelines, for instance. This is called self-regulation, because there is an act of faith by the government that all dam owners will keep their dams in safe condition and will operate them safely. The main challenge when choosing this option relates to the fact that dam owners, public or private, may not undertake the necessary actions to appropriately manage and improve the safety of the dam, and this, coupled with the absence of an oversight authority, could make the necessary change in their conduct particularly difficult.

The second option is to set up a dedicated dam safety authority that provides independent oversight to ensure that dam owners keep the dams that are under their responsibility in safe condition and that they operate them in a proper manner that serves their purpose while protecting the people, property, and downstream environment. Typically, the institutional setup is provided via legislation so that the competent body has the regulatory empowerment needed to undertake its oversight function. The main challenge when choosing this option is having enough human and financial resources to keep the institution running in the face of noncompliance by dam owners with dam safety requirements. In addition to the oversight functions, the regulator can also act as an owner and/or operator (see figure 4.2). This gives rise to questions of independence, which will be addressed first, followed by the possible overarching and specific roles of the regulators.

If all the dams within a portfolio are government-owned, there is limited opportunity for legal recourse, and so there may be little value in enacting specific regulations or establishing independent oversight mechanisms.

FIGURE 4.2 The continuum from minimum to maximum dam safety assurance



Source: Original figure for this publication.

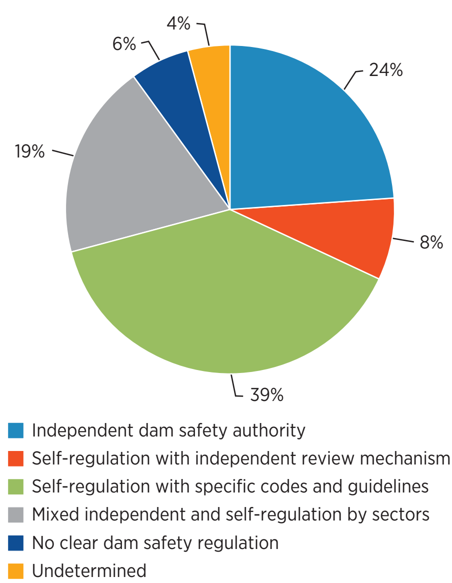
In such instances, the government can adequately self-regulate its dam safety management practices through independent review mechanisms, such as a dam safety review committee and/or a dam safety commission, and hence provide a satisfactory level of assurance for dam safety. Some independent dam safety committees have been established by laws, such as the New South Wales Dam Safety Committee in Australia, which independently oversees water supply dams that are owned by state-owned water corporations, effectively making them a hybrid of private-public owned dams. Such independent committees are generally required to review dam safety standards and the owner's dam designs, carry out compliance audits of the owner's operation and maintenance, and recommend remedies to the regulatory authorities (which would then impose penalties, order emergency remedies, and so forth in case of noncompliance) as defined by laws or regulations.

However, government ownership may apply only in certain sectors (for example, irrigation and water supply dams), and therefore, government self-regulation may be appropriate only for these sectors. If there is a mixed portfolio with other sectors having private ownership (for example, hydropower), more independent regulatory oversight may be required. In other circumstances, the government may prefer to use a concessionaire system of temporary private ownership and/or operation of dams in the portfolio and establish contracted dam safety responsibilities that could then be supervised by a dedicated authority.

An independent system of dam safety regulation provides the maximum level of assurance. This is particularly important for large, high-hazard portfolios. Independent dam safety authorities that do not own or have operational responsibilities for any dams were observed in 24 percent of the case studies (see figure 4.3, table 4.1, and table 4.2). In some cases, such as in France and Portugal, the dam safety authority is the ministry or agency in charge of environmental management, while others have established independent dam safety commissions, such as the state of New South Wales in Australia, which is responsible for all types of dams, and the Regulatory Agency for Dam Safety (Organismo Regulador de Seguridad de Presas) in Argentina, which covers only private hydropower dams.

Private self-regulation can provide sufficient oversight in some jurisdictions. However, this should be ensured through the use of well-developed codes and guidelines,

FIGURE 4.3 Independence of dam safety assurance authorities among the case study countries and jurisdictions



Source: Original figure for this publication.
Note: The total number of cases is greater than the 51 countries as some countries have developed parallel systems for different sectors.

as well as internal discipline and capacity to ensure dam safety management. Such provisions for private self-regulation have been observed in 39 percent of the case studies (figure 4.3, table 4.1, and table 4.2) with specific codes and guidelines (for example, US Army Corps of Engineers and US Bureau of Reclamation). It is possible to ensure sufficient oversight under this model as

TABLE 4.1 Independence of dam safety assurance authorities among the case study countries and jurisdictions, by region

Region	Independent dam safety authority	Self-regulation with independent review mechanism	Self-regulation with specific codes and guidelines	Mixed independent and self-regulation by sectors	No clear dam safety regulation	Undetermined
East Asia and Pacific	3	3	8	4	0	1
Europe and Central Asia	13	0	7	4	0	1
Latin America and the Caribbean	1	1	3	1	1	1
Middle East and North Africa	0	0	4	1	1	0
North America	2	0	2	2	0	0
South Asia	0	1	3	0	1	0
Sub-Saharan Africa	0	1	4	3	2	0
Total	**19**	**6**	**31**	**15**	**5**	**3**

Source: Original table for this publication.
Note: The total number of cases is greater than the 51 country case studies as some countries have developed parallel systems for different sectors.

TABLE 4.2 Independence of dam safety assurance authorities among the case study countries and jurisdictions, by income level

Income level	Independent dam safety authority	Self-regulation with independent review mechanism	Self-regulation with specific codes and guidelines	Mixed independent and self-regulation by sectors	No clear dam safety regulation	Undetermined
High income	14	1	5	5	0	1
Upper middle income	3	3	12	4	2	1
Lower middle income	2	2	12	4	1	1
Low income	0	0	2	2	2	0
Total	**19**	**6**	**31**	**15**	**5**	**3**

Source: Original table for this publication.
Note: The total number of cases is greater than the 51 country case studies as some countries have developed parallel systems for different sectors.

long as independent review or inspection mechanisms and procedures are sufficiently established and practiced. This requires significant institutional capacity, including human capital and financial resources, in the absence of which the quality of oversight can be compromised.

Where there are mixed regulation systems, it is important to ensure mechanisms are in place to minimize the potential for conflicts of interest. Mixed regulatory systems in which the regulators own some types of dams were observed in 19 percent of the case studies. This results in the potential for a conflict of interest between the self-regulation of those dams under their ownership and operation, while independently regulating other types of dams. Minimizing this potential can be realized through a range of instruments empowered through the legal framework or specific guidelines. For example, in South Africa the Department of Water and Sanitation (DWS) functions as the independent regulator across all sectors, including privately owned dams, but also owns and operates its own portfolio of dams. One of the mechanisms to minimize the potential conflict of interest is a legislative requirement that the dam owner's approved professional persons (APPs) responsible for dam safety must be consulted along with the independent Engineering Council of South Africa. The DWS has also established a clear separation of powers between the regulatory branch and the infrastructure branch within the department. In other jurisdictions with mixed systems, such as in Brazil, Indonesia, Japan, and Spain, the regulators use independent review committees or similar bodies in the self-regulation of their own portfolio of dams.

The absence of clear regulatory mechanisms for dam safety increases the likelihood that dam safety does not receive sufficient attention. In 6 percent of the case studies, there were no clear regulatory mechanisms for ensuring the safety of dams or downstream communities (figure 4.3, table 4.1, and table 4.2). In these instances, there were no dedicated legislative provisions, nor were provisions for dam safety observed in the most relevant sector laws, such as those for water or environmental management, or in regulatory provisions for the energy sector. Within this context, the absence of any formal oversight mechanisms raises a number of concerns and should be addressed through portfolio monitoring to ensure there are no significant hazards to the safety of dams or downstream communities.

ROLE OF THE DAM SAFETY ASSURANCE AUTHORITY

The roles and responsibilities of the regulatory authority for dam safety will be determined by the overarching role with which the regulator is charged. There are three broad categories of powers and functions assigned to institutions responsible for oversight of dam safety assurance (see figure 4.4). While it is possible for regulatory authorities to include a mixture of these powers and functions, these typically range across the following:

1. Compliance audit functions that focus primarily on random quality assurance control: This involves checking that the reports and certifications prepared by the owner and/or engineer are in line with the mandates required by the law.
2. Quality assurance functions that assess overall assurance: This entails checking that the reports and certifications prepared by the owner and/or engineer are in line with the mandates required by the law but may also include hazard classification.
3. Direct inspection functions, through which the dam safety authorities are responsible for conducting periodic dam safety inspections, rather than relying on the reports and certification from the owner and/or the engineer: In carrying out the assessments, the authority in this case could end up assuming some responsibility and liability for the decisions relating to the safety of the dam.

Differentiating a clear delineation of the powers and functions among the regulatory authorities from the case study countries and jurisdictions according to the three typologies along the continuum is difficult due to a lack of clarity on all of the relevant legal provisions and precedents. This is further complicated by the fact that many countries have a mixed regulatory system with separate arrangements for different sectors. While many of the dam safety authorities reviewed under the case study countries and jurisdictions have a compliance audit and/or quality assurance role (figure 4.4), these do not exhibit a strong geographic signal but are concentrated among high-income countries (see tables 4.3 and 4.4 in the next section). About one-third of those authorities reviewed have been assigned a more direct,

FIGURE 4.4 Overarching roles of the dam safety assurance authority

Role	Compliance audit	Quality assurance	Direct inspection/ assessment
Function	**Random quality assurance audits only** Otherwise just rubber-stamping reports and certifications provided by owners' engineers in a predominantly hands-off function	**Allover assurance, check all information/reports provided by owners' engineers for every dam** May also do the hazard classification (i.e., more hands-on)	**Performs periodic dam safety inspections and assessments** Highly hands-on function
Capacity	**Low** need for capacity/expertise in authority	**Medium** need for capacity/expertise in authority	**High** need for capacity/expertise in authority
Liability	Accepting **no** liability Authority makes no decisions related to the safety of the dam	Accepting **some** potential liability	Accepting **extensive** potential liability

Source: Original figure for this publication.

hands-on role in assessment and inspections, while a small number exhibit a mix of powers and functions. The distribution and occurrence of hands-on assessor-type dam safety authorities are more prevalent among middle- and low-income countries (see table 4.4 in the next section). Transition in the evolution of the regulatory regime seems to be evident, with most hands-on roles in middle-income countries.

Compliance-audit regulatory systems are found in the majority of cases. For example, in the Australian state of Tasmania the Water Management (Safety of Dams) Regulations (2015) lay out procedural requirements of owners' dam safety activities and required experts' competence and authorization, which correspond to seven dam classes. The regulations also lay out penalties in case of offenses. Almost all technical matters are deferred to Australian National Committee on Large Dams guidelines. The threat of audits and heavy penalties in case of noncompliance seems to provide sufficient pressure for owners to comply with the regulations. The content and format of the regulations indicate that Tasmania has adopted audit-type regulation.

Direct hands-on regulatory systems are found in some cases. For example, in the Canadian province of Quebec the regulator (Quebec Center for Water Expertise, Ministry of Sustainable Development, Environment and Protection Against Climate Change) is responsible for dam classification, approval of remedial measures, and approval of implementation schedules based on dam safety review. According to the regulation, if the owner fails to carry out a safety review and implement the prescribed remedial measures, the ministry may carry out the safety review and/or implement any required remedial measures at the owner's expense. The act (50 articles) and regulation (82 articles) provide details about required safety standards and criteria, including a very elaborate classification system, which demonstrates its hands-on regulation style.

Mixed regulatory or quality-controlled systems are found in a minority of cases. For example, in South Africa the regulator sits within the Department of Water and Sanitation under the Ministry of Water and Environmental Affairs and has responsibility for dam classification, licensing for new dam construction and rehabilitation of existing dams, and conducting dam safety reviews. However, dam owners are required to use APPs to design, supervise, and issue certificates. APPs are also required to perform dam safety evaluations for class II and class III dams with higher risks. The regulator approves the APPs while considering the recommendation of the independent Engineering Council of South Africa. This model can be considered a mix of the two models just presented, which represent either end of the continuum.

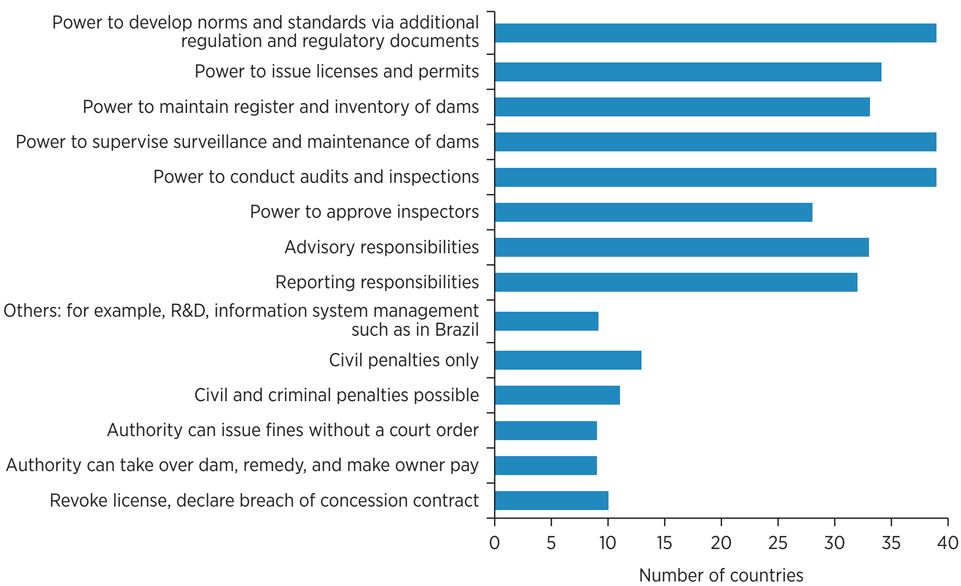
The more directly involved the regulatory authority is in the assurance of dam safety, the more resources and capacity it will require. Moreover, the more the regulatory authority is involved, the more responsibility it assumes and the greater the potential liability for those actions. If the regulatory authority can maintain a strong cadre of in-house technical specialists, it is better able to apply the safety standards in a consistent manner.

SPECIFIC ROLES AND POWERS OF THE DAM SAFETY ASSURANCE AUTHORITY

There is a range of specific roles and powers assigned to the dam safety assurance authority (figure 4.5). The majority of authorities reviewed within the case studies are empowered with the full set of powers. This includes the power to develop norms and standards (39 countries), to issue permits (34 countries), to maintain a register of dams (33 countries), to supervise dam maintenance (39 countries), to conduct inspections (39 countries), to approve inspectors (28 countries), advisory responsibilities (33 countries), and reporting responsibilities (32 countries). Furthermore, some countries have given more powers to regulators, such as to impose civil penalties (13 countries); to take over dams, remedy, and make the owner pay if the owner does not execute required remedies (9 countries); and to remove a license or concession contract (10 countries), among others.

In those countries where such dam safety assurance authorities may not impose fines in case of finding noncompliance, the usual recourse is through a court order. However, some regulators use more soft power over noncompliance by disclosing a list of owners and/or dams in compliance with regulations to the public using its website, in bulletins, and so forth, thus exposing noncompliance. Other regulators may provide technical guidance and education to owners to raise their awareness of risks.

FIGURE 4.5 Specific roles and powers of dam safety assurance regulators among the case study countries and jurisdictions



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

TABLE 4.3 Specific roles and powers of dam safety assurance regulators among the case study countries and jurisdictions, by region

Region	Power to develop norms and standards via additional regulation and regulatory documents	Power to issue licenses and permits	Power to maintain register and inventory of dams	Power to supervise surveillance and maintenance of dams	Power to conduct audits and inspections	Power to approve inspectors	Advisory responsibilities	Reporting responsibilities	Others: for example, R&D, information system management	Civil penalties only	Civil and criminal penalties possible	Authority can issue fines without a court order	Authority can take over dam, remedy, and make owner pay	Revoke license, declare breach of concession contract
East Asia and Pacific	9	9	7	9	9	7	7	7	3	3	3	2	2	5
Europe and Central Asia	15	14	15	16	16	13	15	15	3	6	4	5	3	2
Latin America and the Caribbean	4	2	3	3	2	1	2	1	1	2	1	0	1	1
Middle East and North Africa	2	2	1	2	2	0	1	1	0	0	0	0	0	1
North America	2	2	2	2	2	2	2	2	2	2	0	2	1	1
South Asia	2	0	0	3	3	0	3	2	0	0	1	0	1	0
Sub-Saharan Africa	5	5	5	4	5	5	3	4	0	0	2	0	1	0
Total	**39**	**34**	**33**	**39**	**39**	**28**	**33**	**32**	**9**	**13**	**11**	**9**	**9**	**10**

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

TABLE 4.4 Specific roles and powers of dam safety assurance regulators among the case study countries and jurisdictions, by income level

Income level	Power to develop norms and standards via additional regulation and regulatory documents	Power to issue licenses and permits	Power to maintain register and inventory of dams	Power to supervise surveillance and maintenance of dams	Power to conduct audits and inspections	Power to approve inspectors	Advisory responsibilities	Reporting responsibilities	Others: for example, R&D, information system management	Civil penalties only	Civil and criminal penalties possible	Authority can issue fines without a court order	Authority can take over dam, remedy, and make owner pay	Revoke license, declare breach of concession contract
High income	17	17	17	17	17	17	17	17	4	8	5	7	5	5
Upper middle income	10	7	9	10	9	4	6	7	4	5	2	2	2	1
Lower middle income	9	7	4	10	10	4	8	6	1	0	3	0	1	4
Low income	3	3	3	2	3	3	2	2	0	0	1	0	1	0
Total	**39**	**34**	**33**	**39**	**39**	**28**	**33**	**32**	**9**	**13**	**11**	**9**	**9**	**10**

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

A number of the regulatory authorities examined among the case study countries and jurisdictions have been assigned other functions and powers (see table 4.3 and table 4.4). Among others, these include research and development (such as in the case of China and Sweden). There is a clustering of these specific roles and powers appearing in high- and upper-middle-income countries generally (table 4.4).

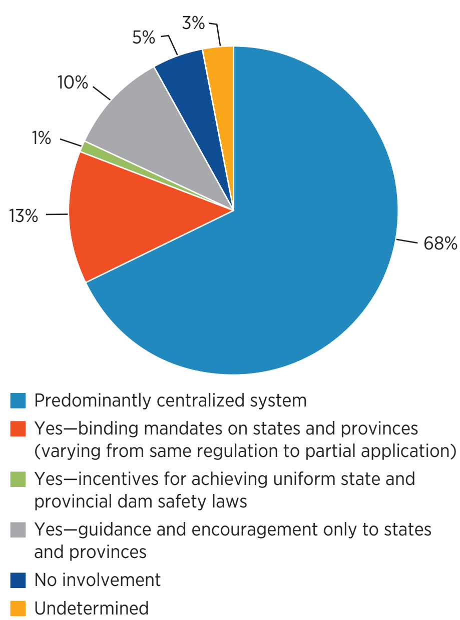
VERTICAL INSTITUTIONAL SYSTEMS ACROSS JURISDICTIONS

Among the countries studied, dam safety is predominantly regulated through centralized national systems. However, these powers and functions are distributed along a continuum depending on the administrative system and on the size of the portfolio and its hazard profile. Centralized systems in which the central governments have legislated the dam safety regulatory system exist in 68 percent of the case studies (figure 4.6, table 4.5, and table 4.6). In such instances, the subnational governments are required to follow the same regulatory system, although they generally have been delegated with the powers and functions to regulate smaller dams with lower safety hazard and requirements.

Where national systems for dam safety are limited, there is an increased potential for inconsistencies among the duty of care across subnational jurisdictions, particularly within the context of transboundary waterways and coordination in case of emergencies. National engagement can be limited to guidance and encouragement to the states or provinces, or the provision of incentives for achieving uniform dam safety laws across subnational jurisdictions such as in India and Malaysia. The Dam Safety Act adopted in the United States in 2006 designates the Federal Emergency Management Agency (FEMA) as the national dam safety coordinator, creating a system that allows the federal government to provide technical and financial assistance to state governments, in conjunction with the Association of State Dam Safety Officials, for ensuring consistent regulation and performance across the country.

While national governments can impose binding mandates on the subnational entities, there are also a number of examples

FIGURE 4.6 National involvement in dam safety assurance among the case study countries and jurisdictions



Source: Original figure for this publication.

TABLE 4.5 National involvement in dam safety assurance among the case study countries and jurisdictions, by region

Region	Predominantly centralized system	Yes—binding mandates on states and provinces (varying from same regulation to partial application)	Yes—incentives for achieving uniform state and provincial dam safety laws	Yes—guidance and encouragement only to states and provinces	No involvement	Undetermined
East Asia and Pacific	10	2	0	2	1	0
Europe and Central Asia	15	4	0	1	1	0
Latin America and the Caribbean	3	1	0	0	0	2
Middle East and North Africa	5	0	0	0	0	0
North America	1	0	1	1	1	0
South Asia	2	0	0	2	0	0
Sub-Saharan Africa	6	1	0	0	0	0
Total	**42**	**8**	**1**	**6**	**3**	**2**

Source: Original table for this publication.

TABLE 4.6 National involvement in dam safety assurance among the case study countries and jurisdictions, by income level

Income level	Predominantly centralized system	Yes—binding mandates on states and provinces (varying from same regulation to partial application)	Yes—incentives for achieving uniform state and provincial dam safety laws	Yes—guidance and encouragement only to states and provinces	No involvement	Undetermined
High income	13	5	1	3	3	1
Upper middle income	13	1	0	1	0	1
Lower middle income	12	1	0	2	0	0
Low Income	4	1	0	0	0	0
Total	**42**	**8**	**1**	**6**	**3**	**2**

Source: Original table for this publication.

where the subnational governments are delegated fully autonomous powers and functions for dam safety. For example, some countries delegate powers and functions relating to dam management in rivers that flow within a single subnational government boundary. In such instances, the subnational entity is still required to follow the same management framework as all jurisdictions and meet minimum standards of care, as exemplified by the legal framework in Brazil and Japan. While others allow subnational governments to establish their own regulations, such as for small dams in Italy and Spain, these are also required to be consistent with the national framework.

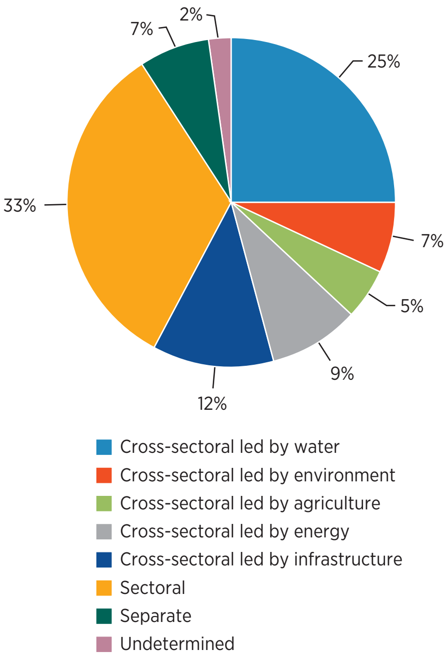
There are a number of other mechanisms to increase alignment between national frameworks and subnational jurisdictions. For example, some countries use fiscal transfer mechanisms to improve the financial resources and/or human capital for improved dam safety. This is observed in both construction and operation and maintenance. Examples can be seen in Indonesia, Japan, and Vietnam, among others. It is also important to recognize that in many countries there is a distributed division of labor between the national or central agencies and subnational entities or regional branch offices. For example, the Regional Directorate of Ecology, Planning and Housing under the Ministry of Environment has responsibility for dam safety in France, while in Spain the regulatory functions are distributed between the headquarters and the regional branch offices of the hydrological basins under the Ministry of Agriculture. Similarly, both the Federal Energy Regulatory Commission in the United States and the Water Resources and Energy Directorate established under the Ministry of Petroleum and Energy in Norway have developed regional offices with specific powers and functions in relation to dam safety, among others.

HORIZONTAL INSTITUTIONAL SYSTEMS ACROSS SECTORS

Sectoral considerations are important to the institutional arrangements for ensuring the safety of dams and downstream communities. The portfolio of dams within a country often includes dams across a range of sectors, often in different proportions. These can include irrigation dams to secure water for agriculture, for hydropower generation, and for water supply or flood protection, and they can be under a range of ownership structures. For example, private sector–owned hydropower facilities may be subject to independent regulation, while dams in other sectors, such as those for irrigation, water supply, or flood control, and owned by government entities may be government self-regulated. Considerations along this continuum of different options should inform the development of appropriate institutional arrangements for ensuring dam safety.

Cross-sectoral regulatory approaches allow a simpler mechanism for the establishment of comprehensive and consistent mechanisms for ensuring

FIGURE 4.7 Institutional arrangements of the regulatory systems among the case study countries and jurisdictions



Source: Original figure for this publication.

dam safety. Such cross-sectoral regulatory systems for dam safety are observed in 58 percent of the case studies. The regulatory functions within these systems are hosted by different sectors depending on the country-specific context and capacities (see figure 4.7, table 4.7, and table 4.8), including water, water resources, or flood management (25 percent); environment or natural resources management (7 percent); agriculture (5 percent); energy (9 percent); or more general infrastructure (12 percent).

Separate sectoral approaches to dam safety often represent a transitional phase or a strong sectoral bias in the country portfolio. Thirty-three percent of the case studies have developed sectoral regulations for different sectors in a parallel manner, including in China, the Lao People's Democratic Republic, and Vietnam, among others. Such sectoral approaches may function well when the portfolio of dams is relatively small or the portfolio is highly skewed toward a particular sector, such as hydropower or irrigation. For example, the energy sector has led in developing comprehensive dam safety regulations in Switzerland through the Federal Office of Energy under the Water Retaining Facilities Act as well as in Norway through the Water Resources Act by the Water Resources and Energy Directorate established under the Ministry of Petroleum and Energy. However, the sectoral approach can pose a number of challenges in evolving portfolios and may face issues with coordination and consistency across sectors and between regulators as the number of dams increases. This is particularly problematic in those basins where there are a number of independently regulated dams under different sectors and no apex institution to ensure consistency and optimization of operations and safety considerations. In some instances, these issues of coordination and consistency can be addressed through apex mechanisms. For example, China has developed two similar but distinct systems for dam classification with their own dam safety inspection and research institutes[1] guided by a multisectoral apex mechanism under the State Council. In contrast, 7 percent of the case studies have developed regulatory systems for dam safety separate from any sectoral ministries or agencies, such as through regional or county councils as in New Zealand and Sweden.

TABLE 4.7 Institutional arrangements of the regulatory systems among the case study countries and jurisdictions, by region

Region	Cross-sectoral led by: Water	Environment	Agriculture	Energy	Infrastructure	Sectoral	Separate	Undetermined
East Asia and Pacific	2	0	0	0	2	7	2	0
Europe and Central Asia	2	3	3	3	3	2	2	1
Latin America and the Caribbean	2	0	0	1	0	3	0	0
Middle East and North Africa	0	0	0	0	0	4	0	0
North America	1	1	0	0	2	0	0	0
South Asia	2	0	0	0	0	2	0	0
Sub-Saharan Africa	5	0	0	1	0	1	0	0
Total	**14**	**4**	**3**	**5**	**7**	**19**	**4**	**1**

Source: Original table for this publication.

TABLE 4.8 Institutional arrangements of the regulatory systems among the case study countries and jurisdictions, by income level

Income level	Cross-sectoral led by: Water	Environment	Agriculture	Energy	Infrastructure	Sectoral	Separate	Undetermined
High income	4	4	3	2	3	3	3	0
Upper middle income	4	0	0	2	1	8	1	1
Lower middle income	3	0	0	0	3	7	0	0
Low income	3	0	0	1	0	1	0	0
Total	**14**	**4**	**3**	**5**	**7**	**19**	**4**	**1**

Source: Original table for this publication.

Other dam safety institutions can also form a crucial part of assuring dam safety through a variety of means (see tables 4.9 and 4.10). The role of other institutions related to dams and dam safety (for example, International Commission on Large Dams [ICOLD] national committees and other professional bodies), can be in the form of provision of guidelines only, through to establishing codes/standards, and actually having a regulatory authority role. Most of the countries studied have other institutions related to dams and dam safety, not including any dam safety administration bodies that contribute in some way to dam safety. These produce support in the form

TABLE 4.9 Involvement of other institutions in dam safety assurance among the case study countries and jurisdictions, by region

Region	Yes—guidelines only	Yes—establish codes and standards	Yes—regulatory authority role	Yes—other	No involvement	Undetermined
East Asia and Pacific	10	1	0	0	0	1
Europe and Central Asia	9	1	3	1	1	3
Latin America and the Caribbean	1	0	0	0	2	2
Middle East and North Africa	2	0	0	0	0	3
North America	1	1	0	0	0	0
South Asia	1	2	0	0	1	0
Sub-Saharan Africa	4	2	0	0	0	0
Total	**28**	**7**	**3**	**1**	**4**	**9**

Source: Original table for this publication.

TABLE 4.10 Involvement of other institutions in dam safety assurance among the case study countries and jurisdictions, by income level

Income level	Yes—guidelines only	Yes—establish codes and standards	Yes—regulatory authority role	Yes—other	No involvement	Undetermined
High income	10	2	2	1	0	4
Upper middle income	6	1	1	0	3	4
Lower middle income	10	3	0	0	0	1
Low income	2	1	0	0	1	0
Total	**28**	**7**	**3**	**1**	**4**	**9**

Source: Original table for this publication.

of developing guidelines for dam safety, such as in the case of Bulgaria, the Philippines, and Thailand, among others, or in establishing codes and standards for dam safety, such as observed in Burkina Faso and Pakistan. In some countries these other institutions have a formal role within the regulatory authority. For example, in Portugal there is a separate dam safety institution that acts as an arbitrator in the case of disputes.

KEY MESSAGES AND CONCLUSIONS

The institutional arrangements governing the assurance of dam safety provide the foundations for ensuring the safe storage and productive utilization of water resources. There is a range of institutional forms with different degrees of independence that exist along a continuum. While oversight institutions should be of a quality assurance nature to maintain independence, regulatory mechanisms need to be aligned to the size and complexity of the portfolio, appropriate for the level of financial capacity and human capital within the country, as well as positioned within the prevailing legal regime, which will then dictate the optimal institutional arrangements. This continuum reflects the individual country characteristics, including the prevailing legal framework along with the evolution of the portfolio and considerations of its size, sectoral distribution, hazard profile, and downstream demographics.

Across countries there are diverse portfolios of existing dams and pipelines of proposed developments. The nature of ownership and the purpose associated with the majority of the dams also differ from country to country. Given this diversity, it is important to consider the most critical elements required for ensuring the safety of dams and downstream communities, along with the required human and financial capacity to realize this safety. Furthermore, it is important to ensure that whatever the regulatory provisions are, they continue to adapt to changing circumstances in the portfolio and in the enabling sociopolitical environment.

The powers and functions for ensuring the safety of dams and downstream communities need to be clearly defined. These should be legally defined to ensure that the roles, responsibilities, and obligations relating to ownership, operations, and oversight are clear and enforceable. While some of these can be delegated or contracted, the dam owner is primarily responsible for the safety of the dam and appurtenant structures, as well as for ensuring that the dam is operated safely. The regulatory authority is primarily responsible for ensuring the safety of downstream communities by establishing the standards of care and prescribing the procedures for monitoring and reporting with which owners and/or operators must comply.

While the dam owner is primarily responsible for dam safety in most of the cases, shared responsibility between the owner and other entities can take place. While in some jurisdictions it is explicitly stated that the dam owner may share responsibility with other relevant stakeholders, such as the dam manager or operator, making it more likely that persons other than the dam owner are responsible for dam safety and potentially liable for dam failure, in other jurisdictions allocation of responsibility among different stakeholders is not that obvious. In addition, the dam safety oversight authority or regulator could also be responsible for dam safety in case it performs the direct dam safety assessment and assurance role that is typically assigned to the dam owner—it is logical that the more involved an entity is in ensuring the safety of the dam the more responsible it is for its safe operation and maintenance. Liability for the dam safety oversight authority generally depends on tort law, but grounds for claims can also depend on the administrative law of a country.[2] The balance between the regulator's oversight functions and responsibilities and its capacity needs to be carefully considered. The capacity development of both regulators and owners warrants urgent attention.

Maximum assurance is usually realized through an independent regulatory authority. Independent agencies are most commonly created to avoid the risk of regulatory capture (Barkow 2010), with independence serving to insulate regulators and protecting the public interest against pressure from specific interests. However, this may be challenging in certain contexts for dam safety, such as where the government both owns and regulates dams within the portfolio; there is a potential conflict of interest and risks associated with accountability. Under modern conditions of political oversight, other design mechanisms can free regulators from capture. Possibilities include having third parties involved in dam safety assurance, such as ICOLD national committees or the Engineering Council of South Africa. Furthermore, the context of dam safety can often be one in which the original intent was to ensure public safety but, instead, the interests of operators are served. Other design elements and mechanisms are often just as important to an agency's ability to achieve its long-term mission relatively free from capture. Dam safety regulatory frameworks will need to consider suitable mechanisms for holding the regulatory authorities accountable and for resolving disputes between the authorities and dam owners.

Maximum assurance is generally realized through uniform national regulations that apply across sectors to ensure uniformity and integrate transboundary considerations. However, the process of institutional development is a gradual one and reflects historical geopolitical considerations and the development of dams in the different sectors. While most countries have developed a centralized dam safety system, some have delegated oversight responsibilities to subnational entities, such as local governments or branches of national governments. Where multiple authorities exist, this can create a complicated institutional framework, particularly as a portfolio grows and issues around coordination become more complicated. These challenges can be addressed through apex institutions designed to coordinate multiple regulatory entities for different sectors across different levels of government. Legislation may be required to realize national-level coordination across subnational jurisdictions, coupled with technical and financial support. Incentive mechanisms can also be used to align subnational responsibilities and actions. These can include fiscal transfer mechanisms to increase alignment between national and subnational jurisdictions. The safety assurance and effective operational coordination of multiple dams in interstate rivers should be addressed.

The powers and functions of the regulating authority exist along a continuum and can include compliance-audit, quality assurance, and/or direct inspection. These should be determined by the portfolio characteristics and distributed with due consideration of issues associated with potential liability and the capacity of the regulatory system to address these. Given the complexity of dam safety, in contrast to generic and formal risk governance models, there is now a focus on the relevance of contextual and practice-based approaches to dam safety risk governance (Boholm, Corvellec, and Karlsson 2012). Understanding the financial and social dynamics of governance across historical, spatial, and institutional contexts will allow the governance framework to better develop reflexive and compatible models.

It is important to establish a continuous process of improvement that can ensure that institutional arrangements adapt to the changing nature of the portfolio and downstream demographics. It should also be emphasized that in countries where private enterprises construct the majority of new dams mainly for hydropower development, such as in Lao PDR and Nepal, the regulatory framework and regulator's capacity need to be developed in an expeditious but gradual manner. The regulation of private sector dams may be more critical and challenging given that many private (and often foreign) developers use their own standards and safety requirements while the oversight capacity of the regulator may be quite limited. Often, long-term safety assurance and sustainable operation of dams and reservoirs require considerations beyond the concession periods, which are typically up to 20 to 30 years.

The institutional arrangements governing the assurance of dam safety can be realized only if the financial resources and human capital are sufficient to fulfill the prescriptions. Considerations of the requisite capacity need to reflect on an objective set of criteria that can adequately reflect the various elements required for ensuring the safety of dams and downstream communities. This includes not only the financial resources and human capital of the various entities involved across the different sectors (regulators, owners, operators, and emergency services, among others) but also the distribution of the functions and powers and the interrelationships between them. These factors need to be examined within the characteristics of the country context and so present a number of inherent challenges. Given the centrality of these to determining the successful application of an institutional framework for ensuring dam safety, this remains an important area of inquiry, and there is an urgent need to have a systematic capacity assessment for ensuring the safety of dams and downstream communities.

NOTES

1. The Nanjing Hydraulic Research Institute Dam Safety Management Center under the Ministry of Water Resources for water resources, irrigation and flood management sector, and the Large Dam Safety Supervision Center under the National Energy Administration in the National Development and Reform Commission for the hydropower sector.
2. Administrative law tends to be more concerned with how the authority executes its powers and decision-making and provides aggrieved parties with grounds to object. The analysis has not focused on this area of law but more on the responsibility that can lead to liability in case of dam failure. Generally, a dam safety authority could limit exposure to liabilities if it limits involvement in the direct assessment and assurance role and in responsibilities that can lead to tortious liability in case of dam failure. Depending on the administrative law, for example, the authority could be liable for *inaction*.

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5

Contents of the Regulatory Regime

CONTEXT AND RATIONALE

The contents of the regulatory regime reflect its specific mandates pertaining to dam safety assurance. Contents include the specific roles, powers, and responsibilities of the regulator, as well as the specific responsibilities and duties of the dam owner, operator, and any other parties involved. They also reflect safety standards and procedural requirements that must be met, including regular surveillance, monitoring, and periodic dam safety reviews, inspection, and reporting.

A central element of any regulatory regime is establishing objective criteria for determining those dams that are to be subject to regulation. First-stage criteria typically rely on minimum thresholds defined by dam geometry or size (for example, height, reservoir capacity, and so forth) and/or the potential consequences associated with failure (that is, hazard potential). The second-stage classification typically uses dam geometry, size, or type and/or hazard potential to further proportion the mandates of the regulatory regime. Among others, these can include the standards mandated for the design of new dams as well as the design review of existing dams for safety against floods and earthquakes. This can be done using one of three approaches: "standards-based" (also known as "deterministic"), "risk informed," or a combination of different methods.

The standards mandated for surveillance, inspections, operation, and maintenance are important for determining the safety of dams and downstream communities. Standards may include the required qualifications for surveillance engineers or inspectors; the level of sophistication and frequency of surveillance, inspections, and dam safety reviews;

along with the associated reporting requirements for different classes of dams. Other specific mandates include the development of a certified operation and maintenance plan, a surveillance or monitoring plan, inspection procedures and schedules, and Emergency Preparedness Plans (EPPs), among others.

Technical archiving and record keeping are also important to the success of any dam safety assurance scheme. Dam owners must act responsibly with any information and material relating to the safety of their dams. This means that all materials, such as original design drawings and design reports, as-built drawings, dam safety reviews, surveillance program descriptions, surveillance and inspection reports, and EPPs must be kept by owners in a special safety file. The file should be stored in a place where it can be inspected by the regulatory authority, and it should be easily accessible to all those concerned should any dam safety issues arise.

Education of and guidance to dam owners are also critical to ensuring awareness of responsibilities and liabilities. In particular, dam owners must be aware of the legal status of dam safety guidelines, design standards or criteria, and any other related guidelines. These guidelines can be mandated by legislative regulations or directives under the discretional power of the dam safety authority,[1] or they can act as nonmandatory guidelines. Training and capacity building for both dam owners and oversight authorities are also critical to ensure compliance with mandated regulations. Ensuring specific provisions within the contents of the regulatory regime relating to training and capacity building can be useful, particularly in lower-capacity environments.

Dam safety regulations should also include the ability to enforce standards through penalties, civil or criminal remedies, and arbitration. Ultimately, the stronger the penalties—such as suspending and revoking an owner's operational permits—the more likely dam owners are to comply with the dam safety scheme's mandates.

CAPTURE OF REGULATED DAMS

Dams that are captured by the prevailing legislation and subject to regulation can be defined according to the size or dam geometry (height, reservoir capacity, and so forth) as well as the type of dam, downstream hazard potential, or a combination of these elements. The comparative analysis (table 5.1) finds that in 49 percent of the case studies, the dams subject to regulation are defined only by size-based criteria (including regulated dams in Japan, Morocco, Myanmar, Peru, Sri Lanka, and Vietnam). In 20 percent of cases, the dams subject to regulation are defined by both size and hazard potential (including regulated dams in Australia, Burkina Faso, France,[2] Indonesia, Mexico, Portugal, Turkey, and the United Kingdom), the majority of which are from civil law jurisdictions. In no cases are the dams subject to regulation defined only by hazard potential or failure consequences–based criteria.

TABLE 5.1 Dam-capturing criteria subject to regulations among the case study countries and jurisdictions

Legal system	Size-based only	Hazard-based only	Combined size- and hazard-based	No capturing criteria	Undetermined
Common law	9	0	1	2	0
Civil law	15	0	8	3	6
Religious law	0	0	0	0	1
Mixed	1	0	1	4	0
Total	**25**	**0**	**10**	**9**	**7**

Source: Original table for this publication.

When using size as a criterion, jurisdictions often attempt to distinguish between large and small dams as defined under regulation. In some cases, only large dams are captured and subject to regulation, such as in China and the Republic of Korea. In other cases, separate regulations apply to large and small dams, such as in Portugal and the Australian state of Victoria. However, the definitions used for large and small dams can vary significantly across countries. For example, a dam in China or Korea is generally considered large if it measures higher than 15 meters, while any dam with a reservoir capacity greater than 10,000 cubic meters in the United Kingdom jurisdictions of Wales and Northern Ireland is considered large enough to be subject to regulation. In the Canadian province of Quebec, any dam higher than 1 meter with a storage capacity greater than 1 million cubic meters, higher than 2.5 meters with a storage capacity greater than 30,000 cubic meters, or higher than 7.5 meters regardless of storage capacity is classified as a high-capacity dam, while in New Zealand any dam higher than 4 meters is considered a large dam for the purposes of regulatory capture.

The International Commission on Large Dams (ICOLD) 2011 constitution defines a large dam as "a dam with a height of 15 meters or greater from the lowest foundation to the crest, or a dam between 5 meters and 15 meters impounding more than 3 million cubic meters, and defined in greater detail in the World Register of Dams." Prior to 2011, the ICOLD definition of large dams included those with (1) a height of more than 15 meters or a height between 10 meters (instead of 5 meters) and 15 meters and (2) complying with at least one of the following conditions: (a) length of crest not less than 500 meters, (b) capacity of the reservoir not less than 1 million cubic meters (which has been subsequently increased to 3 million cubic meters), (c) a maximum flood discharge of not less than 2,000 cubic meters per second, and (d) especially difficult foundations or unusual design. These definitions are still used in several countries, Albania, India, and Portugal among them.

The World Bank used the previous ICOLD definition over the years to determine those dams that would be captured under the Operational Policy on the Safety of Dams (OP 4.37). However, the definition of large dams has changed under the Environmental and Social Framework's (ESF's) Environmental and Social Standard 4 (ESS4) for Community Health and Safety, which was approved in August 2016 and became effective in October 2018.[3] Under the ESF, large dams include dams measuring between 5 and 15 meters high and with a reservoir capacity of more than 3 million cubic meters, in line with the current ICOLD constitution.[4]

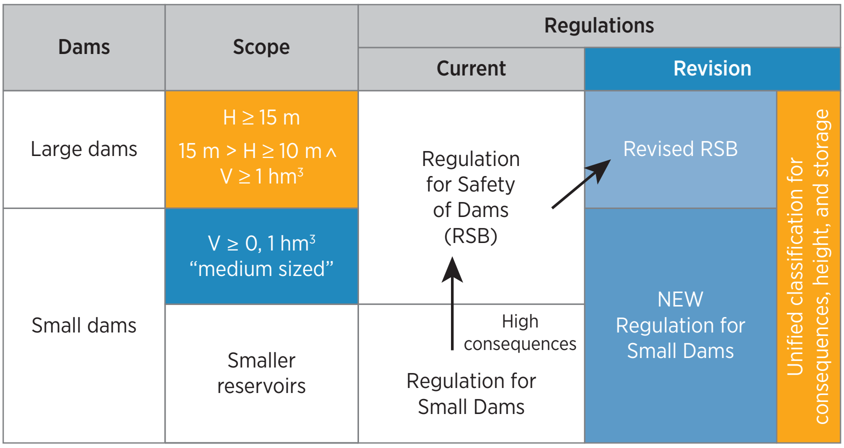
The World Bank's ESF also applies to all other dams regardless of size or retention capacity (referred to as "small dams") that could cause safety risks, such as: (a) an unusually large flood-handling requirement; (b) location in a zone of high seismicity; (c) foundations that are complex and difficult to prepare; (d) retention of toxic materials; (e) potential for significant downstream impacts. The ESF also applies to those dams that are expected to become large dams during their operating life. The provisions also apply to existing dams or dams under construction upon which a World Bank–financed project relies or may rely.

Small dams are defined by ICOLD (2016b) Bulletin 157 as having the following characteristics: (1) measuring between 2.5 and 15 meters high from riverbed to crest level; and (2) having an $H^2\sqrt{V}$ parameter less than 200—this is a deterministic "factor" for weighing potential risk of damages and loss of lives in the dam-break flooding area in the event of a dam breach, where H is the height in meters above riverbed level to maximum crest level, and V is the storage volume in million cubic meters at maximum operating level, which in most cases is equal to the full supply level. However, the minimum height can be lowered to 2 or 3 meters if the dam is located in residential and/or highly populated areas.

Portugal introduced a consolidated dam classification system that defines a dam as small by using the same concept of potential risk of damages and loss of lives. This takes into account both the number of fixed houses downstream from the dam and the $H^2\sqrt{V}$ parameter. This revision allows most dams classified as medium size in Portugal to shift into the category of small dams, allowing for more modest and realistic dam safety requirements for new class II and III dams (see figure 5.1).

Virtually all dams are initially captured for the purpose of registration in more than one-third (37 percent) of the case studies (table 5.2). This is accomplished by establishing very low minimum criteria for registration, so that even small dams are captured. This practice is quite common and found in jurisdictions including in Argentina, the Australian state of Tasmania, Burkina Faso, Sri Lanka, the United Kingdom, and Vietnam. The common approach in jurisdictions with large numbers of small dams is to capture all dams, or at least ones down to a very small size criterion, for initial inventory or registration purposes only—where information on dam size and so forth and preliminary hazard classification are to be provided by owners, and periodically to be reviewed thereafter—and then only those of significant hazard are made subject to the more technical regulatory mandates. This enables the regulator to keep a check of the entire population of dams and whether the hazard classification has changed with time for any (for example, due to growing downstream populations). In 16 percent of the case studies, only large dams are captured for registration, including in China,

FIGURE 5.1 Portugal's consolidated dam classification system



Class	Consequences and potential danger
I	$Y \geq 10$ and $X \geq 1{,}000$
II	$Y \geq 10$ and $X < 1{,}000$ or $0 < Y < 10$, independently of the value of X or Existing infrastructure and important environment values
III	$Y = 0$, independently of the value of X

In which:

- *Y*: fixed housing with permanent living people
- *X*: $H^2\sqrt{V}$ with H = maximum height of dam wall in meters, measured from riverbed level, and V = storage volume of reservoir at full supply level in million cubic meters

Source: Afonso, Pedro, and Caldeira 2015. Used with permission; further permission required for reuse.
Note: m = meters; m^3 = cubic meters; H = height; hm^3 = cubic hectometers; V = volume.

Korea, and Pakistan. In another 16 percent of the case study countries and jurisdictions, both large dams and any smaller dams that are considered hazardous are captured for registration, as observed in Albania, the Australian state of New South Wales (NSW), and Indonesia. In such cases, the smaller dams can be captured only if and when they are brought to the attention of the regulatory authority, meaning some potentially hazardous dams could be left unregulated.

Many countries included in the analysis have statutes specifying minimum height and/or reservoir capacity criteria for determining which dams are subject to the provisions of the legislation, although they vary greatly. For example, the United Kingdom has no minimum height requirements, the Canadian province of Quebec has a minimum height of 1 meter, while statutes in China, India, Italy, Japan, and Korea require only dams with a minimum height of 15 meters to be subject to dam safety regulations. Similarly, minimum storage capacity criteria show significant variation depending

TABLE 5.2 Dams captured for registration among the case study countries and jurisdictions

Income level	Virtually all dams (all dams or very small size criterion used for initial capture and in some cases even smaller dams if hazardous)[a]	Large dams[b] only	Large[b] and/or hazardous dams	No capturing criteria	Undetermined
High income	9	4	4	0	1
Upper middle income	5	1	3	3	3
Lower middle income	4	2	1	4	3
Low income	1	1	0	2	0
Total	**19**	**8**	**8**	**9**	**7**

Source: Original table for this publication.
a. Generally considered to be "very small" when the minimum capture criterion involves a dam height of no more than 5 meters and/or a storage capacity of no more than 50,000 cubic meters.
b. The definition of "large dams" varies in different countries, and it does not necessarily refer to "large" dams within the capture criteria. Generally, the large dam definition adopted by the jurisdiction or any capture criterion that is identical or similar to the International Commission on Large Dams definition of large dams has been accounted for here.

on the local conditions, ranging from very small (for example, 1,000 cubic meters in the Australian state of Tasmania) to large (for example, 1,000,000 cubic meters in Italy).

When deciding on appropriate thresholds for classifying dams, lawmakers and regulators should consider the local context, balancing the provisions with the ability to ensure that hazardous dams are captured by the regulatory regime. The higher the minimum requirements for height and storage capacity, the greater the number of potentially hazardous dams that may not be captured by the regulatory regime; at the same time, lower thresholds may result in so many dams being included under the regulatory provisions that capturing them exceeds available resources and capacity. Classification thresholds may also need to be adjusted over time as conditions change.

Where a high or large size threshold has been adopted, some countries include hazard-based criteria to capture dams—either individual dams or those in a cascade dam system—that may not otherwise be included under the regulatory regime. Such provisions for the registration of hazardous dams outside the standard thresholds are included in the Australian state of NSW and Indonesia, among others. However, where small dams number in the hundreds or thousands, many small hazardous dams can go unnoticed in the absence of a formal inventory or registration process that includes all dams (Pisaniello and Tingey-Holyoak 2017; Pisaniello 2009).

Where the thresholds for size-based criteria are very low or small so as to capture the majority of dams in a jurisdiction for inventory, registration, and/or classification purposes, subsequent hazard classifications can be used to determine which dams are subject to the different legislation provisions (see the sections "Dam Classification and Design Standards," "Requirements for Surveillance and Inspection," and "Requirements for Operation and Maintenance"). In such instances, the majority of small, low-hazard dams can be subject to minimal or no mandates. This approach has been adopted by many jurisdictions, such as the Australian state of Tasmania, the state of Michigan in the United States, the province of Quebec in Canada, and the United Kingdom. Such an approach can also allow for periodic rechecking of hazard classification in case of hazard creep. Again, this approach needs to be balanced against available resources for dam safety regulation and supervision, and adjusted over time to ensure it is fit for its purpose given specific country conditions.

It should be noted that it is not an easy task to complete an inventory and registration of existing dams, particularly if there is no existing baseline. For example, in the Canadian province of Ontario, the Ministry of Natural Resources and Fishing, which serves as the regulator, does not have a complete inventory or registration of dams. Dam owners approach the ministry only when they need permission for new dam construction, major rehabilitation works, or other works impacting the safety of a dam. If small-dam owners are not aware of such regulatory requirements, they may never approach the ministry and seek appropriate approvals.[5] New tools and techniques are being developed to help carry out dam inventories and assessments, using earth observations and machine learning (see box 5.1).

CLASSIFICATION OF DAMS FOR PROPORTIONING REGULATORY MANDATES

The classification of dams is useful for proportioning dam safety mandates and is used widely among the 51 surveyed countries. Such classification schemes allow the proportional application of regulatory requirements, such as design standards and inspection frequency, to the corresponding hazard level of dams under the regulatory regime. Such classification systems can be prescribed in the laws and regulations governing dam safety or be defined in the directives of the regulating agency or more general technical guidelines. Different classification systems are observed among different countries and vary depending on the prevailing socioeconomic and environmental context, such as population density, topography, land-use patterns, and the perception and acceptance of societal risks. Classification systems also relate to the capacity of regulatory agencies, owners, and operators. In some countries where the regulator is more hands-off, the dam owner may be able to determine the classification and submit it for approval, with the potential risk that dam owners do not register dams subject to classification, while in other countries where the regulator is more hands-on, it may take the responsibility for classifying the dams, in which case the regulators need to have sufficient financial and human resources to carry out and complete the classification scheme.

Dam classification can be used to define the scope and extent of dam safety regulations and to set appropriate requirements for design, construction, and operation and maintenance of dams, with due consideration of the potential consequences associated with a dam failure. It is a way of grading

BOX 5.1

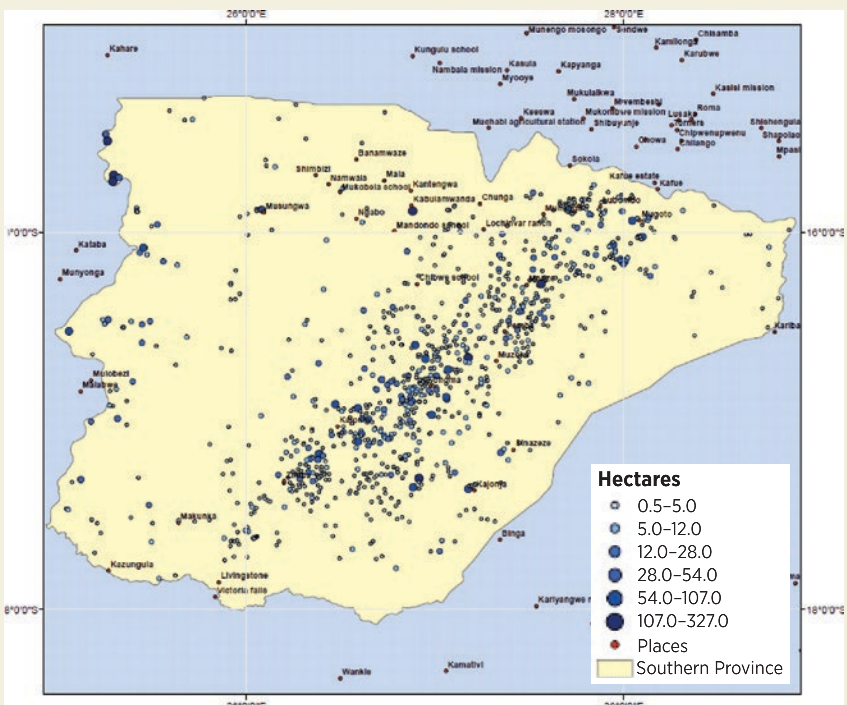
USING REMOTE SENSING AND ARTIFICIAL INTELLIGENCE IN ZAMBIA TO IMPROVE DAM INVENTORIES

The official estimate of the number of dams in Zambia's national portfolio was approximately 2,000 in 2010, situated mostly in the drought-prone semi-arid areas of the Eastern, Lusaka, Central, and Southern provinces. However, other sources indicated the number could be anywhere between 600 and 3,000. This compared to a register of over 10,000 dams in adjacent Zimbabwe.

Using remote sensing techniques, 1,022 reservoirs with a minimal mapping unit of 0.5 hectares were identified in Southern Province alone in 2011 as part of an inventory of small water bodies (map B5.1.1, panel a). A false color composite based on Landsat 5 imaging was used to identify water bodies by contrasting open water from surrounding land (map B5.1.1, panel b). Different land and water classes were delineated by hand to form test sets. This was a labor-intensive task due to the many different shades of water and land, and shades that had to be delineated in order to capture the statistical differences between the different classes.

MAP B5.1.1 Distribution of small dams in Southern Province, Zambia, identified through remote sensing

a. Small dams in Southern Province



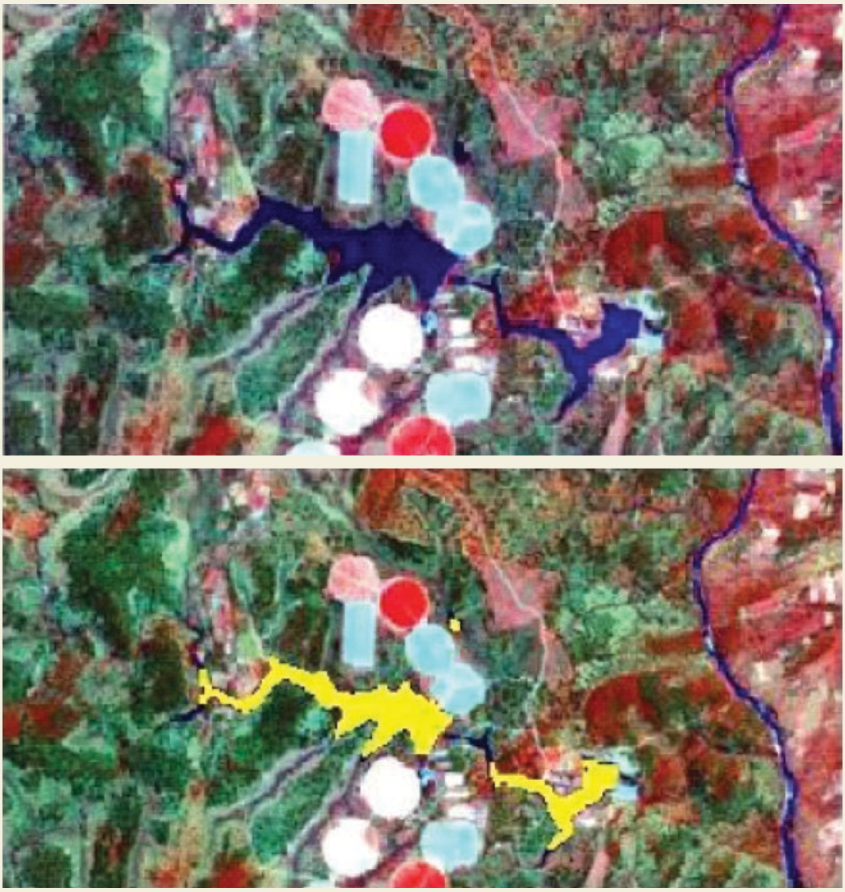
Source: World Bank 2012.

(continued)

BOX 5.1 *(continued)*

MAP B5.1.1 ***(continued)***

b. Reservoir identification in Southern Province using remote sensing



Source: World Bank 2012.

Subsequent improvements in remote sensing technologies, coupled with the advent of pattern recognition and machine learning algorithms, have greatly improved the ability to provide a rapid, cost-effective tool to assist in the identification, inventory, and mapping of dams and reservoirs. These developments have the potential to deliver a georeferenced, global inventory of dams. Through incremental development, building on existing initiatives, such tools and products will accelerate the inventory and support the registration of dams within national portfolios at a fraction of the time and cost it currently takes. Further application of this data will help improve dam safety and the safety of downstream communities through improved spatial analytics and linking to online global forecasting systems, among other benefits.

the dam safety requirements for a broad range of dams in terms of both structural and nonstructural requirements and should reflect a country's economic and social context. By classifying dams, more attention is given to dams with higher levels of hazard potential or consequences in the event of a dam failure, while avoiding unreasonably stringent safety requirements for lower-hazard dams. This contributes to efficient allocation of limited human and financial resources within government and industry.

The main criteria for classifying dams are either geometric parameters, typically height and reservoir capacity combined with dam type, or those based on hazard potential or consequences that would occur as a result of a dam failure, or a combination of these. Roughly one-third (27 percent) of the case studies have a combined classification scheme, another one-third have no classification scheme at all, 22 percent rely on a hazard-based classification, and only 9 percent rely solely on size or a geometry-based classification system (table 5.3 and table 5.4). Of the surveyed case studies, the majority of combined classification systems are found among civil law countries, while common law countries tend to use more hazard-based classification systems.[6]

TABLE 5.3 Type of dam classification system among the case study countries and jurisdictions, by income level

Income level	Size only (height and capacity and also typically dam type)	Hazard only (low, sig, and high)	Combined size and hazard	Other (risk, condition, safety level)	None exists	Undetermined
High income	3	8	3	1	3	1
Upper middle income	0	1	7	2	7	0
Lower middle income	1	3	4	1	6	0
Low income	1	0	1	0	2	0
Total	**5**	**12**	**15**	**4**	**18**	**1**

Source: Original table for this publication.
Note: Sig = significant, a commonly used classification term when there is a "medium" hazard.

TABLE 5.4 Type of dam classification system among the case study countries and jurisdictions, by legal system

Legal system	Size only (height and capacity and also typically dam type)	Hazard only (low, sig, and high)	Combined size and hazard	Other (risk, condition, safety level)	None exists	Undetermined
Common law	2	5	1	0	4	0
Civil law	3	6	13	3	9	1
Religious law	0	0	0	0	1	0
Mixed	0	1	1	1	4	0
Total	**5**	**12**	**15**	**4**	**18**	**1**

Source: Original table for this publication.

Geometry- and Type-Based Classification

As noted, size- or geometry-based classification systems are observed only among 9 percent of the case studies. Such approaches are more suitable for countries where downstream areas of dams are densely populated in a relatively uniform manner, such as in Austria and Korea. Under such circumstances, the geometric parameters like dam height and reservoir volume are used as proxies to represent the impact of flood duration and downstream water depth in the case of dam failure. In those countries using hazard-based classification systems, where the downstream areas are all inhabited with at least 1 but likely more than 10 people, there may be no dams classified among the low or medium hazard classes.[7]

Many of the countries using geometry-based classification, such as France,[8] also use dam type for classification, since failure modes for concrete dams and embankment dams are quite different. Some countries with no classification system, such as Italy and Japan, also apply different safety standards depending on dam types. They set higher hydrological safety standards (longer return-period floods) for embankment dams than concrete dams, considering the former's higher risk of overtopping failure. Some countries, such as Bulgaria, the Russian Federation, and Uzbekistan, also use foundation conditions and construction materials as classification criteria to capture additional vulnerabilities.

Hazard-Based Classification

Hazard classification based on potential consequences associated with dam failure occurs in 22 percent of case study countries and jurisdictions. This classification system directly links safety standards and requirements to the downstream hazard and consequence. Such classification systems are particularly effective and practical in countries with vast lands and low population density in which higher dams could be less hazardous than they are elsewhere, depending on their location.

Those countries that have established hazard- or consequence-based classification systems, such as Australia and Canada, have in general large regional variations in population density and land-use patterns. Hence, the consequences of a dam failure greatly depend on the location of the dam rather than the size of the dam and reservoir. In very remote areas where permanent settlements are scattered or nonexistent, failure of even large dams may have limited or no consequences.

It is important, however, to monitor changes in the downstream conditions of dams in the portfolio. Settlements typically develop over time, leading to "hazard creep," and so the hazard classification may need to be revised and updated. This type of hazard classification should be based on a dam-break analysis and downstream flooding or consequence assessment, depending on the required level of hazard assessment, and thus can require significant time and effort to complete.

It should be noted that there is significant confusion surrounding the interpretation of the term *hazard-based* with respect to the classification of dams. ICOLD Bulletin 59 recommended the use of *hazard rating* as a method of determining safety requirements for existing dams, but it did not precisely define the meaning of the term *hazard*. The term that has gained wide acceptance among the international dam safety community is *hazard potential*. There are subtle differences, however, in how different case study countries and jurisdictions define *hazard potential*.

In some jurisdictions, the hazard potential of a dam refers to the impact of the hazard imposed downstream by the potential energy of water stored behind a dam and is expressed in qualitative terms such as loss of life is *possible*, *probable*, or *unlikely*. However, such qualitative terms often lack specific definitions, and their interpretation is left to the discretion of those making the assessment. In addition, such qualifications do not account for the extent of loss, that is, the number of fatalities. These shortcomings of the original hazard potential classification systems were addressed by introducing the concept of *dam failure consequences*. ICOLD (2005) Bulletin 130 states that "in dams engineering, there is a strongly ingrained practice of seeing hazard as a measure of consequences of dam failure."[9] This agrees with concepts presently used in North America and Australia.[10] Thus, the terms *hazard-based classification*, *hazard potential classification*, and *consequence-based classification* as presently used are based on an evaluation of the potential consequences of failure.[11] These approaches are referred to as *hazard-based approaches* in this book.

Combined Approach

Dam classification systems that combine both geometry (sometimes together with dam type) and downstream hazard and/or consequences are observed in 27 percent of the country case studies (table 5.4). This kind of combined system has been adopted in several countries, including Poland, Portugal, Russia, and South Africa. Such approaches need to consider the population distribution and land-use pattern within the country. Geometric (and dam type) data, which are readily available, would help facilitate classification exercises, as it can take a long time to complete downstream hazard assessments, including dam-break analysis and flood-area mapping for estimating population at risk (PAR), potential loss of life (PLL), and other negative consequences, depending on the owner's and regulator's capacity to complete such assessments.

For countries intending to develop a new classification system using this combined approach, ICOLD (1989) Bulletin 72 could serve as one of the references when constructing the classification system. It introduced a simple classification system using four risk factors:[12] (1) reservoir capacity (million cubic meters), (2) height (meters), (3) evacuation requirements (number of persons), and (4) potential downstream damage. The risk

TABLE 5.5 ICOLD dam classification system

Risk factor	Total score Risk class	<6 I (low)	7–18 II (moderate)	19–30 III (high)	31–36 IV (extreme)
Reservoir capacity (million cubic meters)	Parameter	<0.1	0.1–1	1–120	>120
	Score	0	2	4	6
Dam height (meters)	Parameter	<15	15–30	30–45	>45
	Score	0	2	4	6
Evacuation requirements (number of persons)	Parameter	None	1–100	100–1,000	>1,000
	Score	0	6	8	12
Potential damage downstream	Parameter	None	Low	Moderate	High
	Score	0	4	8	12

Source: ICOLD 1989.
Note: ICOLD = International Commission on Large Dams.

classes, from I (low) to IV (extreme), are based on the computed total scores of these four factors, as shown in table 5.5.[13]

Including Benefits in Dam Classification

The benefits derived from a dam—and the potential socioeconomic losses of those benefits in case of dam failure—can also be used in the dam classification process. Such approaches are used in China. Although this does not directly represent downstream hazard or consequence, benefits derived from the dam, such as irrigation area, flood protection area, and the size of the cities receiving water from the dam, can be considered when assessing potential negative socioeconomic impacts of dam failure. Countries using this approach often use the installed capacity of hydropower generation turbines for classification as well.[14] Such measures are related to the potential economic and financial damages in the case of dam failure or mis-operation. Thus, higher dam safety standards are required for dams with greater socioeconomic benefits.

Assessing the potential benefits and/or negative socioeconomic impacts of dam failure can result in perverse outcomes, and so it is also important to consider other social aspects, such as the vulnerability of downstream communities. Poor and marginalized people are typically more severely affected by natural hazards and climate extremes. First, such groups often face greater exposure to hazards by living in marginal or unsafe areas (for example, on floodplains and along riverbanks) and experience greater vulnerability as they are more likely to live in substandard housing and possess uncertain land ownership rights that provide no incentives for investments in risk reduction. Second, poor and marginalized households are less able to absorb and recover from the impact of hazard events when they hit. With little savings and limited or no access to formal credit, the poor typically rely on a range of sub-optimal coping mechanisms following a disaster. Finally, after being hit with a disaster, poor and marginalized communities can suffer the consequences of uneven relief and recovery efforts. The poor also face obstacles to accessing entitlements, such as government relief or recovery assistance. Special efforts are therefore needed to ensure that any classification system and subsequent provision recognize the context of the downstream communities.

A Detailed Analysis of the Hazard Classification System

Thresholds between Classes: Prescriptive or Specific

The definitions of *failure consequences* and *hazard potential* used for hazard-based classification systems vary by country. The most commonly used hazard-based classification system, however, includes three categories: high, significant, and low. These categories can be broadly described as follows:

1. High hazard: failure would cause considerable loss of life and damage.
2. Significant hazard: failure may cause some loss of life and would cause considerable damage.
3. Low hazard: failure would cause no loss of life and negligible damage.

Descriptive hazard classification systems have been adopted by some countries, including Canada (Quebec), the Lao People's Democratic Republic, Myanmar, Sweden, and the United States (Federal Emergency Management Agency, FEMA). Others have adopted more specific hazard classification systems, where threshold values are prescribed for the different categories, such as the number of people at risk or potential loss of life (Australia, Indonesia, South Africa, Spain, and Washington State in the United States). Other countries use more detailed classification systems with as many as seven categories. The Australian National Committee on Large Dams (ANCOLD) guidelines include specific thresholds for both PAR and PLL, coupled with a descriptive measure of the "severity of damage and loss."

While it is useful to indicate specific numerical threshold values for different hazard categories and to ensure consistency, it may be politically sensitive in many countries. Indicating specific numerical thresholds or values, especially for life-safety impacts, is often perceived as arbitrary or unfair by different stakeholders. Defining such thresholds may also be beyond the capacity of regulators and may warrant authorization from the legislative branch of government, if ever possible.

Other Hazard Classification Elements beyond Loss of Life

A range of other elements can inform the development of a dam hazard classification system (table 5.6). While many countries consider the potential loss of life as the most critical indicator, other countries consider additional losses that can occur as a result of dam failure. For example, the 2016 Canadian Dam Association (CDA) guidelines recommend the following elements for dam hazard classification:

TABLE 5.6 Range of elements that are considered for dam hazard classification for a selection of countries

Country	Population at risk (PAR) or potential loss of life (PLL)	Economic damage	Environmental damage	Social and/or cultural heritage damage	Comments
Australia	✓	✓	✓	✓	Comprises seven hazard categories—very low, low, significant, high C, high B, high A, extreme—determined from a matrix of PAR and PLL against "severity of damage and loss." Can use either PAR or PLL and numerical thresholds provided for these. "Severity of damage and loss" captures all-in-one economic, health, and social and environmental damages, but only descriptive thresholds are provided, ranging from minor to catastrophic. Assessment can be based on either incremental damage or total damage depending on level of conservatism preferred, total damage being more conservative.
Canada	✓	✓	✓	✓	Comprises five classifications—low, sig, high, very high, extreme. The elements are defined as "incremental" impacts by dam failure compared to natural condition, and potential loss of life is provided with numerical thresholds while "environmental and cultural values" and "infrastructure and economics" are provided with descriptive thresholds as per Canadian Dam Association 2013 guidelines. Only Ontario indicates specific threshold values for economic loss in addition to life loss.
Czech Republic	✓	✓	✓		Four classifications (categories 1–4) evaluated on "potential damage" (P) points score. The higher the score, the higher the risk or hazard of the dam. P is determined based on range of human lives endangerment, damages on property and infrastructure, damages from losses of hydraulic structure utility and utilities of public interest, and extent of environmental damage.
Indonesia	✓				Comprises four "danger level" classifications—low, moderate, high, very high. Numerical thresholds for PAR provided only specifically referring to number of families involved and their distance from the dam, with the assumption that each family consists of five people and lives in a house. There does not appear to be any consideration or descriptive thresholds provided for any other types of damage.
Lao PDR	✓	✓	✓	✓	Comprises three hazard categories—high, sig, and low. No numerical thresholds provided. Thresholds are all descriptive and refer to "increase" in loss or impact due to dam failure.
Malaysia	✓	✓	✓	✓	Comprises four classifications—low, sig, high, very high. Numerical thresholds for PAR and descriptive thresholds for infrastructure and economic losses and environmental and cultural losses.
Norway	✓	✓	✓		Comprises five hazard categories of classes 0, 1, 2, 3, and 4. Class 4 represents the highest hazard. Numerical thresholds provided for "consequences on population" with reference made to number of housing units involved, but only descriptive thresholds provided for infrastructure, property, and environmental damage. No notes on whether incremental or total damages should be assessed.
South Africa	✓	✓	✓		Comprises three hazard categories—high, sig, low. Numerical thresholds provided for PLL, but only descriptive thresholds provided for potential economic loss (PEL) (for example, "minimal," "great") and potential adverse impact on resource quality (PAIRQ) (for example, "low," "severe"). The three determinants for hazard (PLL, PEL, PAIRQ) are considered separately, and whichever gives the highest hazard determines the overall hazard rating.
Spain	✓	✓	✓	✓	Comprises three hazard categories of A, B, and C, where A represents the highest hazard. Numerical thresholds provided for "hazard potential on population," with reference made to number of dwellings involved, but only descriptive thresholds provided for "hazard on essential services" (which is essentially social damage), damages generally (which is essentially infrastructure or economic damages), and environmental damages. No notes on whether incremental or total damages should be assessed.
Sri Lanka	✓	✓			Comprises five classifications—very low, low, sig, high, very high. No numerical thresholds provided; thresholds are all descriptive. Loss of the dam itself and associated impact is also considered, even though this is not really a downstream consequence.

Source: Original table for this publication.
Note: Sig = significant, a commonly used classification term when there is a "medium" hazard.

- Risk to human life represented by potential loss of life and whether the population at risk is temporary or permanent
- Economic and infrastructure loss
- Losses to the environment
- Losses to cultural heritage

While the potential loss of life is provided with numerical thresholds, other elements are typically provided with descriptive thresholds, although a few countries put numerical thresholds for economic damage, including in the Canadian province of Ontario and the Czech Republic. While none of the case study countries or jurisdictions included in the assessment include explicit considerations relating to the vulnerability of downstream communities, it is important to acknowledge the potential for perverse outcomes associated with bias due to quantification of elements that inform any hazard classification system. Application of any system should always reflect the local conditions and context, and be proportionate to the size, complexity, potential risk of the dam, and vulnerability of the downstream communities.

Downstream Hazard Assessment Level

While using downstream consequences in case of failure is perhaps the clearest and most pertinent measurement for assessing potential hazard levels, such assessments require sufficient financial, resource, human capital, and technical capacity. It is therefore important to provide guidance on the required level of downstream hazard or consequence assessment and suitable techniques so that the regulator, in coordination with dam owners, can complete an assessment in a timely and reasonable manner proportionate to the context. A proportionate response may be informed by preliminary assessments, as is the case in Quebec, where the regulations that indicate the required level of downstream assessment are informed by the results of the preliminary assessment.

When resources are not sufficient for a comprehensive downstream hazard assessment, interim solutions may be appropriate. Among other considerations, the level of required resources will be informed by the classification system and the number of dams captured by the regulatory regime. For example, if the hazard classification system establishes a relatively high threshold that classifies a majority of the dams as high hazard and subject to the most stringent provisions of the regulatory regime, then the burden on the regulatory authority can be high. Where data are insufficient to meet the requirements, significant efforts may be needed to close the gap. This can take time, during which the prevailing conditions of either the dam or downstream environment can change. In such situations, some simplified downstream hazard assessment methods, along with identification and inventorying of existing dams, could be sufficient. These can be combined with the use of remote sensing and earth observation data to help develop digital terrain models and simplified flood simulations. It would be desirable for dam-break mapping for consequence assessment to then be used for EPP preparation. However, if simplified methods are used for consequence assessment, more detailed dam-break modeling, flood mapping, and loss-of-life assessments should be conducted for preparing emergency plans in the case of high-hazard dams and where there are low-gradient topographies.

Incremental or Total Hazard Assessment

Some countries, such as the United States (FEMA guidelines) and Canada (CDA guidelines) clearly define hazard or downstream consequences by dam failure as *incremental* by comparing scenarios of "with" and "without" dam failure. There may be some cases (small dams, for example) where downstream areas would be severely flooded irrespective of dam failure, and the incremental hazard by dam failure would be minimal. In this case, the hydrological safety level of its spillway could be quite different depending on whether an incremental or *total* hazard approach is used.

In the Australian state of NSW, the regulator requires dam owners to provide estimates of both incremental and total consequences for hazard classification, as it might not be simple to distinguish consequences attributable to dam failure during actual failure events. It may also be challenging for many countries to focus on "incremental" loss of life for determining the suitable standards for dam safety due to the local context, cultural sensitivities, or other resources and capacity constraints.

Indeed, most countries surveyed describe hazard levels for classification without specific reference to incremental hazards or consequences. For example, Ontario, Canada, refers to incremental hazard while other provinces, such as British Columbia and Quebec, do not indicate that incremental hazard should be used for dam classification in their provincial dam safety legislation or regulations.

In order to estimate incremental hazard by dam failure, a series of dam-break analyses and incremental downstream flood-mapping exercises would be needed in order to compare "with" and "without" dam failure scenarios under various conditions, ranging from sunny days to extraordinary flood situations. Although the concept of incremental hazard is clear, it could be burdensome for many countries to adopt this form of hazard classification. In countries dominated by large dams and large populations downstream, detailed analysis may not be necessary to determine what dams fall into the high-level classification.

Population at Risk or Potential Loss of Life

The PAR and measures of PLL both provide methods for determining the consequence categories associated with dam failure. Such approaches are specified in national guidelines in Canada (CDA 2007/2013) and Australia (ANCOLD 2012). While the PAR usually indicates the number of people exposed to hazard within flooding areas in the event of a dam break, PLL generally indicates the potential loss of life considering various factors, such as time of day, advance warning, transport modality, and people's behavior. For example, the state of NSW in Australia has adopted a two-tier approach for consequence-level classification. When PLL figures are not available, the dam owner can base a tentative consequence category on PAR and then later change it to one based on PLL.

However, most countries do not make such a distinction in their hazard classification systems. While the PLL concept is important for preparation of EPPs for high-hazard dams, estimating the PLL requires dam-break analyses, mapping of flood areas, and model simulations of human behavior and movement considering the availability and effectiveness of warnings, traffic conditions, and so on. This requires a relatively high level of data, financial resources, and time, along with human capital and technical capacity, and so can be burdensome for many countries.

Risk-Based Dam Classification

It has become generally accepted practice to establish dam classification systems without considering the structural safety condition of the dam, operational and maintenance status, and availability of nonstructural instruments like EPPs. Also, the actual failure probability is generally not a criterion for the dam's classification.[15]

Risk is defined in dam safety assessments as a measure of the probability of an adverse event and the severity of the consequences. However, the term *risk* is often mistakenly used in relation to downstream hazard or consequences in the case of dam failure.[16] For example, South Africa's dam safety regulations state that dams with a "safety risk" are subject to regulation, but there is only reference to size and hazard for classification without any actual consideration of risk, including likelihood or probability of a failure event. In England, Scotland, and Wales, only dams with a high or medium "risk designation" are subject to inspection and supervision, but the term *risk* in this case mainly refers to consequence in case of dam failure.[17]

Some jurisdictions have established dam classification systems based explicitly on a risk index that considers both the qualitative probability or vulnerability of a structural failure and the downstream hazard or consequences, such as seen in Brazil (box 5.2) and Mexico. Brazil also provides a detailed classification system based on the following:

- The dam's risk, which is, in turn, based on:
    - Technical characteristics (such as height, type, and age)
    - Dam preservation condition (such as spillway reliability, seepage, and deformation and settlement)
    - Dam safety plan (including project documentation, organization structure, staff qualifications, and inspection and monitoring procedures)

- Downstream hazard potential based on reservoir capacity, potential loss of life, and socioeconomic and environmental impacts in case of dam failure

Mexico does not provide a detailed points-based system of risk and downstream hazard classification, but it requires dam safety risk assessment in a qualitative manner for classification. The Canadian province of Quebec provides a detailed points-based system for assessing the risk of each dam (box 5.3) based on (1) the dam's vulnerability, which includes constant parameters, such as dam height, type, reservoir capacity, and variable parameters, such

BOX 5.2

DAM CLASSIFICATION IN BRAZIL

Brazil legislated the Federal Dam Safety Law—National Policy of Dam Safety in 2010. The law requires regulators to classify dams based on both dam risk (three categories) and potential hazard (three categories) under their jurisdictions (Article 7—Classification). The Brazilian National Water Resources Council (CNRH) further issued Normative Resolution no. 143 in 2012 on the classification criteria with the following formula:

Risk Category (RC) = Technical Characteristics Matrix (TCM) Score + Dam Preservation Matrix (DPM) Score + Dam Safety Plan Matrix (SPM) Score.

TCM is calculated by summation of respective points for dam height, length, construction material, foundation type, age, and design flood return period.

DPM is calculated by points for reliability of spillway, reliability of outlet structures, seepage, deformation/settlement, slope deterioration, and sluice gate/hydromechanical maintenance.

SPM is calculated by points for existence of project documentation, organization structure/dam safety staff qualification, dam safety inspection/monitoring procedure, operational rules, and dam safety reports with analysis and interpretation.

Potential Hazard Associated (PHA) is defined based on the points of four elements: (1) storage capacity, (2) potential loss of life, (3) socioeconomic impact, and (4) environmental impacts in case of dam failure. The two factors (RC and PHA) are broadly considered as the proxies for failure probability and consequences, respectively.

The National Water Agency (ANA) subsequently produced a combined matrix grouping into five classes (from A to E) based on the CNRH classification criteria. However, all 121 dams under its jurisdiction (nonhydropower dams under federal rivers) are categorized as the highest risk/hazard class. One reason was that even one potential loss of life in case of dam failure is categorized as high hazard, and the combined matrix gives A for such

(continued)

BOX 5.2 *(continued)*

high-hazard category irrespective of risk category. ANA has modified the classification method, but resulting in very little change. Lack of information, absence of documentation, poor satellite imagery to estimate downstream consequence, and so forth brought many dam classifications, including small dams, into more conservative high-risk and high-hazard categories, requiring higher safety standards. ANA is communicating with dam owners and reevaluating the method.

ANA has also been trying to accelerate downstream consequence assessment. It has introduced a simple flood hazard assessment method using a Digital Terrain Model provided by the Shuttle Radar Topography Mission by NASA. Although the method is not sufficient for Emergency Preparedness Plan preparation, which needs to analyze the dynamic and transient behavior of abrupt flood wave by dam breach, it is considered that the simplified method is sufficient for downstream consequence assessment based on its comparison with the results of more advanced flood wave analyses.

BOX 5.3

DAM CLASSIFICATION IN QUEBEC PROVINCE, CANADA

The Provincial Government of Quebec in Canada passed the Dam Safety Act and its regulations in 2002. The act defines two types of dams: (1) high-capacity dams and (2) low-capacity dams. High-capacity dams are defined as (1) dams 1 meter or more in height having an impounding capacity greater than 1,000,000 cubic meters (m^3); (2) dams 2.5 meters or more in height having an impounding capacity greater than 30,000 m^3; or (3) dams 7.5 meters or more in height, regardless of impounding capacity. Low-capacity dams are defined as dams 2 meters or more in height that are not high-capacity dams. The main dam safety provisions apply to high-capacity dams.

The act requires that a dam shall be classified by the minister prior to authorization for the construction of the dam. A dam owner may apply for a review of the classification of the structure if a supporting report or study made under the responsibility of an engineer is submitted with the application. The act also provides for the establishment of a register for all dams 1 meter or more in height. The dam owners are required to submit information for dam registration, and offense against the provision renders the owner liable to a fine of not less than Can$2,000 and not more than Can$200,000.

The act provides details of the dam classification system based on the degree of risk into five categories with the formula of P (degree of risk) = V (vulnerability) * C (consequences). The vulnerability (V) of a dam is

(continued)

BOX 5.3 *(continued)*

measured by multiplying the arithmetic mean value of "constant physical parameters" by the arithmetic mean value of "variable parameters." The constant physical parameters to be considered are (1) dam height, (2) dam type, (3) impounding capacity, and (4) dam foundation type. The variable parameters to be considered are (1) dam age; (2) seismic zone; (3) dam condition, considering the physical state and structural condition of the dam, the quality and effectiveness of maintenance, aging, possible effects of external factors, and any dam design or structural defects; and (4) reliability of the discharge facilities.

The dam failure consequence (*C*) category is classified into six categories with 1–10 points based on the characteristics of the downstream area that would be affected by the dam failure in terms of population density and the extent of downstream infrastructure and services that would be destroyed or severely damaged in the event of a dam failure. A detailed description of each category is provided, including the number of population, size of enterprises, and so forth in downstream flooding areas.

The act also defines the required level of consequence assessment depending on the consequence category. For example, "If, in the opinion of the engineer in charge, the dam failure consequence category is 'moderate,' only rough inundation maps showing the area that would be affected by a dam failure are required. This mapping consists of a rough assessment of the consequences of a dam failure by means of a delineation of the affected area on topographical maps and identification of the characteristics of the area. The mapping is established on basic hydrologic and hydraulic calculations, such as flood flows and breach flows, as well as on a rough analysis of the downstream watercourse profile and cross-sections. For the purposes of the mapping, the extent of the affected area is determined by adding the breach flow to the 1,000-year flood flow to a point of attenuation or restriction, such as confluence with a large lake or river or another dam." In addition, "If, in the opinion of the engineer in charge, the dam failure consequence category is 'very low' or 'low,' only a characterization of the area that would be affected by the dam failure is required. That characterization consists of a conservative estimate of the consequences of a dam failure by means of a rough delineation of the affected area and a general description of the characteristics of the area. For the purposes of the characterization, the extent of the affected area is established by adding the reservoir depth to the 100-year flood level to a point of attenuation or restriction, such as confluence with a large lake or river or another dam."

Every dam must, according to its class, be the subject of a minimum number of inspections in accordance with the required frequency as per dam classification. On the other hand, it should be noted that design flood is determined by consequence category.

as the dam's condition, age, maintenance quality, and so on, and (2) potential consequence based on downstream area population and other economic factors. The type and number of dam safety inspections are defined according to classification. However, the required design flood-return period is defined by the consequence category alone.

Dam Risk Categorization Separate from Dam Classification

Separate risk classification systems can be used for an existing portfolio of dams, with due consideration for the vulnerability of structural conditions, in combination with the classification system used primarily for new dams. Such approaches may be more practical and easier to introduce for most countries, particularly where there is a large portfolio.

Risk classification systems can be used to prioritize deficient dams for upgrade based on condition and classification. For example, in 2015 FEMA in the United States established five so-called joint federal risk categories for classifying dams, ranging from Category I: Very High Urgency to Category V: No Urgency, and indicated corresponding considerations and potential actions for each category. FEMA's risk category system is built on earlier efforts by the US Army Corps of Engineers and US Bureau of Reclamation. This approach is instrumental in prioritizing higher-risk dams for urgent remedial actions and optimizing budget allocation. The required actions cover not only physical remedial works but also additional investigations, intensified monitoring and evaluation, and checking of EPPs. Similar risk classifications indicating the required level of structural and nonstructural measures of existing dams based on their safety conditions have also been introduced in Japan and Korea.

DAM CLASSIFICATION AND DESIGN STANDARDS

One of the main purposes of a dam classification system is to enable proportioning of the appropriate design standards, specifically those for flood and earthquake design. This ensures that higher standards are mandated for higher-class dams. This is common practice among the majority of countries that have a dam classification system. While there are ample useful guidelines available from ICOLD, Australia, Canada, and the United States, among others, it is important to recognize that different countries have established different design standards and guidelines for floods and earthquakes. The level at which the acceptable standards are set in any particular jurisdiction will be informed by the specific country context. Considerations are usually informed by culturally accepted values of life and risk tolerability, government priorities—including those for the protection of lives, property, and the environment from dam safety risks—how these contrast to other societal risks, as well as the resources and capacity available for higher standards.

Design Flood Criteria

The selection of the design flood varies depending on the jurisdiction and the specific level of risk tolerance. In most instances the design flood is selected on the basis of the dam classification system. This helps to secure a consistent safety level against floods and potential overtopping risk. The magnitude of the selected design flood can vary significantly, from 100-year or 200-year flood for low-hazard dams to 1,000-year, 10,000-year, or probable maximum flood (PMF) for high-hazard dams.[18] For example, FEMA in the United States issued a guideline in 2013 on the selection of inflow design flood for different hazard categories of dams, including economic and environmental aspects. The guideline recommended three hazard-based design criteria: (1) PMF for *high* class (probable loss of life due to dam failure or mis-operation), (2) 1,000-year return period flood for *significant* class (no probable loss of life but potential economic loss, environmental damage, and disruption of life-line facilities due to dam failure or mis-operation), and (3) 100-year return period flood or justified smaller one for *low* class (no probable loss of human life and low economic and/or environmental losses due to dam failure or mis-operation).

Different countries have adopted a wide range of different hydrological safety criteria along a continuum. These reflect the individual country characteristics, informed by the socioeconomic realities and public expectations of safety, as well as technical aspects, such as adequacy and reliability of hydrometeorological data, and other design features, such as freeboard requirements (the vertical distance between the top of the dam and the full supply level or surcharge flood level on the reservoir). Thus, it would be desirable for each country to establish its own hydrological safety level required for different classes of dams. ICOLD Bulletin 82 (1992) and Bulletin 170 (2016d) introduced various kinds of hydrological assessment and safety design criteria with useful examples rather than recommending any specific classification and inflow design flood criteria.

One of the most important recommendations by the ICOLD Bulletin 82 was to check dam safety against the following two floods:

1. Safety check flood (often PMF): Structure is on the verge of failure but exhibits marginally safe performance characteristics during flood.
2. Design flood: Represents required flood discharge under normal conditions with a safety margin provided by freeboard. This is sometimes taken as a percentage of the PMF or a flood with a given probability of exceedance, that is, 1:100, 1:1,000, and so forth.

Specific levels of design flood and safety check flood for different dam classes have been prepared in some countries, including China, France, South Africa, and Spain. Others, including Austria and Switzerland, have specified safety checking of dams with the so-called N-1 rule, by which one or more gates are assumed to be closed due to malfunction during floods. In Canada (except Quebec) and the United States, the only requirement is to determine the safety check flood and use that as the inflow design flood (IDF). ICOLD (2016d)

Bulletin 170 also provides valuable information and recommendations on hydrological assessment techniques, including on coping with uncertainties and determination of design floods and risk analyses. It also includes country cases for selecting design flood criteria according to dam classification.

An interesting case on design flood determination is a new approach by Ontario (Canada). Under its current guideline for the selection of the IDF, a higher standard of care is required for life-safety risks compared to other potential damage. Life-safety risks are clearly differentiated from economic, environmental, and heritage or cultural losses. However, even if there is a potential for loss of life, the design flood may be reduced provided that a minimum of 12 hours advance warning is available from the time of dam failure until the arrival of the inundation wave, and if property, environment, or cultural heritage losses do not prescribe a higher design flood. The approach in Ontario is also illustrative of the increasing focus on environmental and cultural heritage elements of floods, with the required IDF per dam class based on three criteria: life safety, property and environment, and cultural heritage (table 5.7). The IDF can be determined based on the incremental consequence analysis of "with" and "without" dam failure scenarios.

Risk-informed approaches for determining the IDF is an emerging trend. The FEMA guideline notes that "incremental consequence analysis or risk-informed decision-making studies may be used to evaluate the potential for selecting an inflow design flood lower than the prescribed standard."[19]

TABLE 5.7 Inflow design flood, by dam class, in Ontario, Canada[a]

Hazard potential classification	Range of minimum inflow design floods[b]			
	Life safety[c]		Property and environment	Cultural or built heritage
Low	25-year flood to 100-year flood			
Moderate	100-year flood to 1,000-year flood or regulatory flood, whichever is greater			
High	For PLL 1–10	1/3 between the 1,000-year flood and PMF	1,000-year flood or regulatory flood, whichever is greater to 1/3 between the 1,000-year flood and PMF	1,000-year flood or regulatory flood, whichever is greater
Very high	For PLL 11–100	2/3 between the 1,000-year flood and PMF	1/3 between the 1,000-year flood and PMF to PMF	
	For PLL >100	PMF		

Source: Ontario Ministry of Natural Resources 2011a. © Queen's Printer for Ontario, 2011. Reproduced with permission.
Note: PLL = potential loss of life; PMF = probable maximum flood.
a. As an alternative to using the table the inflow design floods can also be determined by an incremental analysis. Incremental analysis is a series of scenarios for various increasing flows, both with and without dam failure that is used to determine where there is no longer any significant additional threat to loss of life, property, environment, and cultural or built heritage to select the appropriate inflow design floods.
b. The selection of the inflow design floods within the range of flows provided should be commensurate with the hazard potential losses within the hazard potential classification table. The degree of study required to define the hazard potential losses of dam failure will vary with the extent of existing and potential downstream development and the type of dam (size and shape of breach and breach time formation).
c. Where there is a potential for loss of life the inflow design floods may be reduced provided that a minimum of 12 hours advance warning time is available from the time of dam failure until the arrival of the inundation wave, provided that property, environment, or cultural or built heritage losses do not prescribe a higher inflow design flood.

BOX 5.4

INCORPORATING CONSIDERATIONS OF CLIMATE UNCERTAINTY

The uncertainty surrounding future climate conditions and the trajectory of change necessitate the use of sound mechanisms to empower decision-makers to act and implement interventions under highly uncertain conditions. Extrapolating the variability observed among global climate models to make predictions relating to future runoff conditions and yields associated with water resources infrastructure is even more uncertain. Because individual future scenarios cannot be assigned a probability of occurrence, the use of broadly applicable robust strategies reframes the management dilemma for climate adaptation.

Since 2016 it has been mandatory for all World Bank–financed projects to conduct a screening of climate-related risks and to incorporate resilience measures. The *decision tree framework* was designed to help World Bank–financed projects confront climate uncertainty in water resources planning and project design (Ray and Brown 2015). The robust decision-scaling approach provides a cost-effective and effort-efficient, scientifically defensible, repeatable, and clear method for demonstrating the robustness of a project to climate uncertainty. This is one of a number of methods being used by water resource planners for decision-making under uncertainty to address climate change and other uncertainties in their long-term plans. There are a number of other sector-specific guidelines, such as the ICOLD (2016c) bulletin on climate change and the *Hydropower Sector Climate Resilience Guide* (IHA 2019).

Risk-informed approaches allow the required discharge capacity to be determined on the basis of total risk evaluation, making the concepts of safety check flood or inflow design flood as safety requirements redundant. Federal agencies within the United States have issued a series of guidelines on risk-informed decision-making, which are discussed further in chapter 6. There are a number of other important considerations in determining the inflow design flood, and the potential effects of climate change on flood hydrology are an increasingly important consideration (box 5.4).

Glacier lake outburst flooding events can also result in large flood events, as can breaches of natural dams created by landslides, particularly in mountainous areas with young geology. The magnitude of outburst floods may be greater than floods caused by precipitation or snowmelt and become a determining factor for IDF. Comprehensive glacial hazard and geohazard assessments may be required depending on potential hazards in such cases.

Design Earthquake Criteria

The required seismic design criteria are often also specified for different classes of dams in many countries. The parameters defining the seismic loading depends on the selected analytical method and may include peak ground acceleration, duration of the earthquake, acceleration response spectrum, earthquake magnitude and distance, earthquake time histories, and foundation fault displacement. Among the country case studies, higher standards are mandated for higher hazard class dams in 44 percent of the countries that classify dams.

These parameters can be determined using a Deterministic Seismic Hazard Assessment (DSHA) and/or a Probabilistic Seismic Hazard Assessment (PSHA), as detailed by ICOLD. DSHA is relevant in zones of high seismicity where active faults are present. PSHA may be relevant in both high seismic zones and where earthquakes are much less frequent. The assessments provide the level of ground shaking from an earthquake when it reaches the dam site.

The level of effort for seismic safety evaluation depends on dam class, type, seismic risk, and operational requirement, among other factors. In general, such detailed seismic hazard evaluation is required only for high-hazard cases. For example, Ontario has developed a classification system indicating the required seismic safety level that considers not only life safety but also potential damages to downstream property, environment, and cultural heritage (table 5.8). Some countries also refer to the seismic zone map developed by their national seismic agency and require the selection of a specific peak ground acceleration based on the seismic zone where the dam is situated. ICOLD (2016a) Bulletin 148 recommends setting two levels of earthquakes:

1. *Safety evaluation earthquake (SEE)*: This is the maximum level of ground motion for which the dam should be designed or analyzed. No uncontrolled release of water should occur when the dam is subject to the SEE. For dams with "great social hazard," SEE is characterized by a level of motion equal to that expected at the site from the occurrence of a deterministically evaluated maximum credible earthquake or of the probabilistically evaluated earthquake ground motion with a very long return period, such as 5,000 to 10,000 years. Depending on the consequences of

TABLE 5.8 Design earthquake criteria, by dam class, in Ontario, Canada

<table>
<tr><th rowspan="2">Hazard potential classification</th><th colspan="4">Earthquake design ground motion (annual exceedance probability)</th></tr>
<tr><th colspan="2">Life safety</th><th>Property and environment</th><th>Cultural or built heritage</th></tr>
<tr><td>Low</td><td colspan="4">500 years</td></tr>
<tr><td>Moderate</td><td colspan="4">500–1,000 years</td></tr>
<tr><td>High</td><td>For PLL 10 or fewer</td><td>2,500 years</td><td>1,000–2,500 years</td><td>1,000 years</td></tr>
<tr><td rowspan="2">Very high</td><td>For PLL 11–100</td><td>5,000 years</td><td rowspan="2">2,500–10,000 years</td><td rowspan="2"></td></tr>
<tr><td>For PLL >100</td><td>10,000 years</td></tr>
</table>

Source: Ontario Ministry of Natural Resources 2011b. © Queen's Printer for Ontario, 2011. Reproduced with permission.
Note: PLL = potential loss of life. The annual exceedance probability levels are to be used for the mean rather than for the median estimates. The mean is the expected value given the epistemic uncertainties and, for typical seismic hazard computations in Canada, the mean hazard value typically lies between the 65th and 75th percentiles of the hazard distribution. The median is at the 50th percentile. Also, generally, a seismic hazard evaluation will not be required for low or moderate hazard potential classification dams unless specifically requested by the minister with supporting rationale.

dam failure, it is recommended to design safety-critical elements against the SEE. Where there is no significant risk to life, the SEE may be chosen to have a lower return period depending on failure consequences.

2. *Operating basis earthquake (OBE):* This is the level of ground motion at which only minor damage is expected. The structure remains functional. Damage is easily repairable. The OBE can be determined from an economic risk analysis or by choosing a minimum return period of 145 years (that is, 50 percent probability of not being exceeded in 100 years). The OBE may also be influenced by local building code limits for critical infrastructure.

REQUIREMENTS FOR SURVEILLANCE, INSPECTION, AND REVIEW[20]

Dam classification is also used to define the level of surveillance and various dam safety inspections. These can include the type and frequency of dam safety review and inspection, the required level of qualifications for the respective inspectors, the level of emergency preparedness required, and differentiated provisions for operation and maintenance (O&M) plans, along with other requirements for ensuring an appropriate level of dam safety. In roughly half of the country case studies, dam owners are required to commission independent surveillance engineers or inspectors (table 5.9).

TABLE 5.9 General standards that are mandated for surveillance and inspection according to hazard class or other criteria among the case study countries and jurisdictions

Income level	Qualification/ composition of engineers /inspectors required to be commissioned by dam owner according to hazard class	Levels of sophistication of inspections and dam safety reviews and associated reporting for different hazard classes	Timing/ frequency of surveillance/ inspections and dam safety reviews and associated reporting for different hazard classes	Other—previous three requirements vary according to size or are a blanket requirement	Nothing mandated	Undetermined
High income	11	11	11	4	1	3
Upper middle income	4	4	5	2	2	5
Lower middle income	3	3	2	0	5	5
Low income	0	0	0	1	3	0
Total	**18**	**18**	**18**	**7**	**11**	**13**

Source: Original table for this publication.

In 35 percent of cases, it is the classification of the dam that determines the level of qualifications required for the inspectors, along with the level of sophistication and the timing of the inspection and review. Examples are found in the Australian state of Tasmania, the state of Michigan in the United States, and in Brazil and Malaysia. While such requirements are typically more prevalent among upper-income countries, such provisions are also found in South Africa and Vietnam. Low-income countries tend to specify limited mandates in this regard, likely reflecting the challenges in supervising compliance of such requirements. In 14 percent of cases, such standards vary depending on size classification of the dam or are a blanket requirement, such as yearly for all regulated dams (for example, in Italy, Poland, the United Kingdom, and Zimbabwe); in 22 percent of the cases there are no specific mandates. The range of different standards that are mandated for surveillance, inspections, and dam safety reviews is illustrated through the following examples:

- In the Australian state of Tasmania, owners of significant- to high-hazard dams are required to arrange safety inspections and reports by an experienced dam engineer (of a required competency) after initial filling and generally every five years thereafter.
- South Africa also requires safety inspections every five years, but the level of required reporting by the approved professional engineer(s) is more sophisticated for dams that are larger or have higher hazard ratings.
- In Indonesia, the government requires a Dam Operational Management Plan. Surveillance, reviews, and O&M by the dam owner are provided through the dam management unit and approved by the regulator. The dam owner can appoint a panel of experts in cases involving either (1) new technology in dam design and construction, (2) dams higher than 75 meters and with a reservoir capacity greater than 100 million cubic meters, or (3) high-hazard dams. The frequency of surveillance includes weekly visual checks, at least monthly instrumentation readings, dam safety evaluations every five years, and additional checks in case of extraordinary events, such as an earthquake or a flood.
- In Spain, detailed periodic safety inspections are carried out by multidisciplinary teams that are independent from the owner. Inspections for dams in categories A and B occur every 5 years, and those for category C dams occur every 10 years.
- Vietnam's Decree 72 (2007) provides for detailed dam safety inspections with varying requirements depending on reservoir capacity. The safety inspection or review must be done periodically, not exceeding 10 years for dams with a reservoir capacity equal to or larger than 10 million cubic meters, and not exceeding 7 years for dams with a reservoir capacity smaller than 10 million cubic meters. The inspection or review is the responsibility of the dam owner, who must select inspection consultants

qualified in accordance with provisions of the Ministry of Agriculture and Rural Development in the case of irrigation dams.

- In the United States, the state of Michigan provides for a strict level of surveillance, inspection, and reporting, whereby owners must submit inspection reports prepared by licensed professional engineers to the state's oversight authority at least once every three, four, and five years for high-, significant-, and low-hazard dams, respectively.
- The State Dam Safety Act in California[21] requires the state of California's Department of Water Resources (Division of Safety of Dams) to inspect significant-, high-, or extremely high-hazard dams at least once per fiscal year and low-hazard dams at least once every two fiscal years.
- In the Canadian province of Quebec, the mandated inspections are also strict, depending on Quebec's five categories of dam classification (table 5.10). A site inspection is intended to make a summary description of the dam's condition and, if a minor deficiency is discovered during a prior inspection, to monitor the evolution of the deficiency. An inspection, on the other hand, is intended to check a dam's condition in all aspects and to monitor its behavior using various analyses and measurements.
- Brazil's national dam safety law (2010) mandates dam safety inspections (article 9) and periodic reviews (article 10) requiring each regulating agency (at federal or state level) to establish the criteria of the inspection frequency, the necessary qualifications of responsible personnel, and the minimum levels of content and detail according to the "risk and hazard" category of the dam. For example, the National Water Agency (ANA) established the safety inspection criteria in its Resolution 742, based on the classification system by the Brazil National Water Resources Council (CNRH) as per Resolution 143. The state of Bahia and the state of Ceará have also developed their dam classification systems and safety requirements.
- In the United Kingdom, dam owners are required to employ both a supervising engineer and an inspection engineer with certified qualifications. The supervising engineer supervises the condition of a dam and provides a report annually, as required by Section 12 of the Reservoirs Act. The inspection engineer conducts statutory inspections at least once every 10 years and at any time recommended by the supervising engineer, as required by Section 10 of the act. All reports are submitted to the dam owner, and copies are sent to the regulator.

TABLE 5.10 Inspection frequency according to dam class, in Quebec, Canada

Type of inspection	Number and frequency of inspections according to dam class				
	A	B	C	D	E
Site inspection	12 per year	6 per year	2 per year	2 per year	1 per year
Inspection	1 per year	1 per 2 years	1 per 5 years	1 per 8 years	1 per 10 years

Source: Original table for this publication.

Performance Monitoring, Reporting, and Disclosure

Most jurisdictions have developed dam classification systems to define the minimum standards for surveillance, inspections, and safety review of dams. These standards are, in some systems, clearly specified under statute, such as in Michigan and South Africa, while in other systems, legislation simply provides power to the enforcement authority to set the requirements, such as in the Australian state of NSW. Aspects upon which minimum standards are set include the frequency and thoroughness of inspections and surveillance procedures, the relevant parties required to arrange for and/or conduct the procedures, and the required content of any subsequent reporting.

Dam owners are required to arrange for surveillance and inspection of dams in most countries. This is usually done by contracting an independent experienced engineer, or in some cases a team of experts, in line with minimum competence standards, and subsequently reporting all information to the relevant enforcement authority. Some countries and entities (such as major hydropower utilities) give more serious consideration to maintaining the capacity of internal technical staff for dam safety surveillance, monitoring, and inspection along with training and mentoring programs. It is important to maintain such capacity for undertaking constant checking of dam safety conditions in connection with daily operational works.

Enforcement authorities also periodically conduct their own formal audit inspections for a quick check of surveillance and inspection information in many cases. If resources for the regulator are limited, then random audits would be appropriate. Some regulators, such as those for the state of Washington in the United States and the province of Quebec in Canada, possess sufficient enforcement capacity to adopt a hands-on supervisory role with the undertaking of periodic, fee-based inspections and reviews. The extent of enforced surveillance or inspection varies both within and between countries, with some systems being stricter than others. Overall, the stricter and more thorough a surveillance and inspection system is, the more effective it will be in reducing risk and increasing safety assurance.

Regulators should consider publicizing and disclosing the overall dam safety condition of existing dams. This can be helpful in encouraging dam owners to improve performance in relation to dam safety management and increase awareness among the public or legislative bodies to the importance of dam safety issues. For example, according to the 2010 Water Act in Brazil, ANA is required to prepare an annual national dam safety report consolidating information submitted by various regulators. Based on this, the National Water Resources Council (CNRH) is required to submit a report on dam safety assessment and recommendations to Brazil's National Congress on an annual basis.[22] ANA has established the National Dam Safety Information System connecting all regulating agencies for different sectors at the federal and state levels to facilitate exchange of information and for preparing a consolidated annual report.

In the United States, FEMA prepares and submits to Congress the National Dam Safety Program biennial report covering the overall regulatory status of all federal and nonfederal dams. In Australia, the Department of Environment, Land, Water and Planning in the state of Victoria serves as the regulator and produces an annual report on statewide dam safety results from a web-based database that is created in coordination with water corporations. These cases are introduced in more detail under the benchmarking section of chapter 6.

The amended State Dam Safety Act in California[23] requires that dam inspection reports for significant-, high-, or extremely high–hazard dams prepared by the Division of Safety of Dams (Department of Water Resources) shall be public records. However, sensitive data, images, or other information that disclose a dam's vulnerability or pose a security threat may be withheld from public release.

These reporting and disclosure requirements of dam safety conditions are instrumental in improving the awareness and capturing the attention of the public and of legislative bodies (which allocate budget and resources) to dam safety issues. Public disclosure also encourages increased accountability and can help in promoting the exchange of lessons learned between dam owners and regulators as part of an overall process of continuous improvement in dam safety management.

REQUIREMENTS FOR OPERATION AND MAINTENANCE

Ensuring that dams are adequately operated and maintained by dam owners is critical for dam safety assurance. It is therefore important to ensure that sufficient funding is available to support O&M works. Specific minimum requirements are often included among the mandates of dam safety assurance legislation. Requirements typically include the following:

- Preparation of an O&M plan with any requisite certification
- Details of appropriate safety monitoring instruments and equipment and frequency of readings for different dam classes
- Procedures for standard reservoir operation and downstream notifications or warnings
- Procedures for reporting to the regulator

Nearly half (45 percent) of all the case study countries and jurisdictions have specific mandates for preparation of an O&M plan (table 5.11), including New Zealand, Norway, Poland, South Africa, and Zimbabwe. Requirements for instrumentation and equipment, along with the associated frequency of readings, are also mandated in 22 percent of these cases (such as in South Africa). Over half of the cases have specifically mandated reporting procedures for O&M (for example, South Africa and Turkey), but only 8 percent

TABLE 5.11 General standards for operation and maintenance requirements among the case study countries and jurisdictions

Income level	O&M plan or manual with any requisite certification	Details of safety monitoring instruments and equipment and frequency of readings	Details of maintenance budget and funding plan to be made available	Reporting procedure	Other	No mandates	Undetermined
High income	12	6	2	15	0	0	3
Upper middle income	7	3	1	8	0	2	5
Lower middle income	3	2	1	3	0	5	5
Low income	1	0	0	2	0	2	0
Total	**23**	**11**	**4**	**28**	**0**	**9**	**13**

Source: Original table for this publication.
Note: O&M = operation and maintenance.

of cases have a requirement for the dam owner to provide details of a budget (such as in Indonesia, Korea, Turkey, and FERC in the United States), while 18 percent of the case studies have no prescribed legislative mandates. These mandated requirements for O&M are more often observed among upper-middle-income and high-income countries.

Establishing standard reservoir operations and downstream warning procedures during floods and pre-drawdown periods to address flood management and public safety downstream is also important to ensuring dam safety. A lack of clear reservoir operations and warning procedures can cause serious safety issues in downstream rivers. Many incidents involving casualties have been reported due to mis-operation of gates or lack of downstream warning in various countries.[24] For example, the International Red Cross pointed to frequent disasters from flooding downstream of the Nangbeto Dam in Togo due to a lack of proper reservoir operations, flood forecasting, and downstream warning systems. Several countries and jurisdictions, such as the Australian state of Queensland, Canada, India, Japan, Spain, the United States, and Vietnam, among others, mandate reservoir operations and downstream flood-warning procedures on a basin scale as part of management or mitigation plans specific to the dam. Such plans aim to define a suitable balance between protecting the structural safety of dams, preserving operational security for water supply and power generation, and mitigating flood hazards to communities located downstream. See box 5.5 for an example.

BOX 5.5

ADVANCED RESERVOIR OPERATIONS COUPLED WITH INTENSIVE HYDRO-MET MONITORING AND FORECASTING SYSTEM IN JAPAN

According to the River Act in Japan, all dams in rivers are regulated by river managers (with the Water and Disaster Management Bureau in the Ministry of Land, Infrastructure, Transportation, and Tourism or MLIT) and the corresponding departments within prefectural governments. The river manager has authority to provide instructions to privately owned dams about required reservoir operations to reduce downstream hazards during extraordinary floods. The River Act also requires private dam owners to include surcharge flood control capacity against 100-year floods in their reservoir plan to prevent abrupt increases in flood water discharge, subject to the river manager's approval. The regulator has also established a financial compensation mechanism for private owners if the reservoir water is not recovered afterward due to pre-drawdown reservoir operations before a flood's arrival.

In order to assist in integrated reservoir operations, MLIT has installed 26 C band and X band multiparameter radars covering almost all national areas, coupled with around 10,000 automatic rainfall gauges under Japan's Meteorological Agency, with a spatial density of one gauge per 38 square kilometers, on average. The high-density monitoring network enables the river managers to measure rainfall volume every minute, on average, over 1 square kilometer. In some urban areas, this is over a 250-meter mesh, enabling a highly advanced, near real-time, and comprehensive flood forecasting system. Furthermore, dam owners and operators are required to establish detailed operational and downstream warning procedures, including siren warnings, patrols, sign boards, and so forth, that must be approved by the river manager.

RECORD-KEEPING REQUIREMENTS

Record keeping by dam owners is an important component of dam safety assurance, and information about dams and their safety should be easily accessible at all times. This is particularly important during emergency situations. Countries and jurisdictions should require dam owners to act responsibly with any information and material relating to the safety of their dams and to keep them in a specific manner. The file should be stored in a place where it can be inspected by the enforcement authority, typically at the dam management office, where it should be easily accessible to all concerned in the event of an issue relating to dam safety.

Record keeping by the owner is mandated in over half (53 percent) of all the country and jurisdiction case studies (table 5.12), including Albania,

TABLE 5.12 Record-keeping requirements among the case study countries and jurisdictions

Legal system	Mandated	Mandated: Specific safety file must be kept in a nominated place	Mandated: Content of the file is prescribed	Nothing mandated	Undetermined
Common law	7	1	1	4	0
Civil law	17	2	2	4	7
Religious law	0	0	0	0	1
Mixed	1	0	0	3	4
Common and civil law	1	0	0	1	0
Total	**26**	**3**	**3**	**12**	**12**

Source: Original table for this publication.

Brazil, China, Spain, and Switzerland. However, in only a few cases (6 percent) are the contents and the location of the file prescribed, such as in Brazil and Spain. There are no specific mandates relating to the owner's obligations for record keeping in 24 percent of cases. Record-keeping mandates are more predominant in civil law jurisdictions (18 out of 22 case study countries and jurisdictions that follow civil law) compared to common law jurisdictions (7 out of 11 cases), reflecting civil law's preference for prescription, detail, and certainty, leaving no room for interpretation.

The dam safety file typically comprises three main parts: (1) as-built engineering details; (2) the O&M plan, including dam safety surveillance, monitoring, and reservoir operation procedures; and (3) an emergency preparedness or contingency plan. Any mandates relating to the content of the file should require information to be sorted into these three components for easier access, as illustrated in Spain's legal provisions. The Reservoirs (Scotland) Act (2011) of Scotland specifically requires the owners of high- and medium-risk reservoirs to keep records that include reservoir water level, leakage, repairs, and settlements along with offenses and fines in case of noncompliance. The Dam Safety Regulation for Quebec (Canada) was updated in 2017 and requires dam owners to maintain a logbook covering all inspection activities, safety reviews, maintenance, and repair and alteration works, as well as dam safety–related events.

To whom the records need to be made available is also an important consideration. This can be limited to only the regulator, or can include provisions requiring that the records also be made available to local municipalities, disaster management agencies, and emergency services, among others. The analysis found that in over half of cases the owner's records must be made available to the regulator (52 percent), for example in Australia, Indonesia, Norway, and the United Kingdom, and in 20 percent of cases owners are required to share records with emergency agencies (for example in Canada, the Czech Republic, and Pakistan). There are no specific mandates relating to the availability of the owner's records in 24 percent of cases.

EDUCATION AND TRAINING

Education and training to ensure the competence of dam owners, operators, and the staff responsible for O&M, as well as the continuous training of regulatory staff, is an important part of dam safety assurance. This is reflected in the fact that more than half (55 percent) of the countries and jurisdictions examined, across all income levels, make provision for owner education and guidance through the publication of guidelines to help owners understand the responsibilities and liabilities associated with their dams. Several countries also require continuing education and training of the regulatory authority's staff within their dam safety regulations. However, as this is within the control of the government, most countries choose to manage this internally rather than stipulate these requirements via regulations. In 18 percent of cases, training of O&M staff is mandated (such as in Argentina, Indonesia, Norway, and Vietnam), while in 16 percent of cases ongoing training of regulatory authority staff is mandatory (such as in Indonesia, Korea, Pakistan, Sri Lanka, Uzbekistan, and Vietnam). Training is not mandatory in 39 percent of the country and jurisdiction case studies.

Specific qualifications and course requirements are stipulated for the owner's staff in Norway's dam safety regulations. Company managers are required to complete a course with emphasis on legal requirements, emergency action plans, and dam safety philosophy. Chartered dam engineers for class 3 and class 4 dams are required to pass an exam after a 10-day course on dam safety. Inspection personnel are required to complete a one-week course with an emphasis on dam safety inspection.

However, the extent of this provision inevitably depends on the amount of funding made available to the assurance program, and it is important for the regulator and owner to discuss and agree on the budget plan; the discussion should include key stakeholders, especially any legislative bodies, ministries, or utilities that are ultimately responsible for the regulation and realization of dam safety.

LEGAL STATUS OF GUIDELINES AND STANDARDS

The legal status of dam safety guidelines and standards must be clear so that all parties know which standards are to be satisfied during the life cycle of a dam. There are various options, including the following:

- Guidelines mandated in the legislation that set the standard to follow
- Guidelines mandated by rule under the discretional power of the dam safety authority
- Guidelines widely accepted as the norm and so set the standard to determine liability and fault in common law systems where negligence applies

- Guidelines that are not mandatory but serve as good references only
- Other possibilities, such as deferring to the international standard set by ICOLD

Country-specific guidelines that are in line with internationally accepted practice, such as found in ICOLD bulletins, are essential to act as guidance for dam owners and their engineers. These are also essential in setting minimum dam safety management and design standards that are appropriate to the circumstances of the country. In most civil law countries, the regulatory authority establishes technical codes, standards, or procedures under its enabled power, which are mandatory for owners to abide by.

Guidelines may have limited influence if they are nonmandatory and rely only on voluntary implementation. When they are issued by a nonregulatory body (for example, a national committee on large dams) and hence not considered mandatory, civil law jurisdictions can make them mandatory by standardizing them as codes of practice. Common law systems can make them mandatory by referring to them within regulations or within the rules of the regulatory authority, or they can be indirectly made mandatory if they are already accepted practice in unregulated common law systems.

The comparative analysis (table 5.13) shows that in 35 percent of cases, guidelines or standards are mandated by legislation. Examples are found in the Australian state of Queensland and in Bulgaria, France, Japan, Lao PDR, the province of Quebec in Canada, Spain, and Uzbekistan. This is predominantly the case in civil law systems (15 out of 26 civil law jurisdictions compared

TABLE 5.13 Legal status of guidelines and standards among the case study countries and jurisdictions

Legal system	Mandated in the legislation to set the standard to follow	Mandated by rule under the discretional power of the dam safety authority, including in self-regulatory systems	Guidelines would set the standard to determine liability/ fault in common law systems where negligence applies	Guidelines only, not mandatory	Defer to international standards (for example, ICOLD)	No guidelines	Undetermined
Common law	2	6	5	4	1	1	0
Civil law	15	11	0	0	0	3	4
Religious law	0	1	0	0	0	0	0
Mixed	0	0	1	1	1	3	4
Common and civil law	1	1	0	0	0	1	0
Total	**18**	**19**	**6**	**5**	**2**	**8**	**8**

Source: Original table for this publication.
Note: ICOLD = International Commission on Large Dams.

to 2 out of the 13 common law examples), where standards need to be highly detailed and prescribed to leave limited room for interpretation or discretion. In 37 percent of cases, guidelines are mandated by rule under the discretional power of the dam safety authority (for example, in the Islamic Republic of Iran, Nigeria, the state of NSW in Australia, and Vietnam). This is also observed in civil law jurisdictions for subsidiary regulations, and more so in self-regulatory regimes. In 10 percent of cases, guideline documents are not mandatory, but in common law jurisdictions, where negligence applies, such cases still set the standard to determine liability or fault and so they are indirectly mandatory (for example, in Australia, India, New Zealand, and South Africa). Only Pakistan and South Africa defer to international standards, although the South African provisions leave this as an option. In 16 percent of cases there are no guidelines.

Such guidelines may not necessarily have to be officially sanctioned by dam safety laws or regulations as long as such guidelines issued by professional entities, such as national committees or societies of large dams, are honored and practiced by dam owners. However, in countries where most dam construction is led by private entities, the formal establishment of guidelines is strongly recommended to ensure that regulators have the ability to require developers to comply with the established minimum safety standards without ambiguity.

Most Australian states refer to ANCOLD guidelines in their dam safety regulations rather than developing detailed guidelines on their own. Some provinces of Canada also refer to CDA guidelines. New Zealand's Dam Safety Guidelines also provide a good example,[25] dealing with all aspects of dam safety management, including applicable dam safety regulation and mandates, in a series of modules that are presented in simple, clear language. This way, each module can be amended separately, relatively quickly, and easily if and when regulations or standards change.

ENFORCEMENT AND DISPUTE-RESOLUTION MECHANISMS

A final critical element of any dam safety assurance scheme is ensuring enforcement of the dam safety requirements. Many countries stipulate license suspension and revocation for private sector dams in laws or regulations. Penalties that include criminal sanctions as additional enforcement to civil penalties would be appropriate, considering the possibly devastating consequences of dam failures.[26] Ultimately, the stronger the penalties are, the more likely dam owners will comply with the mandates of the scheme. At the same time, it can be difficult to achieve agreement on criminal sanctions among key stakeholders. In India, for example, the issue of liability or penalties associated with roles and responsibilities between state and federal governments has been an area of continued debate since 2010 as part of efforts to legislate the national dam safety law.

Punitive enforcement in the form of civil penalties is observed in 18 percent of case study countries and jurisdictions (table 5.14), for example, in Albania, New Zealand, and Sweden. Another 14 percent mandate civil and criminal penalties, such as in Korea, Norway, South Africa, and Zimbabwe, while in 12 percent of cases the regulating authority can also issue fines (Australia and Korea). Another 22 percent of case study countries and jurisdictions have very strong penalties, including severe fines that increase daily and/or criminal sanctions. Stronger penalties are mostly evident in higher-income countries (for example, Korea, Norway, and South Africa), while no punitive enforcement is observed in 22 percent of cases, mostly among middle- to lower-income countries.

Strong and accountable compliance monitoring and enforcement as well as the capacity and resources for the regulator to police and enforce compliance are also critical. If the regulatory authority lacks the capacity or resources to police and enforce compliance, the entire regulatory scheme is undermined and rendered less effective. A rigorous hands-on checking system (such as the ones found in Quebec and Washington State) is unsuitable unless there are sufficient human and financial resources for regulatory authorities. A compliance-audit approach (with only occasional random audits) may be more suitable in such cases, where dam owners are required to use independently approved inspectors and submit reports to the regulator (see the section "Requirements for Operation and Maintenance"). In this approach, the engineering professionals representing dam owners are given more trust, allowing the regulator to dedicate more of its resources to enforcing compliance.

Mechanisms for arbitration or mediation are increasingly important for attempting to resolve disputes between regulators and dam owners.[27]

TABLE 5.14 Enforcement and dispute-resolution mechanisms among the case study countries and jurisdictions

Income level	Civil penalties only	Civil and criminal penalties possible	Authority can issue fines	Penalties are strong	Penalties are weak and achieve low level of compliance	Authority lacks capacity to police	Other	None	Undetermined
High income	7	4	6	8	0	0	0	0	8
Upper middle income	2	1	0	2	0	0	0	3	8
Lower middle income	0	1	0	0	2	0	0	5	6
Low income	0	1	0	1	0	0	0	3	0
Total	**9**	**7**	**6**	**11**	**2**	**0**	**0**	**11**	**22**

Source: Original table for this publication.

This mechanism, when provided for under the dam safety laws, can assist in resolving disputes between the dam owner and the regulator without the need to resort to punitive measures or expensive and lengthy court proceedings (Richardson 1996; Rubino-Sammartano 2014).

For example, the Reservoirs (Scotland) Act 2011, as well as the Reservoirs Regulations of 2016, stipulate the referral procedure to a referee in case dam owners are not satisfied with the direction of inspection reports by the inspecting engineer and direction of safety reports by the construction engineer. Similarly, the Dam Safety Act of Quebec (updated in 2018) indicates the owner's appeal procedure to the Administrative Tribunal of Quebec in the event the owners are not satisfied with the decision of the regulator regarding a dam safety program, remedial measures, and construction or alteration works authorization. Sections 93 and 94 of the Alberta Water Act (2000, updated in 2014) provide for a two-stage dispute-resolution mechanism for any decision made by the regulator pursuant to the act and its subordinate regulations. These include provisions for an initial referral to the director of the responsible department for formal review, and if necessary and agreed upon by all parties, then to formal mediation.

Similarly, in Queensland (Australia), chapter 7 of the Water Supply (Safety and Reliability) Act 2008 provides for reviews, appeals, and arbitration of decisions by the regulator in a process that begins with a simpler internal review and, if necessary, can be either appealed by the dam owner or any other "interested person" in the Planning and Environment Court or can just be referred to arbitration. This approach provides choices to the dam owner if they are not content with the decision of the regulator or its subsequent internal review.

KEY MESSAGES AND CONCLUSIONS

The content of a dam safety assurance regulatory scheme should spell out the specific mandates for regulators and owners. The scope and contents of the regulatory powers need to be defined within the context of the overall roles and responsibilities of the regulatory authority vis-à-vis dam owners. These exist along a continuum depending on the characteristics of the country and the nature of the portfolio. The key elements and provisions that should be included in any dam safety scheme to achieve maximum assurance include the following:

- Capture of regulated dams (dam registry)
- Proportioning mandates according to classification
- Dam safety design standards and criteria
- Requirements for surveillance and inspection
- Requirements for operation and maintenance

- Record-keeping requirements
- Education and training
- Giving legal status to guidelines and standards
- Enforcement and arbitration

In many countries, a minimum height and/or reservoir capacity is specified under statute for standardizing which dams are subject to the provisions of the regulation. Some jurisdictions regulate dams as small as 1.8 meters in height and 1,000 cubic meters in reservoir capacity, recognizing that even small dams can be dangerous, especially in scenarios involving cascade failures or cumulative impacts. Inevitably, the higher or larger the minimum capture criterion is within the scheme, the greater the number of dams left outside the regulatory regime and the higher the potential risk to downstream communities. Improvements in remote sensing technologies and the development of pattern recognition algorithms specific to dams and reservoirs is helping to simplify the initial inventory and capture small dams irrespective of the requirements they may be subject to.

Dam classification is useful in proportioning the dam safety mandates so that higher regulatory requirements (such as for surveillance and design standards) can be applied to higher-hazard dams while lower requirements can be applied for lower-hazard dams. This allows for optimization in the allocation of financial and human resources. Different countries and jurisdictions have developed different systems, such as size-based, hazard-based, or a combined approach, depending on factors including the country's unique socioeconomic conditions and geographic and demographic features.

There are a number of existing guidelines detailing engineering standards that can serve as useful references, such as those made available by ICOLD and the governments of Australia, Canada, New Zealand, and the United States. However, a dam classification system should always be developed with due consideration to the country's characteristics, including the socioeconomic conditions, demographic features, population density, geography and topography, land-use patterns, and societal tolerance of risk. Due consideration also needs to be given to national safety levels and expectations, standards, and criteria in relation to floods, earthquakes, and other kinds of risk. The dam safety criteria and requirements may also need to be coordinated with the country's overall safety regulations and include or overlap with other sectors, such as energy, transportation, and disaster management. Finally, it is important to recognize that economic, environmental, and societal conditions will change over time.

Along with being tailored to the country's condition, the dam classification system should not be overly complex, as this would put an unreasonable burden on dam owners and/or regulators. In many instances, the initial inventory and registration of dams can pose a major challenge, although technological innovations are making this process easier. While a classification system should provide dam safety standards and requirements in a general manner, the exact safety requirements should be determined based on a further detailed safety assessment or review of each dam. A more stringent design process and/or a more intensive monitoring and inspection protocol could be required based on the results of this dam safety review.

Existing dams that do not necessarily comply with modern and stricter safety requirements present a specific challenge for dam safety regulation. The introduction of new requirements could be too onerous and inefficient to apply uniformly across the entire portfolio of existing dams. While the traditional deterministic design, standards-based approach is fundamental, particularly in regulating the construction of new dams, there is a trend toward risk-informed approaches for reviewing the required safety standards for existing dams. For example, US FEMA indicates that incremental consequence analysis or risk-informed decision-making studies may be used to select an alternate inflow design flood lower than the prescribed standard by dam classification.

Most regulatory systems set minimum standards for surveillance, inspection, and review of dams. Aspects upon which minimum standards are set include the frequency and thoroughness of inspections and surveillance procedures, the relevant parties required to arrange for and/or conduct the procedures, and the required contents of subsequent reporting. Dam owners are required to arrange for the surveillance and review of dams within their portfolio. This can be done using internal technical staff, by contracting an independent certified engineer, or, in some cases, by contracting a team of independent experts, in line with the minimum requirements, such as the frequency, scope and depth of surveillance, inspection, and periodic review of dam safety. All information, irrespective of how it is collected, should subsequently be reported to the relevant authority.

In some jurisdictions, regulatory authorities also periodically conduct their own formal audit inspections for a quick check of surveillance information. If resources for the regulator are limited, then random audits would be appropriate. The frequency and extent of required inspections vary between and within countries, with some jurisdictions requiring inspections as often as every three or five years, or even annually, especially for high-hazard dams. Overall, the more stringent and thorough a surveillance and inspection system is, the more effective it will be in reducing risk and increasing the safety of dams and downstream communities.

Ensuring that dams are operated adequately and maintained as necessary is an essential part of dam safety assurance. This is commonly achieved through an O&M plan that must be produced, and often certified, by the dam owner's engineer or engineering team. Specific requirements to be included within the O&M plan can include intensity of periodic inspections, details of instrumentation and equipment and associated frequency of readings, standard reservoir operation and downstream warning, and reporting procedures. Many higher-income countries include such specific requirements under their dam safety regulatory regime.

Downstream flood management is also critical to ensuring the safety of dams and downstream communities. A number of incidents have occurred due to the mis-operation of discharge facilities and the lack of proper downstream warning systems and procedures. Some countries require a basin-wide flood-management plan covering all public and privately owned dams to minimize downstream hazard during large floods. The owners are required to stipulate the reservoir operation, flood discharge, and downstream warning procedure in the operational procedure subject to the approval of the regulatory authority. These are typically covered under the operation and maintenance plan.

Record-keeping requirements are covered by regulation in many countries and are often imposed in a strict manner. These typically require owners to act responsibly with any information and material relating to the safety of dams by requiring a special safety file to be maintained and stored in a place where it can be inspected by the enforcement authority and, if dam safety issues arise, be easily accessible to all concerned. Key information in the safety file should be sorted and filed into three separate parts: (1) as-built engineering details; (2) an O&M plan that includes dam safety surveillance, monitoring, and reservoir operation procedures; and (3) a contingency plan to ensure faster and easier access to relevant information at the time of need.

Provisions for owner education and guidance are important for continuous improvement in efforts to ensure the safety of dams, especially in terms of the risk they might pose to downstream communities. This is typically done through the publication of guidelines to help owners understand the responsibilities and liabilities associated with their dams, in line with the law. In some cases, jurisdictions will require training for O&M staff, which is particularly important, as is continuing education and training for staff from the regulatory agency. This ensures that staff are kept abreast of all modern developments in areas relating to the safety of dams and downstream communities. However, the extent of this provision inevitably depends on the provision of adequate funding and human resources.

Many countries require dam owners to prepare a comprehensive Owner's Dam Safety Program (ODSP) that covers the aforementioned elements and is subject to the approval of regulators. For example, in the United States, FERC requires licensees to submit an ODSP that includes the following basic principles: (1) an acknowledgement of dam safety responsibilities; (2) communication protocols; (3) a clear designation of responsibility; (4) an allocation of resources to dam safety; and (5) learning organization. Similar provisions are found in Australia and Canada. It is important to introduce such comprehensive approaches as a portfolio of dams increases or becomes increasingly hazardous.

Country-specific guidelines are essential for providing guidance to dam owners and their engineers and to set minimum dam safety management and design standards that are appropriate to the circumstances of each country or jurisdiction. To ensure that all dam owners and their engineers and managers follow a uniform set of standards, regulations or codes must include adequate dam safety standards; if standards are only spelled out in guidelines, they should be enforceable through regulation, rule, or through the common law. This is particularly crucial for low-income countries and especially so in those where the majority of dam construction is implemented by private sector developers, such as in hydropower works. Under such conditions, in the absence of formal guidelines, it can be very difficult for regulators to enforce requirements and have developers comply with required safety standards and requirements in a consistent manner.

Finally, provision for strong and accountable compliance monitoring and enforcement is essential to realizing the objectives and intentions of the regulatory regime and its contents. This requires sufficient financial resources, human capital, and technical capacity for the regulator to police and enforce compliance. The strength of enforcement can be enhanced through a range of mechanisms, including the revocation or suspension of the operational license for the dam and/or criminal sanctions, or by increasing monetary penalties the longer that violations go unaddressed. Provisions for arbitration or mediation can also assist to amicably resolve disputes between the dam owner and the regulator without the need to resort to punitive measures or court proceedings.

NOTES

1. While there is no universal definition of "directive," it typically includes orders, rules, or policies that must be followed, the details of which are not included within the wording of the regulation, but are made as necessary and are enforceable by the regulator under a discretional power provided to it under a legal act. For example, in the Australian state of New South Wales (NSW), the regulator is given discretional power under the Dams Safety Act 2015 to "formulate measures (including the development of guidelines) to ensure the safety of dams" and in doing so is to "have regard to the objects of this Act, and . . . apply, as far as is reasonably practicable, best practice regulatory principles" (per sections 9(1)(f) and 9(3)). As a result, the NSW Dams Safety Committee Guidance Sheets must be followed (see www.damsafety.nsw.gov.au/DSC/infosheets.shtm). Whereas when guidelines are mandated by regulations, they are explicitly referred to within the regulations: for example, the Australian state of Tasmania explicitly mandates the use of the Australian National Committee on Large Dams guidelines per schedule 1 of the 2015 Water Management (Safety of Dams) Regulations.
2. The French regulations capture class A, B, and C dams. Classes A and B, which are essentially the larger dams, are based only on size criteria, but class C, while also mostly based on size, has a very small hazard consideration component saying "not in class A, B and with H higher than 2m and V> 50000 m^3 and with at least one residence within 400m downstream of the dam" (ICOLD European Club 2019). For this reason, France's capture criteria are considered to be both size- and hazard-based.

3. It should be noted that ESF ESS4 is applied to all projects whose concept note was approved on or after October 1, 2018. Those projects for which the concept note was approved before October 1 are still subject to OP/BP4.37.
4. ESS4 further notes that the risks associated with a dam are design and situation specific, and will vary depending on structural components, socioeconomic factors, and the environment within which the dam is to be constructed and operated. Application of dam safety requirements will reflect these considerations and be proportionate to the size, complexity, and potential risk of the dam. The World Bank has prepared Good Practice Notes to inform the application of a risk-based approach under ESS4.
5. Personal communication with Dr. P. A. (Andy) Zielinski, ICOLD Committee on Dam Safety Chair, September 2017.
6. Some high-income countries, such as Italy, Japan, and the United Kingdom, among others, do not have dam classification systems. Often this reflects sensitivities to differentiating levels of safety based on the size and/or location of a dam and where most downstream areas are highly populated.
7. As per the Federal Emergency Management Agency guideline for hazard potential classification (2004), low and significant categories are assigned only when no loss of human life is expected; otherwise all dams are categorized as high-hazard dams. In the case of Ontario, Canada, all dams with life loss potential of more than 10 are classified as "very high" hazard out of four categories.
8. As explained in the section "Capture of Regulated Dams," France was considered to have both size- and hazard-based criteria for the purposes of capture. However, in this section it is considered to be size-based only for classification purposes in order to proportion the mandates. This is because only the smaller class C dams have a minor hazard consideration within their classification, and so once dams are captured, the regulatory mandates are proportioned between the three classes essentially based on size only. This is consistent also with ICOLD (2014) Bulletin 167 and ICOLD European Club (2019).
9. Consequences can be measured as *incremental consequences*—resulting from dam failure or mis-operation above those impacts that would occur under the same conditions (flood, earthquake, or other event) but without failure of the dam—or *total consequences*.
10. New South Wales Dam Safety Committee, Guidance Sheet DSC 3A (2010): "The term hazard category, formerly used as a rating of dam failure consequences, has been replaced for some time by the term consequence category."

    US Federal Emergency Management Agency, Federal Guidelines for Dam Safety, Hazard Potential Classification System for Dams (2004): "Hazard Potential—The possible adverse incremental consequences that result from the release of water or stored contents due to failure of the dam or mis-operation of the dam or appurtenances."

    US Federal Energy Regulatory Commission, Engineering Guidelines, chapter I, "General Requirements": "The hazard potential assigned to a dam is based on consideration of the effects of a failure during both normal and flood flow conditions."

    Ontario Ministry of Natural Resources and Forestry, Technical Bulletin, "Classification and Inflow Design Flood Criteria" (2011): "In Ontario, dams are classified using the Hazard Potential Classification (HPC) system. . . . The hazard potential is determined through an assessment of the greatest incremental losses that could result from an uncontrolled release of the reservoir due to the failure of a dam or its appurtenances."
11. In some regulations, hazard potential for life safety is characterized simply by the population at risk (PAR), that is, all people living in the zone affected

by dam failure. The actual consequences, that is, loss of life, depends on many factors and is usually only a fraction of PAR.

12. It is apparent that the word *risk* here does not consider dam failure probability or likelihood, but rather refers to potential hazard or downstream consequence in case of dam failure. As mentioned in the size-/geometry-based classification, the dam height and reservoir capacity are considered as proxy indicators, which may influence potential dam-break flood wave height, duration, and so forth.
13. The bulletin also noted that "in the case of existing dams, other factors, such as the availability or lack of construction and maintenance records, processed instrumentation and surveillance records, the level of effort expended in previous safety evaluations, and new or planned downstream development, may affect the risk associated with a particular structure. Such other factors, however, cannot be easily quantified and should be considered case by case." It could be, however, challenging to introduce such elements into this system, as explained in risk-based classification of this chapter.
14. In some countries, where dams are privately owned, the regulation is not concerned with the owner's losses and leaves it up to the owner to apply stronger safety requirements.
15. For example, ICOLD (2014) Bulletin 167 and ICOLD European Club (2012).
16. ICOLD (2005) Bulletin 130 noted, "Words as used by the population, are sometimes understood differently to the specific meanings given those words by technical professionals. For example, in English the words 'risk' and 'hazard' have much the same meaning, but in technical usage they have distinctly different meanings. Moreover, the meanings in dams engineering differ from those in risk assessment." The bulletin also noted, "Thus in risk assessment, a body of stored water is a hazard. So is a flood, or an earthquake. But, in dams engineering, there is a strongly ingrained practice of seeing hazard as a measure of consequences of dam failure." Also, the term "risk" is defined as a"measure of the probability and severity of an adverse effect to life, health, property, or the environment. In the general case, risk is estimated by the combined impact of all triplets of scenario, probability of occurrence, and the associated consequence. In the special case, average risk is estimated by the mathematical expectation of the consequences of an adverse event occurring, which is, the product of the probability of occurrence and the consequence, combined over all scenarios." Considering this, in this report, the words *hazard* and *consequence* are used in the same manner as the potential losses in the downstream area of the dam in the event of dam failure or mis-operation, and resulting uncontrolled release of large flood waves. Also, the word *risk* is used as the product of the likelihood or probability of occurrence of an adverse event, such as dam failure or mis-operation, and the resulting consequences or hazard.
17. The Reservoir (Scotland) Act 2011 in chapter 3, section 22, indicates that both potential adverse consequences of uncontrolled release of water from the reservoir and the probability of such release are considered for risk designation, and the regulator may consider (1) the purpose of the reservoir, (2) the materials used for construction, (3) the way in which the reservoir was or is being constructed, and (4) the maintenance of the reservoir for probability assessment. However, the guidance in the Scottish Environment Protection Agency's (SEPA's) reservoir risk designation process (2015) indicates in section 3.2, "The practice of considering the probability of dam failure, and thereafter the uncontrolled release of water, is still in development and is a complex matter. There is not currently an agreed process or methodology that is widely used within the UK reservoir industry to determine the probability of an uncontrolled release of water. . . . Until an agreed approach is established, SEPA will assign an

overall score of one for the probability factor for each reservoir, thereby ensuring that each reservoir will receive the same level of prediction for an uncontrolled release of water, and therefore all dams will be considered equal in terms of their probability of failure. If evidence emerges to support the use of certain criteria to predict probability, SEPA will further develop the reservoir risk designation methodology to take account of these new developments. For criteria to be adopted, it would need to be reliable, complete, and accompanied by readily available data to support its use."

18. A relevant and important design criterion that needs to be considered, depending on dam class, is the emergency drawdown capacity and rate. The report, however, does not cover this subject due to limitations.
19. The FEMA (2015) guidelines also made an important recommendation that the practice of prescribing an IDF using arbitrarily selected composite criteria or percentages of hydrologic events should be discontinued in order to apply consistent, safe hydrologic design standards across the nation. "Studies by the National Weather Service indicate that the occurrence of a storm producing Probable Maximum Precipitation (PMP) is not equally probable nationwide. Thus, using a fraction of the PMF results in selecting a safety design flood which varies widely in exceedance probability. As long as the PMF is used to define a probable upper limit to flooding for use in a safety design, this is not a major concern. But, when selecting a safety design flood less than the PMF, use of a fraction of the PMF produces a variation in exceedance probability that results in an inconsistent national safety standard."
20. This section broadly covers surveillance, monitoring, analyses, and interpretation of data as well as long-term inspections and dam safety review that regulations commonly mandate dam owners to commission via independent engineers.
21. California Governor Jerry Brown signed Assembly Bill no. 1270—Dams and Reservoirs: Inspections and Reporting (Section 6102 of the Water Code)—on February 26, 2018. It seeks to strengthen dam inspections following a near disaster that caused the evacuation of almost 200,000 people living downstream from the Oroville Dam. The measure implements several recommendations from experts who reviewed the crisis at Oroville Dam in 2017.
22. CNRH issued Resolution no. 144 in 2012 to establish guidelines for implementation of the national dam safety policy including the National Information System on Dam Safety connecting ANA and other dam safety regulators, including the preparation of a consolidated dam safety report on an annual basis.
23. The Act also requires the department to propose amendments to its dam safety inspection and reevaluation protocols to incorporate updated best practices, including risk management, in consultation with expert organizations. The amendment is required to provide at a minimum reevaluation of extremely high–hazard and high-hazard dams, including the review of the original design and construction records, monitoring and instrumentation, overall dam performance, and other factors. It also requires inspectors to consult periodically with independent experts.
24. On April 7, 2005, Indira Sagar Dam located on the Narmada River in Madhya Pradesh, India, discharged water without downstream warning and washed away and killed about 150 Hindu pilgrims praying on the riverbank.
25. The guideline (2015) was issued by the New Zealand Society on Large Dams, a technical society under the Institution of Professional Engineers New Zealand.
26. Civil penalties (also known as administrative sanctions or penalties in civil law countries) are dealt with under the civil (as opposed to criminal) jurisdiction of the courts. Civil court judges can order wrongdoers to pay monetary or other penalties but not to serve jail sentences. Criminal "penalties and sanctions" mean that a judge can punish the wrongdoer via a jail sentence also, and the penalty

will appear on the wrongdoer's criminal record. The distinction between civil penalties and fines here is that fines can be issued by the dam safety authority without having to get a court order, so enabling the authority to easily and readily try to discourage the wrongdoing. Monetary penalties associated with fines are of smaller scale (also known as *summary offense* penalties issued via expiation notice in common law systems). If the misconduct continues, then enforcement would move up the pyramid of seeking a civil penalty via court order, which can include larger-scale monetary penalties and license revocation or suspension, as well as criminal penalty if that option exists under the legislative provisions.

27. Arbitration is a method of settling a dispute by submitting a disagreement to a person (an arbitrator) or a group of individuals (an arbitration panel) for decision instead of going to court. Arbitration is usually voluntary (not mandatory) in administrative law dispute-resolution provisions, and it can be binding if the parties are required to comply with the decision of the arbitrator or nonbinding if there is no such obligation. Mediation is a method of dispute resolution in which a neutral third party directs the settlement negotiations, but the parties themselves make or agree upon the decision, not the mediator (Richardson 1996,177–80; see also Rubino-Sammartano 2014).

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6

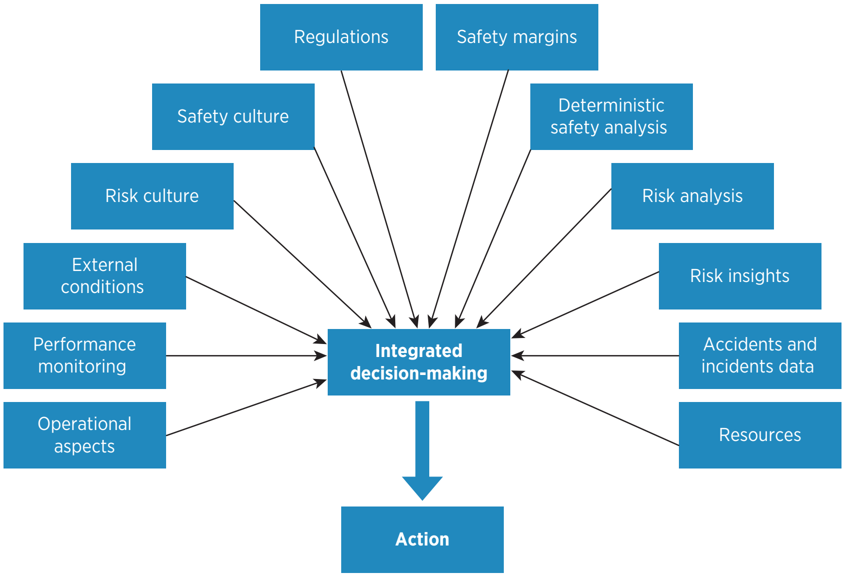
Risk-Informed Decision-Making

CONTEXT AND RATIONALE

Risk-informed approaches are increasingly being used to inform dam safety assurance. This reflects increasing recognition that there are a number of dam safety incidents, caused by both structural and nonstructural elements, that are not well captured by a more traditional, standards-based approach. There is also a greater societal demand for higher levels of safety, full transparency, and more accountability relating to the use of public funds and private investments, as well as a need to prioritize remedial action to reduce risks to either acceptable or tolerable levels. A risk-informed approach is also reflected in the Environmental and Social Framework that was approved by the World Bank's Board of Executive Directors and became effective on October 1, 2018.[1]

Risk-informed dam safety assurance uses the outcomes of a risk assessment as one of the important factors to support decision-making (figure 6.1). ICOLD (2017a) Bulletin 154 on the operational phase of the dam life cycle indicates that approaches to dam safety management should combine insights from deterministic and probabilistic safety analyses with other requirements (such as legal, regulatory, and business). The degrees to which individual components of the decision-making process are included may vary from organization to organization. However, it is important that the dam safety management system clearly establish the structure and parameters of the decision-making model.

FIGURE 6.1 Integrated (risk-informed) decision-making



Source: ICOLD 2017a. Used with permission; further permission required for reuse.

Such approaches enable dam owners, operators, and those responsible for oversight mechanisms, along with other stakeholders, to better understand the system and document information regarding the contributing risk factors. Different methods for carrying out risk analyses are available, ranging from qualitative to fully quantitative. The appropriate method largely depends on the characterization of dam failure probability and the severity of adverse impacts, which can be done using simple indexing or ranking schemes to more elaborate mathematical probabilistic forms.

STANDARDS-BASED APPROACH

Standards-based or deterministic approaches are defined by ICOLD (2005) as "the traditional approach to dams engineering, in which risks are controlled by following established conservative rules as to design events and loads, structural capacity, safety coefficients and defensive design measures." The conventional standards-based approach begins with the classification of dams and ensures that the dam system conforms to a set of prescribed design standards, criteria, and requirements for designing dams and their associated structures to withstand external forces under extreme loading conditions based on the determined hazard level. The dam classification system is designed to require more stringent standards for dams in higher hazard categories.

While the standards-based approach was initially developed for the design of new dams, it has been used traditionally to assess the safety of existing dams. In following the standards-based approach, dam engineers typically try to include an allowance for the uncertainty affecting the assessment process by applying conservative assumptions. The approach emphasizes performance integrity in design, and its use has resulted in a history of dam designs that have an excellent overall record of performance. However, the standards-based approach is becoming increasingly inadequate in providing a basis for deciding how to allocate limited resources for dam operation, repair, and improvement, especially given the increasing demands for full transparency and accountability, uncertainties around climate change, and aging portfolios.

Since numerous aspects of the safety of the dam system cannot be included explicitly in the standards-based safety analysis and all inputs are subject to varying levels of uncertainty, a significantly higher safety margin is usually built into the standards. For example, the standards-based approach considers extremely rare events and loads, such as "probable maximum flood" and "maximum credible earthquake" along with conservative safety margins and "factors of safety." Conservative design practices can result in excessively high costs paid for by public and private owners that result in only modest improvements in dam safety. This may result in the suboptimal allocation of limited resources available for safety improvements across a portfolio of dams.

At the same time, the standards-based approach does not necessarily address all potential risks, all possible chains of events or complex interactions and feedback present in sociotechnical systems created by the presence of dams in the river systems, nor those that could lead to dam failure or the release of large amounts of water in an uncontrolled manner. For example, the standards-based approach could not effectively address a failure of electro-mechanical control systems, which could cause a severe reduction in flow discharge capacity, or the mis-operation of spillway gates due to malfunctions in monitoring instruments, or human errors. A larger number of accidents and casualties have been reported over the past few decades due to these kinds of operational errors compared to structural dam failure.[2]

RISK-INFORMED APPROACHES

Societal expectations are constantly evolving, and there is increasing recognition that safety is not an absolute condition, but rather a tolerated situation with varying levels of residual risk always present. The benefits associated with higher levels of safety come at a cost, and increasing societal demands for higher levels of transparency in decision-making in relation to dam safety management have resulted in the need for the various trade-offs to be examined explicitly in the public domain. Following this shift there have been growing requirements for risks to be identified, assessed, kept under review, and properly controlled. That, in turn, has resulted in the application of risk assessment over a very wide spectrum of public and private activities that have the potential to affect the welfare and interests of the public.

Risk-informed approaches are generally more effective in understanding the process of potential dam failure and defining priorities for remedial works to reduce those risks. As such, they have become increasingly popular (ICOLD 2005, 2017a, 2017b). Specifically, risk-informed approaches do the following:

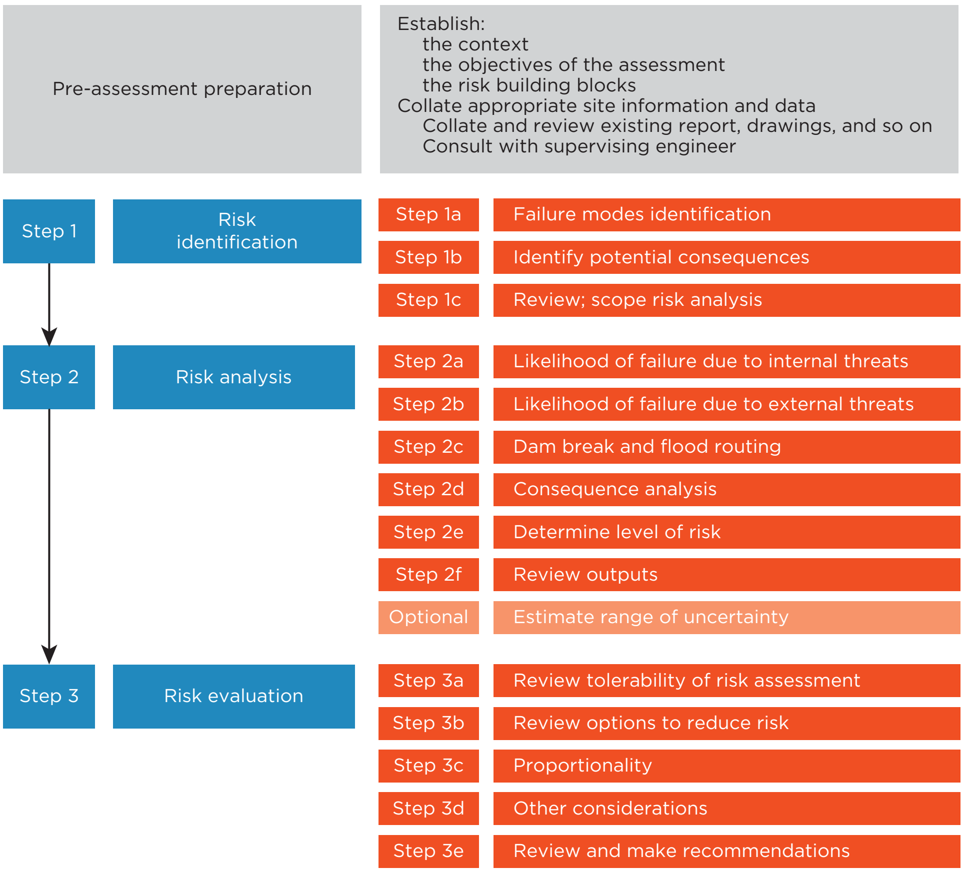
- Enable better understanding of factors contributing to risks
- Highlight gaps in analyses and studies
- Provide a better evaluation of alternative risk-reduction measures
- Result in more informed decision-making processes and more efficient allocation of resources

Risk-informed approaches provide a systematic and structured approach, explicitly addressing the various types of uncertainties and providing deeper insights into all aspects of dam safety and their associated structures, including overall system performance, reliability, and interactions among system components. Risk-informed approaches allow consideration across a broad range of hazards and failure-initiating events as well as the consequences of dam failure. A risk-based approach is better than a traditional standards-based approach at capturing and analyzing risk-related factors, such as flow control, monitoring equipment, and human error in a comprehensive way that includes operational issues.[3] Risk assessment is an approach capable of dealing with complex problems effectively by explicitly taking them into account and expressing them in probabilistic terms. It also provides an improved understanding of the unique way in which different types of structural and nonstructural measures can reduce the risk of dam failure, thereby building greater confidence in the effectiveness of risk-reduction measures.

TYPICAL STEPS IN A RISK-INFORMED APPROACH

Risk-informed approaches to dam safety management typically include the following steps: (1) risk identification, (2) risk analysis, and (3) risk evaluation followed by (4) decision-making and (5) execution of prioritized remedial measures. The structured approach designed for the management of reservoir safety in the United Kingdom (figure 6.2) illustrates this process, including steps requiring detailed risk analyses and evaluation, while others are optional and may be required only for high-risk dams. A similar process for risk-informed decision-making is outlined in *ISO 31000: Risk Management—Principles and Guidelines* (ISO 2009). Guidelines in the United States—such as those by the US Federal Emergency Management Agency (FEMA 2015), US Army Corps of Engineers (USACE), US Bureau of Reclamation (USBR), and US Federal Energy Regulatory Commission (FERC)—also provide a similar framework and outline required steps for dam safety risk management, including identification of failure modes, risk estimation and analysis, risk

FIGURE 6.2 Reservoir safety management in the United Kingdom



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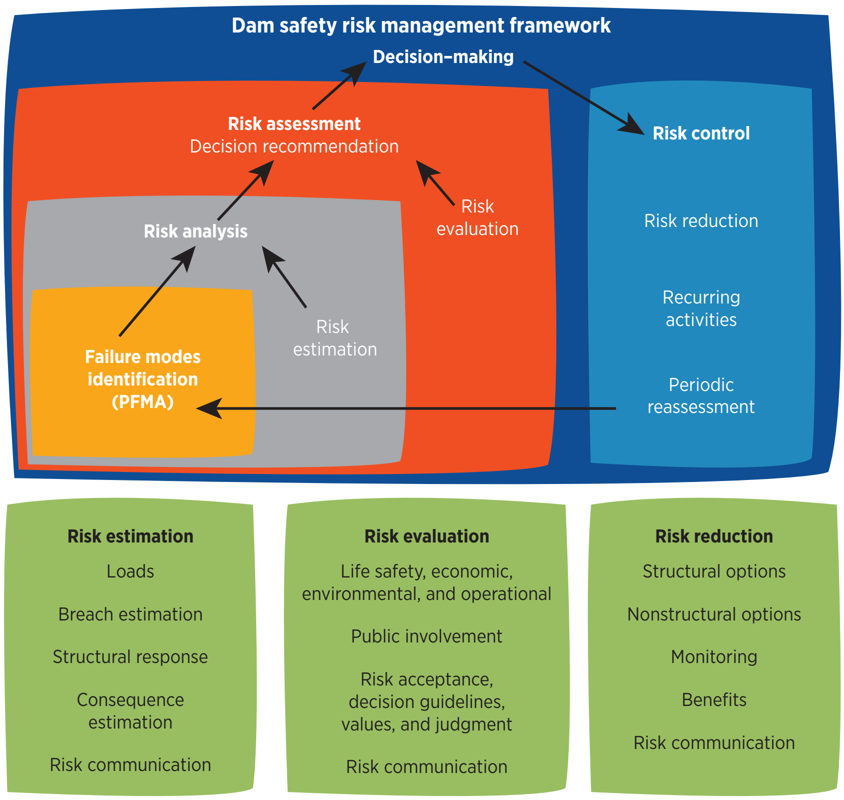
evaluation and assessment, along with decision-making for risk control and the prioritization of risk-reduction measures for a portfolio of dams (figure 6.3).

TYPOLOGY OF RISK ANALYSIS AND ASSESSMENT TECHNIQUES

There are a number of methods available and currently used for dam safety risk assessments. ICOLD (2005, 2017a) Bulletins 130 and 154 provide details of different methods with varying degrees of rigor, providing choices suitable for different contexts. The main approaches range from simple qualitative ranking approaches and semiquantitative risk index approaches to elaborate quantitative approaches involving probability estimation of all identified potential failure modes and scenarios in addition to detailed estimations of failure impacts. (See box 6.1 for examples from the United Kingdom.) The failure modes and effects analysis (FMEA) or potential

FIGURE 6.3 Relationship among risk analysis, risk assessment, and risk management



Source: FEMA 2015.
Note: PFMA = potential failure modes analysis.

failure modes analysis (PFMA) are the most frequently used qualitative analytical methods, applied with varying levels of sophistication as appropriate.

QUALITATIVE AND SEMIQUANTITATIVE RISK ASSESSMENT

Qualitative and semiquantitative risk assessments consider dam safety risks more explicitly than the standards-based approach. Although these kind of assessments do not intend to fully characterize the risk in a probabilistic manner, they aim to identify the scenarios that are considered to pose significant, credible risks for the dam and associated structures. The results of this kind of risk-based approach allow for the design of specific remedies and defense measures to reduce identified risks. Some of the commonly applied qualitative and semiquantitative risk assessment methods are introduced next.

BOX 6.1

THE UNITED KINGDOM'S APPROACH TO RISK-INFORMED DAM SAFETY ASSURANCE

The United Kingdom recommends that dam owners, along with supervising and inspecting engineers, undertake risk assessments and implement risk-informed approaches to dam safety management. The Flood and Water Management Act of 2010, which amended the Reservoirs Act of 1975, defines *risk* in respect to an occurrence assessed and expressed as a combination of the probability of the occurrence with its potential consequences.

The 2010 act differentiates high-risk dams based on consequence assessment. Those dams not designated as high risk are not subject to full-fledged dam safety requirements. The Environment Agency, as the dam safety regulator, may designate a dam reservoir as high risk if (1) the agency thinks that, in the event of an uncontrolled release of water from the reservoir, human life could be endangered, and (2) the reservoir does not satisfy the conditions specified in regulations made by the minister. The conditions specified in regulations may include conditions related to the reservoir purpose, construction materials, construction method, maintenance condition, and so forth.

The *Guide to Risk Assessment for Reservoir Safety Management* was published in 2013 by the Environment Agency under the Flood and Water Management Act of 2010. The guide provides practical advice and guidance on the use and application of risk analysis, risk assessment, and risk management for dam owners along with supervising and inspecting engineers who undertake risk-informed dam safety management. The guide lays out a three-tier approach to risk assessments of reservoirs (figure B6.1.1). Tier 1 is a qualitative assessment that requires the potential failure modes to be identified and assessed, while tier 2 and tier 3 are quantitative assessments of increasing complexity.

The shift toward risk-informed approaches came about due to the continued occurrence of serious incidents despite an excellent record of public safety since the introduction of the Reservoirs Act (1930 and 1975). One such significant event was the spillway failure of Ulley Dam near Rotherham in South Yorkshire in 2007, which resulted in precautionary measures in which 1,000 people were evacuated and the M1 Motorway was closed for two days. In an official review of this incident, Sir Michael Pitt identified action that was needed in the following three areas: (1) development of a better understanding of the defective behavior that caused the incident, (2) improvement of emergency preparedness, and (3) enhancement of a reservoir surveillance culture. Ultimately, Pitt (2008) recommended that legislative changes be made to address these three areas as well as follow more of a risk- and hazard-based approach to dam safety as proposed by the Environment Agency.

(continued)

BOX 6.1 *(continued)*

FIGURE B6.1.1 Selecting the initial tier of risk assessment

When choosing an appropriate level of risk analysis consider that:

- All levels of analysis build from an initial failure modes identification process.
- An initial entry level for risk analysis can be made via any tier, however, the simplest, most rapid assessment method is provided by tier 1.
- Tier 1 provides a qualitative assessment of risk. Tier 2 offers the simplest form of quantitative assessment.
- Tier 3 provides a framework for more complex risk assessment, including more detailed analysis of processes and interdependencies. Tier 3 would be used where risks are uncertain and potentially high, requiring a more detailed assessment.
- For each of the tiers the effort required for analysis is intended to be proportionate to the risk and/or user needs. Hence, tier 1 provides the minimum effort entry level for analysis (qualitative), tier 2 the minimum effort entry level for quantitative assessment, and tier 3 more complex methods for situations with the potential for higher risks.

User needs	Tier	Outputs
• Rapid, simple, qualitative assessment • An initial assessment to understand potential risks • Provides support for a Section 10 assessment	**Tier 1 Qualitative**	• Failure mode identification • Estimation of likelihood and consequence, represented on an impact matrix (that is, risk described as high, medium, low, and so on)
• Quantitative risk assessment	**Tier 2 Simplified quantitative**	• Failure mode identification • Provides numerical estimate of failure probability and risk
• Quantitative risk assessment • Detailed consideration of specific processes and risks, including interdependencies	**Tier 3 Quantitative**	• Failure mode identification • Provides a more refined numerical estimate of failure probability and risk

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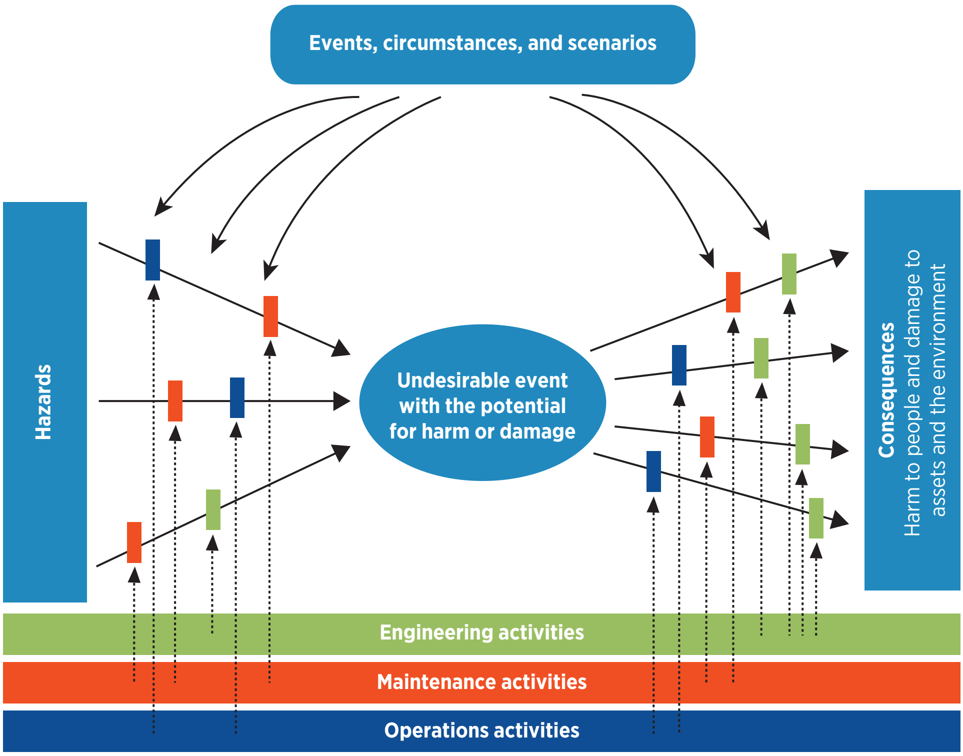
Bow-Tie Method

The so-called bow-tie method of risk assessment, developed by the oil and gas company Royal Dutch Shell in the 1990s as a way to evaluate risks in its operations, visually represents the different stages of risk management with a diagram similar to the shape of a bow-tie (figure 6.4). This method is generally based on a preliminary risk assessment that identifies hazards and describes the circumstances, causes, and barriers leading to an *undesired central event* (UCE). The method then analyzes risk management measures that would mitigate the consequences of such an event.

The diagram places the UCE at the center of the bow-tie. On the left are identified initiating events, and protective measures are placed between the UCE and the identified hazards in the form of a fault tree. To the right

FIGURE 6.4 Bow-tie risk management model, illustrating the components of a bow-tie diagram



Source: ICOLD 2017a. Used with permission; further permission required for reuse.
Note: The dashed vertical arrows have been modified from the original to extend to the relevant colored horizontal bar at the base of the figure.

of the UCE are the potential consequences of the UCE and, in between the UCE and these consequences are the measures that can mitigate them. This is among the primary methods used for risk assessment and management in France and is formally described in the guideline issued by the Ministry of Ecology, Sustainable Development and Energy in its capacity as the regulatory entity for dam safety.

Failure Modes and Effects Analysis and Failure Modes, Effects, and Criticality Analysis

FMEA and failure modes, effects, and criticality analysis (FMECA) are inductive methods for identifying and/or assessing the ways in which a system can fail to function. Both approaches consider each component of a system and analyze its failure modes, their causes, and their effects. The probability and severity of each failure mode is also assessed, which provides a characterization of its criticality in a qualitative manner using ranked scores. This type of approach to risk assessment has been used in Canada and Spain, while FMECA has also been used for risk management of reservoirs in the United Kingdom guided by the Construction Industry Research and Information Association (CIRIA 2000).

Potential Failure Modes Analysis

PFMA is used to systematically identify, describe, and evaluate different ways a dam and its associated structures could fail under all postulated loading conditions. PFMA is a valuable tool in directing dam safety personnel where to focus observations and inspections, and where to strategically perform an investigation or install instruments to monitor dam performance. It can also help to identify and prioritize operation and maintenance deficiencies, identify operational processes for improvement, and focus training needs. PFMAs can also benefit dam owners and regulators by providing a better understanding and appreciation of potential structural and operational weaknesses and operating procedures. PFMA requires a comprehensive review of design documents and operational records before careful assessment of all potential failure scenarios. Success of the PFMA process requires participation of owners, designers, and operators, facilitated by qualified experts. It should be noted that while PFMA can serve as the first step of risk analysis, more advanced risk analysis methods may be needed for complex, high-hazard dams.

PFMA was introduced by the FERC in 2002 as part of the five-yearly inspections for nonfederal hydropower dams in the United States.[4] PFMA requires dam owners to perform a qualitative risk assessment to identify potential failure modes and to assess required remedial works, monitoring instrumentation, and other elements. It has established a basis for the assessment of dam safety performance and provides an opportunity for comprehensive dam safety enhancements that might be overlooked by a traditional standards-based approach. Chapter 14 of the FERC guidelines provides a detailed description of the PFMA process, including key goals and typical outcomes, review of background information, site inspection, and facilitated workshops involving brainstorming sessions to identify and evaluate potential failure modes, consequences, and mitigation measures.

PFMA typically provides a good entry point to start building risk capability, particularly in those countries where risk is not well understood or assessing it is not common practice. The World Bank has assisted a number of countries in applying PFMA during safety reviews of major existing dams, including Nurek Dam in Tajikistan and Jatiluhur Dam in Indonesia. Such analysis is useful in prioritizing additional investigations and remedial works in coordination with key stakeholders, including owners, operators, designers, and entities responsible for oversight. The World Bank also assisted in organizing PFMA training sessions for four riparian countries of the Blue Nile River in collaboration with the Eastern Nile Technical Regional Office under the Nile Basin Initiative.

While PFMA can assist in systematically identifying, describing, and evaluating the different ways in which a dam and its associated structures could fail, it is important to ensure that all potential scenarios are properly identified. For example, the independent forensic team report (France et al. 2018) on the February 2017 Oroville Dam spillway incident in the US state of California concluded that the PFMA process prior to the incident was focused on large-scale failure and uncontrolled release of reservoir water but gave limited consideration to partial or operational failure modes, which can still cause major consequences.[5] These were evidenced by the spillway incident that resulted in state-government-ordered evacuation of about 188,000 people as well as an estimated US$1.1 billion in repairs, rehabilitation, and emergency works. Although the 2014 PFMA of the Oroville Dam identified three potential failure modes related to spillway failure, it fell short in assessing the risks. The forensic report concluded this miscalculation was due to inadequate information or a misunderstanding of geological conditions affecting the dam's spillway chute foundation and unlined auxiliary spillway as well as other signs indicating hydraulic jacking of the concrete slab and poor durability of previous repair works.

The case of the Oroville Dam highlights the need for a more thorough review of probable failure modes and enhancement of the methodology in the guidance. The forensic report concluded that "shortcomings of the current . . . (PFMA) processes in dealing with complex systems must be recognized and addressed. A critical review of these processes in dam safety practice is warranted, comparing their strengths and weaknesses with risk assessment processes used in other industries worldwide and by other federal agencies" (France et al. 2018, S-3).

Risk Index

The risk index approach is a useful way to characterize dam safety risks in a systematic but relatively simple way. Users can evaluate and prioritize safety issues for individual dams and portfolios of dams by assigning points according to a defined process or series of tables for specific aspects of the dam structure. It does not relate the index results to an actual risk or failure probability, making a risk indexing approach to dam safety management a process that is typically easy to implement by individuals with limited understanding of the potential failure modes or risks associated with the dam structure.

Risk indexes or similar tools have been developed and applied in Australia, Canada, the Czech Republic, the Republic of Korea, New Zealand, Poland, South Africa, Sweden, the United Kingdom, and the United States, among others. Similar risk indexing approaches have been used for the risk-based dam classification systems in the Canadian province of Quebec as well as in Brazil, where risk is defined as the product of failure probability represented by the dam's vulnerability parameters (or existing conditions) and consequence parameters. Lacking specific, risk-informed approaches in those jurisdictions, such risk category indices for dam classification typically serve the purpose of prioritizing required remedial works and other safety requirements. The World Bank has supported a number of clients in the application of risk indexing methods, including national-level dam safety projects in Armenia, India, Indonesia, Sri Lanka, and Vietnam. Risk indexing methods have proven to be useful in assessing the safety level before and after project interventions and to prioritize both structural and nonstructural remedial measures in a systematic manner.

It should be noted, however, that risk indexing is only a basic tool for preliminary-level risk analysis that is used only across a portfolio of dams. It may need to be supplemented with more advanced methods depending on the type and hazard of the dams. Since risk indexing approaches largely rely on visual inspection of the condition of dams, some critical failure modes could be missed or underestimated.

QUANTITATIVE RISK ASSESSMENTS

Quantitative risk assessment intends to provide a complete description of all risks and uncertainties by estimating the probability of dam failure and the resulting failure impacts. Both the probability of each failure scenario and the corresponding consequences need to be assessed. This kind of probabilistic evaluation of possible failure scenarios would assist in the identification of main dam failure scenarios driving the total risk. It also aids in the detailed assessment and determination of the urgency of required remedial works.

Determining the probability of failure is a complex task. Reliable statistical data or credible probabilistic models are often not available for assessing probability of poorly understood failure modes, such as piping and other forms of internal erosion. In many low-income countries, there is limited hydrometeorological, geological, and seismic data available, and the reliability of the data sets is often poor. In many cases basic design reports and construction quality information, such as information about embankment materials and foundation treatments, are missing. Furthermore, there are insufficient statistical data and methodologies for analyzing human behavior and human error as well as the effects of nonstructural safety improvement measures.

Given the significant data requirements for determining the probability of a dam failure, it is not surprising that many jurisdictions do not generally recommend quantitative risk assessments. When jurisdictions do provide for quantitative assessments, they are typically applied in special cases and with caution. Such an approach is observed, for example, in France, the United Kingdom, and BC Hydro in Canada, among others. Scotland had intended to use quantitative probability assessment of risk for dam classification but stopped short, stating that there were not sufficient data for conducting such analyses and that a common methodology had not been well established.

However, in higher-income countries the applications of quantitative risk analysis have become more frequent for complicated cases, often with more or less standardized use of event tree analysis as the calculation model of choice. There are well-founded reasons for this choice. First, event trees are relatively easy to use and are conceptually clear. Second, there are excellent off-the-shelf software applications for performing event tree calculations. Third, even junior civil or mechanical engineers have little difficulty understanding the concept of an event tree or of how the probabilities in the tree go together. Fourth, it is often argued the dams and their environment are open systems, and therefore the unstructured nature of an event tree suits the problem. In other industries, the dominant use of the event trees is much less common.

The emerging philosophy across many industries for assessing the safety of constructed facilities is based on an underlying principle of *system safety.* While the concept of a *dam system* has been adopted as a general principle in dam safety risk assessment, it has not been extended to all elements of a broader system comprising all dams and reservoirs (interrelated through physical, operational, and human agency–based links) within the catchment under consideration. Thus, many important dynamic interactions and feedback channels are either not accounted for or are only partially included in the analysis during the development of loading scenarios.

The growing recognition of the importance of treating dams as systems is now challenging the general perception that chain-of-event methods are sufficient for risk analysis of dams, as the events that are ending as failures may be complex combinations of many factors. These may include component failures, inadequate maintenance, problems arising from instrumentation and control, human actions, design errors, errors in the operating plans and procedures, and errors in implementing the operating decisions.

Thus, the chain-of-events models that work well for simple systems are not necessarily appropriate for complex systems. Chain-of-events models are based on the assumption that the behavior of analyzed systems can be explained by a series of linearly related events over time. As a result, they simplify the process leading to failure and may exclude important systemic factors and indirect and nonlinear interrelations between individual events (Leveson 2011).

Emerging methods for analyzing dam safety risks that follow a systems approach are based on stochastic simulations of the dam's behavior (Hartford et al. 2017). They offer an effective way of calculating probability of failure in dam safety risk analysis recognizing the following:

- The probability of dam failure can be expressed as a product of the marginal probability of a demand on the system, and the conditional probability of adverse system response given that demand.
- The demand on the dam system is created dynamically, responding to a variety of factors, which vary with time and can be characterized as stochastic processes.

Quantitative risk assessments tend to be complex, requiring detailed dam monitoring and surveillance data along with supporting analyses of various associated uncertainties with estimated probabilistic values. These exercises are time-consuming and require substantial financial and human resources. Even when such data and resources are available, there could still be significant variation in results due to challenges in estimating probabilities for various possible events. With a lack of data, estimates of probability tend to be by collective expert judgment and therefore depend on the group involved. Notwithstanding these challenges, the risk-informed approach, including quantitative risk assessment, has been used by a large number of dam owners in a range of different countries for more than two decades and has proven to be very useful. It is critical to ensure that the risk estimation procedure is logical, based on accepted scientific knowledge, and, along with a peer review process, transparent.

RISK TOLERABILITY CRITERIA

One of the greatest challenges in performing quantitative risk assessment and using the results to inform decision-making in relation to dam safety is in defining what constitutes a "tolerable" or "acceptable" level of risk. While there has been considerable research into this subject, the definition of what constitutes an acceptable risk during the construction and operation of dams is complex and varies from country to country. For many countries, defining acceptable or tolerable levels of risk is politically and culturally sensitive. It should also be noted that all developed and presently applied risk tolerability criteria are for life-safety risks only (see box 6.2). There are no risk tolerability criteria for environmental, economic, or cultural risks.

The definition of tolerable risk used by ICOLD (2005) is based on the universal framework for life-safety risk tolerability proposed in 2001 by the United Kingdom's Health and Safety Executive (HSE 2001). ICOLD defines tolerable risk according to four principles: "a risk within a range that society can live with (1) so as to secure certain net benefits. It is (2) a range of risk that we do not regard as negligible or as something we might ignore, but rather as something we need to (3) keep under review and (4) reduce it still further if and as we can." The fourth principle applies the concept of "As Low As Reasonably Practicable" (ALARP),[6] which obligates dam owners to reduce risks to the point where additional risk reduction would cost "disproportionately" more than the risk reduction benefit achieved (figure 6.5).

This framework for risk management is both qualitative and quantitative in nature, and it has been adopted by a wide range of hazardous industries in different countries. The International Atomic Energy Agency (IAEA)[7] advises use of risk management approaches for nuclear power plants, while the European Union has also incorporated the concept in regulating the industrial risk of hazardous materials, maritime safety, among other industries.[8] It has also been adapted for regulation of dam safety in a range of

BOX 6.2

LIFE-SAFETY EVALUATION

Three Guiding Principles for the Evaluation of Life Safety

A review of international practices across hazardous industries (such as petrochemical and nuclear power) reveals three guiding principles for evaluation of life safety.

Individual risks: The increment of risk imposed on any person by a facility, such as a dam, should not be more than a specified value, usually a small fraction of the average background risk that the population lives with on a daily basis. This requirement arises from considerations of equity.

Societal risk: The estimated probability of an event that would be expected to result in loss of *N* or more lives should not exceed the value, which is a function of *N*, this value declining as *N* increases. This requirement arises in order to account for the impact on society of disasters involving multiple fatalities and is based in the need for equity in accounting for societal concerns.

ALARP principle: Risks should be As Low As Reasonably Practicable. This requirement arises from the legal duty (in common law countries) 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 in risk achieved (HSE 2001). This principle informs the balance between equity and efficiency, with the balance deliberately skewed in favor of equity.

Source: ANCOLD 2003.

Equity and Efficiency: Two Central Elements of Risk Assessment and Tolerability

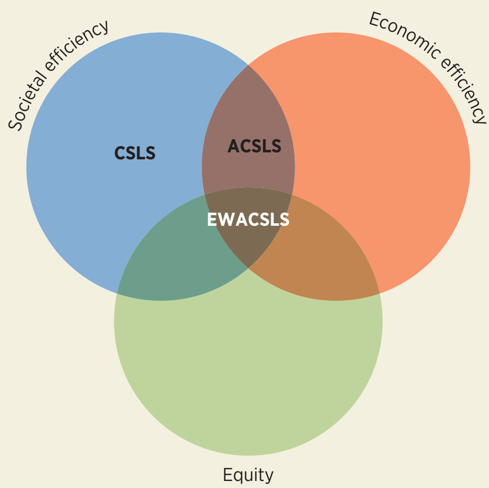
Risk management is usually informed by two basic principles: efficiency and equity. Whereas equity is related to providing a certain level of protection to everybody, efficiency is related to reducing risks at the lowest costs. In many cases, these principles can conflict, producing different prioritizations of risk-reduction measures, and many existing risk indicators, such as *cost per statistical life saved* (CSLS), *adjusted CSLS* (ACSLS), *cost-benefit analysis* (CBA), and so forth are either based on the equity or efficiency principles but cannot accommodate both at the same time.

CSLS compares costs with societal risk reduction, so when considering several measures, the measure with a minimal value of this indicator will be the one that employs the resources in a most efficient way. Therefore, this indicator is based on the principle of societal efficiency. ACSLS (ANCOLD 2003; Bowles 2001) has the same structure as CSLS but introduces an adjustment of the annualized cost to consider the economic risk reduction generated by the implementation of the measures. As in the previous case, it is based

(continued)

BOX 6.2 *(continued)*

FIGURE B6.2.1 EWACSLS in a Venn diagram that shows the relationship between risk-reduction indicators and efficiency and equity principles



Source: Serrano-Lombillo et al. 2016. Used with permission; further permission required for reuse.
Note: ACSLS = adjusted cost per statistical life saved; CSLS = cost per statistical life saved; EWACSLS = equity weighted adjusted cost per statistical life saved.

on the efficiency principle, although for adjusted costs, so it considers both societal and economic efficiency. CBA arises from the comparison of the costs of a measure with the economic risk-reduction benefits resulting from its implementation. It follows the economic efficiency principle.

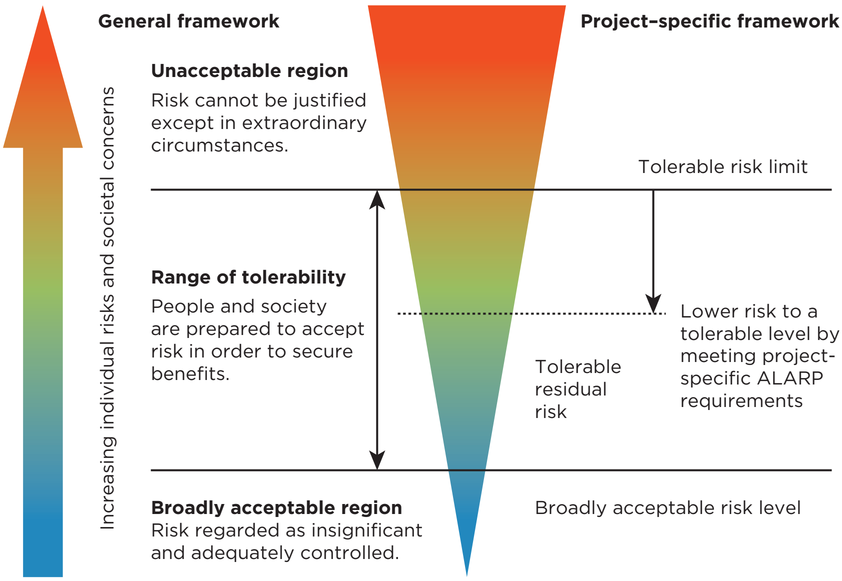
The *equity weighted adjusted cost per statistical life saved* (EWACSLS) indicator enables one to obtain a prioritized sequence that balances efficiency and equity while offering good results for both principles. (figure B6.2.1). In particular, the indicator has been formulated in a flexible way, such that changing one parameter (*n*) would allow assigning a higher weight to either efficiency or equity in the prioritization process. The equity principle modifies the value of the indicator in the cases where individual risk is above the *individual risk limit* (IRL) or tolerability thresholds. If the individual risk is lower than the IRL, the prevailing principle is efficiency in the same manner to the ACSLS.

The utility of this indicator has been proved in a real case study of 27 dams with 93 potential risk-reduction measures to be prioritized in the Duero Basin of Spain. The sequence obtained with EWACSLS has been compared with sequences obtained with other existing risk-reduction indicators, and showed good balanced results compared to other indicators.

Source: Serrano-Lombillo et al. 2016.

different, predominantly common law countries, such as Australia and the United States. Indeed, the term *risk-informed decision-making* was introduced into dam safety management in the early 2000s following the experience of the nuclear industry. While first to acknowledge the potential of risk analysis for the safety assessment of hazardous installations, the nuclear industry does not seem to have officially adopted a risk-based approach to decision-making (Zielinski, Baecher, and Hartford 2009).

FIGURE 6.5 Generalized and project-specific tolerability of risk framework



Source: FERC 2016, adapted from HSE 2001.
Note: ALARP = As Low As Reasonably Practicable.

International guidance on the use of risk assessment in nuclear safety at the time suggested that the reliance on a deterministic approach to analysis of nuclear safety was unlikely to adequately demonstrate that the high levels of safety can be achieved in a consistent way. It also recognized that both deterministic and risk-based (probabilistic) approaches are systematic approaches aiming at ensuring that the risks from the installation are adequately controlled, and they have different strengths and limitations. Therefore, the IAEA (2005) recommended an integrated or risk-informed decision-making process as a structured approach in which all available insights and requirements related to safety or regulatory issues were considered in reaching a decision. The process should include all mandatory requirements and the insights from both deterministic and risk-based analysis.

Tolerability limit criteria for individual life-safety risk are observed among some of the case study countries and jurisdictions, such as the states of New South Wales and Victoria in Australia. These criteria have been established using annual probability thresholds and an F-N curve, a statistical tool used to calculate the societal risk of a dam, where F is the cumulative probability[9] of N (the number) or more fatalities per year. These provisions are based on the ANCOLD (2003) risk guidelines, which define an individual tolerable risk limit of 1 in 10,000 per year for existing dams and a more stringent limit of 1 in 100,000 per year for new dams or major augmentations of existing dams. Risks up to one order of magnitude higher may be considered, but only after careful consideration of the particular circumstances.

The ANCOLD guidelines also require that risks be further reduced below tolerable risk limits to meet ALARP considerations. In following the ANCOLD guidelines, the state of Queensland has provided very specific guidance on life-safety tolerable risk using a cost-benefit assessment *and cost per statistical life saved* (CSLS)[10] methodologies along with their threshold values in the guidelines. In the case of Queensland, this approach is limited to assessing the risks posed by a dam's flood discharge capacity but provides detailed guidance on the time schedule within which owners are required to undertake remedial measures, depending on the deficit level of the spillway capacity compared to an acceptable one.

In the United States, USACE,[11] USBR, and FEMA have all published guidelines on risk-informed dam safety management. These apply to the self-regulation of dams owned by the federal government and include life-safety tolerable risk criteria, individual risk limits, and societal tolerability limits with F-N diagrams and the ALARP principle. However, USBR preferred an "increasing" and "diminishing" justification expression rather than ALARP. The USACE interpretation of ALARP requirements also excludes the disproportionality principle.

FERC guidelines for risk-informed decision-making that govern nonfederal hydropower dams in the United States include risk analysis, assessment, and evaluation, used together with the standards-based approach, as part of five-year dam safety review by independent experts. FERC has been encouraging hydropower licensees to adopt risk-informed decision-making approaches to dam safety management and allowing dam owners to lower discharge capacities for spillways according to hazard-based classification, based on the results of a risk assessment. However, it is still challenging to confirm how the proposed remedial works have met ALARP requirements without specific calculations.

Safety criteria are supposed to establish the extent to which people, property, and the environment should be protected. In civil law jurisdictions, there is scope for establishing numerical risk acceptance criteria where decisions on dam safety are based on predetermined, objective criteria and quantified risk of dam failure and/or mis-operation. While the concept of tolerable risk is not applicable within civil law systems (Bowles 2005), France has established regulations and guidelines that mandate owners to assess risk in a quantitative manner for high-hazard, class A and class B dams (see box 6.3). However, the dam risk assessment guidelines issued by the French Ministry of Ecology (2012) do not indicate the criteria for acceptance. Rather, acceptance is decided case by case, based on the owner's dam safety assessment and risk management plan. The ministry guidelines refer to ALARP as one of the key elements for examining the acceptable level but without mandating specific methodologies or criteria. The ministry and its advisory group include a cautionary note about quantitative risk analysis involving probability calculation of various failure modes, which suggests some difficulty in defining objective numerical limits with a high level of confidence. While still at an initial stage of its application, the 2015 Mexican dam safety regulations similarly refer to

BOX 6.3

RISK-INFORMED APPROACH TO DAM SAFETY IN FRANCE

Key Features of Dam Safety Regulations in 2007 and Updated in 2015

- Three categories of dams: A, B, and C, per geometric criteria
- Requirements differ according to dam category:
  - For all dams: Technical documentation, surveillance and monitoring, operational procedures, incident reporting, and so forth
  - For A and B dams: Risk analysis (RA) every 10 (A) or 15 (B) years
- Regulatory bodies at regional level with national expertise support
- Since 2007: 470 RAs performed for all A and B dams
- Owner profiles are very different, ranging from big utilities with up to 300 dams in their portfolio to single-dam owner

Purpose for Dam Safety RA in France

- Dam safety issues identification
- Dam safety decisions: Owners must propose actions and schedule to fix the issues according to risk
- Portfolio management (including prioritization)

Dam Safety RA Mandated Approach in France

- Dam safety RA methodology is in line with industrial assets risk management: French hazardous assets regulation and Seveso III EU Directive (Directive 2012/18/EU of the European Parliament and of the Council of July 4, 2012, on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC).
- Comprehensive diagnosis performed before RA: Detailed visual inspection and condition assessment of the dam and all its safety-related components
- Template layout of a safety RA defined in a decree
- Guidance document issued by the regulator

Dam Safety RA Methodology in France

- *Functional analysis*: Of the dam and its safety equipment (civil, hydraulic, mechanical, control system, transmission, organization, and so forth)
- *Failure mode analysis*: Failure modes identification—dam body failure (sunny day, large floods), gate failure (unwanted gate opening, and so forth), identification of the *undesired central event* (UCE) in a bow-tie diagram, and consequence assessment (severity level and population at risk for different kinematic zones)

(continued)

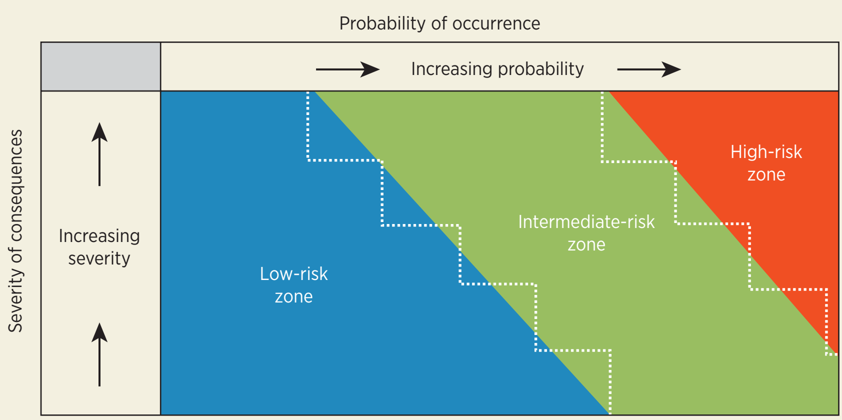
BOX 6.3 *(continued)*

- *Failure scenarios modeling and reliability assessment:*
  - Bow-tie models coupled with fault tree and event tree
  - Identification of all external potential threats and internal potential weakness
  - Detailed assessment of all UCE (bow-tie) from *initiating events* (IEs) to *dangerous phenomena*
  - Probability assessment of occurrence (reliable data and/or frequency classes to quantify IEs)

Assessment of Risk-Reduction Measures and Acceptability

- Criticality matrix (figure B6.3.1): Probability of occurrences (x-axis) versus severity of consequences (y-axis); orange (high-risk), green (intermediate-risk), and blue (low-risk) zones
- Each owner can propose mitigation measures as appropriate
- No specific acceptance criteria: Regulator makes the decision on acceptance or not

FIGURE B6.3.1 Criticality matrix



Source: France, Ministry of Ecology 2012.

Sources: France, Ministry of Ecology 2012; ICOLD 2017b; Balouin et al. 2012; publications of French Committee on Large Dams, Annual Symposiums in 2011 and 2016.

ALARP along with tolerability criteria using an F-N curve. The SPANCOLD guidelines also refer to the ALARP concept for risk evaluation but have only been piloted, in some cases without the regulatory mandates. Although it is not clear how the ALARP concept can be used in civil law domains without specifying criteria or procedures, it seems to be used in many parts of the world, beyond the realm of common law jurisdictions. The application of such regulations in civil law domains, including the regulator's evaluation and acceptance criteria of risks, needs further assessment.

Established tolerability criteria are being reviewed in many common law countries as the users of the approach gain more experience in its application. For example, the Australian state of New South Wales amended its Dams Safety Act in 2015 with the following objectives: (1) to ensure that dam safety risks are of a level acceptable to the community, (2) to promote transparency in dam safety regulation, (3) to encourage proper and efficient dam safety management, and (4) to encourage the application of risk management and the principles of cost-benefit analysis for dam safety. The act also states that a cost-benefit analysis of proposed regulation should be carried out.

A similar logic can be applied to economic losses—the greater the risk of economic loss, the less weight should be given to the factor of cost-of-risk-reduction measure. However, there are no accepted industry-wide criteria for "economic risk criteria" equivalent to the limit of tolerability adopted for societal risk. Regulators are nonetheless likely to take special interest in dams with significant economic costs, particularly where those costs would be borne beyond the organization by downstream communities and wider society (Victoria State Government 2015).

There is very limited guidance on carrying out analyses to confirm that the ALARP principle is met. Some aspects of the ALARP justification, such as whether relevant good practice is met or whether all relevant societal concerns are properly addressed, are rarely discussed at the level supporting practical applications. In particular, societal concerns should be factored into the assessment of ALARP when dams have very high consequences (for example, an identified failure mode leading to a potential loss of life of more than 100), or highly vulnerable populations at risk (such as a preschool immediately downstream of a dam), and so forth (see box 6.4). Strategies to engage with the community on dam safety will require input from a broader range of specialists, such as on communications, and require liaison with other agencies, such as local government authorities and those responsible for emergencies (Victoria State Government 2015). Societal concerns or social elements of risk tolerability criteria that are not adequately addressed in dam safety have been the subject of detailed considerations (Zielinski 2019).

It should be emphasized that risk-informed approaches, including the risk tolerability aspect, should be used as a complement to, and not a replacement for, the standards-based approach for the assessment of dam safety, particularly for existing dams. Australia, Canada, France, Spain, the United Kingdom, and the United States, among others, have all developed risk-informed dam safety assurance practices and guidelines. However, there do not appear to be any jurisdictions among the case studies that use risk assessment as the sole means of dam safety assessment. This aligns with ICOLD (2005) Bulletin 130, which states, "For the foreseeable future, dam safety is achieved following standards-based approaches and traditional and accepted engineering methodologies supported by risk assessments."

BOX 6.4

ENHANCING RESILIENCE OF VULNERABLE COMMUNITIES BEYOND LIFE SAFETY

The severity of losses experienced due to a flood in the case of dam failure will depend on who experiences it, and focusing on asset value may disproportionately affect poor or marginalized communities. Poor and marginalized groups often face greater exposure to hazards by living in marginal or unsafe areas (for example, on floodplains and along riverbanks) and experience greater vulnerability as they are more likely to live in substandard housing and possess uncertain land ownership rights that provide no incentives for investments in risk reduction. The same loss can also have a greater effect on poor or marginalized households as they are less able to absorb and recover from the impact of hazard events when they hit. Their livelihoods often depend on fewer assets, and consumption is closer to subsistence levels. With little savings and limited or no access to formal credit, the poor typically rely on a range of suboptimal coping mechanisms following a disaster; they cannot rely on savings to smooth the impacts, and their health and education are at greater risk. After being hit with a disaster, poor and marginalized communities can suffer the consequences of uneven relief and recovery efforts and may need more time to recover and reconstruct. Poor or marginalized groups may also face obstacles to accessing entitlements, such as government relief or recovery assistance. While life-safety risk is the principle consideration, decisions to prioritize investments in rehabilitation and safety should provide special equity considerations and pro-poor provisions to improve the resilience of vulnerable communities. Such considerations are particularly important when public funds are being programmed and in countries where there is high income inequality.

Source: Adapted from Hallegatte et al. 2017.

THE STATUS OF RISK-INFORMED APPROACHES

Over half of the countries and jurisdictions studied for this analysis allow for or apply risk-informed approaches in dam safety management (table 6.1). In 14 percent of cases, a risk-informed approach is mandatory for large, hazardous dams, based on specific criteria and/or the judgment of regulators or independent inspectors. For example, an analysis and assessment of risk is mandatory for large dams in France (class A and class B), while the Australian state of Victoria requires an assessment of risk for all dams operated by state-owned water corporations providing water and sewerage services. Regulators in South Africa have the option to require risk analysis for large or hazardous dams if deemed necessary. A risk-informed approach is also required for dams in Norway for specific purposes, such as emergency planning, public safety, and information security. In the United States, federal

TABLE 6.1 Status of risk-informed approaches to dam safety management in case study countries and jurisdictions

Legal system	Mandated	Allowed/applied	Not recognized	Undetermined
Common law	3	4	5	1
Civil law	3	14	2	10
Religious law	0	1	0	0
Mixed	1	1	4	2
Total	**7**	**20**	**11**	**13**

Source: Original table for this publication.

agencies such as USACE and USBR have been using this approach for self-regulation and portfolio risk management; FERC has also issued a guideline for a risk-informed approach to the regulation of nonfederal hydropower dams owned by both the public and private sectors, including requirements for PFMA. No provisions are observed in relation to risk-informed approaches in around 22 percent of cases.

Risk-informed approaches are more commonly mandated or allowed for among civil law countries or jurisdictions compared to the common law countries or jurisdictions surveyed. This is significant because civil law systems inherently avoid discretional decision-making, instead preferring decisions to be limited by the prescriptive boundaries of legislation. The fact that risk-informed approaches are being embraced in civil law jurisdictions suggests this type of decision-making is gaining prominence on a global scale.

Four broad applications of risk-informed approaches have been identified among the different case study countries and jurisdictions (table 6.2; see appendix C for more details). The first type of application is mandatory by law or regulations as in the Australian states of New South Wales, Queensland, and Victoria as well as the Canadian province of Alberta, France, Mexico, Norway, and South Africa, along with particular high-risk or high-hazard dams in California (United States). The second type of application is for dam safety self-regulation and management of a large portfolio of dams by US federal agencies, such as USACE, USBR, and FEMA. In the third type of application, risk-informed approaches are applied as part of broader dam safety regulations as in the province of Ontario in Canada, the United Kingdom, and the United States (FERC). The fourth application is to have the approach introduced as good practice without legal mandates, such as in the Australian state of Tasmania, the province of British Columbia in Canada, Spain, and Washington State in the United States. Industry-led applications of risk-informed approaches are observed in dam owners BC Hydro and Hydro Tasmania, while the regulator agency in Washington State has been using this type of tool primarily to strengthen the effectiveness of its own performance and to improve resource allocation. Spain has been undertaking risk-informed approaches on a pilot basis as per the SPANCOLD guidelines, while France is the first of the three civil law countries to have legally mandated a risk-informed approach for dam safety (see table 6.2 for key features).

TABLE 6.2 Case study countries and jurisdictions with risk-informed approaches to dam safety management

Country/ jurisdiction	Risk analysis mandated	ALARP requirement	PRA/PRM requirement	Owner's PRM acceptance criteria by regulator
1. Risk analyses and assessment legally mandated by regulation				
Australia, New South Wales	All regulated dams, but non-"complex" dams can be exempt by owner's exemption application being approved by the regulator subject to certain conditions as per the Dam Safety Regulation (2019) under the Dams Safety Act (2015)	Yes (specific), using "So Far As Is Reasonably Practicable" (SFAIRP) instead of ALARP (see appendix C)	Implicit	A dam owner must calculate the societal and individual risk rating in accordance with the methodology as per the *Gazette* (New South Wales 2019), which provides the societal safety thresholds using F-N curves for (1) new dams and existing dams with major augmentation and (2) existing dams. Draft guideline (March 2020) would define SFAIRP.
Australia, Queensland	Yes (for acceptable flood discharge capacity)	Yes (specific)	Implicit	Very specific with clear acceptance criteria for cost-benefit and statistical life as well as time schedule for hydrological safety upgrading. (ANCOLD guideline is not meant for regulators and has been refined for the purpose.)
Australia, Victoria	Yes (all dams owned by water corporations—these are mostly high and extreme consequence dams)	Yes	Explicit through the Statement of Obligations and annual dam safety report of water corporations	General: 2014 guideline refers to ALARP and notes the needs of balanced resource allocation across the drivers of value creation, compliance, and risk mitigation.
Canada, Alberta	Yes (significant, high, very high, and extreme consequence class dams), exempting only low consequence dams	Yes (general)	Implicit	General
France	Yes (class A and B dams)	Yes (general)	Implicit	General
Mexico	Yes (large dams higher than 15 meters and risky dams based on preliminary analysis)	No	Implicit	Reference to ALARP using F-N curve (risk-based 2015 regulation not yet enforced)
Norway	Only for the purposes of emergency planning, public safety, and information security	NA	NA	NA
South Africa	Class II and III dams only if requested by DWS	Yes (general)	Implicit	General
United States, California	Extremely high- and high-hazard dams	NA	NA	Inspection and reevaluation including risk management but no tolerability criteria

(continued)

TABLE 6.2 *(continued)*

Country/ jurisdiction	Risk analysis mandated	ALARP requirement	PRA/PRM requirement	Owner's PRM acceptance criteria by regulator
2. Risk-informed approach for self-regulation mechanism				
United States, federal agencies	Yes (for self-regulation)	Yes	Yes	NA (self-regulation)
3. Risk-informed approach practiced as part of regulation in coordination with dam owners				
Canada, Ontario	Being formalized	Yes	Yes (draft)	Specific (draft guideline)
United Kingdom	Only if requested by inspection engineer, and following three-tier approaches	Yes	No	General
United States (FERC) over nonfederal hydropower dams	Yes for high-hazard dams and dams requested by FERC	Yes, when required	Implicit or recommended	General
4. Risk-informed approach broadly practiced or piloted without legal mandates				
Australia, Tasmania	No, but practiced by Hydro Tasmania	Refer to ANCOLD	Implicit	No particular
Canada, British Columbia	No, but practiced	Yes (general)	No, but practiced	General
Spain	No, but piloted	No	No, but piloted	No particular
United States, Washington State	No, but used by the state regulator	No	Implicit	No particular

Source: Original table for this publication.
Note: ALARP = As Low As Reasonably Practicable; ANCOLD = Australian National Committee on Large Dams; DWS = Department of Water and Sanitation; FERC = Federal Energy Regulatory Commission; NA = not applicable; PRA = portfolio risk assessment; PRM = portfolio risk management.

In countries where risk-informed approaches to dam safety management are mandated or allowed, the level of sophistication of the assessment requirements normally depends on the hazard level of a particular dam along with the level of capacity. For larger, high-hazard dams, there is generally a preference for quantitative methods compared to simpler, qualitative methods for less hazardous dams. This trend is also generally in line with ICOLD (2005) Bulletin 130. The United Kingdom's risk assessment guidelines (DEFRA 2013) established a framework comprising three different tiers of risk assessment applicable to different risk circumstances, covering the full range of approaches that can be applied upon the recommendation of qualified inspectors and supervisory engineers. Many other countries are adopting similar risk-informed approaches, applying more advanced analytical methods for higher-hazard dams. Although risk assessment is not formally mandated under official legislation or regulation in these countries, many have been piloting risk-informed approaches or applying them on a case-by-case basis. In Spain and the United States, for example, guidelines for risk-informed dam safety assurance have been developed for dam owners and regulators.

PORTFOLIO RISK ASSESSMENT AND PORTFOLIO RISK MANAGEMENT

Portfolio risk assessment (PRA) and portfolio risk management (PRM) provide tools to support programmatic decision-making in the assessment and prioritization of dam safety measures. These can include structural and non-structural measures to reduce the overall risk of a portfolio of dams in an optimal manner. A diverse range of risk analyses and assessment techniques is required for PRA and PRM. These can include simple risk indices to more advanced quantified risk analyses.

A PRA or PRM typically includes (1) assessment of the risk profile of a portfolio of dams to establish the baseline condition, (2) prioritization of deficient or high-risk dams and required remedial measures covering both the short and long term, (3) improvement of the overall dam safety management program along with intensified monitoring and surveillance for higher-hazard dams, and (4) development of a short- and long-term business plan and budget.[12]

Approaches to PRA and PRM can be used to help dam owners prioritize safety improvement measures while balancing the required oversight from regulatory agencies. When developed in collaboration with regulatory agencies, PRM can be used by industry to set its own goals for portfolio dam safety improvement as part of the annual planning or investment programs. This would help utilities prioritize safety improvement measures while reducing the oversight burden for regulators.

The PRA and PRM process also has the potential to enhance the performance of dam owners by way of corporate risk management, covering all safety and operational risks, and business contingency planning in case of both dam failure and nonfailure events. Such tools can also help owners deal with legal considerations, due diligence, internal control, corporate governance, and legal defensibility of dam safety decisions. They can also strengthen community consultation, including risk communication and required emergency measures. PRA and PRM can also help owners meet contractual obligations, licensing requirements, and key performance indicators (ICOLD 2005, sect. 3.4.8).

About half of the case study countries and jurisdictions allow for or have adopted PRMs as part of their dam safety management guidelines (table 6.3). While examples can be found in India, the Islamic Republic of Iran, Nigeria, and Zimbabwe, the Australian state of Victoria is the only jurisdiction to have explicitly mandated such provisions. PRM has either never been considered or is still under consideration and testing in 22 percent of cases, such as is the case in Lebanon and Nepal.

Countries are also in different stages of applying the approach, with some still in the pilot phase and others already intensively using it to manage large portfolios of dams. For many dam owners, information on the condition of existing dams and their original design and construction may not be sufficient to enable a quantitative portfolio risk assessment. In some instances, the burden on available financial and human resources may be too high.

TABLE 6.3 Status of portfolio risk management in the case study countries and jurisdictions

Income level	Mandated	Allowed/ adopted	Under discussion/ being tested	No evidence of being considered	Undeter- mined
High income	1	11	2	0	4
Upper middle income	0	8	1	1	5
Lower middle income	0	6	1	4	5
Low income	0	1	0	2	0
Total	**1**	**26**	**4**	**7**	**14**

Source: Original table for this publication.

Thus, it is important to introduce PRA and/or PRM in a practical way, especially in resource-constrained contexts.

The World Bank has assisted a number of countries in introducing risk index methods for carrying out PRA and supporting PRM, including in Armenia, Indonesia, and Sri Lanka. Such approaches help client countries improve budget optimization and achieve the greatest reduction of people at risk in downstream areas of hazardous dams. These approaches are also intended to help improve the overall risk profile of a large portfolio of existing dams at the national or regional level in a cost-effective way.

There are a number of jurisdictions among the country studies that have developed and practiced a comprehensive approach to PRA and PRM in their dam safety assessment and management programs. These include major dam owners and utilities in Australia, Canada, and the United States. (See table 6.2 for a summary of key findings and appendix D for more details.) As mentioned, only the Australian state of Victoria specifically mandates the use of PRM (table 6.2 and box 6.5). The state-owned water corporations that are responsible for most of the state's large dams are instructed by the minister of water in the Statement of Obligations to carry out PRM and are required to submit their proposed remedial work plans to the regulator with an implementation schedule as part of their annual dam safety plan.

In other jurisdictions that mandate risk assessments, PRM is practically required for owners with a large portfolio of dams, such as in France and the Australian states of New South Wales and Queensland. This is the case for dam owners SunWater and South East Queensland Water in Queensland, and Électricité de France in France, where the regulators are supposed to receive risk assessment results and the proposed scope of remedial works in the form of annual safety plans submitted by the owners. In Queensland, the guidelines by the regulator clearly indicate how risk-reduction measures should be determined and approved by the regulator in line with its ALARP confirmation methodology, including a cost-benefit analysis and CSLS as well as their disproportionality threshold values and execution schedule.

BOX 6.5

PORTFOLIO RISK MANAGEMENT IN VICTORIA, AUSTRALIA

The Statement of Obligations (SoOs) issued to water corporations in Victoria by the Minister for Water under the Water Industry Act 1994 requires the owners to: (1) prioritize risks posed for all of the dam components and types of failure, (2) give priority to reducing risk to life over other risks, (3) base the urgency of reducing risks on the Australian National Committee on Large Dams tolerability limits, (4) base the urgency of reducing risks on the concept of ALARP (As Low As Reasonably Practicable), and (5) where feasible, progressively implement risk-reduction measures to achieve the best outcomes with the available resources.

The SoOs also requires the water corporations to submit an annual dam safety report including: (1) a prioritized list of proposed dam safety works, (2) a summarized risk profile of dams, and (3) a summary of the overall risk-reduction profile of the dams. The state government also issued two guidelines: (1) the Strategic Framework for Dam Safety Regulation (2012 and 2014) and (2) the Guidance Note on Dam Safety Decision Principles (2015). These guidance notes aim to assist dam owners and managers in making key dam safety investment decisions, providing guidance on satisfying the ALARP principle, and clarifies dam safety investment time frames and appropriate target safety levels. To comply with dam safety regulations, water corporations are expected to undertake detailed safety reviews for high- and extreme-consequence dams using both quantitative risk-based and standards-based assessment, to provide a comprehensive understanding of the level of safety of the dams.

In contrast, French regulators have not stipulated such a detailed methodology or acceptance criteria for approving the results of risk assessments and remedial measures to be proposed by owners. It is noteworthy that the regulatory systems for France and the Australian state of Queensland are managed in a way that contrasts with the conventional understanding of how common law systems operate. The Australian state of New South Wales has also stipulated requirements for progressive safety improvement in the risk management framework endorsed by the Cabinet in 2006, but the regulations under the amended Dam Safety Act are still under preparation.[13]

Portfolio risk management approaches have also been introduced by the USACE and the USBR in the United States. These apply to a large portfolio of federally owned government dams under a self-regulatory system and prioritize the most urgent dam safety improvement works required to reduce potential risk to human life. FEMA, along with the federal agencies, has published guidelines for risk assessment and developed joint federal risk categories from 1, indicating "very high urgency," to 5, reflecting "no urgency," and uses these categories for prioritizing dam safety actions within their budget limitations.

All other jurisdictions or countries examined among the country case studies do not have specific mandates relating to the application of PRM approaches. In places where PRM is not specifically mandated, this may be attributed to the potential liability issues associated with regulators endorsing the prioritization of dam safety works within any owner's portfolio, especially if a dam deemed "lower priority" fails before it is rehabilitated. Regulators may not be in a position to review all investigations and risk assessment results submitted by the owners and approve the appropriateness of the proposed remedial works. Further analysis is needed of how jurisdictions that mandate PRM deal with the review and approval of PRM plans submitted by dam owners and associated liability issues.

Recent Trends in Portfolio Risk Assessment and Portfolio Risk Management

Approaches to PRA and PRM are continuously evolving. For example, the Ministry of Natural Resources and Forestry in Ontario, Canada, which is the regulator for dam safety management, developed a risk-screening tool (Donnelly et al. 2013) and a framework to integrate risk-informed decision-making into the regulation of dam safety in partnership with Ontario Power Generation (OPG), Grand River Conservation Authority, and Hatch Ltd. (Passey et al. 2014). Its risk-informed approach is aligned with the life-safety tolerability criteria of the Canadian Dam Association guidelines. OPG has confirmed that the framework is an effective tool for identifying and prioritizing remedial measures from those most urgently needed to those that are unnecessary.[14]

Similarly, BC Hydro has developed a PRA and PRM methodology and submits its work plan to the regulator for approval. Though PRM is not legally mandated in British Columbia, BC Hydro and the regulator have agreed on the methodology and approach. In contrast, Hydro Tasmania in Australia has developed and implemented PRA and PRM tools for their corporate decision-making, but there does not appear to be any formal review or approval of the owner's work plan by the regulator.

Some regulators also either mandate or allow PRA and PRM on a voluntary basis for their own regulatory functions. For example, the Department of Water and Sanitation in South Africa has limited resources compared to the size of the portfolio and work required, and has been trying to optimize its human and financial resources in the review of owners' dam safety reports. Washington State in the United States has also been applying PRM apparently in order to provide more effective regulation.

Benchmarking

Benchmarking is the practice of researching and comparing best practices and performance metrics within a certain industry. Such approaches can be useful for positioning the performance of dam owners and operators in perspective within the sector or a more specific group of institutions. Benchmarking can be done either among dam operators within a country or internationally with owners and operators of a portfolio with similar characteristics. A key element of benchmarking is the identification of institutions that achieve high levels of performance, which can act as examples of good practice. There are typically four primary types of recognized approaches to benchmarking:

1. Internal benchmarking that compares one process to a similar process inside the organization
2. Competitive benchmarking that compares different methods, processes, or performance metrics among organizations
3. Functional benchmarking that compares similar or identical practices within the same or similar functions outside the immediate industry
4. Generic benchmarking that broadly conceptualizes unrelated methods, processes, or procedures that can be practiced in the same or similar ways

As part of the National Dam Safety Program (NDSP)[15] in the United States, FEMA produces a biennial report covering the regulatory status of all federal and nonfederal dams, which is submitted to the Congress. NDSP, in coordination with the Association of State Dam Safety Officials (ASDSO), has developed a benchmarking model called the Model State Dam Safety Program to assist state officials in initiating or improving their state programs. The model outlines the key components of an effective dam safety program and provides guidance on the development of more effective and sustainable state programs to reduce the risks created by unsafe dams. ASDSO conducts statistical analyses of the performance of 50 states in terms of legislation, inspection, staffing and budgeting, emergency action plan planning and response, education and training, and public relations. This allows each state to compare its performance against the national average.

Similar benchmarking approaches have been developed and implemented in other countries and jurisdictions. For example, the regulator in the Australian state of Victoria hosts a web-based database, to which water corporations contribute information on the status of their dam safety programs and progress toward performance targets, and produces an annual statewide dam safety report. This benchmarking exercise encourages the corporations to continuously improve dam safety practices and risk reduction. Brazil has also been preparing similar annual dam safety reports, which are published. Indonesia has also developed a benchmarking tool for assessing the effectiveness of the operation, maintenance, surveillance, and emergency preparedness programs adopted by dam authorities within the country's basin organizations (box 6.6). The benchmarking tool can serve a wide range of functions and is intended to be used as a tool to help identify and prioritize areas for improvement in the dam safety program, compare the performance of the dam safety program over time, contrast the effectiveness

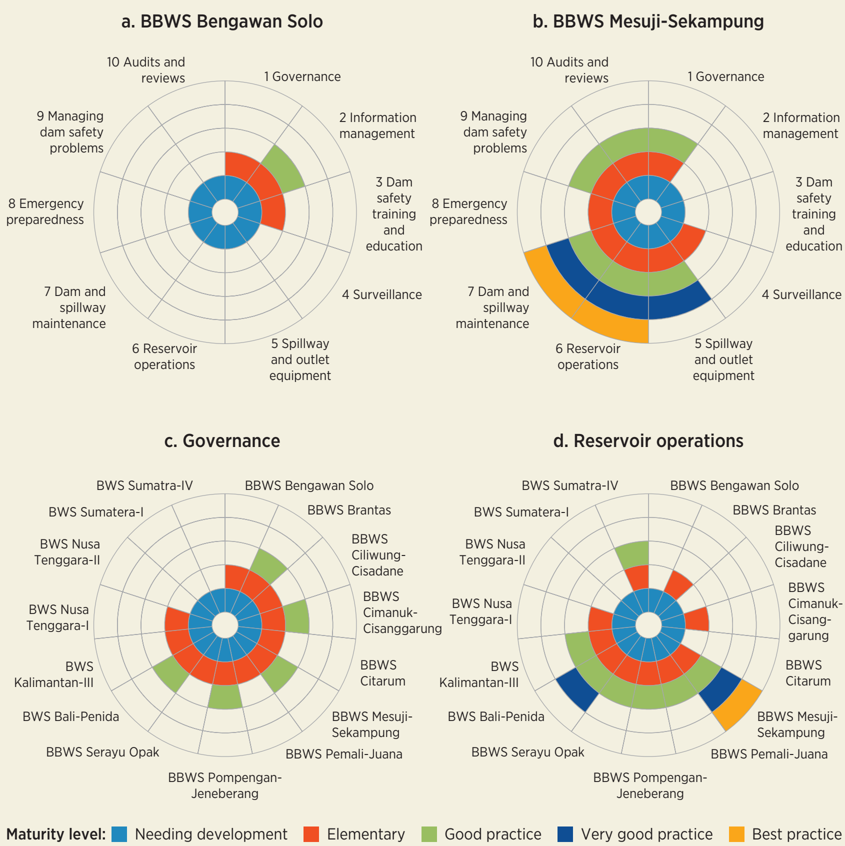
BOX 6.6

INSTITUTIONAL BENCHMARKING OF DAM SAFETY IN INDONESIA

Indonesia has a large and growing portfolio of large dams distributed across the island archipelago. This infrastructure is important in supporting the government's vision of security at the nexus of water, food, and energy and contributing to economic prosperity and poverty reduction measures by storing water for productive purposes.

A benchmarking tool was developed using maturity matrices as a way to objectively assess the effectiveness of the operation, maintenance, surveillance, and emergency preparedness programs under implementation by the Dam Management Units in the *balais*, or river basin organizations (figure B6.6.1). The consultative process for development of the matrices resulted in a tool that is embedded within the legal and institutional framework for dam safety in Indonesia.

FIGURE B6.6.1 Illustrative examples of self-evaluated maturity matrices for dam safety in Indonesia



Source: World Bank 2018.
Note: For details see World Bank 2018. BBWS = Balai Besar Wilayah Sungai; BWS = Balai Wilayah Sungai.

(continued)

BOX 6.6 *(continued)*

The maturity matrices serve a wide range of functions. They can be used to compare performance across different dam management units as well as to compare performance for specific, individual metrics. Other functions include identifying and prioritizing areas for improvement in the dam safety program, comparing the performance of dam safety programs over time, and informing the prioritization and allocation of government resources.

of different programs across different dam management units, and inform the prioritization of resources for dam operation, maintenance, and safety improvement. Benchmarking also provides a useful means to communicate the effectiveness of a dam safety program to wider audiences. As part of continuous improvement initiatives, the benchmarking allows areas requiring improvement to be identified and prioritized for targeted investment and resourcing. This can also be applied over time or across a portfolio to identify systemic issues and target interventions and remedies accordingly. It also allows national regulatory bodies to assess performance across different operators and owners.

KEY MESSAGES AND CONCLUSIONS

The fundamental principles of risk assessment and the development of tools to support their application are increasingly being applied as part of the process for ensuring the safety of dams and downstream communities. This reflects a growing recognition that a number of dam safety incidents are caused by nonstructural elements that are not well captured by the traditional, standards-based approach. While standards-based approaches by qualified engineers have to date generally proven sufficient for ensuring the safety of existing dams, the changing nature of portfolios at the country level coupled with the evolution of societal values and stakeholder expectations, along with the challenge of funding improvements to large portfolios, advocate for the application of more risk-informed approaches.

Since the risks associated with a dam are specific to its design and context, and will vary based on the structural components, socioeconomic factors, and the environment within which the dam is being constructed and will operate, the provisions need to be proportionate to the size, complexity, and potential risk of the dam. Whether they are mandated through specific legislative provisions or voluntary measures, risk-informed approaches allow dam owners, regulators, and the public to better understand the entire operational system and analyze the implications of potential failure scenarios.

Such comprehensive approaches can lead to a more efficient allocation of resources, and prioritized remedial measures and monitoring activities, and they can address some of the concerns around the level of conservatism associated with traditional standards-based approaches.

There is a wide array of tools for risk assessment, ranging from relatively simple, qualitative analyses to semiquantitative assessments such as risk indices to highly probabilistic, quantitative methodologies. The selection of suitable techniques should be based on the complexity of a particular dam safety risk or hazard, along with the specific country context. Some countries have a limited understanding and knowledge of risk methods and require significant investments to develop the requisite capacity to implement PRM practices. Among the various options, qualitative or semiquantitative risk assessment methods have proven to be an effective practical tool for risk identification and prioritization. Such approaches have been applied across a wide range of countries and provide a practical tool for deciding how to best allocate resources in constrained environments.

FMEA and/or PFMA are used in a number of countries to provide a comprehensive evaluation of risks and consequences associated with potential failure modes. Such approaches can be tailored along the continuum of country characteristics with varying degrees of sophistication, with due consideration for the inherent limitations.

While there are clear benefits to risk-informed approaches, they can also be complex and require considerable resources. The application of such approaches needs to be appropriate for the context. High-hazard dams with complicated circumstances may require a detailed quantitative analysis, including a probability estimation of all failure modes and a corresponding numeric consequence assessment, while a simpler analysis or a traditional standards-based approach may be more appropriate for less complicated, low-hazard dams.

Deciding what constitutes an acceptable or tolerable risk threshold for society (for example, life-safety tolerability defined by societal risk limits with F-N charts and by individual risk limits) is a country-specific task and typically not applicable in most civil law countries. It should be further noted that even those countries using risk information in dam safety decision-making have not established adequate guidance on assessing and judging the importance of broad societal impacts inflicted by dam failure. Such decisions will invariably reflect the country's broader societal and cultural values and, importantly, will change over time as society's values and expectations change. Any risk-informed framework needs to be reviewed, revised, and made subject to a process of continuous improvement to assure the continued safety of dams and downstream communities. Given these considerations, it can take time to decide on such procedures and the appropriate approval criteria through a political process on behalf of society.

The use of PRA and PRM can help provide a comprehensive understanding of the comparative risks within a portfolio. Such approaches can also help identify the need for prioritized remedial works within a portfolio of dams allowing for a more targeted use of limited financial resources and human capital. As a result, such approaches are increasingly being employed across a range of diverse countries of different economic standards and legal foundations, particularly by utilities with large portfolios. PRA and PRM methods need to be introduced at an appropriate level determined with due consideration to the size and type of dams in the portfolio, as well as the available financial resources and human capital.

Careful consideration needs to be given to the legal foundations for introducing PRA and PRM. Few countries have formal regulated requirements, mostly because this may introduce a potential liability for regulators related to their review or approval functions. In civil law countries, where a risk-based approach is mandated for high-hazard dams, owners with large portfolios are required to undertake a PRA and PRM and submit their proposed safety improvement plans to the regulator. If the regulator has not stipulated specific acceptance criteria in the guidelines, it could end up assuming a significant level of liability. Alternative models are being developed whereby owners set goals for the portfolio of dam safety programs with the approval of or in consultation with regulators. In some instances, detailed guidelines are being issued to provide instructions to owners on how to develop their proposed safety improvement plans in line with the ALARP principle.

The importance of risk-informed approaches to dam safety management is expected to increase as effective asset management becomes more important and such tools provide a solid basis for development of effective and efficient management of dam safety risks. However, risk-based approaches should be used as a complement to standards-based approaches and should not be the only decision basis that is used in the management of dam safety risks (ICOLD TC 2013). Other elements should include consideration of engineering principles, standards and current good practice, owner or wider societal values, and stakeholder expectations and perceptions (ICOLD TC 2013). Reflecting this trend, the World Bank's Environmental and Social Framework requires all World Bank–financed projects to adopt a risk-informed approach. Properly structured, a risk-informed approach can contribute to effective deployment of resources to assist client countries in developing practical and effective risk management systems that are uniquely suited to the country-specific context.

NOTES

1. The Environmental and Social Framework applies to all new World Bank investment project financing with concept review meetings on or after October 1, 2018.
2. For more, see the National Performance of Dams Program, Dam Incident Database, Stanford University, http://npdp.stanford.edu/.
3. ANCOLD's (2003) *Guidelines on Risk Assessment* provides the basic concept and steps for human reliability assessment in appendix C. While it acknowledges that

quantification of the risks associated with human factors is difficult, it recommends that the procedure developed for other hazardous industries should be adapted to the analysis of dams.

4. Code of Federal Regulations, Title 18: Conservation of Power and Water Resources, Chapter I: Federal Energy Regulatory Commission, Department of Energy, Subchapter B: Regulations under the Federal Power Act, Part 12: Safety of Water Power Projects and Project Works, Subpart D: Inspection by Independent Consultant.
5. The Oroville Dam was regulated by both the California Department of Water Resources and FERC.
6. HSE (2001) defined the ALARP principle as "that principle which states that risks lower than the limit of tolerability are tolerable only if risk reduction is impracticable or if its cost is grossly disproportionate (depending on the level of risk) to the improvement gained." The following factors are commonly taken into account in making a judgment on whether risks are ALARP: the level of risk in relation to the tolerable risk limits; the disproportion between the cost (money, time, trouble, and effort) of implementing the risk-reduction measures and the subsequent risk reduction achieved; the cost-effectiveness of the risk-reduction measures; compliance with good established practice; and societal concerns as revealed by consultation with the community and other stakeholders. Thus, the ALARP evaluation and demonstration is both qualitative and quantitative in nature. HSE (2001), ANCOLD (2003), NSW Dam Safety Committee (2010), and USACE (2014) guidelines specifically require that risks should be further reduced below tolerable risk limits to meet ALARP considerations (Bowles 2013).
7. For example, see on the IAEA website, "Tolerability of Risk and ALARP Philosophy" from 2018, https://nucleus.iaea.org/sites/graphiteknowledgebase/wiki/Guide_to_Graphite/Tolerability%20of%20Risk%20the%20ALARP%20Philosophy.aspx; and "Risk Management: A Tool for Improving Nuclear Power Plant Performance" from 2001, https://www.iaea.org/publications/6201/risk-management-a-tool-for-improving-nuclear-power-plant-performance. It should be noted that the ALARP concept is applied only for individual risk.
8. For example, see Witt (2013); Duijm (2009); Ham et al. (2006); and EMSA (2015). It should be noted that they do not make a distinction between individual and societal risk.
9. Early development of F-N risk criteria referred to F as frequency, but at the present F is typically understood as cumulative probability.
10. CSLS is the cost of achieving an increment of life-safety risk reduction and not a value placed on a human life. For example, a CSLS of $10M would result from reducing a risk by 1 in 10,000 per year for 10 persons at an annualized cost of $10,000 per year as follows: CSLS = $10,000/(10*(1/10,000)) = $10M.
11. USACE has also applied the risk analysis and assessment to the Mosul Dam in Iraq and demonstrated that the dam possesses high failure probability due to erodible foundation rock and extremely high hazard potential in downstream cities, including Mosul and Baghdad, which has led to resource mobilization and execution of critical remedial works.
12. For example, Bowles 2006, sect 3.
13. According to Dam Safety Committee (DSC), NSW, Annual Report (2016/17), until the new act is fully implemented, dam owners will continue to be regulated by DSC (which was established by the Dam Safety Act in 1978). DSC is one of the global leaders for risk-informed approaches to dam safety.
14. Personal communication with P. A. Zielinski, Ontario Power Generation, Technology and Dam Safety, Toronto, Ontario, Canada, September 2017.

15. The National Dam Safety Program Act was signed into law in October 1996, as part of the Water Resources Development Act of 1996. The NDSP was reauthorized in 2002, under the National Dam Safety and Security Act in 2006, and again in 2014 under the Water Resources Reform and Development Act. The NDSP Act is administered through the Department of Homeland Security, FEMA. The program was established to improve safety and security around dams by (1) providing assistance grants to state dam safety agencies to assist in improving their regulatory programs, (2) funding research to enhance technical expertise, (3) establishing training programs for dam safety inspectors, and (4) creating a national inventory of dams, which is managed by USACE. The act also calls for FEMA to provide education to the public, dam owners, and others about the need for strong dam safety programs and to coordinate partnerships among all players.

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7

Emergency Preparedness and Public Safety

CONTEXT AND RATIONALE

Dams are usually designed and constructed to ensure their safety against foreseeable extreme events and maximum loads. However, they can face additional threats, such as extraordinary events beyond the design criteria, structural deficiencies, equipment malfunctions, human errors, deliberate destructive actions such as terrorism and cyber-attacks, and deterioration of structures or equipment due to aging. These threats could result in the temporary disruption of critical functions, the unsafe release of water, severe damage to the structure, or, in extreme cases, dam failure. Hence, it is very important to provide sufficient emergency preparedness measures in case of unforeseen events or threats.

Emergency preparedness is a critical element of ensuring the safety of dams and downstream communities. Emergency Preparedness Plans (EPPs) have always represented good practice and are increasingly being mandated within many jurisdictions. Essential elements relate to the identification and evaluation of potential threats, procedures for warning downstream areas at risk, and emergency actions, including emergency notification and evacuation. These plans allow dam owners, operators, local governments, and emergency agencies to undertake their respective roles and actions in a coordinated and timely manner to minimize damage in areas affected by a potential dam failure or mis-operation.

Public safety considerations include potential dangers resulting from mis-operations, such as sudden increases in turbine discharge or the opening of spillway gates without proper downstream notifications. There are also broader public safety considerations associated with dam operations and emerging issues of security that go beyond dam safety, which is primarily concerned with avoiding dam failure. These include measures to protect against intrusion, sabotage, cyberattacks, and acts of terrorism. Within the evolving context of dams and their role in society, there are a number of important considerations and emerging good practices to assure their continued safety operations and the protection of downstream communities.

EMERGENCY PREPAREDNESS PLAN

The EPP is a critical, nonstructural element of an overall dam safety assurance program that provides guidance to dam owners, operators, regulators, and emergency agencies on a series of actions in the event of an emergency.[1] These include identifying and addressing potential defects that could lead to dam failure or accidents, along with remedial measures to reduce potential consequences, including loss of life and damage to or loss of economic, environmental, and societal assets (see box 7.1).

BOX 7.1

KEY FACTORS IN REDUCING POTENTIAL LOSS OF LIFE AND THE CRITICALNESS OF TIMELY AND EFFECTIVE WARNING

It is critical to assess the potential loss of life in downstream areas in the event of a dam failure or natural floods. Such an analysis is instrumental to developing Emergency Preparedness Plans (EPPs) and improving the effectiveness of emergency action planning, including flood warning and evacuation, in conjunction with disaster risk management authorities and emergency services.

The potential for loss of life depends on various factors: (1) dam-break flood patterns (time to arrival, peak velocity, and flood depth), (2) timing of events (day or night, for example, and weekday or weekend), (3) warning time and its role in understanding the flood severity, (4) effectiveness of evacuation (means and abilities), and so forth. Some factors are related to physical events and structures, while others involve human behavior and societal factors. This makes estimating the potential loss of life challenging.

An analysis of 23 dam failure cases in the United States between 1960 and 1998 demonstrated that most loss of life occurred closer to the

(continued)

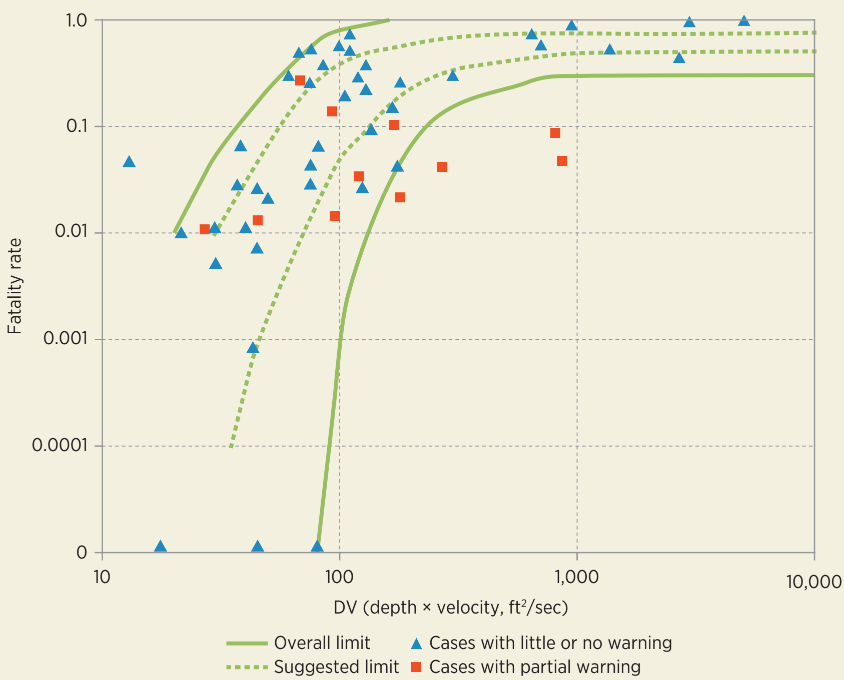
BOX 7.1 *(continued)*

dams (Graham 1999). Of a total of 318 deaths, 50 percent were within 4.8 kilometers of the dam and 99 percent were within 24 kilometers. Timely warnings are therefore very important for the successful evacuation of people at risk in the downstream areas.

The US Bureau of Reclamation (USBR) had carried out studies for estimating life loss from dam failure based on empirical methods using regressions on the downstream population at risk and warning time primarily based on the analysis of dam failure and flood case histories. Graham (1999) improved the method to evaluate fatality rates from dam-break flooding based on (1) flood severity, (2) warning time, and (3) an understanding of flood severity and the effectiveness of the warnings.

The methodology has been further updated through USBR (2015) by adding additional global case studies and a new graphical representation of fatality

FIGURE B7.1.1 Fatality rate: Flood severity with little or no warning



Source: USBR 2015.
Note: This chart is part of USBR's consequence estimating methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology (revised June 2015 to reflect revised case data). DV = the product of maximum depth of flooding and maximum flood velocity; ft^2/sec = square feet per second.

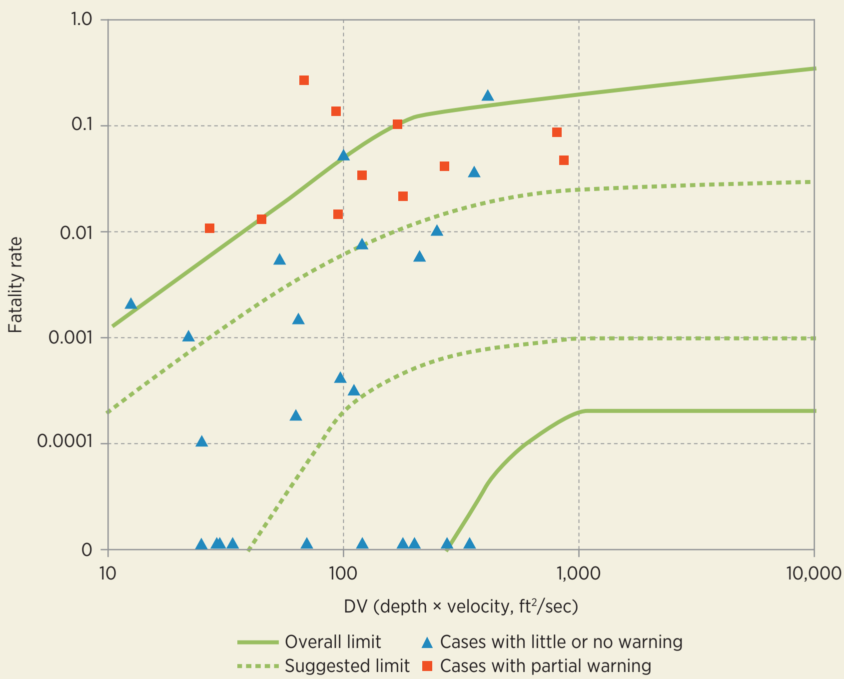
(continued)

BOX 7.1 *(continued)*

rate as a function of flood severity and warning time and effectiveness. Flood severity is defined quantitatively as the product of maximum depth of flooding and maximum flood velocity (DV).

The report presented clear differences in fatality rates by showing the availability and effectiveness of flood warnings in a graphical manner. For example, at the DV (depth times velocity) of 100 square feet per second (ft²/sec), the suggested fatality rate range is between 0.05 and 0.4 in case of little or no warning. This is reduced to the range between 0.0002 and 0.006 where adequate warnings are provided. At the DV of 1,000 ft²/sec, the suggested fatality rate ranges between 0.5 and 0.75 but is reduced to between 0.001 and 0.025 with adequate warnings. The graphs showing the relationship between fatality rate and flood severity with no or limited warning and with adequate warning are indicated in figure B7.1.1 and figure B7.1.2, respectively (USBR 2015).

FIGURE B7.1.2 Fatality rate: Flood severity with adequate warning



Source: USBR 2015.
Note: This chart is part of UBSR's consequence estimating methodology (RCEM, 2014). It is intended to be used only in conjunction with the entire methodology (revised June 2015 to reflect revised case data). DV = the product of maximum depth of flooding and maximum flood velocity; ft²/sec = square feet per second.

Based on the review of regulations and guidelines among the 51 case study countries and jurisdictions, the contents of a typical EPP includes the following:

- Identification and evaluation of potentially hazardous conditions of the dam
- Emergency level classification, activation, and decision-making procedures for undertaking required actions
- Notification of and communication with relevant authorities and stakeholders
- Emergency actions, including evacuation of the population at risk in the event of potential or imminent failure

Good practice includes the creation of an Emergency Response Matrix that provides a simple means to outline different emergency situations with corresponding emergency levels and responses. When an emergency occurs, dam owners or operators have limited time to read reports, even if they have been sufficiently trained in emergency handling. Thus, each cell in the matrix should contain clear indications, such as instrument readings or visual observations, prompting the appropriate response level.

Most of the case study countries and jurisdictions have some provisions requiring EPPs to be prepared for individual dams or for a group of dams within a basin. Mandatory provisions requiring EPPs are found in at least 53 percent of the case study countries and jurisdictions. These mandatory provisions are more prevalent among high- and upper-middle-income countries (see table 7.1), due in part to the capacity and financial resources required for dam owners to develop EPPs and/or regulators to ensure compliance.

Of the case study countries and jurisdictions that require EPPs, about two-thirds mandate them only for high-hazard and/or large dams, with roughly one-third mandating them for both high- and significant-hazard dams. For those countries requiring EPPs for high- and significant-hazard dams, the

TABLE 7.1 Case study countries and jurisdictions that mandate EPPs

Income level	Mandatory	Not mandated, voluntary	Undetermined
High income	17	1	2
Upper middle income	6	5	2
Lower middle income	4	6	4
Low income	0	4	0
Total	**27**	**16**	**8**

Source: Original table for this publication.
Note: EPPs = Emergency Preparedness Plans.

mandates are proportional, with high-hazard dams having much more extensive and sophisticated requirements than those for significant-hazard dams.

Most of the case study countries and jurisdictions that mandate EPPs for dams that are smaller in size, low-hazard, or located far from large numbers of people do not require extensive evaluation or planning processes. Rather, the requirements include a list of all occupied facilities, buildings, and residences potentially at risk in the event of failure or mis-operation, as well as a basic description of the required actions of all parties involved.

Most of the case study jurisdictions requiring EPPs and a wide range of professional bodies have published guidelines for owners and regulators. The following are notable:

- *Dams Sector Crisis Management Handbook: A Guide for Owners and Operators* (US Department of Homeland Security 2015) provides useful guidance to dam owners and regulators on developing an overall program for crisis management.
- *Federal Guidelines for Dam Safety: Emergency Action Planning for Dams* (FEMA 2013) provides detailed guidance on the outline, content, and development procedure of an EPP as well as examples of a notification flowchart, inundation maps, and checklists.
- *Technical Bulletin: Emergency Management for Dam Safety* (CDA [Canadian Dam Association] 2019) promotes the development of an emergency management process for dam safety that contributes equally to building an effective and integrated operational response for the dam owner and others as well as more resilient communities that are less vulnerable and better able to cope with disasters, recover from them, and learn from the experience.
- *New Zealand Dam Safety Guidelines* (NZSOLD 2015) also provide useful guidance on the preparation of EPPs, including a sample format for medium- and high-consequence dams.
- *Dam Safety Guidelines—Technical Note 1: Dam Break Inundation Analysis and Downstream Hazard Classification* (Schaefer 2007), issued by Washington State's Department of Ecology in 2007, uses a simple and useful format that shows how to estimate dam breach parameters, including peak discharge, the downstream routing of resulting floods, and inundation mapping in a simple and useful format.

Increasingly, EPPs are required to address broader public safety and flood management issues, in addition to dam failure events. Such events are more common than dam failure and lead to more frequent activation of the EPP, which helps to ensure it is treated as a living document. For example, one of the features of the 2013 FEMA guidelines that sets it apart from the previous version (2004) is the addition of a fourth emergency category for "high flow events" that complements the other three original categories: "nonfailure," "potential failure," and "imminent failure."

Under the FEMA (2013) guidelines, dam owners are expected to develop an effective hydrometeorological monitoring and flood forecasting system. In addition, there needs to be a table that correlates gate openings and/or reservoir levels with outflows, likely downstream impacts, and agencies that will need to be contacted. Such provisions are particularly important in many low- and middle-income countries where the downstream river discharge capacity is often limited compared to the spillway discharge flow of the dams.

It is important that the EPPs be prepared in coordination with all entities required to fulfill the range of roles and responsibilities relating to disaster risk management and emergency services. The roles and responsibilities can be distributed among various agencies, depending on the country context, but typically include emergency identification, evaluation, classification, notification, and warning, along with ensuring that sufficient information dissemination and awareness-raising activities are undertaken and evacuation and emergency responses are prepared and maintained.

As part of the approval process, EPPs are typically subject to review and approval by regulatory authorities responsible for the safety of dams and downstream communities, as well as those agencies responsible for disaster risk management and emergency services. Among the 51 case study countries and jurisdictions, 21 have specific mandates relating to multi-institutional coordination in the preparation of EPPs (see table 7.2). Among those countries and jurisdictions where EPPs are mandated, it is also required

TABLE 7.2 Some characteristics of EPP mandates among case study countries and jurisdictions

Income level	EPPs mandated only for specific classes of regulated dams	Mandated EPPs: sophistication varies for different dams and/or classes	Mandated EPPs require multi-institutional coordination	Mandated EPPs require information dissemination and awareness raising for downstream communities	Mandated EPPs have other specific requirements (e.g., mock drills, brochures)
High income	17	6	14	14	10
Upper middle income	6	3	3	2	2
Lower middle income	4	0	4	3	1
Low income	0	0	0	0	0
Total	**27**	**9**	**21**	**19**	**13**

Source: Original table for this publication.
Note: EPPs = Emergency Preparedness Plans.

that the EPP and associated documents be reviewed and updated periodically throughout the life cycle of the dam as part of the periodic dam safety reviews.

To improve the efficacy of the EPP, it is also advisable to prepare and disseminate concise materials to improve awareness among downstream communities that could potentially be affected by mis-operations, accidents, or dam failure. Such provisions are found among 19 of the case study countries and jurisdictions, where there are specific requirements in the EPPs for information dissemination and awareness raising among downstream communities.

Increasing use of the Common Alerting Protocol (CAP) allows emergency messages to be simultaneously disseminated over a wide variety of public alert systems.[2] The CAP is an international technical data specification developed by the Organization for the Advancement of Structured Information Standards (OASIS) for exchanging all-hazard emergency alerts and public warnings over all kinds of networks. CAP allows a consistent warning message to be disseminated simultaneously over many different warning systems, increasing the likelihood that recipients will receive an alert.

While the identification, evaluation, classification, and notification of an emergency situation is generally initiated by the dam owner or operator, warnings and evacuation orders for the general public are typically implemented by those agencies legally mandated with responsibility for emergency or disaster management. As a result, some countries and jurisdictions divide the EPP into two categories:

1. *An internal EPP for dam owners and operators:* Internal EPPs typically cover potential defects that could lead to dam failure or accidents, along with remedial measures to reduce potential consequences as guidance to dam owners, operators, regulators, and emergency agencies.

2. *An external EPP for agencies in charge of emergency or disaster management:* External EPPs may cover all kinds of disasters, including earthquake, hurricane, tsunami, and so forth handled by the emergency management agencies.

The different EPPs need to clearly articulate the demarcation of responsibilities between dam owners and operators as well as those authorities responsible for emergency management in the event of a dam failure or mis-operation. While warnings and evacuation orders for the general public are typically implemented by those agencies legally mandated with responsibility for emergency or disaster management, dam owners may need to notify people directly downstream of dams who could be inundated immediately after a dam failure or mis-operation. Both the internal and external EPP should therefore clearly define and indicate the notification procedure and contact information of all relevant agencies and their personnel, as well as communication systems, equipment, materials, and other resources required for emergency actions.

An EPP should include specific information on potential failure modes and consequences as well as specific remedial actions, including warnings for and the evacuation of the population at risk downstream. Preparation of an EPP should include dam-break analyses and downstream flood simulations, which are needed to prepare inundation maps. Inundation maps provide critical information on the extent of potential flooding, including the projected arrival time and depth of flood waves at critical locations.

The techniques engaged in preparation of an EPP and the level of sophistication required should reflect the potential hazards and consequences associated with the individual dam. These include, but are not limited to, the downstream population density, land use, and topography. The saddle dam failure or near-failure cases of the Xepian Xenamnoy Dam (the Lao People's Democratic Republic, August 2018) and Oroville Dam (California, United States, February 2017) highlight the importance of having an EPP that includes potential failure modes resulting in high consequences. (See other cases in box 7.2.) A concise and practical EPP may also be required during construction if the failure of a cofferdam or other event could cause serious downstream consequences.

BOX 7.2

A TALE OF TWO DAMS: EMERGENCY ACTION AND PREPAREDNESS PLANNING IN INDONESIA

Case Study 1: Situ Gintung

The 10-meter-high Situ Gintung dam was built in 1933, during the Dutch colonial era. It was located on a tributary of the Pesanggrahan near the village of Cirendeu in the Banten province, which has become part of suburban Jakarta. The dam was initially used for the irrigation of rice paddies, but these paddies were replaced over time by residential development, and the size of the reservoir was reduced. A number of residential dwellings located downstream of the dam may have been illegal and in violation with Spatial Law no. 24/1992 and no. 26/2007.

On March 27, 2009, the Situ Gintung dam failed. Heavy rains increased the water level of the reservoir, causing overtopping and erosion of the dam surface. This resulted in a breach around 2 a.m. The uncontrolled released of nearly 1 million cubic meters of water created a flash flood that inundated more than 400 residential dwellings, displaced 170 people, and claimed the lives of about 100 people. There had been no early warning system in place to avoid the loss of life. One year prior to the event, there had been reports about the vulnerability of the dam, but no action was taken to reduce the risk of dam failure.

(continued)

BOX 7.2 ***(continued)***

Case Study 2: Way Ela

On July 13, 2012, a 5.6-magnitude earthquake hit central Maluku and triggered a landslide that blocked the flow of the Way Ela River. This event resulted in the creation of a natural dam of 215 meters in height and 300 meters in width with a reservoir capacity of 19.8 million cubic meters. Recognizing the potential risk to the 4,777 residents of Negeri Lima village, which was located 2.5 kilometers downstream of the dam, the Directorate General for Water Resources carried out a survey in the immediate aftermath of the event to assess the condition of the dam. The survey results indicated that demolishment of the dam would likely trigger additional landslides. In this context, the government decided to take action to protect the dam and to conduct preparedness activities with the community to maintain public safety in the event of dam failure.

Upstream preparedness efforts of the Maluku River Basin Organization (RBO) focused primarily on the conservation of the natural dam and continuous on-site monitoring. Activities included the installment of water pumps, the construction of a toe drain to collect seepage, and the construction of an emergency spillway to provide controlled release from the dam. In addition, the RBO was involved in monitoring the dam, mostly in terms of the water level and the amount of seepage discharge; establishing an early warning system; and developing an emergency action plan. The early warning system consisted of various sensors to measure the water level, rainfall intensity, and the level of debris, and to provide an early alert of potential dam failure. In the event of dam failure, the system would automatically activate sirens to warn the downstream community. At the same time, downstream efforts focused on avoiding the loss of life in the event of dam failure. While the Maluku RBO took responsibility for conducting a community awareness campaign related to the emergency action plan, the provincial emergency authorities (Indonesia's Regional Agency for Disaster Management, or BPBD) focused on the preparation of the evacuation routes and signs and the organization of different types of simulation exercises with the community to test the standard operating procedures and logistics.

The efforts from July 18 to July 25, 2013, to reduce the water level of the reservoir failed and the condition of the dam became critical. Following the procedures of the emergency action plan, the head of the Maluku RBO notified the governor of Maluku, the regent of Maluku Tengah, and BPBD to start the evacuation. When the dam eventually collapsed within a period of 12 hours on July 25, 2013, nearly all residents of Negeri Lima had moved to the designated evacuation zones. In the end, the timely and effective public alert had saved almost 5,000 lives.

The regulations and guidelines among the case study countries and jurisdictions highlight good practices for emergency preparedness planning. These include (1) periodic review and updating of the plan to reflect organizational changes, (2) training, (3) providing orientation sessions and drills for relevant staff of the dam owner or operator and emergency agencies to ensure their familiarity and common understanding of the procedures, and (4) several levels of testing of the effectiveness of emergency systems (call tests, tabletop exercises, and functional tests), including communication systems and backup systems, and ensuring their satisfactory performance and reliability. It is also common practice to prepare addenda to EPPs in response to changing conditions, such as changes prior to, during, and upon completion of dam safety upgrades, that can affect the risk profile (see box 7.3 on the Kariba Dam rehabilitation).

BOX 7.3

ENSURING CONTINUOUS IMPROVEMENT IN EMERGENCY PREPAREDNESS PLANNING: THE CASE OF THE KARIBA DAM

The rehabilitation of the 128-meter-high Kariba arch dam between Zambia and Zimbabwe highlights the importance of ensuring an adaptive process of continuous improvement to safety and emergency preparedness planning. Given the large reservoir capacity (181 cubic kilometers), a possible catastrophic failure of the dam is predicted to result in devastating flooding, significant loss of human life, and unprecedented economic damage in the region downstream in the Zambezi River, with an estimated 3 million people living in the potential impact area and over US$8 billion of assets at risk.

A dam safety assessment completed in 2010 identified several category I interventions requiring immediate attention. In response, the World Bank, the European Development Fund, and the African Development Bank mobilized to assist the operator, the Zambezi River Authority, in securing the long-term safety and reliability of the Kariba Dam. The works under the Kariba Dam Rehabilitation Project include reshaping of the 80-meter-deep plunge pool at the downstream toe of the dam (photo B7.3.1) and refurbishment of the six spillway gates, which have a total capacity of 9,000 cubic meters per second. The project is also enhancing operations to bring them in line with international dam safety standards (World Bank 2014).

An Emergency Preparedness Plan (EPP) was prepared in January 2014 to be operationalized should an emergency arise. An Operation and Maintenance Plan that covered the reservoir operation procedure, among other elements, was also developed in 2014, and this will be updated and finalized to reflect new operating rules and maintenance requirements six months before

(continued)

BOX 7.3 *(continued)*

PHOTO B7.3.1 Cofferdam construction for the reshaping of the Kariba Dam plunge pool

Credit: Stucky Limited. Used with the permission of Stucky Limited; further permission required for reuse.

recommissioning. In the absence of the rehabilitation works, these require that the operating rule curve be lowered by 3.5 meters.

To inform the EPP for the rehabilitation period and the postrehabilitation operation of the dam, a dam-break analysis was undertaken, financed by grant funding from Sweden and the United Kingdom. Given the transboundary consequences of dam failure to the whole cascade, the analysis and flood inundation mapping covered the whole lower Zambezi River. This included extensive high-resolution LiDAR mapping of the downstream topography in Malawi, Mozambique, Zambia, and Zimbabwe to fill critical information gaps. The flood inundation and risk maps derived from the dam-break analysis are to be integrated into the EPP along with the results from a potential failure modes analysis carried out for the dam.

In preparation for the implementation of the works, specifically before the dewatering of the plunge pool begins, the EPP will be reviewed and will integrate the emergency plans of the contractors. As the works progress, the EPP will be updated as needed before it is finalized one year before recommissioning. Even after the rehabilitation works are completed, the full EPP will be a "living" document, subject to periodic review and revision as relevant facts about the dam and the river basin evolve.

Source: World Bank 2014.

Advanced modelling tools, such as the Life Safety Model (HRW 2019), the LifeSim Model (USACE 2019b), or the lighter HEC-FIA model (USACE 2019a), have been developed to estimate the potential loss of life in case of dam failure or flooding (see box 7.4). These more advanced models may be appropriate when detailed loss of life estimates are required for densely populated urban areas. Such model estimates provide more detailed information that can help dam owners and emergency management authorities improve the effectiveness of emergency planning and responses. However, it is important to give due consideration to the suitability and the limitations of any models to be adopted, particularly within the specific country context. Furthermore, any model estimates relating to the potential loss of life should be subject to evaluation and ground-truthing in association with people familiar with the potentially affected areas.

BOX 7.4

ADVANCED DAM-BREAK FLOOD SIMULATION MODELS

The LifeSim model was developed by Utah State University with support from the US Bureau of Reclamation (USBR), US Army Corps of Engineers (USACE), and Australian National Committee on Large Dams (Aboelata and Bowles 2005) and is a spatially distributed, dynamic simulation model for estimating potential life loss and economic damage by simulating a set of event-exposure scenarios, including various dam failure modes, flood severities and timing (day versus night and weekend versus weekday), and so forth. USACE has also been using HEC-FIA, which contains a simplified version of the LifeSim model.

The Life Safety Model (LSM) was developed by BC Hydro (Lumbroso et al. 2011) with HR Wallingford (UK) and is a physics-based, dynamic numerical model to simulate a set of probable scenarios including variables such as the effectiveness of warning, road capacity, and time-varying population density. The model uses results of flood water depth and velocity from two-dimensional hydraulic models over the course of the event. The model is particularly useful in assessing dam failure and evacuation scenarios in densely populated urbanized areas. The model can be used to simulate evacuation patterns and traffic congestion, simulating the movement of flood water and its interaction with people who may be located within structures, in motor vehicles, or on foot. Fatalities are estimated based on criteria including flood depths, velocity, and exposure periods. USBR has also started using the LSM on a limited basis.

PUBLIC SAFETY

Dam safety programs have been concerned primarily with the prevention of dam failure. They are typically focused on assuring dam structural integrity and protection of downstream populations from catastrophic flooding resulting from a dam breach. Over the years, however, there have been a rising number of casualties resulting from mis-operations, such as sudden increases in turbine discharge, opening of spillway gates without proper downstream warning and patrolling, and other events. This has been accompanied by an increasing public interest in recreation and water sports, much of it taking place in lakes formed behind the dams and in downstream reaches of the river.

As a result, dam safety guidelines and regulations are increasingly including specific provisions to address public safety issues. Examples can be found in Canada (CDA 2011), France, Japan, Norway, and the United States, to name a few. These provisions typically require dam owners to identify potential hazards; install adequate barriers, warning signs, and audible and visual danger signals; and restrict people from downstream watercourses before opening gates and valves for increased power generation or flood discharge. Specific procedures for opening gates and valves are also found in some operation and maintenance plans, along with provisions for downstream warnings. The International Commission on Large Dams European Club's 2012 working group report on public safety at dams (ICOLD 2012) provides information on public safety regulations and good practices in several European countries, noting that France and Norway have taken the lead in public safety management and that integrated safety programs are becoming common practice, including site-specific risk assessment and mitigation measures.

Public safety risk assessments for dams, their appurtenant facilities, and operations are useful in identifying potential public safety hazards and informing the preparation of public safety plans. Public safety plans can include operating practices, warning systems, physical safety measures, public education, and incident reporting. Guidelines published by the Ontario Ministry of Natural Resources in Canada (OMNR 2011) outline the requirements for dam owners in carrying our public safety risk assessments and in the preparation of public safety plans. Similarly, regulations among some European countries require dam owners to report dam safety accidents and incidents and disclose such information to the public. This provides a stronger incentive for companies to enhance their public safety capacity. Some dam owners, such as EDF in France, proactively engage the public in raising awareness about the potential hazards and required precautions. As part of its communications campaign, EDF has disseminated brochures and taught students in schools about safety (EDF 2016).

SECURITY

Dams typically involve many critical assets, the failure or disruption of which could lead to casualties, massive property damage, and other severe long-term consequences. Failure or disruption can also result in interruptions in dependent sectors such as water, energy, and transportation. The consequences of a deliberate attack on any of these critical assets could be wide ranging, depending on the purpose of the facility, the dam's failure modes, system redundancies, downstream population density, and the extent of any associated regional integration. In the United States, dams are defined as 1 among 16 critical infrastructure sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital that their incapacitation or destruction would have a debilitating effect on military security, economic security, national public health or safety, or any combination thereof.

Large dams have already been shown as high-level targets in some parts of the world. The hijacking of the Mosul Dam in Iraq by ISIS, which held it for more than a year, led to the suspension of critical grouting works for reducing foundation seepage and erosion. This raised a number of security concerns. The dam's failure could have resulted in large areas of Mosul (home to around 3 million people) and even Baghdad being flooded. Fortunately, the Iraqi government regained control of the dam and resumed the needed structural and nonstructural remedial measures to secure its continued safe operation in coordination with USBR and other partners.

Issues associated with security are typically discussed only in general terms in the regulatory provisions for dam safety. Where such provisions exist, they typically require the owner to implement measures as directed by the responsible regulatory authority. Other provisions for the security of infrastructure, particularly that of strategic national importance, may be found in other regulatory provisions, and some countries have specific provisions for the national security hazard of dams depending on their location, size, special features, and consequences of failure. Canada, Norway, and the United States, for example, have begun specifically assessing security vulnerabilities of dams to cyberattack, intrusion, sabotage, and terrorism. Special measures have been established, and dam owners are working in collaboration with security agencies to protect the dams from such threats.

Recognizing the severe consequences that could result from the failure of many critical assets in the portfolio of dams across the country or from the disruption to their operations, the US Department of Homeland Security published *Worldwide Attacks Against Dams: A Historical Threat Resource for Owners and Operators* in 2012. The report lists 25 attacks on dams around the world from 2001 to 2011 (see table 7.3), reinforcing the seriousness of the security threats to dams. All of the documented occurrences included physical attacks, involving explosive devices, assault teams, or weapons.

The increasing use of remote supervisory control and data acquisition systems opens a new threat from cyberattacks. A significant cyber incident would likely consist of two distinct but related parts: the actual network penetration (to include data theft or manipulation) and the resulting physical effects of that penetration. In September 2013, the Bowman Avenue Dam in Rye Brook, New York, was the target of such an attack (box 7.5). The hacker accessed the supervisory control and data acquisition system of the dam using a cellular modem but caused no damage because the gate was disconnected for maintenance. If the dam had been operating at the time,

TABLE 7.3 Chronological summary of dam attacks around the world, 2001–11

Facility	Country	Date	Attack type
Lhokseumawe Reservoir	Indonesia	August 17, 2001	Explosive device
Panauti Plant	Nepal	November 24, 2001	Explosive device
Kidapawan Reservoir	Philippines	March 19, 2003	Standoff weapons (rockets)
Kajaki Dam	Afghanistan	May 2, 2003	Standoff weapons (rockets)
Gomal Zam Dam	Pakistan	September 21, 2004	Assault team
Zelenchuck	Russian Federation	September 21, 2004	Assault team
Dumarao	Philippines	December 15, 2004	Explosive device
Selaghat Dam Project	Nepal	December 19, 2004	Explosive device
Mirani Dam	Pakistan	May 18, 2005	Explosive device
Haditha Dam	Iraq	August 2, 2005	Explosive device
Haditha Dam	Iraq	September 2005	Standoff weapons (rockets)
Kajaki Dam	Iraq	September 17, 2005	Explosive device
Hlaingbwe Dam	Myanmar	May 2007	Explosive device
Hlaingbwe Dam	Myanmar	May 2007 and September 2, 2007	Standoff weapons (mortar)
Waeng Station	Thailand	August 1, 2007	Explosive device
Kajaki Dam	Afghanistan	March 30, 2008	Explosive device
Tipaimukh Dam	India	April 26, 2008	Assault team, explosive device
Mosul Reservoir Dam	Iraq	May 1, 2009	Explosive device
Balimela Power Station	India	December 19, 2009	Incendiary device
Mytikyina Dam	Myanmar	April 17, 2010	Explosive device
Thawt Yin Kha Dam	Myanmar	April 27, 2010	Explosive device
Black Rock Dam	United States	July 4, 2010	Incendiary device
Baksan Power Plant	Russian Federation	July 20, 2010	Assault team, explosive device
Machlagho Dam	Afghanistan	July 18, 2011	Assault team
Thawt Yin Kha Dam	Myanmar	July 20, 2011	Standoff weapons (rockets)

Source: US Department of Homeland Security 2012, 9.

the hacker would have been able to open the floodgate remotely. Reducing such risks usually involves removing threat sources, addressing vulnerabilities, and lessening impacts.

Given these threats, owners and operators of critical dams across the United States and other countries have instituted security programs based on risk-informed management principles, including provisions to increase their security posture during heightened threat conditions. The *Dams Sector Crisis Management Handbook* (US Department of Homeland Security 2015)[3] guidance is relevant to any country seeking to develop similar security programs within their dam safety assurance scheme. Recommendations for owners and operators include the following: (1) security plans should be coordinated with EPPs, and an appropriate security representative should be involved in development of the EPP; (2) for dams that involve cyber systems for operating, dam safety incidents caused by cyberattack should be considered during development of the EPP; and (3) dam sites already subject to security incidents might remain dangerous because the perpetrators may still be in the area and may attempt to harm responders. The EPP should address necessary site security actions during these situations.

BOX 7.5

CYBERATTACKS: THE BOWMAN DAM INTRUSION

Between August 28, 2013, and September 18, 2013, computer hackers repeatedly obtained unauthorized access to the supervisory control and data acquisition systems of the Bowman Avenue Dam, a small 20-foot, flood-control dam in Rye Brook, 25 miles north of New York City. The hackers reportedly broke in through a cellular modem.

This access allowed the hackers to repeatedly obtain information regarding the status and operation of the dam, including information about the water levels and temperature, and the status of the sluice gate, which is responsible for controlling water levels and flow rates. Although such access would normally have permitted the hackers to remotely operate and manipulate the sluice gate, it had been manually disconnected for maintenance at the time of the intrusion.

In bringing charges against the hackers, Manhattan Attorney Preet Bharara said, "The infiltration of the Bowman Avenue dam represents a frightening new frontier in cybercrime. . . . We now live in a world where devastating attacks on our financial system, our infrastructure, and our way of life can be launched from anywhere in the world, with a click of a mouse" (US Department of Justice 2016).

Much of the world's infrastructure is privately owned and poorly defended. "These sectors may be particularly vulnerable to cyberattack because they rely on open-source software or hardware, third-party utilities, and interconnected networks," the Congressional Research Service (CRS) warns. The ability to run such systems remotely, as well as conduct maintenance and update software via the web itself, offers hackers all the access they need. Such networks are particularly tempting because they often control operations, and not merely information, potentially magnifying the impact of any attack on them. "Attacks against operations technology are different than information technology attacks because OT attacks can produce kinetic effects," that is, physical destruction, which the CRS report noted with studied understatement (Thompson 2016).

At this point, the effects of a major cyberattack are largely theoretical. The history of significant cyberattacks against critical infrastructure is a short one—few effects have been lasting, and almost none have caused loss of life or systemic costs. A significant cyber incident would likely consist of two distinct but related parts: the actual network penetration (to include data theft or manipulation) and the resulting physical effects of that penetration. With the right tools and intent, malicious actors could damage critical infrastructure in ways that replicate the effects of a major natural disaster.

(continued)

BOX 7.5 *(continued)*

The United States has defined 16 critical infrastructure sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital that their incapacitation or destruction would have a debilitating effect on military security, national economic security, national public health or safety, or any combination thereof. These critical infrastructure sectors are chemicals; commercial facilities; communications; critical manufacturing; dams; defense industrial base; emergency services; energy; financial services; food and agriculture; government facilities; health care and public health; information technology; nuclear reactors, materials, and waste; transportation systems; and water and wastewater systems (Tehan 2017).

While most cyberattacks have limited impacts, a successful attack on some components of critical infrastructure—most of which is held by the private sector—could have significant effects on national security, the economy, and the livelihood and safety of individual citizens. Reducing such risks usually involves removing threat sources, addressing vulnerabilities, and lessening impacts (Fischer 2016).

KEY MESSAGES AND CONCLUSIONS

EPPs are essential in providing a predetermined plan of action that a dam owner should implement if a dam safety emergency develops. Emergency situations can range from temporary disruption of critical functions, to unsafe releases of water, and to severe damage to dams, including their structural failure. Potential dam failure that can lead to high-hazard consequences can result not only from the main dams but also from associated structures, such as saddle dams and cofferdams during construction. Depending on downstream topographical and land-use conditions, a suitable level of survey and flooding simulation should be undertaken to prepare flood mapping with sufficient information (water depth, velocity, arrival time, and so forth) for emergency preparedness purposes.

These emergencies can arise from naturally occurring events (for example, floods and earthquakes), structural deficiencies, equipment malfunctions, accidents, aging infrastructure, or deliberate destructive actions (for example, terrorism and cyberattacks). It is essential that adequate emergency preparedness include public safety and security measures in a dam safety assurance program. Flood water discharge from dams, even well below the maximum spillway discharge capacity, could cause major flooding damage along downstream rivers; proper spillway gates operation and downstream warning procedures should be carefully established and implemented. An emerging area of dam safety focuses on security considerations about vulnerabilities and potential failure or incidents due to deliberate destructive actions.

Clear legal requirements for EPPs should be included in the prevailing regulations. The requirements and level of sophistication for EPPs may vary among different classes of dams but should include minimum requirements. This differentiation should avoid placing an undue burden on owners of smaller, less hazardous dams. A targeted approach for high-hazard, high-risk dams and a less-imposing approach to lower hazard dams should be considered.

Clear technical guidelines should be established for the scope and preparation of EPPs, using potential failure modes analyses where appropriate. The comparative analysis found that EPPs and associated tasks are mandated in most high-income countries, with the following elements typically stipulated among the regulations: (1) the scope of EPP triggering incidents, including dam breach, excessive spillage, and security incidents; (2) guidelines for EPP preparation scope and procedure; (3) clear definition of institutional roles and responsibilities; (4) clear stipulation of consultation and public awareness raising; and (5) types of communication and warning system linked with broad disaster management mechanisms.

Clear institutional responsibilities should be defined, including agencies in charge of emergency management. The EPP should specify a procedure to identify potential emergency conditions at a dam and the actions the dam owner should take to moderate or alleviate the problems, and to minimize loss of life and property damage. It should contain procedures and information to assist the dam owner in issuing early warnings and notifications to responsible authorities in charge of emergency management. It should also contain inundation maps to inform emergency management authorities of the critical areas for action in the event of an emergency. Those authorities have a responsibility to warn downstream communities and guide them in timely evacuation should an emergency associated with a dam develop.

Public safety concerns include events such as failure of a dam's electromechanical system, operations resulting in sudden or unsafe releases of water, and unrestricted public access to hazardous areas around dams and reservoirs. Public safety should also be covered as part of any effective dam safety assurance program. Recent guidelines and regulations in high-income countries have begun to address public safety issues by requiring dam owners to identify potential hazards; install adequate warning signs, sirens, or other devices; and ensure there are no people in downstream river stretches before increasing turbine or flood discharge. Sufficient and appropriate stakeholder consultation and awareness raising should be carried out, and adequate communications and warning systems should be established. Where possible, these should use existing community-disaster-management mechanisms. These examples represent good practice and offer lessons for other countries.

NOTES

1. The EPP is one of four dam safety plans required of clients under the World Bank Safeguard Policy on Safety of Dams (OP/BP 4.37). In the case of new dam construction, a comprehensive EPP must be completed no later than 12 months prior to the first reservoir impoundment. In the case of rehabilitation of an existing dam, a comprehensive EPP should be completed as early as possible during implementation so that any potential emergency situation relating to the dam will not affect downstream investment works, communities, or assets. In all instances, the EPP Framework should be submitted to the World Bank for review before completing appraisal. Although the EPP is sometimes referred to as an Emergency Action Plan, this report uses the term EPP as per OP/BP 4.37 and the Environmental and Social Framework, Standard 4: Community Health and Safety, Appendix 1: Safety of Dams, without any differentiation. It should be noted that ESS4 also uses the term Emergency Response Plan within the broader context, which is considered synonymous to the EPP for dams in appendix 1 of ESS4.
2. See OASIS (Organization for the Advancement of Structured Information Standards), Common Alerting Protocol Version 1.2, July 2010, http://docs.oasis-open.org/emergency/cap/v1.2/CAP-v1.2-os.html.
3. For additional information, see other guides by the Department of Homeland Security: US Department of Homeland Security 2007, 2017.

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8

Funding Mechanisms for Dam Safety Assurance

CONTEXT AND RATIONALE

A financial framework that ensures sufficient funding for sustainable dam operations and a dam safety assurance scheme is critical both for safety and for maximizing the productive life and value of dams. Financing is needed to address deterioration due to aging infrastructure, changing technical standards, and improved dam safety techniques. It is also needed to sustain the evolving policy environment in the sector context. The latter requires understanding precipitation conditions, changes in downstream populations, and shifts in land-use patterns, among others.

The quality of dam safety management and the level of assurance are heavily dependent on financial capacity. Several factors determine the resource requirements and revenue mechanisms: the ownership structure (public or private), the type of operations (hydropower, water supply, irrigation, flood protection, and so forth), and the nature of the oversight mechanisms (self-regulation or autonomous regulators).

The dam owner is responsible for dam safety assurance and needs to make certain that financial resources are available for regular operations, routine maintenance, continued surveillance, and capital expenditures for more significant maintenance or rehabilitation. These are typically balanced against the cost of services to users and, when there is private ownership or participation, incoming revenue and returns to owners. Owners must also budget for the costs of meeting the technical requirements of the regulatory regime. Many dam owners, especially small private dam owners, find it difficult to finance measures needed to upgrade or rehabilitate to meet the changing context.

Adequate financial resources are also required to sustain oversight mechanisms for dam safety assurance. Costs may include support for training private or community dam owners and operators. The costs of planning and policy making at the governmental level may include recruiting staff and/or strengthening the skills and capacities of professionals and technicians as well as the purchase and development of software, data capture, recordkeeping, and information management, among other things. The allocation of resources for these has a direct and sustained impact on the success of dam safety regulation.

Ensuring sustainable and reliable resources remains a challenge in many countries. While the owner is ultimately responsible for dam safety in most jurisdictions, the ability to meet the requirements expected for dam safety assurance in many parts of the world is undermined by tariffs below full cost recovery and competing financial demands on limited government budgets. Without adequate resources, dam owners and/or operators will be unable to carry out the full scope of maintenance and surveillance activities required to ensure adequate safety levels. Similarly, dam owners may not have sufficient resources for the capital-intensive maintenance or rehabilitation works needed throughout a dam's lifetime. In cases where regulatory functions are funded out of the government's regular recurrent budget, competition with other public obligations can lead to underfunding. In a competitive fiscal environment, it is important to have mechanisms in place to ensure resources are deployed in the right place, at the right time, and in the right amounts (box 8.1).

BOX 8.1

COSTS OF DAM REHABILITATION IN THE UNITED STATES

The Association of State Dam Safety Officials in the United States estimated in 2019 that it would cost more than US$70 billion to rehabilitate both the country's nonfederal and federal dams. The Report Card for America's Infrastructure estimates actual spending was only US$5.6 billion.

The association estimated the total cost for 87,640 nonfederal dams at US$65.89 billion, with US$20.42 billion of that applying to 14,343 high-hazard-potential dams. Since 2012, the cost to rehabilitate the 3,828 federally owned dams has increased to US$4.78 billion, with US$3.35 billion of this attributed to 1,286 high-hazard-potential dams.

High-hazard-potential dams are those where failure or mis-operation will likely lead to loss of human life. As populations in many downstream communities grow and those communities develop, the overall number

(continued)

BOX 8.1 *(continued)*

of high-hazard-potential dams will increase. The rehabilitation costs will continue to rise as maintenance, repair, and rehabilitation are delayed.

The US Army Corps of Engineers (USACE) estimates that roughly US$24 billion will be required to address dam deficiencies for approximately 700 dams that it operates and maintains nationwide and in Puerto Rico. Approximately 95 percent of the dams managed by USACE are more than 30 years old, and 52 percent have reached or exceeded the 50-year service lives for which they were designed. Dam safety projects executed by USACE are cost-shared with a local sponsor and vary based on original authorization. The construction is fully funded by the US government up front and billed back to the sponsor over a period of years following construction. Dams with the highest life-safety risk receive 100 percent of what can be efficiently expended in the program year, taking into account both budgeted funds and carryover balances. This includes dams that are currently under study (haven't reached final budget requirement decision) but have fully funded interim risk-reduction measures in place during the ongoing budgetary process. At current investment rates, these repairs would take over 50 years.

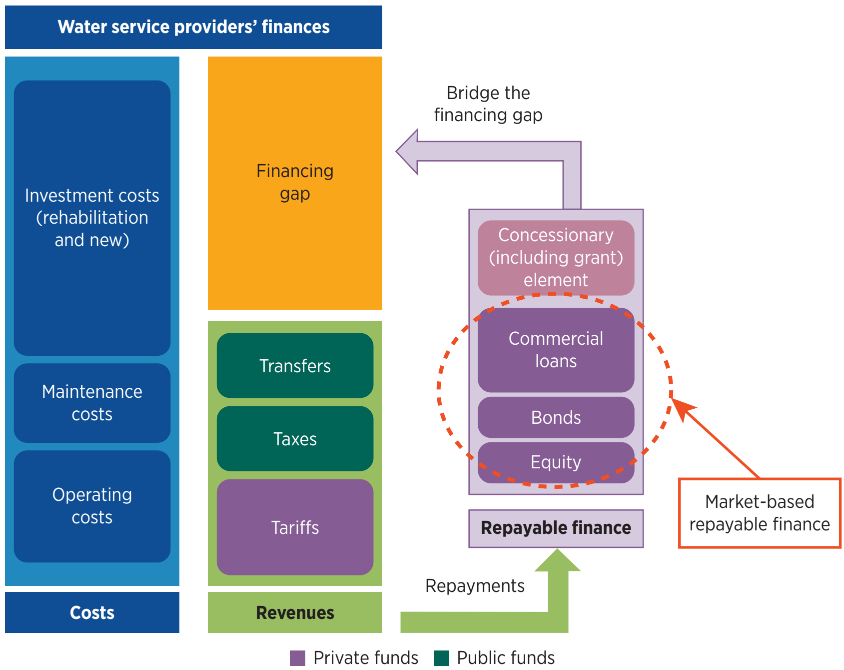
FINANCIAL FRAMEWORK FOR DAM SAFETY

The resources required to sustain dam operations, maintenance, and safety interventions can be derived from three basic sources of sustainable revenues (OECD 2009):

1. Tariffs, which refer to the revenues from users for services provided or charges levied by the regulatory authority
2. Taxes, which are the monies provided by domestic taxpayers to government coffers and subsequently diverted to the water sector, commonly referred to as *subsidies*,[1] or provided to the regulatory authority through government budget allocations
3. Transfers, which are nonrepayable monies provided in the form of grants or in-kind contributions from external sources, such as through official development assistance

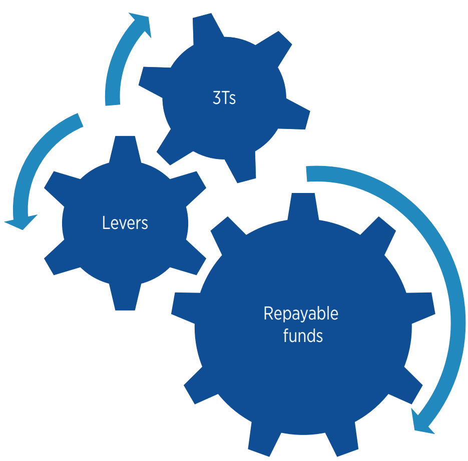
A workable financial framework for dam safety management and assurance disentangles the contributions made by these three sources—tariffs, taxes, and transfers—to distinguish among the direct funding by end users, indirect funding from governments or their agencies, and funding from private sources of finance (figure 8.1). These so-called 3Ts provide a useful entry point for understanding the sources of funding that can sustain dam safety management and assurance (figure 8.2).

FIGURE 8.1 General financing model for the water sector



Source: OECD 2011. Used with permission; further permission required for reuse.

FIGURE 8.2 Financial mechanisms in dam safety management and assurance



Source: Original figure for this publication.
Note: 3Ts = tariffs, taxes, transfers.

Tariffs, taxes, and transfers provide cash flows that can form the basis for attracting repayable finance, such as loans, bonds, and equity, which in turn provide an interim mechanism for bridging funding gaps. Repayable financing is usually mobilized to finance capital expenditure for the development, rehabilitation, or expansion of infrastructure, while ongoing operating costs and ordinary maintenance are routinely financed from a mix of the 3Ts.

There are various ways of leveraging funding raised through the 3Ts to attract repayable finance. These levers work either by mitigating specific risks that would otherwise hamper financing, or by packaging the finance in forms attractive to potential suppliers. These forms could include guarantees, insurance, cofinancing, B-loans, and blending, among other options. The funds themselves can be applied to provide public or private goods that in turn generate revenues. Strategic financial planning is central to finding the right mix of the three sources of funding and leveraging repayable sources of finance.

Loans are an essential part of the financial structure of dams and form a crucial part of ongoing safety initiatives at the owner level. Short-term loans can cover working capital requirements of regulator operation and maintenance, especially if cash flows from dam operations (if any) are unpredictable. However, short-term loans are usually at higher interest rates than others and are commercial in nature, the terms being dependent on revenues from operations. Long-term bank loans are often difficult for owners to access, given the challenges in forecasting the long-term returns associated with large-scale water infrastructure. As a result, they often involve guarantees. Dam owners in countries and jurisdictions where revenue streams may be uncertain or even absent often rely on loans from international financial institutions, which may provide more flexible financing.

Bonds are securities issued by governments, or by utilities and companies, offering a fixed rate of return interest for a number of years and full repayment at a specified date. These are currently employed by various state governments in the United States, where many bonds earmarked for financing infrastructure are tax-exempt. These typically require that there be ring-fenced funding for operation and maintenance, with bond proceeds placed in a trust that is drawn upon to cover operation and maintenance costs over the life of the asset.

In the case of dams, this can have a positive impact on dam safety. In the US state of Pennsylvania, the Department of Environmental Protection requires private owners of high-hazard dams to post a financial guarantee adequate to cover the costs of a breach of the dam if the owner does not comply with department safety requirements (Wilson 2014). An annual permit fee is imposed on dam owners to cover a portion of the department's costs to administer the Dam Safety Program. High-hazard dams in Pennsylvania that are publicly owned do not have to prove fiscal responsibility and are not subject to annual fees. As the required fiscal guarantee can be difficult to meet for many private owners who would be unable to obtain a surety bond to cover the costs of rehabilitation, the department has introduced a scheme whereby private owners can provide a certificate of deposit that the department can draw from if the dam fails (Wilson 2014).

Equity refers to a financial contribution from an investor who then shares the risks for a share in the profits. This can be public or private and is highly flexible. However, for maintenance of dams and their associated structures, the equity contributed needs to earn rates of return conforming to market expectations, which can be challenging to specify. Public-private partnerships can provide a solution, as they typically allow the public sector to retain ownership and a degree of control over dams, while providing private concessionaires the power to operate the infrastructure. The deals tend to bring in private sector expertise, management, and fundraising capabilities, which can be positive for dam safety programs.

Various kinds of risk-sharing and guarantee mechanisms can be used to help dam owners access repayable finance. These mechanisms work either by mitigating risks that would otherwise hamper financing or by packaging the finance in a form that is more attractive to potential suppliers, such as those identified by the Global Water Partnership (GWP 2017). For example, partial risk guarantees provide insurance against dam safety regulatory (assurance) and contractual (operational) risk, while monoline insurance companies offer coverage against the risks of financial default.

Attracting repayable commercial financing for large-scale water projects depends on the prospects for sustaining the future flows of basic revenues derived from the 3Ts. Financial tools such as loans, bonds, and equity cannot substitute for the absence of basic revenues, which are needed for future debt and equity service payments.

FUNDING DAM SAFETY MANAGEMENT

Funding for dam safety management is normally the responsibility of the dam owner and needs to be sufficient to sustain daily operation and maintenance activities, as well as those required under the regulatory regime. Owners and operators typically have more discretion over short-term budget allocations, as these largely depend on the revenues generated through the sale of services, than over long-term allocations for the oversight mechanisms, which typically rely on government budget funding or service fees.

The financial resources available to dam owners and operators are largely determined by the nature of the services they provide. For example, hydropower dams often have stronger revenue streams, linked to the sale of power, as opposed to dams that provide irrigation services, which are linked to food security or rural revitalization policies, or those that provide services in the public interest, such as flood protection. Decisions about the level of service fees are often informed by government policy, which varies among countries and among sectors.

Regardless of the sector and resources, all dam owners have an implicit incentive to assure the safety of the dam and downstream communities. However, dam safety efforts are often affected by the discrepancy between the funding needed versus the funding available, as well as a persistent lack of public awareness about dams and safety (Ingram 2012). Government policies relating to revenues from service fees, or funding strategies on the part of the owners, that focus only on one kind of dam, sector, or the services they provide, at the expense of others, risk undermining dam safety and water security at the national or regional scale (WEF 2011; Peri, Vandone, and Baldi 2014).

When a private dam owner is also the operator, the responsibility for operation and maintenance falls to it to ensure a sustainable flow of revenues and the long-term safety and performance of the works. This arrangement with the owner being responsible for operation and maintenance is often most cost-effective for the owner, since no other party has to bear any of the risks. Depending on the type of dam, in many countries if the owner is a public entity, it may not be in a financial position to ensure a proper level of operation and maintenance and dam safety assurance solely with its own resources given competition for the public budget. This is especially true for sectors with weaker revenue streams.

However, when the operator is a private or semiprivate independent operator, the operation and maintenance responsibility can be fully or partially transferred from the public owner to the private operator through a contract. This type of structure can compensate for weaknesses of public owners, but it is difficult to set up fair contracts balancing risks and rewards.

FUNDING DAM SAFETY REGULATION

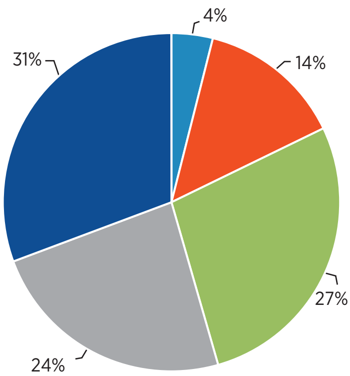
This section refers to the roles and responsibilities of any regulatory bodies with oversight of dam safety assurance. Typically they are financed in one of three ways: taxes dispersed by the government through budget allocations, tariffs received through user-pay systems or service fees, or a combination of both. Funding from tariffs can be collected from users (of electricity, irrigation water, or water supply, for example) or generated through service fees related to dam registration, permits, licenses, inspections, or audits. These can be one-off or annual payments and are often determined either by dam class or a time-based arrangement. In some cases, the regulator may act as a fee-charging consultant.

Information on financing mechanisms for the regulatory regime is often difficult to come by. No data were available in nearly one-third of the case study countries and jurisdictions evaluated (31 percent). No dedicated funding mechanisms were required for a quarter of the case study countries and jurisdictions where there are no formal regulatory oversight mechanisms in place. In the case study countries and jurisdictions where the government funds the regulatory oversight mechanism, the funding generally comes annually via a government consolidated fund as a public good or else it consists of funds set aside specifically for dam safety assurance programs.

Central government revenues are used to fund the dam safety regulatory and assurance scheme in 14 percent of the case study countries and jurisdictions (figure 8.3). This means that the country's entire regulatory regime can be funded via general taxation or through other sources of government revenue without having to set aside specific dam- or water-related funds or revenues. Such set-asides can be challenging in systems where these are ill-defined or there is a lack of user fees or tariffs to generate funds for such schemes.

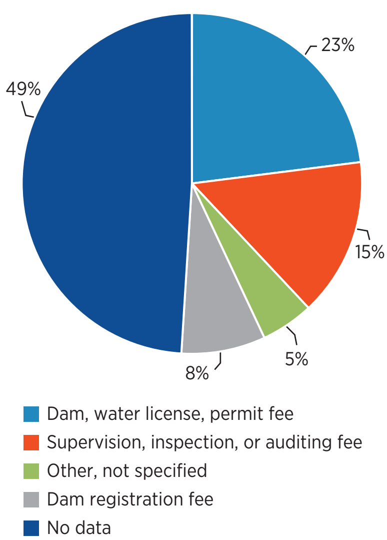
User-pay systems to fund the dam safety regulatory regime were observed only among a small number of the case study countries and jurisdictions (4 percent) and were typically found in places where there are large numbers of privately owned dams. This means that the country's regulatory regime is fully funded through user-compensated schemes via fees levied through

FIGURE 8.3 Funding schemes for dam safety oversight among the case study countries and jurisdictions



Source: Original figure for this publication.

FIGURE 8.4 Types of user-pay systems among the case study countries and jurisdictions



Source: Original figure for this publication.

dam safety or water licenses, dam permits, or similar types of infrastructure and water storage fees.

The more common approach to funding the regulatory regime for dam safety is through a combination of government revenue and user-pay systems (27 percent of case study countries and jurisdictions). This means that equitable funding for assurance of infrastructure from which the user benefits can be supported and supplemented by unspecified government revenue. This is particularly helpful in cases where high rates of poverty make it difficult to raise revenue through user-pay systems.

Types of User-Pay Systems

The most common form of user payments among the case study countries and jurisdictions that rely on these schemes comes from the money that users pay to buy a license or a permit to use the dam itself or access the water it stores. This sort of direct fee arrangement is observed among 23 percent of the case study countries and jurisdictions that have either a user-pay system alone or a mixed system (figure 8.4). This means that the revenues derived from the use of the dam and the storage of water are directly related to assuring the safety of the structure (and surrounding structures) for the benefit of users and the region as a whole.

A more direct user-pay mechanism is a supervision, inspection, and/or auditing fee charge based on the class of dam or a time-based fee calculated according to the time expended by the inspectors or auditors. This is observed in 15 percent of case study countries and jurisdictions. This more closely ties the services provided by the dam safety assurance regime to the benefits received by the owners and users of the infrastructure. This approach also ties the safety performance of the infrastructure more closely to the financing of the dam safety assurance scheme.

The remaining case study countries and jurisdictions that depend on a user-pay system (8 percent) charge users a dam registration fee. Two cases highlighted alternative systems, such as a tax system to fund dam safety assurance or public-private partnerships to fund the scheme. For the majority of cases there are no data available (49 percent). In Sweden, dam owners are required to pay an annual fee to the supervisory authority determined in accordance with a classification system reflecting the societal consequence of a dam failure (see box 8.2).

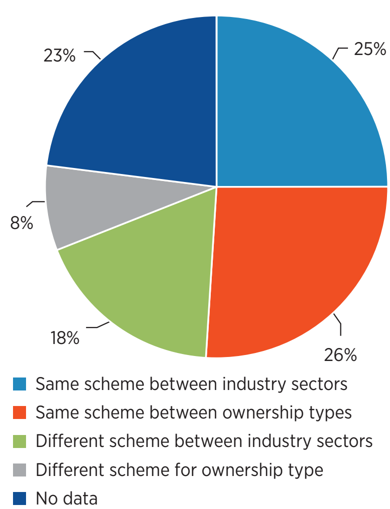
Funding by Sector and Ownership

Funding of the regulatory regime for dam safety assurance must be predictable, reliable, and sufficient to pay for the minimum functions of the regime. While data are limited, only 14 percent of the case study countries and jurisdictions demonstrated or had evidence that the regulatory regime for dam safety assurance is well funded. In 20 percent, dam safety management and assurance is generally accepted to be underfunded.

Overall, hydropower dams that sell electricity according to a Power Purchase Agreement generally have a stronger, more predictable revenue stream compared to dams in other sectors. In many parts of the world, irrigation is linked to government policies on rural development and food security. Water is often free or heavily subsidized by the government. If irrigation service fees do exist they are typically determined on the basis of the irrigated area, rather than on preventive and scheduled maintenance needs of irrigation infrastructure (see box 8.3). Irrigation canal maintenance tends to be prioritized over dam maintenance, which leads to the deterioration of dam structures. Dams built for flood protection often have no direct revenue base, as these services are typically provided as a public good. Where a multipurpose dam is providing public benefits such as flood protection services in addition to its main purpose—hydropower generation, for example—there are instances of private dam owners being financially compensated for the associated generation losses, such as in Japan (box 8.4).

While the case study countries and jurisdictions reported different kinds of dam safety regulation models and funding models among sectors, the analysis found that the financing mechanism for dam safety assurance is typically the same between sectors of industry (25 percent) and public and private sector ownership (26 percent) (figure 8.5). In these instances, hydropower, water supply, irrigation, and both public and private sector owners are all under the same financing scheme for dam safety assurance. However, different financing mechanisms are employed in different sectors in nearly one-fifth (18 percent) of cases and are differentiated based on ownership in 8 percent of cases. This differentiation allows the regulatory regime to take advantage of differences in revenue-generating potential. It also allows an opportunity to cross-subsidize dam safety regulation across sectors.

FIGURE 8.5 Types of user-pay systems between sectors and ownership type among the case study countries and jurisdictions



Source: Original figure for this publication.

BOX 8.2

DAM SAFETY IN SWEDEN

The Swedish National Grid (Svenska kraftnät) acts as the national authority for dam safety and is responsible for promoting dam safety in Sweden. This is achieved by issuing guidelines, providing supervisory guidance on dam safety issues to county administrative boards, supporting the development of emergency preparedness planning for dam failures, and promoting research and development within the dam safety field. Each year, Svenska kraftnät reports to the government about dam safety developments.

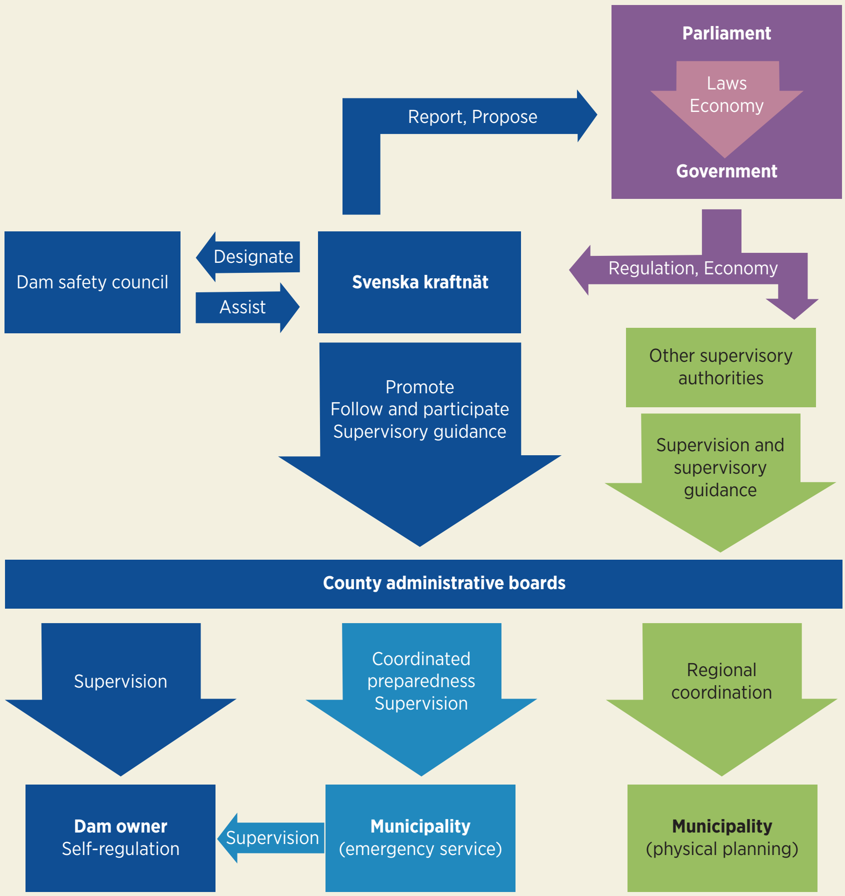
Dam owners have overall responsibility for dam safety, including a liability for consequences of dam failure, and are required to prepare and follow procedures for self-regulation. Sweden's 21 county administrative boards are responsible for dam safety supervision, in accordance with the Environmental Code (see figure B8.2.1 for the country's scheme). This involves confirming adherence with the regulatory framework and the terms of permits allotted by the Environmental Court and that actions are taken by the owner-operator when necessary to improve safety. The county administrative boards are also in charge of ensuring that the municipalities comply with the country's Civil Protection Act. In addition, approximately 290 municipalities across the country are responsible for planning for and providing rescue services in the event of floods caused by dam failure. The municipalities are also responsible for supervising the compliance of dam owners with the Civil Protection Act for dams classified as dangerous facilities.

There are roughly 10,000 dams in Sweden, of which about 500 would result in significant consequences in the event of a dam failure. Dam owners are required to pay an annual fee to the supervisory authority. This is determined in accordance with a societal consequence of a dam failure classification system. Dam Safety Class A includes severe national consequences in the event of a dam failure, and owners are required to pay SKr 96,000. Dam Safety Class B would have severe regional and local consequences, and owners are required to pay SKr 36,000, while Dam Safety Class C would result in severe local consequences from a societal point of view in the event of a dam failure, and owners are required to pay SKr 6,400. On demand, an additional fee of SKr 800 per hour can be charged for relevant supervision.

(continued)

BOX 8.2 *(continued)*

FIGURE B8.2.1 Interacting roles regarding dam safety in Sweden



Source: Svenska kraftnät 2020. Used with permission; further permission required for reuse.

Svenska kraftnät also supports research and knowledge development relating to dam safety. For example, it supports projects under the dam safety program of the Swedish Energy Research Centre (Energiforsk) as well as the Swedish Hydropower Centre (Svenskt Vattenkraftcentrum), which is focused on higher education and research regarding hydropower and dam safety.

BOX 8.3

FINANCING FRAMEWORK FOR DAM SAFETY IN VIETNAM

Vietnam has an extensive network of dams and hydraulic infrastructure that includes over 7,000 irrigation dams and nearly 300 hydropower facilities of different types and sizes. In 2008, Government Decree no. 115 exempted water charges for rice cultivation, animal husbandry, industrial crops, aquaculture, electricity generation, transportation, and tourism. The funding required for operation and maintenance is provided by the state and local authorities, according to established criteria.

The proposed new Government Decree no. 72 on dam safety provides for "Funding the Implementation of Dam Safety Management" under Article 23. Commercial enterprises are required to finance dam safety measures from their own resources, while the funding for the safety for irrigation dams is required to comply with the State Budget Law, specifically: (1) expenditures for nationally important dams and large dams are guaranteed by the central budget allocated by annual plans and other legitimate funding sources, and (2) expenditures for small and medium dams are financed by local budgets and other legitimate funding sources. This includes both capital and recurrent expenditures.

The irrigation water charge rates are established according to the specific irrigation method (gravity, pumping, and combination of them) and according to the region, and are used to provide subsidies. For centrally run irrigation schemes, the state covers 100 percent of the irrigation charges under several scenarios. Where localities transfer 50 percent or more of the income to the central budget, they are responsible for 100 percent of the exempted irrigation charge amounts. Where localities transfer less than 50 percent of income to the central budget, they are responsible for 50 percent of the exempted irrigation charge amounts. Localities offset the difference between the actual exempted irrigation charge amounts and the support from the central budget. These irrigation water charges were increased in 2012.

Investments in major rehabilitation works and new construction are based on norms and unit costs stipulated by the Ministry of Construction, while routine operations and management budgets are prepared by Irrigation Management Entities, agricultural cooperatives, and communes based on surveys of actual needs. These are aggregated through the annual work plan and budget and submitted to the central level for review and to the provincial level for approval. This approval typically takes place toward the end of each fiscal year, and budgets are allocated toward the end of the first quarter of the following fiscal year.

In 2015, the World Bank approved a US$415 million loan to the government for the Dam Rehabilitation and Safety Improvement Project. The project's

(continued)

BOX 8.3 *(continued)*

development objective is to improve the safety of targeted dams under the Government's Dam Safety Program to protect downstream communities and economic activities through priority investments and capacity enhancement. In addition to supporting deferred maintenance and rehabilitation, the project is aimed at supporting the government's efforts to introduce asset management systems that assist in assessing the specific operation and maintenance needs for specific dams and use this to guide budgeting decisions calculated on an as-needed basis.

BOX 8.4

THE JAPAN WATER AGENCY'S FINANCING MECHANISM

The Japan Water Agency (JWA) was established as an incorporated administrative agency in October 2003 by legislation transforming the Water Resources Development Public Corporation. It is tasked by the national government to carry out "administrative tasks and projects, implementation of which should ensure public benefits such as stable public life and social and economic activities."

JWA has adopted management methods of the private sector and is given considerable autonomy in its operations. Responsible for water resources development of seven major river systems covering large metropolitan areas based on the country's Basic Plan for Water Resources Development, it is engaged in the construction of dams, barrages, canals, and so forth as well as their operation and maintenance (O&M) after completion.

The agency has two main sources of funding: (1) government funding for flood control functions associated with multipurpose dams through annual allocations in the public budget; and (2) tariffs from users who benefit from its provision of urban water supply, irrigation, and hydropower services. Users—including national government ministries, electric power companies, water utilities, and farmer-led Land Improvement Districts (LIDs)—commission JWA to develop new water infrastructure projects, and they bear their share of construction, as well as O&M, costs.

The cost allocation scheme for multipurpose dams is defined by the 1967 Multipurpose Dam Act and its ordinance: "The Total Cost (TC) is divided into: i) Separable Costs (SC) and ii) Non-Separable Costs (NSC)." The SC for each participant is determined based on the incremental cost when it participates in the project as the "last" participant. The NSC is the residual of the TC minus the total SC of all participants, also referred to as the

(continued)

BOX 8.4 *(continued)*

"remaining joint project cost." The NSC is allocated to all participants proportional to the remaining benefit (RB) for each participant. The RB is determined by first calculating the substitute construction cost (SCC) for each participant: the cost of a hypothetical single-purpose "substitute" dam in the absence of the joint project. The second step is to calculate the feasible (or justifiable) investment costs (FIC) for each participant based on the economic or financial benefits. The third step is to calculate the RB for each participant by deducting the cost of constructing its dedicated facility and SC from the lower cost of either SCC or FIC for each. Finally, the allocated cost of the total cost for each participant is calculated as the sum of SC and RB. Each participant also covers the cost of any dedicated facilities.

The JWA leverages the different sources of funding to raise money by issuing water resources bonds. These can reduce initial investment costs for large multipurpose dam projects, allowing the water users for domestic, industrial, and irrigation to repay their portion in an amortized manner over a longer period.

Participatory Irrigation Management: Land Improvement Districts in Japan

Japan's LIDs are participatory irrigation management organizations established by the Land Improvement Law of 1949. Beneficiary farmers are responsible for irrigation water management and O&M of facilities under the "beneficiaries-pay-principle." More than two-thirds of farmers in an LID must agree on the implementation of new projects, and after they are constructed, most project facilities are operated and maintained by either the local government or the LID.

The required O&M costs are covered by "ordinary levies" collected from the LID member farmers. On average, about two-thirds of total annual O&M cost is covered by the commissioning LID, and the remaining one-third is covered by farmers' voluntary services, according to Japan's Ministry of Agriculture, Forestry and Fisheries (MAFF). As of 2013, about 58 percent of Japan's major irrigation facilities, including dams, weirs, and pumping station projects implemented by MAFF, have been transferred to and managed by LIDs.

LIDs manage 68 percent of the dams in operation in Japan, followed by local governments (27 percent) and the national government (5 percent). Japan also has around 210,000 *tameike,* or traditional farm ponds. Three-quarters of these off-river water storage facilities were built before the Meiji Restoration in 1867, and about 70 percent of them are now managed by LIDs.

Creating Incentives for Funding Dam Safety Management and Regulation

Public funding for dam safety assurance has to contend with competing priorities in a fixed budget environment. Despite the low probability of dam failure, the risk of societal consequences often results in governments prioritizing dam safety assurance in the context of other risks and areas that require policy intervention. Indications show that nearly one-third of all case study countries and jurisdictions prioritized dam safety assurance, with another 25 percent placing a moderate priority on dam safety assurance. However, this does not necessarily translate into financial allocations, and only 14 percent of the case study countries and jurisdictions have a well-funded dam safety assurance program. A similar portion of the case study countries and jurisdictions did not clearly identify any priority interventions around dam safety assurance, typically when there is no assurance or dam safety program in place. Specific measures can be introduced to facilitate the prioritization and allocation of resources.

Economic and Financial Incentives to Improve Assurance

There are a few different forms of economic and financial incentives that can be used to achieve policy objectives for safe and sustainable dam management. These depend largely on the specific country circumstances. For example, government agencies can provide financial incentives to dam owners in the form of lump sums, installments, or tax benefits that are linked to achieving certain goals and performance targets (Debailleul 1997; Tingey-Holyoak 2014).

Although such incentives can impose recurrent costs on the government, they may be more cost-effective than dealing with the consequences of a dam failure. Additionally, the inclusion of positive incentives can remove the need for more coercive instruments that might be costly to administer and monitor (Pisaniello 2016; Pisaniello, Tingey-Holyoak, and Burritt 2012). Previous research has shown that positive incentives can motivate dam owners to move from unsafe, unsustainable dam practices to improved management (Gunningham and Grabosky 1998).

The main resistance to changing practices relating to the regulation of dam safety management is typically the potential financial burden imposed on owners, operators, and communities. However, much of this can be overcome through education and information. In some cases, water rights can create ownership for a resource and a subsequent incentive to manage the resource sustainably.

KEY MESSAGES AND CONCLUSIONS

The financial framework for ensuring an adequate level of funding for dam safety and the regulatory assurance scheme is critical to sustainable dam operations and also extends the dam's value and life. However, the analysis revealed limited available data on how countries and jurisdictions finance dam safety management and regulation. Where such data are available from the case study countries and jurisdictions, distinct differences are revealed in the financing mechanisms for both dam safety assurance and management when considering the sector and ownership models.

These differences often reflect the revenue-generating potential of a dam, which can create inequities in the dam safety assurance regime. For example, long-term contractual arrangements, such as power purchase agreements associated with hydropower projects, provide more reliable and predictable sources of finance to support dam safety management and assurance. This is in contrast to public investments in sectors that might be prone to the influence of competing policy priorities, such as the irrigation sector, where service fees are often too low to ensure secure and sufficient revenues. Mechanisms can be introduced to restructure these inequities, such as facilitating cross-subsidization between the public and private sectors or between different sectors.

Ownership structures can create barriers to investment, even in the most developed countries. For example, 58 percent of all US dams are privately owned, most of them in the farming sector. These dams produce only on-farm revenue from production and are financially isolated from the dam safety assurance scheme, aside from the permits and water licensing required by several state governments (Ingram 2012). Local and state governments own about 20 percent of dams nationwide; the federal government and public utilities own only a small percentage. As a result, water rates and other types of revenue are limited in being able to fund large-scale assurance schemes beyond self-assurance and regular operation and maintenance (ASDSO 2016; ASCE 2017).

The operation, maintenance, and rehabilitation of dams can cost from the low thousands to millions of dollars, and responsibility for these expenses lies with owners. While loans and green bond programs exist in several countries, funding assistance through public or private sources is relatively low (see, for example, ASDSO 2019). As such, economic theorizing and analysis of the link between water storage sectors and ownership types, and their correlations on a global scale, are still needed. While data are notoriously challenging to obtain, further analysis could consider price relationships and the interrelationships with revenue sources from both private and public sectors.

Funding mechanisms for dam safety assurance could be identified for fewer than half of the case study countries and jurisdictions; most of what could be found relied on a mixture of central government allocations and user-pay systems. For those relying on user-pay systems in some way, payments commonly took the form of license and/or permit fees for either the dam itself or the water it stores. Where the regulatory oversight mechanism is government funded, it is generally funded annually from the government's consolidated fund as a public good or from earmarked funds set aside for dam safety assurance programs. While data are limited, only 14 percent of cases analyzed demonstrated or had evidence that their dam safety regulation and assurance programs are well funded. In 20 percent of country cases, dam safety management and assurance is generally accepted to be underfunded.

Sources of funding for the dam safety regulatory regime are generally limited to the so-called 3Ts: tariffs, taxes, and transfers. And the 3Ts approach is not without challenges when it comes to dam safety. Usually these are oriented around the notion that taxes can be challenging to prioritize: public budgets are limited, and taxes generally get subsumed by general budgets. Furthermore, when taxation systems are involved, there can be competition from more powerful stakeholders whose economic argument may not be well supported.

Repayable finance can help leverage revenue streams to bridge financing gaps through capital markets, issue of loans, bonds, or equities. Strategic financial planning coupled with tools to facilitate the prioritization of dam safety measures and resources within a portfolio approach can be useful in limited budget environments. These should be positioned within a multicriteria framework that can match the resources with the requirements to address the broad range of needs.

NOTE

1. All subsidies are referred to as *transfers* under the System of National Accounts and the System of Environmental-Economic Accounts for Water. These provide a comprehensive, consistent, and comparable (the 3Cs) framework established by the United Nations for measuring the financing mix by national statistical agencies. Subsidies can have domestic or foreign sources. Under the so-called 3Ts, monies paid through subsidies coming from domestic sources are included as taxes, while subsidies paid through foreign sources of money are included as transfers.

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9

Transboundary Implications for Dam Safety Assurance

CONTEXT AND RATIONALE

Dams located in international or subnational transboundary river basins create complex interdependencies. Each presents a unique set of considerations for the safety of dams and downstream communities. These include different—and sometimes conflicting—legal, cultural, and political regimes; enabling institutional arrangements; and historical considerations informed by socioeconomic and biogeographical features. Dam safety is typically administered at the national and/or state levels, and there are diverse public safety and economic security considerations shared among different countries or subnational jurisdictions concerning dams in transboundary rivers.

The common-pool nature of water resources in transboundary river basins and associated mutual dependencies have fostered a set of legal principles establishing equitable and reasonable use and the due diligence obligation to prevent significant harm. While the considerations involved in collaborative and cooperative action present complex challenges, they also provide opportunities to optimize regional benefits and mitigate shared risks related to the safety of dams and downstream communities. These risks include those of climate variability and climate change, which often disproportionately impact poor and vulnerable communities.

Non-cooperative and competitive behavior among riparian states and subnational jurisdictions in transboundary basins can result in less than optimal development outcomes and increase the risks associated with the safety of dams and downstream communities. There are several barriers that can accentuate the challenges of ensuring the safety of dams in the transboundary context and of optimizing opportunities around common-pool, transboundary water resources. These include the asymmetric information available among the riparian states or subnational jurisdictions, technical uncertainties, conflicting individual versus collective interests, political and sovereign rationality, asymmetric characteristics among riparians, and a disconnect between the interests of those upstream of a dam and those downstream. This is particularly true if one country or jurisdiction places unilateral demands on available water resources while ignoring the costs and risks imposed on other riparian states or subnational jurisdictions that depend on those resources. Dams often represent the most acute manifestation of these risks.

In contrast, cooperation around the development and management of transboundary waters and dam safety can substantially increase long-term development gains, provide sustainable benefits (Subramanian, Brown, and Wolf 2012), and enhance the safety of dams and downstream communities. Benefits at the basin level can include the following:

- More effective emergency preparedness
- Improved management and coordinated operation of water infrastructure to accommodate multipurpose water use
- The possibility of jointly facing common external threats, such as floods, droughts, and other climate risks
- Optimized location of infrastructure to increase benefits and reduce costs
- Enhanced resilience and environmental sustainability
- Increased financial and economic returns
- Increased economies of scale
- Improved political stability and peace dividends
- Accelerated economic development

Transboundary cooperation around dam safety aims to improve the capacity of countries or subnational jurisdictions to manage risks related to the safety of dams and downstream communities and to reduce the probability of a dam failure or mis-operation. Failure to acknowledge and address the interdependencies associated with dams in transboundary basins may result in serious impacts across boundaries. These can accentuate flooding, impacting downstream communities, undermining the integrity of other infrastructure in the basin, and otherwise having regional economic implications (see box 9.1). Proper management of dam safety–related risks with transboundary impact contributes to the improvement of environmental governance and performance across the region, which safeguards communities as well as the natural environment. Transboundary cooperation on dam

BOX 9.1

REGIONAL DEPENDENCIES ASSOCIATED WITH THE KARIBA DAM REHABILITATION

The Kariba Dam has been generating electricity and regulating flows in southern Africa's Zambezi River Basin since it was completed in 1959. With a height of 128 meters, a crest length of 617 meters, and a reservoir capacity of 181 cubic kilometers, this double-curvature concrete arch dam impounds one of the largest reservoirs in the world. While originally built to provide power to the rapidly developing mining economies of the then Federation of Rhodesia and Nyasaland (modern-day Malawi, Zambia, and Zimbabwe), today the reservoir plays an important role in ensuring the stability of the Southern Africa Power Pool and in regulating flows on the Zambezi River. With a total installed capacity of 1,830 megawatts, it is the second-largest hydroelectric scheme in the Zambezi River Basin; the largest is the Cahora Bassa complex (2,075 megawatts) situated downstream in Mozambique.

In 2014, the Zambezi River Authority launched the Kariba Dam Rehabilitation Project to improve the dam's safety and reliability with support from the World Bank, the European Development Fund, and the African Development Bank. Given its large reservoir capacity, a catastrophic failure of the dam could result in devastating regional flooding, significant loss of human life, and unprecedented economic damage in downstream communities along the Zambezi River. Model estimates suggest a catastrophic failure would likely result in a flood volume four times larger than the largest ever flood on record for the Zambezi River Basin. This could result in the loss of roughly 40 percent of the Southern Africa Power Pool's generation capacity, impact an estimated 3 million people downstream, and place more than US$8 billion of assets at risk.

Source: World Bank 2014.

safety contributes to the creation of a regulatory and institutional environment conducive to sustained economic growth in the entire transboundary basin (Karabanov 2017).

The number of large-scale infrastructure projects being developed by one or more of the riparian countries and/or subnational jurisdictions in shared river basins is likely to increase as competition for water resources grows, projects in national basins are exhausted, and climate change intensifies hydrological variability and unpredictability. In addition, shared river basins covered by an agreement present higher rates of dam construction (table 9.1) and a more equitable distribution of dams across the different sections of the transboundary basin. Therefore, as transboundary water cooperation increases, it could be expected that the rate of dam construction and thus transboundary dam safety–related risks will also increase.

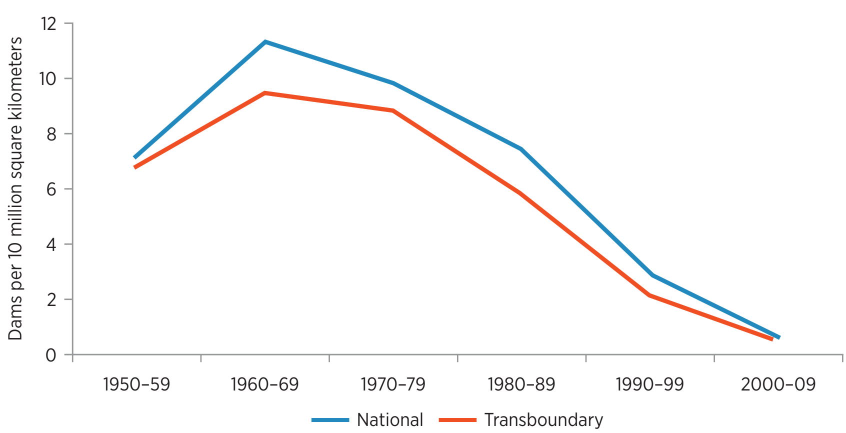
Historically, the number of large-scale infrastructure projects that have been developed in national river basins has been higher than in transboundary basins (figure 9.1). However, the divergence between the number of new projects being developed in national basins has reduced at a greater rate than those in transboundary basins, approaching an inflection point. This trend is broadly reflected in the portfolio of World Bank–financed projects, which has shown an upward trend since 2004 in financing for large dam projects either in, or dependent on, international transboundary waterways (figure 9.2). The highest number of dam safety–related projects in international transboundary waterways is in Sub-Saharan Africa. This is not surprising, given the high level of dependency among countries in Sub-Saharan Africa on international waters and the fact that every country across Sub-Saharan Africa shares at least one river with another country.

TABLE 9.1 Dams constructed in transboundary basins with and without governing agreements

Location within transboundary basin	Number of dams constructed (per 100,000 km^2 per year)	
	Without agreement	With agreement
Upstream	1.8	4.6
Midstream	0.7	2.9
Downstream	1.0	4.5

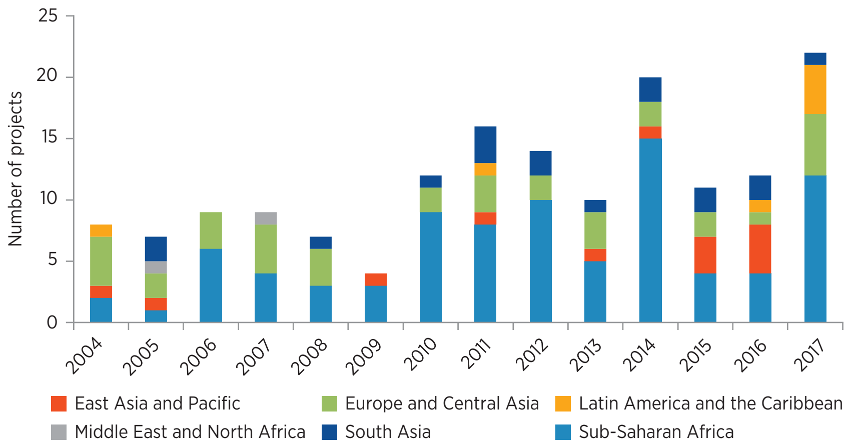
Source: Petersen-Perlman 2014. Used with permission; further permission required for reuse.
Note: km^2 = square kilometers.

FIGURE 9.1 Dam construction in transboundary and national basins, 1950–2009



Source: Petersen-Perlman 2014. Used with permission; further permission required for reuse.

FIGURE 9.2 World Bank–financed transboundary projects related to dam safety approved in FY04–FY17, by region



Source: Original figure for this publication.

The successful development of large-scale infrastructure projects in transboundary basins relies heavily on equitable agreements that enable cooperation and coordination among participating countries or jurisdictions. Data suggest that the presence of these international agreements leads to a greater number of such projects being developed in the basins that have them. Under the general principles of international transboundary law, the interests of all riparian states have to be taken into account and coordination mechanisms put in place—including institutions and alignment equivalent to national legal frameworks—to assure the safety of the dams and downstream communities. Riparian and subnational states can benefit from optimizing the location of infrastructure, enhancing the exchange of information relating to operations, and coordinating emergency preparedness to avoid harm to other riparian countries or subnational states in the basin (box 9.2).

BOX 9.2

REGIONAL DAM SAFETY PROGRAMS IN CENTRAL ASIA

Increasing concern in Central Asia over the safety of dams and other water-control facilities, located mostly on transboundary rivers, prompted Kazakhstan, the Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan to embark on a regional program to improve the capacity for cooperation on dam safety.

(continued)

BOX 9.2 *(continued)*

Aging dams and inadequate maintenance, coupled with population growth in downstream communities, have resulted in an increasing risk to life, infrastructure, and the environment in Central Asia. The countries launched a new program of cooperation aimed at the development of institutions, legislation, capacity building, and subregional cooperation for the safety of dams located on transboundary rivers in the region, with support from the United National Economic Commission for Europe, in partnership with a dozen international and regional organizations.

The program was implemented over more than a decade through three phases. The objectives were to (1) improve interstate cooperation as well as awareness on dam safety and related issues, (2) improve national legislation and regulatory frameworks related to dam safety, (3) increase the technical and legal capacity of experts and officials on dam safety issues, and (4) improve safety and transboundary cooperation on individual dams.

In addition to providing a forum for dialogue, the program also contributed to the development of a regional legal framework for dam safety and influenced national legislation, standards, and institutional responsibilities for dam safety, while building capacity and expertise that have served as concrete vectors for confidence building and practical transboundary cooperation.

Source: UNECE n.d.

CRITERIA FOR DETERMINING TRANSBOUNDARY DAM SAFETY

Understanding the importance and magnitude of the potential issues around the safety of dams and downstream communities in transboundary river basins depends on the criteria and definitions used to identify projects. The International Commission on Large Dams (ICOLD) considers a large dam to be international only when the abutments are located in different countries.[1] According to this criterion, ICOLD's World Register of Dams database identifies 59 such dams with a transboundary character. The majority of these are located in Europe and Central Asia. However, extending the definition to include dams located in transboundary basins that could have a transboundary effect in case of failure or mis-operation, that number increases considerably. Any dam situated on a transboundary river upstream of a border can cause a downstream impact in another country and requires special consideration to ensure the safety of downstream communities, assets, and the environment. According to this broader definition, the number of large transboundary dams increases from 59 to more than 2,924 large dams (see table 9.2, map 9.1, and map 9.2), located in 40 percent of the world's more than 310 transboundary river basins.[2] This transboundary context creates an additional complexity for assuring the safe operation and maintenance of hydraulic infrastructure and the safety of downstream communities.

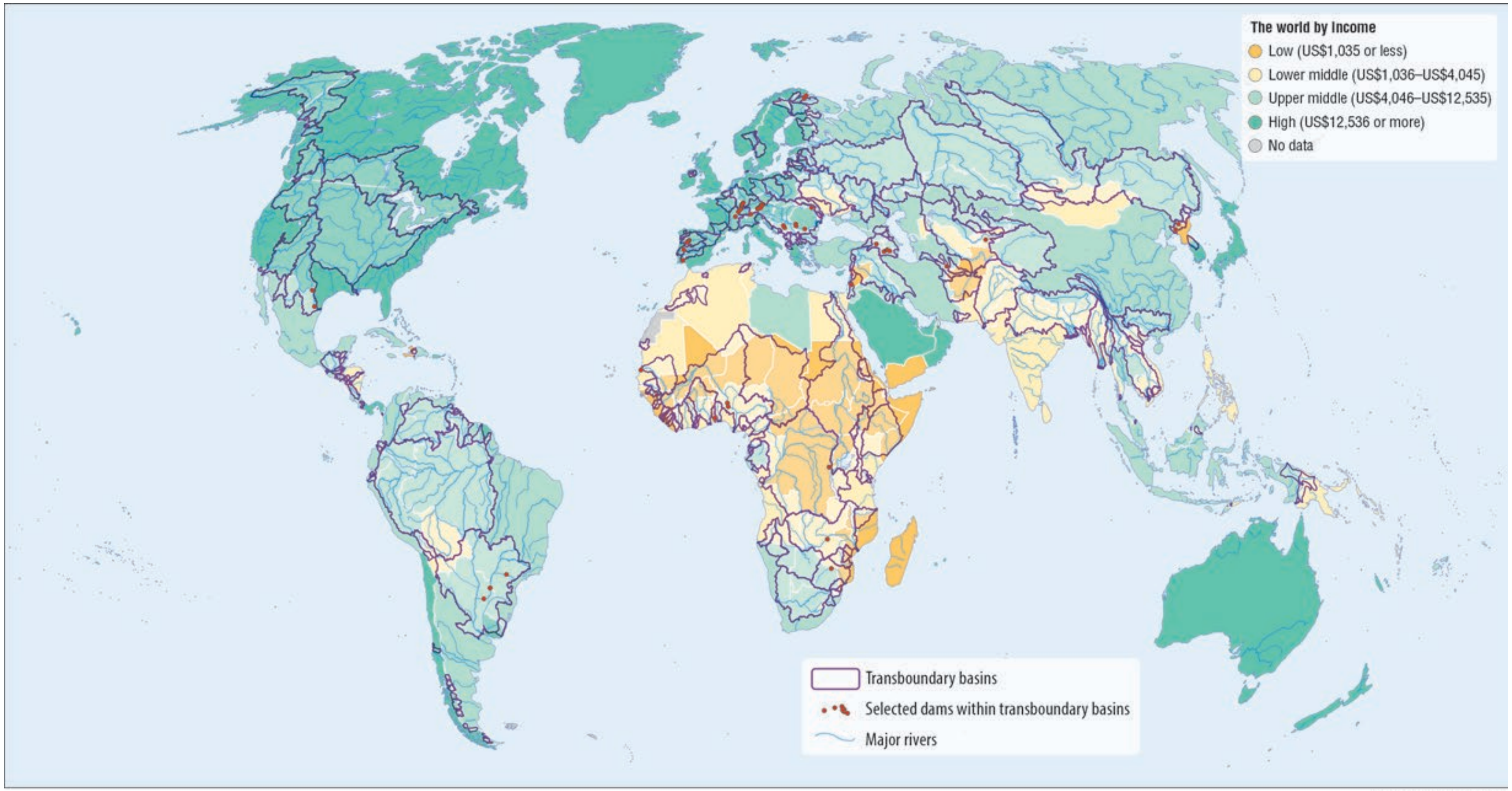
There are also an estimated 1,416 new large dams and water diversions under construction or planned in at least 57 transboundary river basins worldwide (map 9.3). The highest number of dams proposed, planned, or under construction in transboundary basins is in Asia, with 807 identified projects, followed by South America (354), Europe (148), Africa (99), and North America (8). These projects are highly concentrated in very few basin country units (BCUs),[3] with 16 BCUs accounting for 77 percent of projects. Three of these BCUs have over 100 dams either planned or under construction, including 183 projects in the Ganges-Brahmaputra-Meghna Nepal BCU, 155 projects in the Amazon-Brazil Basin, and 115 projects in the Ganges-Brahmaputra-Meghna India BCU (de Stefano et al. 2017).[4]

TABLE 9.2 Breakdown of transboundary dams versus dams located in transboundary river basins, by World Bank geographic region

Region	Total number of dams	Transboundary dams	Dams located in transboundary basins
East Asia and Pacific	29,588	2	127
Europe and Central Asia	7,113	42	772
Latin America and the Caribbean	2,633	4	151
Middle East and North Africa	1,507	1	59
North America	10,435	2	1,212
South Asia	5,381	0	120
Sub-Saharan Africa	1,861	8	483
Total	**58,518**	**59**	**2,924**

Sources: Total number of dams and transboundary dams: ICOLD World Register of Dams database, https://www.icold-cigb.org/GB/world_register/world_register_of_dams.asp. Dams located in transboundary basins: Global Reservoir and Dam Database (GRanD), http://globaldamwatch.org/grand/.
Note: The World Bank's list of countries by region can be found at https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

MAP 9.1 Transboundary dams with abutments located in more than one country



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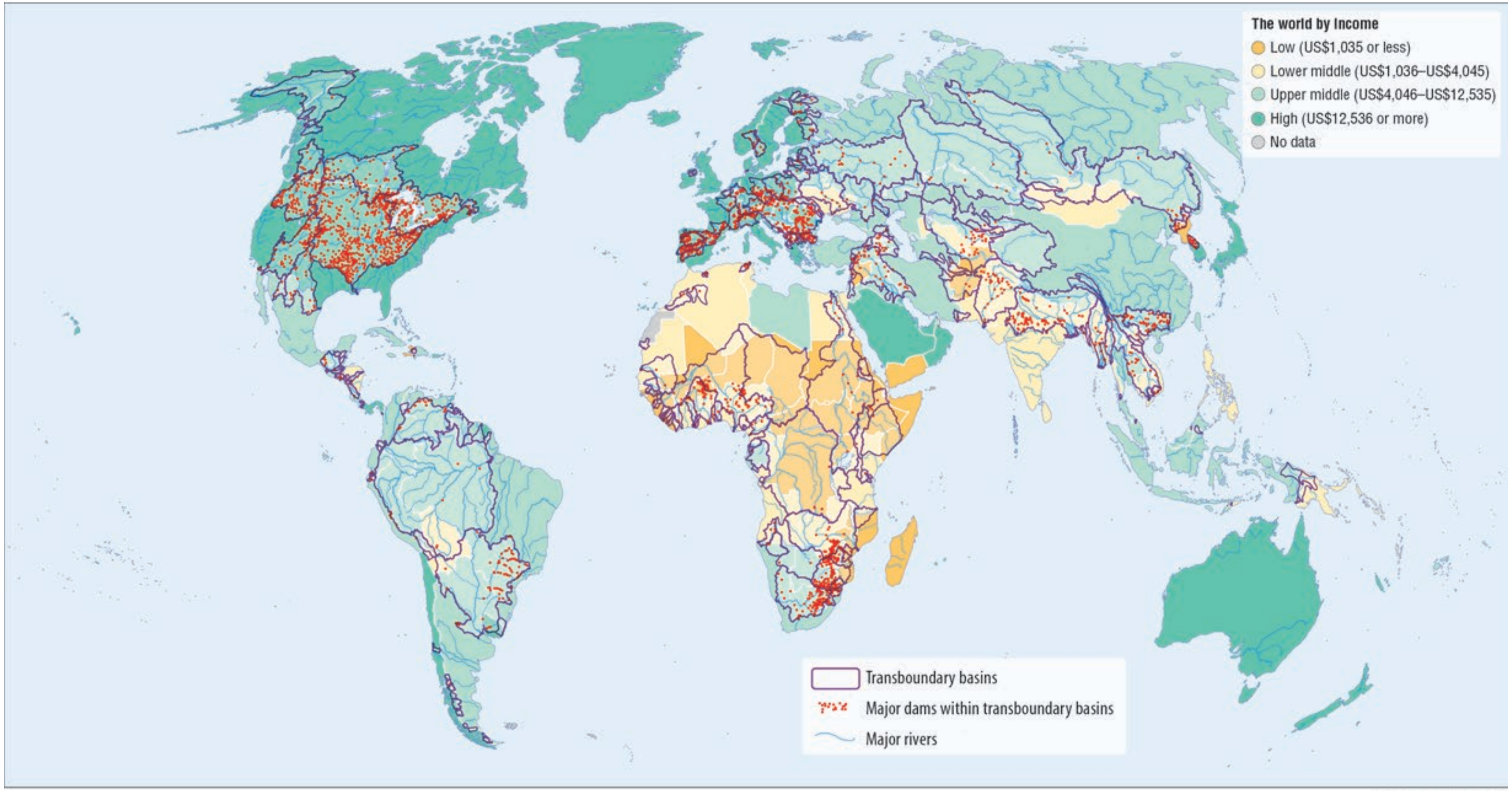
Source: World Bank, based on ICOLD, World Register of Dams database.
Note: Income levels are gross national income per capita for 2019 and are defined using the World Bank Atlas method. See https://datahelpdesk.worldbank.org/knowledgebase/articles/906519/.

MAP 9.2 Dams located in transboundary river basins, based on the Global Reservoir and Dam Database (GRanD)



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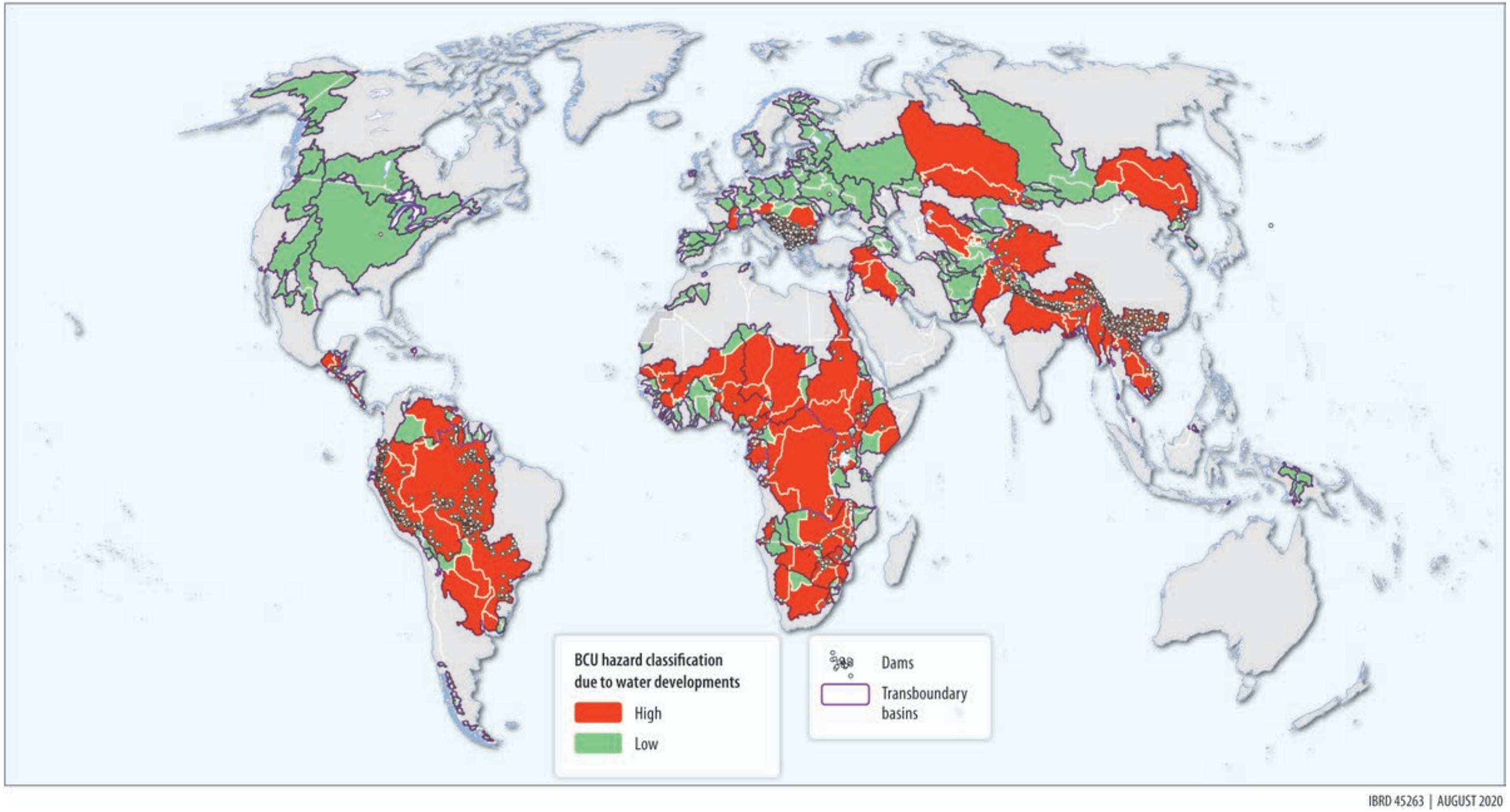
Source: World Bank, based on the Global Reservoir and Dam Database.
Note: Income levels are gross national income per capita for 2019 and are defined using the World Bank Atlas method. See https://datahelpdesk.worldbank.org/knowledgebase/articles/906519/.

MAP 9.3 Distribution of large dams and water diversions planned and under construction in transboundary BCUs



Source: de Stefano et al. 2017. Adapted from Transboundary Freshwater Dispute Database (TFDD), College of Earth, Ocean, and Atmospheric Sciences, Oregon State University; cartography by Eric Sproles. Additional information about the TFDD can be found at: https://transboundarywaters.science.oregonstate.edu/. Used with permission; further permission required for reuse.
Note: A BCU (basin country unit) is the land area portion of a transboundary river basin that belongs to a riparian country. "BCU hazard classification due to water developments" means a classification of BCUs according to the potential downstream stresses that dam development could bring. High hazard (in red) means that potential new dam development in the BCU or upstream of it could impact the BCU. Low hazard (in green) means that there is no presence in the BCU or upstream of it of any new dam development. The data analysis for this map used the data stored in the TFDD as of December 2014: http://gis.nacse.org/tfdd/index.php.

LEGAL FRAMEWORKS FOR TRANSBOUNDARY DAM SAFETY

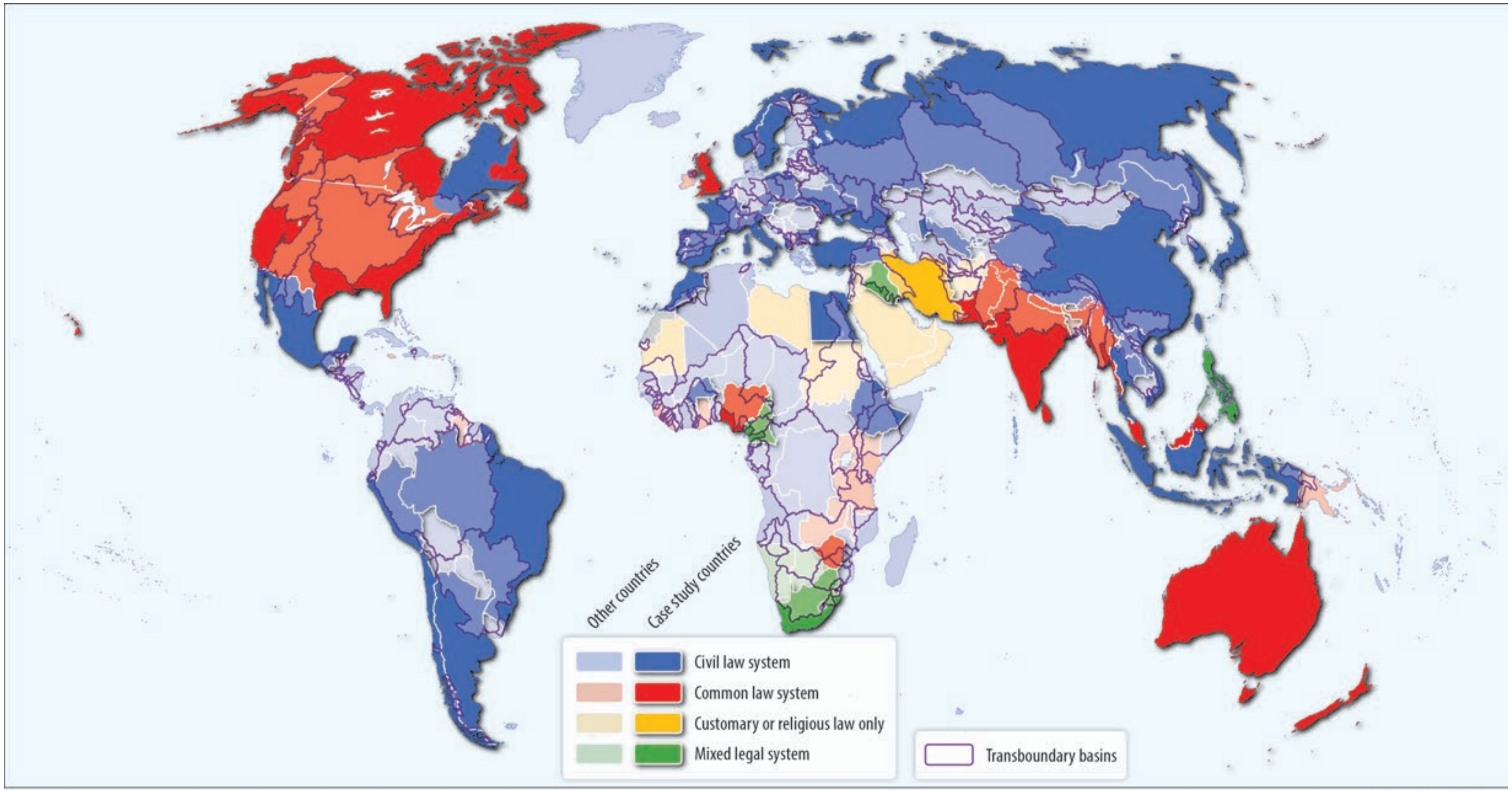
The 51 case study countries and jurisdictions include dams located in 208 (67 percent) of the world's estimated 310 transboundary river basins. These 208 basins include most of the world's largest transboundary rivers, accounting for roughly 40 percent of the world's total land area and 97 percent of the total land area covered by transboundary basins. The total population in these 208 transboundary basins is estimated to be on the order of 2.74 billion people—nearly 40 percent of the world's total population and 98 percent of all those living in transboundary basins.[5]

The prevailing legal regimes in the transboundary basins reflect those of the riparian states and include a combination of civil and common law systems (map 9.4). The development of civil and common law systems also exhibits strong regional signals. Several large transboundary river basins emerge as having riparian states with different legal jurisdictions.

This is particularly prevalent in Africa, where every country has at least one internationally shared river basin and where the geopolitical history has created a complex mosaic of legal systems. For example, the Nile River Basin is shared by eleven countries, including the Arab Republic of Egypt and Ethiopia, both of which are civil law countries; Uganda, a common law country; and Sudan, which has a legal system based on a mix of religion and cultural practices. Among the nine riparian states in the Niger River Basin, Nigeria has a common law system, while the other riparian countries have civil law systems. Examples of transboundary basins with different legal systems can also be found in North America, with the Saint Lawrence River Basin shared by both common law jurisdictions from Canada and the United States and the civil law system of Quebec Province. Similarly, the Colorado and Grande River Basins, shared by Mexico and the United States, are governed under both common law and civil laws. In the Middle East, the Tigris River flows through a range of civil, mixed, and religious legal systems as it moves through the Islamic Republic of Iran, Iraq, and Turkey, among other jurisdictions. In Asia, the Brahmaputra/Yarlung Tsangpo River—shared by Bangladesh, Bhutan, China, and India—is governed by civil law systems in China and common law systems in Bangladesh and India. The six riparian states of the Lancang-Mekong River Basin also exhibit a range of different legal regimes. These different legal regimes reflect geopolitical historical contexts and add complexity to international efforts toward improved cooperation.

The coexistence of different legal regimes in transboundary river basins creates the potential for different, and even conflicting, duties of care. While these have the potential to accentuate tensions between riparian and subnational states, ensuring a degree of equivalence between administrative jurisdictions can enhance the collective benefits and improve the safety of downstream communities. For example, civil law relies heavily on legislative power to determine the content of the regulatory regime and the dam owner's obligations, whereas common law allows for elements of the regulatory

MAP 9.4 International transboundary river basins shared by riparian states with different legal systems



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Source: Original World Bank map for this publication.
Note: Canada's shading indicates that it has both civil law and common law jurisdictions.

regime to be left outside the purview of the law. In the case of BCUs governed by common law, the regulatory regime can be undefined, either because the case law is responsible to determine the law or because the substantive content sits in a set of guidelines that are outside of a legal instrument but may be referenced by the law. The potential flexibility informs the ability of a country's legal framework to adapt and harmonize the contents with other legal frameworks; some frameworks may be more agile than others to adapt and evolve.

Several important implications arise when countries or jurisdictions in the same basin have different legal frameworks or the content of the regulatory regime does not consider circumstances that are specific to transboundary settings. These include the following:

- Differences in dam classification, hazard definitions, and dam design and review standards
- The coexistence of different standards of care requirements and definitions, and whether they are defined by a statute or through case law
- Transboundary dam safety–related risks that are not captured by the regulatory regime (box 9.3)
- The question of whether and how a dam owner can be held liable in tort (for example, due to negligence or strict liability) for damage caused across an administrative border

BOX 9.3

TRANSBOUNDARY EMERGENCY PREPAREDNESS: FRANCE AND ITALY

The national dam safety regulatory regime may not be designed to capture transboundary dam safety–related risks that are specific to transboundary settings. This regulation gap can have important consequences for transboundary dam safety and emergency preparedness. This is particularly true where one country's dam is situated immediately upstream of a downstream population located in a different country.

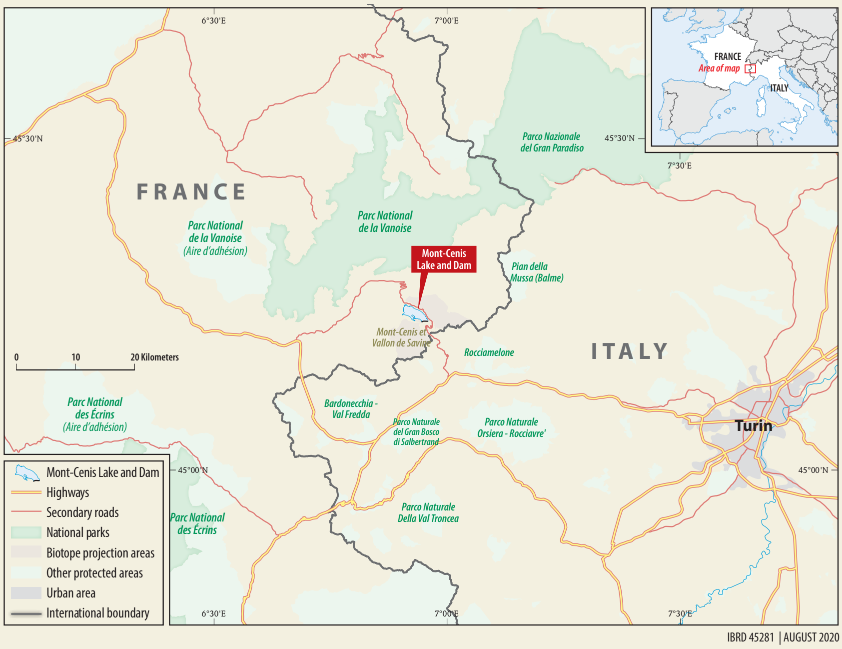
The Mont-Cenis Dam is 120 meters high with a 315-cubic-hectometer reservoir used mainly for hydropower. The dam is located in the French part of the Po River Basin, which is shared with Italy, and it sits roughly 50 kilometers upstream of Turin, Italy (map B9.3.1). Since there is no population at risk in France, French law does not require an Emergency Preparedness Plan (EPP). However, given the population at risk in Italy, a joint EPP was prepared through a bilateral arrangement between the two countries.

A working group prepared a general emergency plan, with mutually agreeable warning procedures, that was then submitted to a wide range of stakeholders representing national, subnational, and local governments, the armed forces, and relevant rescue services and operators of essential services. Any modification to the general emergency plan requires a repeat of the same process.

(continued)

BOX 9.3 *(continued)*

MAP B9.3.1 Location of the Mont-Cenis Dam in France, upstream of Turin, Italy



Source: Original map for this publication.

Such differences can lead to practical complications. For example, a higher standard of care among downstream dam operators can be undermined by lower-level requirements among upstream operators. Such differences can manifest because either the standards of care have been defined differently in each of the riparian or subnational states, reflecting the prevailing legal regime, or because the standard of care is not clearly defined in one or more of the riparian or subnational states, which infer different requirements in terms of the standard of care.

Moreover, the prevailing portfolio of dams in different riparian or subnational states may demand different legal frameworks, institutional arrangements, and levels of financial and human resource capacity. For instance, a downstream riparian or subnational jurisdiction may have a large portfolio of high-hazard dams, significant technical capacity, and a robust legal framework with a clearly defined duty of care and oversight mechanism, but the safety of its dams and communities may be undermined by an upstream riparian or subnational jurisdiction with a relatively small portfolio of low-hazard dams that does not demand the same levels of technical, human resource, institutional, and financial capacity. When one or more states adopt different approaches to dam safety for different sectors in the country, the situation becomes even more complex. This increases the number of institutions that need to be included in any coordination mechanism.

In practice, this means that transboundary river basins often do not have a uniform or equivalent legal framework in place for addressing dam safety. When riparian or subnational states in the same transboundary river basin have different legal systems, portfolio characteristics, or institutional capacity, efforts should be made to determine the degree of equivalence for dam safety. In some instances, harmonization may be needed among the different jurisdictions in the basin to ensure uniformity regarding the most basic elements of the regulatory regime. In some regions, this may argue for the need to create regional institutional arrangements to ensure equivalent safety regimes among all riparian or subnational states.

Given the regulatory gaps relating to transboundary dam safety and the potential disparity of dam safety legal regimes in a transboundary basin, a minimum level of coordination among riparian or subnational states is required to ensure the safety of dams and downstream communities. While there are many transboundary agreements to facilitate cooperation around transboundary water resources, these rarely include an explicit consideration of dam safety. These agreements are typically established to balance competing interests and promote collective actions among the riparian states. One exception is the Albufeira Convention, signed by Spain and Portugal in 1998, that includes specific provisions regulating the safety of hydraulic infrastructure and the assessment of associated risks that could lead to significant adverse effects in the case of a dam break or serious accident (see box 9.4).

International agreements can provide a mechanism to facilitate improved cooperation around the safety of dams and downstream communities. For example, the 1997 United Nations Watercourses Convention, article 26, codified the development of international agreements, including for entering into consultations on dam operation and maintenance where there is a risk of transboundary impact. Article 26 also considers dam safety aspects that are related to external influences on dams. Article 9 of the United Nations Economic Commission for Europe Water Convention has similar provisions.

Improved cooperation around these issues can also be realized through the exchange of information and data and the coordination of operations among dam owners. These practices can be facilitated through institutions, agreements on flow regimes and water-release operations, jointly prepared Emergency Preparedness Plans (EPPs), research initiatives on flood management, and working groups on issues of mutual interest. All of these may provide platforms around which to promote dialogue and jointly decide on the allocation of resources to address the most pressing challenges relating to dam safety, among other activities. In such cooperative ventures the focus on technical issues such as the legal framework for dam safety among the riparian states can help facilitate the broader political economy considerations while also improving coordination around dam safety (box 9.5).

BOX 9.4

TRANSBOUNDARY DAM SAFETY MANAGEMENT: SPAIN AND PORTUGAL

Spain and Portugal share five river basins on the Iberian Peninsula, representing 45 percent of the peninsula's surface area. Although these basins represent almost two-thirds of Portugal's territory, most of the upstream rivers are in Spain. Extreme variations in rainfall coupled with irrigation needs in both countries and an overall overuse in water resources due to low pricing have often resulted in water scarcity and tensions between the countries.

In 1993, Spain announced the transfer of 1 billion cubic meters of water from the Douro ("Duero" in Spanish) River to its Mediterranean region without first consulting Portugal, which shares the Douro Basin with Spain. Portugal objected, and in 1998 the two countries signed the Albufeira Convention, a water treaty covering the five shared river basins (map B9.4.1 and figure B9.4.1). Not only did the treaty establish the flow regime between the countries, it contained provisions relating to the safety of dams located in the shared basins.

For example, article 12 of the convention states, "The parties will jointly develop specific programs about the safety of hydraulic infrastructure and assessment of actual and potential risks that could lead to significant adverse effects upon any of the riparians in case of dam break or serious accident." The convention also requires transboundary impact assessments for those projects or activities less than 100 kilometers upstream or downstream of the border that could significantly alter the flow regime or cause the discharge of pollutants.

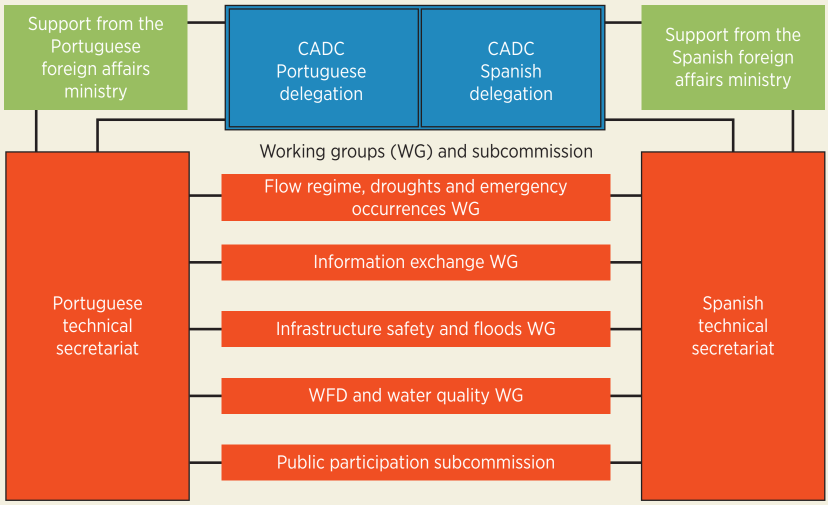
MAP B9.4.1 Transboundary river basins shared between Spain and Portugal covered by the Albufeira Convention

Source: Original map for this publication.

(continued)

BOX 9.4 *(continued)*

FIGURE B9.4.1 Organizational chart of the Commission for the Application and Development of the Convention



Source: INBO 2008.
Note: CADC = Commission for the Application and Development of the Convention; WFD = Water Framework Directive.

The convention establishes two cooperative bodies composed of representatives from each country: (1) the Conference of the Parties to solve those issues on which an agreement could not be reached and (2) the Commission for the Application and Development of the Convention, which can create subcommissions and working groups to exercise its responsibilities, including one to oversee the safety of infrastructures.

According to provisions of the convention, the countries should do the following:

- Jointly develop programs on hydraulic infrastructure safety and assessment of actual and potential risks that could lead to significant adverse effects upon any of the riparians in case of dam break or serious accident (article 12)
- Cooperate by developing dam safety plans as well as internal and external emergency plans for transboundary dams and other dams considered to have associated risks
- Coordinate activities and establish mechanisms to minimize the effects of floods (article 18.1)
- Jointly carry out studies about floods to define measures aimed at mitigating their effects, particularly, rules for the operation and management of hydraulic infrastructure in flood situations (article 18.7)

The Working Group for Dam Safety and Floods was created in December 2003 to support emergency preparedness for transboundary dams and reservoirs and the required institutional framework. The group comprises members from Portugal and Spain. Portugal is represented by the National Fire Service, Civil Protection, Water Institute, Civil Engineering National Laboratory, Portuguese

(continued)

BOX 9.4 ***(continued)***

Company for the Production of Energy, and the Company for the Development and Infrastructure of Algueva. Spain is represented by the General Directorate for Water (under the Ministry of Agriculture), Civil Protection, and representatives of the five river basins commissions under the Albufeira Convention.

The working group also provides a mechanism to address emerging transboundary challenges relating to insurance premiums affecting Portuguese dams located close to its border with Spain. Portuguese dam owners downstream of the Spanish border had been facing increasing insurance premiums due to, among other reasons, perceptions of the risks associated with dams located upstream in Spain.

The working group's responsibilities in support of emergency preparedness for transboundary dams and reservoirs included the following directives:

- Identify relevant information in case of emergency and flooding and secure mechanisms to exchange information.
- Promote the development of joint studies on flooding and rules for the management of hydraulic infrastructure with potential transboundary impact.
- Study the legal and institutional frameworks regarding the safety of hydraulic infrastructure that could impact the bilateral relations between the countries, particularly the role of the hydraulic administrations, concessionaries, and dam owners.
- Develop a work program on those issues related to dam safety, emergency plans, and the assessment of potential dam failure risks and serious accidents with transboundary impact.

Among other tasks, the working group has assisted in the following activities:

- Exchange of information about a transboundary infrastructure that should have an emergency plan including technical guidelines for emergency situations and specific emergency plans for dams and reservoirs
- Exchange of dam safety management instruments, rules, and criteria
- Exchanges of delegations and technical experts to present aspects of the emergency plan in process
- Coordination of activities during exceptional flooding via the automatic information exchange system existing in the Tagus River Basin
- Exchange of information about the procedures for monitoring the behavior of the dam and foundations, controlling its safety conditions, and checking the need for corrective measures
- Emergency drills in several dams with the participation of civil protection authorities from both countries
- Analysis of emergency plans of the riparian states to include the comments of the other riparian
- A sub–working group to harmonize emergency plan development procedures
- Exchange of information on the first impoundment of at least one reservoir and the commissioning of at least one hydropower plant

Source: UNDESA 2013.

BOX 9.5

IMPROVING THE LEGAL FRAMEWORK AND CAPACITY FOR DAM SAFETY IN THE EASTERN NILE REGION

Thirty dams operate in the Eastern Nile region with a combined storage capacity of 210 billion cubic meters, providing critical services such as flood protection, irrigation, hydropower generation, and water supply to the more than 150 million people living in the Eastern Nile subbasin, which spans the Arab Republic of Egypt, Ethiopia, South Sudan, and Sudan. The Eastern Nile Technical Regional Office (ENTRO) of the Nile Basin Initiative works with Eastern Nile countries through its dam safety program to build technical capacity and establish national and regional safety norms.

The riparian states recognized that attention to dam safety is critical, with design issues or inadequate monitoring and maintenance having the potential to increase the risk of dam failure. This could, in turn, have significant flood consequences and affect riverbank settlements, fisheries, power generation, agriculture, and the environment and potentially destabilize the region's economy. With support from the multidonor trust fund for Cooperation in International Waters in Africa, administered by the World Bank, a series of dam safety workshops carried out by ENTRO have trained nearly 200 dam operators, regulators, government officials, academics, and civil groups in Ethiopia, South Sudan, and Sudan in improved dam safety tools and techniques. A dam safety training module was developed for Eastern Nile universities to continue to train technical personnel and build long-term professional dam safety capacity in the region.

Reference dam safety guidelines for the Eastern Nile countries have also been developed to enhance existing dam planning and operation. Social, environmental, and evolving economic considerations in these guidelines are intended to improve the productive lifetime and sustainability of dams in the basin. In addition, the guidelines offer flexible design options, and operating rules are expected to help ensure that the guidelines' safety recommendations are able to handle more frequent and extreme rains and dry periods due to climate change.

Meanwhile, the governments of Ethiopia, South Sudan, and Sudan are working to establish national dam safety units in each country to implement the proposed guidelines and ensure that neighboring countries coordinate in dam planning, operation, and maintenance. Future endeavors could include the proposed development of a regional framework to coordinate cascade operations and the development of guidelines for preparedness in the case of an emergency to protect communities downstream.

Source: World Bank 2016.

INSTITUTIONAL ARRANGEMENTS FOR TRANSBOUNDARY DAM SAFETY

Institutions provide the rules that govern and constrain the interactions of riparian and subnational states in transboundary river basins (North 1990; World Bank 2002; Leftwich and Sen 2010). These institutional mechanisms can include formal rules, written laws, informal norms (including behavioral norms), and shared beliefs about the world, as well as the means of enforcement to achieve desired outcomes. When effective, such institutions provide for predictable and stable patterns of interaction that can best be thought of as durable social rules and procedures, formal and informal, which structure but do not determine the social, economic, and political relations and interactions of those affected by them (Leftwich 2006, 2007). These institutional mechanisms are framed by the policies and agreements that articulate the goals and desired outcomes around shared transboundary water resources. While there are a number of transboundary dam operators, there are few formal institutional arrangements to govern the safety of dams and downstream communities.

Organizations—such as river basin organizations, joint commissions, and authorities—are often advocated as a requirement to balance competing interests and promote collective actions around transboundary water resources. These multilateral organizations are typically established with the objective of fostering cooperative actions that can provide sustainable benefits, minimize the impacts of externalities, and increase collective gains through mitigating risk-averse, individualistic behavior among riparian or subnational states while satisfying equity concerns and encouraging collective action. They are intended to provide a set of accepted principles, norms, or rules to govern operations in transboundary basins through collective actions and cooperative mechanisms to promote or protect shared interests. The organizational form and character, both nationally and internationally, creates a framework that determines the manner in which sovereign, political, and economic factors relate to technical issues around water resources.

The International Law Association (1978) adopted the Guidelines for the Establishment of an International Water Resources Administration in 1976 as an input to the 1977 Mar del Plata UN Water Conference. They define the elements to be considered when establishing an international water resources administration, including its form, membership, duration, decision-making procedures, legal status, territorial competence, functions and powers, objects and purposes, financial and economic matters, and dispute settlement mechanisms. The guidelines are considered *de lege ferenda*, or what the law ought to be even if it is not.

According to the guidelines, the functions and powers of an effective international water resources administration may include the following:

- *Advisory* functions that also extend to consultative, coordinating, and policy-making functions, in which case agreements should specify the procedural rules for deciding on conflicting rights and interests, notifications, objections, and timing
- *Executive* functions, which may include the carrying out of investigative studies and surveys, the preparation of feasibility reports, inspection and control, construction, operations, maintenance, or financing
- *Regulatory* functions, which may include the implementation of the decisions of the administration, as well as law making, in which decisions may take effect directly or after acceptance by member states
- *Judicial* functions, which may include arbitration, mediation, fact-finding, and settlement of disputes arising from the interpretation and implementation of the founding treaty

Most transboundary organizations have advisory or executive functions, with few dedicated regulatory or judicial organizations mandated with ensuring the safety of dams and downstream communities in transboundary river basins. However, most efforts are focused on establishing organizational mechanisms to facilitate technical cooperation among dam operators in an advisory capacity, such as the Joint Operating Technical Committee of Dam Operators in the Zambezi River Basin in southern Africa (box 9.6). A number of special-purpose vehicles, however, have been established among riparian and subnational states to carry out executive functions relating to investigations and feasibility studies for large dam projects in transboundary river basins, as well as their construction, financing, operation, and maintenance. Such organizations are not mutually exclusive, and the riparian states may choose to distribute the functions among a range of different organizations and instruments to represent their interests.

A key component for the sustainable development and safety of dams is ensuring suitable financing mechanisms for operation, maintenance, and capital costs. These organizations may involve the collective action of all riparian or subnational states governed by specific agreements that outline the sharing of costs, as well as the benefits, along with the duty of care relating to dam safety. However, such special-purpose vehicles for the development of dams in transboundary basins more typically involve a subset of riparian or subnational states around a specific project. This can create a complex operating environment in which to regulate and ensure dam safety with a combination of nationally owned large dams coexisting in the basin alongside dams jointly owned by a subset of riparian or subnational states and a range of organizational responsibilities.

Transboundary organizations responsible for the ownership and operations of large dams are typically established through international agreements. As such they are typically recognized as international public law corporations subject to founding agreements and established

BOX 9.6

ZAMBEZI DAM OPERATORS JOINT OPERATIONS TECHNICAL COMMITTEE

The Zambezi River Basin in southern Africa includes eight riparian states and a mix of national and jointly owned and operated infrastructure. These include the Kariba Dam, owned by Zambia and Zimbabwe and operated by the Zambezi River Authority; Cahora Bassa, owned by Mozambique and operated by Hidroeléctrica de Cahora Bassa; the Itezhi-tezhi and Kafue Gorge Hydro-Electric Schemes, owned and operated by Zambia's national power utility; and more than 30 other smaller dams located in Malawi, Zambia, and Zimbabwe.

The Zambezi Watercourse Commission was established in 2014 as an intergovernmental organization under a 2004 basin-wide agreement with the aim of promoting equitable and reasonable utilization, as well as the efficient management and sustainable development, of the basin's water resources. In addition, dam operators in the basin have established a Joint Operations Technical Committee (JOTC) to facilitate the exchange of hydrometeorological and dam-related information as a contribution to improving and informing the management of the water resources in the basin. Specifically, the JOTC was established with the following goals in mind:

- Better understanding of the Zambezi River hydrological system
- Better control of flood and drought situations in the basin
- Reduction of the negative effects of floods and droughts in the three countries
- Better utilization of the water resources for power generation
- Regular sharing of expertise and experiences in the development and implementation of hydrological models for reservoir operations
- Timely accessibility to hydrological, environmental, and water utilization data that enables informed decision-making
- Better management of flood prevention and environmental flow requirements
- Integrated dam safety monitoring and analysis
- Establishment of working provisions in cases of floods, droughts, and any emergency situations
- Development of better dam operating rules for water resource management in the catchment
- Capacity building through knowledge sharing and exchange of notes
- Networking for future projects

A joint dam-break analysis was initiated under the auspices of the JOTC to provide a comprehensive assessment of the potential consequences of a partial or full dam breach at one or several dams on the Zambezi and

(continued)

BOX 9.6 *(continued)*

Kafue Rivers. This included (1) an analysis of potential flood hydrographs based on plausible dam breach scenarios for the existing dams, (2) the routing of such floods through the downstream river stretches to assess impacts and potential subsequent damage or breach of downstream dams, (3) detailed topographical surveys for selected river stretches and flood-prone areas to improve on emergency preparedness, and (4) the production of flood inundation maps and characteristics for floods generated through malfunctioned dam operations or dam failures.

Sources: Zambezi Watercourse Commission website, http://www.zambezicommission.org; and Zambezi Dam Operators Joint Operations Technical Committee website, http://www.jotc-zambezi.org.

governing bodies with their own legal personality different from that of the shareholders. As such, they are not usually subject to the national dam safety regimes of the states that might own them or other riparian or subnational states in the transboundary basin. In the absence of prevailing legislative provisions, such organizations typically establish their own dam safety requirements and standards with appropriate references to other jurisdictions.

KEY MESSAGES AND CONCLUSIONS

Assuring the safety of dams and downstream communities in the context of transboundary river basins involves a unique set of considerations that have largely been underestimated to date. Traditionally, international transboundary dams have been understood to mean those whose abutments are shared by riparian states. However, such definitions ignore those dams that, although located in the territory of a sovereign state or subnational jurisdiction, are situated in a transboundary river basin, meaning their management and use can have major implications for the safety of downstream communities, regardless of national boundaries.

To better understand the implications, there is a need to reexamine the criteria used to define the international character of dams in transboundary river basins. Repositioning the understanding of dams with international character and ensuring their safe operation in a broader transboundary context that acknowledges the relationship between dam owners and operators significantly increases the global portfolio of dams that need to be considered and the magnitude of the associated issues. The number of planned dam projects, increasingly uncertain climatic conditions, and changing patterns of human settlement indicate that this will be an increasingly important consideration.

The coexistence of different legal regimes for dam safety assurance among riparian states or subnational jurisdictions can create new hazards. These can manifest through different classification systems, levels of surveillance, duties of care, institutional arrangements, or capacity among the different jurisdictions to ensure a uniform level of assurance. Very few of the national legal frameworks for dam safety and very few of the transboundary river basin agreements include explicit provisions for addressing obligations in relation to the safety of dams and downstream communities, which cause important regulatory gaps that need to be addressed so that dam safety–related risks specific to transboundary settings can be properly captured in national dam safety regulatory regimes. Provisions in the basin and among the riparian states or subnational jurisdictions should be evaluated to determine the degree of equivalence among the legal regimes and ensure a minimum level of assurance across the basin.

International dams need to be properly captured by the dam safety assurance regime. This should be done at national levels or in the subnational administrative unit but reconciled across the transboundary basin. To achieve this, equivalent standards of care need to be established across the basin and dams subjected to adequate surveillance according to their size, hazard, and potential risk. EPPs in transboundary basins should ideally be developed and sensitized at the basin level, but at a minimum need to take into consideration not only dams and their operators but downstream communities and civil protection agencies that may potentially be impacted in the case of dam failure or mis-operation.

Institutional arrangements need to consider the regional context to best facilitate cooperation around the improved safety of dams and downstream communities. Considerations may include the size of the portfolio in the different riparian states or subnational jurisdictions, population distribution and growth projections, the level of human and financial capacity, as well as the prevailing national arrangements for ensuring the safety of dams and downstream communities. Where transboundary basin organizations exist, they can play an important regulatory function in facilitating basin-level dam safety assurance, particularly where executive functions reside in national jurisdictions or special-purpose vehicles for infrastructure ownership and operations.

Regional dam safety programs can play a meaningful role in promoting improved safety of dams and downstream communities, while also contributing to broader cooperative ventures. Such programs can help facilitate equivalence across frameworks in the basin and strengthen the regional network of technical professionals. Regional dam safety units or peer-to-peer arrangements can also be useful in addressing capacity constraints by capitalizing on economies of scale, expertise, and portfolio differences. Such regional programs should facilitate the joint development of tools that contribute to improved safety of dams and downstream communities, such as flood-mapping simulations, dam-break analyses, development of emergency action plans, and community safety nets to be deployed in case of dam failure or mis-operation.

NOTES

1. See World Register of Dams (database), "Starting Guide," page 5, ICOLD, Paris. https://www.icold-cigb.org/userfiles/files/CIGB/registre%20base%20presentation-ENG-FR.pdf.
2. This number is most likely a gross underestimation. The 2,924 dams were identified from the transboundary basins using the Global Reservoir and Dam Database (GRanD), http://globaldamwatch.org/grand/. This includes over 6,000 dams and is the most comprehensive georeferenced database currently available. This is equivalent to roughly 10 percent of the dams registered in ICOLD's World Register of Dams, which is not consistently georeferenced.
3. A basin country unit is the portion of a country in a particular transboundary river basin.
4. More information on the methodology used to generate map 9.3 can be found in de Stefano et al.'s research paper.
5. The total population in the world's transboundary basins is estimated to be 2,816,457,000 people, with 2,742,678,000 people estimated to inhabit the 208 transboundary basins relevant to the 51 countries included in the comparative analysis.

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10

A Regulatory Framework for Dam Safety Assurance

A CONTINUUM: DEFINING THE REGULATORY MIX FOR DAM SAFETY ASSURANCE

The foundation for effective dam safety assurance is an appropriate and well-designed regulatory framework, one that captures the legal, institutional, technical, and financial elements in a particular jurisdiction. An aging infrastructure, diminishing returns on new projects, changes in climate and weather patterns, and shifting patterns of human settlement require ever-increasing attention to the safety of dams and downstream communities. A fit-for-purpose regulatory framework is necessary for assuring the quality of dam design, construction, and operations; it must include safety measures reflective of the risks inherent in managing these structures and the context in which they are developed. Such frameworks need to be developed as part of a holistic strategy for water management that is integrated in basin and regional planning processes.

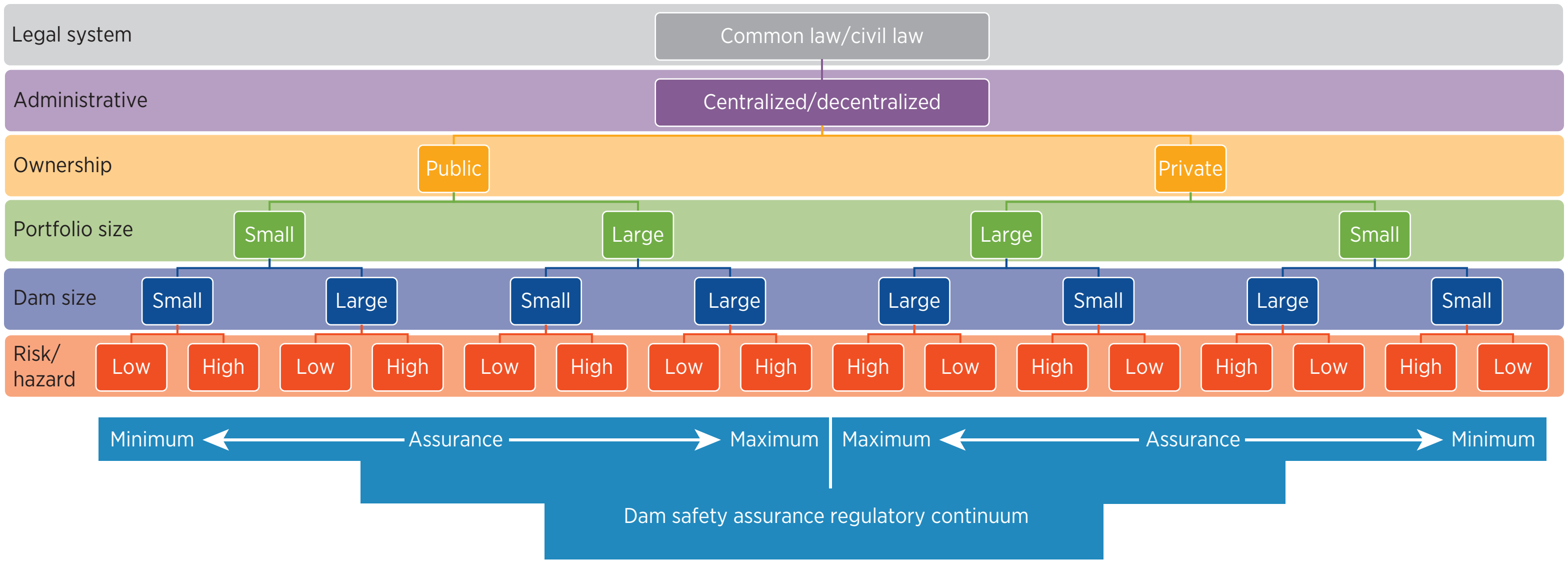
While there is a range of options for how such regulatory frameworks can be realized, some universally accepted principles apply. Foremost among these is the principle that the dam owner is ultimately responsible for implementing dam safety measures in a clearly defined legal regime. However, the exact formulation of the regulatory framework for assuring the safety of dams and downstream communities should be informed by the characteristics of a particular jurisdiction. The form that the regulation and oversight take depends on the country characteristics, including the prevailing legal system, the administrative arrangements, and socioeconomic context. It should also reflect the technical characteristics of the portfolio of dams, including the number and type of dams, the nature of ownership and financing arrangements, and the sectoral distribution and hazard profile of the portfolio (figure 10.1). It is also important that the regulatory framework evolve with changes in the portfolio and country conditions. It is therefore necessary to provide a continuum of legal and institutional options against which countries can assess their needs and requirements.

The desired regulatory framework for ensuring the safety of dams and downstream communities is one that affords the maximum level of assurance. This level of assurance depends not only on the structural elements and the prevailing policy environment but also on the ability to realize the framework's intentions. Traditionally, the favored policy mechanism has been command-and-control regulation (Gunningham 1993; Gunningham and Sinclair 2017). However, this system, whereby legislators prescribe behavior and create agencies to monitor compliance, has often been ineffective, especially where there are resource constraints or a number of institutional actors in the policy setting (Gunningham and Sinclair 2006; Pisaniello and Tingey-Holyoak 2017). Multiple instruments can be used to produce an "optimal" regulatory environment that meets the criteria of flexibility, efficiency, cost-effectiveness, and equity in the given boundary conditions (OECD 1991; Gunningham 1998). More adaptable and pluralistic approaches to regulation are required (Ayers and Braithwaite 1992; Gunningham and Grabosky 1998; Gunningham and Sinclair 2017) that do not rely exclusively on one form of regulation but rather seek an optimal regulatory mix (Johnstone and Sarre 2004) that considers the local context to assure the safety of dams and downstream communities.

Managing the complex challenges associated with ensuring the safety of dams requires a policy mix that incorporates instrumental and institutional combinations. This is particularly important when considering issues of long-term sustainability and the risk to future communities. Such considerations will not only save resources but also help to avoid regulatory overload (Gunningham and Grabosky 1998). These can include policy innovations such as information and educational elements, self-regulation, and economic tools (Gunningham 1998; Pisaniello and Tingey-Holyoak 2016). This approach to regulatory pluralism can utilize not only governments but also owners and third parties, thereby incorporating a greater range of potential actors, such as communities, insurers, interest groups, and international financial institutions (Gunningham and Sinclair 2017; Pisaniello, Dam, and Tingey-Holyoak 2015; Pisaniello, Tingey-Holyoak, and Burritt 2012).

Ensuring the safety of dams and downstream communities requires a range of legal and institutional options appropriate to jurisdictional circumstances with different portfolio characteristics, human and financial resources, and population locations and growth. However, the policy process must further provide an equilibrium that allows poorly resourced countries to have regulatory options that ensure safe and secure communities and environments. A series of design principles have been identified in regulatory mix theory that emphasizes the importance of choosing complementary combinations of

FIGURE 10.1 Key elements and determinants informing regulatory frameworks for dam safety assurance



Source: Original figure for this publication.

regulatory instruments and elements that can be mixed to enable movement from minimum assurance to maximum assurance (Gunningham and Grabosky 1998; Gunningham and Sinclair 2017; Pisaniello, Tingey-Holyoak, and Burritt 2012). This continuum should allow for adaptation to changing circumstances relating to urbanization, climate variations, changes in market conditions, and other macro- and microeconomic factors that increase the complexity associated with the safety of dams and downstream communities. The desired policy goals must first be identified; then the unique characteristics of a country's situation need to be addressed in order to design the optimal regulatory mix of minimum and maximum dam safety assurance elements (Gunningham and Grabosky 1998; Pisaniello, Dam, and Tingey-Holyoak 2015).

CHARACTERISTICS INFORMING A CONTINUUM

There are several key elements that inform the nature of the regulatory framework for dam safety assurance. These often provide the definitive precursors in which the specific considerations need to be positioned. Such elements include the following:

- *Legal foundations such as the constitutional basis for law making and administration*. For example, the common law or civil code characteristics of a country will determine the approach to development and realization of the legal framework for dam safety assurance. Similarly, a unified administrative system will differ in the requisite elements for ensuring dam safety compared to a federal system with decentralized roles and responsibilities to the subnational administrative units. These characteristics rarely, if ever, change.
- *Institutional arrangements such as the allocation of responsibilities, sectoral considerations, human capital, and financial capacity*. These are informed by the enabling legal framework and should clearly define the allocation of responsibilities for ownership, operations, and oversight, as well as the approach to private sector participation and sectoral considerations. The nature of the institutional arrangements will reflect the composition and structure of the portfolio as well as financial capacity and human capital. These characteristics are subject to infrequent changes but need to adapt to changes in the portfolio and downstream demographics.
- *Technical considerations such as the nature and characteristics of the portfolio*. These include considerations around the size of the portfolio (small single sector to large multisectoral), the relative importance of different sectors (irrigation, hydro, supply, flood protection, and so forth), and the hazard classification. These characteristics are subject to more frequent changes depending on sectoral demands and development, demographic changes, and changes in land use and the enabling financial considerations, among others.
- *Financing considerations such as the revenue streams available to support operation and maintenance (O&M)*. These are typically determined by government

policy and are subject to economic regulation. They, in turn, determine the availability of financing and transfer mechanisms to support O&M, as well as the financing of oversight mechanisms. These characteristics can be subject to frequent changes depending on prevailing economic conditions and government policies.

There are also a number of more deliberative determinants of the regulatory framework for dam safety assurance. These are typically defined by the portfolio characteristics and informed by technical considerations, including (1) the classification of dams in the portfolio, usually by dam size and/or reservoir capacity, (2) the size of the portfolio itself, (3) the relative proportion of public and private ownership of dams in the portfolio, and (4) the hazard level or risk associated with dams in the portfolio.

These key elements and determinants come together to present a continuum of key considerations (figure 10.1). This continuum can be used to position key considerations in a decision framework of options based on a grouping of key elements and determining factors. These can be used to (1) inform the establishment of an appropriate regulatory framework for dam safety assurance in any jurisdiction, (2) provide a framework for gap analyses aimed at enhancing existing legal regimes and institutional arrangements for dam safety assurance, and (3) guide technical specialists in designing projects aimed at supporting the establishment or strengthening of regulatory frameworks for dam safety assurance. It is important to note that while the type of legal system (common or civil law) and the type of administration under a country's constitution (centralized or decentralized) are important overarching determinants, all the pathways possible from these elements have not been fully reflected in figure 10.1. Paring has been done to ensure clarity and avoid unnecessary repetition. These overarching elements are instead considered in detail in appendix E, which provides for all of the possible jurisdictional circumstances and types of portfolios.

Finally, it is important to reiterate that the regulatory framework must evolve with changes in portfolio and country conditions. It is therefore necessary to provide a continuum of options against which countries can assess their specific needs and requirements at regular intervals. Specific considerations should also be afforded to regulatory considerations that capture dam safety requirements specific to transboundary settings in order to ensure a comprehensive system of dam safety assurance across boundaries that reaches all downstream communities.

LEGAL OPTIONS ALONG A CONTINUUM

There needs to be careful consideration and delineation of the legal and regulatory provisions for ensuring the safety of dams and downstream communities. This will depend on the determining characteristics of the country and affect how the roles and responsibilities for dam safety are allocated and assured. If a country is operating under a federal system, then state-only legislation is possible (for example, in Australia and the United States) or a combination of federal and state legislation (for example, in Brazil). The need for uniformity, however, is more likely to be met if both federal and state laws are in place (see Pisaniello 2011). For maximum assurance, clear and uniform safety assurance policies are needed to ensure that all communities and environments downstream are valued equally, regardless of the jurisdiction in which they exist (Pisaniello 1997, 2009, 2011; Pisaniello, Tingey-Holyoak, and Burritt 2012; Pisaniello, Dam, and Tingey-Holyoak 2015). The following options, among others, must be considered when delineating legal and regulatory provisions.

Legislative and regulatory provisions. These can be located in stand-alone, dedicated dam safety documents or embedded in broader enabling provisions. A dedicated law on dam safety is desirable where there is a large portfolio of high-hazard dams. Where there is a medium-size portfolio, a mix of hazard classifications, or a portfolio in transition, enabling legislation containing specific dam safety requirements may be appropriate. Dam safety provisions are typically found in legislative and regulatory provisions relating to water and/or the environment, but they may also be found in legislation covering building and construction or hydraulic infrastructure more broadly. In some instances, specific provisions are contained in sectoral legislation. While this allows for tailored solutions, it can result in different design criteria, hazard classifications, or operational considerations. If dam safety provisions are included in more general enabling legislation, then it is important to ensure that there is a dedicated section that references the dam safety provisions. Irrespective of the form in which these provisions are conveyed, they should always be publicly available.

Minimum assurance and self-regulation. Where there is no legal framework in place, or there is a small portfolio of low-hazard dams, a minimum level of assurance can be realized through self-regulation. This approach relies on persuasion as opposed to regulation and requires the owners' discretion as to whether they adopt Good International Industry Practices and to what extent. Existing laws relating to water, environment, or other areas may be able to cover dam safety elements as part of the broad considerations around the safety of hydraulic infrastructure, supported by technical guidelines that make reference to international standards and good practices. Depending on the legal code, these guidelines can be legally nonbinding, such as those issued by a national committee of the International Commission on Large Dams (ICOLD) or other professional body. Ultimately, self-regulation typically involves some sort of government initiation and third-party involvement without reliance on the extreme of coercion (Gunningham and Sinclair 1998). At a minimum, self-regulation should be informed through information and education mechanisms, dam registration, awareness of responsibility and liability, and a checklist of dam safety options. In practice there can be significant problems with pure self-regulation for dam safety assurance, primarily associated with difficulties in monitoring (Grabosky and Gunningham 1998). In reality, the only way to ensure that minimum assurance through self-regulation works is if the dam owners have an interest in safe and sustainable dams and it is in their self-interest to manage dams accordingly. Alternatively, a less pure form of minimum assurance can occur when an industry body or organized group regulates the behavior of its members by setting rules and standards (OECD 2004; Gunningham and Sinclair 1998). Such industry-supported self-regulation can be efficient when standard-setters have some dam safety knowledge, baseline data and education facilities, and can create a useful setting to facilitate effective monitoring (Gunningham and Sinclair 1998).

Maximum assurance. To ensure maximum assurance, there needs to be fit-for-purpose dam safety requirements mandating criteria and/or guidelines (in common law countries) or standards or codes (in civil law countries) for safety requirements, including public safety during operations (Pisaniello, 2016; see also chapter 7 in this volume). These requirements should include standard procedures of O&M, inspections, and Emergency Preparedness Plans (EPPs) (Pisaniello, Dam, and Tingey-Holyoak 2015) and should be proportioned to size and/or hazard. Cost burdens to small dam owners can be minimized by making available affordable dam design and safety review processes and tools (Pisaniello 2016). The requirements developed by the regulators for maximum assurance would need not only to prescribe improved dam safety and sustainability for new and existing dams, but also to define and uphold the precise safeguarding measures an owner or operator must use in specific situations (Gunningham and Sinclair 1998).

Regulations and/or technical guidelines. These need to be revised on an ongoing basis to reflect changes in the characteristics of the portfolio. Given the need for such changes, it is better to maintain general references in the prevailing legislation and retain the specific considerations giving direction to those under regulation in regulations. For elements that are subject to more frequent changes or evolution through research and the development of good practices, these provisions may also be supplemented by nonbinding technical guidelines. Where there is a large portfolio of high-hazard dams, a full set of technical standards, including design criteria, dam classification, standards of care, and so forth, should be issued by by-law or ordinance. For a medium-hazard or mixed portfolio, a by-law or ordinance on technical standards should be developed, as these can be issued as part of broader mandates of the regulatory authority for water resources.

Clearly articulated responsibilities of all parties involved in dam safety. It is universally accepted that the dam owner is responsible for ensuring that the dam is safe, and that it is operated and maintained in a safe condition—the regulatory authority is responsible for establishing the dam safety standards. These standards are what the dam owner must comply with. It is essential that the regulatory framework (1) clarify that the dam owner is responsible for dam safety, (2) specify the owner's responsibilities for the O&M of the dam and how the owner should review the safety of the dam, (3) ensure that the regulatory authority is clearly identified and mandated with the responsibility for monitoring the owner's performance, and (4) explain the ways in which the regulatory authority can perform its monitoring functions. The framework should also include the identity of the authority responsible for handling any emergencies that are caused by dam failure or mis-operation. For a small portfolio of low-hazard dams, the owner's responsibility and mandates for dam safety should be clearly defined and mandated at least in the form of the regulator's memorandum for instructing dam owners on dam safety requirements, such as use of certified engineers for dam safety review, and so forth. For a medium-hazard or mixed portfolio, the owner's responsibility and mandates should be clearly stipulated in the law and/or by-laws covering all phases of dams (life cycle). Regular surveillance and periodic safety reviews should be specified and proportioned according to the dam's classification. In addition, the owner's dam safety program should be comprehensive and clearly defined subject to the approval of the regulator. Owners should fulfill dam safety requirements using external certified engineers for periodic dam safety review, in addition to internal engineers for regular surveillance.

Clearly articulated dam safety standards and specifications. The difference in operations of dam owners, combined with diverse spatial orientation, means that self-regulation based on only information and allocated responsibility and liability can be challenging for safe and sustainable dam management. On top of baseline information and education, some elements of a regulatory checklist will be required, depending on circumstances. These can include O&M inspections, instrumentation support, emergency preparedness planning, design and review standards, and public safety considerations (Pisaniello, Tingey-Holyoak, and Burritt 2012; Pisaniello, Dam, and Tingey-Holyoak 2015). Based on these elements, the owner themselves, or third parties, might assist in developing and implementing an appropriate checklist for self-regulation as an alternative to government intervention. A checklist approach to minimum assurance of safe management could come from an industry or community body with significant influence over the group, which would possibly need to be region specific—an owner with the unsafe and unsustainable dam would be passively coerced into improving practice due to the potential for perceived loss of support from the community and industry.

Differentiated responsibilities and liabilities. Dam safety responsibility applies to universal principles for maintaining the safety of a dam. These apply to any person in a given situation—whether an owner, operator, or third party to which responsibility is assigned—and cannot be waived, delegated, or distributed (Bovins 1998). Liability, however, applies only to specific people at a specific time and place and can be delegated or distributed. When enforced, it is usually punishable. By defining responsibility and liability in this way, owners are made aware that they should manage and review their dams and take appropriate action where necessary in order to minimize the risk of failure and avoid liability for possible consequences of failure (Pisaniello 2011; Pisaniello, Dam, and Tingey-Holyoak 2015). Mechanisms should be put in place to inform and educate all parties involved with the safety of dams and downstream communities of their responsibilities, potential risks, and liabilities.

Scope of regulation associated with the safety of downstream communities. For a small portfolio of low-hazard dams, the threshold of regulated dams should be low enough to capture all potential hazardous dams irrespective of size. For a medium or mixed portfolio, the definition of regulated dams should be carefully considered, with attention to the potential hazard of small dams versus available resources of regulators and owners, particularly as the portfolio size increases. For a large portfolio of high-hazard dams, the definition of regulated dams should be carefully considered based on their potential hazard. While a set of detailed dam safety requirements should be introduced for regulated dams, a minimum safety requirement would be defined for small dams.

Form of regulation. The form through which dam safety provisions are captured should always be cognizant of the implications for subsequent changes. Legal instruments passed by legislative branches of government can be difficult to amend. Since changing such an instrument requires legislative approval, it should be kept relatively simple and contain only the objectives of and the general principles governing the regulatory framework (Gunningham and Sinclair 2017). Similarly, if the dam safety provisions are embedded in enabling legislation, they can become hostage to broader unrelated considerations and unintended consequences. The details of the regulatory scheme should be contained in legal instruments, such as regulations and decrees, which are relatively easy to change.

INSTITUTIONAL OPTIONS ALONG A CONTINUUM

The institutional arrangements for ensuring the safety of dams and downstream communities will reflect the administrative arrangements of the country. They will be informed by constitutional provisions relating to federal or unitary state administration and the approach to sectoral considerations in the administrative regime.

The authority for dam safety should be clearly identified and its powers and responsibilities should be articulated in the legal and institutional framework. Where there is a large portfolio of high-hazard dams and potential risk to downstream communities, the authority should be independent from all those who make decisions about whether to build dams and all those who are involved in the ownership and operation of dams. A dedicated office with a set of clear legal mandates should be established and include a team of experienced dam engineers. An independent dam safety review commission can be mandated by law and/or regulations and will serve as a technical arm of the regulator. This will help ensure a maximum level of assurance.

In many countries, however, the regulatory authority deals with dam safety as part of broader regulatory responsibilities. This can include dams, water, or environmental management more generally. These are appropriate where there is a small portfolio of low-hazard dams; in this context such a multisectoral regulator can cover dam safety management through a minimum set of regulations. These are focused mainly on a review of the owner's dam safety reports, prepared by qualified dam engineers, to ensure compliance. In the case of self-regulation, an independent review mechanism should be established separate from the units responsible for dam design and construction. For medium or mixed portfolios, dam safety management can be formally incorporated into an existing regulatory mechanism along with a set of clear dam safety oversight functions coupled with sufficient capacity. In such cases, an external advisory body may be helpful to supplement the regulator's internal capacity.

Centralized regulation is common in unitary states and where there is a relatively small portfolio of large dams. Having a national body can help ensure uniformity across different jurisdictions and sectors, and can also leverage economies of scale. The national regulator can ensure the application of consistent dam safety requirements in terms of design criteria and operational procedure. This also allows challenges of transboundary dam safety to be easily addressed. However, national regulators may require significant human and financial resources to manage dams across the country without a local presence. In some instances, the national regulator may establish branch offices with sufficient delegated authority. In other examples the national government may delegate responsibilities to local governments for certain classes of dams or types of rivers.

Decentralized regulation is common in federal systems where the state or provincial government regulators have a legal mandate and authority for dam safety assurance. This may be sufficient for countries with very few interstate rivers and informal coordination through a professional society. However, this can result in inconsistencies among the regulations applied in the same river system across multiple states or provinces. This is particularly important in countries, states, or provinces where there is a large portfolio of high-hazard dams. As the portfolio evolves and develops, consideration should be given to the establishment of national dam safety legislation and/or a consolidated national regulator to increase uniformity in the application of specific dam safety standards. In such countries, the regulatory scheme should address the relationship between the different levels of government in order to accommodate the prevailing administrative governmental structure and to avoid duplication or ambiguity in the regulatory framework applicable to any particular dam.

There needs to be a clear differentiation among laws and regulations relating to dam safety. Generic dam safety considerations can be provided to cover all dams across different sectors and types of ownership, or there can be sector-specific considerations. Consolidated cross-sectoral regulation enables the application of consistent dam safety criteria and requirements across sectors. However, in many cases, the main ministry owning a large share of dams is designated as the regulator, and some self-regulating issues may arise. Independent regulatory mechanisms may have been established by a nonsectoral regulator who has no ownership of any dams. While it is effective for the designated ministry to regulate other sector dams, some independent review mechanism should be introduced for self-regulating dams. In contrast, sectoral regulation is where different sectors, typically water resources/irrigation and hydropower, have developed their own regulatory system. They are familiar with the sectoral issues and associated facilities with dams. However, this can result in another set of challenges with different design criteria for dams in the same region or river basins under different sectors, creating potential inconsistency and conflicts in their reservoir operations.

While an apex independent oversight body is ideal, the body must be fully independent and empowered. That is, it has the power to develop norms and standards via additional regulation and/or regulatory documents, to issue licenses and permits, to maintain registers and inventory of dams, to supervise surveillance and maintenance of dams, to conduct audits and inspections, and to approve inspectors; it also has advisory responsibilities. Furthermore, the independent oversight body should have a quality assurance role, which can range from simple compliance audits to more hands-on quality assurance. However to retain independence, direct surveillance is not recommended (Pisaniello 2011, 2016). The optimal mix of roles depends on internal financial, human, and technical capacity. If less regulator involvement is warranted, pulling back from maximum assurance could mean that independent nongovernment bodies can be included in the regulatory framework to assist the regulator in executing its functions (Gunningham 2007).

The regulator's mandate and powers for dam safety should be clearly identified. For small portfolios of low-hazard dams, the regulator's mandates can be minimal and focused mainly on checking the compliance of dam owners with the prescribed requirements. However, the regulator's capacity should be enhanced with training and possibly technical support by external experts. For medium or mixed portfolios, the regulator should have a comprehensive mandate that covers all phases of the life cycle, but which is carefully defined considering the resource implications of the prescriptions. If an adequate number of qualified engineers are available in the private sector, the regulator can take more of a quality assurance role, ensuring that owners assign certified engineers for dam design, construction supervision, and safety review, depending on the hazard level. For large portfolios of high-hazard dams, the regulator's mandates should be defined in a comprehensive manner that covers all phases of the life cycle. This should enable the regulator to undertake rigorous review and, if required, prescribe remedial measures for high-hazard dams. Sufficient human and financial capacity of the regulators should be secured either through government budget allocation and/or fees from dam owners. A dam safety unit comprising experienced engineers should be maintained internally for reviewing the overall dam safety assurance system and periodically undertaking supplemental measures.

The regulation of public dams, in which the line ministries in charge of water, irrigation, or energy own and self-regulate dam safety, poses a number of challenges. Where the portfolio is relatively small or low hazard, self-regulation can be realized through ensuring sufficient sectoral expertise, including dam safety management, and a clear set of guidelines for self-regulation. However, in the absence of specific dam safety mandates in the legal regime or constraints with financial and/or human capacity, there are a number of challenges associated with ensuring minimum standards of dam safety. These can be addressed by delegating authority for regulatory oversight to a different ministry from those owning and operating dams. If there is no suitable independent regulatory mechanism, or the portfolio does not warrant such arrangements, an independent committee or commission can be established by law or regulations to give stronger and more objective safety checking. If regulation must occur in the same ministry, at least the unit for checking dam safety should be separated from the units in charge of project preparation and/or execution and should report to a higher level. External technical assistance for dam safety and capacity-building programs may be required, including for preparation of suitable regulations and guidelines.

The regulation of privately owned dams requires a tailored approach depending on the type of portfolio. Large private sector dam owners, such as semi-autonomous utilities for hydropower and water supply, may possess sufficient internal management capacity due to the resources available through the energy and/or water production system. However, having this capacity depends on ensuring that tariff structures are sufficient to ensure strong revenue streams to support the profitability of the company and its operations. The cost of regulatory requirements, therefore, becomes an important consideration in tariff setting. In some circumstances, the regulator can agree on the owner's dam safety program, including portfolio risk management approach, so that it can focus more on overall compliance checking and progress in the dam safety program. Small private developers, primarily for hydropower, require a different set of considerations, and it is extremely important for regulators to stipulate a clear set of dam safety requirements under the law or a by-law so that the regulators can check their compliance in a clear and straightforward manner. Detailed technical guidelines should be prepared under the law or by-law to provide specific design criteria and safety requirements for private developers.

TECHNICAL CONSIDERATIONS ALONG A CONTINUUM

Information. The provision of accurate information is critical for any regulatory mix, particularly for safe and sustainable dam management. It is essential to know the location and number of dams via a register as a baseline element for successful minimum dam safety assurance. The importance of such information is not only due to its cost-effectiveness for operators and any regulators but also because of the isolation of operators, operator resistance to regulation, economic and general conservatism, and the positive impact of information and education on attitudes and behaviors (Gunningham and Sinclair 2017; Pisaniello 2010, 2016; Tingey-Holyoak and Pisaniello 2015).

Register of dams. An inventory and register of dams can assist the regulators and the public in identifying, locating, and monitoring the portfolio of dams and in understanding the scope of the regulatory authority's responsibilities. Under maximum assurance, this element requires that all dams are both registered and classified, in addition to their data being maintained in an inventory. The registration can be based on size or a combination of size and hazard, and ideally the register will be publicly available in a well-maintained database. Local authorities at least should maintain a register of all dams in each of their jurisdictions and assign some sort of hazard ratings. This at least provides a database for governments to monitor the density of potentially hazardous dams and also the potential for "cumulative" dam safety problems in catchments as downstream areas develop.

Dam classification. It is not essential that all dams be included under regulation, and a classification system can assist the regulator in ensuring that dam owners secure the required level of safety in a consistent manner and that those that are excluded are easily identified and too insignificant to cause harm in the case of failure. Classification can be determined based on size and/or hazard. For a small portfolio of low-hazard dams, the safety criteria and requirements can be defined on a case-by-case basis. Where there is a medium-size portfolio or one that involves a range of different sector types, the dam classification system should be based on a consideration of the downstream hazard. The classification system should be practical and manageable considering available resources of the regulator and owners so that it can help optimize resource allocation for both regulator and owners. For a large portfolio of high-hazard dams, a comprehensive dam classification system should be established requiring higher design criteria and standards of care. Hazard assessment should be undertaken in a comprehensive manner and should include potential loss of life, economic loss, environmental damage, and so forth.

Risk-informed approaches. A risk-informed approach can help identify those dams that are most in need of remedial action. This is particularly helpful for large portfolios and in situations where there are fiscal constraints and where prioritization attached to specific dam safety considerations can be useful. For a small portfolio of low-hazard dams, a simple risk assessment can be undertaken, with regular monitoring to determine any changes in the hazard classification. Change could be due to demographic changes or conditions following specific events, such as earthquakes. For medium or mixed portfolios, a portfolio risk management approach should be considered in addition to deterministic dam classification approaches. This can be particularly helpful in defining dam safety requirements, and the approach can serve as an additional tool for effective budget allocation for both regulators and dam owners. A high-hazard dam may warrant more detailed risk assessment using qualitative risk assessment tools, such as probable failure mode analysis, and semi- or fully quantitative risk assessment approaches. For a large portfolio of high-hazard dams a full-fledged risk assessment should be conducted along with a systematic portfolio risk management approach for both regulators and owners. While it can be gradually introduced without legal mandates, clear guidance on risk assessment requirements and methodologies for high-hazard dams should be provided officially by the regulator.

Dam safety criteria and standards of care. The specific standards that must be met in the inspections and surveillance activity related to dam safety are usually developed by the regulatory authority outside of the prescribed legal framework. For a small portfolio of low-hazard dams, the required dam safety criteria and standards of care can be defined using a basic classification system. However, for medium or mixed portfolios, the required dam safety criteria and standards of care should be defined using more elaborate methods, preferably based on downstream hazard. For large portfolios of high-hazard dams, the required dam safety criteria and standards of care should be clearly defined in an elaborate manner using a comprehensive classification system covering all of the essential elements. Careful consideration is needed to balance the required level of safety and the resources needed to ensure compliance with such requirements. The regulator's annual dam safety reporting and disclosure could be helpful in raising awareness and securing required budget for regulators.

Operation and maintenance. Manuals or plans for O&M and surveillance are important to ensure that these tasks remain consistent with current dam safety practices and procedures. For a small portfolio of low-hazard dams, the O&M Plan should be prepared on a case-by-case basis in a manner commensurate with the dam's potential hazard. For medium or mixed portfolios, the preparation of the O&M Plan should be clearly defined in the regulations, covering regular O&M work and reservoir operation procedure. The scope and level of details should depend on the dam's hazard as per its classification. For a large portfolio of high-hazard dams, the O&M Plan should prescribe the reservoir operation and downstream warning procedures, in addition to the procedures for regular O&M work, surveillance, periodic inspection, and dam safety review, which are subject to the regulator's approval. Coordination procedures between different dam owners around reservoir operations, particularly during floods, should also be defined.

Emergency preparedness. Dam owners should always be prepared for dam failures, and regulators should be monitoring dams and owners to ensure that they are prepared and that the responsibilities for interacting with the appropriate disaster risk management authorities and potentially affected communities are clearly articulated. For a small portfolio of low-hazard dams, the EPP prepared by the owner, in coordination with the regulator, national and local authorities, and other relevant stakeholders, should reflect the dam's hazard. For medium or mixed portfolios, preparation of the EPP should be required for all high-hazard dams and stipulated in the dam safety regulations along with suitable technical guidelines. For large portfolios of high-hazard dams, detailed EPPs should be required and prepared by the owners in coordination with all key stakeholders, including the regulator, national and local authorities, and other relevant stakeholders. For extremely hazardous dams, the consequence of failure should be assessed carefully using a comprehensive model including dam break, flood wave, and an assessment of people's behaviors and movements in the event of an emergency. Based on this, a detailed emergency action plan should be formulated. In many cases, the agency with primary responsibility for handling emergencies is not the agency with primary responsibility for dam safety. In these cases, the relevant agency, in addition to the dam safety authority, must be informed about the emergency plans.

Public safety. The assurance of public safety should be assessed and covered in the O&M Plan, with provision for suitable warning and awareness-raising mechanisms for people engaged in activities downstream and in surrounding areas. For a small portfolio of low-hazard dams, the public safety assurance measures can be determined on a case-by-case basis. For medium or mixed portfolios, public safety should be included formally as part of dam safety review and establishment of safety programs by the dam owners. The regulators should provide technical guidelines specifically relating to public safety requirements for dam owners. For large portfolios of high-hazard dams, public safety should be included in the regulations and owner's dam safety program. The required measures should be reviewed periodically by regulators, and the regulator should prepare and disclose an annual dam safety report indicating the degree of compliance by dam owners.

Record keeping and reporting. Adequate reporting plays a critical role in command-and-control regulation, as any activity or compliance with government-enforced maximum assurance standards must be checked. Record-keeping requirements should require owners to act responsibly with any information and material relating to the safety of dams by requiring a special safety file to be maintained and stored in a place where it can be inspected by the enforcement authority. If dam safety issues arise, the file must be easily accessible to all concerned. Key information in the safety file should be sorted and filed into three separate parts: (1) as-built engineering details; (2) an O&M Plan including dam safety surveillance, monitoring, and reservoir operation procedures; and (3) a contingency plan to ensure easier and quicker access to relevant information at the time of need. However, if a country's circumstances mean that it is not possible to enforce maximum levels of assurance, audits can be employed to complement many instrument combinations. Governments may provide tax incentives to undergo audits, potentially targeting a much wider group of dam owners who would willingly have their dam safety management audited.

Education and training of dam owners. These are most effective when the self-interest of owners and operators is captured. For example, if the provision of dam safety and sustainability education and training could provide benefits to the operators' activities and operations, generating more efficient and effective allocation of scarce resources, then there is considerable potential for improved management practices (Grabosky and Gunningham 1998; Gunningham and Sinclair 2017; Pisaniello 2016; Tingey-Holyoak 2014). In the case of dam safety assurance, there will be an element of win-win behavior that would result from the provision of education and training, such as would result from knowledge of the safety of the structure for ongoing revenue and successful operations, and so it is a central minimum assurance element.

FINANCIAL CONSIDERATIONS ALONG A CONTINUUM

The regulatory authority and owners must be provided with adequate financial resources to ensure that they can adequately perform prescribed functions and responsibilities. In some countries it may be possible to achieve this objective by having the authority raise a significant portion of its financing by charging fees for issuing licenses, permits, or annual fees that are paid by dam owners. In other cases, budgetary rules may require that the regulatory authority cannot retain the funds it obtains from charging fees. In these cases, the government will have to fund the regulatory authority through its normal budgetary allocation procedures. The following are essential considerations.

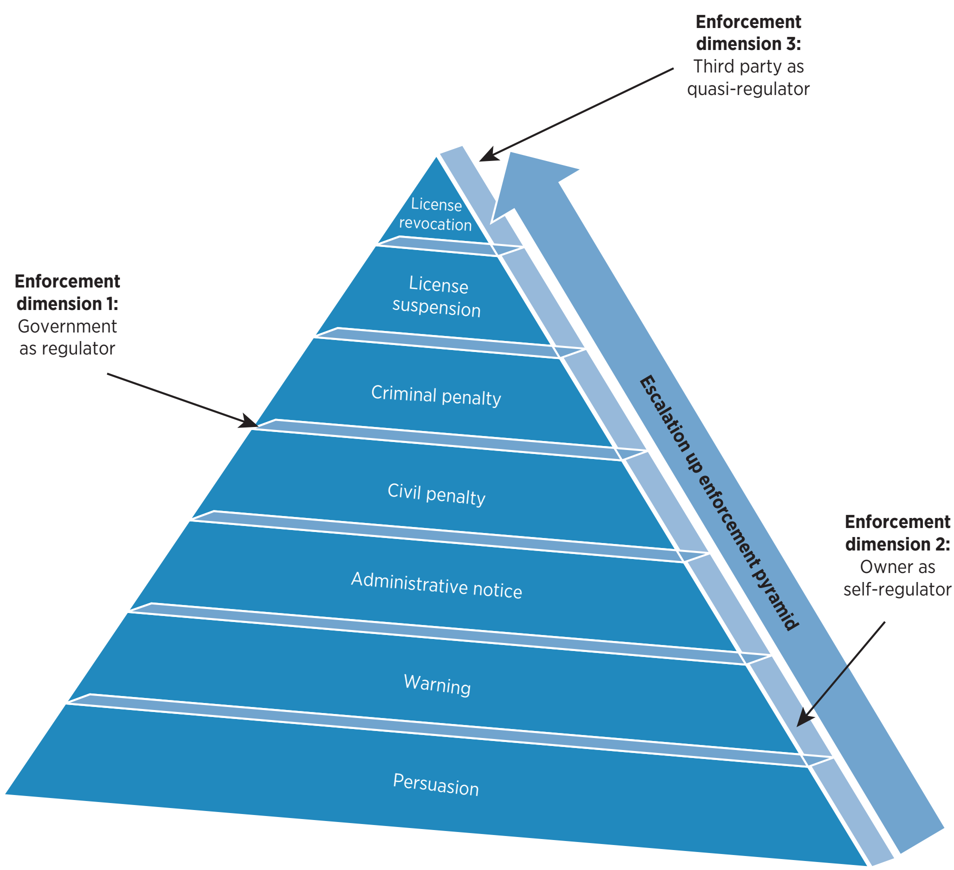
Adequate funding and capacity for the enforcement body. In addition to the registration of dams and extensive supervisory remit for authorities, there needs to be provision of sufficient funding to ensure efficient and effective administration of the policy. Ideally, the enforcement body has sufficient internal financial resources and human capacity or the potential to outsource. Financing can be done via tariffs through user-pay mechanisms, directly through government budgets via tax revenues, or through a combination of the two. Revenues secured through tariffs can provide more assured financial resources, particularly when subject to independent price regulation, and are more frequently found in the hydropower sector. In those sectors where there is a strong influence of other public policy objectives, such as in the irrigation sector in many countries, financial resources can be less secure and subject to a broader range of competing demands.

Economic and financial incentives to improve assurance. There is a narrow range of economic tools that can be included in the minimum assurance policy element mix to achieve desired policy objectives for safe and sustainable dam management, depending on the country's circumstances. Tools focused on incentives may be given as a cash-based lump sum, installments over time, or tax benefits linked to achieving certain objectives (Debailleul 1997; Tingey-Holyoak 2014). Although such incentive-based tools involve potentially significant and recurrent costs to the government, they may be more cost-effective than dealing with the consequences of a dam failure. The inclusion of positive incentives can remove the requirement for more coercive instruments, which might be costly to administer and monitor (Pisaniello 2016; Pisaniello, Tingey-Holyoak, and Burritt 2012). Positive incentives can motivate dam owners to move from unsafe, unsustainable dam practices to improved management (Grabosky and Gunningham 1998; Gunningham and Sinclair 2017). The main resistance to changing dam management practices will be the potential for financial hardship for owners, operators, and communities. However, much of this can be overcome by education and information strategies. In some cases, water rights can create ownership for a resource and a subsequent incentive to manage the resource sustainably.

ENFORCING COMPLIANCE WITH THE POLICY MIX

Compliance enforcement must be available to policy makers in a maximum assurance model. Coercive sanctions contrast other elements by mandating the reduction of the unsafe and unsustainable activity (Grabosky and Gunningham 1998; Gunningham and Sinclair 2017). Coercive instruments can be useful as a last resort when escalating up an enforcement pyramid (see figure 10.2) and could include the outright prohibition of poor management practices, dam safety and sustainability fees based on condition monitoring, or dam owner certification, which must be renewed on a regular basis. The regulatory nature of coercive sanctions means that they are expensive to administer. In addition, they may be met with resistance by dam owners in many countries and

FIGURE 10.2 Example of an expanded enforcement pyramid



Sources: Original figure for this publication, adapted from Gunningham, Sinclair, and Grabosky 1998 and Gunningham and Sinclair 2017.

regional settings (Tingey-Holyoak and Pisaniello 2015). Nevertheless, as with any industry, there will be dam owners and operators who do not respond to other, less intrusive policy instruments, and compliance enforcement may be the only way to control this (Grabosky and Gunningham 1998; Gunningham and Sinclair 2017; Pisaniello, Tingey-Holyoak, and Burritt 2012).

Escalation up an enforcement pyramid can be used to achieve policy goals and build regulatory responsiveness (Gunningham and Sinclair 1999a). Regulatory enforcement commences at a pyramidal base of cooperative, flexible regulation with warnings and negotiated outcomes and escalates to administrative penalties, improvement, and prohibition notices in the middle, culminating in a highly interventionist peak (Ayers and Braithwaite 1992). Under such models, regulatory enforcement can begin at lower levels, such as with quasi-regulatory involvement by the insurance industry or other industry actors, and move up the pyramid should stronger responses be required. There is also evidence to suggest that less interventionist measures, such as involvement by third parties like insurers, are less costly, facilitate faster decision-making, and reduce resistance from those whose activities are being regulated (Pisaniello, Tingey-Holyoak, and Burritt 2012; Tingey-Holyoak and Pisaniello 2015). The pyramidal model is advanced here to include self-regulation by dam owners under minimum assurance, in addition to a third dimension involving the inclusion of a quasi-regulator (Gunningham and Sinclair 1999a, 1999b; Gunningham and Sinclair 2017).

Under the pyramidal model, it is possible to commence on lower levels, such as dam owner self-regulation or third-party-provided persuasion, and then move up the pyramid should the level of responsiveness demand. Controlled escalation of this variety is possible only when the minimum-to-maximum elements can be easily manipulated for a given circumstance, such as the optimal mix of self-regulation and command-and-control regulation (Gunningham and Sinclair 1999a; Pisaniello, Tingey-Holyoak, and Burritt 2012).

Less interventionist measures are also preferred where highly coercive or prescriptive instruments, requiring high levels of administration and lacking flexibility, are undesirable. There is evidence to suggest that not only are high interventionist measures unattractive to the dams sector (Gunningham and Sinclair 1999a, 1999b; Pisaniello, Tingey-Holyoak, and Burritt 2012) but that less interventionist measures are less costly, facilitate faster decision-making, and create less resistance (Gunningham and Sinclair 1998; Tingey-Holyoak and Pisaniello 2015).

However, there are possible scenarios in which vertical integration is not useful and a horizontal approach is preferable. Situations where there is a high risk of catastrophic loss, such as with a series of cascading high-hazard, highly unsafe dams, cannot wait for the regulator to decide how best to integrate vertically. In this situation a horizontal "underpinning of a regulatory safety net" is warranted (Gunningham and Young 1997). Because it is often the case that an instrument combination will not be viable, it is important to rely on "triggers" to undertake instrument sequencing where escalation occurs from the least interventionist to the most interventionist options (Gunningham and Sinclair 1999b). These triggers are benchmarks to alert regulators to the need for increased intervention. For dam safety, this could be in the form of random inspections by regulators, mandatory reporting and independent auditing of safety records and reports, independent structural auditing and community oversight, and right-to-know programs (Gunningham 1993; Gunningham and Sinclair 2017).[1] An additional strategy to the use of triggers is the use of "circuit breakers" that provide a form of complementary regulation through positive inducement. For example, if private dam owners were provided with a right to compensation for the maintenance of dams and spillways, it could result in a behavioral shift, with short-term measures replaced by more standard policy responses and longer-term incentives for ensuring the safety of dams and downstream communities.

The notion of the quasi- or third-party regulator also forms a part of the regulatory mix theory. This enables analysis of owner behavior in terms of instrumental threats to comply with the law compared to one that considers the power of social pressures in policy implementation (Tingey-Holyoak and Pisaniello 2015). Therefore, the expanded pyramid models not only the power of self-regulation and government regulation but a third face that empowers surrogate or quasi-regulators (Gunningham 1993; Gunningham and Sinclair 1999a, 1999b; Gunningham and Sinclair 2017; Pisaniello, Tingey-Holyoak, and Burritt 2012). Quasi-regulators effectively expand the regulatory toolbox (Grabosky 1994) and could include industry groups, environmental groups, or financial services providers. Governments do not have limitless resources to apply to areas of policy demand, and thus the ability to use groups in powerful positions or work with markets, although difficult to generate, can result in solutions to situations where government cannot bear the weight of all the regulation.

Financial institutions, such as banks and insurers can also be used to ensure that owners report consistently on actual and potential liabilities of the dam. This can significantly enhance their capacity to assess and act on safety or equity issues (Gunningham, Phillipson, and Grabosky 1999; Pisaniello, Tingey-Holyoak, and Burritt 2012). Insurance can be a powerful tool, as insurers have strong incentives to be aware of any potentially catastrophic consequences caused by their policyholders. Insurance companies can also have a part in effective sustainability management by helping the relevant industry (for example, hydropower and irrigation) understand the importance of risk and safety management addressing the consequences of unsafe and unfair water sharing.

KEY MESSAGES AND CONCLUSIONS

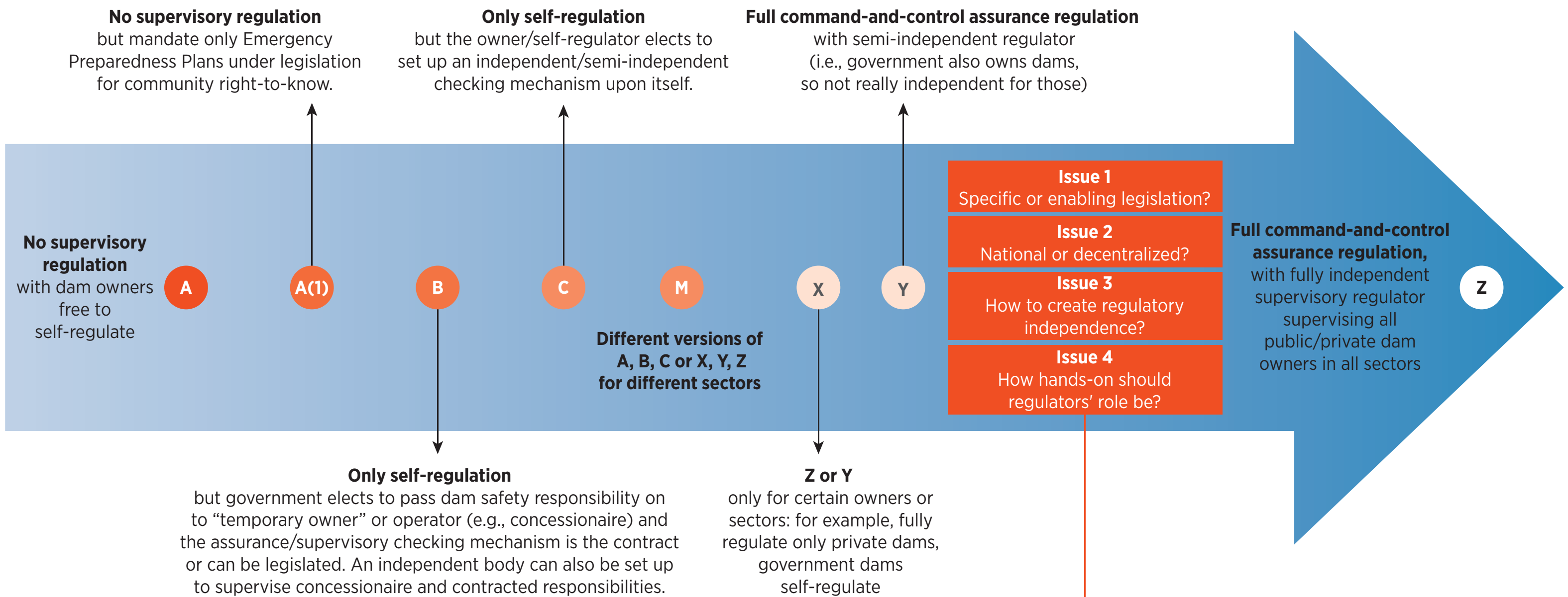
Each country has its own legal and administrative traditions informed by considerations of its geopolitical history. The regulatory framework for the safety of dams and downstream communities needs to be consistent with these traditions, as well as being realizable in light of the resource constraints of the country. The problem with optimal solutions is that the world in which they are realized is very sensitive to context. While maximum assurance can be considered ideal, it is not always the most optimal. Historically, the maximum elements have met with opposition, and they have also failed because of country-specific circumstances. Such elements can be difficult to monitor and enforce without extensive capacity and resources. Relying solely on the maximum assurance elements and high amounts of command-and-control regulation also lacks efficiency, which is a critical feature of the optimal dam safety assurance policy. Designing the optimal regulatory mix can entail finding a position on a spectrum between the minimum (see "A," figure 10.3) and the maximum (see "Z," figure 10.3) mixture of elements. Table 10.1 provides a summary of key considerations at each end of the continuum.

Ultimately, designing an optimal regulatory mix is critical and requires considering the continuum in a particular country's circumstances—and this requires consolidation of the elements into a dam safety assurance "decision framework" that incorporates country-specific circumstances to simplify making the choice of elements for an optimal mix (figure 10.3 and appendix E). However, when used in a well-planned regulatory design, despite the mentioned drawback, maximum assurance with clear parameters and standards makes the regulator's task much more straightforward and dam owners and operators more aware of their regulatory responsibilities, as long as it is adequately enforced.

The basic principles applied to the mix of regulatory elements for dam safety assurance, the notion of the continuum, and escalation up an enforcement pyramid apply to all dams. However, reasonable judgment needs to be made in their application commensurate with the size, complexity, and hazard of each dam—dependent on the country's portfolio and jurisdictional circumstances. For example, self-regulation and co-regulation also form part of the enforcement pyramid model. It has been argued that regulatory responses should not be confined to escalations up the enforcement pyramid, but should also consider industry responses or allow instruments to be implemented by professional bodies and associations as well as regulators (Baldwin and Black 2007, 11).

Ensuring the safety of dams and downstream communities requires design of an appropriate regulatory framework to account for the low probability of a dam failure or mis-operation that could have significant consequences. Ultimately, the optimal policy mix is context-specific. The context includes (1) the classification of dams in the portfolio (small or large), (2) the size of the portfolio (few/small or many/large), (3) the main ownership type (private or public), and (4) the hazard level or risk associated with dams (low or high). While the nature of overall social and environmental threats will dictate the precise combination of instruments, possible complementary combinations based on these four decision-making criteria specific to country settings are highlighted in the decision framework (appendix E).

FIGURE 10.3 The continuum from minimum to maximum dam safety assurance



Role	Compliance audit	Quality assurance	Direct inspection/assessment
Function	**Random quality assurance audits only** Otherwise just rubber-stamping reports and certifications provided by owners' engineers in a predominantly hands-off function	**Allover assurance, check all information/reports provided by owners' engineers for every dam** May also do the hazard classification (i.e., more hands-on)	**Performs periodic dam safety inspections and assessments** Highly hands-on function
Capacity	**Low** need for capacity/expertise in authority	**Medium** need for capacity/expertise in authority	**High** need for capacity/expertise in authority
Liability	Accepting **no** liability Authority makes no decisions related to the safety of the dam	Accepting **some** potential liability	Accepting **extensive** potential liability

Source: Original figure for this publication.

TABLE 10.1 Summary of minimum and maximum assurance elements

Minimum assurance	Maximum assurance
1. Register/inventory	**1. Register/inventory**
2. Dam owner education and training	**2. Dam owner education and training**
3. Defining dam safety responsibility and liability, negligence-based versus strict liability	**3. Defining dam safety responsibility and liability, negligence-based versus strict liability**
4. Checklist—determine on case-by-case basis, considering the following: • O&M inspections • Instrumentation • EPP • Design and review standards • Public safety	**4. Clearly articulated uniform laws and regulations on dam safety:** • If federal, is only state legislation possible, or both federal and state? • Common law systems—enabling or specific • Civil law systems—specific only
	5. Full independent oversight body: • Apex ideal • Fully empowered: – To develop norms and standards via additional regulation and/or regulatory documents – To issue licenses and permits – To maintain register or inventory of dams – To supervise surveillance and maintenance of dams – To conduct audits and inspections – To approve inspectors – To carry out advisory responsibilities • Quality assurance role: – The role can range from simple compliance audit (hands-off) to more hands-on quality assurance – A direct surveillance role is not recommended – The optimal mix of role depends on internal financial and technical capacity, and the extent of potential residual liability the regulatory body is prepared to accept • Consider including independent, nongovernment body in regulatory framework to assist regulator in executing its functions
	6. Dams classification and capture by the regulatory regime: • Register or inventory of all dams and classification • Classification based on both size and hazard • Publicly available database system maintained
	7. Dam safety requirements: • Mandate criteria and/or guidelines (common law) or standards/codes (civil law) • Fit for purpose and fit for country's circumstances • Provide for the following mandated safety requirements (noting that tailings different to water dams) including public safety during operations: – O&M – Inspections and dam safety reviews i. Frequency ii. Sophistication iii. Qualifications of inspector/reviewer – EPPs i. Both for dam break and operational ii. Dam design and review • Deterministic and risk informed where appropriate (mandate risk analysis where possible) • Proportioning requirements according to hazard

(continued)

TABLE 10.1 *(continued)*

Minimum assurance	Maximum assurance
	8. Record keeping and reporting: • Institutional reporting (authority reports to minister) and publicly available • Mandate owner record-keeping safety file with three main parts: – As-built engineering details – O&M data – EPP data
	9. Compliance enforcement: • Stronger penalties including criminal sanctions = increased compliance • With company owners, penalties can catch directors rather than just owners
	10. Adequate funding and capacity for enforcement body: • Internal capacity or outsourced – User pays (for example, in hydropower) and/or government budget (irrigation): more user pay is more ideal

Source: Original table for this publication.
Notes: EPP = Emergency Preparedness Plan; O&M = operation and maintenance.

Any model needs to consider the complexities of dam safety regulation along with the varying jurisdictional circumstances, geopolitical and socioeconomic context, and the characteristics of the portfolio. The various elements that combine to provide the enabling legal and institutional framework exist along a continuum to provide minimum to maximum levels of assurance. When supported by regulatory mix theory, these elements provide regulatory flexibility to induce novel approaches to compliance that may transcend minimum requirements of informational regulation (such as the community's right to know and reporting on performance) and reaching a more original mix of elements. Such approaches can extend beyond the maximum levels of assurance required and thus further appeal to and benefit owners and communities in appropriate jurisdictions (including fast-tracking of licenses or permits, reduced fees, public recognition for good performance, penalty discounts under certain conditions, and reduced burdens from routine inspections), providing greater flexibility to achieve compliance.

Policy makers are confronted by intensely different dam contexts, financial situations, and institutional arrangements around the world. By leaning on a baseline theoretical framework through regulatory mix theory, the legal, institutional, and technical considerations along this continuum enable development of elements and models that can be considered along a spectrum for varying circumstances. Single-instrument approaches are unlikely to be successful for regulating dam safety assurance in any setting, and in order to avoid the consequences of dam failures, minimum and maximum assurance elements need to be positioned in such a way as to provide a spectrum of options with various enforcement models. When combined with comparative analysis of the country case studies, use of this spectrum enables development of a consolidated dam safety assurance framework specific to country settings illustrated through a series of worked examples in appendix E: "A Decision Support Tool to Inform and Assess Regulatory Frameworks for Dam Safety Assurance."

NOTE

1. Community right-to-know principles are designed to inform the community of dam owners' activities and the potential for these activities to affect the community (Pisaniello 2011; Pisaniello, Tingey-Holyoak, and Burritt 2012; Pisaniello, Dam, and Tingey-Holyoak 2015). The benefits from this legislation being realized in the United States from the prominent Emergency Planning and Community Right-to-Know Act 1986 (EPCRA 1986) include providing community groups with increased political leverage, exposing companies to community pressure, and the establishment of "good neighbor agreements," lessening the need for heavy regulation (Gunningham and Cornwell 1994; Gunningham and Sinclair 1998).

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Appendix A: Case Study Countries and Characteristics

TABLE A.1 Case study country characteristics, by region

Country	Total number of dams	Number of large dams	Total renewable water resources (10^9 m^3 per year)[a]	Total storage capacity (km^3)[b]	Population (thousands)[c]	Land area (1,000 km^2)	Population density (people per km^2)	GDP per capita (current US$)[d]	Legal system
East Asia and Pacific		29,302	10,061	1,141	2,219,384	21,940	101		
Australia	735,570	570	492	77.79	24,602	7,682	3	53,794	Common law
China	>97,988	23,842	2,840	829.80	1,386,395	9,389	148	8,827	Civil law
Indonesia	>5,000	132	2,019	23.02	263,991	1,812	146	3,846	Civil law
Japan	>200,000	3,113	430	28.98[e]	126,786	365	348	38,430	Civil law
Korea, Rep.	17,306	1,306	70	16.20[f]	51,466	97	528	29,743	Civil law
Lao PDR	No data	85	334	7.81[g]	6,858	231	30	2,457	Civil law
Malaysia	>72	51	580	22.45	31,624	329	96	9,952	Common law
Myanmar	356	200	1,168	15.46[h]	53,371	653	82	1,257	Common law
New Zealand	1,290	96	327	16.89	4,794	263	18	42,583	Common law
Philippines	No data	19	479	6.28[i]	104,918	298	352	2,989	Mixed
Thailand	>5,000	218	439	68.28[j]	69,038	511	135	6,595	Civil law
Vietnam	>10,750	51	884	28.04[k]	95,541	310	308	2,342	Civil law

(continued)

TABLE A.1 *(continued)*

Country	Total number of dams	Number of large dams	Total renewable water resources (10^9 m³ per year)[a]	Total storage capacity (km³)[b]	Population (thousands)[c]	Land area (1,000 km²)	Population density (people per km²)	GDP per capita (current US$)[d]	Legal system
Europe and Central Asia		6,088	6,522	>1,208	644,121	21,265	30		
Albania	597	307	30	4.03	2,873	27	105	4,538	Civil law
Austria	271	171	78	2.13	8,798	83	107	47,381	Civil law
Bulgaria	2,001	181	21	6.52	7,076	109	65	8,228	Civil law
Czech Republic	25,118	118	13	3.18	10,594	77	137	20,380	Civil law
France	36,712	712	211	9.98	67,106	570	118	38,484	Civil law
Italy	8,830	542	191	No data	60,537	294	206	32,110	Civil law
Norway	6,335	335	393	33.28	5,277	365	14	75,704	Civil law
Poland	328	69	61	2.96	37,975	306	124	13,864	Civil law
Portugal	3,217	217	77	11.63	10,300	92	112	21,291	Civil law
Russian Federation	No data	69	4,525	801.50	144,497	16,377	9	10,749	Civil law

(continued)

TABLE A.1 *(continued)*

Country	Total number of dams	Number of large dams	Total renewable water resources (10^9 m³ per year)[a]	Total storage capacity (km³)[b]	Population (thousands)[c]	Land area (1,000 km²)	Population density (people per km²)	GDP per capita (current US$)[d]	Legal system
Europe and Central Asia *(continued)*									
Spain	76,082	1,082	112	53.81	46,593	500	93	28,208	Civil law
Sweden	10,200	200	174	35.96	10,058	407	25	53,253	Civil law
Switzerland	213	167	54	3.34	8,451	40	214	80,343	Civil law
Turkey	1,884	1,267[l]	212	157.30	80,745	770	105	10,546	Civil law
Ukraine	No data	38	175	55.50[m]	44,831	579	77	2,640	Civil law
United Kingdom	>12,596	596	147	5.27	66,023	244	271	39,954	Common law
Uzbekistan	>54	17	49	22.16[n]	32,387	425	76	1,534	Civil law
Latin America and the Caribbean		2,481	12,788	1,002	432,942	15,062	29		
Argentina	184	114	876	131.60	44,271	2,737	16	14,398	Civil law
Brazil	300,000	1,392	8,647	700.40	209,288	8,358	25	9,812	Civil law
Chile	>3,096	96	923	14.44	18,055	744	24	15,346	Civil law

(continued)

TABLE A.1 *(continued)*

Country	Total number of dams	Number of large dams	Total renewable water resources (10^9 m³ per year)[a]	Total storage capacity (km³)[b]	Population (thousands)[c]	Land area (1,000 km²)	Population density (people per km²)	GDP per capita (current US$)[d]	Legal system
Latin America and the Caribbean *(continued)*									
Mexico	4,900	813[o]	462	150.00[p]	129,163	1,944	66	8,910	Civil law
Peru	>740	66	1,880	5.77	32,165	1,280	25	6,572	Civil law
Middle East and North Africa		1,006	318	370	258,813	3,515	74		
Egypt, Arab Rep.	>7	7	58	168.20	97,553	995	98	2,413	Civil law
Iran, Islamic Rep.	>802	802	137	32.24	81,163	1,629	50	5,594	Religious law
Iraq	>30	30	90	151.80	38,275	434	88	5,018	Mixed
Lebanon	>18	17	5	0.23	6,082	10	595	8,809	Civil law
Morocco	>350	150	29	17.96	35,740	446	80	3,023	Civil law
North America		10,435	5,971	1,628	361,855	18,251	20		
Canada	>14,000	1,170	2,902	892.00	36,708	9,094	4	44,871	Common law[q]
United States	68,515	9,265	3,069	735.90	325,147	9,157	36	59,928	Common law

(continued)

TABLE A.1 *(continued)*

Country	Total number of dams	Number of large dams	Total renewable water resources (10^9 m³ per year)[a]	Total storage capacity (km³)[b]	Population (thousands)[c]	Land area (1,000 km²)	Population density (people per km²)	GDP per capita (current US$)[d]	Legal system
South Asia		5,359	2,421	258	1,586,945	3,950	402		
India	75,102	5,102	1,911	224.00[r]	1,339,180	2,973	450	1,979	Common law
Nepal	No data	6	210.2	0.09	29,305	143	204	849	Common law
Pakistan	>223	163	246.8	27.81	197,016	771	256	1,548	Common law
Sri Lanka	12,850	88	52.8	5.94[s]	21,444	63	342	4,074	Common law
Sub-Saharan Africa		1,472	776	234	412,337	4,361	95		
Burkina Faso	1,080	19	13.5	5.34	19,193	274	70	642	Civil law
Cameroon	>6,000	14	283.1	15.61	24,054	473	51	1,452	Mixed[t]
Ethiopia	>50	19	122	31.48	104,957	1,104	95	768	Civil law
Nigeria	264	52	286.2	50.67	190,886	911	210	1,968	Common law
South Africa	5,226	1,114	51.35	31.02	56,717	1,213	47	6,151	Mixed
Zimbabwe	7,654	254	20	99.93	16,530	387	43	1,333	Common law

(continued)

TABLE A.1 *(continued)*

Country	Total number of dams	Number of large dams	Total renewable water resources (10^9 m^3 per year)[a]	Total storage capacity (km^3)[b]	Population (thousands)[c]	Land area (1,000 km^2)	Population density (people per km^2)	GDP per capita (current US$)[d]	Legal system
Total case studies		50,784	38,857	5,841	5,916,397	88,344	67	11,351	
Total ICOLD countries		58,518	47,880	8,025	6,744,122	148,940	50	11,190	

Data sources:

Total number of dams: Country case studies.

Number of large dams: ICOLD-CIGB. World Register of Dams, database, accessed June 15, 2017. https://www.icold-cigb.org/GB/world_register/world_register_of_dams.asp.

Total renewable water resources (10^9 m^3/year): FAO (Food and Agriculture Organization of the United Nations). AQUASTAT main database, accessed April 24, 2019. http://www.fao.org/aquastat/en/.

Total storage capacity (km^3): FAO. AQUASTAT main database, accessed April 24, 2019. http://www.fao.org/aquastat/en/.

Population (thousands): World Bank. World Development Indicators, database, accessed April 24, 2019. http://databank.worldbank.org.

Land area (1,000 km^2): World Bank. World Development Indicators, database, accessed April 24, 2019. http://databank.worldbank.org.

Population density (people per km^2): Calculated.

GDP per capita (current US$): World Bank. World Development Indicators, database, accessed April 24, 2019. http://databank.worldbank.org.

Legal system: Country case studies.

Note: The total storage capacity of Canada is calculated as 8,986,241 million m^3 by ICOLD database, but here 892,000 million m^3 is used through communication with and confirmation by the Canadian Dam Association. GDP = gross domestic product; ICOLD = International Commission on Large Dams; km^2 = square kilometers; km^3 = cubic kilometers; m^3 = cubic meters.

a. Data are for dates between 2013 and 2017 unless otherwise noted.
b. Data are for dates between 2013 and 2017 unless otherwise noted.
c. Last available data are for year 2017.
d. Last available data are for year 2017.
e. Last available data are for year 1993.
f. Last available data are for year 1994.
g. Last available data are for year 2010.
h. Last available data are for year 2005.
i. Last available data are for year 2006.
j. Last available data are for year 2010.
k. Last available data are for year 2010.
l. Dincergok, T. 2017. Peer reviewer for World Bank Global Dam Safety Study, personal communications, June 28.
m. Last available data are for year 2012.
n. Last available data are for year 2010.
o. ICOLD. 2014. "Regulation of Dam Safety: An Overview of Current Practice Worldwide." Bulletin 167. Paris: ICOLD/CIGB.
p. Last available data are for year 2011.
q. Canada has a legal system based in common law except for in Quebec, where a civil code system is used.
r. Last available data are for year 2005.
s. Last available data are for year 1996.
t. Cameroon is a bijural system, with common law operating in anglophone regions and civil law operating in the francophone regions.

Appendix B: Heads of Analysis

The comparative analysis was based on a pro forma template intended to provide a consistent structure and format across all of the case studies. Critical points of consideration were developed in order to provide a comprehensive "heads of analysis" and elements from which data could be collected for each of the case study countries and jurisdictions. This drew on global data sets and publicly available information, with the information subject to an iterative and consultative process that engaged more than 300 specialists, including World Bank specialists and other international and national experts, formal peer review, and consultations with professional bodies. These heads of analysis then formed the basis for the quantitative and qualitative comparative analysis of legal, regulatory, institutional, and technical metrics, along with analysis of financial and operating models, to identify a continuum of elements of Good International Industry Practice and precedents. These heads were at both the macro and micro levels.

MACRO LEVEL: DAM SAFETY ASSURANCE POLICY, REGULATIONS, AND INSTITUTIONS

Country Characteristics, Including Dam Safety History and Regulation Development

1. Demographics, including population and land surface area
2. Income characterization, including gross domestic product and gross national income per capita

3. Definition used for large and small dams, nationally and, if relevant, at state, provincial, and jurisdiction levels
4. Physical characteristics, including approximate number of dams, number of large and small dams, total dam capacity, storage per capita, renewable water resources (internal, external, and total), total exploitable water resources, interannual and seasonal rainfall variability, number of dams of significant or higher hazard, number of regulated dams, both nationally and if relevant at state, provincial, and jurisdiction levels
5. The main safety risks the country has experienced or is vulnerable to: for example, flood, earthquake, landslides, inadequacies in dam design, construction or maintenance, and cascading disasters
6. A list of dams and classification tables: by purpose, type, size, age, hazard, and so forth where available
7. Type of legal and political and/or economic system: for example, common/statute law, civil/code law, religious law, or hybrid
8. Constitutional aspects, including any aspects of a country's constitution relevant to dam safety regulation enactment and implementation: for example, federalism, national and state-based, and national only or state only
9. Any recorded dam failures at the national level—if recorded, how many and any specific details such as statistics on dam types, failure types, and so forth—otherwise, any specific significant individual dam failure stories; if available, any statistics on the number of deaths from dam failures generally or from individual cases
10. Any failures that specifically triggered dam safety policy or regulation
11. Any interesting details regarding progression of dam safety policy or regulation development

Legal Basis for Dam Safety Responsibility and Legislation

1. Primary responsibility for dam safety established under what key acts and regulations (Who is primarily responsible: for example, dam owner or regulator, any others, and how is *dam owner* defined?)
2. Responsibility for private and public dams and any other distinguished dam types: for example, federal dams, community-owned dams, tailings dams, nuclear industry dams, hydro dams, multipurpose dams (Where is responsibility derived from: same acts and regulations as in the previous bullet or different, including any critical definitions that distinguish different dam types—for example, how multipurpose dams are defined?)
3. Any duty of care responsibility on dam owners from common law: for example, precedent-based tort/negligence law

4. Liability for dam failures: for example, determined through common law and/or dealt with under statute
5. Any use of dam safety insurance (either mandatory, voluntary, or subsidized taken up by dam owners and operators or by downstream communities) within the legal framework of any of the noted dam types

Governance, Empowerment, and Institutional Arrangements for Dam Safety Assurance

1. Key acts establishing dam safety assurance regulator responsibility
2. Type of dam safety assurance legislation: for example, specific, enabling, or other
3. Responsible authorities (If possible include organogram of the sector and those involved, including legal basis and framework for empowerment and responsibilities of different ministries and agencies for different purposes of dams.)
4. Institutional arrangements for publicly owned dams and any other distinguished dam types: for example, federal dams, mining dams, nuclear industry dams, and hydro dams
5. Roles and powers the noted dam safety assurance statutes provide: for example, broad supervisory, quality assurance, and/or audit-type powers to ensure accepted dam safety management standards applied by dam owners and their engineers *or* more-specific powers to direct and check specific code-like dam safety standards applied
6. Details of specific roles and powers of the regulating authority, for example:
   i. Power to develop norms and standards via additional regulation and/or regulatory documents
   ii. Power to issue licenses and permits
   iii. Responsibility to maintain register or inventory of dams
   iv. Power to supervise surveillance and maintenance of dams
   v. Power to conduct audits and inspections
   vi. Power to approve inspectors
   vii. Advisory responsibilities
   viii. Reporting responsibilities, to whom, including any public reporting
   ix. National versus any state-based powers and responsibilities: for example, extent of national involvement in federal systems

7. Role of any nonregulatory institutions: for example, International Commission on Large Dams national committee, among others
8. Any arrangements for transboundary river dams: for example, special treaties or regulating authority—and any specific details relating to dam safety management

Contents and Technical Requirements of the Regulatory Regime

1. Dams required to be registered and criteria adopted
2. Dams captured by the main dam safety assurance provisions, criteria adopted, including any risk- or hazard-based dam classification system
3. Scope of the regulatory regime
4. Standards and specifications for the planning, design, and construction of new dams, including design criteria for flood and earthquake probability, and whether risk assessment is mandated
5. Standards and specifications for surveillance, inspections, and dam safety reviews, including any mandating of risk-assessment or portfolio risk management
6. Any mandated operation and maintenance requirements
7. Requisite qualifications of inspectors and dam safety reviewers
8. Reporting requirements
9. Requisite timing of inspections and safety reviews
10. Technical archives and record keeping
11. Fees for inspections, permits, and licenses
12. Any integration with land-use planning and development policy to account for hazard creep when new land developments are proposed downstream of existing dams
13. Any integration with water allocation policy: for example, to stop spillway blocking and unfair water sharing
14. Emergency Preparedness Plans (EPPs): which dams are they required for; which institutions must be involved; requisite sophistication for different dams, including any emergency identification, communication, and warning procedures; dam-break analysis and downstream flooding simulation and mapping; any required budget level; EPP information dissemination and awareness raising for downstream communities, and so forth
15. Enforcement of the dam safety regulations: penalties, civil or criminal, and so forth

16. Liability for dam failures: specific details of any statutory provisions
17. Dam owner education and guidance: extent of and any guidance documents produced by regulator that set the standard for owners, applicable national committee guidelines, and so forth
18. Small dams: any special provisions, guideline publications, accounting of cascade or cumulative threat

Funding of the Regulatory Regime (Financial Framework) and Performance Assessment

1. A user pays system via license and permit and/or inspection fees
2. Regulator acts as fee-charging consultant
3. Any funding from government's general revenue
4. Any different financing mechanisms for different dam sectors
5. Any reports of the existing financing being robust, weak, or nominal
6. Any self-assessment of how the system performs by the regulatory authority
7. Any external independent assessment of system performance
8. Recent results of any such assessments

MICRO LEVEL (DAM OWNER): DAM SAFETY MANAGEMENT PRACTICES AND TECHNICAL INSTRUMENTS

At the micro level, information, documents, and/or files were collected only if readily available (in the public domain or from country representatives) on any models or sample study dams that may provide examples of good, cost-effective practice in any of the following areas.

Corporate Governance

1. Models and/or examples of management structure and internal governance of dam safety management (What sort of people and positions are needed to design an effective dam safety management organization?)
2. Models or templates for dam safety program documentation: Going beyond how data are collected to how they are organized, analyzed, and applied, and also what checks and balances are in place
3. How interests of stakeholders are managed, for example, those of owners, board, management, government, community, and so forth

Portfolio Risk Management (PRM)

1. The stage of PRM in the country (Has it never been considered, is it under discussion, being tested, or legislated, and what is its historical development?)
2. Any guidelines or manuals available
3. Summary of procedure: how dams are classified for hazard and risk, qualitative or quantitative risk assessment, or simplified index method, tolerable risk setting, and application for real budget allocation

Operation and Maintenance (O&M)

1. Regular O&M by case study of dam owner, can include government-owned dams—one sample study dam, if possible, for each purpose of dams (hydro, irrigation, multipurpose, and so forth):
    i. Any example of O&M plan or manual, any standard format
    ii. Any budget information (If it is a government or utility dam, check annual budget of relevant ministries and utilities for O&M.)
    iii. Any periodic rehabilitation or reengineering needs, including budget allocation
    iv. Number of staff at dam site and local administration offices as well as their capacity, training opportunities, and so forth
    v. Monitoring and reporting requirements and procedure: periodic inspection, annual reports
    vi. Any coordination with other agencies: catchment conservation and so forth
    vii. Instrumentation used, measurement of system levels, and condition level
2. Reservoir operation by case study dam owner:
    i. Reservoir operation during flood, drought, and normal periods: independent or integrated (on a basin level) and their norms, procedures, and so forth for different types of dams
    ii. Hydrometeorological monitoring and flood forecasting: institutional arrangement, procedure, technology levels, and so forth
    iii. Hydropower cascade operations
    iv. Environment management, such as any environmental release procedures and so forth
    v. Sedimentation management, including checking seriousness of any sediment issues (Is there a sediment management plan, and

if so, what are the key details and criteria—for assessment and mediation measures, determination of dead storage volume [50 or 100 years], challenges, innovation, and so forth?)

Dam Safety Review and Design

1. Any simple cost-effective tools available to assist the review and design of dams for the following:
   i. Structural integrity
   ii. Spillway and flood capability
   iii. Earthquake resistivity
2. Any useful and exemplary ways to improve the safety level of existing dams to meet current standards, including any hardware and/or software measures

Emergency Preparedness Plans

1. Any good example case study EPPs, including any simple and cost-effective ones for smaller, less hazardous dams
2. Institutions and parties involved
3. In addition to dam failure, coverage of extraordinary cases, such as large flood release from spillways and turbines
4. If and how stakeholder consultation occurs
5. Emergency identification, communication, and warning procedures, including details of any downstream warning procedures during flood discharge by spillway gates opening
6. Technical matters such as dam-break analysis and downstream flooding simulation and mapping
7. Required budget level
8. EPP information dissemination and awareness raising for downstream communities: any mock drills or brochures prepared for more general public dissemination

TRANSBOUNDARY RIVER DAMS (APPLICABLE ONLY TO SELECTED COUNTRIES WITH TRANSBOUNDARY DAM MANAGEMENT SCHEMES)

1. Details of arrangements for managing transboundary river dams: for example, special treaties, regulating authority, and so forth
2. Powers of any transboundary dam safety authority, including details of any joint ownership or agreements and legal covenants between riparian countries on the basin scale

3. Specific details relating to dam safety management, including (1) what criteria are used to assess what is a transboundary dam; (2) the technical contents of the legal covenants such as sharing of information, water release operations during first reservoir impoundment and during wet and dry seasons, and type of notification between riparian countries including for EPPs; and (3) whether and how parties exchange such information
4. Any useful technical information on how EPPs are dealt with for any transboundary dams
5. Any special funding mechanisms associated with transboundary dam safety assurance schemes

Table B.1 provides a checklist template for soliciting information on Good International Industry Practices from case study countries. It includes provisions for identifying the key elements across macro- and micro-practices, where they exist in a country, such as dam registration regulations that work well for a particular reason (macrolevel, row 1), or novel ways of funding remedial works on a dam to improve safety (microlevel, row 4), and so forth.

TABLE B.1 Checklist template for identifying Good International Industry Practices examples

	Examples of Good International Industry Practices	
	Dam safety assurance: Macrolevel	**Dam safety management: Microlevel**
1	**Classification and registration**	
2	**Legal and institutional framework and empowerment**	
3	**Form and content of regulation**	
4	**Financial framework** Funding the administration of the assurance policy	**Financial framework** Funding dam safety works
5	**Portfolio risk management** If and how mandated at the jurisdictional level	**Portfolio risk management** At the organization or community level
6	**Enforced standards and dam safety instruments for design, construction, and O&M: risk-based or standards-based** These include: • Structural integrity assurance • Flood capability assurance • Earthquake resistivity assurance • Environment and sedimentation management, dam-break analysis, flooding simulation, and so forth • Climate change effects	**Dam safety instrument used** This includes: • O&M manual • Comprehensive safety assessment, including electromechanical issues • Climate change effects • Actual O&M levels and condition • Reservoir operation: for example, hydropower cascade operations and joint coordination with multiple dams on basin scale with flood forecasting system • Sedimentation management process

(continued)

TABLE B.1 *(continued)*

Examples of Good International Industry Practices	
Dam safety assurance: Macrolevel	**Dam safety management: Microlevel**
7 EPP Types of EPPs mandated for different types of dams	**EPP** • What actual EPPs include • EPP operationalization, including consultation with relevant agencies and downstream municipalities • Information dissemination, mock drills, and consultation materials used
8 Owner and community education, participation, insurance, and guidance • Community awareness and participation schemes • Subsidized and/or mandatory insurance schemes • Cost-effective tools	**Owner and community education, participation, insurance, and guidance** • Tools and instruments used and applied at the dam management level • Community awareness raising and the possible community participation in surveillance of small dams, and so forth

Source: Original table for this publication.
Note: EPP = Emergency Preparedness Plan; O&M = operation and maintenance.

Appendix C: Comparative Jurisdiction Review of Risk-Informed Approaches

TABLE C.1 Risk analyses and assessment legally mandated by regulation

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Australia, New South Wales	Dams Safety Act (2015) Dams Safety Regulation (2019) Dam Safety Regulatory Policy (2020) Draft Guideline (March 2020): The Meaning of "So Far As Is Reasonably Practicable" (SFAIRP) Draft Guideline (March 2020): Cost-Benefit Analysis Government Gazette (November 2019): Societal and Individual Risk Rating Methodology for Dams Safety Act 2015 Government Gazette (November 2019): Declared Dams Consequence Category Assessment and Determination Methodology for Dams Safety Act 2015	Dams Safety NSW, Ministry of Regional Water With the issuance of the Dam Safety Regulation (2019) and Dam Safety Regulatory Policy (2020), the 2015 Dam Safety Act (2015) is considered to be fully applied.	As per the 2019 Dam Safety Regulation, Dams Safety NSW may, on application by an owner of a dam, exempt the owner of the dam from the requirements of risk analysis, risk treatment, and SFAIRP demonstration (see three points in the right column) subclauses if it is satisfied that the dam is not complex. The exemption may be subject to conditions, including conditions that require the owner of the dam to use a different risk evaluation process or risk treatment process. The regulation also requires that an owner of a declared dam must calculate the societal and individual risk rating of the dam (or proposed dam) in accordance with the methodology as per the Gazette (2019). The Gazette provides the *societal safety thresholds* using F-N curves for (1) new and existing dams with major augmentation and (2) existing dams.	The 2015 act stipulates that the proposed regulations on dam safety standards should be based on a cost-benefit analysis and stakeholder consultations. According to a news article, private dam owners showed strong dissatisfaction over too-onerous dam safety requirements under the previous regime, which apparently led to this new legislation with an emphasis on cost-benefit analysis on dam safety standard. The 2019 Dam Safety Regulation includes the following: 1. The risk analysis process must employ an evidence-based quantitative methodology that identifies and analyzes the potential failure modes of various parts of a system, risk mitigation measures, and risk evaluation process based on risk-informed decision-making with a systematic process in which the results of risk analysis and other major considerations influencing the safety of a dam are considered in making decisions relating to the safety of the dam. 2. The risk treatment process must identify risk reduction measures that are to be implemented to eliminate or reduce risks, but only insofar as is reasonably practicable. 3. In determining whether it is reasonably practicable to implement a risk reduction measure, a cost-benefit analysis may be carried out taking into account all relevant matters, including the risk-occurrence likelihood, degree of harm, availability or suitability, and cost of the relevant risk reduction measures.

(continued)

TABLE C.1 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Australia, New South Wales (*continued*)				Per the SFAIRP and cost-benefit analysis guidelines (March 2020), the test for "reasonably practicable" is that a safety measure *should* be implemented unless the cost of doing so is so grossly disproportionate to the benefit that it would be clearly unreasonable to justify the expenditure. The need for the cost to be "grossly" disproportionate is established under the common law as identified by ANCOLD (2003) Guidelines on Risk Assessment and acknowledged by the cost-benefit analysis guideline under section 1.2.2. Effectively, dam owners are expected to consider all possible precautions and objectively balance up according to their "professional judgement" (per section 1.2.2 of the cost-benefit analysis guideline) situations that represent a gross disproportion and ones that do not. The regulator leaves such judgments that apply in determining SFAIRP beyond the tolerable risk threshold entirely up to the dam owner, accepting no responsibility or potential liability for such decisions. Dam owners are free to follow ANCOLD (2003) guidelines, which apply gross disproportion factors in cost-benefit analysis that will require owners to do more to reduce risk, or can avoid using such factors. The regulator simply strictly monitors and enforces that a risk-informed approach is undertaken and that the risk is kept below the tolerable risk threshold for all potential failure modes at all times through the risk rating scheme. There is no link between the dams subject to risk analysis and the class of dams. The consequence-based classification system (based on "potential loss of life" or people at risk as well as severity of damage and loss) has been developed including seven categories from very low to extreme in the Gazette (2019).

(continued)

TABLE C.1 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Australia, New South Wales (*continued*)				The Draft SFAIRP Guideline (March 2020) provides some explanation on the SFAIRP and ALARP ("As low As Reasonably Practicable") as follows: • There has been some confusion regarding the difference between SFAIRP and ALARP. The UK Health and Safety Executive (HSE) considers that duties to ensure health and safety SFAIRP and duties to reduce risks ALARP call for the same set of tests to be applied. However, the HSE highlights that SFAIRP and ALARP are not always interchangeable because legal proceedings will have to employ the particular term cited in the relevant legislation. As noted above, in NSW the legislation cites SFAIRP. • The two approaches may set out to achieve the same outcome, that is, to demonstrate due diligence with regard to safety, but the implication that having achieved ALARP will forensically satisfy SFAIRP post-event is potentially misplaced. The processes required to demonstrate each approach are different, especially for high-consequence, low-likelihood events such as those faced in dam safety management. • ALARP asks what the risk is associated with the hazard and then can that risk be made as low as reasonably practicable. • SFAIRP asks what the available practicable measures are and then tests which are reasonable based on the common law balance (of the significance of the risk versus the effort required to reduce it). • The possibility of the results of the two processes being identical is extremely unlikely; some commentators state "nil." In view of the requirements for SFAIRP under the regulation, this distinction between SFAIRP and ALARP is a critical issue for dam owners (and the others involved with dam safety management). (ANCOLD believes that ALARP and SFAIRP are the same and intends to continue referring to ALARP in its guidelines as ALARP would satisfy the common law duty and standard of care for negligence.)

(continued)

TABLE C.1 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Australia, Queensland	Water Legislation (Dam Safety) Amendment Act (2017) to amend the Water Supply Safety and Reliability Act (2008)	Department of Energy and Water Supply Guidelines for Failure Impact Assessment of Water Dams (2012), Guidelines on Acceptable Flood Capacity for Water Dams (2017)	Based on failure impact assessment as per Guidelines for Failure Impact Assessment of Water Dams (2012). Only category 1 and 2 dams are referable, and a dam with a "no failure impact" rating (less than two people at risk) is not a referable dam. The failure impact assessment includes a description of failure events considered, and the scenario producing the maximum population at risk must be used to determine the failure impact rating. No quantitative risk assessment is required in the failure impact assessment. However, hydrological safety risk must be checked using a risk assessment procedure in a quantitative manner, with a specified cost-benefit analysis and value of statistical life method. The guideline on flood capacity is derived from the act (see in the right column).	The Guidelines on Acceptable Flood Capacity for Water Dams (2017) under the act defined the required acceptable flood capacity and assessment methods, including (1) small dams standards, (2) fallback option, and (3) risk assessment procedure, incorporating ALARP ("As Low As Reasonably Practicable"). The first method used a simple diagram to determine the required annual exceedance probability depending on the population at risk. The second method indicates a hazard-based classification system based on people at risk (four classes) and severity of damage and loss (four classes) in which the acceptable flood capacity (probable maximum flood or return period) are specified. The third method, risk assessment, referred to the ANCOLD guidelines but refined them with specific tolerable criteria. The method assesses compliance with the ALARP principle by formulating additional risk reduction options that would bring the risk profile further below the limit of tolerability and undertaking a cost-benefit analysis for the upgrade options required to reduce the risk profile below the limits of tolerability based on: (1) incremental cost and benefits to reduce the risk profile beyond the tolerability limit; (2) the cost-benefit methodology; and (3) a "value of a statistical life" with a specific threshold value. There is no requirement for applying a gross disproportion factor in cost-benefit analysis for determining "reasonably practicable," as is done in the ANCOLD (2003) Guidelines on Risk Assessment. There was an attempt to place a higher value on human life to compensate for this, but the higher value has eroded over time, and the assessment is now effectively left with no requirement to use a gross disproportion factor and no compensation for it. The guideline also defines the required schedule for dam safety upgrading, depending on the shortage of spillway capacity compared to acceptable capacity (three tranches).

(continued)

TABLE C.1 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Australia, Victoria	Water Act (1989) Strategic Framework for Dam Safety Regulation (2012 and 2014) Guidance Note on Dam Safety Decision Principles (2015)	Water Group of Department of Environment, Land, Water, and Planning, Ministry of Water, with Dam Safety Advisory Committee	High- and extreme-consequence category dams, out of very low, low, significant, high A, B, and C and extreme as per the *Guidelines on the Consequence Categories for Dams*, Australian National Committee on Large Dams (ANCOLD 2012) Risk-informed approach is through the Statement of Obligations and annual report submission to the regulator.	Victoria requires dam owners to adopt risk-informed practices. The safety of dams owned by Victoria's water corporations is regulated through Statements of Obligations (SoOs) issued to water corporations by the minister for water under the Water Industry Act 1994. The SoOs refer to dam safety guidelines prepared by the ANCOLD. The safety of privately owned dams is regulated by Section 67 of the Water Act 1989. The Department of Environment, Land, Water, and Planning (Department) of the state is the lead agency for regulating dam safety in Victoria. The state government issued two guidelines: (1) Strategic Framework for Dam Safety Regulation (2012) and (2) Guidance Note on Dam Safety Decision Principles (2015). These guidance notes aim to assist dam owners and managers in making key dam safety investment decisions, providing guidance about satisfying the "As Low As Reasonably Practicable" (ALARP) principle and clarify dam safety investment time frames and appropriate target safety levels. To comply with dam safety regulations, water corporations are expected to undertake detailed safety reviews for high-consequence and extreme-consequence dams using both quantitative risk-based and standards-based assessment, to provide a comprehensive understanding of the level of safety of the dams. The SoOs require the owners to: (1) prioritize risks posed by the corporation's dams over all dams, components of dams, and the types of failures; (2) give priority to reducing risks to life above other risks; (3) base the urgency of reducing the risk posed by a dam on the relativity of risks to the tolerability limits as defined in the ANCOLD Guidelines; (4) base programs for reducing risk on the concept "As Low As Reasonably Practicable"; and, (5) where feasible, progressively implement risk reduction measures to achieve the best outcomes for the available resources. The SoOs also require the water corporations to submit an annual dam safety report including: (1) a prioritized list of proposed dam safety works, (2) a summary of the risk profile of dams, and (3) a summary of the overall risk reduction profile of the dams. The government also issued a guideline for the Strategic Framework for Dam Safety Regulation in 2014. The guideline also refers to ALARP and F-N curve, but also indicates five categories for required owner's actions and regulator's response for high- and extreme-consequence dams.

(continued)

TABLE C.1 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Canada, Alberta	Water Act (2017) Alberta Regulation 205/98 Water (Ministerial) Regulation Alberta Dam and Canal Safety Directive (2018)	Alberta Environment and Parks	For a dam with an accepted consequence classification of significant, high, very high, or extreme, a dam or canal owner must, in accordance with this directive, undertake risk assessment along with engineering inspections, annual performance reviews, and safety reviews. Only dams under "low" consequence classification (i.e., with no "population at risk") are exempt. Dams are generally classified as "significant" when people are only temporarily located downstream of the dam, for example, visitors to a park. Thus, it appears that quite a large portion of dams are required to undertake risk assessment under the regulation. However the risk assessment requirement is qualified by the Directive (2018, s5.22), which states that a "formal risk assessment" must be undertaken only "when: (a) a critical safety deficiency is identified for that dam or canal; or (b) an established quantifiable performance objective for that dam or canal is not met."	**Alberta Water (Ministerial) Regulation (205/98)** **Part 6: Dam and Canal Safety** **Investigations, design, construction, assessments, and evaluations** 30(1) A dam/canal owner shall ensure that: (a) the dam or canal is designed by qualified professionals and constructed in accordance with the accepted design and the Safety Directive, (b) all the construction is: (i) supervised by a qualified professional in accordance with the authorizations and the Safety Directive, and (ii) in conformity with the accepted drawings and the Safety Directive. (2) Unless otherwise directed in writing by the Director, a dam/canal owner shall ensure that all site investigations, surveillance, safety assessments, safety evaluations, and *risk assessments* (authors' emphasis) that are required by the Safety Directive are: (a) performed by qualified individuals in accordance with the authorizations, and (b) reported to the Director, in accordance with that Directive. **Risk assessments** 34.3 *A risk assessment must be performed in accordance with the Safety Directive* (authors' emphasis) through the use of a systematic process of analysis and evaluation of risk that: (a) involves the use of a formal failure mode and effects analysis procedure or a similar technique, and (b) includes: (i) a decision as to whether or not the risk in question is tolerable relative to existing risk management measures, and (ii) if that decision is in the negative, recommendations for risk management or mitigation measures.

(continued)

TABLE C.1 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Canada, Alberta (*continued*)			The Water (Ministerial) Regulation is the secondary statute that provides information on the administration of the Act. It includes definitions of important terms, identifies the basis for Water Act approvals, and outlines regulatory requirements. Part 6 specifies the regulations for dam and canal safety.	**Alberta Dam and Canal Safety Directive (2018)** **5.5 Dam or canal design requirements** (1) A dam/canal owner must comply with all of the following in respect of the design of a dam or canal: (a) the design of the dam or canal, including the design basis, inflow design flood, earthquake design ground motions, freeboard, and factors of safety for various failure modes, must be commensurate with the risk to factors at risk posed by the dam or canal, using the best available technology and best available practices; (b) the design must use and apply either: (i) a standards-based approach; or (ii) a performance-based approach that uses quantifiable performance objectives. **5.6 Target stability criteria and selected factors of safety must be justified** (1) A dam/canal owner must demonstrate that the target stability criteria and selected factors of safety used in the design of structures for a dam or canal: . . . (d) are justifiable having regard to, at a minimum, all of the following: . . . (ix) the ability and practicality of implementing an effective risk management system to reduce or mitigate the residual risks associated with the uncertainties of the selected factors over the life cycle of the structures. **5.18 Requirement to undertake assessments/evaluations** (1) For a dam or canal that has an accepted *consequence classification of significant, high, very high or extreme,* a dam/canal owner must, in accordance with this Directive, undertake: (a) engineering inspections; (b) annual performance reviews; (c) safety reviews; and (d) *risk assessments*. (2) A dam/canal owner must: (a) enter into the master deficiencies list any safety deficiencies and critical safety deficiencies that are identified through annual engineering inspections, annual performance reviews, safety reviews, risk assessments, and other safety assessments and safety evaluations; and (b) enter into the master non-conformances list any non-conformances that are identified through annual engineering inspections, annual performance reviews, safety reviews, risk assessments, and other safety assessments and safety evaluations.

(continued)

TABLE C.1 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Canada, Alberta (*continued*)				**5.22 Risk assessment** 1. A dam/canal owner must undertake a formal risk assessment regarding the safety of a dam or canal when: (a) a critical safety deficiency is identified for that dam or canal; or (b) an established quantifiable performance objective for that dam or canal is not met. 2. A risk assessment must be performed and documented by a qualified individual. 3. A risk assessment must, at a minimum: (a) have a scope and a level of detail that is commensurate with (i) the risk to factors at risk posed by the dam or canal; and (ii) the complexity of the structures of the dam or canal; (b) be performed based on current industry standards and best practices; (c) describe the process and approach that were used in undertaking the risk assessment; (d) include a determination of all potential failure modes of the structures; (e) identify all credible failure modes of the structures and their possible consequences by utilizing a formal failure mode and effects analysis process; (f) include an assessment of the probability of each credible failure mode under various triggering events; (g) using qualitative or semiquantitative methods and current safety standards and best practices, assess the level of residual risk related to the identified credible failure modes of the structures; (h) determine appropriate risk categories, using sound engineering principles and judgments; (i) confirm that the ongoing residual risks related to the credible failure modes of the structures are tolerable, based on (1) current safety standards and best practices; and (2) the risk matrix used for the assessment, or the criteria used for determining tolerability of risk; (j) should the structures not meet the adopted tolerable residual risk criteria, recommend appropriate risk management or mitigation measures that should be taken to keep the residual risks as low as reasonably practicable until the structures meet the adopted residual risk criteria. 4. A dam/canal owner must submit the risk assessment to the Director, in writing, not less than 90 days after the risk assessment has been completed.

(continued)

TABLE C.1 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Canada, Alberta (*continued*)				5. If, in the opinion of the Director, the risk assessment submitted by the dam/canal owner has been developed in accordance with this Directive: a dam/canal owner shall implement measures outlined in the risk assessment as authorized in writing by the Director. If, in the opinion of the Director, the risk assessment submitted by the dam/canal owner has not been determined in accordance with this Directive: (a) the dam/canal owner must submit additional information regarding the methodology, assumptions, data sources, and references that were used to assess the risk; and/or (b) the dam/canal owner must submit additional information for the purposes of demonstrating that the risk assessment that was submitted by the dam/canal owner has been developed in accordance with this Directive.
France	Law on Water and Aquatic Environment (2006), Decree of December 2007 that defines the classes of dams, among others, and the Decree of May 2015 update for the rules applicable to structures built to prevent flooding and to the safety rules for hydraulic structures Dam Risk Assessment Guideline (2012)	Ministry of Environment, Energy, and Sea	Class A and B dams (out of A, B, and C). Dam owners are required to conduct risk analysis every 10 and 15 years for A and B class dams, respectively.	The purposes of risk analysis are dam-safety-issues identification, decisions for remedial measures, and portfolio management. The guideline issued by the ministry provides details for risk assessment procedures, including risk identification, characterization in terms of probability, intensity, kinetic effects, and consequence-severity based on dam-break flood wave analysis using the bow-tie method; "failure, mode effects, and criticality analysis," and so forth. For some rare phenomena for which statistics or fitted probabilistic models are not available, qualitative analysis can be suggested to assess the probability using qualitative classification with four or five classes. The guideline noted that the regulatory body must be cautious in the use of quantified probability and aware of the uncertainty level and other constraints, emphasizing the importance of relative ranking of different failure and accident scenarios. The guideline noted that it is not possible to define clear tolerable risk limits but rather provided a judgment base using the criticality matrix (failure probability versus consequence severity) classifying risks into three zones (red, orange, and green) without any specific criteria but reference to the "As Low As Reasonably Practicable" (ALARP) principle. It is not clear why it uses the term *possible* instead of *practicable*, which is more standard. The regulator may face challenges in approving the proposed mitigation measure's scope and implementation schedule.

(continued)

TABLE C.1 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
France (*continued*)				It is interesting to see that the civil law legal system in France refers to tolerable risk using the ALARP requirement derived from the common law system. This risk analysis mandate is in line with the French hazardous assets regulation and EU Seveso III Directive (2013) on the control of major accident hazards involving dangerous substances.
Mexico	National Water Act and Metrology and Standardization Act Safety Operation of Dams Part 1: Risk Analysis and Classification of Dams (NMX-AA-175-SCFI-2015) by General Directorate of Standards of Ministry of Economy (2015)	National Water Commission (CONAGUA) under the Ministry of Environment and Natural Resources	Formal risk study is required for dams higher than 15 meters and with more than 1 million cubic meters in reservoir capacity; it is also required if a preliminary risk study indicates high risk for dams 5–15 meters high and with more than 500,000 cubic meters in reservoir capacity.	The risk analysis includes failure modes assessment using event trees and estimation of failure modes probability, and the annualized risk is calculated based on the probability of occurrence and failure consequences in terms of loss of life and the monetary value of damages, including loss of income, costs of replacement, environmental damage costs, and so forth. The regulation also includes a modified version of f-N curve based on the US Bureau of Reclamation (USBR) risk guidelines, which do not consider tolerability or acceptability but evaluate the risk in terms of strength of justification (increased or diminishing justification) to reduce it. CONAGUA has not initiated risk assessment but is expected to apply this to some critically important dams that supply water to the Metropolitan Area of Mexico City.
Norway	Water Resources Act 2000 Dam Safety Regulations 2009	Norwegian Water Resources and Energy Directorate (NVE), Ministry of Petroleum and Energy	Class 2, 3, and 4 (out of 4), which require Emergency Action Plans (EAPs)	The regulation requires owners to undertake risk analyses for the purposes of emergency planning, public safety, and information security, but not for overall dam safety assessment. However, NVE issued guidelines on risk analysis (1997), and Statkraft, the largest dam owner in Norway, has been performing risk and vulnerability analyses in line with the regulation requirements on preventive safety and emergency preparedness, reliability of energy supply covering extreme natural events, technical accidents and intended vandalism, and so forth.

(continued)

TABLE C.1 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
South Africa	National Water Act 1998 and Dam Safety Regulation 2012	Dam Safety Office of Department of Water and Sanitation (DWS)	Class II and III dams (out of I, II, and III)	Dam owners may be required to undertake dam safety risk analysis and/or risk assessment of a dam, ancillary structures, and foundations with an indication of failure probabilities, when requested by the director general of DWS, according to the regulation. In addition, the DWS, both as regulator and owner of dams, has been undertaking a simplified probabilistic method to identify dams that should receive priority for remedial works. A simple algorithm is used to determine the total expected loss during the life of a dam based on (1) total failure probability, (2) failure consequences, and (3) reduction factor depending on operation and maintenance standards. The probability of failure and the reduction factors are determined by choosing values from descriptive tables. The DWS has also developed a risk-based decision model and methodology for the probabilistic safety evaluation of dams and has applied it to its own dams since 1987. Most cases employ a level 0 analysis, using a simple probability calculation along with experienced engineering judgment. Higher levels of risk analyses (levels 1 and 2) mainly involve increased accuracy of parameters, but the calculation methods are similar. The approach is useful in optimizing the limited human resources capacity of the DWS for identifying and checking the safety issues of most critical dams.
United States, California	AB-1270 Dams and reservoirs: inspections and reporting (Section 6102 of Water Code) (February 2018)	Division of Safety of Dams, Department of Water Resources	Risk management approach for dam safety inspection and reevaluation was mandated in legislation in February 2018. The legislation stated, "This amendment is to be proposed by the regulator in consultation with various entities." The new legislation also now requires that "Dam safety inspection for significant, high, and extremely high hazard categories dams are also mandated at least once per fiscal year."	The new legislation stated that the "Division of Safety of Dams shall propose amendments to its dam safety inspection and reevaluation protocols to incorporate updated best practices including risk management to ensure public safety in consultation with independent, national dam safety and dam safety risk management organizations, including [Association of State Dam Safety Officials] and [US Society on Dams]."

Source: Original table for this publication.

TABLE C.2 **Risk-informed approach under self-regulation mechanism**

Country	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
United States, federal agencies	Federal Emergency Management Agency (FEMA): National Dam Safety Program Act as part of Water Resources Reform and Development Act (2014); managing National Dam Safety Program (NDSP) in coordination with Association of State Dam Safety Officials, and federal and state agencies Federal Guidelines for Dam Safety Risk Management (2015) US Army Corps of Engineers (USACE): Various federal laws for water, river, harbor, and so forth Engineer Regulation ER 1100-2-1156: *Engineering and Design* - Safety of Dams-Policy and Procedure (2014); Engineering and Construction Bulletin: Interim Approach for Risk-Informed Designs for Dam and Levee Projects (2019) US Bureau of Reclamation (USBR): Reclamation Act (1902) and subsequent laws. Dam Safety Public Protection Guidelines—A Risk Framework to Support Dam Safety Decision-Making (interim) 2011. And others. Best Practices in Dam and Levee Safety Risk Analysis (USBR and USACE in 2012 and updated in 2015)	FEMA: Administrator of the NDSP USACE: managing more than 700 federal dams in 44 states USBR: managing more than 470 federal dams in 17 western states	USACE, USBR, and so forth operate their dams as per their dam safety programs under their own guidelines. They have been developing risk-informed dam safety management approaches over long years. However, these do not seem to be statutory requirements but are evolving good practices for addressing dam safety in an optimized manner. The National Inventory of Dams has used three categories in a hazard-based classification system as per the FEMA guideline on dams classification. However, those federal agencies seem to have developed much more elaborate dam safety programs based on risk analysis and assessment. Most states have developed hazard- and consequence-based classification systems (mainly three or four descriptive categories) as per the FEMA guideline but with differences in their definitions.	In 2011, USBR issued the guidelines that present the basis and guidance for dam safety risk management. In 2012, USBR and USACE issued “Best Practices in Dam and Levee Safety Risk Analysis,” updated again in 2015 and 2019. Also, USACE issued Engineer Regulation ER 1100-2-1156: Safety of Dams-Policy and Procedure (2014). Based on these 2011 guidelines from USBR and USACE and USBR (2012), FEMA (2015) issued “Federal Guidelines for Dam Safety Risk Management.” The FEMA 2015 guideline explained the relationship between risk analysis, risk assessment, and risk management. First, risk identification is the process of identifying credible failure modes. Second, risk analysis involves the results of risk identification, that is, consequences of all credible failure modes, and risk estimation, which is defined as the process of quantifying probabilities. Third, risk assessment includes the result of risk analysis and risk evaluation, which is the process of examining and judging the significance of estimated risk. It also refers to a societal F-N plot, which shows the cumulative risk posed by all failure modes and the associated potential life loss. Last, risk management involves risk-informed decision-making and prioritizing risk reduction measures for a portfolio of dams in an optimized manner. The FEMA (2015) guideline also indicated the Joint Federal Risk Categories with five urgency classes (from category I, very high urgency, to category V, no urgency) in which characteristics and considerations and potential actions corresponding to each urgency category building on earlier efforts by USACE and USBR are indicated.

Source: Original table for this publication.

TABLE C.3 Risk-informed approach practiced as part of regulation in coordination with dam owners

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Canada, Ontario	Lakes and Rivers Improvement Act (1990) Regulation 454/96, Administrative Guide (2017) S series of Technical Bulletins	Ministry of Natural Resources and Forestry (MNRF)	Very high- and high-hazard potential dams (out of four categories) are required to undergo dam safety review, including dam safety analysis, at least once in 10 years. Alteration, improvement, or repair to a dam that may affect the dam's safety or structural integrity, the waters or natural resources, and so forth, in addition to construction of a dam, require minister's approval. The ministry engineer is responsible for review and approval of the submitted plans and specifications. In exceptional circumstances, the ministry may request work or studies (dam safety review) where there are significant concerns or uncertainties on the dam's condition. Owners are also required to prepare an annual performance assessment demonstrating that the performance goals and objectives set out in the performance agreement are being met, subject to the review of the ministry.	Ontario's Dam Safety Reviews: Best Management Practices (2011) covers dam safety analysis, including potential failure modes and criticality, as well as adequacy of design, construction, and operation features addressing these failure modes, among many. MNRF, both regulator and owner of around 400 dams, has developed a Dam Safety Asset Management Plan on a life cycle basis using a software (Total Capital Planning Solution) and a key performance indicator module (Hatch), which includes application of a risk-based profiling system based on USBR original works. MNRF is also considering risk-informed decision-making over a standards-based approach in coordination with Ontario Power Generation (OPG). A draft risk evaluation and tolerability guideline is under review based on Canadian Dam Association suggested criteria. OPG's maturity and soundness of risk analysis methodology is nearly complete. Quantitative approaches for portfolio risk management, dam safety evaluation and upgrading decision-making, and qualitative indexing are incorporated for public safety around dams. A risk analysis approach based on systems engineering principles and stochastic simulation has been developed by OPG. A pilot project demonstrating credibility of the approach has been completed and is under review by the MNRF.

(continued)

TABLE C.3 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
United Kingdom	England: Reservoirs Act (1975) as applied in England Flood and Water Management Act (2010) has amended the Reservoirs Act as applied in England	England: Environment Agency (EA) Wales: Natural Resources Wales Scotland: Scottish Environment Protection Agency Northern Ireland: Department for Infrastructure, since May 2016 (previously Department of Agriculture and Rural Development)	There are no specific legal mandates for undertaking risk analyses or assessment. However, an inspection report is required to specify any measures that the inspection engineer considers should be taken in the interests of the safety of the reservoir. **England** All regulated dams, that is, high risk (meaning hazard), are required to be inspected by an "inspecting engineer" at least once in 10 years and at any time when requested by the "supervising engineer." The 2010 Flood and Water Management Act that amended the 1975 Reservoirs Act states that "risk" means a risk in respect of an occurrence assessed and expressed as a combination of the probability of the occurrence with its potential consequences. The 2010 act introduced a provision that categorizes high-risk versus non-high-risk dams based on consequence assessment, and non-high-risk dams are not subject to full-fledged dam safety requirements. The capacity threshold of a large raised reservoir is reduced from 25,000 to 10,000 cubic meters.	The Department for Environment, Food and Rural Affairs (DEFRA) of the UK's EA issued a guideline, "Guide to Risk Assessment for Reservoir Safety Management," for England and Wales in 2013 that has provided guidance on the application of risk analysis, assessment, and management for reservoirs and has been used by inspecting and supervising engineers. The risk assessment is based on a three-tier approach: tier 1 is qualitative, while tiers 2 and 3 are quantitative. Although not a legal requirement, it is recommended that the inspecting engineer should undertake the equivalent of a tier 1 qualitative risk assessment, which could be escalated to tier 2 or 3 if required. The Construction Industry Research and Information Association issued the guideline Risk Management for United Kingdom Reservoirs in 2000. This covers qualitative and semiquantitative risk analysis methods, such as "failure modes, effects, and criticality analysis" using LCI (location, cause, and indicator) diagrams rather than quantitative analysis. Interestingly, Scotland tried to incorporate failure probability for reservoir risk classification in the 2011 act, but stopped short of its application due to lack of an agreed process or methodology. Indeed, all UK member countries assign an overall score of 1 for failure probability factor. For further details, the Scotland Reservoirs Act 2011 in chapter 3, section 22, indicates both potential adverse consequences of uncontrolled release of water from reservoir and the probability of such release are considered for risk designation, and the regulator may consider (1) the purpose of the reservoir, (2) the materials used for construction, (3) the way in which the reservoir was or is being constructed, and (4) the maintenance of the reservoir for probability assessment.

(continued)

TABLE C.3 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
United Kingdom (*continued*)			The EA may designate a dam reservoir as a high-risk one if (1) the EA thinks that, in the event of an uncontrolled release of water from the reservoir, human life could be endangered, and (2) the reservoir does not satisfy the conditions specified in regulations made by the minister. The conditions specified in regulations may include conditions related to the reservoir's purpose, construction materials, construction method, maintenance condition, and so forth. DEFRA of the EA issued the *Guide to Risk Assessment for Reservoir Safety Management* (2013) for England and Wales, in which the risk is defined as the function of the failure likelihood and consequence. Tier 1 qualitative assessment requires owners to identify and assess potential failure modes, which may be raised to tier 2 or 3 considering required level of risk assessment.	However, the guidance from the Scottish Environment Protection Agency's (SEPA's) reservoir risk-designation process (2015) indicates in section 3.2 that "the practice of considering the probability of dam failure, and thereafter the uncontrolled release of water, is still in development and is a complex matter. There is not currently an agreed process or methodology that is widely used within the United Kingdom reservoir industry to determine the probability of an uncontrolled release of water. . . . Until an agreed approach is established, SEPA will assign an overall score of 1 for the probability factor for each reservoir, thereby ensuring that each reservoir will receive the same level of prediction for an uncontrolled release of water, and therefore all dams will be considered equal in terms of their probability of failure. If evidence emerges to support the use of certain criteria to predict probability, SEPA will further develop the reservoir risk designation methodology to take account of these new developments. For criteria to be adopted, they would need to be reliable, complete, and accompanied by readily available data to support its use."
	Wales: Reservoirs Act (1975) as applied in Wales Flood and Water Management Act (2010) has amended the Reservoirs Act as applied in Wales Scotland: Reservoirs Act (2011)		**Wales** Same as above. **Scotland** High-risk (i.e., hazard) and medium-risk dams are included. High-risk dams are inspected at least once in 10 years and at any time when requested by the supervising engineer and when recommended by the inspection report. Medium-risk dams are inspected at any time when requested by the supervising engineer and when recommended by the inspection report.	

(continued)

TABLE C.3 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
United Kingdom (*continued*)	Northern Ireland: Reservoirs Act (2015)		**Northern Ireland** Same as above, but high- and medium-risk dams are prescribed as high and medium "consequence" dams. **All United Kingdom member countries** Supervising engineer must give the reservoir manager an annual written statement with a copy to the regulator (for High risk reservoirs in England and Wales; High and Medium risk reservoirs in Scotland; and High and Medium consequence reservoirs in Northern Ireland).	
United States, Federal Energy Regulatory Commission (FERC) over nonfederal hydropower dams	Energy Policy Act (2005) after Federal Power Act: FERC Code of Federal Regulations, Title 18, Chapter I, Subchapter B, Part 12: Safety of Water Power Projects and Project Works, Subpart D: Inspection by Independent Consultant	Division of Dam Safety and Inspection, Office of Energy Projects, FERC	Dams with high hazard potential and determined by the regional engineer or the authorized FERC representative to require inspection by independent consultant as per Part 12-D.	Part 12-D: Inspection by Independent Consultant as well as Engineering Guidelines for the Evaluation of Hydropower Projects, Chapter 14-Dam Safety Performance Monitoring Program: The latter defines the probable failure mode analysis, Supporting Technical Information Document, and Surveillance and Monitoring Plan with independent consultant and reporting. FERC issued the interim Risk-Informed Decision-Making Guideline (RIDM) (2016) building on USACE/USBR/FEMA guidelines. FERC Strategic Plan (2014–18) also states using RIDM to evaluate dam safety as one strategy. FERC indicated that setting the tolerable risk limits is challenging and ALARP (including the grossly disproportionate cost for remedies) is subject to difficult judgment.

Source: Original table for this publication.

TABLE C.4 Risk-informed approach broadly practiced or piloted without legal mandates

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Australia, Tasmania	Water Management Act (1999) Water Management (Dam Safety) Regulations (2015)	Department for Primary Industries and Water	Risk analyses and assessment are not explicitly mandated in the act nor in the 2015 regulations. Clause 165 C part (f) of the 1999 act states that one of the functions of the minister is "to formulate measures to ensure the safety of dams and, in particular, plans to remove or minimize risks to persons or property or the natural environment arising from an incident." In Part 2 of the old dam safety regulations in 2003, the design standards refer to the DSC2C on Surveillance Reports for Dams by the NSW Dam Safety Committee and Australian National Committee on Large Dams (ANCOLD) Dam Safety Management and Risk Assessment Guidelines. However, the 2015 regulations only referred to the ANCOLD Guidelines on Dam Safety Management and Consequence Categories for surveillance inspection. The Tasmania Guidelines for Five-Year Dam Safety Surveillance Report (Tasmanian Government 2013) states that the surveillance report should cover detailed recommendations, including time frames for completion of any work required to bring the dam to an acceptable safety standard among many. The regulation stipulates eight dam safety requirements and qualification of authorized safety reviewers for each of seven categories of dam classification.	Although there is no legal risk assessment mandate, Hydro Tasmania (owning 204 dams) has been applying risk assessment since 1998. It has a businesswide integrated business risk management (IBRM) framework, which includes risk criteria for health and safety, environmental and social, financial, legal, stakeholder, and business strategy loss categories. The IBRM risk assessment categorizes risks as low, moderate, high, or extreme. The Dam Safety Risk Management Policy aligns the societal risk tolerability criteria included in the 2003 ANCOLD Guidelines on Risk Assessment with the IBRM criteria. This is a powerful method of transparently rating dam safety risks against other asset and business risks. The policy then describes the organizational response required for the risk categories described. The process of managing dam safety here attempts to achieve the best balance between compliance with good practice and engineering standards and the tolerable management of risk. For intolerable risk of dams, it applies the ALARP principle to determine which mitigation options, combination, and sequencing provide the best risk mitigation value, and produce an intended risk reduction pathway for each dam and the portfolio of intolerable risk dams. It is not clear to what extent the regulator reviews and approves the risk reduction schedule and program, considering the owner's financial capacity and affordability.

(continued)

TABLE C.4 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Canada, British Columbia	Dam Safety Regulation (2016) under the Water Sustainability Act (2014)	Dam Safety Section, Water Management Branch, Ministry of Forests, Lands, and Natural Resource Operations	Owners of dams with classification of high, very high, or extreme (out of five classes) are required to conduct a dam safety review by qualified professionals and prepare a report on the safety of the dam, for acceptance by the dam safety officer.	No explicit risk analysis requirement is stipulated in the act and regulation. There is no guidance on performance expectations or risk tolerance targets. However, as per the act, BC Hydro implements the dam safety program and submits quarterly reports to its Hydro Board of Directors and annual reports, including a summary of new issues identified, assessment of risk, and progress on implementation plans, to the provincial government and the controller of water rights. Furthermore, BC Hydro has developed and been using a vulnerability index (qualitative or semiquantitative assessment) rating as a surrogate for probability of future poor dam performance, which is an aggregate rating based on all known issues and deviations from good practice and current standards with priority attention to very high and extreme consequence classification dams. It also conducts dam safety analysis using hazards and failure modes analysis; fault tree–based vulnerability analysis; failure mode, effects, and criticality analysis; and quantitative risk analysis as appropriate and scientifically feasible. Further, it has developed and applied a life-safety model for emergency action plan. BC Hydro uses a maturity matrix system similar to Indonesia but developed for hydropower companies to benchmark its internal dam safety activities. The findings are communicated to senior executives and the regulator.

(continued)

TABLE C.4 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Spain	Water Law (Royal Legislative Decree 2001, last modified December 2013) Regulations of Hydraulic Public Domain (Royal Decree 849/1986, last modified December 2016)	Dam Safety Office of Ministry of Agriculture, Food, and Environment and Water Basin Authorities (Hydrological Confederations) as well as autonomous governments	Risk assessment and management is not legally mandatory. Spanish Regulations of the Hydraulic Public Domain, article 364, states that "technical regulations for the safety of dams and reservoirs, the basic criterion for determining safety requirements, will be the potential risk that may arise from the breakage or malfunction of the same, evaluated in the process of classification of the dam." Class A and B dams per consequence- or hazard-based classification (three classes) are subject to five-year safety inspections, and emergency action plans (EAPs) are mandatory. Class C dams are subject to 10-year inspection without EAPs.	Spain has established risk assessment guidelines: *Technical Guide on Operation of Dams and Reservoirs*, vol. 1, *Risk Analysis Applied to Management of Dam Safety* (PACE and SPANCOLD 2012). Risk assessment and risk-informed dam safety management have been applied in Spain by a number of public and private owners, including but not limited to the Duero River Authority, 40 dams in the Extremadura region owned by the regional government, and privately owned hydropower and supply dams.
United States, Washington State	State Dam Safety Act (last updated in 2012)	Washington State Dam Safety Office, Department of Ecology	There seem to be no clear legal mandates for risk analyses and assessment. The State Dam Safety Act (updated 2012) defines a dam classification system based on both size-based (three classes) and hazard-based (five classes) criteria but does not specify risk analysis or assessment. However, the regulator's mandates for reviewing projects' design reports, plans, specifications as well as periodic inspection of existing dams are quite broad and intensive. The regulator has the authority to conduct routine periodic inspection of all existing dams with high and significant downstream hazard, including not only visual inspection but also full dam safety evaluation covering hydrologic and hydraulic capabilities, structural and seismic stabilities, and so forth, and evaluation of operation and maintenance procedure, EAP, and other aspects.	As part of the dam safety regulatory program, the state Dam Safety Office has been employing a risk-based approach for its dam safety regulation since the 1990s, using a simplified quantitative risk assessment system, including a numerical rating format in terms of failure consequence, warning adequacy, and seriousness of each structural deficiency of a dam. Based on this, prioritization ranking of dams and their risk reduction measures is calculated. The state seems to have accomplished a successful result using such a risk-based approach.

Source: Original table for this publication.

TABLE C.5 Risk classification using risk index as legal mandates

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Brazil (federal)	Dam Safety Law—National Policy of Dam Safety (Law no. 12.334) in 2010	Brazil has 45 dam safety regulatory entities. At the federal level, these are Brazilian Electricity Regulatory Agency (ANEEL), National Water Agency (ANA), National Department of Mineral Production (DNPM), and Brazilian Institute for Environment and Renewable Natural Resources (IBAMA). Other agencies operate at the state and municipal levels. However, under the law, ANA has been playing a more central role in the institutional framework relating to dam safety, assuming additional regulatory responsibilities apart from those it was already accountable for as stipulated by its creation law (Law no. 9.984/2000).	The Law applies to all dams with at least one of the following characteristics: (1) height equal to or greater than 15 meters, (2) total reservoir capacity equal to or greater than 3 million cubic meters, (3) reservoirs containing hazardous waste, or (4) reservoirs classified from medium to high in the levels of potential hazard. The law's article 7 states that dams shall be classified by the regulating entity by risk category, by hazard, and by size, based on general criteria established by the National Water Resources Council (CNRH). §1. Classification of high, medium, or low risk shall be in accordance with the technical characteristics and the state of conservation of the project and its compliance with the Dam Safety Plan. §2. Classification of high, medium, or low hazard shall be in accordance with the potential loss of human life as well as economic, social, and environmental impacts of a dam failure. In connection with dams classification, ANA has also been organizing, implementing, and administering the National Dam Safety Information System and leading the coordination among the various dam safety regulatory entities in the production of the *Dam Safety Report* published every year.	There are no detailed risk analysis or assessment requirements, but the risk classification is required for all dams subject to the law, which sets the level of dam safety requirements, including dam safety inspection, periodic dam safety review, preparation of Emergency Action Plan, and so forth in a proportionate manner to the risk and potential hazard of dams. The law requires regulators to classify dams based on both dam risk (three categories) and potential hazard (three categories) under their jurisdictions (Article 7—Classification). CNRH further issued Normative Resolution no. 143 in 2012 on the classification criteria with the following formula: Risk Category (RC) = Technical Characteristics Matrix (TCM) Score + Dam Preservation Matrix (DPM) Score + Dam Safety Plan Matrix (SPM) Score. TCM is calculated by summation of respective points for dam height, length, construction material, foundation type, age, and design flood return period. DPM is calculated by points for reliability of spillway, reliability of outlet structures, seepage, deformation/settlement, slope deterioration, and sluice gate/hydromechanical maintenance. SPM is calculated by points for existence of project documentation, organization structure/dam safety staff qualification, dam safety inspection/monitoring procedure, operational rules, and dam safety reports with analysis and interpretation. Potential Hazard Associated (PHA) is defined based on the points of four elements: (1) storage capacity, (2) potential loss of life, (3) socioeconomic impact, and (4) environmental impacts in case of dam failure. The two factors (RC and PHA) are broadly considered as the proxies for failure probability and consequences, respectively. According to the resolution, each regulatory entity may set its own procedures and deadlines. The law mandates dam safety inspections (article 9) and periodic reviews (article 10) requiring each regulating agency (at federal or state level) to establish the criteria of the inspection frequency, the necessary qualifications of responsible personnel, and the minimum levels of content and detail according to the "risk and hazard" category of the dam. For example, ANA established the safety inspection criteria in its Resolution 742, based on the aforementioned classification system by the CNRH.

(*continued*)

TABLE C.5 *(continued)*

Country/ jurisdiction	Law and/or regulations	Regulators	Targeted dams	Contents of risk analysis and/or assessment and their application
Canada, Quebec	Dam Safety Act and Dam Safety Regulation (2002)	Ministry of Sustainable Development and Environment and the Fight against Climate Change (MDDELCC)	All high-capacity dams must be classified on the basis of the risk they present for persons and property. High-capacity dams are defined as (1) dams 1 meter or more in height having an impounding capacity greater than 1 million cubic meters (m^3); (2) dams 2.5 meters or more in height having an impounding capacity greater than 30,000 m^3; or (3) dams 7.5 meters or more in height, regardless of impounding capacity.	There are no requirements for detailed risk analysis and assessments, but the act and regulation stipulate the classification procedure of high-capacity dams and the dam safety requirements as per classification in a proportionate manner to the risk of dams. The regulation provides details of the dam classification system based on the degree of risk into five categories with the formula of P (degree of risk) = V (vulnerability) * C (consequences). The vulnerability (V) of a dam is measured by multiplying the arithmetic mean value of "constant physical parameters" by the arithmetic mean value of "variable parameters." The constant physical parameters to be considered are (1) dam height, (2) dam type, (3) impounding capacity, and (4) dam foundation type. The variable parameters to be considered are (1) dam age; (2) seismic zone; (3) dam condition, considering the physical state and structural condition of the dam, the quality and effectiveness of maintenance, aging, possible effects of external factors, and any dam design or structural defects; and (4) reliability of the discharge facilities. The dam failure consequence (C) category is classified into six categories with 1–10 points based on the characteristics of the downstream area that would be affected by the dam failure in terms of population density and the extent of downstream infrastructure and services that would be destroyed or severely damaged in the event of a dam failure. A detailed description of each category is provided, including the number of population, size of enterprises, and so forth in downstream flooding areas. The purpose of the act is to increase the safety of dams and thereby protect persons and property against the risks associated with the presence of dams by providing minimum requirements to dam owners. The main requirements for high-capacity dam owners pertain to the request for approval of the outline of remedial measures and implementation schedule resulting from periodic dam safety reviews; the request for authorization for the construction, structural alteration, or removal of a high-capacity dam; the preparation and update by an engineer of the impounded water-management plan for the applicable high-capacity dams; the preparation and update of an emergency action plan for the applicable high-capacity dams; the preparation and update of a logbook; and the regular maintenance and monitoring of a high-capacity dam which includes inspections by an engineer.

Source: Original table for this publication.

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Appendix D: Comparative Matrix of Portfolio Risk Management Approaches

TABLE D.1 Comparative matrix of portfolio risk management approaches

Country/ jurisdiction	Risk analysis mandated	Failure probability estimation	Tolerability with F-N of F-N diagram	ALARP requirement	PRA and/or PRM requirement	Owner's PRM acceptance criteria by regulator
Australia, New South Wales	Yes, dams required by Dam Safety Committee or requested by dam owners (New guidance is under preparation per the 2015 Dams Safety Act and 2019 Dams Safety Regulation.)	Yes	Yes	Yes	Implicit	Specific with safety improvement schedule for three stages (New guidance is under preparation per the 2015 act and 2019 regulation.)
Australia, Queensland	Yes (for acceptable flood discharge capacity)	Yes	Yes	Yes (specific)	Implicit	Very specific, with clear acceptance criteria for cost-benefit and statistical life as well as time schedule for hydrological safety upgrading (Australian National Committee on Large Dams guideline is not meant for the regulator and has been refined for the purpose.)
Australia, Victoria	Yes (high- and extreme-consequence dams under water corporations)	Yes	Yes	Yes	Explicit through the Statement of Obligations and annual dam safety report of water corporations	General (2014 guideline refers to ALARP and notes the needs of balanced resource allocation across the drivers of value creation, compliance, and risk mitigation.)
Canada, British Columbia	No, but practiced	Cautious	No	Yes (general)	No, but practiced	General
Canada, Ontario	Being formalized	Yes	Yes (draft)	Yes	Yes (draft)	Specific (draft guideline)
France	Yes (class A and B dams)	Cautious	No	Yes (general)	Implicit	General

(continued)

TABLE D.1 *(continued)*

Country/ jurisdiction	Risk analysis mandated	Failure probability estimation	Tolerability with F-N of F-N diagram	ALARP requirement	PRA and/or PRM requirement	Owner's PRM acceptance criteria by regulator
Mexico	Yes (large dams higher than 15 meters and risky dams based on preliminary analysis)	Yes	Yes	No	Implicit	Uses a modified version of the US Bureau of Reclamation risk guideline which includes f-N diagram but does not follow ALARP. The risk-based 2015 regulation has not been enforced.
South Africa	Yes (class II and III dams if requested by Department of Water and Sanitation)	Yes	No	Yes (general)	Implicit	General
United Kingdom	Yes (if requested by inspection engineer, and following three-tier approach)	Cautious	No	Yes	No	General
United States, federal agencies	Yes (for self-regulation)	Yes	Yes	Yes	Yes	NA (self-regulation)
United States, Federal Energy Regulatory Commission	Yes (for high-hazard dams and dams requested by the commission)	Yes, when required	Yes, when required	Yes, when required	Implicit or recommended	General
Classification based on risk index						
Brazil	No, but dam classification considers risk level by index	No (index only)	No	No	No, but index	No
Canada, Quebec	No, but dam classification uses risk index	No (risk index rating only)	No	No	Risk index-based classification for dam safety requirements	Standard-based regulation
Risk-informed approach only using risk indexes[a]						
Australia, Tasmania	No, but practiced	Yes (practiced)	Yes (practiced)	Yes (practiced)	Practiced	ANCOLD guideline

(continued)

TABLE D.1 *(continued)*

Country/ jurisdiction	Risk analysis mandated	Failure probability estimation	Tolerability with F-N of F-N diagram	ALARP requirement	PRA and/or PRM requirement	Owner's PRM acceptance criteria by regulator
Canada, Alberta	Yes for dams with consequence classification of significant, high, very high, or extreme. Formal risk assessment is required when there is a critical safety deficiency, and a quantifiable performance objective is not met.	Yes	No clear indication	Yes	Implicit	General (Tolerable residual risk criteria are mentioned without specifics in the directive.)
Norway	Classes 2, 3, and 4 out of 4.	No	No	No	No	No (Risk analysis is required mainly for Environmental and Social Action Plan preparation.)
Spain	No (but piloted)	Yes (piloted)	No (only piloted)	No (only piloted)	Piloted	No
United States, California	The 2018 legislation stated that "Division of Safety of Dams shall propose amendments to its dam safety management protocols, including risk management, which details are not yet available."	Unknown	Unknown	Unknown	Likely	Unknown
United States, Washington State	No	Yes (practiced)	Unknown	Unknown	Yes (practiced by the regulator)	Unknown

Source: Original table for this publication.
Note: ALARP = As Low As Reasonably Practicable; F-N = the probability per year of causing N or more fatalities; PRA = portfolio risk assessment; PRM = portfolio risk management.
Some description of dams requiring risk analyses and assessment is simplified. Please see appendix C for more details. Also note the following:

- No case-studied jurisdiction relied solely on risk analysis and assessment but also used deterministic standards-based checking, particularly for new dams.
- The requirement of PRA/PRM is considered as "implicit" in France, US FERC, and others where utilities are required to undertake risk analyses and assessment of large portfolios of dams, and their proposed PRM (risk mitigation measures and schedule) are subject to review and approval of regulators.
- The requirement for PRA/PRM is considered as "explicit" in Victoria, Australia, where regulations and guidelines require owners with a portfolio of dams to submit PRM. Victoria, Australia, stipulates this obligation in the Statement of Obligations issued to water corporations by the minister under the Water Industry Act.
- Some utilities, such as Hydro Tasmania (Australia) and J-Power (Japan), have been implementing PRM-type approaches, which are, however, not necessarily reviewed and overseen by their regulators. Some other entities, such as Spain and Washington State in the United States, have also been using the PRM approach without specific legal mandates for risk-informed approach.

a. Because these countries do not conduct risk analysis/assessment except in specific risk index application, this is not included in appendix C. However, these countries are included here as the risk index has been used for portfolio risk assessment and management.

Appendix E: A Decision Support Tool to Inform and Assess Regulatory Frameworks for Dam Safety Assurance

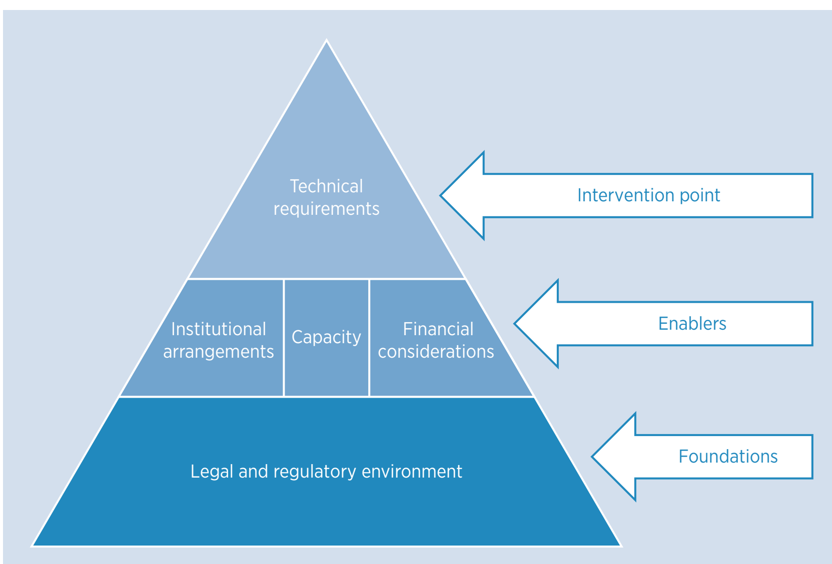
The foundation for effective dam safety assurance is an appropriate and well-designed regulatory framework that captures the legal, institutional, technical, and financial elements in the reality of a particular jurisdiction. Aging infrastructure, diminishing returns on new projects, changes in climate and weather patterns, and shifting trends of human settlement require ever-increasing attention in the effort to ensure the safety of dams and downstream communities. Establishing and maintaining a regulatory framework that is fit for purpose is, therefore, necessary for assuring the quality of dam design, construction, and operations. The framework also ensures that safety measures are reflective of the risks inherent in managing these structures and the context in which they are developed. Such frameworks need to be developed as part of a holistic strategy for water management that is integrated in basin and regional planning processes.

The regulatory framework for dam safety assurance is informed by several key elements and deliberative determinants. These have been identified and defined through a comprehensive review and comparative analysis of the regulatory frameworks for dam safety assurance among 51 countries with a diverse set of economic, political, and cultural circumstances. There are various options relating to the legal, institutional, technical, and financial elements that should be considered when designing a regulatory environment for dam safety assurance. While the type of legal system and the type of administration that is constitutionally possible will define how the regulatory environment can be implemented, the type of ownership and the size of a country's portfolio of dams, their geometric dimensions, and their hazard potential and vulnerability will guide the main features of a suitable regime. The key elements often provide the definitive precursors in which the specific considerations need to be positioned (figure E.1). These are considered important for the following main reasons:

- *Legal foundations such as the constitutional basis for law making and administration.* The common law or civil code characteristics of a country, for example, will determine the approach to development and realization of the legal framework for dam safety assurance. Common law jurisdictions have opportunity to be less prescriptive in statute laws with regard to acceptable standards of care and associated dam failure liability (and can be silent on such matters or refer to industry guidelines to set the acceptable standards of care). In contrast, civil law jurisdictions must be highly prescriptive, as they cannot rely on precedent to ensure consistent decision-making among the courts. In a civil law system, a judge merely establishes the facts of a case and applies remedies found in the codified law: the codified law has to be detailed enough so that a judge does not even have to interpret it. These characteristics rarely, if ever, change.

  Similarly, the distinction between centralized (unitary) and decentralized (federal) administrative systems is an important consideration because it determines the options that are available for achieving a uniform regulatory regime across an entire country. A unified administrative system will differ in the requisite elements for assuring dam safety compared to a federal system with decentralized roles and responsibilities devolving to the subnational administrative units. In decentralized systems national

FIGURE E.1 Elements of a dam safety assurance system



Source: Original figure for this publication.

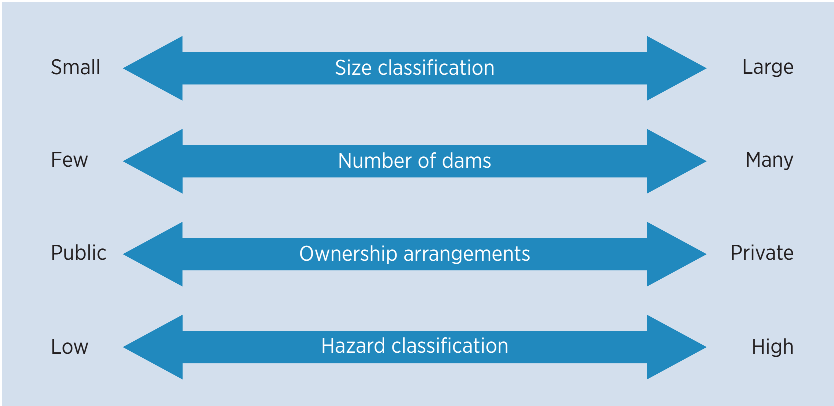
legislation often cannot constitutionally bind states or provinces to adopt uniform dam safety laws, and so other mechanisms must be explored at the national level to achieve uniformity. These characteristics rarely, if ever, change.

- *Institutional arrangements such as the allocation of responsibilities, sectoral considerations, human capital, and financial capacity.* These are informed by the enabling legal framework and should clearly define the allocation of responsibilities for ownership, operations, and oversight, as well as the approach to private sector participation and sectoral considerations. The nature of the institutional arrangements will reflect the composition and structure of the portfolio as well as financial capacity and human capital. These characteristics are subject to infrequent changes but need to adapt to changes in the portfolio and downstream demographics.
- *Technical considerations such as the nature and characteristics of the portfolio.* These include considerations regarding the size of the portfolio (small, single-sector to large, multisectoral portfolios), the relative importance of different sectors (irrigation, hydroelectricity, supply, flood protection, and so forth), and the hazard classification. These characteristics are subject to more frequent changes depending on sectoral demands and development, changes in demography and/or land use, and the enabling financial considerations, among others.
- *Financing considerations such as the revenue streams available to support operation and maintenance (O&M).* These are typically determined by government policies and are often subject to economic regulation; they determine the availability of financing and transfer mechanisms to support O&M as well as the financing of the oversight mechanisms. These characteristics can be subject to frequent changes depending on prevailing economic conditions and government policies.

In contrast, the deliberative determinants of the regulatory framework for dam safety assurance are typically defined by the portfolio characteristics and informed by technical considerations (figure E.2). Among others, these include (1) the classification of dams in the portfolio, usually by dam size and/or reservoir capacity (small or large), (2) the size of the portfolio (few/small or many/large), (3) the main ownership type (private or public), and (4) the hazard level or risk associated with dams in the portfolio (low or high).

These key elements and deliberative determinants come together to present a range of options along a continuum that should inform the regulatory framework for dam safety assurance (figure E.3). This continuum can be used to position key considerations and support decisions to (1) inform the establishment of an appropriate regulatory framework for dam safety assurance in any jurisdiction, (2) provide a framework for gap analyses aimed at enhancing existing legal regimes and institutional arrangements for dam safety assurance, and (3) guide technical specialists in designing projects

FIGURE E.2 Portfolio determinants that should shape the dam safety system



Source: Original figure for this publication.

aimed at supporting the establishment or strengthening of regulatory frameworks for dam safety assurance.

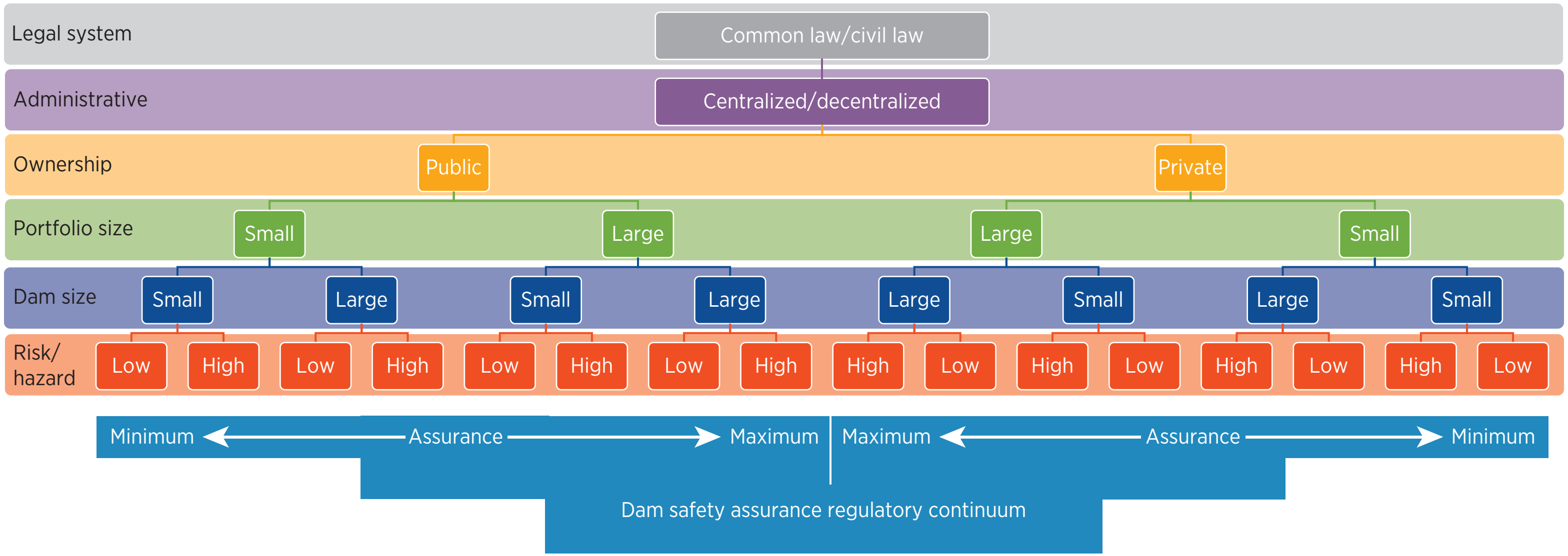
The following sections provide examples that illustrate how the Decision Support Tool can be used to inform considerations of the relevant elements along the continuum for different types of portfolios and within specific jurisdictional circumstances. It should be noted that there are no absolute definitions for many of the key elements and deliberative determinants and each should be considered in the specific country context. The differentiating factors in the decision framework are used to explain the relative legal, institutional, technical, and financial considerations along a continuum depending on different scenarios. Some examples of design standards and standards of care are provided to highlight these relative differences in return periods, inspection frequency, and so forth depending on different scenarios, and these should not be interpreted or cited as actual recommendations.

It is also important to note that the regulatory framework evolves with changes in the portfolio and country conditions. It is therefore necessary to provide a set of options along a continuum against which countries can assess their specific needs and requirements at regular intervals. Specific considerations should also be afforded to transboundary settings in order to ensure that a comprehensive regulatory framework or system of dam safety assurance across boundaries is implemented and provides protection for all downstream communities.

NOTES FOR USERS

Risk is defined in *Laying the Foundations: A Global Analysis of Regulatory Frameworks for the Safety of Dams and Downstream Communities* as the measure of the likelihood or probability and severity of an adverse consequence or impact to life, health, property, or the environment. However, the Decision

FIGURE E.3 Key elements and determinants informing regulatory frameworks for dam safety assurance



Source: Original figure for this publication.
Note: Portions of this figure are used in subsequent sections of this appendix addressing specific sectors and considerations.

Support Tool uses *risk* in a broader sense, with reference to International Commission on Large Dams (ICOLD) (1989) Bulletin 72, which provides a simple concept of risk classification using four parameters: (1) dam height, (2) reservoir capacity, (3) number of people potentially affected, and (4) other potential consequences. While dam height and reservoir capacity can be considered to represent the magnitude of a flood wave's energy (water depth, velocity, and so forth) and correlate with flooded area and duration in case of dam break, the number of people potentially affected and other potential consequences can be considered to represent downstream hazard or consequences in case of dam failure.

While *hazard* is defined in *Laying the Foundations* as "a source of potential harm or a situation with the potential to cause loss," it is often used as a measure of the consequences of dam failure in dam safety. Hence, the terms *hazard* and *consequence* are used interchangeably as the potential losses in the downstream area of the dam in the event of dam failure or mis-operation and resulting uncontrolled release of flood waters.

Many countries have developed different classification systems depending on their economic, environmental, and social conditions.[1] The main criteria for dividing dams into classes are generally either geometrical parameters (typically a dam's height and reservoir capacity, sometimes including the type of dam) and/or incremental consequences or hazard potential that would occur as a result of a dam failure, or a combination of these.

Thus, the terms *risk* and *hazard* used in this Decision Support Tool provide relative measures that are used in a broader manner for the classification of dams, considering the diversity of dam classification systems used throughout the world.

Similarly, different criteria and thresholds have been developed by different countries for large versus small dams. While some countries place very low thresholds for dams to be considered large, thus including almost all dams under regulation, other countries have established relatively higher thresholds, subjecting many small dams to less rigorous safety requirements. Hence, the differentiation between large and small dams in this Decision Support Tool is conceptual only and presents a relative scale that does not rely on specific definitions or thresholds.

The Decision Support Tool provides illustrative suggestions on dam safety standards, requirements, or duty of care, such as the return period of the design flood,[2] inspection frequency,[3] and so forth. These are only indicative examples. In reality, the type of dam (such as concrete or embankment) and other elements also need to be considered when determining the design flood level, with some countries considering a check flood in addition to the design flood. The required level of public safety measures will also depend on the dam's operating regime (for example, the requirements of hydropower dams with frequent rapid turbine discharge should be high) and downstream hazard and consequence, including both the permanent and impermanent populations in downstream areas.

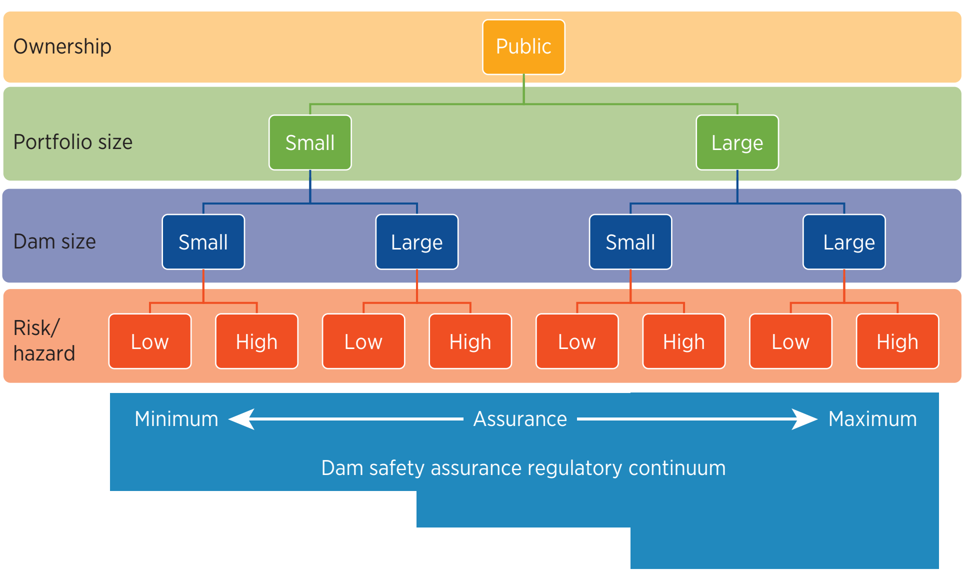
The Decision Support Tool provides a conceptual framework for the development or assessment of the regulatory framework for dam safety assurance. It does not incorporate specific provisions relating to other elements, such as dam safety standards and requirements. The purpose of the Decision Support Tool is to illustrate the broad range of important elements and determinants for the dam safety assurance system. The details of each element and determining factor, such as design standards and safety requirements, need to be assessed and developed in an adaptive manner that considers national and local contexts.

The examples and references included herein are provided as indicative examples only. They do not represent a prescribed set of increasing assurance levels. Each branch of the decision tree provides an illustrative representation and examples of how a jurisdiction may assess its needs to achieve an appropriate general level of assurance. A more comprehensive reference for each of the subject areas is provided in the relevant sections of *Laying the Foundations*.

COUNTRIES WITH MAINLY PUBLIC DAM OWNERSHIP

Figure E.4 shows the portfolio characteristics that can help policy makers determine appropriate features of a regulatory regime for contexts with mostly publicly owned dams. The following sections explore in more detail different portfolio scenarios and corresponding elements of the dam safety assurance system.

FIGURE E.4 Considerations for publicly owned dams



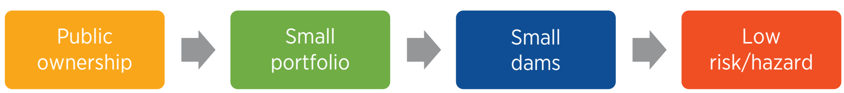
Source: Original figure for this publication.

Overall, in the case of publicly owned dams, it is important to give due consideration to the following:

- Establish clear dam safety standards and requirements that public entities are required to abide by when preparing and implementing projects, as well as operating and maintaining dams.
- Establish and maintain sufficient human, technical, and financial capacity of public entities responsible for reviewing, preparing, or implementing projects, and those operating and maintaining dams.
- Ensure that there is a clear distribution of roles and responsibilities among public entities for all critical dam safety requirements, including inspection and instrumentation, public safety, emergency preparedness, and so forth, and that potential conflict of interest issues are avoided where possible.
- Require independent review of designs and construction plans, as well as periodic and/or formal dam safety reviews.

These should be proportionate to the size and type of portfolio of dams, as explained in the subsequent sections.

Publicly Owned, Small Portfolio of Small Dams That Are Largely Low Risk/Hazard



In this scenario, given the small portfolio size and the low-risk/low-hazard profile of small dams, it is appropriate to simplify legal, institutional, and technical requirements in order to reduce unnecessarily high transaction costs in the system. As a result, the elements of this scenario represent self-regulation, positioned at the minimum assurance end of the continuum.

Legal Underpinnings

Self-regulation is appropriate. There is no need for dedicated legislation, but responsibility for dam safety and liability in the event of dam failure should be clearly defined. In common law systems, this may come from existing case law or precedent, including whether responsibility is based on negligence or strict liability. In civil law systems, the responsibilities for dam safety and liability in the event of dam failure should be clearly defined in existing law, or they may need to be prescribed in a new law.

Institutional Arrangements

A dedicated government unit or authority is not necessary; if community cooperatives or water-user associations operate the dams, third-party quasi-regulatory oversight may be helpful in overseeing the safety of dams in an effective and uniform way. At a minimum, the regulator should provide the dam owner with appropriate education and training related to dams and their safety.

Technical Requirements

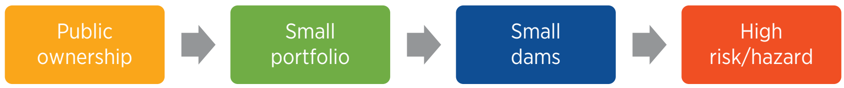
There should be a minimum dam safety review system, including an up-to-date inventory of all dams with a unit designated to monitor and update the inventory as changes occur. There should also be a checklist to determine minimum safety assurance requirements on a case-by-case basis. Such a checklist would include the following:

- *Design and review standards.* A simple, deterministic set of design and review standards would be appropriate. In spillway design flood, for example, small, low-risk/low-hazard dams may be required to meet the 1-in-100 to 1-in-200 years return period.
- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of small and low-risk/low-hazard dams, this can be relatively infrequent. Routine visual inspection could be monthly, while detailed formal inspections could be every 10 years.
- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard for the dams. Thus, for small, low-risk/low-hazard dams, instrumentation can be very minimal and basic and included as part of the O&M.
- *Emergency Preparedness Plan (EPP).* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. For small, low-risk/low-hazard dams, where no lives and/or economic, environmental, or societal assets are at risk, an EPP may not be required.
- *Public safety.* Public safety during dam operation can be addressed with simple downstream warnings and signs, as appropriate.

Financial Considerations

The overall budgetary implications depend on the size of the portfolio, and given the simplicity of the institutional arrangements and the basic nature of the technical requirements, the resources required to maintain the dam safety assurance system are minimal. The entity responsible for maintaining the inventory of dams—for example, the designated local authority—should have sufficient resources for this task. The relevant line ministry or local government authority should also allocate enough resources to sufficiently perform mandated O&M provisions for dam safety. There would also be a small budget implication for the provision of needed staff education and training.

Publicly Owned, Small Portfolio of Small Dams That Are Largely High Risk/Hazard



In this scenario, the legal and institutional arrangements are relatively simple in order to reduce the transaction costs for a small portfolio of small dams. There are higher technical requirements, however, due to the dams being deemed high hazard or high risk. The resulting elements fit between the minimum end and middle of the dam safety assurance continuum.

Legal Underpinnings

There is no need for dedicated legislation due to the high transaction cost associated with a complex system for only a few hazardous dams. The responsibility for dam safety and the liability in the event of dam failure should, however, be clearly defined. In common law systems, this may come from existing case law or precedent, including whether it is based on negligence or strict liability. In civil law systems, dam safety responsibility and liability for dam failure should be clearly defined in existing law, or they may need to be prescribed in a new law. The regulations should require dam operators to submit annual or other periodic reports to demonstrate how they have fulfilled the dam safety responsibilities in compliance with the dam safety requirements.

Institutional Arrangements

A dedicated government unit or authority may not be necessary but could include a unit in charge of dam safety in the existing governmental structure; third-party quasi-regulators may be instrumental in enhancing the regulatory oversight. If community cooperatives or water-user associations operate the dams, they should be trained to perform basic dam safety surveillance and report anomalies to the dam safety unit. If necessary, the government could set up a legal regime for community cooperatives. At a minimum, the dam safety unit should undertake periodic compliance review of the operator's dam safety program, performance, and capacity. Consideration should be given to periodic independent dam safety assessments.

Technical Requirements

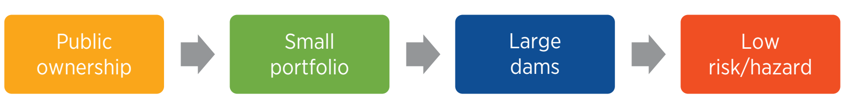
There should be a safety review system in place including an up-to-date inventory of all dams in which their classification is maintained; it should be updated as changes occur. Reference to small dam safety guidelines is needed, but it is not necessary for customized guidelines to be created. Instead, they may refer to existing guidelines published by reputable sources, such as ICOLD Bulletins 109 and 157 (ICOLD 1998, 2016) and/or the Food and Agriculture Organization's (FAO's) manual on small earth dams (Stephens 2010). There should also be a checklist to determine minimum safety assurance requirements on a case-by-case basis. Such a checklist would include the following:

- *Design and review standards:* A simple, deterministic set of design and review standards would be appropriate. In spillway design flood, for example, small and high-risk/high-hazard dams may be required to meet the 1-in-200 to 1-in-1,000 years return period.[4]
- *O&M and safety inspections:* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of small, high-hazard dams, this should be relatively frequent. Routine inspections could be daily or weekly, and detailed formal inspections every three years.
- *Instrumentation:* The level of instrumentation should be proportionate to the size and risk/hazard. Thus, for small, high-risk/high-hazard dams, instrumentation can be limited to essential elements only, but an effective management system should be in place, including data monitoring and interpretation.
- *EPP:* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. Simpler EPPs and tools may be mandated for small dams, with the EPP requirements prioritized for dams that could cause human casualties and/or loss of economic, environmental, or societal assets. It is important to ensure training for dam operators and coordination with the disaster risk management authority and other relevant emergency agencies.
- *Public safety:* Public safety during dam operation can be addressed with simple downstream warnings and signs as required.

Financial Considerations

For the oversight authority, a minimal budgetary implication is associated with the maintenance of the inventory of dams. The relevant line ministry or local government authority should also allocate enough resources to sufficiently perform mandated O&M provisions for dam safety. There would also be a small budget implication for the provision of needed staff education and training. The relevant line ministry may collect fees from water users to carry out the noted functions.

Publicly Owned, Small Portfolio of Large Dams That Are Largely Low Risk/Hazard



In this scenario, the legal and institutional arrangements are relatively simple in order to reduce the transaction costs for a small portfolio of large dams that are relatively low-risk/low-hazard. The technical requirements are relatively basic but essential due to the large dams being deemed low-risk/low-hazard.

The resulting elements fit between the minimum end and middle of the dam safety assurance continuum.

Legal Underpinnings

There is no need for dedicated legislation due to the high transaction cost associated with a complex system for only a few large, low-risk/low-hazard dams. The responsibility for dam safety and liability in the event of dam failure should, however, be clearly defined. In common law systems, this may come from existing case law or precedent, including whether it is based on negligence or strict liability. In civil law systems, dam safety responsibility and liability for dam failure should be clearly defined in existing law, or they may need to be prescribed in a new law.

Institutional Arrangements

A dedicated government unit or authority is not necessary, but consideration should be given to the establishment of an appropriate unit in charge of dam safety, which may be accommodated in an existing ministry in charge of water resources or other relevant resource. At a minimum, the dam safety unit undertakes compliance review of the operator's dam safety program, performance, and capacity.

Technical Requirements

There should be a basic dam safety review system in place, including an up-to-date inventory of all dams with a person designated to monitor and update the inventory as changes occur. There is no need to develop custom dam safety guidelines, but reference may be made to existing guidelines published by recognized industry groups such as ICOLD, the Canadian Dam Association (CDA), the Australian National Committee on Large Dams (ANCOLD), and others. There should also be a checklist to determine minimum safety assurance requirements on a case-by-case basis. Such a checklist would include the following:

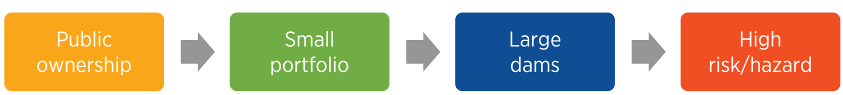
- *Design and review standards.* A simple, deterministic set of design and review standards would be appropriate. In a spillway design flood, for example, large and low-risk/low-hazard dams may be required to meet the 1-in-200 years to 1-in-1,000 years return period.
- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of large and low-risk/low-hazard dams, this can be relatively infrequent. Routine inspections could be weekly, and detailed formal inspections every five years.
- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard of the dams. Thus, for large, low-risk/low-hazard dams, instrumentation can be basic, but essential instruments should be maintained.

- *EPP.* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. For large, low-risk/low-hazard dams, where no lives and/or economic, environmental, or societal assets are at risk, a simple EPP may be sufficient. It is important to ensure training for dam operators and coordination with the disaster risk management authority and other relevant emergency agencies.
- *Public safety.* Public safety during dam operation can be addressed with simple downstream warnings and signs, as appropriate.

Financial Considerations

The overall budgetary implications depend on the size of the portfolio, but given the simplicity of the institutional arrangements and the basic nature of the technical requirements, the resources required to maintain the dam safety assurance system are minimal. The entity responsible for maintaining the inventory of dams—the designated local authority for example—should have sufficient resources for this task. The relevant line ministry or local government authority should also allocate enough resources to sufficiently perform mandated O&M provisions for dam safety. If a specified unit in the government is responsible for dam safety, a budgetary line item should also be clearly specified. Cross-subsidization is also possible by way of government transfers from dams with strong revenue streams (that is, with a tariff structure providing full cost recovery) to dams with weaker revenue streams. The relevant line ministry or local authority may also collect fees from water users to finance dam safety measures.

Publicly Owned, Small Portfolio of Large Dams That Are Largely High Risk/Hazard



In this scenario, the legal and institutional arrangements are relatively simple in order to reduce the transaction costs for a small portfolio of dams. For large and high-risk/high-hazard dams, however, the technical requirements are high. The resulting elements fit toward the middle of the dam safety assurance continuum.

Legal Underpinnings

There is no need for dedicated legislation, but responsibilities for dam safety and liability in the event of dam failure should be clearly defined. In common law systems, this may come from existing case law or precedent, including whether responsibility is based on negligence or strict liability. In civil law systems, the responsibility for dam safety and liability in the event of dam failure should be clearly defined in an existing law, or it may need to be prescribed in a new law. The regulations should require dam operators to submit annual or other periodic reports to demonstrate how they have fulfilled the operator's dam safety responsibilities in compliance with the dam safety requirements.

Institutional Arrangements

A dedicated government unit or authority is not necessary, due to the small size of the portfolio, but a unit responsible for dam safety should be established in an existing governmental structure for water resources management or the like. The dam safety unit could establish an independent advisory panel to assist with technical oversight and/or periodic inspections. At a minimum, the dam safety unit needs to undertake the design review of new dams and periodic compliance review of the operator's dam safety program, performance, and capacity.

Technical Requirements

There should be an adequate dam safety review system in place, including an up-to-date inventory of all dams with a unit designated to review the dam design and safety compliance and monitor and update the inventory as changes occur. In this scenario, a high-level dam safety program needs to be established and a rigorous compliance review is required by the regulator (that is, dam safety unit), with the technical assistance and oversight of an independent panel of experts. There is no need to develop custom dam safety guidelines given the small size of the portfolio. Instead, reference may be made to existing guidelines published by recognized industry groups such as ICOLD, CDA, ANCOLD, and others. The guidelines should cover the following:

- *Design and review standards.* Standards should be deterministic and risk informed where appropriate. Risk analysis, such as potential failure mode analysis, should be mandated or recommended where possible. The adequacy of the design, construction plans, and dam safety requirements should be ensured by a qualified owner's engineer and an independent panel of experts. Design and review requirements should be proportionate to the risk/hazard. High-risk/high-hazard dams are typically required to meet 1-in-1,000 to 1-in-10,000 years or probable maximum flood (PMF) design standards.
- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. For large and high-risk/high-hazard dams, this should be frequent enough to detect any anomalies at an early stage. Routine inspections could be daily, and detailed formal inspections every three years.
- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard. Thus, for large, high-risk/high-hazard dams,

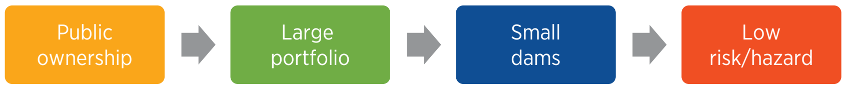
instrumentation should be comprehensive, sophisticated, and reliable. It is also critical to ensure an effective management system, including data monitoring and interpretation.

- *EPP.* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. For large, high-risk/high-hazard dams, an EPP should be required for operational issues as well as for dam-break scenarios. The EPP must be highly sophisticated, including detailed dam-break analyses and well-planned coordination among all relevant parties, including disaster risk management authorities and the military, as appropriate. The EPP must also include the installation of warning systems and should include the implementation of mock drills. For high-risk/high-hazard dams, EPPs should be elaborated based on dam-break analysis and flooding simulation/mapping and include notification and coordination procedures for emergency actions, including evacuation of the downstream population. The EPP should also include a compilation of all the persons who should be contacted in case of dam failure. For example, in South Africa, category 3 dams require comprehensive plans with detailed flood maps, whereas category 2 dams require only a summary of intended actions by relevant parties, a listing of telephone contacts, and a basic map with approximate dam-break flood lines.
- *Public safety.* Public safety during dam operation must be given serious consideration, with reference to guidelines from reputable institutions,[5] including all the necessary precautions to be taken and downstream warning tools to be used. This can be addressed with downstream warnings and signs as required.

Financial Considerations

The overall budgetary implications depend on the size of the portfolio, but given the simplicity of the institutional arrangements, the resources required to maintain the dam safety assurance system are relatively low. The entity responsible for maintaining the inventory of dams should have sufficient resources for this task. The relevant line ministry or local government authority should also allocate enough resources to sufficiently perform mandated O&M provisions for dam safety. If a specified unit in the government is responsible for dam safety, a budgetary line item should also be clearly specified. Cross-subsidization is also possible by way of government transfers from dams with strong revenue streams (that is, with a tariff structure providing full cost recovery) to dams with weaker revenue streams, such as from hydropower to irrigation. The relevant line ministry or local authority may also collect fees from water users to finance dam safety measures.

Publicly Owned, Large Portfolio of Small Dams That Are Largely Low Risk/Hazard



In this scenario, even though the size of the portfolio may be large, a dam safety framework between the middle and minimum end of the continuum would be appropriate given the dam owner is the government itself, the dams are small, and their risk/hazard classification is deemed low.

Legal Underpinnings

There is no need for dedicated legislation, but dam safety responsibility and liability for dam failure should be clearly defined. In common law systems, this may come from existing case law or precedent, including whether responsibility is based on negligence or strict liability. In civil law systems, the roles and responsibility for dam safety and liability for dam failure should be clearly defined in existing law, or they may need to be prescribed in a new law.

Institutional Arrangements

A dedicated government unit is not necessary; an appropriate level of oversight could be provided by community cooperatives or water-user associations if they also operate the dams. If necessary, the government could set up a legal regime for community cooperatives. Preferably, this oversight responsibility would be vested in local authorities, empowered to ensure an essential level of dam safety assurance and to provide technical support for dam operators, such as community cooperatives. At a minimum, the regulator should provide the dam operator with a minimum essential education and training related to dams and their safety.

Technical Requirements

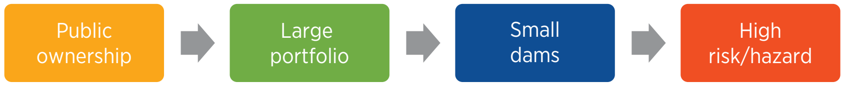
There should be a basic regulatory framework for dam safety including an up-to-date inventory of all dams as well as a simple classification system that is periodically reviewed for "hazard creep."[6] Dam operators and local authorities should follow a set of guidelines on safety for small dams, but it is not necessary for them to establish their own, unique guidelines. Instead, they may refer to existing guidelines published by reputable sources, such as ICOLD (1998, 2016) Bulletins 109 and 157 and/or the FAO's manual on small earth dams (Stephens 2010). The guidelines should cover the following:

- *Design and review standards.* A simple, deterministic set of design and review standards would be appropriate. In spillway design flood, for example, small and low-risk/low-hazard dams may be required to meet the 1-in-100 to 1-in-200 years return period. It should also be recognized that the cumulative risk posed by many small dams in catchments can be higher than their individual risks/hazards, in which case higher hydrological safety requirements may be warranted for those dams.
- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of small and low-risk/low-hazard dams, this can be relatively infrequent. Routine inspections could be monthly, and detailed formal inspections every 10 years.
- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard. Thus, for small, low-risk/low-hazard dams, instrumentation can be very minimal and basic and included as part of the O&M.
- *EPP.* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. For small, low-risk/low-hazard dams where no lives and/or economic, environmental, or societal assets are at risk, an EPP may not be required.
- *Public safety.* Public safety during dam operation can be addressed with simple downstream warnings and signs, as appropriate.

Financial Considerations

The overall budgetary implications depend on the size of the portfolio, but given the simplicity of the institutional arrangements and the basic nature of the technical requirements, the resources required to maintain the dam safety assurance system are minimal. The entity responsible for maintaining the inventory of dams, the designated local authority, for example, should have sufficient resources for this task. The relevant line ministry or local government authority should also allocate enough resources to sufficiently perform mandated O&M provisions for dam safety. If a specified unit in the government is responsible for dam safety, a budgetary line item should also be clearly specified. Cross-subsidization is also possible by way of government transfers from dams with strong revenue streams (that is, with a tariff structure providing full cost recovery) to dams with weaker revenue streams. The relevant line ministry or local authority may also collect fees from water users to finance dam safety measures. If water-user associations operate and maintain the dams, they may also collect fees to finance those tasks.

Publicly Owned, Large Portfolio of Small Dams That Are Largely High Risk/Hazard



Given the presence of a large portfolio of small dams deemed to be high risk or high hazard, this scenario moves from the middle toward the maximum assurance end of the continuum.

Legal Underpinnings

There should be consideration given to the inclusion of dam safety provisions in general or enabling legislation, such as a water act or environmental protection act, via a ministerial order or guideline. The regulations should require dam operators to submit annual or other periodic reports to demonstrate how they have fulfilled the dam safety responsibilities in compliance with the dam safety requirements.

Common law responsibility for dam safety and liability for dam failure should be clearly defined. This may come from existing case law or precedent, including whether responsibility is based on negligence or strict liability. In civil law systems, roles and responsibility for dam safety and liability for dam failure should be clearly defined in existing laws, or they may need to be prescribed in a new law.

The government should also develop a compliance review system for the dam safety program and performance management. If dams are operated or overseen by community cooperatives or water-user associations, the government may set up an appropriate legal regime that governs their roles and responsibilities.

Institutional Arrangements

Consideration should be given to the creation of a dedicated unit in the relevant line ministry or government agency with the role of providing quality assurance for dam safety. This may range from the execution of simple compliance audits, which may be suitable for small dams, to more hands-on quality assurance. The optimal mix of responsibilities given to this unit will depend on internal financial and technical capacity. Provisions should be included for periodic independent dam safety assessments.

At a minimum, the dam operator needs to have an appropriate dam safety program along with adequate education and training, and the compliance should be reviewed periodically. In this case of publicly owned dams, internal government staff would be required to have these capabilities. A water-user association or community cooperative could also function as a dam operator with sufficient training.

Technical Requirements

There should be a basic regulatory framework for dam safety, including an up-to-date inventory of all dams as well as a classification system that accounts for scenarios involving cascades or cumulative failures, which are common for small dams. There is a need for dam safety guidelines for small dams. These may be specific guidelines, developed to suit the country's circumstances, or reference can be made to existing guidelines from reputable sources, as appropriate. Examples include ICOLD (1998, 2016) Bulletins 109 and 157 and/or the FAO's manual on small earth dams (Stephens 2010).

The technical requirements are essentially the same as those recommended at the maximum assurance end of the continuum. However, standards may be kept simple and allow for the use of simple design and portfolio risk assessment tools: for example, common law systems can rely on existing or external guidelines, but in civil law systems, the following need to be explicitly referenced:

- *Design and review standards.* A simple set of design and review standards would be appropriate. In a spillway design flood, for example, small high-risk/high-hazard dams may be required to meet the 1-in-200 to 1-in-1,000 years or higher return period.[7] It is important to note that small dams that may be low-risk/low-hazard individually may warrant a high-risk/high-hazard classification due to their cascade or cumulative threat when they exist in multiple numbers in catchments, in which case higher hydrological safety requirements may be warranted for those dams.

- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of small, high-hazard dams, this should be relatively frequent. Routine inspections could be daily/weekly, and detailed formal inspections every three years. Simple, indices-based tools can be used for portfolio risk assessment in situations with many small but poorly maintained and vulnerable existing dams in order to prioritize where resources should be directed.

- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard. Thus, for small, high-risk/high-hazard dams, instrumentation can be limited to essential elements, but an effective instrumentation system should be in place, including data monitoring and interpretation.

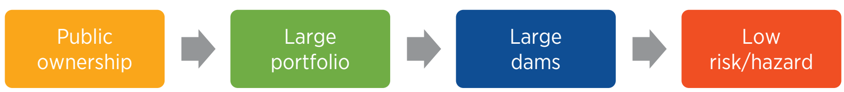
- *EPP.* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. Simpler EPPs and tools may be mandated. EPP requirements should be prioritized for dams that could cause many human casualties and/or loss of economic, environmental, or societal assets. It is important to ensure training for dam operators and coordination with the disaster risk management authority and other relevant emergency agencies.

- *Public safety.* Public safety during dam operation should be addressed with downstream warnings and signs as required.

Financial Considerations

The overall budgetary implications depend on the size of the portfolio. The relevant line ministry or local government authority should allocate enough resources to sufficiently perform mandated O&M provisions for dam safety. A budgetary line item should be clearly specified for the dedicated unit tasked with dam safety quality assurance. The resources allocated should be commensurate with the scope of responsibilities. Cross-subsidization is also possible by way of government transfers from dams with strong revenue streams (that is, with a tariff structure providing full cost recovery) to dams with weaker revenue streams. The relevant line ministry or local authority may also collect fees from water users to finance dam safety measures. If water-user associations operate and maintain the dams, they may also collect fees to finance those tasks.

Publicly Owned, Large Portfolio of Large Dams That Are Largely Low Risk/Hazard



This scenario, characterized by a large portfolio of large dams, requires a level of oversight well beyond the minimum criteria. Consisting of dams deemed to be low risk/hazard classifications, it does not require the maximum level of assurance and thus it rests away from the maximum assurance end of the continuum and more toward the middle. It is worth noting, however, that it would be unlikely to find a real-world example of a large portfolio of large dams that are mostly low-risk/low-hazard.

Legal Underpinnings

In order to regulate and supervise a large portfolio of large dams, including hazard creep over long periods, it is necessary to have dedicated legislation on dam safety, or enabling legislation with dam safety provisions stipulated via a ministerial guideline, as appropriate. In a federal system, it may be appropriate to have legislation at the state level, as in the case of Australia and Canada, or possibly at both the state and federal levels, as in Brazil and the United States.

In common law systems, responsibility for dam safety and liability for dam failure should be clearly defined. This definition may come from existing case law or precedent, including whether it is based on negligence or strict liability. In civil law systems, roles and responsibility for dam safety and liability for dam failure should be clearly defined in existing law, or they may need to be prescribed in a new law.

The government should also develop a compliance review system for the operator's dam safety program and performance management.

Institutional Arrangements

There should be a dedicated unit in the relevant line ministry or government agency with the role of providing quality assurance for dam safety. This may range from the execution of simple compliance audits to more hands-on quality assurance. The optimal mix of responsibilities given to this unit will depend on internal financial and technical capacity.

At a minimum, the regulating unit should undertake periodic compliance review of the operator's dam safety program and standard of care with sufficient management capacity. In this case of publicly owned dams, internal government staff would be required to have these capabilities.

Technical Requirements

There should be a comprehensive dam safety review system in place for confirming the design and construction of new dams and reviewing the safety condition of existing dams, along with a suitable dam classification system. It should be mandated that an up-to-date inventory of all dams is maintained internally along with the dam safety conditions, risks, and required remedies. Those dams should also be periodically classified to check for hazard creep. Given the large number of large dams, the government should consider developing its own guidelines on safety of large dams, suitable for the country circumstances. These guidelines should use existing guidelines by recognized industry groups, such as ICOLD, CDA, and ANCOLD, among others, as a reference. At a minimum they should cover the following:

- *Design and review standards.* A simple, deterministic set of design and review standards would be appropriate for new dams. For example, the spillway design flood for large and low-risk/low-hazard dams may be required to meet the 1-in-200 to 1-in-1,000 years return period.

- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of large and low-risk/low-hazard dams, this can be relatively infrequent. Routine inspections could be weekly, and detailed formal inspections every five years. Portfolio risk assessment using simple risk indices may be introduced for a large portfolio of existing dams.

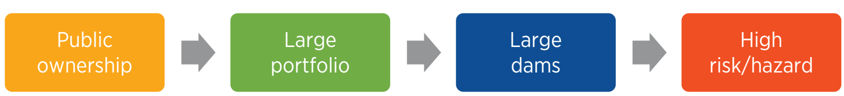
- *Instrumentation.* The level of instrumentation should be proportionate to the size, type, and risk/hazard of the dams. Thus, for large, low-risk/low-hazard dams, instrumentation can be basic, but essential instruments should be maintained.

- *EPP.* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. For large, low-risk/low-hazard dams, where no lives and/or economic, environmental, or societal assets are at risk, a simple EPP may be sufficient. It is important to ensure training for dam operators and coordination with the disaster risk management authority and other relevant emergency agencies.
- *Public safety.* Public safety during dam operation can be addressed with downstream warnings and signs, as appropriate.

Financial Considerations

The overall budgetary implications depend on the size of the portfolio, but given the simplicity of the institutional arrangements and the basic nature of the technical requirements, the resources required to maintain the dam safety assurance system are minimal. The relevant line ministry or local government authority should allocate enough resources to maintain the inventory of dams and sufficiently perform mandated O&M provisions for dam safety. A budgetary line item should be clearly specified for the dedicated unit tasked with dam safety quality assurance. The resources allocated should be commensurate with the scope of responsibilities. Cross-subsidization is also possible by way of government transfers from dams with strong revenue streams (that is, with a tariff structure providing full cost recovery) to dams with weaker revenue streams. The relevant line ministry or local authority may also collect fees from water users to finance dam safety measures.

Publicly Owned, Large Portfolio of Large Dams That Are Largely High Risk/Hazard



With a large portfolio of large, high-risk/high-hazard dams, a greater level of oversight is needed. Thus, this scenario rests toward the maximum end of the dam safety assurance continuum, requiring more complex legal and institutional arrangements and higher technical requirements.

Legal Underpinnings

Given the size and complexity of the portfolio, dedicated legislation on dam safety is necessary. This should be in the form of clearly articulated, uniform laws and regulations. The regulations should require dam operators to submit annual or other periodic reports to demonstrate how they have fulfilled the dam safety responsibilities in compliance with the dam safety requirements. In a federal system, it may be appropriate to have legislation at the state level, as in the case of Australia and Canada, or possibly at both the state and federal levels, as in Brazil and the United States.

In common law systems, responsibility for dam safety and liability for dam failure should be clearly defined. Definition may come from existing case law or precedent, including whether it is based on negligence or strict liability. If case law precedent does not exist, the dam safety legislation would need to define the responsibility for dam safety and liability in case of dam failure. In common law systems, either specific dam safety legislation or enabling legislation may be appropriate. In the case of enabling legislation, wide, discretional powers pertaining to dam safety would be given to an existing authority under an existing law. In a specific dam safety law, powers pertaining to dam safety would be prescribed to a specific dam safety authority. In civil law systems, responsibility for dam safety and liability in the event of dam failure must be specific and would be found in an existing dam safety statute and/or in the broader civil liability law. In civil law systems, specific dam safety legislation would have to be highly prescribed, but it could be in the form of an enabling law and specific regulations. The government would also need to develop a strict compliance review system for dam safety performance management requiring independent reviews by expert commissions or similar provisions for high-risk/high-hazard cases and a secure budget for critical remedial works.

Institutional Arrangements

A fully independent oversight body is recommended in this scenario. An apex institution with responsibility for oversight is ideal, but sectoral institutions would also be appropriate. Consideration must be given to ensuring independence of the oversight body. For example, internal controls could be put in place to separate dam operations from safety monitoring, such as in South Africa, where the ownership of dams is situated in a different branch of the Department of Water and Sanitation from the Dam Safety Office, which administers dam safety regulations. Alternatively, the oversight body could be located in a different ministry from the ministry entrusted with dam ownership, as is the case in Peru, where the National Water Authority, which is empowered to oversee dams, is situated in the Ministry of Environment and does not own any dams, whereas most large dams are owned by the Ministry of Agriculture and Irrigation. The oversight body should be fully empowered with the following:

- Authority to develop norms and standards
- Authority to issue licenses and permits
- Authority to supervise maintenance and surveillance of dams
- Authority to conduct audits and inspections
- Authority to approve inspectors
- Responsibility for maintaining the inventory of dams
- Responsibility to provide advisory support

- Authority to impose penalties and fines in case of noncompliance
- Authority to revoke license, concession contract, and so forth, in case of noncompliance

The quality assurance role of the oversight body may range from the execution of simple compliance audits to more hands-on quality assurance. The optimal mix of responsibilities given to this unit will depend on internal financial and technical capacity. Provisions should be included to ensure periodic, independent dam safety assessments.

The oversight body should report to the relevant minister, and its reports should be publicly available, providing transparency of performance of dam operators as well as the oversight body. In Brazil, for example, the federal Dam Safety Law mandates that regulatory agencies report to the National Water Authority via the National Dam Safety Information System. The National Water Authority reports to Congress by way of the annual national report on dam safety, which is publicly accessible. Staff of the oversight body as well as the authorities entrusted with dam operations must have appropriate levels of qualification and training related to dams and their safety.

Technical Requirements

It should be mandated that an up-to-date inventory of all dams is maintained and that this database is publicly available. It should be mandated that there is a classification system in place, based on both size and hazard.

It also should be mandated that the government develop its own guidelines (in the case of common law systems) or standards (in the case of civil law systems). These guidelines or standards must be fit for purpose and account for the values and policy priorities of the country. They should cover the following:

- *Design and review standards.* Design and review standards should be deterministic and risk informed where appropriate. Risk analysis, such as potential failure mode analysis, should be mandated or recommended where possible. The adequacy of the design, construction plans, and dam safety requirements should be ensured by a qualified owner's engineer and an independent panel of experts. Design and review requirements should be proportionate to risk/hazard, but deterministic standards may provide a large range of differentiation between the low and high ends of the classification system as suitable. For example, ANCOLD in Australia has classifications of Very Low, Low, Significant, High C, High B, High A, and Extreme, with acceptable design flood standards ranging from 1-in-100 years to probable maximum flood. High-risk/high-hazard dams are typically required to meet 1-in-1,000 to 1-in-10,000 years or PMF design standards.
- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of large and high-risk/high-hazard dams, this should be sufficiently frequent to detect any

anomalies at an early stage. For example, routine inspections could be daily, and detailed formal inspections every three years. The oversight body should undertake rigorous compliance review of the dam safety program and performance, and also perform its own random audits or inspections. The requisite sophistication of the inspection and qualification of the inspectors must also be proportionate to the risk/hazard of the dam. For high-risk/high-hazard dams, it is necessary to have a highly qualified team, with qualifications certified by the oversight body or an independent professional body. For example, in South Africa, inspectors and dam safety reviewers must come from the list of "approved professional persons," registered with the national engineering council and approved by the minister of water and sanitation. In England and Wales, legislation establishes "panel engineers" and "supervising engineers" with different roles in the monitoring and inspection of dams. Record keeping should also be mandated. The safety file should be easily accessible to all those concerned and should include three main parts: (1) the as-built engineering details, (2) O&M records and monitoring data, and (3) EPP documents.

- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard. Thus, for large, high-risk/high-hazard dams, instrumentation should be comprehensive, sophisticated, and reliable. An effective management system should also be in place, including data monitoring and interpretation.

- *EPP.* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. For large, high-risk/high-hazard dams, an EPP should be required for operational issues as well as for dam-break scenarios. The EPP must be highly sophisticated, including detailed dam-break analyses and well-planned coordination among all relevant parties, including disaster risk management authorities and the military, as appropriate. The EPP must also include the installation of warning systems and should include the implementation of mock drills. For high-risk/high-hazard dams, EPPs should be elaborated based on dam-break analysis and flooding simulation/mapping and include notification and coordination procedures for emergency actions, including evacuation of the downstream population. The EPP should also include a compilation of all the persons who should be contacted in the case of dam failure. For example, in South Africa, category 3 dams require comprehensive plans with detailed flood maps, whereas a category 2 dam requires only a summary of intended actions by relevant parties, a listing of telephone contacts, and a basic map with approximate dam-break flood lines.

- *Public safety.* Public safety during dam operation must be given serious consideration, with reference to guidelines from reputable institutions,[8] including all the necessary safety measures, including downstream warning system, public awareness and education, incident reporting procedures, and so forth.

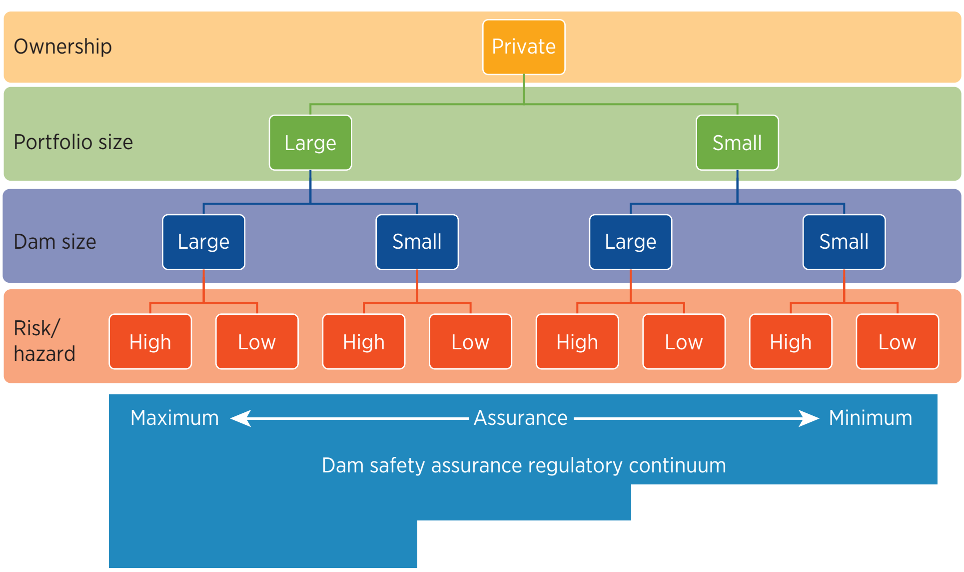
Financial Considerations

Adequate funding and capacity for the oversight body are required. An independent body can be financially autonomous through collection of fees (intragovernmental transfers) for dam safety surveillance services. A base budgetary line item may be provided, either from the central government budget, grants, or funds earmarked from revenue from related services, such as water supply or hydropower generation. Cross-subsidization is also possible by way of government transfers from dams with strong revenue streams (that is, with a tariff structure providing full cost recovery) to dams with weaker revenue streams. The oversight body may choose to immediately build its internal capacity or to outsource certain functions to outside expertise initially. Regardless, the relevant line ministry or government authority should allocate enough resources to maintain the inventory of dams and sufficiently perform mandated O&M provisions for dam safety. The relevant line ministry or authority should also allocate resources for training of authority staff and for dam operators.

COUNTRIES WITH MAINLY PRIVATE DAM OWNERSHIP

Figure E.5 shows the portfolio characteristics that can help policy makers determine appropriate features of a regulatory regime for contexts with mostly privately owned dams. The following sections explore in more detail

FIGURE E.5 Considerations for privately owned dams



Source: Original figure for this publication.

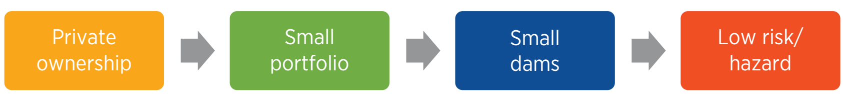
different portfolio scenarios and corresponding elements of the dam safety assurance system.

Overall, in the case of privately owned dams, it is important to give due consideration to the following:

- Establish clear dam safety standards and requirements that private entities are required to abide by when preparing project and/or concession agreements.
- Establish and maintain sufficient capacity of governmental regulators for reviewing and approving design documents, concession agreements, and so forth to be submitted by private entities.
- Ensure that all critical dam safety requirements are covered, including inspection and instrumentation, required remedies, public safety, emergency preparedness, and so forth in the concession agreements and other legally binding documents.
- Require private entities to confirm the design, construction plan, and dam safety requirements with their owner's engineers and an independent panel of experts.

These should be proportionate to the size and type of portfolio of dams, as explained in the subsequent sections.

Privately Owned, Small Portfolio of Small Dams That Are Largely Low Risk/Hazard



In this scenario, given the small portfolio size and the low-risk/low-hazard profile of small dams, it is appropriate to simplify legal, institutional, and technical requirements with their clear essentials in order to reduce unnecessarily high transaction costs in the system. As a result, the elements of this scenario are positioned near the minimum assurance end of the continuum.

Legal Underpinnings

There is little need for dedicated legislation or reference to dam safety provisions in enabling legislation, but dam safety responsibility and liability for dam failure should be clearly defined. In common law systems, this definition may come from existing case law or precedent, including whether it is based on negligence or strict liability. In civil law systems, dam safety responsibility and liability for dam failure should be clearly defined in existing law, or they may need to be prescribed in a new law.

Institutional Arrangements

A dedicated government unit or authority is not necessary, but there should be a unit designated to oversee the dam safety of private dams, including maintaining an inventory of dams. It should be ensured that the dam owners have appropriate staff and training related to dams and their safety.

Technical Requirements

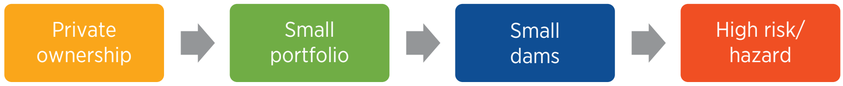
There should be a minimum but essential set of dam safety regulations, including an up-to-date inventory of all dams with a unit designated to monitor and update the inventory as changes occur. There should also be a checklist to determine minimum safety assurance requirements on a case-by-case basis. This is more important for countries with mainly private dam ownership due to relatively lower levels of public consultation and similar requirements for construction of small private dams. It should include the following:

- *Design and review standards.* A simple, deterministic set of design and review standards would be appropriate. In spillway design flood, for example, small and low-risk/low-hazard dams may be required to meet the 1-in-100 to 1-in-200 year return period.
- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of low-risk/low-hazard dams, this can be relatively infrequent. Routine inspections could be monthly, and detailed formal inspections every 10 years.
- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard. Thus, for small, low-risk/low-hazard dams, instrumentation can be minimal and basic and included as part of the O&M.
- *EPP*. The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. For small, low-risk/low-hazard dams, where there are no lives and/or economic, environmental, or societal assets at risk, an EPP may not be required.
- *Public safety.* Public safety during dam operation can be addressed with simple downstream warnings and signs, as appropriate.

Financial Considerations

For the oversight authority, a minimal budgetary implication would be associated with the review of new dam applications and safety requirements as well as maintenance of the inventory of dams. A small budget should also be allocated for dam owner education and awareness on common or civil law responsibilities for dam safety. The dam owner or operator should have a sufficient revenue stream to perform the necessary O&M tasks as well as the basic aspects of the technical requirements checklist.

Privately Owned, Small Portfolio of Small Dams That Are Largely High Risk/Hazard



In this scenario, the legal and institutional aspects are relatively simple to reduce transaction costs for a small portfolio of small dams, but the technical requirements are more sophisticated due to the high-risk/high-hazard nature of the portfolio.

Legal Underpinnings

There is no need for dedicated legislation due to the high transaction cost associated with a complex system for only a few high-risk/high-hazard dams. The regulations should require dam owners/operators to submit annual or other periodic reports to demonstrate how they have fulfilled the owner's dam safety responsibilities in compliance with the dam safety requirements. The responsibility for dam safety and liability in the event of dam failure should, however, be clearly defined. In common law systems, this may come from existing case law or precedent, including whether they are based on negligence or strict liability. In civil law systems, dam safety responsibility and liability for dam failure should be clearly defined in existing law, or they may need to be prescribed in a new law. Consideration should be given to inclusion of dam safety requirements in existing licensing stipulations and concession agreements. Financial and other forms of penalties, such as revocation of licenses, may be considered and clearly defined in the regulation in the event of noncompliance.

Institutional Arrangements

There is no need for a dedicated authority, but an existing authority can establish an appropriate unit in charge of dam safety, including the review of new dam applications and safety requirements, as well as managing of an inventory of dams and checking compliance of owners' dam safety requirements. These could be supported by periodic, independent dam safety assessments. In a federal system of government, where dams are located only in some states, consideration should be given to the creation of decentralized dam safety units rather than a central institution to provide oversight in those states. This would reduce the regulatory burden. If a licensing regime already exists, the relevant authority could oversee dam safety license conditions and require reporting, for example, to an existing multisector regulator. At a minimum, the regulator should have the capacity to undertake compliance checking, and the dam owner should have sufficient capacity to comply with the dam safety requirements. Owners should also be educated about potential liability.

Technical Requirements

A clear dam safety review mechanism should be mandated for new dam applications and compliance for existing dams, as well as an up-to-date inventory of all dams and their classification that is maintained and updated as changes occur. Consideration should be given to having an independent assessment of risk of the dams, and it is recommended that private entities establish an independent review mechanism for design, construction plans, and so forth. For a small portfolio of small, high-risk/high-hazard dams, reference should be made to existing small dam safety guidelines published by recognized industry groups.

Along technical lines, there should still be a register or inventory of all dams, but for a high-hazard portfolio, reference should be made to available small dam safety guidelines, as appropriate. Examples include ICOLD (1998, 2016) Bulletins 109 and 157 and/or the FAO's manual on small earth dams (Stephens 2010). Consideration should be given to requiring owners to undertake independent assessment of dam safety of high-hazard dams.

The technical requirements are essentially the same as those recommended at the maximum assurance end of the continuum. However, standards may be kept simple and allow for use of simple design and review tools. In the case of lower-middle-income countries where the development of dams is led by private developers, some formal establishment of guidelines is recommended so that regulators can require developers to comply with the established minimum safety standards and requirements without ambiguities. The following need to be explicitly referenced:

- *Design and review standards.* A simple, deterministic set of design and review standards would be appropriate. In spillway design flood, for example, small and high-risk/high-hazard dams may be required to meet the 1-in-200 to 1-in-1,000 years return period.[9]

- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of small, high-hazard dams, this should be relatively frequent. Routine inspections could be daily, and detailed formal inspections every three years.

- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard. Thus, for small, high-risk/high-hazard dams, instrumentation can be limited to essential elements, but an effective management system should be in place, including data monitoring and interpretation.

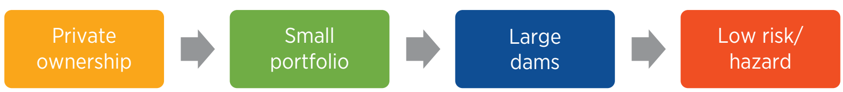
- *EPP.* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. Simpler EPPs and tools may be mandated for low-risk/low-hazard dams. EPP requirements should be prioritized for dams that could cause high casualties and/or loss of economic, environmental, or societal assets. It is important to ensure training for dam owners and/or operators and coordination with the disaster risk management authority and other relevant emergency agencies.

- *Public safety.* Public safety during dam operation can be addressed with downstream warnings and signs as required.

Financial Considerations

The oversight authority should secure sufficient budget for undertaking compliance review of the owner's dam safety requirements and for enforcement of noncomplying entities. It should also have a sufficient budget for its own staff capacity development and dam owner education and awareness on dam safety requirements. The dam owner or operator should have an adequate revenue stream to perform the O&M tasks and comply with the dam safety requirements as per the technical checklist. The concession agreement should clearly define such safety requirements and financial and other forms of penalties in case of noncompliance.

Privately Owned, Small Portfolio of Large Dams That Are Largely Low Risk/Hazard



In this scenario, even though the small portfolio consists of low-risk/low-hazard dams, the elements are positioned toward the middle of the continuum due to the large size of the dams.

Legal Underpinnings

There is no need for dedicated legislation, but provisions could be included in sector-specific legislation, such as for mining or energy. Dam safety responsibility and liability for dam failure should be clearly defined. In common law systems, this may come from existing case law or precedent, including whether the definition is based on negligence or strict liability. In civil law systems, dam safety responsibility and liability for dam failure should be clearly defined in existing civil law, or they may need to be prescribed in a new civil law.

The regulations should require dam owners to submit annual or other periodic reports to demonstrate how they have fulfilled the dam safety responsibilities in compliance with the dam safety requirements either in bylaws under an existing law or in licensing or concession agreements. Consideration should be given to mandating periodic, independent assessment of dam safety. Any associated expenses should be financed by the dam owner or operator. Consideration should also be given to the introduction of financial penalties or other forms of penalties, such as license revocation, in the event of noncompliance under the concession agreements or other noncompliance.

Institutional Arrangements

There is no need for a dedicated authority, but consideration should be given to establishing an appropriate unit under an existing ministry or agency in charge of water resources or related sectors. The regulator should consider requiring dam owners to periodically undertake independent dam safety assessment in an acceptable manner to the regulator. At a minimum, the regulator should have a compliance review system and enforcement capacity, and the dam owner needs to have sufficient capacity to undertake dam safety requirements in compliance with the regulations; this capacity may come through education and training programs. Owners should also be educated about financial and other forms of penalties in case of noncompliance.

Technical Requirements

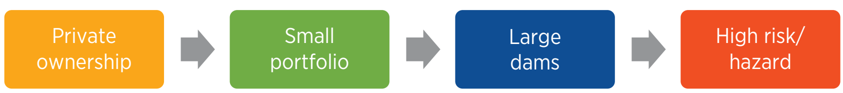
The entity responsible for regulatory oversight should maintain an up-to-date inventory of all dams and the classification system. Consideration should be given to requiring owners to undertake independent dam safety assessment. The regulator may not need to develop custom dam safety guidelines, but can refer to existing guidelines published by recognized industry groups such as ICOLD, CDA, ANCOLD, and others. There should also be a checklist to determine minimum safety assurance requirements on a case-by-case basis, and it should include the following:

- *Design and review standards.* A simple, deterministic set of design and review standards would be appropriate. In spillway design flood, for example, large and low-risk/low-hazard dams may be required to meet the 1-in-200 to 1-in-1,000 years return period.
- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of low-hazard dams, this can be relatively infrequent. Routine inspections could be weekly, and detailed formal inspections every five years.
- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard. Thus, for large, low-risk/low-hazard dams, instrumentation can be basic, but essential instruments should be maintained.
- *EPP.* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. For low-risk/low-hazard dams, a simple EPP may be sufficient. It is important to ensure training for dam operators and coordination with the disaster risk management authority and other relevant emergency agencies.
- *Public safety.* Public safety during dam operation can be addressed with simple downstream warnings and signs, as appropriate.

Financial Considerations

For the oversight authority, a minimal budgetary implication is associated with the development of the compliance review system. A sufficient budget should also be allocated for the regulator's capacity development and dam owner education and awareness on dam safety requirements. Taxes or fees may be justified to finance independent assessments or provisions included requiring the owners to do so. As an existing authority or multisector regulator is recommended to fulfill compliance or audit functions, an appropriate level of resources should be clearly allocated for this role. The dam owner or operator should have a sufficient revenue stream to perform the necessary O&M tasks as well as the dam safety requirements in compliance with the checklist noted.

Privately Owned, Small Portfolio of Large Dams That Are Largely High Risk/Hazard



Even though the portfolio size is small, the presence of large, high-risk/high-hazard, private dams necessitates a more complex legal and institutional regime along with stronger technical requirements. Thus, this scenario fits toward the middle of the dam safety assurance continuum.

Legal Underpinnings

There is no need for dedicated legislation, but enabling provisions should be included in sector-specific legislation, such as for water, mining, or energy. In addition to the enabling provisions, it should be determined whether more specific regulations are required. This applies to civil law systems. In common law systems, an existing authority can be empowered to discretionarily control dam safety, and existing or external guidelines can be used as a basis for setting standards. The regulations should require dam owners/operators to submit annual or other periodic reports to demonstrate how they have fulfilled the owner's dam safety responsibilities in compliance with the dam safety requirements.

The responsibility for dam safety and liability in the event of dam failure need to be clearly defined. In common law systems, this may come from existing case law or precedent, including whether it is based on negligence or strict liability. In civil law systems, dam safety responsibility and liability for dam failure should be clearly defined in existing law, or they may need to be prescribed in a new law. In civil law systems, the definitions of responsibility for dam safety must be more prescriptive and standards need to be explicitly referenced. In this setting, dam safety requirements could be included in existing licenses. Furthermore, insurance could be mandated or incentivized, including using subsidies.

Institutional Arrangements

Responsibility for overseeing dam safety assurance should be vested in a dedicated authority. This can be an existing multisector regulator or housed in one of the relevant line ministries. While the regulator should obtain some general budget allocation for fulfilling its main function, such as compliance checking or monitoring in line with licenses and concession agreements, it may partially rely on license fee revenues from private dam owners to enhance its institutional capacity. Provisions should be included for periodic, independent dam safety assessments.

Technical Requirements

The entity responsible for regulatory oversight should maintain adequate capacity for reviewing new dam applications and clearance, as well as maintaining an up-to-date inventory of all dams and their classification system. Dam owners should be required to undertake independent dam safety assessment for design, construction plans, and so forth for new dams and compliance review of existing dams. There may be no need to develop custom dam safety guidelines due to the small size of the portfolio, but reference can be made to existing guidelines published by recognized industry groups such as ICOLD, CDA, ANCOLD, and others. The guidelines should cover the following:

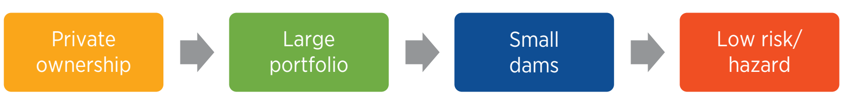
- *Design and review standards.* Design and review standards should be deterministic and risk informed where appropriate. Risk analysis, such as potential failure mode analysis, should be mandated or recommended where possible. The dam owner or operator should be required to ensure the adequacy of the design, construction plans, and dam safety requirements through a qualified Owner's Engineer and an independent panel of experts. Design and review requirements should be proportionate to the risk/hazard. High-risk/high-hazard dams are typically required to meet 1-in-1,000 to 1-in-10,000 years or PMF design standards.
- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of high-hazard dams, this should be relatively frequent. Routine inspections could be daily, and detailed formal inspections every three years. The owners should be required to submit an annual dam safety report to the regulator. For high-risk/high-hazard dams, it is recommended that owners would be required to undertake risk analysis/assessment by an independent body and complete required remedies in a manner satisfactory to the regulator.
- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard. Thus, for large, high-risk/high-hazard dams, instrumentation should be comprehensive, sophisticated, and reliable, and an effective management system should be in place, including data monitoring and interpretation.

- *EPP.* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. In case of high-hazard dams, EPPs should be required for large flood discharge scenarios without dam break in addition to dam-break scenarios. They must be highly sophisticated, including detailed dam-break analyses and well-planned coordination among all relevant parties, including disaster risk management authorities and the military, as appropriate. The EPP must also include the installation of warning systems and implementation of mock drills. It should also include a compilation of all the persons who should be contacted in case of dam failure.
- *Public safety.* Public safety during dam operation must be given serious consideration, with reference to guidelines from reputable institutions,[10] including all the necessary precautions to be taken and downstream warning tools to be used. This can be addressed with downstream warnings, signs, and awareness-raising programs, as required.

Financial Considerations

There are financial implications associated with the oversight authority, which should be appropriately resourced to enable it to carry out its mandated functions. A tax or fee may be used to finance or supplement the resources of the oversight authority and enhance its institutional capacity. Taxes or fees may also be justified to finance inspections. As an existing authority or multisector regulator may be recommended to be empowered for compliance or audit functions, an appropriate level of resources should be clearly allocated for this role. Financial and other forms of penalties should be assessed and be defined in regulations or concession agreements for noncompliance. The dam owner or operator should have a sufficient revenue stream to perform the necessary O&M tasks as well as other mandated responsibilities for dam safety. The relevant line ministry or multisector regulator should allocate resources for educating dam owners on their responsibilities for dam safety.

Privately Owned, Large Portfolio of Small Dams That Are Largely Low Risk/Hazard



In this scenario, even though the size of the portfolio may be large, a dam safety framework between the middle and minimum end of the continuum would be appropriate, given that the dams are small and low-risk/low-hazard, necessitating relatively simple legal, institutional, and technical aspects.

Legal Underpinnings

There is no need for dedicated legislation, but responsibilities for dam safety and liability in the event of dam failure should be clearly defined. In common law systems, this definition may come from existing case law or precedent, including whether it is based on negligence or strict liability. In civil law systems, dam safety responsibility and liability for dam failure should be clearly defined in existing law, or they may need to be prescribed in a new law.

Institutional Arrangements

A dedicated oversight authority is not necessary, but existing departments or units in charge of water resources, energy, or related fields should maintain an inventory of dams and their classification. At a minimum, the dam owner needs to be clearly instructed about the required level of standard of care and reporting procedures to the regulator ensuring sufficient capacity of the regulator to enact the required standard of care.

Technical Requirements

There should be a basic dam safety review system in place, including the review of designs, construction plans, and dam safety conditions, an up-to-date inventory of all dams, and a simple classification system that is periodically reviewed for hazard creep. Dam owners, operators, and local authorities should follow a set of guidelines on safety for small dams, but it is not necessary for them to establish their own, unique guidelines. Instead, they may refer to existing guidelines published by reputable sources, such as ICOLD (1998, 2016) Bulletins 109 and 157 and/or the FAO's manual on small earth dams (Stephens 2010). The guidelines should cover the following:

- *Design and review standards.* A simple, deterministic set of design and review standards would be appropriate. In spillway design flood, for example, small and low-risk/low-hazard dams may be required to meet the 1-in-100 to 1-in-200 years return period. It should also be recognized that the cumulative risk posed by many small dams in catchments can be higher than their individual risks/hazards, in which case higher hydrological safety requirements may be warranted for those dams.
- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of low-risk/low-hazard dams, this can be relatively infrequent. Routine inspections could be monthly, and detailed formal inspections every 10 years.
- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard. Thus, for small, low-risk/low-hazard dams, instrumentation can be very minimal and basic and included as part of the O&M.
- *EPP.* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. For

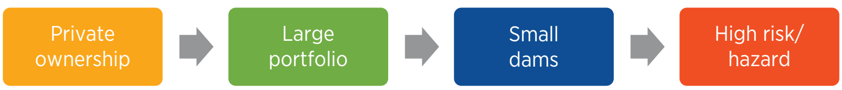
small, low-risk/low-hazard dams where there are no lives and/or economic, environmental, or societal assets, an EPP may not be required.

- *Public safety.* Public safety during dam operation can be addressed with simple downstream warnings and signs, as appropriate.

Financial Considerations

The overall budgetary implications depend on the extent of the large portfolio. The responsible regulatory entity should allocate enough resources for undertaking compliance review of the owner's dam safety program, performance, and capacity. The owner or operator should have an adequate revenue stream to perform necessary O&M and other mandated dam safety measures. Given the large number of dams, revenue from a user or service fee or related tax could be generated to finance dam safety inspections by the existing authority, if possible. Financial penalties for noncompliance may be assessed.

Privately Owned, Large Portfolio of Small Dams That Are Largely High Risk/Hazard



Given the presence of a large portfolio of small dams deemed to be high-risk or high-hazard classifications, this scenario fits between the middle and the maximum assurance end of the continuum.

Legal Underpinnings

Depending on the size and type of the portfolio, dedicated dam safety legislation or specific sectoral regulation is necessary. This should be in the form of clearly articulated, uniform laws and regulations. The regulations should require dam owners/operators to submit annual or other periodic reports to demonstrate how they have fulfilled the owner's dam safety responsibilities in compliance with the dam safety requirements. In a federal system, it may be appropriate to have legislation at the state level, as in the case of Australia and Canada, or possibly at both the state and federal levels, as in Brazil and the United States.

In common law systems, the responsibility for dam safety and the liability in the event of dam failure should be clearly defined. This may come from existing case law or precedent, including whether it is based on negligence or strict liability. If case law precedent does not exist, the dam safety legislation would need to define dam safety responsibility and liability. In common law systems, either specific dam safety legislation or enabling legislation may be appropriate. In the case of enabling legislation, wide, discretional powers pertaining to dam safety would be given to an existing authority under an existing law. In a specific dam safety law, powers pertaining to dam safety would be prescribed to a specific dam safety authority. In civil law systems, definitions of dam safety responsibility and dam failure liability must be specific and would be found in an existing dam safety statute and/or in the broader civil liability law. In civil law systems, specific dam safety legislation would have to be highly prescribed, but it could be in the form of an enabling law (for example, energy, water, or other laws depending on the types of portfolio) and specific regulations. Consideration should be given to the use of strong penalties, such as fines, revocation of licenses, and so forth for noncompliance.

Institutional Arrangements

Consideration should be given to the creation of a unit responsible for oversight of dam safety but not necessarily an authority dedicated solely to dam safety. For example, the ministry of energy or power could have responsibility for hydropower dam safety oversight and provide quality assurance in case a majority of large high-hazard dams are for hydropower. This may range from the execution of simple compliance audits, which may be suitable for small dams, to more hands-on quality assurance. Provisions should be included to support periodic independent dam safety assessments.

At a minimum, it is important for the regulator to establish a clear set of dam safety requirements and/or standard of care and undertake periodic compliance review and order remedies if necessary. The dam owner should demonstrate sufficient performance and capacity in line with the dam safety requirements. The regulator may introduce sanctions against noncompliance entities, such as penalties, fines, revocation of licenses, concession agreements, and so forth. Such concession agreements should be carefully prepared to enable the regulator to exercise remedies against noncomplying private entities.

Technical Requirements

There should be a sufficient dam safety review system in place, including an up-to-date inventory of all dams as well as a classification system that accounts for scenarios involving cascades or cumulative failures, which are common for small dams. There is a need for dam safety guidelines for small dams. These may be specific guidelines, developed to suit the country circumstances, or reference can be made to existing guidelines from reputable sources, as appropriate. Examples include ICOLD (1998, 2016) Bulletins 109 and 157 and/or the FAO's manual on small earth dams (Stephens 2010).

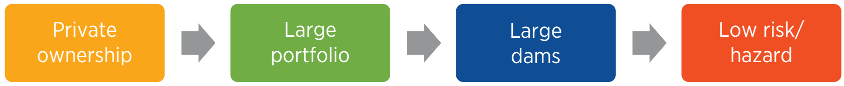
The technical requirements are essentially the same as what are recommended at the maximum assurance end of the continuum. However, standards may be kept simple, clear, and deterministic and allow for use of simple design and review procedures. In particular, for lower-middle-income countries where the development of dams is led by private developers, some formal establishment of national guidelines is recommended so that the regulator can require developers to comply with the established minimum safety standards and requirements without ambiguity. The following should be explicitly defined:

- *Design and review standards.* A simple, deterministic set of design and review standards would be appropriate. In spillway design flood, for example, small and high-risk/high-hazard dams may be required to meet the 1-in-200 to 1-in-1,000 years or higher return period.[11] It is important to note that small dams that may be low-risk/low-hazard individually may warrant a high-risk/high-hazard classification due to their cascade or cumulative threat when there are several in catchments.
- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of small, high-risk/high-hazard dams, this should be relatively frequent. Routine inspections could be daily, and detailed formal inspections every three years.
- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard. Thus, for small, high-risk/high-hazard dams, instrumentation can be limited to essential elements only, but an effective management system should be in place, including data monitoring and interpretation.
- *EPP.* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. Basic EPPs and tools should be mandated for high-risk/high-hazard dams in the project or concession agreement. It is important to ensure training for dam operators and coordination with the disaster risk management authority and other relevant emergency agencies.
- *Public safety.* Public safety during dam operation can be addressed with downstream warnings and signs as required.

Financial Considerations

The overall budgetary implications depend on the extent of the large portfolio. The relevant line ministry or authority should allocate enough resources for dam safety quality assurance. A budgetary line item should be clearly specified for this dedicated unit. The resources allocated should be commensurate with the scope of responsibilities. The owner or operator should have a revenue stream sufficient to perform necessary O&M and other mandated dam safety measures. A user fee or appropriate tax could be considered to finance dam safety inspections by the regulatory entity. Financial penalties for noncompliance may be considered. The relevant line ministry or local authority in charge of dam safety should clearly stipulate the minimum safety standard or safety requirements and the amount of penalties or fines in case of noncompliance.

Privately Owned, Large Portfolio of Large Dams That Are Largely Low Risk/Hazard



This scenario, characterized by a large portfolio of large dams, requires a level of oversight well beyond the minimum criteria. Consisting of dams deemed to be low-risk or low-hazard classifications, it does not require the maximum level of assurance and thus it rests away from the maximum assurance end of the continuum and more toward the middle. It is worth noting, however, that it would be unlikely to find a real-world example of a large portfolio of large dams that are entirely low-risk/low-hazard.

Legal Underpinnings

It is not required to have dedicated legislation on dam safety, but the portfolio should be monitored for hazard creep. Dam safety provisions could be included in an existing law or in licensing requirements, including mandated periodic, independent assessment of the risk at the expense of the operator.

In common law systems, responsibility for dam safety and liability in the event of dam failure should be clearly defined. The definition may come from existing case law or precedent, including whether it is based on negligence or strict liability. In civil law systems, dam safety responsibility and liability for dam failure should be clearly defined in existing law, or they may need to be prescribed in a new law. If the above mandates are introduced, consideration should be given to the inclusion of financial penalties for noncompliance.

Institutional Arrangements

There is no need for a dedicated authority, but a regulatory entity responsible for dam safety oversight should be clearly established in an existing governmental structure. Consideration could be given to self-regulation, with an existing authority empowered to require independent assessment of risk. The role of this authority would largely be for quality assurance, which may range from the execution of simple compliance audits to more hands-on quality assurance, but simple compliance audits may be appropriate for low-risk/low-hazard large dams.

At a minimum, the regulator should establish the dam safety standards or safety requirements and undertake the compliance review of private dam owners. Owners should demonstrate their dam safety program, performance, and capacity. Owners should be informed of such standards or requirements and penalties in case of noncompliance.

Technical Requirements

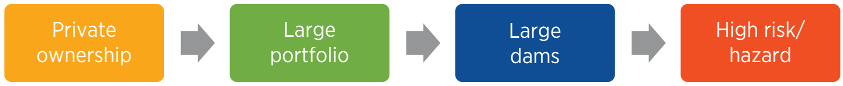
There should be an effective dam safety review system in place, including an up-to-date inventory of all dams. Their classification should be maintained and periodically checked for hazard creep. Consideration should be given to owners having independent assessment of risk of the dams. Given the large number of large dams, the government should consider developing its own guidelines on the minimum standards of dams and safety requirements of large dams, suitable for the country circumstances. These guidelines may refer to existing guidelines published by recognized industry groups such as ICOLD, CDA, ANCOLD, and others. They should cover the following:

- *Design and review standards.* A simple, deterministic set of design and review standards would be appropriate. In spillway design flood, for example, large and low-risk/low-hazard dams may be required to meet the 1-in-200 to 1-in-1,000 years return period.
- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. In the case of low-risk/low-hazard dams, this can be relatively infrequent. Routine inspections could be weekly, and detailed formal inspections every five years.
- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard. Thus, for large, low-risk/low-hazard dams, instrumentation can be basic, but instruments should be properly maintained.
- *EPP.* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. For large but low-risk/low-hazard dams, a simple EPP may be sufficient. It is important to ensure training for dam operators and coordination with the disaster risk management authority and other relevant emergency agencies.
- *Public safety.* Public safety during dam operation can be addressed with downstream warnings and signs, as appropriate.

Financial Considerations

The relevant line ministry or local government authority should allocate resources commensurate with the size and type of the portfolio and the scope of responsibility for dam safety. The owner or operator should have a revenue stream sufficient to perform necessary O&M and other mandated dam safety measures. A user fee or tax could be considered to finance dam safety inspections by the regulator. Penalties including fines, revocation of licenses, concession agreements, and so forth for noncompliance should be assessed and defined. The relevant line ministry or local authority should allocate resources for developing the design standards, regulatory framework, and the required capacity.

Privately Owned, Large Portfolio of Large Dams That Are Largely High Risk/Hazard



With a large portfolio or large, high-risk or high-hazard dams, a greater level of oversight is needed. Thus, this scenario rests toward the maximum end of the dam safety assurance continuum, requiring more complex legal and institutional arrangements and higher technical requirements.

Legal Underpinnings

Given the size and type of the portfolio, dedicated legislation or sectoral legislation on dam safety is necessary. For example, if a majority of the portfolio consists of hydropower dams, the ministry of energy or power may develop the dam safety regulation framework under its sectoral laws and regulations. This should be in the form of clearly articulated, uniform laws and regulations. The regulations should require dam owners/operators to submit annual or other periodic reports to demonstrate how they have fulfilled the owner's dam safety responsibilities in compliance with the dam safety requirements. In a federal system, it may be appropriate to have legislation at the state level, as in the case of Australia and Canada, or possibly at both the state and federal levels, as in Brazil and the United States.

In common law systems, the responsibility for dam safety and liability in the event of dam failure should be clearly defined. This definition may come from existing case law or precedent and should include information on whether it is based on negligence or strict liability. If case law precedent does not exist, the dam safety legislation would need to define dam safety responsibility and liability. In common law systems, either specific dam safety legislation or enabling legislation may be appropriate. In the case of enabling legislation, wide, discretional powers pertaining to dam safety would be given to an existing authority under an existing law. In a specific dam safety law, powers pertaining to dam safety would be prescribed to a specific dam safety authority. In civil law systems, definitions of dam safety responsibility and dam failure liability must be specific and would be found in an existing dam safety statute and/or in the broader civil liability law. In civil law systems, specific dam safety legislation would have to be highly prescribed, but it could be in the form of an enabling law and specific regulations. Increased compliance can be achieved with stronger penalties, including civil and criminal sanctions and revocation of licenses, concession agreements, and so forth.

Institutional Arrangements

A fully independent oversight body would be preferable under such a scenario. An apex institution with responsibility for oversight is ideal, but sectoral institutions would also be appropriate depending on the type and size of the portfolio. The oversight body should be fully empowered with the following:

- Authority to develop norms and standards
- Authority to issue licenses and permits
- Authority to supervise maintenance and surveillance of dams
- Authority to conduct audits and inspections
- Authority to approve inspectors
- Responsibility for maintaining the inventory of dams
- Responsibility to provide advisory support
- Authority to impose penalties and fines (even criminal penalties) in case of noncompliance
- Authority to revoke license, concession contract, and so forth in case of noncompliance

The quality assurance role of the oversight body may range from the execution of simple compliance audits to more hands-on quality assurance. The optimal mix of responsibilities given to this unit will depend on internal financial and technical capacity. Consideration should be given to establishing an advisory body composed of independent experts to assist the regulator in the execution of its functions relating to high-risk/high-hazard dams.

The oversight body should report to the relevant minister, and its reports should be publicly available, providing transparency of performance of dam owners and operators as well as the oversight body. In Brazil, for example, the federal Dam Safety Law mandates that regulatory agencies report to the National Water Authority via the National Dam Safety Information System. The National Water Authority reports to Congress by way of the annual national report on dam safety, which is publicly accessible. Staff of the oversight body and dam owners must have appropriate levels of education and training related to dams and their safety.

Technical Requirements

There should be a comprehensive and elaborate dam safety review system in place, including review and approval of new dam design, construction plans, and dam safety requirements, as well as the safety condition of existing dams and required remedies. An up-to-date inventory of all dams should be maintained, and this database preferably should be publicly available. It should be mandated that there is a classification system in place considering size and hazard.

It should be mandated that the government develop its own guidelines (in the case of common law systems) or standards (in the case of civil law systems). These guidelines or standards must be fit for purpose and account for the values and policy priorities of the country. They should cover the following:

- *Design and review standards.* Design and review standards should be deterministic and risk informed where appropriate. Risk analysis, such as potential failure mode analysis, should be mandated or recommended where possible. The dam owner or operator should be required to ensure the adequacy of the design, construction plans, and dam safety requirements through a qualified Owner's Engineer and an independent panel of experts. Design and review requirements should be proportionate to risk/hazard, but deterministic standards may provide a large range of differentiation between the low and high ends of the classification system depending on the country's context. For example, ANCOLD in Australia has classifications of Very Low, Low, Significant, High C, High B, High A, and Extreme, with acceptable design flood standards ranging from 1-in-100 years to probable maximum flood. High-risk/high-hazard dams are typically required to meet 1-in-1,000 to 1-in-10,000 years or PMF design standards.
- *O&M and safety inspections.* The frequency of regular routine inspections and longer-term periodic and detailed formal inspections should be proportionate to the risk/hazard for the dams. For the large and high-risk/high-hazard dams, this should be sufficiently frequent and intensive to detect any anomalies at an early stage. For example, routine inspections could be daily, and detailed formal inspections every three years. The oversight body should, at the very least, also perform its own random audits or inspections. The requisite sophistication of the inspection and qualification of the inspectors must also be proportionate to the risk/hazard of the dam. For high-risk/high-hazard dams, it is necessary to have a highly qualified team with qualifications certified by the oversight body or an independent professional body. For example, in South Africa, inspectors and dam safety reviewers must come from a list of approved professional persons registered with the national engineering council and approved by the minister of water and sanitation. The safety file should be easily accessible to all those concerned and should include three main parts: (1) the as-built engineering details, (2) O&M records and monitoring data, and (3) EPP documents. Risk analyses, such as potential failure mode analysis, should also be mandated or recommended where possible, recognizing that a risk-informed approach has been effectively used for the review of many existing high-risk/high-hazard dams.
- *Instrumentation.* The level of instrumentation should be proportionate to the size and risk/hazard. Thus, for large, high-risk/high-hazard dams, instrumentation should be comprehensive, sophisticated, and reliable,

and the effective management system should be in place, including data monitoring and interpretation.

- *EPP.* The level of detail in the EPP should be commensurate with the downstream hazard/potential consequence in case of dam failure. For large, high-risk/high-hazard dams, an EPP should be required for operational issues as well as for dam-break scenarios. The EPP should include detailed dam-break analyses and well-planned coordination among all relevant parties, including disaster risk management authorities and the military, as appropriate. The EPP must also include the installation of warning systems and implementation of mock drills. For less hazardous dams, EPPs may not be so sophisticated and can be based on dam-break inundation zone estimates and clear but simple implementation or coordination procedures between different entities. It should also include a compilation of all the persons who should be contacted in case of dam failure. For example, in South Africa, category 3 dams require comprehensive plans with detailed flood maps, whereas a category 2 dam requires only a summary of intended actions by relevant parties, a listing of telephone contacts, and a basic map with approximate dam-break flood lines.
- *Public safety.* Public safety during dam operation must be given serious consideration, with reference to guidelines from reputable institutions,[12] including all the necessary precautions taken including downstream warning tools, incident reporting procedures, public awareness raising and education, and so forth.

Financial Considerations

Adequate funding and capacity for the oversight and enforcement body are required. An independent authority should allocate resources commensurate to the scope of regulatory responsibilities. Ideally, the oversight body is funded through a user-pays system, but this could be combined with resources allocated from the government budget. To ensure independence, the regulator should be insulated from the financial performance of owners and operators, that is, fees should be fixed and not dependent on fluctuating revenues. Financial and other forms of penalties should be considered for noncomplying entities and should be clearly defined in the regulations. The oversight body may choose to build its internal capacity or to outsource certain functions to expertise initially, or do a combination, with a long-term strategy for capacity development. The relevant line ministry or authority should also allocate resources for training of authority staff and dam owners. If dam owners are mandated to have insurance, or purchase it voluntarily, then the insurance industry can also monitor adherence to acceptable standards, rewarding good performance with lower premiums.

USING THE DECISION SUPPORT TOOL: EXAMPLE CASES

Rapid Portfolio Growth

Scenario Description

Country A is a small, mountainous, middle-income country with a significant freshwater endowment. More than half of the country's small population is concentrated in the capital city, which is in the western part of the country on a high plateau, surrounded by increasingly commercial agricultural lands. The farmers, organized into cooperatives and water-user associations, operate 20 small irrigation dams, which they use for irrigation of cash crops. In the eastern part of the country, there are 6 large dams for hydropower under construction. The government has plans to develop at least another 18 dams in the next decade with a vision of becoming an exporter of electricity to neighboring industrializing countries.

Legal Underpinnings

Country A has a civil law legal system. There is no dedicated dam safety legislation. There are dam safety provisions in various sectors' legislation, including the Irrigation Act and the Electricity Act, which empower the Agriculture and Energy Ministries, respectively, to regulate dam safety.

Institutional Arrangements

The Energy Ministry has imported dam safety expertise to support the oversight function of the ministry during the design and construction of the six hydropower dams under development. Although the experts have strong qualifications and significant experience in the region, the Energy Ministry itself has no experience in monitoring and surveillance of operational dams. The Agriculture Ministry, in principle, has a long history of regulating dam safety for the small irrigation dams across the western part of the country, but its enforcement capacity is weak, and it lacks sufficient human capital to carry out regular inspections. The de facto situation is self-regulation by the water-user associations.

Technical Requirements

Country A does not have its own dam safety guidelines, neither for small nor large dams. It relies on guidance issued by reputable industry associations.

Financial Considerations

General budgetary allocations to the responsible ministries are used to finance their dam safety oversight functions. The water-user associations collect fees from their members for basic O&M.

Using the Decision Framework

Country A's dams are primarily publicly owned. With new investments, the portfolio is growing, and its composition is shifting toward large dams.

There will also be intensive development of hydropower resources in the same basins, increasing the risk of cascade failure.

Legal Underpinnings

Country A should consider instituting dedicated legislation solely for dam safety that covers all sectors, ensuring that it defines responsibility for dam safety. The government may also develop an internal compliance checking and safety review system for dam safety performance management, using independent review mechanisms for high-hazard dams.

Institutional Arrangements

The government should establish a dedicated oversight entity for dam safety, either as an independent authority or as a department or unit in an existing ministry. Depending on the extent of future dam development plans and the risk/hazard classifications of the dams, it may be advisable that this body be a fully independent, apex institution in coordination with existing regulatory systems under the Energy Ministry and Agriculture Ministry. To ensure independence of the body, internal controls could be put in place to separate dam operations from safety monitoring and compliance checking, or ownership of dams could be situated in a different branch of the ministry or a different ministry entirely from that which is responsible for oversight of dam safety regulations. It is first advisable to conduct a series of stakeholder workshops covering the energy, irrigation, water, disaster management, and other sectors to assess various institutional options and agree on the most optimal arrangement.

Technical Requirements

The government should develop its own set of dam safety standards, customized to the country context. Design and review standards can be deterministic but use a risk-informed approach for high-hazard cases. With the number of large and high-hazard/high-risk dams increasing, the owners should have robust dam safety programs, and the regulator should have a robust system for checking compliance and performance. The regulating body should provide clear definitions of design standards, safety requirements, and the standard of care, depending on a dam's classification. For large, high-hazard/high-risk dams, an EPP should be required not only for dam-break scenarios but also for large flood discharge scenarios without dam-break, as the latter would be more frequent but still cause significant consequences.

Financial Considerations

Public resources should be allocated for the maintenance and development of the regulator's compliance checking system and staff capacity development for enforcement. As the dams are publicly owned in this scenario, the government should also allocate sufficient resources for O&M and dam safety requirements. It would be advised to use the portfolio risk assessment/portfolio risk management (PRA/PRM) approach for optimizing budget allocation, starting with a simple risk index and using failure mode analysis for high-hazard cases. Fees may be collected from water users to finance the activities of the oversight body, including inspections.

Privatization and Hazard Creep

Scenario Description

Country B is a rapidly industrializing country. It has largely developed its hydropower potential, with 40 large hydropower schemes and over 100 smaller schemes in operation. Many of the dams are more than 30 years old, and areas that were previously rural floodplains have developed into medium-size towns downstream of the dams. In a bid to attract foreign investment, Country B has embarked on a medium-term utility reform program, including the privatization of most of its mature electricity and water supply utilities and their assets. About a third of the hydropower assets and a quarter of the water supply assets have successfully been divested to the private sector.

Legal Underpinnings

Country B has a civil law legal system with a national dam safety law, which prescribes dam safety mandates and appoints the Office of Utilities Regulation, a multisector regulator, to oversee and enforce dam safety regulations.

Institutional Arrangements

The Office of Utilities Regulation is currently mapped under the Ministry of Energy, which also owns most of the hydropower facilities and is in the process of divesting some of the schemes. The office has set up a dam safety unit that regulates both public and private dams, separating its unit from the project planning, implementation, and operation departments.

Technical Requirements

Country B has its own custom dam safety standards, which are over a decade old. Its design and review standards are deterministic.

Financial Considerations

The budget for the oversight body is included with the budget for the Ministry of Energy. The ministry also allocates resources to the department responsible for the project planning, implementation, and O&M of dams. Limited resources are made available for ministry and oversight body staff training.

Using the Decision Framework

Country B has a large portfolio of dams, both large and small. With the divestment program, the portfolio is transitioning from one comprising mostly publicly owned dams to one comprising mostly privately owned dams. As development has taken place in the downstream areas, the potential consequences of dam failure have increased significantly from the time when the dams were originally built.

Legal Underpinnings

The national dam safety law should define the roles and responsibility for dam safety between dam owners and the regulator. The legislation must be highly prescribed. Compliance enforcement is critical. Increased compliance can be achieved with stronger penalties, including fines, revocation of licenses, and so forth by clearly stipulating terms in regulations and/or concession agreements.

Institutional Arrangements

The government should make the dam safety unit independent in, or locate it separately from, the Office of Utilities Regulation. It should be fully empowered with sufficient financial and human capacity. An external experts commission could be established to review high-hazard cases. Its reports should be publicly available, providing transparency around the performance of dam owners and operators as well as the oversight body.

Technical Requirements

The dam safety review standards should incorporate risk-informed decision-making including PRA/PRM for a large portfolio of dams and also risk analysis, such as potential failure mode analysis, for high-hazard cases. Such an approach may be mandated in the regulations, licenses, concession agreements, and so forth as suitable. Owner record keeping and periodic reporting to the regulator should also be mandated.

Financial Considerations

To ensure the independence of the Office of Utilities Regulation, it should secure its own budget, possibly including licensing and/or safety review fees from private owners in addition to the budget allocation under the Ministry of Energy. Enough resources should be allocated to the oversight body to maintain the compliance review of owners' dam safety programs, performance, and capacity. Sufficient resources should also be allocated to the part of the ministry that owns the dams for mandated O&M and dam safety requirements. With the number of privately owned dams increasing with the divestment program, the oversight body should seek to transition to a user-pay system. To ensure independence, the oversight body should be insulated from the financial performance of owners and operators: that is, fees should be fixed and not dependent on fluctuating revenues. Financial and other forms of penalties should be carefully reviewed and defined for noncompliance in the case of private dams.

Federal System of Governance

Scenario Description

Country C is a large, populous country with a federal system of governance. The states have significant autonomy and are very powerful compared to the central government. The country has a very diverse resource base and high economic inequality across states. One state in the northern part of the country is richer than the others, with higher human development, thanks to mining and hydropower royalties. This contrasts with the largest state in the south, which is regarded as the breadbasket of the country and is highly dependent on irrigated agriculture. The remaining states in the country have service- and tourism-based economies, with only a few small dams as part of the water supply system.

Legal Underpinnings

Country C has a common law legal system and is a federation of states where law making and administration are possible for dams and their safety only at the state or provincial level, and national involvement is limited to encouragement or incentives to the states to develop uniform dam safety laws. There exists a national dam safety law, and most states have some form of dam safety legislation, although their adequacy is very uneven. In general, dam safety legislation tends to be strongest in the states with significant private sector involvement, such as in the energy and mining sectors, while the states with agrarian economies have weaker dam safety legislation due to perceived lower risk of smaller dams.

Institutional Arrangements

A federal dam safety agency exists to coordinate and promote dam safety in order to encourage the establishment and maintenance of effective state dam safety programs, but this agency cannot impose binding mandates on the states.

Technical Requirements

The federal dam safety agency currently has a national register of dams, which it produces by collecting inputs from the states. It also has a national dams classification system based on hazard. There are technical guidelines for dam design, review, O&M, instrumentation, and EPPs for federally owned dams, but these are not binding on the states for dams owned by the states or the private sector.

Financial Considerations

The federal dam safety agency is funded entirely from intragovernmental transfers from the federal government. It has a specific budget line item for its overhead costs as well as O&M of federally owned infrastructure and the maintenance of the national dam safety register. The state governments have also allocated budget for dam safety assurance programs at the state level.

Using the Decision Framework

Country C has a large portfolio of dams, but at the state level, the portfolios are differentiated by purpose, size, and risk/hazard classification. While some states have robust dam safety assurance regimes, others do not. The federal government is, however, limited by the constitution to impose dam safety mandates on the states. Country C must, therefore, consider what tools are at its disposal to encourage, improve, and promote uniform dam safety regulation.

Legal Underpinnings

While the federal dam safety agency cannot bind the states with its own technical mandates, the federal government can offer incentives to the states to develop consistent dam safety legislation, which covers the key aspects laid out in the mandates for federally owned dams. The federal government may consider legislating a new dam safety law to ensure enhanced coordination and consistency in dam safety regulations between different states, and in particular for dams on rivers that cross states.

Institutional Arrangements

The federal dam safety agency should seek to establish close relationships with the states, providing advice and review of their dam safety assurance regimes. It can also develop specific training programs for dam owners and public outreach programs for communities that aim to increase public awareness of dam safety risks. It can also provide guidance and encouragement by disseminating informational materials to educators and the press as well as by offering courses and seminars on dam safety to organizations and universities.

Technical Requirements

The federal dam safety agency may consider broadening its technical guidelines to be used as a nonbinding resource for the states. The federal government should periodically review the consistency in dam safety regulation under different states and ensure adequate coordination, in particular for operation of dams in interstate rivers.

Financial Considerations

The federal government can establish a program of financial incentives to promote uniformity of dam safety regulation and to improve its effectiveness in the states. This could be in the form of grants for states to help them implement mandates consistent with those at the federal level. Resources would also need to be allocated for the other activities to promote appropriate dam safety measures. The central government can also provide fee-based advisory services to states.

Transboundary Basin

Scenario Description

Country D's eastern border is formed by a major transboundary river, shared with four other riparian countries. The country has plans to construct several large, multipurpose dams on one of the main tributaries of the transboundary river in its national borders. The dams are to be government owned but operated and maintained by a private operator. The other riparian countries have similar development plans, and there exists one large dam for flood protection and irrigation on the main stem downstream in a neighboring country. A nascent river basin organization was established a decade ago with the purpose of coordinating development in the basin. There are also early discussions of creating a regional power pool.

Legal Underpinnings

Country D has a common law legal system. There is no dedicated dam safety legislation and no apex regulator for dam safety. There are dam safety provisions in the existing Water Act, which empowers the Water Resources Development Department in the Water Ministry to oversee the safety of dams.

Institutional Arrangements

The Water Resources Development Department has a small complement of staff, all based in the capital city, with the requisite training to oversee safety of the existing small, privately owned dams in the country.

Technical Requirements

Country D has its own custom guidelines for the safety of small dams but relies on external guidance for the safety of large dams.

Financial Considerations

The Water Resources Development Department is fully funded through general budgetary allocations to the Water Ministry. The department charges a small fee for inspections, but these fees do not come close to covering the costs associated with its dam safety oversight function.

Using the Decision Framework

In the absence of a strong river basin organization, Country D and the other riparian countries in the basin have, until this point, taken a unilateral approach to managing and developing their water resources. The riparian countries do, however, share a number of international water law principles, and currently there is a good-faith agreement to eventually move toward a basin coordination approach for future water resources development, with the river basin organization responsible for collective planning and management of water resources. While all the dams in the basin are wholly in national borders, the intention is to ensure that all the riparian countries' interests are represented in the basin development plans, regional benefits are optimized, and shared risks are mitigated. The river basin organization currently lacks the capacity and authority to act as an implementer of dam projects in the basin, so it is focused on strengthening interstate cooperation and supporting dialogue around dam safety in the transboundary context.

Legal Underpinnings

Country D and the other riparian countries share a similar colonial history and, as a result, have similar legal systems and institutional structures. The status of dam safety regulation is, however, heterogenous due to variations in the composition of each country's dam portfolio. While for Country D, there is no dedicated dam safety legislation, the Water Act regulates dam safety for all dams except for tailings dams. In some of the other riparian countries, dam safety is regulated at the sector level, with different mandates and empowered authorities for different sectors. Country D, given its development plans, should consider passing dedicated dam safety legislation. It should also work with the river basin organization to encourage harmonization of dam safety regulation to the extent possible with the other riparian countries.

Institutional Arrangements

Country D should consider the creation of an apex regulator, which is fully empowered, given the intention of developing several large, high-risk dams in the basin and the potential involvement of private concessionaires. It also needs to raise the technical and legal capacity of experts and officials on dam safety issues.

At the basin level, the riparian countries should seek to increase their dialogue on dam safety and consider the establishment of a regional dam safety center, under the auspices of the river basin organization. This center could host trainings and exchanges to foster shared understanding of dam safety issues among the countries, improve capacity at the national level to manage safety issues, and facilitate cooperation among national dam safety authorities.

Technical Requirements

With the shifts in the portfolio composition of Country D, there is a need for a greater level of surveillance, enhanced instrumentation, and greater requirements in terms of emergency preparedness. Consideration should be given to the development of custom dam safety guidelines for large dams, which take into consideration the specific country and transboundary basin context.

At the basin level, the riparian countries should consider developing dam operation rules and emergency procedures in a collaborative way. Specifically, they should look at co-developing warning procedures, flood management initiatives, and agreements on flow regimes.

Financial Considerations

The riparian countries will have to agree on a sustainable financing regime for transboundary dam safety management. This should be accomplished through transferring resources and financial autonomy to the dam safety center or by national dam safety authorities working on their own national budgets toward a shared program.

NOTES

1. See chapter 5 of *Laying the Foundations* and ICOLD (2018b) Bulletin 170 for a comprehensive consideration of dam classification systems and hydrological safety requirements.
2. Design flood criteria can differ from one country to another, and the magnitude of the selected design flood can vary significantly, depending on the perception and acceptance of societal risks, the prevailing socioeconomic and environmental context and public policy priorities of government, as well as technical aspects, such as adequacy and reliability of hydrometeorological data, among other considerations. In most instances, the design flood is selected on the basis of the dam classification system, which helps to secure a consistent safety level against floods and potential overtopping risk. For more detailed information, see ICOLD (2018b) Bulletin 170, which provides information and recommendations on hydrological assessment techniques, including on coping with uncertainties and determination of design floods and risk analyses.
3. Inspection types typically include routine, periodic, and formal inspections. Routine inspections are frequent visual observations that generally include a combination of continuous daily, weekly, monthly, and/or annual observations, while periodic inspections are usually every two or three years and include summaries of monitoring results, checks and tests, and so forth or for special requirements. Formal inspections, or dam safety reviews, are generally undertaken every 5 or 10 years, or on special request, and include detailed inspections and investigations as needed. The frequency of inspected items would also differ depending on their criticalness to dam safety and other considerations. Checking and testing of hydromechanical equipment, such as spillway gates and bottom outlets, are also important for dams, particularly those with gated spillways. This Decision Support Tool suggests only an indicative, generic frequency for routine and formal inspections. For more detailed information, see ICOLD (2009) Bulletin 138, "Basic Elements in a 'Dam Safety' Process," and ICOLD (2018a) Bulletin 158, "Dam Surveillance Guide."
4. The return period of the design flood for small dams is typically lower than that of large dams due to the fact that small dams with height between 2.5 and 15 meters and with $H^2 \cdot \sqrt{V} < 200$ (i.e., hydraulic force / impacts in case of dam failure are generally smaller than that of large dams) basically correspond to Potential Hazard Classification Zones I and II, warranting up to a 1,000-years or higher return period for design flood as per ICOLD (2016) Bulletin 157 on "Small Dams." This is not to imply that the life of a person living downstream of a large high-risk/high-hazard dam is valued any differently than the life of a person living downstream of a similar high-risk/high-hazard small dam.

5. See, for example, ICOLD European Club 2012; CDA 2011; and TVA n.d.
6. Hazard creep is caused by changes in a catchment that may result in changes to the hazard potential classification for a dam. For example, new development in the inundation zone downstream of a dam, or upstream development or landcover changes that increase runoff from floods, can result in higher potential consequences if the dam were to fail or release water in an uncontrolled manner.
7. The return period of the design flood for small dams is typically lower than that of large dams due to the fact that small dams with height between 2.5 and 15 meters and with $H^2 \cdot \sqrt{V} < 200$ (i.e., hydraulic force / impacts in case of dam failure are generally smaller than that of large dams) basically correspond to Potential Hazard Classification Zones I and II, warranting up to a 1,000 years or higher return period for design flood as per ICOLD (2016) Bulletin 157 on "Small Dams." This is not to imply that the life of a person living downstream of a large high-risk/high-hazard dam is valued any differently than the life of a person living downstream of a similar high-risk/high-hazard small dam.
8. See, for example, ICOLD European Club 2012; CDA 2011; and TVA n.d.
9. The return period of the design flood for small dams is typically lower than that of large dams due to the fact that small dams with height between 2.5 and 15 meters and with $H^2 \cdot \sqrt{V} < 200$ (i.e., hydraulic force / impacts in case of dam failure are generally smaller than that of large dams) basically correspond to Potential Hazard Classification Zones I and II, warranting up to a 1,000 years or higher return period for design flood as per ICOLD (2016) Bulletin 157 on "Small Dams." This is not to imply that the life of a person living downstream of a large high-risk/high-hazard dam is valued any differently than the life of a person living downstream of a similar high-risk/high-hazard small dam.
10. See, for example, ICOLD European Club 2012; CDA 2011; and TVA n.d.
11. The return period of the design flood for small dams is typically lower than that of large dams due to the fact that small dams with height between 2.5 and 15 meters and with $H^2 \cdot \sqrt{V} < 200$ (i.e., hydraulic force / impacts in case of dam failure are generally smaller than that of large dams) basically correspond to Potential Hazard Classification Zones I and II, warranting up to a 1,000 years or higher return period for design flood as per ICOLD (2016) Bulletin 157 on "Small Dams." This is not to imply that the life of a person living downstream of a large high-risk/high-hazard dam is valued any differently than the life of a person living downstream of a similar high-risk/high-hazard small dam.
12. See, for example, ICOLD European Club 2012; CDA 2011; and TVA n.d.

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Glossary

act. A statutory law passed by a legislative body, usually the parliament of a jurisdiction.

annual exceedance probability. The probability of a specified magnitude of an event being equaled or exceeded in any year.

As Low As Reasonably Practicable. Principle stating how far a residual risk shall be reduced, where additional risk reduction would be impractical or if its cost is grossly disproportionate to the risk-reduction benefit achieved.

assurance for dam safety. Assuring the community through some form of regulatory framework that dams are being managed to acceptable standards of safety.

basin country unit. The portion of a country within a particular river basin.

benchmarking. A process of measuring performance of an entity's activities, products, systems, or processes against those of another entity considered to be the best in the industry or field.

cascade (or cumulative) failure. The sequential failure of multiple dams within the same catchment basin triggered by the same event.

case law. Principles of law that arise from judicial decisions and that establishes precedent for future decisions. Also referred to as common law and provides a common contextual background for certain legal concepts, and how they are applied in certain types of cases.

catchment. The area from which all the water drains naturally into one stream or other body of water.

civil law legal system. Civil law systems rely on written statutes and other legal codes that are highly prescriptive and constantly updated and that establish legal procedures, punishments, and what can and cannot be brought before a court. In a civil law system, judgments do not establish precedent for future decisions as in common law systems: a judge merely establishes the facts of a case and applies remedies found in the codified law. As a result, lawmakers, scholars, and legal experts hold much more influence over the way the legal system is administered than judges.

code. Compilation of all safety-related legal requirements and regulations into a single source, referring to the design, construction, and operation of dams and reservoirs and also to the protection of a population.

command-and-control regulation. The process whereby an industry or activity is governed by legislation underpinned by policy objectives that states, and by an authority that enforces, what is permitted, the standard to which it is permitted, and what is illegal; encompasses a variety of methods, controlling behavior through laws, threats, penalties, contracts, and agreements.

common law legal system. Common law systems rely primarily on case law and the concept of judicial precedent. Judges take an active role in shaping the law in such systems, since the decisions a court makes are then used as a precedent for future cases. While common law systems have statute laws that are created by legislators, it is up to judges to rely on precedents set by previous courts to interpret those laws and apply them to individual cases. In general, a parliament can pass any statutory law to override the common law. In certain common law countries, courts (e.g., the Supreme Court of the United States and the High Court of Australia) have the ability to strike down laws that were passed by legislators if those laws are deemed unconstitutional and in violation of federal law. By contrast, in the United Kingdom, the concept of parliamentary sovereignty means that legislation can be amended or revoked only by Parliament, not the courts.

consequence. Impacts downstream of a dam, or other areas, caused by a partial or complete failure of the dam or its appurtenances or resulting from mis-operation and an uncontrolled reservoir water release. In relation to risk analysis, it represents the outcome or impact of a failure event.

customary law. The long-established system of customs or practices (standards of community) of a particular place or locale that the general law regards as a lawful practice based on the accepted and expected conduct in a community, profession, or trade.

dam. An artificial barrier that can impound water or any liquid-borne material for the purpose of storage or control.

dam failure. The uncontrolled release of water, sediment, or other stored contents of a reservoir through partial or complete collapse of the impounding dam, or the inability of a dam to fulfill the intended design purposes.

dam operator. Any person, organization, or legal entity that is responsible for the control, operation, and maintenance of the dam and/or reservoir and the appurtenant works.

dam owner. Any person, organization, or entity legally deemed to be the owner and/or responsible entity of the dam.

dam portfolio. All of the dams that fall under the responsibility of a single owner or single regulatory regime, or are located within a specific jurisdiction.

dam safety. Variously defined, often depending on the country context, but considered the art and science of ensuring the integrity and viability of dams such that they do not present unacceptable risks to the public, property, and the environment. The safety of a dam manifests itself in being free of any conditions or developments that could lead to its deterioration or destruction. The margin that separates the actual conditions of a dam, or the conditions it is designed for, from those leading to its damage or destruction is a measure of its safety.

dam safety management. The systematic application of management policies, procedures, and practices to the tasks of identifying, analyzing, assessing, mitigating, and monitoring dam safety. Managing the safety of a dam includes managing its design, construction, operation, maintenance, surveillance, review, emergency preparedness, and decommissioning.

decommissioned dam. A dam that has been taken out of service, partially or completely dismantled in order to make it safe or allow ecosystem restoration, due to safety issues, the filling of its reservoir with sediment, or its original purpose no longer being needed.

deterministic. A process with an outcome that is always the same for a given set of inputs, hence, the outcome is determined by the input.

East Asia and Pacific. Refers to World Bank Region for East Asia and the Pacific. Countries can be found at https://www.worldbank.org/en/region/eap.

efficiency. Relates to reducing risks at the lowest cost.

emergency. Any condition that develops unexpectedly; endangers the integrity of the dam or downstream life, property, or the environment; and requires immediate and coordinated action.

enabling legislation. Provisions incorporated in an existing or new broader framework law (such as that for water, environmental, or other related laws), to enable the control or regulation of dam safety management.

The incorporated provisions look to define and distribute the different roles and responsibilities needed to ensure the safety of dams.

equity. Related to providing a certain level of protection to people and environments fairly and evenly.

Europe and Central Asia. Refers to World Bank Region for Europe and Central Asia. Countries can be found at https://www.worldbank.org/en/region/eca.

event. Something that happens or takes place with implications for the safety of a dam.

exposure. The extent to which population, infrastructure, and other assets or valued elements in an area are subject to impacts from hazardous events, such as dam failure.

factors of safety. Expresses how much greater the resisting capacity of a structure or component is relative to an assumed maximum design load.

failure mode/scenario. A way that failure can occur, defined by the means by which element or component failures occur to cause loss of the subsystem or system function.

F-N curve. A curve that shows the cumulative risk posed by all failure modes and the associated potential loss of life. It relates F (the probability per year of causing N or more fatalities) on a y axis to N (estimated number of fatalities) on an x axis. This is the complementary cumulative distribution function. Such curves may be used to express societal risk-to-life criteria and to describe the safety levels of particular facilities, such as a dam.

f-N curve. A curve that shows the cumulative risk posed by individual failure modes and the associated potential loss of life. It relates f (the annualized probability of the failure) on a y axis to N (estimated number of fatalities) on an x axis. An f-N plot may be used for both societal (impacting society as a whole) and individual risk (impacting the most exposed individual subjected to dam breach flows).

full supply level. The maximum normal operating water surface level of a reservoir when not affected by floods.

function. An activity that is natural to or the purpose of a person or thing.

funding. Financial resources provided either by (1) a dam owner to pay for necessary upgrades, maintenance, rehabilitation, and so forth, or (2) an organization or government for the particular purpose of resourcing institutions and actors in developing, implementing, and monitoring adherence to dam safety requirements and guidelines.

governance. The process through which state and nonstate actors interact to design and implement policies within a given set of formal and informal rules that shape, and are shaped by, power.

greenfield. Denoting or relating to previously undeveloped sites for development.

guidelines. A practical advisory and/or reference document providing a set of general principles, technical procedures, good practices, and recommendations to promote a common approach to dam safety management, covering various phases of dam design, construction, and operational and maintenance phases. In general, this document should not be regarded as a standard but rather interpreted by qualified and experienced professionals considering circumstances surrounding the dams.

hazard. A source of potential harm or a situation with the potential to cause loss; a threat or condition may result from either an external cause (for example, earthquake, flood, or human agency) or an internal vulnerability, with the potential to initiate a failure mode. In dam safety, hazard is often seen as a measure of the consequences of dam failure. The terms *hazard* and *consequence* are used in the same manner, as the potential losses in the downstream area of the dam in the event of dam failure or mis-operation and resulting uncontrolled release of flood waters.

hazard creep. Hazard creep is caused by changes in a catchment that may result in changes to the hazard potential classification for a dam. For example, new development in the inundation zone downstream of a dam, or upstream development or landcover changes that increase runoff from floods, can result in higher potential consequences if the dam were to fail or release water in an uncontrolled manner.

hazard potential category or hazard consequence category. The scale of adverse consequences subsequent to a dam failure.

height of the dam. Normally the maximum height from the lowest point of the mean foundation level to the top of the dam (but noting that some legislation takes the lowest point along the downstream toe).

high-hazard/high-consequence dam. Scale that is given to different hazard potential/consequence categories. See also *hazard potential category*. High-hazard/high-consequence dams will commonly have potential to cause considerable life loss and property and/or environmental damage at failure.

high-income country. Defined using the World Bank Atlas method as those with a gross national income (GNI) per capita of US$12,536 or more in 2019. See https://datahelpdesk.worldbank.org/knowledgebase/articles/906519.

high risk. When the probability of a hazard or consequence materializing is categorized as high, or where the product of the probability of dam failure and the subsequent consequence or hazard is high.

incident. An event that could deteriorate to a very serious situation or endanger the dam, or an event that would cause harm or damage to downstream people, property, or the environment due to mis-operation.

incremental risk. The increment of risk imposed on a particular individual by the existence of a hazardous facility including a dam. This increment of risk is an addition to the baseline risk to life, which the person would live with on a daily basis if the facility did not exist.

individual risk. The risk of death (or serious injury) to which specific individuals are exposed. The increment of risk imposed on any individual by a hazardous facility, including a dam, should not be more than a specified value, usually a small fraction of the average background risk that the population lives with on a daily basis. This requirement arises from considerations of equity.

inspecting engineer. A suitably trained engineer recognized under dam safety laws to competently inspect and assess an aspect of a dam in, for example, statutory periodic inspections, dam safety reviews, and so forth.

inspection. A careful and critical observation and examination of all visible aspects of a dam, searching for abnormal visible phenomena on the surface and inside of the dam. There are generally several levels of inspection: from routine inspections undertaken by on-site operators to specialized inspections undertaken by experienced dam engineers. Inspection leads to qualitative knowledge about the visible part of the dam.

institution. Consistent organization, group, rule, or foundations for rules created to pursue a particular type of endeavor, such as water resource management or dam safety.

instrumentation. An arrangement of monitoring instruments or devices installed into dams or surrounding areas, possibly including the slopes of abutments and reservoir rims, that provide for measurements that can be used to evaluate the structural behavior as well as load and performance parameters of the structure and surrounding areas.

large dam. Typically defined as dams with either (1) a height of 15 meters or greater from the lowest foundation to the crest or (2) between 5 and 15 meters in height impounding more than 3 million cubic meters, but can vary between countries and can be uniquely defined under legislation.

Latin America and the Caribbean. Refers to World Bank Region for Latin America and the Caribbean. Countries can be found at https://www.worldbank.org/en/region/lac.

life safety. Consideration to loss of life with regard to the safety and potential failure of a dam.

limit of tolerability. The limit of the tolerable risk range; see *tolerable risk*.

load. Amount of energy delivered or required at a given point; forces, weights, pressures, or accelerations applied to structures that would cause stresses, deformations, and displacements in structures.

load factor. The ratio of an average load to the maximum load.

low-hazard/low-consequence dam. Scale that is given to different hazard potential/hazard consequence categories. See also *hazard potential category*. Low-hazard/low-consequence dams commonly have no potential to cause life loss but may have potential to cause property and/or environmental damage.

low-income country. Defined using the World Bank Atlas method as those with a GNI per capita of US$1,035 or less in 2019. See https://datahelpdesk.worldbank.org/knowledgebase/articles/906519.

lower-middle-income country. Defined using the World Bank Atlas method as those with a GNI per capita between US$1,036 and US$4,045 in 2019. See https://datahelpdesk.worldbank.org/knowledgebase/articles/906519.

maintenance. The routine work required to maintain existing facilities and systems (civil engineering structures, hydraulics, mechanical and electrical equipment, and so forth) in a safe and reliable working condition to fulfill the intended designed purposes with routine or regular checking, testing, and repair works.

mandates. Requirements under law; requirements that are legally enforceable.

market-driven regulation. The process whereby an industry or activity is governed indirectly through instruments that influence actors' behavior by linking it to market forces, such as economic incentives or need for legitimacy, rather than controlled through explicit directives.

maximum credible earthquake. The largest hypothetical earthquake that may reasonably be expected to occur along a given fault or other seismic source that is identified by deterministic seismic hazard assessment.

medium-hazard/medium-consequence dam. Scale that is given to different hazard potential/hazard consequence categories. See also *hazard potential category*. Medium- or significant-hazard or signficant-consequence dams may commonly have potential to cause life loss but will have considerable potential to cause property and/or environmental damage.

Middle East and North Africa. Refers to World Bank Region for the Middle East and North Africa. Countries can be found at https://www.worldbank.org/en/region/mena.

mis-operation. Incorrect operation of the dam resulting in an uncontrolled release of water, due to not following proper operational procedures for hydraulic facilities and/or providing required notification or warning to downstream or other areas, possibly causing casualties and damage.

monitoring. The observing of measuring instruments and devices that can provide quantitative data of physical parameters (for example, displacements, strains, water pressure, and leakage) that indicate the performance and behavioral trends of a dam and appurtenant structures, either on its surface or inside its body, as well as the recording and review of such data in order to detect any deficiencies in the dam behavior.

multipurpose dam. A dam designed for two or more purposes, such as irrigation, hydropower generation, flood control, municipal and industrial water supply, recreation, and fish and wildlife benefits, in any combination; contrast to single-purpose dams that serve only one purpose.

operation and maintenance. The operation, maintenance, repairs, replacements, testing, and exercising of any or all portions of the dam's structure and appurtenant facilities for the life of the system that are required to ensure facilities and systems are in a safe and reliable working condition to fulfill the intended purposes.

organization. An entity, institution, or association comprising one or more people and having a particular purpose.

population at risk. Number of persons directly exposed to floodwaters within the dam break–affected zone if they took no action to evacuate.

portfolio risk assessment. A particular form of risk assessment or analysis that aims to make a comparative estimation of risks over all, or many, of the dams of a single owner or single regulatory or other jurisdiction.

portfolio risk management. Managing all of, or many of, the dams of a single owner or single regulatory or other jurisdiction by prioritizing the dams that would warrant interventions and effective remedies in an optimal manner based on a particular form of risk assessment or analysis.

potential consequences/hazard classification. Classification of a dam according to its potential consequences as a result of a dam failure; the consequence/hazard classification of a dam can change over time (see *hazard creep*).

potential failure mode. Any one of a number of mechanisms or set of circumstances that could result in a dam failure or uncontrolled release of a large amount of water.

potential failure mode analysis. A process to systematically identify, describe, and evaluate ways a dam and its appurtenant structures could fail or cause uncontrolled release of a large amount of water.

potential loss of life. A subset of *population at risk* considering a fatality rate and the number of fatalities that would be highly likely due to a dam failure or mis-operation, even if people take action to evacuate.

powers. The ability or capacity to do something or act in a particular way.

probability. A measure of the likelihood that a specific event, outcome, or consequence will occur.

probable maximum flood. The largest theoretical flood that may occur at a given point resulting from the most severe combination of critical meteorological and hydrological conditions reasonably possible in a particular catchment.

probable maximum precipitation. The largest theoretical depth of precipitation for a given duration that is physically possible over a given storm area at a particular geographical location at a certain time of the year.

public safety. Protection of the welfare of the general public. Public safety considerations include potential dangers resulting from mis-operations, such as sudden increases in turbine discharge or the opening of spillway gates without proper downstream or other notifications. There are also broader public safety considerations associated with dam operations and emerging issues of security that go beyond dam safety, which is primarily concerned with avoiding dam failure.

qualitative risk analysis. An analysis using descriptive or numeric rating scales to describe the system failure likelihood and the magnitude of the subsequent consequences, considering all potential scenarios leading to dam failure or uncontrolled release of water.

quantitative risk analysis. An analysis based on numerical values of the probability of a series of system failure events and the magnitude of subsequent consequences, considering all potential scenarios leading to dam failure or uncontrolled release of water.

regulation. Written law passed by the executive arm of government under the authority of a statutory law or act that has been passed by the legislative arm of government.

regulator. The authority that administers the relevant act that controls any aspect of dam safety.

regulatory framework. The structure behind regulations describing the interaction between the regulatory instrument (for example, legislation, regulations, codes, industry standards, guidelines, or even self-regulatory documents) and the expected roles and responsibilities of the regulator and the person or entity being regulated.

regulatory mix. The use of multiple, complementary regulatory instruments in a framework (rather than a single-instrument approach), maintaining the minimum number of instruments necessary to achieve the desired result.

religious law. Religious law emanates from the sacred texts of religious traditions. Religious legal systems are systems in which the law emanates from texts or traditions in a given religious tradition. Religious laws generally are used in countries that also have other legal systems, such as civil or common law.

requirements relating to dam safety. Required minimum criteria and procedures that need to be followed regarding dam registration, licensing, construction permission, safety regulation, investigation, design, operation and maintenance, surveillance, inspection, and so forth.

reservoir. An artificial lake, pond, or basin created by the concrete or embankment structures of a dam for storage, regulation, and control of water.

reservoir capacity. The total storage capacity of the reservoir at full supply level or surcharge water level.

residual risk. The amount of risk or danger associated with an action or event remaining after natural or inherent risks have been reduced by mitigation measures.

resilience. The capacity of dam safety systems to absorb, accommodate, and adapt to hazards and threats beyond the design criteria, thus preserving the critical core systems for maintaining the overall structural safety of the dam and its water storage and control functions.

responsibility. A duty that one is required to do as part of a job, role, or legal obligation. For dam safety, it refers to the care and consideration that needs to be given to ensure that a dam is kept in safe condition. This includes the accountability of the person or group of persons that are responsible for the safety of the dam throughout its life and, most important, for maintaining it in proper condition during the operation phase to meet the needs that fit its purpose, whether it is water supply, irrigation, energy production, flood protection, or a combination of these. A clear statement of primary responsibility for the safety of the dam is a key element of any legal framework for dam safety.

risk. Measure of the likelihood or probability and severity of an adverse consequence or impact to life, health, property, or the environment. In a general case, risk is estimated by the combined impact of scenario, probability of occurrence, and the associated consequence. In a special case, average risk is estimated by the mathematical expectation of the consequences of an adverse event occurring (that is, the product of the probability of occurrence and the consequence, combined over all scenarios).

risk analysis. Used to identify potential failure modes, structural performance, and adverse consequences of dams using qualitative or quantitative procedures, and estimate the risk, that is, combination of likelihood of concurrence and magnitude of consequences.

risk assessment. Used to examine the safety of dams, evaluating the results of risk analysis along with relevant social, environmental, economic, and other factors, and make recommendations on risk-reduction measures as needed, including additional investigations and enhanced monitoring.

risk-based approach. Uses the outcomes of a risk assessment as the basis for decision-making.

risk index. A basic qualitative risk analysis tool for preliminary risk screening of a portfolio of dams. The risk index is not a measure of risk but a relative indication of potential level of risk.

risk-informed approach or risk-informed decision-making. Uses the outcomes of a risk assessment as one of the important factors to support decision-making, along with other factors such as risk uncertainty, deterministic analyses, and other local and/or regional considerations.

risk management. The systematic application of management policies, procedures, and practices to the tasks of identifying, analyzing, assessing, mitigating, controlling, and monitoring risk.

roles. The function assumed, or part played, by a person, object, or institution in a particular situation.

safety review. A procedure for assessing the safety of a dam, comprising a detailed examination of structural, hydraulic, hydrological, and geotechnical design aspects and of all relevant design, construction, and surveillance records and reports to assess the integrity of a dam.

self-enforced regulation. The process whereby an industry or activity is governed by its own adherence to legal, ethical, or safety standards, rather than having an outside, independent agency such as a third party or governmental regulator monitor and enforce those standards.

significant-hazard/significant-consequence dam. Scale that is given to different hazard potential/hazard consequence categories. See also *hazard potential category*. Significant/medium hazard/consequence dams may commonly have potential to cause life loss but will have considerable potential to cause property and/or environmental damage.

small dam. Typically defined as any retention structure that is not defined as a large dam, but can vary among countries and can be uniquely defined under legislation.

so far as is reasonably practicable. Principle stating how the residual risk shall be reduced, by which the dam owner must consider everything possible that can be done to reduce all foreseeable risk and ensure safety, and whether it is reasonably practicable in the circumstances to do whatever is possible based on an assessment of the safety benefits against the costs. The test being that a safety measure should be implemented unless the cost of doing so is so grossly disproportionate to the benefit that it would be clearly unreasonable to justify the expenditure.

societal risk. The risk of widespread or large-scale detriment to societies from the realization of a defined hazard; the estimated probability of an event that would be expected to result in loss of N (number of fatalities). The societal risk rating is then determined by multiplication of the estimated annual probability of failure of a dam (f-N) with the best estimate loss of life ≥ N where N is the estimated number of fatalities due to dam failure. This requirement arises in order to account for the impact on society of disasters involving multiple fatalities and is based in the need for equity in accounting for societal concerns.

South Asia. Refers to World Bank Region for South Asia. Countries can be found at https://www.worldbank.org/en/region/sar.

specific legislation. Refers to a dedicated act or statute pertaining solely to dam safety, in which case mandates are mostly prescribed.

spillway. A weir, channel, conduit, tunnel, gate, or other hydraulic structure designed to permit discharges from the reservoir normally, under flood conditions or in anticipation of floods in a manner that controls the discharge amount and reservoir water level, and protects the structural integrity of the dam by preventing the rise of the reservoir water above the design flood level.

standards. Established rules and norms required by laws and/or regulations, and also recommendations by guidelines. In particular, design standards cover technical requirements and procedures to enable preparation of designs, documents, and reports related to design, construction, and operation and maintenance of dams. Sometimes standards refer to more detailed design criteria pertaining to design for event and load structural capacity, safety coefficients, defensive design measures, and so forth.

standards-based approach. The traditional approach to dams engineering, in which risks are controlled by following established rules as to design events and loads, structural capacity, safety coefficients, and defensive design measures.

statute law. The body of principles and rules of law laid down in statutes or acts. A statute law is a written law produced by parliament as a matter of public policy. It is the highest type of law, which passes acts to the houses of parliament, which debate whether the act should exist or not. Statute law plays a part in both civil law and common law systems. In common law systems, statute law will override common law if that is the clear intent of the statute (statute law supremacy).

Sub-Saharan Africa. Refers to World Bank Region for Sub-Saharan Africa. Countries can be found at https://www.worldbank.org/en/region/afr.

supervising engineer. A suitably trained engineer recognized under dam safety laws to competently supervise all or specific aspects of a dam's design and construction or ongoing management.

surcharge water level. The maximum water elevation for flood control by which incoming flood water is stored to reduce flood discharge to downstream rivers.

surveillance. The continuing examination of the condition of a dam and its appurtenant structures aimed at managing risk and reducing the probability of occurrence by providing a means of early identification of any phenomena that can compromise the structural and operating integrity of the structure or its related operating equipment, including monitoring instrumentation, data interpretation, routine supervision, visual observation or inspection, tests of safety related hydromechanical equipment, periodic audit, and dam safety review.

threat. Event that might cause damage or danger to the safety of a dam.

toe of the dam. The junction of the downstream (or upstream) face of a dam with the ground surface (foundation). Similarly, the *heel* of a dam is the upstream junction of a dam with the ground surface.

tolerable risk. A level of risk within a range considered acceptable to society so as to secure certain net benefits; a range of risk that is not regarded as negligible or ignorable, but rather as something that needs to be kept under review and reduced still if and as is practicable.

transboundary dam. A dam having a potential effect across any jurisdictional boundary, including local district, region, state, national, and international boundaries. Note that the International Commission on Large Dams attributes international character to a dam only when the abutments of the dam infrastructure lie in different countries.

upper-middle-income country. Defined using the World Bank Atlas method as those with a GNI per capita between US$4,046 and US$12,535 in 2019. See https://datahelpdesk.worldbank.org/knowledgebase/articles/906519.

upstream events. Events occurring in the upstream of dams that could affect the safety of dams, such as landslides, debris flow, glacial lake outburst flood, and so forth.

user pays. A funding approach based on the idea that the most efficient allocation of financial resources occurs when dam owners pay the cost of regulation via fees, charges, and so forth. Also referred to as *beneficiary pays*.

vulnerability. The level or degree of exposure of structures or areas to being adversely affected by potential hazards due to their locations, conditions, and other relevant factors.

watershed. An area or ridge of land that separates waters flowing to different rivers or basins.

ECO-AUDIT

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green press INITIATIVE

Laying the Foundations

Dam safety is central to public protection and economic security. However, the world has an aging portfolio of large dams, with growing downstream populations and rapid urbanization placing dual pressures on these important infrastructures to provide increased services and to do it more safely. To meet the challenge, countries need legal and institutional frameworks that are fit for purpose and can ensure the safety of dams. Such frameworks enable dams to provide water supplies to meet domestic and industrial demands, support power generation, improve food security, and bolster resilience to floods and droughts, helping to build safer communities.

Laying the Foundations: A Global Analysis of Regulatory Frameworks for the Safety of Dams and Downstream Communities is a systematic review of dam regimes from a diverse set of 51 countries with varying economic, political, and cultural circumstances. These case studies inform a continuum of legal, institutional, technical, and financial options for sustainable dam safety assurance.

The findings from the comparative analysis will inform decision-makers about the merits of different options for dam safety and help them systematically develop the most effective approaches for the country context. By identifying the essential elements of good practices guided by portfolio characteristics, this tool can help identify gaps in existing legal, institutional, technical, and financial frameworks to enhance the regulatory regime for ensuring the safety of dams and downstream communities.

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