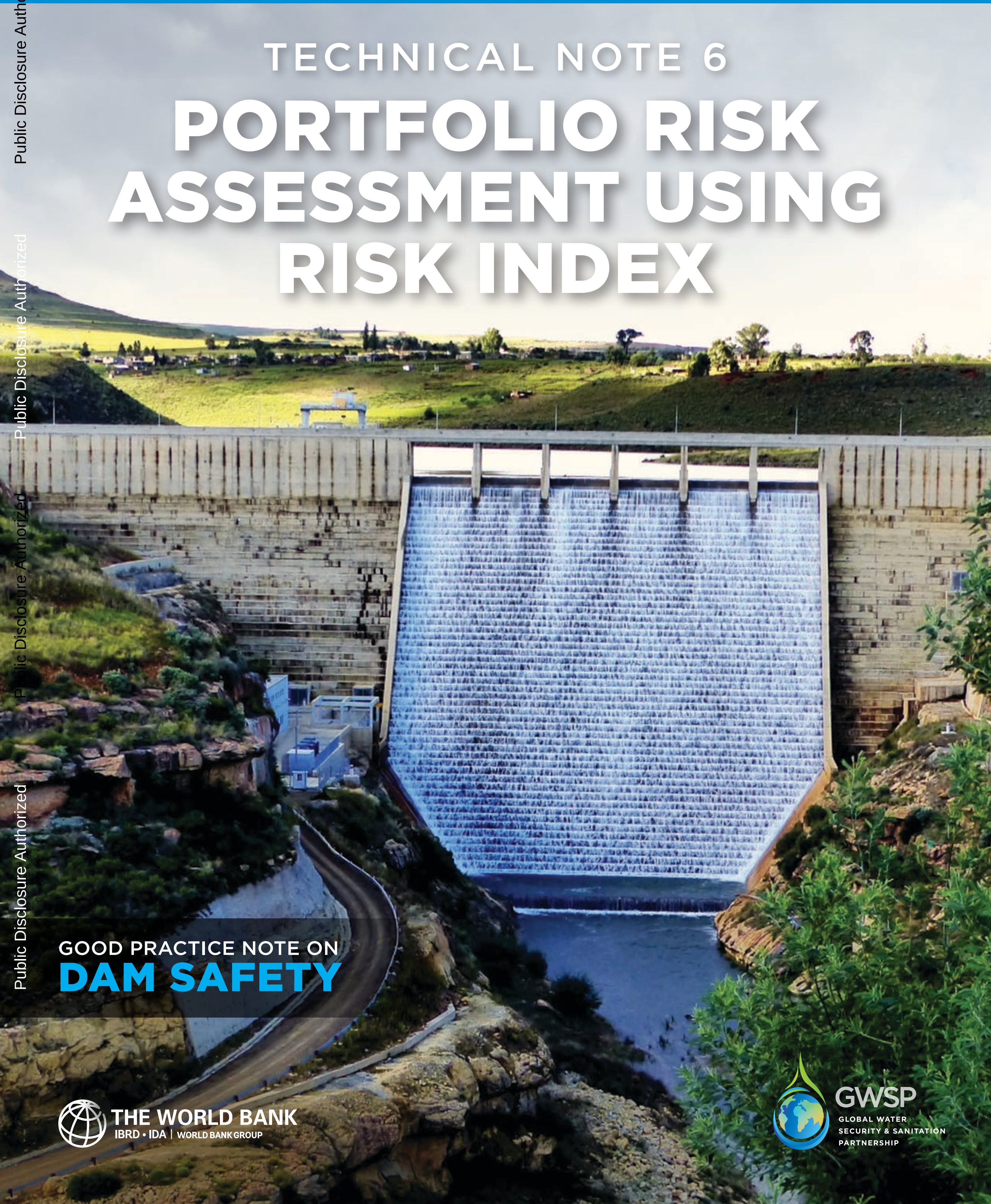
SAFETY OF DAMS AND DOWNSTREAM COMMUNITIES

TECHNICAL NOTE 6

PORTFOLIO RISK ASSESSMENT USING RISK INDEX



GOOD PRACTICE NOTE ON
DAM SAFETY

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Technical Note 6: Portfolio Risk Assessment Using Risk Index

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Introduction

Before the mid 1990s, a few organizations in International Commission on Large Dams (ICOLD) member countries started to practice risk analysis in the context of dam safety programs. Since that time, several methods and frameworks have been introduced into dam safety and risk analysis.

The Risk-Based Profiling System (U.S. Bureau of Reclamation 2000) is one of the qualitative approaches, which is based on the "failure index" concept, that is, load x response associated with hydrological-hydraulic, seismic, and static (normal) conditions. The failure index is multiplied by a loss-of-life factor to characterize the consequences associated with a failure and is called the *risk index* (RI).

RI methods provide a useful way of characterizing dam safety risks in a systematic, qualitative, and relatively simple manner to help evaluate and prioritize safety issues for individual dams and portfolios of dams. The approach strives to describe and communicate the significance of risk by using numbers or categorical values for the purpose of identifying and comparing risks using:

- Color-coded risk matrices
- Additive scoring methods for characterization of failure likelihood.

The RI allows the user to assign points reflecting the significance of risk by following a defined process or series of matrices characterizing some specific aspects of the dam structure, but it does not relate the resulting index to an actual probability of failure. Thus, the process is typically easy to roll out and can also be implemented by individuals with limited understanding of the potential failure modes or risks associated with the dam structure.

The approach presented herein is called a *risk index* because it provides an indication of potential levels of risk that might be associated with a dam failure. This tool is not a measure of risk estimating failure probability, but it provides a relative indication of potential levels of risk. These potential risks are quantified as deficiencies in the current physical state or condition of the dam and are weighted by their overall importance to the safety of the dam and the vulnerability and downstream hazard/consequence potential of the dam.

Several countries have developed similar tools, including Australia, Canada, Czech Republic, New Zealand, Poland, Republic of Korea, South Africa, Sweden, the United Kingdom, and the United States (ICOLD 2005 and Wishart et al 2020).

The World Bank has applied such methods in several national or subnational dam safety projects, such as in Armenia, Indonesia, Sri Lanka, and Vietnam. In these projects, RI was found to be a useful tool to assess the potential risk of portfolios of dams, enabling prioritization of riskier dams and their remedial works by means of both structural and nonstructural measures and comparing pre- and post-project interventions in a programmatic manner.

The World Bank also recently assisted the Central Water Commission (CWC) in India for developing an RI scheme, building on the Brazilian system but adapting it to India's context through a series of expert consultations with CWC and state-level officials. The Excel spreadsheet indexing tool and user manual has been prepared and validated using a series of case studies and examples by multiple groups (Zielinski, et al 2021).

This Technical Note provides detailed information on the Brazilian risk classification system using the RI approach and the Indian RI system for the initial risk screening of a large portfolio of existing dams. Annex A provides basic information about the RI approach used in Quebec, Canada, for its dam classification system.[1] These RIs are used for prioritization of required remedial works and other safety requirements.

It should be noted, however, that RI is also a basic tool for preliminary level risk analyses for portfolios of dams and initial screening of risky dams, which may need to be supplemented by more advanced methods, depending on the type and potential risk of the dams. Because RI largely relies on visual inspection of the dams' conditions, some critical failure modes could be missed. underestimated, or overestimated. In the higher risk cases, or whenever deemed appropriate, more detailed risk analyses, such as potential failure mode analysis (PFMA), can fill some of the gaps.

RI methods should be tailor-made with due consideration to the local context, including the size and makeup of a country's portfolio of dams. A recommended approach is to go through the following three steps:

1 Mozambique has also developed a similar type of existing dam classification system to that of Brazil (Pinheiro et al. 2015).

1. Assign simple preliminary classification, using readily available information

2. Assign scores to a set of appropriate indexes for the specific dam or portfolio of dams

3. Assign weights to each index

Risk Index Method in Three Steps

Step One: Classify Dam Risk

The method described in ICOLD (1989) is based on four parameters of simple quantification even at the early stage of dam safety assessment. It is recommended that such a method be used as the initial step of dam safety risk assessment, as introduced in the main Good Practice Note (GPN). The method described in table 1 allows dams to be assigned a risk class out of four categories: low, moderate, high, and extreme.

For estimating the number of people for evacuation requirements, the number of population at risk (PAR) is estimated by assessing the number of households or people in the inundation areas in the case of dam failure. Then, the PAR can be converted into the potential loss of life by considering the fatality rate. Annex C provides diagrams used by the USBR on fatality rates with and without adequate warning under the Reclamation Consequence Estimating Technology (USBR, 2014). Fatality rates are based on warning time for each group of people at risk and flood severity. The flood severity is calculated as the product of inundation depth and flow velocity, which should be estimated using dam break and flooding simulation.

Step Two: Select Relevant Measures for Indexing Risk

RI methods have evolved since the earliest USBR application, with different entities with dam safety responsibility having adopted their own versions.

TABLE 1. Assigning a Risk Class to Dams

Potential hydraulic force in case of dam failure	Reservoir capacity (million cubic meters)	<0.1	0.1 to 1	1 to 120	>120
	Points	0	2	4	6
	Dam height (meters)	<15	15 to 30	30 to 45	>45
	Points	0	2	4	6
Potential downstream consequence in case of dam failure	Evacuation requirements (number of people)	None	1 to 100	100 to 1,000	>1,000
	Points	0	4	8	12
	Potential damage downstream	None	Low	Moderate	High
	Points	0	4	8	12
Total risk points (summation of the four factors' points)		**<6**	**7 to 18**	**19 to 30**	**31 to 36**
Class		**I (low)**	**II (moderate)**	**III (significant)**	**IV (high)**

Source: Adapted from ICOLD 1989.

Brazil's risk classification system using risk index

Among such specific country adaptations is the framework developed in Brazil (Brazil CNRH 2012). The Brazilian risk classification system has a good structure and has proved to be manageable.

In the Brazilian system, the risk (R) is defined as the product of risk category/vulnerability (RC) and potential hazard (PH).

$$R = RC * PH.$$

RC is subdivided into three elements:

- Technical characteristics (TC), calculated by summation of respective points for dam height, length, construction material, foundation type, age, design flood return period, and so on
- Existing condition of dams (EC), calculated by points for reliability of spillway, reliability of outlet structures, seepage, deformation/settlement, slope deterioration, sluice gate/hydromechanical maintenance, and so on
- Dam safety plan (SP), calculated by points for existence of project documentation, organization structure/dam safety staff qualification, dam safety inspection/monitoring procedure, operational rules, dam safety reports with analysis and interpretation, and so on

RC score is the sum of three subdivision scores.

$$RC = TC + EC + SP$$

Table 2, 3, and 4 provide a list of sub-parameters under TC, EC, and SP respectively under RC. The RC index can be regarded as a proxy of the likelihood of failure reflecting three aspects relevant to dam safety.

PH is defined based on the points of four elements: (a) storage capacity; (b) potential loss of life; (c) socioeconomic impact; and (d) environmental impacts in case of dam failure, and the PH score is the sum of these three subdivision scores as shown in Table 5.

As previously mentioned, R is defined as the product of RC and PH. Although this risk is not a formal risk metric (no probabilities are assigned), it can be used as a proxy for comparing the level of risk of individual dams within a portfolio and meaningfully adapted to a country's context.

India's Risk Index Scheme

India's RI scheme is based on Brazil's system but modified for India's dam safety context. Although the overall RI framework as the product of fragility (or vulnerability) and potential hazard/consequence is like that of Brazil, various key parameters and indicators have been selected based on the ICOLD general risk analysis framework (ICOLD 2017) and fault tree method. The simplification from a comprehensive probabilistic approach to RI was demonstrated to show the backward links and logic in constructing the indexing scheme. Further detailed mythology is provided in Annex B.

TABLE 2. Score for Technical Characteristics

Technical Characteristics Criteria (TC)					
Height (H), m (a)	**Length (L), m and L/H (b)**	**Type (c)**	**Foundation (d)**	**Age, yrs (e)**	**Design Flood (f)**
≤ 15(1)	Embankment: L ≤ 200 and L/H > 3 concrete/masonry stone/cyclopean concrete/concrete gravity: L ≤ 200 (1)	Concrete arch (1)	Very good[2] (0)	30 to 50 (1)	PMF (1)
15 < H < 30 (2)	Embankment: 200 < L < 500 and L/H > 3 concrete/masonry stone/ cyclopean concrete/concrete gravity: 200 < L < 500 (2)	Concrete gravity (2)	Good[3] (2)	10 to 30 (2)	5,000 years (2)
30 ≤ H ≤ 60 (3)	Embankment: 200 < L < 500 and L/H ≤ 3 or 500 ≤ 2,000 and L/H > 3 concrete/masonry stone/cyclopean concrete/concrete gravity: 500 ≤ L ≤ 2.000 (3)	Masonry stone/cyclopean concrete/ concrete gravity (3)	Acceptable[4] (3)	5 to 10 (3)	1,000 years (5)
60 < H ≤ 100 (4)	Embankment: 500 ≤ L ≤ 2,000 and L/H ≤ 3; or L > 2,000 concrete/masonry stone/cyclopean concrete/concrete gravity: L > 2,000 (4)	Zoned earth-fill and earth/ rock-fill[1] (4)	Poor[5] (8)	< 5 or > 50 or without information (4)	500 years (8)
> 100 (5)		Homogeneous[1] (5)	Very poor[6] (10)		< 500 years or unknown (10)
TC = Σ (a - f)					

Source: Adapted from Resolution No. 143 of the Conselho Nacional De Recursos Hídricos (CNRH) or National Council of Water Resources, July 10, 2012, Ministry of Environment, Brazil

Note: TC = technical characteristics; m = meters; PMF = probable maximum flood

[1] Add (1) to the weight when any conduit is in direct contact with or penetrates the embankment.

[2] Very good: Adequate mechanical and hydraulic characteristics of the foundation according to the dam type (no treatment required)

[3] Good: Adequate mechanical characteristics and adequate hydraulic treatment of the foundation according to the dam type

[4] Acceptable: Adequate mechanical and hydraulic treatment of the foundation according to the dam type

[5] Poor: Non-existent or inadequate mechanical or hydraulic treatment of the foundation according to the dam type

[6] Very poor: Problematic soil or rock foundation

Step Three: Assign Weights to Risk Indexes

The final step in the methodology is to combine the results of the dam safety review including onsite inspection with the results of the relative importance determination to generate a set of risk indexes, or "weighted" risk scores, for the current condition of existing dams.

Although weights are project-specific and best assigned by expert elicitation, it is important to optimize the balance of weights between different indexes pertaining to each group, that is, TC, EC, and SP.

In India's RI scheme, for example, it deviates from Brazil's system by appropriately adapting the sub-elements of the RI under the categories of TC, EC, SP, and PH.

TABLE 3. Score for Existing Conditions

Existing Conditions Criteria (EC)					
Spillway Reliability (g)	**Outlet Works Intake Structure Reliability (h)**	**Seepage (i)**	**Deformations and Settlements (j)**	**Slope Deterioration (k)**	**Locks (l)**
Civil and hydro-electromechanical structures in full working conditions/unobstructed approach channel or uncontrolled spillway (including morning glory) (0)	Civil and hydro-electromechanical structures in adequate conditions, maintained and functioning (0)	Totally controlled by drainage system (0)	None (0)	None (0)	None (0)
Civil and hydro-electromechanical structures in operating conditions but without an emergency plant/approach channel or uncontrolled spillway (including morning glory) with erosion or obstructions but without risk to spillway structure (4)	Civil and hydro-electromechanical structures with identified problems, with reduction in flow capacity and corrective actions underway (2)	Stabilized and monitored wet areas in downstream areas, slopes, or abutments (3)	Presence of some cracks and depressions without adverse effect (1)	lack of maintenance in slope protection, presence of some small bushes without adverse effect (1)	Civil and hydro-electromechanical structures, well maintained and functioning (1)
Civil and hydro-electromechanical structures with identified problems, with corrective actions underway for reduction in flow capacity/approach channel of uncontrolled spillway (including morning glory) with erosion and/or partially obstructed, with risk of compromising spillway structure (7)	Civil and hydro-electromechanical and uncontrolled structures with identified problems, with reduction in flow capacity, and without corrective actions (4)	Wet areas in downstream areas, slopes, or abutments without treatment or under investigation (5)	Significant presence of cracks and depressions that may lead to sinkholes, requiring additional studies or monitoring (5)	Surface erosion, exposed steel, generalized vegetation growth, and animal burrows requiring monitoring or corrective action (5)	Civil and hydro-electromechanical structures with identified problems and corrective actions underway (2)
Civil and hydro-electromechanical structures with identified problems, reduction in flow capacity without corrective actions/approach channel of uncontrolled spillway (including morning glory), obstructed or with damaged structures (10)	Uncontrolled structures with identified problems or conduit with seepage emerging downstream without corrective actions (8)	Emerging in downstream areas, slopes, or abutments with soil migration or increasing flow (8)	Significant presence of cracks, sinkholes or slides, with potentially compromised structural safety (8)	Significant erosion and deep gullies, with potentially compromised slope stability and safety (7)	Civil and hydro-electromechanical structures with identified problems and without corrective actions underway (4)
EC = Σ (g-l)					

Source: adapted from Resolution No. 143 of the Conselho Nacional De Recursos Hídricos (CNRH) or National Council of Water Resources, July 10, 2012, Ministry of Environment, Brazil
Note: EC = existing condition.

TABLE 4. Score for Dam Safety Plan

Dam Safety Plan Criteria (SP)				
Existing Design Documentation (n)	**Organizational Structure and Technical Qualifications of Dam Safety Professional Team Members (o)**	**Safety Inspection Report and Monitoring Procedures (p)**	**Operational Regulations of Discharge Facilities (q)**	**Dam Safety Reports with Analysis and Interpretation (r)**
Plans/specs, as-built, and construction records (0)	Have organizational structure with dam safety technician (0)	Have and use inspection and monitoring procedures in accordance with the regulations (0)	yes or have uncontrolled spillway or other discharge structures (0)	Submit report periodically in accordance with the regulations (0)
Plans/specs, as-built, and construction records (2)	Have dam safety technician (4)	Have and seldom use inspection procedures in accordance with the regulations (3)	None (6)	Submit report irregularly in accordance with the regulations (3)
Basic design (4)	Does not have organizational structure nor dam safety technician (8)	Have and does not use Inspection and monitoring procedures in accordance with the regulations (5)		Does not submit reports in accordance with the regulations (5)
Feasibility or conceptual design (6)		Does not have nor use inspection and monitoring procedures in accordance with the regulations (6)		
None (8)				
SP = Σ (n - r)				

Source: Adapted from Resolution No. 143 of the Conselho Nacional De Recursos Hídricos (CNRH) or National Council of Water Resources, July 10, 2012, Ministry of Environment, Brazil.
Note: SP = Dam Safety Plan.

The process of allocating weighting scores was guided by the approach founded on the Analytical Hierarchy Process that uses a Saaty's Scale of Relative Importance (Saaty 1987) via pairwise comparisons of all fragility factors. The knowledge (experts') elicitation process involved a team of international experts, staff, and engineers from the Central Water Commission, State Dam Safety Organizations, and other dam management agencies.

Based on the World Bank's experience of various dams' safety and rehabilitation projects and the recent discussions with the international and national experts for a project in India, the weighting factor (WF) for India can be used as an initial reference in the case of existing dams, which represents the prevalent application in World Bank-supported operations.

However, it may occasionally be necessary to deal with a program of new dams, in which screening and ranking of investment options needs to be done. In that case, the WFs should be different, at least because EC and SP are expected to be satisfactory for new dams. Table 6 reflects such considerations

TABLE 5. **Score for Potential Hazard**

Reservior Total Volume, hm^3 (a)	Loss of Life Potential (b)	Environmental Impact (c)	Socio-Economic Impact (d)
Small ≤ 5 (1)	NON-EXISTING (no persons permanently or temporarily occupy nor drive in/ through affected area downstream of dam) (0)	SIGNIFICANT (affected area of dam is not environmentally relevant protected under specific legislation, or lacking its natural conditions) (3)	NON-EXISTING (infrastructure and navigational services do not exist in area affected by potential failure of dam) (0)
Medium 5 to 75 (2)	LITTLE FREQUENT (no persons permanently occupy affected area downstream of dam but a locally used road exists) (4)	VERY SIGNIFICANT (affected area of dam is envionmentally relevant protected under specific legislation) (5)	LOW (small concentration of residential commercial agricultural industrial areas and infrastructure in area affected by dam or ports navigational services) (4)
Large 75 to 200 (3)	FREQUENT (persons permanently occupy affected area downstream of dam plus municipal stale federal highway and or a possibly permanent place with people that may be impacted) (8)		HIGH (large concentration of residential, commercial, agricultural industrial areas and infrastructure and tourist leisure services in area affected by dam or ports & navigational services) (8)
Very large >200 (5)	EXISTING (persons permanently occupy affected area downstream of dam and lives may be impacted) (12)		
		PH-Σ (a - d)	

Source: Adapted from Resolution No. 143 of the Conselho Nacional De Recursos Hídricos (CNRH) or National Council of Water Resources, July 10, 2012, Ministry of Environment, Brazil.
Notes: PH = potential hazard.

TABLE 6. **A Sample of the Weighting Factors Distribution for Existing and New Dams**

Weighting Factors (WFs)		
Classification element (Brazil and India)	**WFs for existing dams**	**WFs for new dams**
Technical characteristics	0.10	0.40
Existing conditions	0.35	0.00
Dam safety plan	0.05	0.10
Potential hazard	0.50	0.50

Source: Original compilation.

and provides a sample of the WFs considering the Indian RI scheme, which builds on the Brazilian risk classification system.

It must be reiterated that the proposed WFs are for initial reference only. Actual WFs should reflect specificity of each project, adapting to local conditions, and they are best assigned by expert elicitation. It is important to test the RI system for some sample dams and ensure that the ranking results by RI are generally consistent with the overall understanding of the dam owners and regulators regarding the safety condition of the portfolio of dams and their priority of rehabilitation needs.

Risk Assessment for a Portfolio of Dams

The typical application of RI methods is in portfolio risk assessment (PRA) or portfolio risk management (PRM). They are useful in assessing the risk profiles of a portfolio of dams and prioritizing higher-risk dams and risk-reduction measures including structural and nonstructural measures in an optimized and programmatic manner. The results typically include:

- Assessment of risk profile of portfolio of dams as baseline conditions
- Prioritization of risky dams and required remedial measures covering both short- and long-term ones
- Improvement of overall dam safety management program along with intensified monitoring and surveillance for higher-risk dams
- Confirmation of project impacts comparing the risk profile before and after the project interventions
- Development of a short- and long-term business and budget plan

Risk Assessment for an Individual Dam

RI methods do not provide a quantified risk assessment; therefore, it is not possible to compare dam conditions with any tolerable risk level. Nevertheless, RI methods can still offer value when applied to an individual case; for example:

- They prompt the users to focus on key safety-related issues.
- They help in identifying gaps of knowledge (for example, dam records, hydrological data, instrumentation adequacy, and so on) and to address them on a priority basis.
- Using another dam with quantified risk level as a benchmark can assist in empirical quantification of risk.
- They can help evaluate the effects of risk reduction and dam safety enhancement measures on the risk score.

Required Cautions for Using Risk Index Approach

It is noted that the RI method is suitable for periodic re-evaluation of dam safety aspects during project implementation as more information and resources become available. When significant changes are anticipated, it could be advisable to include such a provision and appropriate budget under the project.

Recognizing the benefits from applying RI approaches, it is also necessary to keep in mind their limitations. The most important among these are:

- Poor classification of risk levels in characterizing failure likelihood and adverse consequences or improper size of intervals (either too narrow or too wide) for each level of risk class. It can result in assignment of identical ratings to very different level of risks.
- Incorrect assigning of higher qualitative ratings to quantitatively smaller risks. For risks with negatively correlated reliabilities or likelihoods of failure and adverse consequences, it can lead to serious mischaracterization of risk.
- Ambiguity and subjectivity in characterization of risk index parameters. It can cause different users to arrive at different ratings of the same quantitative risks. Categorizing parameters used for the index requires subjective judgments and arbitrary decisions about aggregation of multiple small and frequent events as opposed to fewer and less frequent but more severe events.[2]
- Need to adjust the structure of the RI depending on the national economic, social, and cultural realities and traditions. Risk aversion or risk tolerance differs from country to country, and these differences must be reflected in the RI.

These limitations suggest that RIs should always be used with caution and only with detailed explanations of judgments applied to the development of RIs/matrices and the calculations of outcomes.

Although the information obtained with the help of RI can be extremely useful for preliminary screening or ranking of riskier dams, especially for a large portfolio of dams, it is recommended that those identified higher risk dams should be subject to further detailed risk assessment, using PFMA or other qualitative or quantitative risk analysis. This will inform decision making on priority remedial works at the next stage.

2 Ambiguity can be reduced by a better description of risk index parameters and arbitrariness by a detailed guidance on interpretation and selection. Consistency across the portfolio of dams and consistency in applications by different analysts or teams can be improved by a comprehensive training.

Annex A: Dam Classification System Using Risk Index by Quebec Province of Canada

The classification of dams in Quebec, Canada, is derived from an RI based on characterization of dam's vulnerability and potential consequences if the dam fails. The regulation provides detailed instructions on how the RI should be applied.

The Provincial government of Quebec, Canada, passed the Dam Safety Act and its regulation in 2002. The act defines two types of dams: (a) high-capacity dams and (b) low-capacity Dams.

High-capacity dams are defined and categorized as:

- *I-a*. Dams one meter or more in height having an impounding capacity greater than 1 million cubic meters
- *I-b*. Dams 2.5 meters or more in height having an impounding capacity greater than 30,000 cubic meters
- *I-c*. Dams 7.5 meters or more in height, regardless of impounding capacity

The main dam safety provisions apply to high-capacity dams.

Low capacity dams are defined as dams with 2 meters or more in height that are not high capacity dams.

The Act requires that a dam be classified by the minister before 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 one meter or more in height. The dam owners are required to submit information, including documents for dam registration, and offense against the provision renders the owner liable for a fine of not less than US$2,000 and not more than US$200,000.

The Act provides details of the dam classification system based on the degree of risk, which has five categories from A to E, with the formula of *P (degree of risk) = V (vulnerability) * C (consequences)*. The 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: (a) dam height, (b) dam types, (c) impounding capacity, and (d) foundation types. The variable parameters to be considered are: (a) dam age as per dam type, (b) seismicity (seismic zone), (c) dam condition, and (d) reliability of the discharge facilities. The dam condition is assessed 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.

The dam failure consequence (C) category is classified into six categories from very low to severe, with 1 to 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 people and size of enterprises, and so on in downstream flooding areas. The dam classification system using these indexes is summarized as below.

Dam Classification System Using Risk Index in Quebec

1. Dam's Vulnerability
   a. Constant physical parameters
      i. Dam height
      ii. Dam types
      iii. Impounding capacity
      iv. Foundation types
   b. Variable parameters
      i. Dam age as per dam type
      ii. Seismicity (seismic zone)
      iii. Dam Condition
      iv. Reliability of discharge facilities
2. Consequence

The Act also defines the required level of consequence assessment depending on the consequence category. For example,

> *The delineation of the area that would be affected by a dam failure and identification of the characteristics of the area are based on a dam failure analysis that includes inundation maps. That analysis, using recognized methods, consists of a detailed evaluation of the consequences of a dam failure by means of an accurate delineation of the affected area and identification of the characteristics of the area. The analysis involves an examination of various dam failure scenarios under normal conditions and in flood conditions. It includes a description of the assumptions and procedures that were used to select the scenarios examined and to determine the dam break flood wave, flood wave arrival times and the extent of the affected area. For scenarios in which the dam fails during a flood, the affected area would be the area that would be inundated due entirely to the dam failure.*
>
> *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 1000-year flood flow to a point of attenuation or restriction, such as confluence with a large lake or river or another dam.*

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 the 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 solely by consequence category.

Annex B: India's Risk Index Scheme under World Bank Financing

Table B.1 indicates India's RI scheme for a recently approved Bank-funded project. The risk of a dam is defined as the product of the fragility (or vulnerability) of the dam and the potential hazard associated with the dam. The fragility score is calculated as the sum of scores for the following three subcategories: (a) TC largely related to the design of the dam, (b) EC relating to the current condition of the dam, and (c) SP for dam safety. Each of these three categories is subdivided into more-detailed risk factors.

TABLE B.1. India's Risk Index Scheme – Fragility Categories and Factors

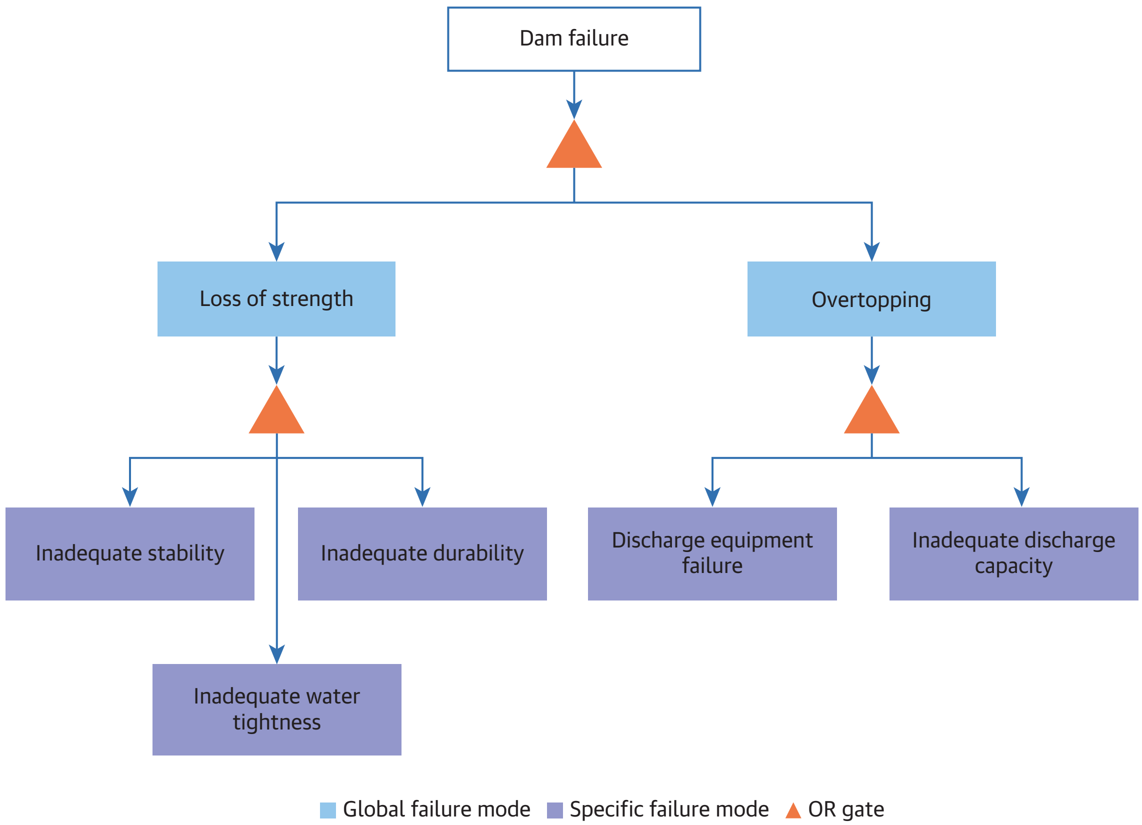
Technical characteristics		Existing conditions		Safety plan	
1	Dam age	1	Seismic design	1	Design documentation
2	Inflow design flood	2	Installed flow control equipment	2	Operation and maintenance manual
3	Seismic zone	3	Flow control equipment condition	3	Emergency Preparedness Plan
4	Landslide, glacier lake outburst flow, landslide dam outburst flow, debris flow	4	Presence of back-up power	4	Organization, staff number, capacity, qualification
5	Length	5	Access to site	5	Safety inspection, monitoring, and reporting
6	Conduits	6	System operation	6	Dam safety reports, analysis, and interpretation
7	Filters	7	Concrete gravity structure	7	Follow-up actions
8	Foundation and abutments	8	Spillway structure		
		9	Masonry structure		
		10	Embankment, foundation and abutments		

The potential hazard is also subdivided into three factors: (a) threat to life safety characterized by population at risk (PAR), (b) environmental impacts, and (c) socioeconomic impacts.

The Indian National Dam Inventory Assessment (INDIA) includes the user manual and Excel spreadsheet indexing tool (Zielinski, et al 2021) provides detailed guidance on how to assess and assign scores for each of fragility and hazard potential indicators.

Figure B.1 shows the fault tree model as the foundation of India's RI system based on the general risk analysis framework as recommended by ICOLD (2017). The model provides the logical framework for the characterization of possible dam failure scenarios in terms of both sequence of events leading to the dam failure as well as probabilities involved. As such, the model is of a general nature and is capable to fully characterize the risk of dam failure if numerical values of all relevant probabilities are available. For the screening purposes of portfolios of dams, especially when the portfolio is large, full numerical characterization of probabilities is either not feasible or simply cost ineffective. In such cases, a simplified process can be applied, and the simplification replaces the numerical values of probabilities by scoring indexes which are therefore the proxies for unknown probabilities.

FIGURE B.1. Fault Tree Model for Risk Indexing Scheme



Furthermore, table B.2 shows the relationship between global/specific potential failure modes and fragility factors based on the fault tree model in figure B.1. The cells with x means that potential failure modes on the horizontal axis can be triggered by fragility factors in TC, EC, and SP on the vertical axis. For example, x in the cells of the fourth column indicate which of the fragility factors can increase the likelihood of mass movement occurring. Increasing the scores for the factors serve as proxies for increasing probabilities of occurrence.

TABLE B.2. Relationship between Fragility Factors and Potential Failure Modes

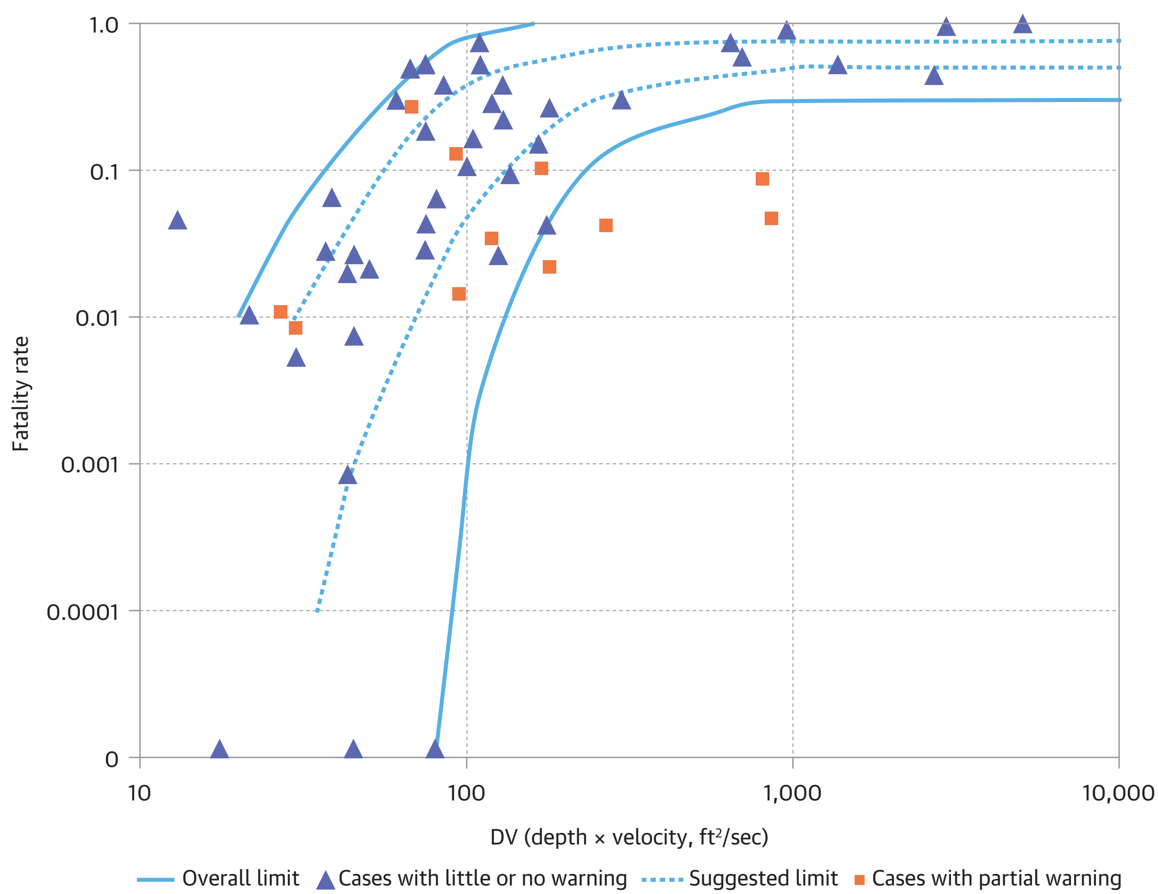
			Inadequate stability		Inadequate durability		Inadequate water tightness		Overtopping		
									Inadequate discharge capacity		Discharge capacity
			Mass movement	Loss of support	Instant. change of state	Structural weakening	Seepage through the dam	Seepage around the dam	design	installed	not available
Technical Characteristics (TC)	TC-1	Dam age	x	x	x	x	x	x			x
	TC-2	Inflow design flood							x		
	TC-3	Seismic zone	x	x	x	x	x	x	x		x
	TC-4	Landslides, GLOFs, LDOFs and debris flow	x	x	x	x			x	x	x
	TC-5	Dam length					x	x			
	TC-6	Conduits				x	x				
	TC-7	Filters	x	x	x	x	x	x			
	TC-8	Foundation and abutments	x	x	x	x		x			
Existing Conditions (EC)	EC-1	Seismic design	x	x	x	x	x	x	x		
	EC-2	Installed flow control equipment								x	
	EC-3	Flow control equipment condition									x
	EC-4	Backup power									x
	EC-5	Access to site									x
	EC-6	System operation								x	
	EC-7	Concrete gravity structure		x		x			x		
	EC-8	Spillway structure	x	x		x			x	x	x
	EC-9	Masonry structure		x		x	x		x		
	EC-10	Embankment, abutments and foundation	x	x	x	x	x	x			
Safety Plans (SP)	SP-1	Documentation	x	x	x	x	x	x	x	x	x
	SP-2	Operation & maintenance manual	x	x	x	x	x	x			x
	SP-3	Emergency Preparedness Plans									
	SP-4	Organization, manpower and qualifications	x	x	x	x	x	x	x	x	x
	SP-5	Safety inspections, monitoring, and reporting	x	x	x	x	x	x			x
	SP-6	Dam safety reports, analysis and interpretation	x	x	x	x	x	x		x	x
	SP-7	Follow and up actions	x	x	x	x	x	x	x	x	x

Source: Zielinski, et al (2021)
Note: GLOF = glacial lake outburst flood; LDOF = landslide dam outburst flood.

Annex C: Fatality Rates with and without Adequate Warning

Figures C.1 and C.2 (USBR 2014) give some ideas on the fatality rate along the y axis corresponding to the hydraulic force, which is the product of inundation depth and flow velocity, in the x axis. The inundation depth and flow velocity should be estimated using dam break and flooding simulation. The dots in the two figures generally indicate the anticipated fatality rate in the case of little or no warning versus adequate warning. These figures are useful in estimating the number of potential loss of life depending on the Emergency Preparedness Plan availability and deployment of the emergency notification/warning system. The fatality rates should however be referred to only for general reference but be adapted to different countries' contexts considering their societal, cultural and economic conditions.

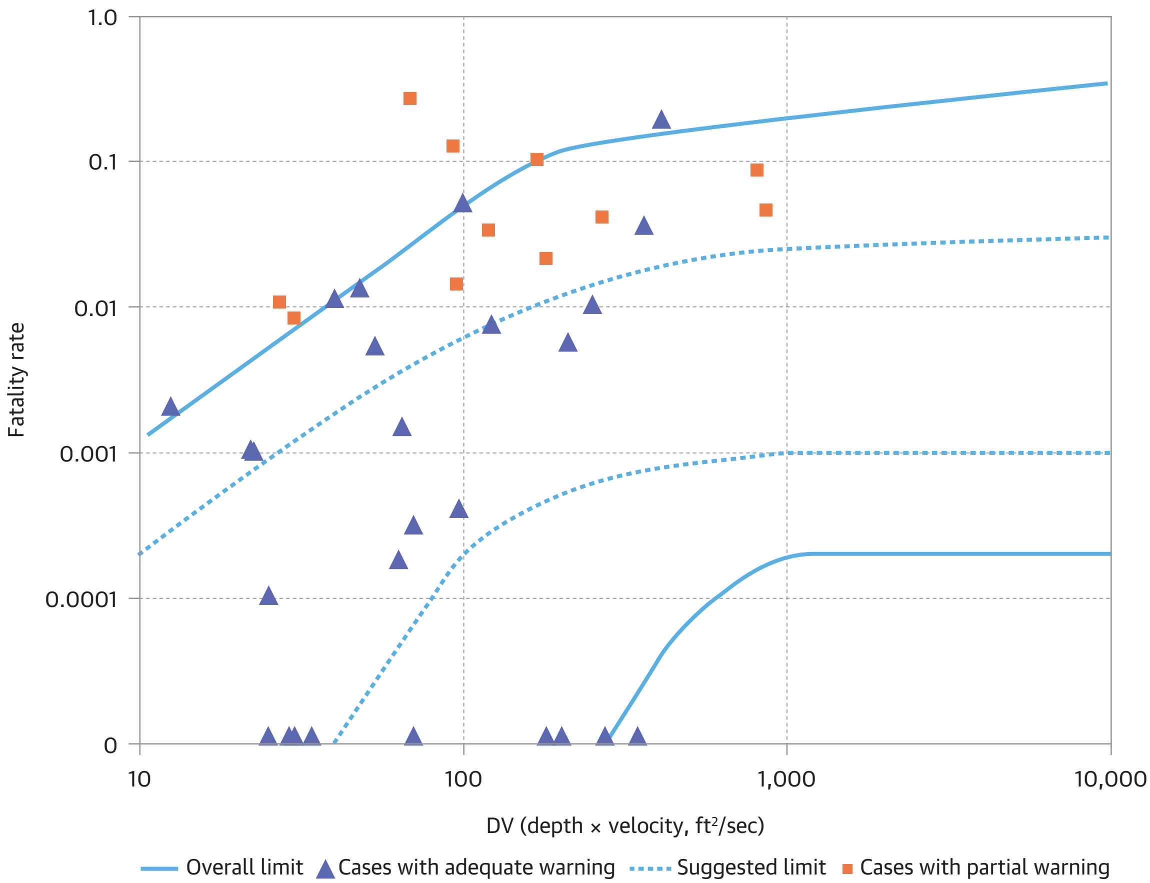
FIGURE C.1. Fatality Rate—Flood Severity with Little or No Warning



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.

FIGURE C.2. Fatality Rate—Flood Severity with Adequate 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.
Note: ft^3 = cubic feet.

References

Brazil. Conselho Nacional De Recursos Hídricos (CNRH) or National Water Resources Council, Ministry of Environment. Resolution No. 143. 2012. "*It lays down general classification criteria for dams by risk category, potential damage associated with the volume of the reservoir in attention to article 7 of Law 12344 of September 2010*."

ICOLD. 1989. *Bulletin 72: Selecting Seismic Parameters for Large Dams*. Paris: ICOLD.

——. 2017. *Bulletin 154: Dam Safety Management: Operational Phase of the Dam Life Cycle*. Paris: ICOLD.

——. 2005. *Bulletin 130: Risk Assessment in Dam Safety Management: A Reconnaissance of Benefits*. Paris: ICOLD.

Pinheiro, A., J. Mora Ramos, L. Caldeira, E. Jossefa, and A. Boavida. 2015. *Proposal for the Dam Safety Regulation of Mozambique*. Paper presented at the Dam World Conference, Lisbon, Portugal.

Saaty, R. W. 1987. "The Analytic Hierarchy Process: What It Is and How It Is Used," *Mathematical Modelling* 9(3-5), 161-176.

USBR (U.S. Bureau of Reclamation). 2000. "Risk Based Profiling System." Denver, Colorado.

USBR (US Bureau of Reclamation). 2015. "Reclamation Consequence Estimating Methodology (RECM): Interim Guidelines for Estimating Life Loss for Dam Safety Risk Analysis." Denver, Colorado.

Wishart, Marcus J., Satoru Ueda, John D. Pisaniello, Joanne L. Tingey-Holyoak, Kimberly N. Lyon, and Esteban Boj Garcia. 2020. "Laying the Foundations: A Global Analysis of Regulatory Frameworks for the Safety of Dams and Downstream Communities." Sustainable Infrastructure Series, Washington, D.C.: World Bank.

Zielinski, A. Przemyslaw, Pramod Narayan, C. Richard Donnelly, Eric Halpin, Jonathan Quebbeman, Halla Maher Qaddumi, Chabungbam Rajagopal Singh, Satoru Ueda, and Marcus Wishart. 2021. "Risk screening tool in dam safety assessment." manuscript for Hydropower & Dams: Aqua-Media International Ltd. Surrey, UK.

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