Current state-of-practice in risk-informed decision-making for the safety of dams and levees

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FOREWORD

At the 2013 Committee meeting in Seattle the Committee on Dam Safety approved the proposal and the plan for developing a new Bulletin aimed at (i) the characterization of different methods and approaches to assessment of dam risks, and (ii) the characterization of advantages, disadvantages and limitations of identified approaches and methods currently in practice. The expectation was that such review would provide a useful insight into the path of necessary future developments in the area of risk assessment for dam safety. The initial Working Group included representatives from Canada, China, France and United States and was later expanded by representation from Australia and the Netherlands.

In early stages of work differences of opinions amongst the Working Group members regarding the extent of characterization of advantages, disadvantages, and limitations of different approaches to risk assessment prevented the Group from advancing the progress of work. After several years of discussions within the Group as well as with the entire Committee at the annual Committee meetings a compromise plan was accepted resulting in splitting the task into two parts. The content of this Bulletin represents the first part focused solely on gathering and compiling the information on the state of practice in these countries represented in CODS that agreed to provide information. The unedited information that Committee members participating in two surveys sent to the Working Group is reproduced in the Bulletin without any analysis or commentary, as requested by some members of the Working Group and by some participants at the discussions during the Committee meetings between 2014 and 2017. Therefore, part of the original task has been achieved by outlining the state of practice in countries participating in the review.

The other, equally if not more important part of the original task, will be addressed in a separate Bulletin which will provide a critical review of currently used methods and approaches. This is a necessary step in advancing our state of knowledge and planning how to leverage this knowledge in continuing improving of our approach to the use of information about risk in managing safety of dams. By doing this, the Committee will follow the advice of Edwin Thompson Jaynes Jr., a physicist and a mathematician, and one of the greatest minds of 20th Century science who helped in developing interpretation of probability theory from being largely unknown to a research area that is being applied daily in engineering, economics, biology, physics, and many other disciplines. Jaynes' the most important observation was

> *As knowledge advances, we are able to invent better and better models, which reproduce more and more features of the real world, more and more accurately. Nobody knows whether there is some natural end to this process, or whether it will go on indefinitely. …We expect that any model we are now able to construct will be replaced by more complete ones in the future, and we do not know whether there is any natural end to this process.*

This is what the authors of the next Bulletin need to do – analyze what we have accomplished until now and recognize the shortcomings and weaknesses. Only a thorough and critical analysis of the present state-of-the-art can guide us toward the most effective path to gaining better information about dam safety risks and help in numerous and increasing challenges of modern dam safety management.

Przemyslaw A. Zielinski
Chair, ICOLD Committee on Dam Safety

ACKNOWLEDGMENTS

The Committee on Dam Safety gratefully acknowledges the contribution of members of the Committee's Working Group and the support provided by their sponsoring organizations. The final text of the Bulletin is the result of the effort of many members of CODS who provided the information and data. The crucial role of the entire Committee in providing general guidance and valuable input during the period of 2014 to 2019 cannot be overestimated.

The task of designing and collecting the surveys and then assembling the responses in the Bulletin rested with the Working Group which included:

1. Dr. Gregory B. Baecher, University of Maryland, USA;
2. Dr. D.S. Bowles, Professor Emeritus of Civil and Environmental Engineering, Utah State University, Logan, Utah, USA;
3. Mr. Douglas Boyer, Federal Energy Regulatory Commission, USA;
4. Dr. D.N.D. Hartford, Principal Engineering Scientist, Dam Safety, BC Hydro, Canada;
5. Mr. J.P.F.M. Janssen MSc Eng. – Rijkswaterstaat, the Netherlands;
6. Mr. S. McGrath –Mr. S. McGrath, SGM Consulting (Australia) Pty. Ltd., Australia;
7. Dr. Zeping Xu, Department of Geotechnical Engineering, China Institute of Water Resources and Hydropower Research, China;
8. Dr. P. A. Zielinski, Principal, HYDROSMS Inc., Canada;
9. Mr. M. Poupart, previously Dam Safety Advisor at Electricité de France, presently Independent Consultant, France.

CODS SURVEY I

Survey I was issued to all members of the Committee on Dam Safety in February 2016. 13 responses were received, and the information provided can be found below.

The purpose of Survey I was to:

- identify the practitioners of dam safety risk assessment in the country,
- provide the country input to the scope of the review.

SURVEY I QUESTIONS

Question 1: Who in your country is practicing dam safety risk assessment?

Of interest are risk assessments that are qualitative, semi-quantitative or quantitative for any dam safety related purposes, such as screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others. Where practices are common amongst a group of practitioners, a small representative of the group can be provided.

a) **the dam owners** who are using dam safety risk assessments for to inform decision making

Name	Affiliation	Email

b) **the people** who perform dam safety risk assessments

Name	Affiliation	Email

c) **the safety or economic regulators** who are open to considering dam safety risk assessments

Name	Affiliation	Email

Question 2: What aspects of dam safety risk assessment would your national committee like to see included in our review? In addition to indicating if the suggested topics listed below are of interest, please add other topics of interest to your national committee at the bottom of the list.

	Example Topics	Should this be included? (Yes/No)
1	Guidelines or similar documents relevant for risk analysis/assessment for dams	
2	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment	
3	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	
4	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	
5	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	

	Example Topics	Should this be included? (Yes/No)
6	The scientific basis of approaches which are in use	
7	Portfolio risk assessment approaches	
8	How risk assessment results are used in decision making	
9	Other	

RESPONSES RECEIVED FROM CODS MEMBERS

ARGENTINA

Comment about dam safety management in Argentina:

- Risk informed dam safety is not a normal practice. Dam safety management and regulations are under the traditional practice. Risk assessment practice still is very limited. Nevertheless, interest and understanding of the importance of risk analyses and evaluation is increasing during the last years. Most applications are mainly qualitative or semi quantitative.
- Some owners are using RCM1 and RCM2 (Reliability Central Maintenance) for hydro mechanical and electromechanical equipment, and periodic systemic qualitative risk analysis by expert's judgment.
- Risk assessment practice and risk informed is limited to a few specific cases or problems, and mainly qualitative or semi quantitative, complementary to traditional practice.
- Recently ORSEP began a program of dam safety risk assessment under the advice of iPresas from Valencia, Spain (Dr. I. Escuder Bueno y associates). The program tends to dam safety assessment, screening and prioritization of 30 hydro national dams.

Question 1: Who in your country is practicing dam safety risk assessment?

a) Dam owners who are using dam safety risk assessments to inform decision making

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Question 2: What aspects of dam safety risk assessment would your national committee like to see included in our review? In addition to indicating if the suggested topics listed below are of interest, please add other topics of interest to your national committee at the bottom of the list.

	Example Topics	Should this be included? (Yes/No)
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2.	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment	Yes
3.	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	Yes
4.	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	Yes
5.	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	Yes
6.	The scientific basis of approaches which are in use	Yes
7.	Portfolio risk assessment approaches	Yes
8.	How risk assessment results are used in decision making	Yes

AUSTRALIA

Question 1: Who in your country is practicing dam safety risk assessment?

a) Dam owners who are using dam safety risk assessments to inform decision making

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Question 2: what aspects of dam safety risk assessment would your national committee like to see included in our review? In addition to indicating if the suggested topics listed below are of interest, please add other topics of interest to your national committee at the bottom of the list.

	Example Topics	Should this be included? (Yes/No)
1.	Guidelines or similar documents relevant for risk analysis/assessment for dams	Yes
2.	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment	Yes
3.	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	Yes
4.	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	Yes
5.	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	Yes
6.	The scientific basis of approaches which are in use	Yes
7.	Portfolio risk assessment approaches	Yes
8.	How risk assessment results are used in decision making	Yes
9.	Methods for estimating probability and consequences	
10.	Methods for estimating uncertainty	
11.	"As low as reasonably practicable" and "so far as is reasonably practicable "concepts	
12.	Cost – benefit analysis	
13.	Defining what is practicable for dam safety upgrades	
14.	Consider practices in other hazardous industries	

CANADA

The practice of risk informed decision making is evolving in Canada. Many dam owners have adopted various approaches to identifying failure modes and analyzing their effects to inform dam safety decisions. Ontario Power Generation and BC Hydro have made use of risk assessment to deal with some dam safety issues in their systems. Recently, Alberta Environment and Parks have adopted a semi-quantitative hybrid PFMA/FMEA approach to risk informed assessments on two of their systems.

Regulatory practices vary by Province

British Columbia

In British Columbia, the Dam Safety Review Assurance Statement introduces the term "reasonably safe" which is intended to mean that the dam owner has implemented all dam safety management measures which conform to those norms that are considered by the regulatory authority and the qualified professional engineer to reasonably reflect established engineering and dam safety management practices.

The Ministry accepts the results of the safety assessment that can be represented in various ways as illustrated in ICOLD Bulletin 154 and in the concepts of risk-informed identification of safety engineering solutions. The CDA Dam Safety Guidelines contain guidance on the threshold levels for risk. However, the use of this approach in British Columbia is currently under review by the MFLNRO Dam Safety Section.

Alberta

Alberta Dam and Canal Safety Directive issued by dam safety regulator Alberta Environment and Parks (AEP) requires dam owners to conduct risk assessment in specific situations.

Saskatchewan

Saskatchewan does include informed approaches in their dam safety practices.

Manitoba

In Manitoba, the need to establish a method of prioritizing the work required at the Provincial Dams (driven by the discrepancy between workload volume, and staffing and financial constraints) adopted a prioritization.

Ontario

Currently, the dam safety regulator in Ontario does not permit the use of risk-informed approaches for assessing the safety of dams.

Newfoundland and Labrador

In Newfoundland and Labrador, the MAE Dam Safety Regulation draft has incorporated a schedule to assess dam risk levels for the consequences of failure, which are determined qualitatively based on CDA dam classification and probability of failure criteria. Dam owners are then required to take different levels of corrective action based on the dam risk level.

While risk informed decision-making is practiced in several jurisdictions, none have specifically identified it as a means to ensure the safety of dams.

Question 1: Who in your country is practicing dam safety risk assessment?

a) Dam owners who are using dam safety risk assessments to inform decision making

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Question 2: What aspects of dam safety risk assessment would your national committee like to see included in our review? In addition to indicating if the suggested topics listed below are of interest, please add other topics of interest to your national committee at the bottom of the list.

	Example Topics	Should this be included? (Yes/No)
1.	Guidelines or similar documents relevant for risk analysis/assessment for dams	Yes
2.	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment	Yes
3.	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	Yes
4.	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	Yes
5.	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	Yes
6.	The scientific basis of approaches which are in use	Just like a reference. It is not specific for dams
7.	Portfolio risk assessment approaches	Yes
8.	How risk assessment results are used in decision making	Yes

CHILE

Question 1: Who in your country is practicing dam safety risk assessment?

a) Dam owners who are using dam safety risk assessments for to inform decision making

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c) Safety or economic regulators who are open to considering dam safety risk assessments

Name	Affiliation	Email
None		

Question 2: What aspects of dam safety risk assessment would your national committee like to see included in our review? In addition to indicating if the suggested topics listed below are of interest, please add other topics of interest to your national committee at the bottom of the list.

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1.	Guidelines or similar documents relevant for risk analysis/assessment for dams	Yes
2.	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment	Yes
3.	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	Yes
4.	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	Yes
5.	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	Yes
6.	The scientific basis of approaches which are in use	Yes
7.	Portfolio risk assessment approaches	Yes
8.	How risk assessment results are used in decision making	Yes
9.	One hands-on qualitative risk assessment example	Yes
10.	One hands-on semi-qualitative risk assessment example	Yes
11.	One hands-on quantitative risk assessment example	Yes

CZECH REPUBLIC

Owner of majority of large dams is Czech Republic represented by Ministry of Agriculture. Five state enterprises (according to main river basins) own and operate most of dams and other hydraulic structures. Smaller number of large dams are owned by el. power company ČEZ, a.s. as well and forest company Lesy ČR. Dam owners are responsible for dam safety and they are obliged to perform regular dam supervision at their own expense. They are also obliged to maintain all dams and other hydraulic structures at the best possible condition to minimize the threat to the safety of persons, property and other protected interests.

Moreover, there are several independent consulting companies authorized by Ministry of Agriculture to perform dam safety such works, such are special measurement, results evaluation, periodic dam safety reports, recommendation of effective measures etc. These independent companies perform dam safety supervision for dam owners and in cooperation with their own dam safety experts and stuff. The dam owner is obliged to perform dam safety supervision by independent authorized company for dam category I. and II. In general, approaches to risk assessment are qualitative and quantitative in Czech Republic.

Dams and other hydraulic structures are divided from the view of dam safety to categories I (highest hazard), II, III and IV. This classification is anchored in the Water Act. Only the highly qualified and specialized company can be authorized subject for dam safety.

The principal authorized independent subject for dam safety is VODNI DILA – TBD which is the authorized subject at more than 95 % of Czech dams and other hydraulic structures of categories I. – III. There are also state regulators represented by region authorities who are controlling the dam owner dam safety duties.

Question 1: Who in your country is practicing dam safety risk assessment?

d) Dam owners who are using dam safety risk assessments for to inform decision making

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3.	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	Yes
4.	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	Yes
5.	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	Yes
6.	The scientific basis of approaches which are in use	Yes
7.	Portfolio risk assessment approaches	Yes
8.	How risk assessment results are used in decision making	Yes

FRANCE

France has a dam legislation which requires the use of risk analysis for Class A and B dams. All owners of these dams have therefore already carried out a risk analysis in recent years, i.e. about 500 Risk Analysis.

It would therefore be difficult to indicate the names of all these dam owners and consultants that carry out these analyses. On the other hand, within the French Committee of Dams and Reservoirs there is a working group whose objective is “safety of the dams and risk analysis”. This working group includes about 8 people with representatives of owners, consultants, researchers and French regulator. It seems to us that this working group is the best interlocutor to answer the questionnaires to come. The members of this group have been informed of your initiative and some of its members are “key practitioners” and are ready to participate actively in the planned activities, including the workshop.

We give below the names of the two animators of this group, and in section c) the name of a representative of the regulator, to whom you can address the elements to come:

Question 1: Who in your country is practicing dam safety risk assessment?

Name	Affiliation	Email
Laurent PEYRAS,	IRSTEA	laurent.peyras@irstea.fr
Michel POUPART	Independent Consultant	poupart.m@free.fr

a) Dam owners who are using dam safety risk assessments for to inform decision making

Name	Affiliation	Email
As above		

b) People who perform dam safety risk assessments

Name	Affiliation	Email
As above		

c) Safety or economic regulators who are open to considering dam safety risk assessments

The French authorities in charge of Dam regulation depend on the Ministry of Environment within a specific department in charge of hydraulic structures. They are in charge of issuing regulations (which includes risk Analysis requirements since 2007). One of the members of the French Committee WG belongs to this department. His name and Email are indicated below.

Name	Affiliation	Email
Guirec PREVOT	BETCGB (*)	Guirec.Prevot@developpement-durable.gouv.fr

(*) Bureau d'Etudes et de Contrôle des Grands Barrages (This central entity belongs to the Ministry of Environment and is in charge of technical support to the regional regulators; there are about 10 experts in this Bureau, Guirec PREVOT being particularly in charge of Risk Analysis control and feedback.)

Question 2: What aspects of dam safety risk assessment would your national committee like to see included in our review? In addition to indicating if the suggested topics listed below are of interest, please add other topics of interest to your national committee at the bottom of the list.

	Example Topics	Should this be included? (Yes/No)
1.	Guidelines or similar documents relevant for risk analysis/assessment for dams	Yes
2.	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment (is there legal requirements (agreement?) about the qualification of people undertaking a RA?)	Yes
3.	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	Yes
4.	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	Yes
5.	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	Yes
6.	The scientific basis of approaches which are in use	Yes
7.	Portfolio risk assessment approaches	Yes
8.	How risk assessment results are used in decision making	Yes
9.	Synthetic description of the methodologies used	Yes
10.	Number of Risk Analysis carried out, feedback of the experience gained, and development perspectives	Yes
11.	Research works	Yes
12.	Methods for estimating downstream consequences, assessments of damage to property and persons	Yes
13.	What are the main trends / results in the overall assessment of the safety of dams in a country ... is one in the green, orange or red? i. e. is the dam portfolio well located in the criticality table (FN Chart or other) or are a large number of significant risk reductions to be expected over a significant fraction of the portfolio?	Yes
14.	In terms of mitigation measures, could the most frequent measures be given generically?	Yes

ITALY

Question 1: Who in your country is practicing dam safety risk assessment?

a) Dam owners who are using dam safety risk assessments to inform decision making

Name	Affiliation	Email
none		

b) People who perform dam safety risk assessments

Name	Affiliation	Email
Massimo Meghella	RSE	Massimo.Meghella@rse-web.it

c) Safety or economic regulators who are open to considering dam safety risk assessments

Name	Affiliation	Email
Vincenzo Chieppa	Dam Safety Authority	vincenzo.chieppa@mit.gov.it
Carlo Ricciardi	High Council Public Works	carlo.ricciardi@mit.gov.it

Question 2: What aspects of dam safety risk assessment would your national committee like to see included in our review? In addition to indicating if the suggested topics listed below are of interest, please add other topics of interest to your national committee at the bottom of the list.

	Example Topics	Should this be included? (Yes/No)
1.	Guidelines or similar documents relevant for risk analysis/assessment for dams	Yes
2.	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment	Yes
3.	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	Yes
4.	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	Yes
5.	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	Yes
6.	The scientific basis of approaches which are in use	Just like a reference. It is not specific for dams
7.	Portfolio risk assessment approaches	Yes
8.	How risk assessment results are used in decision making	Yes

JAPAN

Question 1: Who in your country is practicing dam safety risk assessment?

a) Dam owners who are using dam safety risk assessments to inform decision making

Name	Affiliation	Email
(None)	(None)	(None)

b) People who perform dam safety risk assessments

Name	Affiliation	Email
Name	**Affiliation**	**Email**
(None)	(None)	(None)

c) Safety or economic regulators who are open to considering dam safety risk assessments

Name	Affiliation	Email
(None)	(None)	(None)

Question 2: What aspects of dam safety risk assessment would your national committee like to see included in our review? In addition to indicating if the suggested topics listed below are of interest, please add other topics of interest to your national committee at the bottom of the list.

	Example Topics	Should this be included? (Yes/No)
1.	Guidelines or similar documents relevant for risk analysis/assessment for dams	Yes
2.	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment	Yes

	Example Topics	Should this be included? (Yes/No)
3.	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	Yes
4.	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	Yes
5.	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	Yes
6.	The scientific basis of approaches which are in use	Yes
7.	Portfolio risk assessment approaches	Yes
8.	How risk assessment results are used in decision making	Yes

[Supplemental remarks] Safety management of dams in Japan

- In Japan, risk assessment related to dam safety is in the research stage and not implemented.
- Meanwhile, the following measures are being promoted in Japan in order to appropriately evaluate and improve the safety of the dam.

1. Advanced dam safety management system by periodic and comprehensive inspection

The safety management system for dams in Japan consists of regular (daily / monthly / yearly) inspections, emergency inspection, periodic inspection and comprehensive inspection. A comprehensive inspection is done about 30 years after completion of the dam. A wide range of detailed evaluations are conducted on the current status of the dam body and equipment based on the field survey and measurement data.

References: S. Takasu et al., Safety management system and comprehensive inspection for dams in Japan, 7th East Asian Dam Conference, 2011.

2. (Seismic performance evaluation of dams during large earthquakes

The basic design of dams in Japan is conducted using traditional pseudo-static analysis. Dams in Japan have never been damaged that have serious impact on their safety in the past large-scale earthquakes. Meanwhile, based on the recent large-scale earthquake occurrence and progress of analytical techniques, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has established "Guidelines for seismic performance evaluation of dams during large earthquakes", and on the basis of the guideline, seismic performance evaluation has been implemented on a trial basis.

References: K. Shimamoto et al., Trial implementation of new Japanese guidelines for seismic performance evaluation of dams during large earthquakes, ICOLD 75th annual meeting symposium, 2007

3. Adaptation to floods due to climate change

Regarding the increase in intensity and frequency of flood caused by climate change, it is important to fully understand the characteristics, range of application and limit of each adaptation option and select a measure or combination of several options considered appropriate for each river basin. Specific adaptation measures by the dam are as follows; construction of dams, enlarging existing dams, improving discharge facilities, improving short-term precipitation prediction technology and reservoir operation technology, etc.

References: River bureau of MLIT, Practical guidelines on strategic climate change adaptation planning – flood disasters – 2010.

THE NETHERLANDS

Question 1: Who in your country is practicing dam safety risk assessment?

ICOLD dams in The Netherlands are mainly owned and managed by Rijkswaterstaat, however some of them are owned by a Waterboard. Levees on which a large part of our safety risk assessment is applied, are mainly owned and managed by the Waterboards. Our Ministry (Infrastructure and Environment) issues the dam safety regulation.

a) Dam owners who are using dam safety risk assessments to inform decision making

Name	Affiliation	Email
Marc Walraven	RWS	marc.walraven@rws.nl
Soer van Herk	RWS	soer.van.herk@rws.nl
Hans v.d. Sande	Waterboard Scheldestromen	Hans.vanderSande@Scheldestromen.nl
Jan Willem Nieuwenhuis	Waterboard NZV	J.W.Nieuwenhuis@noorderzijlvest.nl

b) Dam owners who are using dam safety risk assessments to inform decision making

Name	Affiliation	Email
Ruben Jongejan	RWS (consultant RMC)	ruben.jongejan@jongejanrmc.com
Marko Ludeking	RWS	marko.ludeking@rws.nl
Deon Slagter	RWS	deon.slagter@rws.nl

a) Safety or economic regulators who are open to considering dam safety risk assessments

In the Netherlands risk assessment is obligatory in safety decisions. Therefore, this question does not really apply. Regulators are:

Name	Affiliation	Email
Ilka Tanczos	RWS	ilka.tanczos@rws.nl
Anouk te Nijenhuis	DGRW	Anouk.te.Nijenhuis@minienm.nl

Question 2: What aspects of dam safety risk assessment would your national committee like to see included in our review? In addition to indicating if the suggested topics listed below are of interest, please add other topics of interest to your national committee at the bottom of the list.

	Example Topics	Should this be included? (Yes/No)
1.	Guidelines or similar documents relevant for risk analysis/assessment for dams	Yes
2.	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment	Yes
3.	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	Yes
4.	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	Yes
5.	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	Yes
6.	The scientific basis of approaches which are in use	Yes
7.	Portfolio risk assessment approaches	Yes
8.	How risk assessment results are used in decision making	Yes

All topics are deemed necessary to inform future users about risk assessment approaches and their possibilities

NORWAY

Question 1: Who in your country is practicing dam safety risk assessment?

b) Dam owners who are using dam safety risk assessments to inform decision making

Name	Affiliation	Email
Statkraft, attn: Anne Marit Ruud	(Statkraft = power producer)	Anne.marit.ruud@statkraft.com
Sira-Kvina; attn: Rolv Guddal	(Sira-Kvina = power producer)	Rolv.guddal@sirakvina.no

It is not possible to give names for all owners (a) and practitioners (b), but those mentioned here are quite active at the moment, and at a fairly advanced level. Others have been doing risk analyses earlier (for several purposes), and all owners do risk analyses as part of emergency preparedness processes and for public safety purposes (mostly preliminary hazard analyses).

c) People who perform dam safety risk assessments

Name	Affiliation	Email
Suzanne Lacasse	NGI	Suzanne.lacasse@ngi.no
Kaare Høeg	NGI	Kaare.hoeg@ngi.no
Farrokh Nadim	NGI	Farrokh.nadim@ngi.no
Per Magnus Johansen	Norconsult	Per.magnus.johansen@norconsult.com

Suzanne Lacasse is currently leading a risk analysis project in Norway and is probably one of the persons that have the best overview of the topic at the moment – together with Kaare Høeg.

d) Safety or economic regulators who are open to considering dam safety risk assessments

Name	Affiliation	Email
NVE, Section for Dam Safety	Grethe H. Midttømme, Lars Grøttå, Vebjørn Pedersen	ghm@nve.no, lag@nve.no, vep@nve.no

Question 2: What aspects of dam safety risk assessment would your national committee like to see included in our review? In addition to indicating if the suggested topics listed below are of interest, please add other topics of interest to your national committee at the bottom of the list.

	Example Topics	Should this be included? (Yes/No)
1.	Guidelines or similar documents relevant for risk analysis/assessment for dams	Yes
2.	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment	Yes
3.	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	Yes
4.	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	Yes
5.	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	Yes
6.	The scientific basis of approaches which are in use	Yes
7.	Portfolio risk assessment approaches	Yes
8.	How risk assessment results are used in decision making	Yes

SLOVENIA

Question 1: who in your country is practicing dam safety risk assessment?

a) Dam owners who are using dam safety risk assessments to inform decision making

Name	Affiliation	Email
Nina Humar	Hidrotehnik d.d. (former) for the owner: Directorate for water	nina.humar@izvrs.si
	Savske elektrarne	humar.nina@gmail.com

b) People who perform dam safety risk assessments

Name	Affiliation	Email
Andrej Kryžanowski	Faculty of civil end geodetic engineering	andrej. kryžanowski@fgg.uni-lj.si
Nina Humar	Hidrotehnik d.d. (now Institute for water)	nina.humar@izvrs.si
Krešimir Kvaternik	IBE d.d.	Kresimir.Kvaternik@ibe.si

c) Safety or economic regulators who are open to considering dam safety risk assessments

Name	Affiliation	Email
Milica Slokar	Ministry of defense	milica.slokar@gov.si
Tone Cezar	Ministry of environment (Directorate for Water)	tone.cezar@gov.si

Question 2: What aspects of dam safety risk assessment would your national committee like to see included in our review? In addition to indicating if the suggested topics listed below are of interest, please add other topics of interest to your national committee at the bottom of the list.

	Example Topics	Should this be included? (Yes/No)
1.	Guidelines or similar documents relevant for risk analysis/assessment for dams	Yes
2.	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment	Yes
3.	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	Yes
4.	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	Yes
5.	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	Yes
6.	The scientific basis of approaches which are in use	Yes
7.	Portfolio risk assessment approaches	Yes
8.	How risk assessment results are used in decision making	Yes

SRI LANKA

Question 1: who in your country is practicing dam safety risk assessment?

d) Dam owners who are using dam safety risk assessments to inform decision making

Name	Affiliation	Email
Irrigation Department of Sri Lanka	Director General of irrigation	dgiirrigation@gmail.com
Mahaweli Authority of Sri Lanka	Executive Director	herathhpp@yahoo.com.sg
Ceylon Electricity Board	General Manger	
North Provincial Council	Chief Secretary	chiefsecnpc@gmail.com

e) People who perform dam safety risk assessments

Name	Affiliation	Email
Eng H M Junaid	Director (Assets Management) of Irrigation Department	hmjunaid25@yahoo.com.au
Eng S R K Aruppola	Director (Headworks) of Mahaweli Authority of Sri Lanka	aruppola@yahoo.com
Eng Kamal Laksiri	Project Director of Ceylon Electricity Board	laksirikamal@gmail.com

f) Safety or economic regulators who are open to considering dam safety risk assessments

Name	Affiliation	Email
None		

Question 2: What aspects of dam safety risk assessment would your national committee like to see included in our review? In addition to indicating if the suggested topics listed below are of interest, please add other topics of interest to your national committee at the bottom of the list.

	Example Topics	Should this be included? (Yes/No)
1.	Guidelines or similar documents relevant for risk analysis/assessment for dams	Yes
2.	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment	Yes
3.	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	Yes
4.	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	Yes
5.	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	Yes
6.	The scientific basis of approaches which are in use	Yes
7.	Portfolio risk assessment approaches	Yes
8.	How risk assessment results are used in decision making	Yes
9.	Successes and failures of previous attempts in dam safety risk assessment	

UNITED STATES OF AMERICA

Question 1: who in your country is practicing dam safety risk assessment?

a) Dam owners who are using dam safety risk assessments to inform decision making

Name	Affiliation	Email
Brian Becker	US Bureau of Reclamation	bbecker@usbr.gov
Nate Snorteland	US Army Corp of Engineers	Nathan.Snorteland@usace.army.mil
Nick Von Gersdorff	Southern California Edison	

b) People who perform dam safety risk assessments

Name	Affiliation	Email
David Bowles	Utah State University	david_s_bowles@hotmail.com
Marty McCann	Stanford University	mccann@jbasic.best.vwh.net
Dom Galic	US Bureau of Reclamation	dgalic@usbr.gov

c) Safety or economic regulators who are open to considering dam safety risk assessments

Name	Affiliation	Email
Doug Boyer	Federal Energy Regulatory Commission	dboyer@ferc.gov
Bill McCormick	State of Colorado	Bill.mccormick@state.co.us

Question 2: What aspects of dam safety risk assessment would your national committee like to see included in our review? In addition to indicating if the suggested topics listed below are of interest, please add other topics of interest to your national committee at the bottom of the list.

	Example Topics	Should this be included? (Yes/No)
1.	Guidelines or similar documents relevant for risk analysis/assessment for dams	Yes
2.	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment	Yes
3.	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	Yes
4.	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	Yes
5.	A list of references to reports, technical papers or documents that are specific to risk analysis/assessment activities in that country	Yes
6.	The scientific basis of approaches which are in use	Yes
7.	Portfolio risk assessment approaches	Yes
8.	How risk assessment results are used in decision making	Yes

SUMMARY OF RESPONSES

	Aspects of dam safety risk assessment to be included in review	Argentina	Australia	Canada	Chile	Czech Republic	France	Italy	Japan	The Netherlands	Norway	Slovenia	Sri Lanka	United States
		1	2	3	4	5	6	7	8	9	10	11	12	13
	Topics suggested by Working Group													
1	Guidelines or similar documents relevant for risk analysis/assessment for dams	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	Legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment. There are legal requirements regarding qualification of people undertaking a RA.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	The range and purposes or risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, and others	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4	Policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5	A list of references to reports, technical papers or documents that are specific to risk analysis and assessment activities in that country	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
6	The scientific basis of approaches which are in use	✓	✓	✓	✓	✓	✓	Just like a reference. It is not specific for dams	✓	✓		✓	✓	✓
7	Portfolio risk assessment approaches	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
8	How risk assessment results are used in decision making	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Additional topics suggested by individual countries	
1	Successes and failures of previous attempts in dam safety risk assessment (SRI LANKA)
2	Methods for estimating probability and consequences (AUSTRALIA)
3	Methods for estimating uncertainty (AUSTRALIA)
4	“As low as reasonably practicable” and “so far as is reasonably practicable “concepts (AUSTRALIA)
5	Cost – benefit analysis (AUSTRALIA)
6	Defining what is practicable for dam safety upgrades (AUSTRALIA)
7	Consider practices in other hazardous industries (AUSTRALIA)
8	One hands-on qualitative risk assessment example (CHILE)
9	One hands-on semi-qualitative risk assessment example (CHILE)
10	One hands-on quantitative risk assessment example (CHILE)
11	Synthetic description of the methodologies used (FRANCE)
12	Number of risk analyses carried out, feedback of the experience gained, and development perspectives (FRANCE)
13	Research works (FRANCE)
14	Methods for estimating downstream consequences, assessments of damage to property and persons (FRANCE)
15	What are the main trends / results in the overall assessment of the safety of dams in a country ... is one in the green, orange or red? i.e. is the dam portfolio well located in the criticality table (FN Chart or other) or are a large number of significant risk reductions to be expected over a significant fraction of the portfolio? (FRANCE)
16	In terms of mitigation measures, could the most frequent measures be given generically? (FRANCE)

CODS SURVEY II

Survey II was issued in February 2019 to these members of the Committee who answered Survey I.

BACKGROUND TO THE SURVEY

The Committee on Dam Safety has been examining and discussing risk assessment practices amongst member nations for over 20 years. An ICOLD Bulletin: *Risk Assessment in Dam Safety Management – A Reconnaissance of benefits, methods and current applications* was published in 2005. In 2013, the Committee, through a Working Group initiated a literature review of current risk assessment practices for dams in ICOLD countries that had published various guidance documents on the subject (e.g. Australia, Spain, United Kingdom and the United States). The Working Group also posed some general questions concerning risk assessment, risk analysis and risk evaluation that it considered would provide important insights into the philosophical, scientific and regulatory underpinnings of risk assessment practices for dams.

A Preliminary Summary of the Review was presented at the ICOLD Congress in Stavanger in 2015. However, the Summary of the Review did not receive widespread acceptance for various reasons, not the least of which being that it did not represent either a Working Group consensus or a Committee consensus. The various objections that had been raised led to numerous discussions with an eventual decision at the Committee meeting in Johannesburg in 2016 to work towards revising and updating Bulletin 130. A survey of practices in ICOLD countries submitted by the national committee members was a key element of the process of developing Bulletin 130, and it was decided that a two phased approach to conducting the survey would be pursued.

As already indicated above the first phase focused on identifying the scope of practices in different countries and on identifying individuals who could be approached to provide responses to more detailed questions.

This second phase involved a comprehensive range of questions that addresses:

1. Legal, regulatory and enforcement arrangements (15 sub-questions)
2. General considerations (6 sub-questions)
3. Risk Analysis (11 sub-questions)
4. Risk Evaluation (11 sub-questions)
5. Risk Management (5 sub-questions)
6. Risk Communication (3 sub-questions)

Survey II was distributed to the National Committee representatives on the Committee on Dam Safety with the expectation that it was re-directed to the individuals nominated by their National Committees to respond to more detailed questions. The responses were returned by the National Committee representatives as the statement national practice.

The Committee has discussed various ways to facilitate securing as comprehensive a response as practicable to this survey. Options that have been considered included phone or face-to face interviews, and even a major workshop on the Survey. The Phase II Survey has been designed to ultimately support a major workshop on the subject of risk assessment practices in dam safety management where the six survey themes described above would provide the themes for the sessions in the workshop. In this regard the large number of issues raised in this second phase questionnaire was intended to provide insights into the nature and extent of risk assessment, risk management and risk communication arrangements across the ICOLD community that can then serve as an authoritative statement on the subject.

While the original objective of the Committee was to focus on risk assessment, the response to Survey I indicated that the focus on risk assessment without consideration of its role within risk management could have the unintended effect of excluding standards-based management of risk where consideration of risk is implied rather than made explicit. This distinction was made in Bulletin 154 on Dam Safety Management in the Operational Phase of the Life-cycle (Appendix B), and it reflects the view that many decisions and actions with respect to risk issues are taken and implemented in the absence of formal consideration of risk.

It was concluded that to be reasonably representative of the very broad spectrum of applications of the different interpretations and types of risk assessment within the ICOLD community that a comprehensive set of questions would be an appropriate means of eliciting more detailed information than that received from Survey I.

Based on previous feed-back, the overarching requirements of the Survey and the compilation and interpretation of the results were that the survey be inclusive of all practices, and that the interpretation of the responses be non-judgmental.

INTERPRETATION OF RISK ASSESSMENT ON THIS SURVEY

Risk Assessment, and its component activities of risk analysis and risk evaluation exists in many forms and for many purposes, ranging from personal decisions such as crossing a road to an aid to the assessment of the adequacy of the integrity of the performance of complex engineered systems. Risk Assessment is an endeavour with a long history and with several different interpretations depending on the industry involved. For example, in insurance, the risk refers to the loss (consequence), i.e. what is at risk, whereas in medicine, the risk is the threat (death, injury or sickness). In the domain of technological risk, which is the focus of this bulletin, the term risk refers to the characterization of the probability or chance that something will go wrong and the resulting consequences. It is worth noting that the development of risk assessment for technological systems is a relatively new addition to the domain of risk assessment having been introduced in the 1960's and having evolved from methods of reliability analysis. Application of risk analysis for dams, although considered in conceptual form in the 1960's and again in the 1970's and 1980's did not emerge in formalized way until the late 1980's.

Risk assessment is typically an iterative endeavour with the assessment becoming more refined as the process proceeds. As is the case with any endeavour, the overall direction of a risk assessment is controlled by the motivating objectives. Common with other endeavours an initial scope of a risk assessment might be refined and adjusted as information becomes available. Experience has shown that qualitative, scoping methods are suited to the early phases of the development of a risk assessment with more refined methods being applied as more information becomes available. In addition, the objectives of the study will determine if comparison to a quantitative criterion is required. This in turn defines the objectives and scope of the risk evaluation component of the risk assessment.

A general framework and process for risk assessment emerged in the 1990's and general guidance was formalized through national and international standards setting organizations. However, these guidance frameworks and processes are generic and must be adapted to suit the risk situation that is under consideration. Further, these guidance frameworks do not deal with the policy aspects of risk assessment, nor do they typically deal with the relationship between risk management and legal duties and other vitally important factors such as the role of government in regulating risk.

CONTEXT FOR THE SURVEY

With the above as introductory background, this survey is framed in the context of a flexible interpretation of what is meant by risk assessment. The survey is designed to permit National Committee representatives to provide responses in the context of the four decision-framework types described in Bulletin 154 (4.4.5., pages 120/121) as follows:

- Standards-based framework
- Generally accepted framework
- Risk-based framework
- Risk informed framework

In this context and with reference to the UK HSE's Reducing Risks, Protecting People[1] engineering standards can be considered as follows: *"Standards can be regarded as generic control measures that must be applied to eliminate or reduce the risks for a particular hazard. The scope of the standard is set by specifying the circumstances in which the hazards give rise to the risk. One feature of using standards is*

[1] UK HSE (2001). *Reducing Risks, Protecting People:* HSE's decision-making process. HMSO. HSE Books.

that once adopted they may be regarded as applying to the hazard rather than to the risk in the sense that they are applied to control risks whatever the circumstances, for example, however short the actual exposure to the hazard." In the majority of circumstances, conformance to engineering standards results in a generally acceptable risk condition that does not engender societal concern or regulatory intervention. For dams, the generally accepted framework is set out in ICOLD Bulletins 59 and 61. Together, the Standards-based and the Generally accepted frameworks usually involve controlling the hazard or the effects of the hazard (or both) and are in place regardless of the probability of initiation of the failure mechanism. In this regard, the standards-based and generally accepted frameworks control the risk by means of control over the hazard or failure initiating condition.

Against this background, this survey is set in a broader context than that of Bulletin 130 which focused on the narrower probabilistic interpretation of risk assessment.

PRACTICAL CONSIDERATIONS IN THE DESIGN OF THE SURVEY

A significant challenge in designing this survey was to effectively cater for the full spectrum of degrees of maturity of risk assessment as it is applied to dams in the ICOLD member countries. The survey takes as a premise that all dam safety activities, regardless of the underlying analytics and decision processes entail the control of risk from dams, and that this premise is universally applicable.

In order to address this broad and diverse spectrum, and with reference to Sections 4.4.5 and 4.6 of Bulletin 154, the term risk assessment in the survey should be interpreted in one or more (where more than one exists) of the following ways:

- Standards-based risk assessment
- Generally accepted assessment framework (supported by engineering principles).
- Risk-based assessment where the result of the assessment produces the decision directly
- Risk informed assessment where the results of the risk computations are used to inform a decision process that also incorporates a range of other relevant considerations

When responding to the questionnaire the responder is requested to state which of the above four types of risk assessment is being referred to. As noted above, risk assessment can be carried out to varying degrees of detail in various ways with the result that each of the above four types of risk assessment covers a spectrum ranging from rudimentary qualitative approaches to sophisticated quantitative approaches. Not surprisingly the levels of effort can cover a very wider range of cost and effort that can span from minor levels required for preliminary engineering assessments to enormous costs and effort running into the millions of dollars and many person years of analytical effort. Presently the survey does not attempt to capture these cost and effort dimensions of risk assessment practices.

Against this background, there is no "right' form of risk assessment nor is there a "right" way to go about performing a risk assessment. The reality is that the term risk assessment covers a wide range of approaches to assessing situations that may or may not invoke risk avoidance, risk reduction or risk control measures. Thus, the term risk assessment can be reasonably prefixed by the qualifier "some type" with the onus on the initiators, developers and users of the risk assessment to clearly lay out the "type" of assessment and its quality attributes. Noting that there is no "correct" way to define "type", the notion of different "types" of risk assessment might be illustrated for how to discriminate between choices between qualitative and quantitative risk assessment methods.

The scales are descriptive and relative and will vary from case to case. Within each cell of the matrix below, further discrimination is possible. For example, there are several forms of quantitative risk assessments (Qn) ranging from detailed, physics-based quantitative analysis supported by a great deal of directly relevant data at one extreme, to subjective thought models that rely on beliefs and judgments to define parameters in the thought model in the absence of data. There is a spectrum of choices between these extremes and it may well be that a single analysis involves several of the types within the spectrum.

Notional Framework for discriminating between risk assessment types

Estimated probability	CONSEQUENCE			
	Catastrophic	Major	Minor	Negligible
High	Qn	Qn	Qn	Ql
Moderate	Qn	Qn	sQn	Ql
Low	Qn	sQn	sQn	NR
Very low	Qn	sQn	Ql	NR
Negligible	sQn	Ql	Ql	NR

Quantitative	Qn
Semi-quantitative	sQn
Qualitative	Ql
Not Required	NR

The risk evaluation process which is not shown in the above matrix may influence the distribution of risk assessment types in the notional matrix above. For example, it may well be that some catastrophic situations (e.g. Frequent-Catastrophic) are to be avoided at all costs and in such cases a decision to eliminate the risk could be made on the basis of a preliminary qualitative risk assessment.

SURVEY II QUESTIONS

	1. Legal/Regulatory Framework and Enforcement Regime
1.1	What is the legal context within which the owners are making decisions about the safety of dams? For example, are there laws that define either in qualitative or quantitative way, the State's expectations for the protection of the public from harm from hazardous industries (including dams)?
1.2	In addition to these laws, are there any specific regulatory requirements for dam safety?
1.3	Are there any social or cultural traditions that prevent or limit the use of some type of risk assessment?
1.4	Are there any moral and ethical considerations that control the type or practice of risk assessment? If so, what are the dominant moral and ethical considerations
1.5	What are the laws that a dam owner must comply with and how is risk assessment used in the process of complying with those laws? Please list the laws individually and the role of risk assessment in demonstrating compliance with the laws and regulations.
1.6	Has there been any legal actions taken against a dam owner for noncompliance with laws and regulations whether with or without a risk assessment?
1.7	Are there legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment and dam safety decision making informed by risk?
1.8	If such legal and regulatory framework is absent, are there plans to develop and implement it?
1.9	List the regulatory documents defining how the process of risk analysis, evaluation and reduction is to be carried out. If the regulation is absent, list the guidelines or other documents used in developing the process.
1.10	What arrangements are in place to determine if the laws and, where relevant the regulations, are being complied with?
1.11	Are there any penalties for non-compliance even if there has not been an incident or failure?
1.12	Can the enforcement authority direct an owner to implement risk reduction measures? If so, are there any limitations on the costs of improvements directed by the Responsible Authority.
1.13	Is the owner solely liable for the damages caused by dam failure under all circumstances, or does conducting a risk assessment limit the liability of the dam owner?
1.14	Can criminal responsibility or culpability be assigned to an Owner or a Consultant if a dam that has been determined to be acceptably safe in accordance with a risk assessment fails or causes damage?
1.15	Are there any specific laws or regulatory instruments/directives that impose a particular economic philosophy or principles with respect to the economics (e.g. cost-benefit analysis) of safety improvement projects.

	2. GENERAL
2.1	What are the ranges and purposes of risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, decisions that a dam is acceptably safe, and other applications?
2.2	Characterize the reasons why dam safety risk assessments are carried out in your country, considering that the following may apply: • It is required by regulation • It is allowed by regulation as an alternative to traditional safety assessment based on engineering standards • It is carried out for exploratory reasons • It is carried out to optimize dam safety expenditures

2. GENERAL	
	• Other Describe typical risk assessment studies (purpose, context and scope: including owner, regulator and stakeholder considerations and risk assessment scoping factors such as types of outcomes, hazards considered, failure modes, types of consequences, desired level of confidence and how uncertainty was addressed).
2.3	What type(s) of risk analysis: qualitative, semi-quantitative, quantitative are used
2.4	Provide a general characterization of risk criteria or guidelines applied in the risk evaluation process
2.5	Describe the quality control and quality assurance arrangements and how they are implemented
2.6	What are the public consultation processes with respect to safety decisions for individual dams?

Generally, there are two different areas of applications of risk management in dam safety (1) safety of individual dams, and (2) safety of a portfolio of dams. Considering that analytic and evaluation methods may differ for these two areas of application, provide the answers to questions below for

- individual dams
- portfolios of dams

3. RISK ANALYSIS	
3.1	What are the fundamental principles of currently applied risk analysis methodology?
3.2	Does the risk analysis include dams as part of a system, not only as part of a portfolio of dams, but also with respect to surrounding water defences?
3.3	Does the risk analysis process treat dams or complexes of dams as dynamic systems and apply modern systems engineering concepts and analytic techniques? Are dynamic aspects of system responses accounted for in calculating the probability of dam failure and if they are, how it is being done?
3.4	What methods and analytic techniques are used to determine probability of dam failure?
3.5	What are the relative extents of the use of physics-based models and inductive models of failure and failure consequences processes? For example, are analyses based on largely engineering judgment-based estimates, statistical data or models of physical processes?
3.6	Is expert judgment used in order to estimate the probabilities associated with dam safety risk analysis? If it is, what methodology is used for expert opinion elicitation?
3.7	Explain methods that are used for estimating impacts on affected population
3.8	Explain methods for estimating downstream consequences and assessment of: • Damage to property (direct, indirect or both), • Damage to environment, • Damage to cultural heritage • Societal impacts
3.9	Assessment of uncertainty aspects of risk analysis – characterization of what is included in the assessment and the outline of assessment methodology
3.10	Number of risk analyses carried out, feedback of the experience gained, and development perspectives.
3.11	Are there any formal or informal training or minimum qualification guidelines established for people performing risk analyses?

4.	**RISK EVALUATION**
4.1	What are the fundamental principles of establishing risk evaluation principles, criteria or guidelines?
4.2	What entity is responsible for the Risk Evaluation Process? Is it the Responsible Authority, the organization that licenses engineers, the Dam Owner, Consultants, or NGO's such as National Committees of ICOLD
4.3	What are the public consultation process for risk evaluation and the bases for determining that the benefits of the dam sufficiently outweigh the risk associated with the dam and its operation?
4.4	What are the policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations or non-governmental organizations?
4.5	What are the criteria or guidelines for risk tolerability/acceptability used to address societal concerns?
4.6	What are the criteria or guidelines for risk tolerability/acceptability used to address the environmental damage?
4.7	What are the criteria or guidelines for risk tolerability/acceptability used to address the damage to cultural heritage?
4.8	If intangible failure consequences listed in Questions 4.3, 4.4 and 4.5 do not have associated risk tolerability criteria, how the risks related to these consequences are addressed in the risk evaluation process?
4.9	Is any form of benefit-cost calculation performed with the risk assessment to assist in dam safety decision making? Please provide examples?
4.10	Within your country are you aware of any dam owners who have established their own corporate tolerability of risk guidelines or policies?
4.11	Is the principle of As Low as Reasonably Practicable (ALARP) applied and if it is, what is the legal context within which it is applied and how it is used in demonstrating the tolerability of risk?

5.	**RISK MANAGEMENT**
5.1	What is the risk assessment being used for? A portfolio risk assessment undertaken at a screening level is generally only used to identify the priorities for further studies or perhaps some minor interim risk reduction measures, but not used for dam safety decision making?
5.2	How are risk assessment results used in decision making?
5.3	What prioritization measures are used as a result of the risk assessment and how are they established and managed?
5.4	Outline of the decision-making process applied to risk reduction
5.5	Outline the decision process for determining that risk reduction measures are not required

6.	**RISK COMMUNICATION**
6.1	How are risk results communicated internally with dam owner's management and decision makers?
6.2	Are the results of risk studies communicated with the stakeholders and the public? If so, how?
6.3	What are the challenges you have experienced in communicating risk results internally and externally?

RESPONSES RECEIVED FROM CODS MEMBERS

FOCUS AREA 1 - LEGAL/REGULATORY FRAMEWORK AND ENFORCEMENT REGIME

QUESTION 1.1

What is the legal context within which the owners are making decisions about the safety of dams? For example, are there laws that define either in qualitative or quantitative way, the State's expectations for the protection of the public from harm from hazardous industries (including dams)?

Argentina

- There is no dam safety law in Argentina. A proposal for a dam safety law was recently submitted for consideration of the National Congress.
- ORSEP (Organismo Regulador de Seguridad de Presas), created by a Nation Decree 239/1999 is the Dam Safety Authority over private concessions of all the nation hydroelectric dams.
- ORSEP provides dam safety technical assistance to Provinces through specific agreements.
- Provincial dams are regulated by local governmental institutions.

Australia

The legal context is broadly similar across Australian States. Four of the six States have Acts of parliament specific to dam management and regulation. These reference State and ANCOLD guidelines. There is also common law precedent in Australia. Most States and Territories have similar workplace health and safety laws that apply to workers and the public requiring risk to them to be reduced so far as is reasonably practicable. In the individual States:

New South Wales

NSW Dams Safety Act 1978 (still active); [revised] NSW Dams Safety Act 2015 (will supersede, late 2019)

Tasmania

There are laws in Tasmania that set out dam owner requirement for all types of dam including tailings dams, these cover dam design, construction, supervision, reporting and ongoing monitoring and surveillance, and emergency management

Queensland

Specific dam safety legislation supported by statutory guidelines. There are also common law drivers to maintain best practice dam management. The basis for the dam safety standards is based on ANCOLD guidelines.

Victoria

Owners are responsible for their assets. Common law tenets apply. Also, the Water Act has broad requirements relating to dam safety management and powers of the portfolio Minister to enforce.

Canada

Canada has a dual legal system. The Roman-Napoleonic Code of Law is in place in the Province of Québec whereas English Common Law prevails in the rest of Canada. In Québec the provisions of the legal code must be met. In the rest of Canada, strict liability considerations generally apply to dam owners concerning the consequences of dam failure.

The status of regulation varies by jurisdiction (10 Provinces and 3 Territories).

The four (4) jurisdictions that have Dam Safety Regulations in place differ somewhat in the details of their respective Dam Safety Programs, but there are some fundamental similarities. The overarching goal of all the Provincial guidelines and regulations is to ensure that the public, the environment and important cultural heritage are protected against unacceptable incremental loses in the event of a dam failure. However, there are also some important differences. For example, the Provinces of British Columbia and Quebec regulate the requirements for inspection and the types of inspections that are required. The other Provinces (including Ontario) do not regulate this standard of care, although the pending update of Alberta's regulation might include this requirement.

The key features of each Province's dam safety regulations are described in the following paragraphs.

British Columbia (BC)

The BC Dam Safety Regulation sets requirements and best practices for all aspects of dam design, construction, operation, maintenance, removal and decommissioning of dams[2]. The Dam Safety Regulation under the B.C. Water Sustainability Act came into effect on February 29, 2016, replacing the former B.C. Dam Safety Regulation (2000). The Regulation applies to owners of dams that store or divert water from a stream or aquifer or both and makes them (i.e., owners) responsible for inspecting, reporting and maintaining their dams to a standard of care and diligence that will minimize the risk associated with their dam. The Regulation also holds owners of dams liable for any damage caused by the construction, operation or failure of their dam. In addition, the owners of dams are responsible for obtaining a water license and complying with its terms and conditions.

Risk concepts are not discussed in the regulations. However, the qualified professional performing Dam Safety Reviews is required to assess the failure modes applicable to the dam and specifically comment on whether each failure mode has been adequately accounted for and whether the risk or risks it presents has/have been mitigated. If the failure mode is not applicable, the specific reasons why it is not applicable must be stated.

Alberta

Alberta Environment and Parks (AEP) provides regulatory oversight in the Province to ensure that non-energy water dam owners are in compliance with the Alberta Water Act, the Water (Ministerial) Regulation, Alberta Dam and Canal Safety Directive and Alberta's Dam Safety Guidelines. The main purpose of Alberta's Dam Safety Regulatory System is to ensure that dams and their appurtenant hydraulic structures are designed, constructed, maintained, operated and decommissioned using best available technology and best applicable practices.

Saskatchewan

In Saskatchewan, there are currently no dam safety standards, regulations or legislation. The Saskatchewan Water Security Agency (WSA) regulates dams for water supply through the Water Security Agency Act, with hydroelectric dams regulated under the Water Power Act. These acts do not stipulate design criteria, post-construction, dam safety management or specific dam safety provisions, but rather, they specify the approvals process required to construct and operate dams and the right to use water.

Manitoba

In 2006, Manitoba Infrastructure (MI) – Water Management, Engineering and Construction (WMEC) became responsible for the operation and maintenance of all Provincial waterways and the related water control infrastructure, including dykes and dams. Currently, the Province of Manitoba does not have specific legislation for the regulation and/or management of dams. The two pieces of legislation giving the Province

[2] For the purposes of this document, and in the context of the BC regulation, the term "dam" includes both conventional water-retaining dams and tailings dams. However, within the regulation the discussions focus on conventional water dams with only limited reference to Mining dams or Tailing Storage Facilities. These structures are regulated under the Mines Act and associated Code

jurisdiction over water control works are the Manitoba Water Rights Act and the Water Resources Administration Act.

The Manitoba Water Rights Act, enacted in 1988 and recently amended in 2006, gives the Minister all rights to the use, diversion or control, of all water in the Province. It protects the water rights of all Manitobans from being negatively impacted by illegal works. The Manitoba Water Resources Administration Act, enacted in 1987 and recently amended in 2009, provides the Minister with direction and control on all matters related to the construction or operation of public water control works. Through the Water Resources Administration Act, MI operates and maintains water control works (including dams) that are either declared to be Provincial Waterways (through Orders in Council) or are infrastructure that is not privately owned or that does not fall under someone else's jurisdiction.

Ontario

In Ontario, a regulated dam is defined under the LRIA as a structure or work that forwards, holds back or diverts water. The Lakes and Rivers Improvement Act Administrative Guide outlines the broad requirements of the LRIA, including roles and responsibilities, application of the Act, and steps of the LRIA review and approval process.

Accompanying the Administrative Guide are Technical Bulletins that provide technical standards and criteria used by the Ministry of Natural Resources and Forestry (MNRF) in the review of applications for approval under the LRIA (Sections 14 and 16). The Technical

Quebec

In Quebec, the regulation is very specific in its application. Although it does not differ significantly from the CDA approach in many aspects (e.g., in the safety management requirements and most engineering criteria), it is philosophically different in its approach to dam classification, the selection of the inflow design flood (IDF), the definition of life safety (the concept of persons at risk is used in Quebec), spillway capacity requirements and the requirements for the design basis earthquake (DBE). The Quebec Dam Safety Act and its attendant regulation (Dam Safety Regulation) came into effect in 2002.

Most of the Act's provisions apply to high-capacity dams. Owners of existing high capacity dams must comply with the minimum safety standards under section 75 of Dam Safety Regulations. Owners of high-capacity dams must also have their dam undergo a safety review by an engineer to verify the exact condition of the works and determine, where applicable, the proposed remedial measures for increased safety of the works and compliance with today's standards. Owners of existing dams have three to ten years to have the safety review carried out, depending on dam failure consequences, the dam's condition and the reliability of its discharge facilities.

The Dam Safety Act imposes measures governing the construction, alteration and operation of high-capacity dams[3]. It requires that dam owners regularly maintain their structure in a state of good repair and monitor their works. Dam safety reviews are required to be performed by an engineer to verify the condition of the works and to determine, where applicable, if the proposed remedial measures for increased safety of the works are appropriate and in compliance with most recent Quebec Dam Safety standards.

An important and unique feature of the Quebec regulations is that the Quebec Ministry may approve an owner's dam safety program for a dam that does not fully comply with all of the Provinces dam safety requirements[4,5] provided that the program includes all the elements of a well-managed system. This represents a *de facto* acceptance of risk reduction measures to enhance the safety of dams.

[3] For existing high capacity dams, owners must comply with minimum safety standards related to flood and earthquake resistance standards as is set out under section 15 of the Act. The process to request approval for dam safety remedial measures and the implementation schedule for such measures is outlined under section 17 of the Act.
[4] In accordance with Section 23 of DSA. However, safety standards under Section 15 must still be satisfied.
[5] Only applicable for dam owners who own at least 10 high-capacity dams.

Atlantic Provinces

There are no dam safety regulations in the Atlantic Provinces of Canada. The CDA guidelines are used for dam safety management.

Newfoundland and Labrador

In Newfoundland and Labrador, the Department of Municipal Affairs and Environment (MAE) was authorized by cabinet to develop Dam Safety Regulations in 2015. A first draft has been developed, but it will take some time before the regulations are finalized.

Comparison of Regulated Requirements in Canada

Province	Ministry/Agency	Legislation	Regulation	Guidelines
British Columbia	Ministry of Forests, Lands and Natural Resource Operations & Rural Development Ministry of Mines, Energy and Petroleum Resources	Water Sustainability Act Mines Act	Dam Safety Regulation Health, Safety and Reclamation Code for Mines in British Columbia	Legislated Dam Safety Reviews APEGBC Professional Practice Guidelines - Plan Submission Guidelines for Construction & Rehabilitation of Dams - Guide & Template for Preparing a Dam Emergency Plan in BC - APEGBC Professional Practice Guidelines for Site Characterization for Dam Foundations in BC - Downstream Consequence of Failure Classification Interpretation Guideline - Dam Safety Audit Program
Alberta	Alberta Environment and Parks Alberta Energy Regulator	Water Act	Water (Ministerial) Regulation, Part 6: Dam and Canal Safety	Alberta Dam Safety Guidelines (2018) (not released yet)
Saskatchewan	Water Security Agency	Water Power Act Water Security Agency Act	None	Reference is made to CDA Guidelines
Manitoba	Manitoba Infrastructure – Water Management and Structures (WMS)	Manitoba Water Rights Act Water Resources Administration Act	None	None
Ontario	Ministry of Natural Resources and Forestry	Lakes and Rivers Improvement Act (LRIA)	Ontario Regulation 454/96: Construction	LRIA Administrative Guide, Technical Bulletins, Best Management Practices
Quebec	Ministère Du Développement durable, de l'Environnement, de la Lutte contre les	Dam Safety Act	Dam Safety Regulation	None

Province	Ministry/Agency	Legislation	Regulation	Guidelines
	Changements Climatiques (MDDELCC)			
Newfoundland and Labrador	Department of Municipal Affairs and Environment	Water Resources Act	None	Reference is made to CDA Guidelines

Czech Republic

Basically, there is a Water Act (Nr. 254 from 2001) defining that dam owner must be dealing with dam safety (For I. to III. Category via authorised company by Ministry of Agriculture) dam categorization, dam safety periodical inspections and reports. There is also Emergency Management Law (Nr. 240 from 2000) defining that emergency action plans at all levels must be defined by municipalities, regions and government for all possible risks including dam break floods hazard which must be provided by dam owners.

France

There is a regulation on the safety of dams. Published in the Environmental Code, some orders define more precisely the expected requirements. The regulation is based on three aspects: minimum guarantees in terms of performance of works (design), monitoring, operating and surveillance, and then, preparedness plan for the largest dams. A periodic Safety Review (named "Etudes de Dangers" in France) makes a revision of the dams on these different topics. See answer to Question 1.5 for the text regulations references.

Italy

The subject is regulated for all infrastructures by national laws that prescribe precise safety standards and obligations on concessionaires.

The Netherlands

In the Netherlands dams are almost always for flood protection. The primary flood defences have to comply with set standards enshrined in national law, the Water Act, in terms of maximally accepted probability of failure, based on extensive risk analyses. All primary defences are listed in the annex of the act. Standards for non-primary flood defences are set by provincial/regional governments or by the Waterboards except for the ones maintained by Rijkswaterstaat. The Water Act requires a periodic safety assessment, the results of which must be reported to parliament. For the primary structures, the procedure and rules for this assessment are set by the ministry. When a dam is not up to standard the Water Act holds the framework for financing of reconstruction. The Dutch system is described in the "Fundamentals of Flood Protection" (available at https://www.enwinfo.nl/images/pdf/Grondslagen/GrondslagenEN-lowresspread3-v.3.pdf).

Slovakia

There is a Water Act (Nr. 364/2004 Coll.) defining that dam owner have to provide technical safety supervision according to category (I. to IV.) of the water construction (dams, levees, weirs, ponds, tailings dams etc.) on his own costs via authorized professionally competent person and even more – for I. or II. category must be this authorized person employed by state owned company entrusted by Ministry of Environment for the performance of technical safety supervision, dam categorization, providing of examination for dam safety authorization and publishing the list of categorized water structures.

Sri Lanka

In Sri Lanka, all dams are managed by government organization or semi government organizations. Hence the respective organizations are responsible for the safety of their dams.

There is no legislation to cover dam safety matters exclusively. Initiative has taken to introduce Dam safety Regulations and still under approval process.

United States of America

Federal Energy Regulatory Commission (FERC)

This is best summarized in the document 'Legal Liability for Dam Failures', by Denis Binder. "First, each state is a separate jurisdiction free to impose its own theories of recovery as well as limitations on liability. Thus, legal standards in Maine may be inapplicable to California. Second, even though legal principals may vary by jurisdiction, principals of engineering apply universally. Third, in today's litigious society it is safe to assume that in the case of a catastrophic dam failure, extensive litigation will ensue. Any competent lawyer, representing the victims, will sue all possible wrongdoers in seeking redress. Lawsuits will therefore most probably be filed against everyone remotely connected to the dam's existence, including the architects, engineers, contractors, sub-contractors and consultants involved in the original construction, as well as those responsible for any subsequent modifications. Potential defendants would clearly include the owners and operators of the facility, quite possibly the state engineer or private dam safety inspectors, and conceivably any insurance company which performed a safety inspection of the facility. Fourth, regardless of the jurisdiction, should a dam failure result in loss of life, personal injury or substantial property damage, it is fairly certain today that most jurisdictions will fashion a means to compensate the victims. The basis for these premises is that the overriding purpose of modern tort law is to compensate an innocent victim for any injuries caused by the wrongful acts of another."

US Army Corps of Engineers

The U.S. Army Corps of Engineers (USACE) is a self-regulated Federal dam owner in the United States. There are no governing laws that set a qualitative or quantitative expectation for public safety downstream of dams. However, the public has a reasonable expectation of safety. The Federal Guidelines for Dam Safety, the Federal Guidelines for Dam Safety Risk Management, The National Dam Safety Act and USACE discretionary authority set the broad legislative framework and authority to conduct Dam Safety activities. USACE has internal policies (e.g. ER 1110-2-1156) that define our dam safety program, including governance, portfolio prioritization, risk management, risk assessment, evaluations, and controls.

US Bureau of Reclamation (USBR)

The Bureau of Reclamation is a self-regulated Federal dam owner in the United States. There are no governing laws that set a qualitative or quantitative expectation for public safety downstream of dams. However, the public has a reasonable expectation of safety. The Federal Guidelines for Dam Safety, The National Dam Safety Act and Reclamations Safety of Dams Act set the broad legislative framework and authority to conduct Dam Safety activities. The Bureau of Reclamation has developed our Public Protection Guidelines which define our practice of risk analyses, evaluation and management.

State of Colorado

CRS 37-87-104. Liability of owners for damage.
CRS 37-87-105. Approval of plans for reservoir.
CRS 37-87-107. Safety inspections – amount of water to be stored.

QUESTION 1.2

In addition to the laws addressed in Question 1.1, are there any specific regulatory requirements for dam safety?

Argentina

Dam safety requirements are included on the private concession's contracts for hydro nation dams. ORSEP has the authority and power to require dam safety improvements or corrective actions and to enforce the compliance with all the dam safety regulations and objectives specified in the concession's contracts.

Australia

This varies, some states have regulatory requirements that are specifically documented. Other States legislation is interpreted by the Regulator.

New South Wales

Under the 1978 Act: 2006 Risk Regulatory Framework and DSC Guidance Sheets.
Under 2015 Act: Dams Safety Regulation 2019 (late 2019), along with a new suite of guidance material.

Tasmania

Yes - Water Management (Safety of Dams) Regulations 2015, sets out the level of competence of a person undertaking dam activity, and Departmental and ANCOLD guidelines to be used when undertaking each activity.

Queensland

No - the regulatory body interprets the law and regulates accordingly.

Victoria

Yes, there is a regulatory instrument called the Statement of Obligations issued by the portfolio Minister. This requires large dam owners to manage dam safety risks and meet ANCOLD requirements and reporting requirements to the regulator.

Canada

Yes, there is a legal code on dam safety in the Province of Québec (Dam Safety Act and Regulations). The Dam Safety Act in Québec refers to protection against the risks associated with the presence of dams. For Flood and Earthquake hazards, the Québec specifies minimum requirements based on consequence class with flood standards set in terms of flood frequency or Probable Maximum Flood. The design basis earthquake is specified to have an annual exceedance frequency of 1:2500.

In the rest of Canada, Dam Safety is covered in various aspects of Government legislation relating to water resources and the environment. There are specific regulations on dam safety in the Provinces of Alberta, British Columbia and Ontario. Where specified, the performance expectations for floods and earthquakes are broadly similar to Québec regulations and the CDA Guidelines.

Comparison of Regulated Requirements in Selected Canadian Provinces

		BC	Alberta	Saskatchewan[6]	Manitoba[1]	Ontario	Quebec	Newfoundland and Labrador
Regulated Dams	New Dams	Y	Y			Y	Y	
	Existing Dams	Y	Y				Y	
	Dam Repairs	Y	Y			Y	Y	
	Tailings Dams	Y[7]	Y				Y[8]	
Defined in Regulation	Dam Definition	Y	Y			Y	Y	
	Classification	Y	Y				Y	
	Qualified Professional	Y	Y			implied[9]	Y	
	Risk Concepts							
	Inspection Requirements	Y	Y				Y	Y

[6] There are no regulations in Manitoba or Saskatchewan specifically related to dams.
[7] BC Ministry of mines regulates tailing dams.
[8] Regulated dams are determined based on height and impounding capacity. Any tailings dam meeting these criteria is governed by legislation.
[9] Under the LRIA an engineer is defined as "a person licensed under the *Professional Engineers Act* to practice professional engineering and appointed by the Minister for the purposes of this Act". Under LRIA 19(1), inspectors and engineers can be appointed for the purposes of the Act.

		BC	Alberta	Saskatchewan[6]	Manitoba[1]	Ontario	Quebec	Newfoundland and Labrador
	Annual Reporting	Y					Y	
	OMS Manual	Y	Y				Y	
	EPP	Y	Y				Y	
	Public Safety	Y						
	Dam Registry	Y					Y	
	Flow Control Testing	Y	Y				Y	
	Instrumentation	Y					Y	
	Fees					implied[10]	Y	

Czech Republic

There is Ordinance for dam safety supervision (Nr. 471 from 2001) defining more dam categorisation in more detail according to the potential of losses in case of dam break, dam safety supervision programme, reports, periodicity of measurements and inspections, etc. It is important to notice, that the categorization process is considering only potential life losses and damages, but the probability of failure is not taken into consideration.

Another one is the Ordinance for technical requirements for water structures (Nr. 590 from 2002 novelized by Nr. 367 from 2005). This ordinance defines basic technical rules and requirements for construction and rehabilitation of water structures and especially is defining the dam safety requirements for safe flood passages related to dam category, when for the large dams of I. and II. category there must be safe passage of flood wave with return period of 10 000 years.

There is also Methodology for Dam Safety Supervision (Nr. 1 from 2010) by Ministry of Agriculture (water structures categorization, small dam surveillance, vegetation maintenance on levees, safety of temporary flood protection structures on levees).

There are many national and European (Eurocodes) technical standards as well with relation to dam safety as well. Important is the national standard CSN 75 2935 assessment of dam safety at floods which is providing a detailed guidance for the process of flood wave routing, stability calculations and limit safety reservoir water levels.

France

None

Italy

For dams there is a specific technical regulation that fits in the context of general civil protection rules.

The Netherlands

In addition, constructions such as sluices must comply with building regulations most importantly the Eurocode.

[10] Fees are enforceable under LRIA 14(6) and 15(2). However, fees are not clearly defined, and no dollar amounts are given.

Slovakia

Yes, there is Decree of Ministry of environment for dam safety supervision (Nr. 119/2016 Coll.) defining system, procedures and methods of the technical safety supervision. The Annex Nr. 1 of the Decree contains categorization criteria and these are actually criteria for simple risk assessment based especially on quantification of potential life losses and damage of property, construction, industrial and agricultural production and of course environment caused by dam breach.

Sri Lanka

There is not any specific regulatory requirement for dam safety

United States of America

Federal Energy Regulatory Agency

Applicable FERC regulatory requirements for dam safety include two key documents: 1) the Federal Power Act, and 2) the Code of Federal Regulations. 16 U.S.C.A. §803(c) states “Each licensee hereunder shall be liable for all damages occasioned to the property of others by the construction, maintenance, or operation of the project works or of the works appurtenant or accessory thereto, constructed under the license, and in no event shall the United States be liable therefore."

18 CFR12 contains the FERC regulations related to dam safety.

Additional regulation and guidance is included in the FERC Engineering Guidelines for the Evaluation of Hydropower Projects.

US Army Corps of Engineers

USACE is self-regulated. USACE reports progress on dam safety activities to the U.S. Congress on a biennial basis as required by the National Dam Safety Act.

US Bureau of Reclamation

As stated above the Bureau of Reclamation is self-regulated. Reclamation reports progress on dam safety activities to the US Congress on a biennial basis as required by the National Dam Safety Act. Reclamation also coordinates dam safety activities at specific facilities within the individual States.

State of Colorado

2020 Rule 5. Methods to Determine Safe Storage Level.

Includes use of safety inspections, potential failure modes analysis, and Comprehensive Dam Safety Evaluations (CDSE). This is Colorado Dam Safety’s process for a consistent semi-quantitative risk assessment approach.

QUESTION 1.3

Are there any social or cultural traditions that prevent or limit the use of some type of risk assessment?

Argentina

There are no traditions that prevent or limit the use of some type of risk assessment.

Australia

No

Canada

Apparently not, but this matter has not yet been explored or tested in the public domain with respect to dams in any formal or structured way. However, given the spectrum of risk assessment methods available

ranging from standards-based through semi-probabilistic to full probabilistic, some type of risk assessment (usually standards–based scaled to a hazard frequency) is carried out routinely.

Czech Republic

Not known at this moment.

France

No, there are not. On the contrary, risk analyses performed within the safety review required that the owners and their consultant change their practices and integrate a new approach on many domains (not only civil engineering)

Italy

There are no graduations which in any way admit an acceptable risk calculated

The Netherlands

No, there are not.

Slovakia

No, as far as I know

Sri Lanka

There are not any social or cultural barriers for risk assessment of dams in Sri Lanka.

United States of America

Federal Energy Regulatory Commission

None that prevent the use; however, traditionally the US has used a conventional standards based (deterministic) approach to dam safety. Slowly, risk-informed (probabilistic) methods have started to be incorporated into use.

US Army Corps of Engineers

Generally, there are no social or cultural traditions that limit the use of risk assessment.

US Bureau of Reclamation

Generally, there are no social or cultural traditions that limit the use of risk assessment. There is sensitivity associated with life loss estimates and the tolerance implied in risk management decision-making. Native American cultures seems hyper-sensitive to life loss estimates.

State of Colorado

The biggest hurdles have been helping dam owners understand the benefit of risk analysis in helping to manage risk at their dam(s). There is still a significant group initially resistant to the risk process, primarily concerned about the unknown outcomes and the belief that their dam has performed “fine” for many years, “why do we need to dig into things more now?” In addition, dam safety practitioners in the US (including Colorado) have been reticent to educate those at risk, or their risks.

“We don’t want to scare people who live in dam failure inundation zones.” This leads to a lack of awareness on the part of those at greatest risk.

QUESTION 1.4

Are there any moral and ethical considerations that control the type or practice of risk assessment? If so, what are the dominant moral and ethical considerations?

Argentina

There are no moral or ethical considerations against any practice of risk assessment

Australia

No

Canada

Apparently not from a public perspective. However, these matters with respect to dams have not been explored or tested yet in the public domain yet. Further, risk assessment involves professional engineering activities and in Canada, the practice of professional Engineers has overarching an ethical expectation with respect to the safety of the public, property and the environment being held paramount. Research and other investigations into these matters are underway. The Canadian Dam Association is embarking on developing an approach to dealing with these issues.

Czech Republic

It is very sensitive to express the value of the life loss in money, so sometimes in some analysis the life loss is evaluated separately to the damage expresses in money.

France

No moral and ethical consideration limits or controls this type of practice. The regulations is relatively open to the different approaches

Italy

It is a traditional general approach of all national rules

The Netherlands

Protection of human life is most important. The standards are based on all type of losses such as loss of life, environmental losses, financial and economic losses by means of a CBA. The standard must be such that the probability for the Loss of life of an individual can nowhere be higher than 1:100,000 per year.

Slovakia

No, as far as is known –the evaluation of life value could be disputable

Sri Lanka

There are no moral and ethical considerations that control practice of risk assessment. However, professional ethics of dam engineers over their responsibilities to ensure safety during life cycle of the dam prevails dominant.

United States of America

Federal Energy Regulatory Agency

There doesn't appear to be any moral or ethical considerations regarding the use or lack of thereof of risk assessment. However, the dam owner and operator are in the legal position of being responsible for the safety of their dam, its operation, and the consequences of a failure should one ever occur. All dam owners should fully understand and appreciate their legal, regulatory, moral, and social obligations of owning a dam. Without a deliberate effort to understand the risks that a dam imposes on its surroundings, in both the magnitude and frequency of the hazards and magnitude of potential consequences, including impacts to life, health, and property, an owner cannot fulfil these obligations.

In addition to community interests, such as risks to life, third-party property (economic), and the environment, the owner needs to consider the financial risk relevant to business and asset risk management. This consideration should include business responsibilities to consumers and the

community, credibility and political issues, and potential financial and legal liabilities arising from a dam failure. Such considerations could warrant a higher level of safety than indicated by the assessed risk to life, economic, and environmental risks.

Dam owners, in setting their own tolerable risk policies, need to have regard to FERC's RIDM guidelines, legal and political constraints within which they operate, the legitimate interests of society as a whole, and to recognize good practice.

Finally the owner has a duty and responsibility to communicate information to the community on the risks associated with dam failure, operation, and flooding.

US Army Corps of Engineers

There are no known moral or ethical considerations that control risk assessments; however, these do factor into decision-making.

US Bureau of Reclamation

Moral and ethical considerations seems to stem from traditional standards-based practices and a level of design perceived to be void of risk. However, risk analyses have shown traditional standards-based practice to be just the opposite, and no dam can ever be completely fail-safe. Any tolerance for life loss seems to dominate the moral and ethical issues.

State of Colorado

For Colorado Dam Safety, our highest priority mission is to ensure public safety. While we pride ourselves on being "partners" with the dam owners whose structures we regulate, we are ultimately stewards of public safety and our moral obligation is to objectively assess design, construction, and performance history of a dam and complete an objective risk informed decision making process. This is typically a balance with the realization that in the semi-arid west (Colorado) some consideration must be given to the societal value of stored water. Next on the moral scale is the reality of economics; i.e., how much are we willing or able to spend to eliminate all risk.

QUESTION 1.5

What are the laws that a dam owner must comply with and how is risk assessment used in the process of complying with those laws? Please list the laws individually and the role of risk assessment in demonstrating compliance with the laws and regulations.

Argentina

Owners (concessionaires) must comply with dam safety provisions included in the concessions contracts and the regulations dictated by ORSEP (Nation Decree 239/1999). ***Australia***

Australia

These laws vary by jurisdiction. Examples from 4 states are given below.

New South Wales

Dams Safety Act 1978: Risk Assessment or Standards Based Approach allowable.

Dams Safety Act 2015: Risk regulatory approach will apply.

Dams Safety Regulation 2019: The owner of a declared dam must, as part of the safety management system for the dam, establish a risk management framework.

A risk management framework must include the following components:

(a) a hazard identification process,
(b) a risk analysis process,
(c) a risk evaluation process,
(d) a risk treatment process.

Tasmania

Water Management Act 1999 -sets out broad dam owner requirements. Water Management (Safety of Dams) Regulations 2015-sets out the level of competence of a person undertaking dam activity, and Departmental and ANCOLD guidelines that must be used when undertaking each activity.

Victoria

Refer section 5.3 of the following document.
https://www.water.vic.gov.au/__data/assets/pdf_file/0015/54330/Statement-of-Obligations-General.pdf

Queensland

Water Supply (Safety and Reliability) Act 2008 - guidelines articulate how risk assessment is incorporated into acceptable flood capacity for a dam. These laws vary by jurisdiction. Examples from 4 states are given below.

Canada

British Columbia

Water Sustainability Act and supporting Dam Safety Regulation. The Professional Practice of Dam Safety Reviews is in terms of Guidelines prepared by Engineers and Geoscientists BC, the professional licensing body.

Alberta

Water Act and supporting regulations, directives and codes of practice. The safety of dams and canals is administered in terms of part 6 of the Water (Ministerial) Regulation; the Water (Offences and Penalties) Regulation, the Alberta Dam and Canal Safety Directive, Ministerial orders and guidelines.

Saskatchewan

Water Security Agency Act. Reliance on CDA Guidelines

Manitoba

Water Rights Act

Ontario

Lakes and Rivers Improvement Act, an associated Administrative Guide and supporting technical Bulletins as well as a Dam Construction Regulation.

Québec

(Civil Code): Dam Safety Act and Dam Safety Regulation

New Brunswick

Clean Water Act

Prince Edward Island

Nova Scotia

Environment Act and supporting Regulation

Newfoundland and Labrador

Water Resources Act. Reliance on CDA Guidelines

Northwest Territories

Mackenzie Valley Resource Management Act (MVRMA), the Waters Act and Regulations, and the Mackenzie Valley Land Use Regulations. Requirement to follow CDA Guidelines

Nunavut

Nunavut Waters and Nunavut Surface Rights Tribunal Act

Dams under Canada Nuclear Industry

Nuclear Safety and Control Act

Parks Canada

Self-regulating Agency of Government of Canada.

Czech Republic

Described in 1.1. and 1.2

France

Decree N° 2015-526 of May 12th, 2015 relative to the rules for hydraulic structures preventing the floods and the rules for safety of the hydraulic structures. Order of 13th August 2015 giving the license rules for the consultants working in the field of the safety of hydraulic structures. Order of 15th March 2017 specifying the technical documents relating to the dams. Order of 17 March 2017 determining the height and volume of dams for their classification. Order of 6th August 2018 laying down technical requirements relating to the safety of dams. Order of 3rd September 2018 amending the order of 12 June 2008 defining the framework of the safety review of dams and specifying the content. This safety study is the document that proves the safety of the dam. In particular, it must gather the justification for respecting all the laws through these different chapters. This Safety review is compulsory for every A and B dams

Italy

For each HPP must performed a specific test that defines the correspondence of the work to the technical standard in force, Over time, circular letters have been issued on specific topics such as updates on hydrological and seismic safety levels to which all barriers must conform

The Netherlands

Standards are prescribed by the Water Act as maximum probability of failure based on a risk analysis (see 1.1 and 1.4). It must be shown that the structure has a probability of failure smaller than the set maximum.

Slovakia

Use of risk assessment is not prescribed by law.

Sri Lanka

The laws for dam owners to comply with are not developed in Sri Lanka.

United States of America

Federal Energy Regulatory Agency

Each state has its own set of laws that dam owners must follow. In addition, nearly every state has developed their own set of rules and regulations for dam safety that dam owners must follow. We are not aware of any state law, rule, or regulation requiring the use of risk assessment for dam safety.

US Army Corps of Engineers

There are no laws that USACE must comply with in the practice of dam safety. There are no laws that USACE must comply with in the practice of dam safety.

US Bureau of Reclamation

There are no laws that the Bureau of Reclamation must comply with in the practice of dam safety.

State of Colorado

CRS 37-87-105. Approval of plans for reservoir.

2020 Rule 7

CRS 37-87-107. Safety inspections – amount of water to be stored.

See response to 1.2 above.

QUESTION 1.6

Have there been any legal actions taken against a dam owner for noncompliance with laws and regulations whether with or without a risk assessment?

Argentina

Yes, there have been several legal actions taken against dam owners for noncompliance with dam safety regulations

Australia

Four in New South Wales. None recorded elsewhere

Canada

None recorded.

Czech Republic

Very seldom as the large dams are operated by state enterprises or large power station companies. There are a few cases known at private owned small dams.

France

Yes. Administrative and financial penalties may be enforced by the authorities. These tools have already been used against owners who do not respect the regulations in terms of dam safety.

Italy

Actions by state authorities have the effect of fines or increasing the order of partial or total decommissioning of the dam.

The Netherlands

Flood protection in the Netherlands is a public matter. The local Waterboards or the Ministry owns the majority of the flood protection structures. Private ownership of flood protection structures however is possible, but the owner has to comply with regulations issued by the local Waterboard or the Ministry. The responsibility is for the regulating party. There have been court cases, most recently about a dam failure in Wilnis in 2003. They set the jurisprudence.

Slovakia

Yes, there is possibility, but very seldom is used, to punish the owner with a financial penalty for not providing technical safety supervision

Sri Lanka

No.

United States of America

Federal Energy Regulatory Agency

Yes. See Binder document for a summary of some examples.

US Army Corps of Engineers

Lawsuits have been filed against USACE for a variety of reasons, but none of which involve the outcome of risk assessments.

US Bureau of Reclamation

There has not been any legal action taken against the Bureau of Reclamation for non-compliance with the Public Protection Guidelines. We seem to get resistance from Congress and the public for compliance with the Public Protection Guidelines and the justification to take action to reduce risk.

State of Colorado

3 elements of actions have been taken including:

A. Safe storage restriction – CRS 37-87-107. When a dam is deemed to be unsafe, Colorado Dam Safety has many times applied a safe storage restriction to temporarily reduce the hydraulic load on a structure. The storage restriction can be lifted once the owner proceeds through 37-87-105 process to complete designed/approved modifications to regain the safe storage in the reservoir.

B. Partial breach/lowering – when a safe storage level has been determined, but the dam owner has no physical conveyance means to maintain that reservoir level, a partial breach has been ordered.

Full dam breach – when a negligent owner has shown no response to compliance plans to meet safe storage levels, full legal recourse has been taken by State of Colorado Attorney Generals to breach a dam. 37-87-110 Allows the State Engineer to assume control of a dam and recoup any costs from the owner in ensuring the safety of the dam.

QUESTION 1.7

Are there legislative and regulatory provisions on dam safety that relate specifically to risk analysis/assessment and dam safety decision making informed by risk?

Argentina

No. There are not.

Australia

This varies by state jurisdiction. The requirement to risk assessment is deemed good practice and if not legislated; there is a requirement through statutory guidelines. NSW will have a legislated requirement by the end of 2019. There are two States with no legislation for dam safety, but there the major public dam owners follow the ANCOLD Guidelines on risk assessment.

Canada

The Alberta Dam and Canal Safety Directive (2018) requires that a dam/canal owner must undertake a formal risk assessment regarding the safety of a dam or canal when either (i) a critical safety deficiency is identified for that dam or canal, or (ii) an established quantifiable performance objective for that dam or canal is not met.

Czech Republic

Not explicitly

France

Yes, the orders of June 12 2008 and September 3 2018 provide the table of contents of a safety review and risk analysis (see question 1.9). At the moment decision making is not derived directly from the risk analysis results, but rather with a risk informed approach.

Italy

For each dam is planned the study of the areas affected by dam break and opening of gate openings

The Netherlands

See answer 1.1 and 1.5.

Slovakia

No

Sri Lanka

There is no legislative and regulatory provision on dam safety that relate specifically to risk assessment.

United States of America

Federal Energy Regulatory Agency

In 2016 FERC published draft risk-informed decision-making guidelines for dam safety that outlines the responsibilities and process for dam owners in pursuing risk-informed decision making.

US Army Corps of Engineers

As a self-regulating Federal dam owner, USACE is not subject to external regulatory provisions.

US Bureau of Reclamation

The Bureau of Reclamation is not compelled by regulatory provisions specifically related to risk analysis/assessment and decision-making.

State of Colorado

2020 Rules:

Rule 4.23. Potential Failure Modes

Rule 4.24. Potential Failure Modes Analysis

Rule 4.28. Risk, Risk Management, Risk Analysis

Rule 5. Determination of Safe Storage Level

Rule 5.2.2 Potential Failure Modes Analysis

Rule 7. Use of AEP to size spillways.

Comprehensive Dam Safety Evaluation

Process, PFM Templates, Risk decision guidance

QUESTION 1.8

If such legal and regulatory framework is absent, are there plans to develop and implement it?

Argentina

There is a Dam Safety Law proposed under consideration of the National Congress.

Australia

In the states without a requirement for risk assessment, there are no plans to develop and implement. ANCOLD is referred to in these jurisdictions.

Canada

The practical implementation of the Alberta Directive is at an early stage.

Other than Ontario which has had potential risk assessment regulations in place for several years, there are no other cases of authorities embarking on developing a regulatory framework based on risk.

Czech Republic

There are no special plans for further development at this moment known.

France

-

Italy

Nothing concrete

The Netherlands

-

Slovakia

It is only on the discussion level at present time

Sri Lanka

Yes. The dam safety regulatory body is proposed to be established to achieve these targets. A suitable national level institutional structure has been proposed by a panel of experts after studying the current issues in Sri Lanka and experience of other countries, specially referring to ICOLD publications over the matter.

United States of America

Federal Energy Regulatory Agency

Currently the FERC RIDM guidelines are issued as draft and dam owners are not required by FERC rules or regulation to perform risk assessments.

US Army Corps of Engineers

No plans known

US Bureau of Reclamation

No, a legal and/or regulatory framework around the practice of risk analysis/assessment and decision making would not serve the Bureau of Reclamation well.

QUESTION 1.9

List the regulatory documents defining how the process of risk analysis, evaluation and reduction is to be carried out. If the regulation is absent, list the guidelines or other documents used in developing the process.

Argentina

There is neither specific regulation nor guidelines for formal risk analysis, evaluation and reduction.

Standards Based, Generally Accepted Frameworks, expert and engineering judgement and experience are the basis of engineering analyses and dam safety decisions process.

Australia

State guidelines generally refer to ANCOLD risk assessment procedures with some local specific requirements.

Canada

In Alberta since 2018, a formal failure modes and effects analysis process is to be utilised. Otherwise there are no regulatory documents pertaining to the processes if risk analysis, risk evaluation and risk reduction. The Alberta Dam and Canal Safety Directive provides general broad requirements for conducting risk analysis.

Czech Republic

As the process of risk analysis is not commonly performed, there are no specific documents.

France

The process of the risk analysis is given in the Order of 3rd September 2018 amending the order of 12 June 2008. The framework and the required content is detailed : 0/Non-Technical Summary 1/ Administrative Information 2/ Scope of the study 3/ Functional and Descriptive analysis (internal and external to the scheme) 4/ Safety policies and management 5/Technical diagnosis accompanied by a condition, behavior and design reviews 6/ natural hazards, 7/ Accidentology and Incidentology study, 8/ risk analysis 9/ Risk reduction measures. Guidelines are provided by the authorities and the Frenchcold are working on a deliverable on the first version of risk assessment.

Italy

NN

The Netherlands

The national Water Act and all regulation that follows from it and the National building regulations, in particular the Eurocode.

Slovakia

Risk analysis as defined by ICOLD is not commonly performed, so there are no specific guidelines

Sri Lanka

Regulatory documents are not available in Sri Lanka.

In all Major, Medium & Minor dams -The level of risk due to failure of the dams is measured on the impact for the downstream reservoirs and the cascade system. Hence guidelines prepared by each organization for operation, maintenance and management are followed for risk assessments.

Hence, all the major dams are supervised, inspected, operated and maintained through procedures developed by each dam owner organizations following Technical guidelines published by Irrigation Department, SEED Manual of USBR and relevant ICOLD bulletins.

United States of America

Federal Energy Regulatory Agency

In 2016 FERC published draft risk-informed decision-making guidelines for dam safety.

US Army Corps of Engineers

No external regulations exist to define USACE processes/practice. ER 1110-2-1156 is the internal regulation that USACE adheres to. It is generally consistent with FEMA's "Dam Safety Guidelines" and "Dam Safety Risk Management". USACE, Reclamation, FERC, and TVA have contributed to and generally

adhere to the Best Practices for Dam and Levee Safety Risk Analysis that can be found at https://www.iwrlibrary.us/#/series/Best%20Practices-Manual

US Bureau of Reclamation

The Bureau of Reclamation's Public Protection Guidelines.

State of Colorado

Guidelines defined in CDSE process mentioned above. At this point, there is not a requirement for owners to complete the guidelines within the CDSE, instead Colorado Dam Safety is currently managing the completion of semi-quantitative risk assessments in concert with dam owners.

QUESTION 1.10

What arrangements are in place to determine if the laws and, where relevant the regulations, are being complied with?

Argentina

Owners are obliged to present monthly and annual dam safety reports to the regulatory authority ORSEP about compliance with all dam safety activities.

On site periodic inspections are carried out by ORSEP and owners dam safety agents

Dam Safety is periodically review by a board of independent consultants. These review takes place between one to five years (according the age of the dam or condition) and include civil and electro mechanic installations, structural behaviour, design criteria reviews, surveillance and monitoring provisions, emergency action plans and all other pertinent dam safety items. Owners are obliged to follow recommendations and to take corrective actions or to submit to ORSEP alternative solutions for approval.

Australia

Compliance activities vary but broadly speaking, dam owners are required to provide evidence of required regulatory or statutory guideline compliance. E.g. annual or 5 yearly inspection reports. There is also requirement for reporting of basic risk assessment outcomes to determine refer-ability and also to demonstrate compliance with flood capacity requirements.

Canada

Compliance arrangements vary considerably between Provinces and Territories. In general terms dam owners are expected to be able to demonstrate that they have completed Dam Safety Reviews at specific time intervals as required by regulations or as indicated in the CDA Dam Safety Guidelines. In some Provinces, formal inspections and audits are carried out by the Government authorities and fees/penalties can be applied.

Some jurisdictions have the power to order dam owners to comply with dam safety orders.

Czech Republic

No one.

France

A dam safety authority exists in each region of France. Dam safety Officers ensure compliance with the regulation on the safety of the works through, in particular, periodic inspections and by the examination of the various regulatory documents including the Safety Review

Italy

NN

The Netherlands

The national Inspectorate of Environment and Transport has the supervision over all aspects of Flood Risk Management by the water boards. According to the Water Act, the owner of primary water defences is obliged to carry out a safety assessment every 12 years. In case of the primary defences the instruments for safety assessment are provided by the Ministry and are known as the "WBI" Legal Assessment Instrument; the WBI consists of hydraulic boundary conditions and guidelines for safety assessment. The results have to be reported to the ministry (and the Inspectorate on Environment and Transport). In turn, the Ministry reports to Parliament. Besides in-depth safety assessments every 12 years, there are also regular maintenance actions and frequent visual inspections, the latter especially around flood events. Also, the owner must report annually to the Inspectorate on Environment and Transport to prove that he is in control (maintenance, action on results of the safety assessment, etc.)

Slovakia

Periodical controls made by state water authority (Environmental Care Department) on the district level

Sri Lanka

Not applicable.

United States of America

Federal Energy Regulatory Agency

Regulatory compliance with license articles and regulations are monitored and addressed internally within FERC.

US Army Corps of Engineers

The USACE Dam Safety Program is overseen by the HQ Dam Safety Officer (DSO). Each subsequent level of USACE (Divisions and Districts) has a DSO and Dam Safety Program Manager (DSPM) that oversee the technical aspects and day-to-day responsibilities of dam safety. Each District Commander has ultimate responsibility for dam safety. Extensive program metrics exist with which to monitor program performance, identify shortfalls in budget/execution, and results are rolled up to Division level and further to the Enterprise level. An independent external peer review (IEPR) of dam safety experts reviews and evaluates USACE Dam Safety Program every three years, and internal audits are conducted as needed.

Agencies are subject to audits by the Government Accountability Office (GAO) and the Office of the Assistant Secretary of Army for Civil Works (ASA(CW)) provided general policy and budget oversight.

US Bureau of Reclamation

The Bureau of Reclamation has a Dam Safety Officer separate from the program practice and execution to oversee and evaluate activities to ensure public safety on an ongoing basis. In addition, an independent external review panel (IRP) of dam safety experts reviews and evaluates Reclamations Dam Safety Program, annually.

State of Colorado

Coordination with owners through annual inspections.

QUESTION 1.11

Are there any penalties for non-compliance even if there has not been an incident or failure?

Argentina

There are penalties for non-compliance with dam safety requirements, even if there has not been an incident or failure.

Australia

Yes - varies across jurisdiction

Canada

Yes, typically but varies with jurisdiction.

Czech Republic

No

France

If non-compliance with the requirements there are possibilities of sanctions. However, this is progressive: information, formal notice, administrative and financial sanctions.

Italy

The operating limitation measure or complete exemption

The Netherlands

No, but in case of damage compensation can be claimed and one may start a trial because of negligence.

Slovakia

Yes

Sri Lanka

No. There may be internal inquiries to check whether the officers have neglected their duties

United States of America

Federal Energy Regulatory Agency

US Army Corps of Engineers

While there are no formal penalties for non-compliance, USACE strives to respond and resolve any issues or deficiencies identified by the Dam Safety Officer and/or the IEPR for the purpose of continuous program improvement. Frequent issues of non-performance could be grounds for removing DSO's or DPM's from their position.

US Bureau of Reclamation

There are no formal penalties for non-compliance. Reclamation is compelled to respond and resolve any issues or deficiencies identified by the Dam Safety Officer and/or the IRP. The Dam Safety Program reports progress to resolve issues identified in an annual accomplishments report.

State of Colorado

See response to 1.6, above.

QUESTION 1.12

Can the enforcement authority direct an owner to implement risk reduction measures? If so, are there any limitations on the costs of improvements directed by the Responsible Authority.

Argentina

ORSEP can direct and enforce an owner to implement risk reduction measures. Exceptions are when reduction measures imply a modification to the original design of the dam or it represents a disproportional alteration of the economic equation of the owner.

Australia

Regulator can direct the dam owner. The powers under which this can be done vary from specific - related to intolerable risk or under emergency powers.

Canada

In general, relevant authorities can direct dam owners to make dam safety improvements and to reduce reservoir elevations if necessary pending remedial works.

Czech Republic

Yes, the enforcement authority can direct an owner to implement risk reduction measures.

There are no limitations on the costs of improvements directed by the Responsible Authority

France

After a safety review, risk reduction measures are proposed by the dam owner. A prefectoral order enumerates them and imposes them with a deadline to the owner. The authority may also ask the manager to study new or other measures and impose them within the limits of the regulation. Orders can also lead to reduce the water level in the dam lake for safety reasons.

Italy

Dams are granted and the public authority has no limits in its power to request improvements

The Netherlands

No. Only when something goes wrong the question of liability comes forward.

Slovakia

Yes, it is possible and also used and there are no limits.

Sri Lanka

Since there are no enforcement authority it is not happening now. But the government can enforce through Disaster Management Act, if realised the extent of danger.

United States of America

Federal Energy Regulatory Agency

Penalties can be enforced for non-compliance with license provisions. Penalties can include monetary fines and can ultimately lead to termination or surrender of the license.

US Army Corps of Engineers

There is no applicable enforcement authority aside from chain of command. The USACE DSO could compel the Agency to implement risk reduction measures or order not to implement if there is insufficient risk justification or if it is not cost effective. There are no formal limitations on the cost, however cost effectiveness is a measure considered during plan formulation.

US Bureau of Reclamation

There is no applicable enforcement authority. Reclamation's Dam Safety Officer could compel the Agency to implement risk reduction measures. There are no formal limitations on the cost. Public Safety is paramount.

State of Colorado

When safe storage level orders are issued, Colorado Dam Safety provides a compliance plan providing a minimum list of risk reduction measures that can be used by the owner to develop a plan/budget for restoration of full reservoir storage.

QUESTION 1.13

Is the owner solely liable for the damages caused by dam failure under all circumstances, or does conducting a risk assessment limit the liability of the dam owner?

Argentina

The dam owner is solely liable for the damages caused by dam failure under all circumstances. Conducting a risk assessment does not limit the liability of the dam owner.

Australia

The dam owner is solely liable.

Canada

The dam owner is solely liable in all circumstances.

Czech Republic

The owner is fully responsible, but for example in case that the dam is ready to pass the control flood (let say 10 000 years flood), the owner would probably be OK if the dam would fail at even bigger flood. But this is not easy to say for 100%.

France

In theory, this is the owner who is the identified responsible. However, in the event of a major failure on a structure, a legal action will be taken, and the judges will define the responsibility of each stakeholder (owner, operator, authority ...). It is difficult to answer precisely to this question

Italy

Both the concessionaire and the supervisory authority have a role in the reliability of the system of protection of the territory and citizenship but in no case the risk assessment lightens their responsibilities

The Netherlands

In case of a flooding the event will most likely be declared a national disaster and costs are carried by the national government.

Slovakia

The owner is fully responsible, but the person providing a Dam safety supervision has its responsibility, too. Conducting a risk assessment is not the crucial question. But conducting the care of the dam according to law and recommendation of the dam safety authorized person has very decisive weight

Sri Lanka

As there are no private owners of dams, government organization has to take the responsibilities and the respective officers assigned to the dam site is answerable and shall be liable to face inquiries. However, the damages caused by dam failures under any circumstances are recovered with national government funding so far.

United States of America

Federal Energy Regulatory Agency

Yes

US Army Corps of Engineers

USACE operates with the acceptance of liability as entrusted by the public in the unlikely event of a dam failure.

US Bureau of Reclamation

There is no legal precedence, but Reclamation operates with the acceptance of liability as entrusted by the public in the unlikely event of a dam failure.

State of Colorado

CRS 37-87-104. Liability of owners for damage.

Determination of negligence must be shown.

QUESTION 1.14

Can criminal responsibility or culpability be assigned to an Owner or a Consultant if a dam that has been determined to be acceptably safe in accordance with a risk assessment fails or causes damage?

Argentina

If a dam fails or causes damage the Owner or a Consultant shall be charged for criminal responsibility or culpability, independently that the dam has been determined to be acceptably safe.

Australia

This is unknown presently as hasn't been tested in the courts but is theoretically possible if duty of care hasn't been complied with and this was able to be demonstrated.

Canada

There are no precedents at this stage. However, such a situation can be expected because of the way the legal systems operate. In particular the current position appears to be that a probabilistic (uncertain à priori) progression of a sequence of events in a failure will not lead to a negation of the certainty of the cause after the fact.

Czech Republic

Difficult to say, but probably not. Depend on the court process.

France

It is the Justice responsibility. In any case, in the French regulations on the safety of industrial assets, this point is not tackled

Italy

In the event of an accident all the actors are called to account of their activity before the law

The Netherlands

No, the responsibility lies with the Waterboard or Rijkswaterstaat; never with an individual or company, see also 1.6 an 1.13.

Slovakia

It depends on the situation and circumstances – in the end on the judgement of the court.

Sri Lanka

With regards to dam incidents there is no precedent so far. However, there is a trend developing on taking legal action against the officers who have neglected their duties. (After a recent incident of terrorist attack,

the Inspector General of Police and the Secretary of the Defence Ministry were charged against the negligence of duties.) Hence there is a possibility of assigning culpability to the higher officials of the dam owner organizations.

United States of America

Federal Energy Regulatory Agency

Courts will decide on liability for damages in a case by case basis. No known US case law for dam safety risk assessments limiting liability.

US Army Corps of Engineers

Criminal responsibility is difficult to access to an Agency of the Federal Government or its employees. Again, USACE would likely be liable in all situation if a dam were to fail regardless of the results of any risk assessment. Negligence would also be a factor for the courts to determine. Releases from USACE dams are made according to the Water Control Plan for each dam, and it represents a sort of legal contract between USACE and the public for how the facility will be operated in both normal and flood control conditions. Operating outside of the Water Control Plan could be grounds for criminal negligence in a court of law.

US Bureau of Reclamation

Criminal responsibility is difficult to access to an Agency of the Federal Government or its employees. Again, Reclamation would likely be liable in all situations if a dam were to fail regardless of the results of any risk assessment.

State of Colorado

See response to 1.13 above.

QUESTION 1.15

Are there any specific laws or regulatory instruments/directives that impose a particular economic philosophy or principles with respect to the economics (e.g. cost-benefit analysis) of safety improvement projects.

Argentina

There are not.

Australia

The principle of ALARP applies where dams are risk assessed as below the limit of tolerability which includes cost benefit analysis as one of several measures. Above the limit, given increased risks, there are none, the principle of equity applies.

Canada

There are not.

Czech Republic

There are no such specific laws or directives, but this is usually an internal process of the dam owner in his dam portfolio, or this process is undertaken at the Ministry of Agriculture higher level for large dams.

France

No regulations on this subject. Such a proposal was studied by the administration but was not considered relevant in the French regulatory context. Nevertheless, the safety review in their conclusions were able to propose ALARP approach

Italy

No exceptions to the principle of maximum caution

The Netherlands

The standards are based on a CBA. The Flood Protection Subsidies Regulation regulates what should happen if an important upgrade is to be performed due to an unsatisfactory result of a periodic safety assessment. Upgrading projects are financed by both the Waterboards and the State.

Slovakia

No, at present time

Sri Lanka

No specific laws and regulations at the moment. Cost benefit analysis of a project is considered by the government before implementation of the project. Even in the analysis, costs incur in safety is not considered specifically.

United States of America

Federal Energy Regulatory Agency

That would require a response from a legal professional.

US Army Corps of Engineers

While there are no specific laws or regulations that impose an economic philosophy, USACE considers cost effectiveness during plan formulation and also considers the principle of As Low As Reasonably Practicable (ALARP) when comparing various viable dam safety risk reduction alternatives. While there are no specific laws or regulations that impose an economic philosophy, USACE considers cost effectiveness during plan formulation and also considers the principle of As Low As Reasonably Practicable (ALARP) when comparing various viable dam safety risk reduction alternatives.

US Bureau of Reclamation

No, there are no specific laws or regulations that impose an economic philosophy. The Bureau of Reclamation considers ALARP when comparing various viable dam safety risk reduction alternatives.

State of Colorado

No. However, when project costs are high, local legislators sometimes get involved at the behest of dam owners, implying that dam safety regulation is excessively expensive.

FOCUS AREA 2 – GENERAL CONSIDERATIONS

QUESTION 2.1

What is the range and purposes of risk assessments e.g. screening, periodic dam safety review, prioritization, dam safety upgrade decisions, decisions that a dam is acceptably safe, and other applications?

Argentina

Traditionally dam safety risk assessments are required by regulation (standard based and generally accepted frameworks).

Risk assessment studies are carried out by the owner (concessionaries) under the traditional engineering practice (ICOLD B 61 criteria). No formal risk analysis is required. There is no explicit treatment of uncertainties. Factors of safety, standard based approach, traditionally engineering principles and expert judgement are applied. Regulation tends to require absolute levels of safety. Dam safety decisions and actions are taken in order to control hazards and consequences, in general without formal (explicit) consideration of risk.

The National Dam Safety Regulator ORSEP has made qualitative and semi quantitative risk assessments for dam safety risk screening and prioritization on a portfolio of dams.

Also has currently underway a detailed quantified risk assessment programme for 30 national dams. This is the first formal risk analyses and assessments program for dams in Argentina.

Australia

Risk assessments are used for all the reasons defined. Portfolio risk assessments were initially used by most large dam owners to understand the risks from their dams and prioritize dam safety upgrade programs. A number used the portfolio risk assessments to drive a program that got the overall societal risks below the ANCOLD "Limit of Tolerability" and individual risks to acceptable. After nearly 20 years, some organizations have achieved their risk goals and are now regularly reviewing the risk assessments as part of normal dam safety management programs. However, many owners are still progressing a program of risk reduction projects.

Smaller dam owners tended to do detailed risk assessments as part of / or after dam safety reviews to understand their risk. Risk assessments are also required by regulators in a number of states and they have been completed to satisfy reporting requirements to these regulators. It is generally required by these regulators that the dam owners are managing and reducing the risk of their dams in a programmed manner.

Risk assessments have also been used to determine risk management strategies to be incorporated during construction where work activities potentially increase the risk of the dam.

Canada

The use of risk assessments is very much dependent on the dam owner. A small number of the largest dam owners have used the full suite of available methods. Other owners have used a limited range of semi-quantitative and qualitative risk analysis techniques, including the PFMA methodology. In general, risk assessment (involving the full complement of risk analysis, risk evaluation and risk assessment) is not practiced by Canadian dam owners.

Periodic Dam Safety Reviews increasingly follow the related CDA Technical Bulletin on Dam Safety Reviews which included a structured approach to identification characterisation of hazards and failure modes. This approach includes consideration of combinations of causative conditions that give rise to failure modes.

Czech Republic

The described tools range is used in general

France

EDD every ten years for A-dams and 15 years for B-dams. A dead line is also set up, for every A-dams and B-dams to be in accordance with the goals of the order of the 2018/08/06

Italy

Each dam has ITS own specific control rules (FCEM) based on knowledge of their observed behaviour, the correct application of these check lists is monitored by the authorities by means of inspections, usually half-yearly.

On individual topics are issued address circular letters to which dealers must adapt

The Netherlands

As stated in answer 1.1, law lays down the safety standards in the Netherlands. According to that law, safety-assessments must be carried out every 12 years (see answer 1.10). In addition, the owner must report annually to the Inspectorate on Environment and Transport to prove that he is in control (maintenance, action on results of the safety assessment, etc.). The Flood Protection Subsidies Regulation regulates upgrade and prioritization.

Slovakia

This range and purposes of risk assessments will be very useful.

Sri Lanka

All above and allocation of funds on priority basis. Search of funds from lending organizations if the cost indicate by risk assessment cannot be covered within the available budget.

United States of America

The use of Risk Analysis and Risk Management in the United States is still limited mostly to the large dam owning Federal Agencies. A few dam owners and States begun exploring this area. They include PacifiCorp Energy, California Department of Water Resources, Grant Co PUD, and Chelan Co PUD. The major reason is that the State regulators have long been understaffed and underfunded and that limits their ability to move from traditional practice. Dam owners are reluctant to enter into risk assessments for fear of increased liability, higher insurance premiums, and a prevailing, if uninformed, belief that performing risk assessments is too slow and expensive.

The challenges perceived by the industry as reasons for not embracing risk: expensive to implement, difficulty of communicating what/how of risk, inconsistent methodology/terminology, and uncertainty. In addition some regulators are concerned with the lack of a uniform and consistent approach to risk analysis and risk evaluation criteria that will be appropriate across the entire country.

Federal Energy Regulatory Agency

Yes, all of these.

US Army Corps of Engineers

USACE utilizes the full range of risk analysis types (qualitative, semi-quantitative, and fully quantitative) for a variety of purposes described below. The analysis type should be no more complex than the level needed to make a decision. In general, all hazards are considered when formulating potential failure modes and consequences are rigorously estimated for both property damages and life losses.

Routine screening and portfolio prioritization – typically involves semi-quantitative approaches where all failure modes and loading conditions are considered, along with determination of both economic damages and life loss consequences. A Dam Safety Action Classification (DSAC) assignment is made to aid in portfolio prioritization.

Issue Evaluations – Team risk analysis conducted to better characterize risk and reduce uncertainty. Can use either semi-quantitative or fully quantitative methods. Outcome will form basis for recommendation to a) take action to reduce risk, b) investigate further, or c) return to routine activities with or without interim risk reduction measures.

Dam Safety Modification Study – Detailed risk analysis conducted to more fully characterize risk and reduce uncertainty of very specific subset of risk-driving failure modes. Can use either semi-quantitative or fully quantitative methods. Develops alternatives to reduce risks to a tolerable level. Outcome will form basis to take actions to reduce risks or return to routine activities with or without interim risk reduction measures.

Construction Risk Assessment – Detailed risk analysis, evaluate risks during construction, reservoir drawdown, construction phasing, timing, etc.

Post Implementation Evaluation – Detailed risk analysis, evaluate as-designed/as-built to verify success of risk reduction actions, project closeout.

US Bureau of Reclamation

Semi-Quantitative Risk Assessment – Periodic Dam Safety reviews, all failure modes considered, prioritization, identify issues and specific failure modes for further investigation/analysis

Issue Evaluation Risk Assessment – Team risk analysis, better understand risk, reduce uncertainty, specific failure modes evaluated, inform decisions to take corrective action as necessary

Corrective Action Risk Assessment – Team risk analysis, multiple evaluations during design process, better understand risk, reduce uncertainty, compare risk reduction alternatives, identify preferred alternative.

Construction Risk Assessment – Team risk analysis, evaluate risks during construction, reservoir drawdown, construction phasing, timing, etc.

Risk Reduction Verification – Team risk analysis, evaluate as-designed/as-built to verify success of risk reduction actions, project closeout.

State of Colorado

Primary statutory basis for Colorado Dam Safety is based upon CRS 37-87-107 – Determination of Safe Storage Level. SQRA based CDSE process' primary use is to help provide confidence in determining safe storage level at regulated dams. However, applications of this risk based decision making process have also been used in Colorado Dam Safety's inventory for screening, dam safety upgrade decisions, and emergency response actions. The SQRA process has also been valuable in general dam safety decision making.

QUESTION 2.2

Characterize the reasons why dam safety risk assessments are carried out in your country, considering that the following may apply:

- **It is required by regulation**
- **It is allowed by regulation as an alternative to traditional safety assessment based on engineering standards**
- **It is carried out for exploratory reasons**
- **It is carried out to optimize dam safety expenditures**
- **Other**

Describe typical risk assessment studies (purpose, context and scope: including owner, regulator and stakeholder considerations and risk assessment scoping factors such as types of outcomes, hazards considered, failure modes, types of consequences, desired level of confidence and how uncertainty was addressed).

Argentina

Traditionally dam safety risk assessments are required by regulation under standard based and generally accepted frameworks.

ORSEP is running a risk assessments programme to complement traditional dam safety assessments, prioritization of upgrade dam safety on the nation existing dams, optimize safety expenditure in the future and orientation on dam risk tolerability.

Risk assessment studies are carried out by the owner (concessionaries) under the traditional engineering practice (ICOLD B 61 criteria). No formal risk analysis is required by regulation. There is no explicit treatment of uncertainties. Factors of safety, standard based approach, traditionally engineering principles and expert judgement are applied. Regulation tends to require absolute levels of safety. Dam safety decisions and actions are taken in order to control hazards and consequences, in general without formal consideration of risk.

The Nation Dam Safety Regulator ORSEP has made qualitative and semi quantitative risk assessments for dam safety risk screening and prioritization on a portfolio of dams.

Also is running a programme for a detailed risk assessment of 30 national dams. Main purposes are prioritization and complementary support for future dam safety decisions. This are the first formal risk analyses and assessments program underway for dams in Argentina.

Australia

Either as an independent dam or in a portfolio assessment of multiple dams, the dam owner / manager will seek services from a dams consultancy (or internal engineering sections in some states with an external reviewer) to complete a detailed risk assessment as per ANCOLD 2003 Guidelines on Risk Assessment. The methodology applied is as per Qu. 3.1 below.

The reason for a dam owner to complete the risk assessment varies. Around the time the 2003 guidelines were released, owners began to explore risk assessments as a way to determine how urgent remedial works were and how to reduce the scope of works to mitigate deficiencies highlighted in dam safety reviews as not complying to "standards based design". The required remedial works to complete "standard based designs" on a portfolio of dams was usually cost prohibitive and would result in serious cost implications to users. Risk assessments were beginning to be used as a way to determine the urgency of works and prioritize them to form a risk reduction strategy for the owners.

Later, regulators and larger state-based water authorities began to require all large dams with Hazard / Consequence categories greater than "Significant" to have risk assessments completed and regular reporting of the dams risk status. In recent years this has been extended to smaller dams such as service basins and retarding basins by water authorities.

The main outcome required by all dam owners from a risk assessment is an indication of how the dam compares to the ANCOLD 2003 Risk to Life criteria. The ANCOLD Societal F-N chart is largely looked at as a graphical depiction of the risk status of a dam, although individual risk criteria also needs to be satisfied, it is generally a lesser requirement to be met.

Based on the risk outcome, the owner often then wants an understanding of works/costs that can be completed to reduce the risk. Finally, owners want to know their obligation and timing to complete any works. Where risks are unacceptable, industry precedent and requirements by most regulators is to reduce the risk as soon as practicable. Where risks are below the "Limit of Tolerability", an ALARP assessment is required and again industry precedent, and more recently regulator guidance, depicts the timeframe that works are required. In general, industry and regulators want to see a logical and order strategy to incrementally reduce the risk of dam portfolios.

Canada

Risk assessment when it is used tends to be very case specific. Types of risk assessment have ranged from simple scoping level qualitative assessments up to an including the most rigorous seismic liquefaction risk assessments that has been carried out to date.

For routine safety assessments, identification, and characterization of hazards (and their combinations) and failure modes, structured in terms of Fig. 21 of ICOLD Bulletin 154.

Overall, where risk assessment is carried out in Canada, the concepts and approach set out in Chapter 4.4 – 4.6 of ICOLD Bulletin 154 are followed.

Often, risk assessments or risk screening is carried out in combination with Standards Based Assessments to optimize and prioritize dam safety expenditures.

Czech Republic

- It is required by regulation
- It is carried out to optimize dam safety expenditures

These studies and dam documents are usually elaborated in the process of regular dam safety supervision system by authorized companies, or sometimes by designers at the preparation process of dam rehabilitation. But usually, the probabilities of failure modes are not calculated and only failure modes analysis is performed. Also, the consequences are not expressed, so these studies are not fully risk analysis

France

It is required by regulation and • It is allowed by regulation as an alternative to traditional safety assessment based on engineering standards. Both are indicated here because we have regulations on dam safety which give objectives in terms of failures (order 2018/08/06) and other targets not covered by this regulation where the risk analysis may complement it (2018/09/03). The regulations give minimal requirement on selected hazards and failures (order 2018/08/06). For more details on the methodology of risk analysis, types of outcomes, hazards considered, failure modes, types of consequences, the dam risk assessment guidelines can be downloaded from the French environment ministry (http://www.barrages-cfbr.eu/IMG/pdf/risk_assessment_french_guidelines.pdf). What's more, a FrenchCOLD deliverable will be published soon on the risk analysis, to illustrate the methods of risk assessment used by the owners and their consultants to comply with the regulations' requirements

Italy

It is required by regulation

The studies on the possible risks induced by a dam follow general guidelines of the existing legislation and specific sector rules that are part of the Civil Protection Plans of each territory

The Netherlands

Dam safety risk assessment is required by regulation. See also answer 1.1 and 1.5. All the accepted models and other tools used within the field flood risk are subject to a review-process involving experts, users and stakeholders. Models and descriptions are maintained by the Ministry and are in principle available for all users. All standards have been certified by the parliament after an extensive political discourse primarily in the Delta Program. For details see VNK report "The National Flood Risk Analysis for the Netherlands" to be downloaded on https://www.helpdeskwater.nl/publish/pages/131663/vnk-rapport-eng-lr.pdf+C9

Slovakia

I think the 2nd (It is allowed by regulation as an alternative to traditional safety assessment based on engineering standards) and 4th (It is carried out to optimize dam safety expenditures) are most often used reasons

Sri Lanka

In Sri Lanka it is carried out to optimize dam safety expenditures and in limited cases for exploratory reasons. Most of the ancient earthen embankment dams in Sri Lanka are major dams except recently constructed few concrete and rock fill dams.

Hence risk assessment has been carried out under a project with the assistance of external consultants to produce emergency action plan, to identify the roles and responsibilities of stake holders, identify the failure modes in individual dams, mapping the inundation areas, assessment of social and environmental damages

United States of America

Federal Energy Regulatory Agency

The many benefits of the RIDM approach are well documented (ANCOLD, 2003; Bowles, 1998; Regan and Boyer, 2009). Examples of some of the purposes risk has been used to inform dam safety decisions include (modified from Environment Agency, 2009):

- To systematically identify and better understand potential failure modes.
- To identify, justify and prioritize investigations and analyses to reduce uncertainties in risk estimates for individual dams and an inventory of dams.
- To strengthen the formulation, justification, and prioritization of risk reduction measures for individual dams and an inventory of dams.
- To justify decisions on reservoir operating restrictions.

- To identify ways to improve dam safety through changes in reservoir operation, monitoring and surveillance, safety management systems, staff training, emergency action planning, and business decisions related to dam safety.
- To identify opportunities to improve the effectiveness of warning and evacuation plans.
- To identify cost-effective options for more rapidly achieving reduced dam safety risks.
- To justify expenditures on dam safety improvements to owners and economic regulators.
- To identify and understand those risks that exist through normal operation (non-failure risk) of the project.
- To provide a framework for quantifying engineering judgment and communicating technical issues with dam owners in a more open and transparent manner.
- To facilitate the evaluation of dam safety risks to the public in a manner that allows comparison with other infrastructure and technological hazards.
- To provide a non-technical basis for communicating dam safety risks to the public.
- To provide a basis for development of a safety case or safety demonstration for owners and regulators.
- To assess the adequacy of insurance coverage.
- To strengthen the basis for corporate governance related to dam safety risks.
- To strengthen the exercise of the owner's duty of care, due diligence and legal defensibility with respect to dam safety incidents or dam failure.

A few benefits are worth highlighting:

- A greatly improved understanding of the safety of a dam. Risk analysis greatly improves the understanding of the dam's safety by the systematic analysis of the logic of failure mechanisms. In this sense, it is not just the numerical results, which usually have wide uncertainty, but the risk analysis process, which is the real benefit of risk assessment.
- A means of analyzing and assessing risks in areas where no traditional standards have been established. There are areas of dam safety where no clear, widely accepted SBA has been established, in particular for evaluation of the safety of existing dams, for example the reliability of spillway gates, internal erosion, and human/operational factors, to name just a few. Risk assessment provides a systematic and rationale approach for dealing with such areas.
- A proper understanding of the potential liabilities of dam ownership. The estimation and evaluation of the risks specific to a dam provides an owner with an appreciation of the liabilities that the business faces. Such an appreciation is critical to business planning.
- A basis for demonstration of due diligence.

Many dam safety engineers and managers have taken the view that, if a dam meets the traditional engineering standards, then the residual risks are negligible and can therefore be tolerated. Many in the profession have come to this potentially incorrect conclusion through a long process of discussion and experience, but without actually knowing what the residual risks are. However, the residual risks are rarely zero. Risk assessment involves an examination of all hazards, an explicit estimation of residual risks, such as risks to life, and a judgment of their tolerability, and is therefore an aid to a dam owner in foreseeing risks to others and in taking timely and proportionate action to reduce risk where needed, thereby demonstrating the discharge of the duty of care.

US Army Corps of Engineers

See response above.

Risk assessments are carried out to screen and prioritize dam safety issues; evaluate specific issues identified during a periodic review or as a result of monitoring or observed unusual condition; identify needed additional information or investigations; evaluate, compare and optimize risk reduction alternatives; evaluate construction risks; evaluate and verify risk reduction.

Uncertainty is addressed in the course of risk assessments either qualitatively or quantitatively, depending on level of analysis and magnitude of the decision to be made. The uncertainty is used by decision-makers to judge whether it can be reduced and how it can affect the decision to proceed to the next step.

US Bureau of Reclamation

See response above.

Risk assessments are carried out to:

- screen and prioritize dam safety issues,
- evaluate specific issues identified during a periodic review or as a result of monitoring or observed unusual condition
- identify needed additional information or investigations
- evaluate, compare and optimize risk reduction alternatives
- evaluate construction risks
- evaluate and verify risk reduction

Risk assessment generally consider life loss consequences and the level of confidence increases and uncertainty is reduced as the risk assessments become more refined through the process from issue identification to resolution.

State of Colorado

Colorado has 100+ year old dams in our inventory. Issues are not always obvious and there is a desire to understand, so-as-to-avoid consequences of latent defects built into our existing portfolio of high hazard dams (430 as of this writing). The dams that were designed well, constructed well, and have performed well can be differentiated from the opposite. Future inspections can be focused on areas of concern, safe storage levels can be determined and actions to reduce risks identified. Allocating the right and right amount of resources to a given dam is the goal, so that limited resources can be utilized strategically for the greatest risk reduction. The process starts with digitizing historic files and cataloguing them by date, document type, topic, recipient(s), etc., into a content management system. With an easy to follow, sort and differentiate set of project documents, the detailed file review can be done efficiently to determine weakness in design, construction or manifested in performance histories. Dam owners and their engineers are brought in to the early stages of this process to work alongside regulators so they all understand the dam's strengths and weaknesses at the same time. Facilitated PFMA starts with a screening list of PFM's, determining which to carry forward. Carried forward PFM's are worked through and positive and adverse factors described. PFM likelihood is determined as are consequences. Results are plotted on an F-n chart and appropriate actions are determined to address risks and/or increase confidence in likelihoods. The process is repeated for various PFM's and the risk drivers are identified. By the end of the process, invariably, all involved can see clearly the issues at hand (good and/or bad) and know that the actions recommended are justified and in the best interest of all.

QUESTION 2.3

What type(s) of risk analysis: qualitative, semi-quantitative, quantitative are used

Argentina

ORSEP risk assessments program, currently underway, include failure mode analyses, qualitative and detailed quantitative risk analyses and assessments.

Semi-Quantitative Risk Assessment (SQRA): Screening level approach; FMEA failure modes and effects analyses; rough estimates for consequences, loss of life and direct economic loss.

Australia

Qualitative and semi-quantitative assessments have not been used for dam safety purposes generally for 20 years. Assessments now are completed using detailed quantitative processes. Qualitative and semi-quantitative methods are only used for review of less tangible consequences such as Work, Health and Safety (WH&S), Environmental Impacts, Business Risk, Cultural Heritage, Societal Concerns etc.

Canada

These different types of risk analysis are used quite extensively by some of the largest dam owners. Qualitative, semi-quantitative and quantitative methods have been used as has stochastic simulation. The most common approaches to risk analysis are qualitative and semi-quantitative using Failure Modes and Effects Analysis, Event Tree Analysis and Fault Tree Analysis. There has been some limited use of the Potential Failure Modes Analysis methodology.

Recently, Alberta Environment have explored the use of a semi-quantitative hybrid PFMA/FMEA approach to assessing the safety of their dams. Currently, TransAlta is preparing for a comprehensive risk assessment study of two river systems with TransAlta dams. The study will utilize stochastic simulations approach in analyzing systems' risk.

Czech Republic

It depends on many factors. Quantitative is not used often, the probabilities of failures are not usually defined numerically.

France

On natural hazards quantitative risk analysis could be used. In the major part, it is more a semi-quantitative or qualitative estimation (for example on sealing failure, drainage system failure, gate dysfunction…) based on expert opinion.

Italy

No responses

The Netherlands

Quantitative analysis. See also answer 1.1 and 1.5.

Slovakia

There was not made any study about risk analysis use.

Sri Lanka

Major dams, through portfolio risk assessment, quantitatively and semi-quantitatively.

For small dams identifying dam breach sections and impact analyzing.

United States of America

Federal Energy Regulatory Agency

Yes, all of these

US Army Corps of Engineers
All, but most commonly semi-quantitative.

US Bureau of Reclamation

All, but most commonly quantitative.

State of Colorado

Colorado Dam Safety's CDSE process/guidelines are based on semi-quantitative risk assessment approach. However, Colorado Dam Safety has a strong background and understanding in quantitative risk assessments as well as an accepted practice for determining the annual exceedance probability for inflow design flood events (REPS/MetPortal). Colorado Dam Safety team members have the ability to refine risk estimates using a quantitative approach, but ultimately express likelihoods of risk and consequences qualitatively to speak in plain language to dam owners.

Colorado Dam safety experience has shown that, in general, the SQRA approach is sufficient for our decision making and risk management needs.

QUESTION 2.4

Provide a general characterization of risk criteria or guidelines applied in the risk evaluation process

Argentina

ORSEP risk assessment program currently follows USACE and ANCOLD criteria and SPANCOLD guidelines.

Australia

ANCOLD (1993) Risk Guidelines evaluation criteria is used for risk to life (Societal and Individual Risk). Economic Risk is determined for owners to assess their business risk. Probability of failure is used by some owners to review other less tangible risks such as to the environment, reputation, societal concerns etc. to compare against their own risk management criteria.

Canada

In Québec, and given the probabilistic characterization of natural hazards, the criteria specified in the Dam Safety Regulation serve as risk criteria.

There are no Government authorised risk evaluation criteria or guidelines in the rest of Canada. The CDA Dam Safety Guidelines provide guidance similar to ANCOLD, although its use in decision-making has generally not been reported. There is potentially one case that might set a precedent in the future.

Individual dam owners are required to arrive at their own interpretations of the CDA Guidelines, relevant ICOLD Bulletins, and generally accepted international practices to the extent that they are contextually relevant to the specific situation.

Czech Republic

Risk evaluation process in full range is not being performed normally for dams.

France

Except the minimum criteria set in the order of 6th of August 2018 for certain failure scenarios, the tolerability of scenarios is left to the free appreciation of the owner and his consultant.

Italy

No responses.

The Netherlands

See answer 1.1 and 1.4. The criteria are loss of life, material damage, non-material damage such as damage to ecological- and cultural heritage, vital infrastructures and group risk.

Slovakia

Risk evaluation process is not being used in dam safety performance regularly

Sri Lanka

Risk criteria are basically over the loss of life, social disruption, and economic loss to the nation.

United States of America

Federal Energy Regulatory Agency

The following fundamental principles apply to the overall objectives of the FERC Risk Guidelines:

1. Life safety is paramount.
2. 'Do no harm' must underpin all actions intended to reduce dam safety risk.
3. Risk should inform the decision process. Decisions are not 'risk-based'.
4. Identify and reduce the risk to life and property posed by dams and reduce those risks to as low as reasonably practicable (ALARP).
5. The urgency of completing dam safety actions should be commensurate with the level of risk.
6. Dam safety inspections, surveillance and monitoring, emergency action plans and testing, owners dam safety plan, Part 12D Reports, training, and other routine dam safety activities are all essential parts of an effective dam safety risk management program.
7. Risk communication must be well planned, timely, and involve all parties potentially affected by the decision or a failure of the dam.

The FERC RIDM Risk Guidelines provide tolerable risk guidelines for life safety (both societal and individual). The tolerable risk guidelines are similar to other US dam safety agencies and international organizations.

US Army Corps of Engineers

USACE describes its criteria in detail in Chapters 1, 2, and 5 of ER 1110-2-1156. It generally follows the framework outlined in HSE's "Reducing Risk and Protecting People" document from 2001. USACE is working with Reclamation, FERC, and TVA to achieve a common risk management framework and guidelines as outlined in the Federal Guidelines for Dam Safety Risk Management,

US Bureau of Reclamation

Reclamation' Public Protection Guidelines

State of Colorado

SQRA likelihood and consequence categories and quantitative boundaries are based upon USBR guidance documents. For example, a "Very High" likelihood of failure has a lower limit of 10^{-2} AEP. In other words, a high hazard dam where there is potential loss of life should not fail during a 100-year storm event. The consequence categories are based on orders of magnitude of loss of life and also allow for consideration of property and environmental damage. Colorado Dam Safety has found significant value in the use of "confidence" as part of the likelihood determination.

QUESTION 2.5

Describe the quality control and quality assurance arrangements and how they are implemented.

Argentina

Owners are responsible for dam safety activities, operation and maintenance of the dam and auxiliary works and installations, in compliance with ORSEP regulations and obligations and standards set up in the concession contracts.

Monthly and annual dam safety reports are submitted to ORSEP for review and approval. Monthly reports include monitoring and instrumentation data, dam behaviour, detailed description of activities, special features or incidents eventually occurred. Dam safety annual reports summarizes the structural behaviour and condition of the dam and auxiliary works and installations, incidents and response actions taken, dam safety improvements, electro mechanical testing on discharge facilities, anomalies which have occurred and corrective actions, emergency action plan exercises and any significant dam safety information.

Periodic field inspections by regulatory officials in conjunction with the owner are made at the site of the dam, in order to audit the compliance with regulations, dam safety procedures, the correct maintenance and functioning of the installations.

Annual testing of discharge devices, valves and gates, are performed by the owner with the presence of ORSEP officials.

Large high consequences dams are periodically audit by independent dam safety experts with participation of owner`s engineers, technical staff, independent consultants and ORSEP officials. Technical audits include all civil and electromechanical installations. Independent consultants must review all aspects of dam safety, structural and functioning behaviour, validity of design criteria, quality control provisions, emergency action plans and other pertinent dam safety issues.

Australia

Generally, dam owners recognise a select group of companies and individuals to perform the risk assessments. Risk assessments are also generally completed in a workshop environment, so a single bias is not allowed into the assessment. Generally, an independent pier reviewer or panel is appointed to review the assessment.

Canada

Independent peer review by eminent expert consultants is common for major dam safety assessments of all types. If the assessment is in the form of a periodic Dam Safety Review which is by far the most common type, the dam owner will rely on the Consultant's Quality Assurance process. In British Columbia, the Engineers of BC has additional quality assurance requirements and all formal dam safety reviews and audits must be reviewed and accepted by the regulator.

Czech Republic

Usually during the elaboration there are regular meetings where owner and risk analysis author

France

Safety reviews should be led by a licensed consultant, and the risk analysis (in this safety review) should be performed by a multi-disciplinary group. Finally, the dam safety authority examines the report.

Italy

No responses

The Netherlands

See answer 2.2. Besides that for all safety related documents the quality is controlled by a group of water defence specialists in the so called Expert Panel Water Defences.

Slovakia

It is not prescribed officially

Sri Lanka

Individual dam owners are practicing different emergency management procedures giving special focus on flood controls with 24/7 surveillance roster systems and supplied with additional resources stationed at Dam sites with machinery etc.
Emergency Action Plans have been prepared for reasonable number of high-risk dams.

In house review have been done by dam owner organizations. Sharing of experience and obtaining technical advice from competent organization too are being practiced.

United States of America

Federal Energy Regulatory Agency

Formal review processes are established for the independent review of risk assessments through the formation of a Risk Review Board (RRB) for quantitative risk analyses. In addition, FERC will review risk assessment reports submitted by licensees.

US Army Corps of Engineers

All risk assessments whether they are done internally by USACE or externally by consultants are peer reviewed for technical and methodological consistency. The magnitude of the reviews are scaled depending on the importance of the safety decision. At a minimum, risk assessments are reviewed by two groups of agency experts. For complex decisions, external consultant boards review both the risk assessments and the actions taken by the agency.

US Bureau of Reclamation

Technical analyses and Risk Assessments are peer and technically reviewed. Technical Products, recommended action and recommended decisions are reviewed by a Dam Safety Advisory Team. Decisions are approved by a three party TRIAD of stakeholders. All decisions and actions are reviewed by and independent Dam Safety Officer.

State of Colorado

Programmatic peer and manager review provide consistency QA/QC around the State.

QUESTION 2.6

What are the public consultation processes with respect to safety decisions for individual dams?

Argentina

There are no public consultation processes with respect to safety decisions for individual dams. ORSEP have different communication programmes and activities, to media, schools and society, about dam safety policies and activities.

Australia

Experience to date is that the public is not generally involved in risk assessments or dam safety decisions. Need to complete work is decided primarily by owners and regulators. The public is generally made aware of dam safety upgrades as part of community consultation prior to commencing works. However, there are several cases where the community have been consulted on deciding the scope of risk reduction works.

Canada

This depends on the dam owner and the jurisdiction. The range of consultation activities and the amount of consultation is highly variable, but expensive public deliberations taking months or years are sometimes required, especially if there are several groups with entitlement to utilise the water.

Czech Republic

There is no

France

The public is only informed about the result of the risk analysis, in particular consequences.

Italy

No responses

The Netherlands

See answer 2.2. Besides that for all safety related documents the quality is controlled by a group of water defence specialists in the so called Expert Panel Water Defences.

Slovakia

There are no public consultation processes prescribed

Sri Lanka

There is no practice for public consultations for arriving safety decisions. However, information provided by general public during dam incidents is taken seriously. Voluntary organizations offer their support for emergency repairs etc.

During a recent dam safety rehabilitation project direct beneficiary of the irrigation reservoirs were consulted to get their views over improvements necessary such as emergency access, common bathing place, etc.

United States of America

Federal Energy Regulatory Agency

Typically public consultation is the responsibility of the dam owner.

US Army Corps of Engineers

Prior to modifying any structure, and especially during a Dam Safety Modification Study, the National Environmental Policy Act (NEPA) is followed to engage the public for comment on the study and proposed risk management measures. Public meetings are held, and public outreach materials are prepared and presented in the form of brochures/pamphlets as well as on web sites. The public does not participate in the risk analysis, assessment, or decision-making.

US Bureau of Reclamation

Project stakeholder and beneficiaries are engaged throughout the risk identification, evaluation, assessment process. Project stakeholder, beneficiaries, Congress and the public are engaged on corrective actions at individual dams.

Stat of Colorado

Colorado Dam Safety has established a public facing website that allows for public tracking of dam information including hazard classification, condition assessments, safe storage level, dam safety projects under review, including modifications and new dams. The public not consulted in our work, but they have the opportunity to review and comment on our regulatory actions. Further, CRS 37-87-109 requires Colorado Dam Safety to respond to public complaints of unsafe dams.

FOCUS AREA 3 – RISK ANALYSIS

QUESTION 3.1

What are the fundamental principles of currently applied risk analysis methodology?

Argentina

Under currently risk analysis methodology (traditional dam engineering), regulated by ORSEP, risk analysis is implicitly (not explicitly) considered in dam safety assessments. The overarching dam safety objective is to protect people, property and the environment from the harmful effect of mis-operation or failure of dams and reservoirs. Efforts tend to the highest standards of safety that can reasonably achieve. Dam safety decisions are supported by standards, safety factors, traditional engineering and expert judgement.

ORSEP risk assessments program underway follows ANCOLD and USACE fundamental principles for risk analysis (Hazards identification, failure modes and effects analysis, risk controlled, review and risk communication, f-N, ALARP and Cost Benefit Analysis are recognized). SPANCOLD Guidelines for Risk Analyses are followed. This program is complementary to the traditional established dam safety practice regulated by ORSEP.

Australia

The first step of a risk assessment is to identify the different components of the dam, screen the hazards (initiating events) to be considered, and identify all possible associated failure modes. The failure modes are also screened to identify potential credible failure mode that could lead to an uncontrolled release of water through the embankment or foundations, for inclusion in the risk assessment as part of a Failure Modes Effects Analysis (FMEA).

Loading domains, covering the full range of events likely to impact the dam from the annual event to the extreme event, are partitioned into load states for use in the risk assessment. For risk reporting purposes the load states are usually grouped into normal operating conditions, flood conditions and seismic events.

The failure modes are then broken down into the sequence of events required to lead to a failure and the system response (conditional probability) of each event calculated. Event trees are used for each failure mode to estimate the system response.

The system response is then combined with the probabilities of the load states to determine the annual probability of failure for each load state in each failure mode. The annual failure probabilities are then corrected to account for common cause factors (e.g. water load or earthquake loading common to a number of failure modes), and then multiplied with the consequences to calculate the annual risk.

The societal risk and individual risks of a dam breach are then calculated to complete the risk assessment. Finally, the results of the assessment are evaluated against current risk evaluation criteria to determine whether the risks from the dam are tolerable.

Canada

Fundamental principles, originally derived from Canadian Standard on Risk Analysis CAN/CSA-Q634-M91 and ISO 31000 – Risk Management pertain to:

- Competence and accountability
- Systematic and structured
- Explicit treatment of uncertainty
- Documentation and transparency
- Quality assurance and verifiability

The approach of a structured Failure Modes Identification and Event Tree analysis that was first introduced in 1993 by BC Hydro provides the basic platform for risk analysis for dams in Canada where risk analysis is used. This structure has all the characteristics of the structured approach to characterisation of the failure modes fault tree illustrated in Figure 21 of ICOLD Bulletin 154. The CDA Technical Bulletin on Dam Safety Reviews includes this structured approach and provides extensive advice on its implementation.

Czech Republic

Fundamental principles of risk analysis are everywhere the same. Otherwise it would not be risk analysis. I mean probability of failure and consequences must be calculated (estimated).

France

A comprehensive diagnosis is performed before risk analysis - detailed visual inspection and condition assessment of the dam and all its safety related components;
Then “Standard” Risk Analysis steps are used:

- Functional analysis
- Failure modes analysis - inductive approach starting from the Undesired Central Event (UCE) going backward to Initiating Events (IE)
- Failure scenarios modeling - bow-tie diagram
- Reliability assessment - semi-quantitative approach, probability classes
- Consequences assessment - estimation of impacted people based on inundation maps
- Mitigation measures analysis

Italy

Risk analysis not applied

The Netherlands

See answer 1.1 and 1.5. Individual (external) risk, and considerations on costs-benefits, group risk and critical infrastructure are considered.

Slovakia

Risk analysis methodology is not obligatory prescribed

Sri Lanka

In Sri Lanka, fundamental principles are based on analysis of failure modes of Individual dams and in only certain cascades where few high dams are located to analyze the cascade effects.

United States of America

Federal Energy Regulatory Agency

As defined by the International Commission on Large Dams (ICOLD), risk analysis is “the use of available information to estimate the risk to individuals or populations, property or the environment, from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification, and risk estimation.” (ICOLD, 2005).

The risk analysis process involves the scientific characterization of what is known and what is uncertain about the present and future performance of the dam system under examination (ICOLD, 2005). It is a structured process aimed at estimating both the probability of failure of the dam or dam components and the consequences of failure (often, though not always, restricted to those consequences resulting from uncontrolled release of the reservoir).

The risk analysis results will be reviewed, scrutinized, and debated. The risk analyst or team must be prepared to explain and defend the logic behind the risk estimate. This process leads to better decisions in an environment of imperfect information. A group of experts will rarely agree on all of the details of a risk analysis but can usually obtain agreement on the key decisions and the path forward. This agreement is achieved by working for consistency between the risk estimate, recommended actions, and understanding of the situation (i.e. does it make sense?).

US Army Corps of Engineers

That the risk analyses should be based upon the best available scientific methodologies, information, and data; the characterizations of risks and of changes in the nature or magnitude of risks should be consistent with available data; the judgments used in developing a risk assessment, such as assumptions, defaults, and uncertainties, should be stated explicitly along with the rationale for these judgments and their influence on the risk assessment; they should encompass all appropriate hazards, considering the full population at risk; and the risk analyses should strive for consistency and be peer reviewed to achieve the highest professional standards.

US Bureau of Reclamation

Reclamation does not perform risk analysis at the portfolio level (risk management only). All of the answers below are related to the risk analysis of individual dams.

That the probability of failure by an individual PFM can be calculated as the intersection probability of the trigger and response events that comprise the PFM. That the probability of failure for an individual dam can be calculated as the union probability of the controlling PFMs at the facility.

State of Colorado

Historically, consequences of dam failure have been captured within the hazard classification of the dam. More recently, we have more closely evaluated the consequences of failure within a given hazard classification (i.e. high hazard). Fundamental aspect of our risk approach is to identify the risk driving potential failure modes for the highest consequence dams. This allows us to focus our efforts on dams with the highest risks.

QUESTION 3.2

Does the risk analysis include dams as part of a system, not only as part of a portfolio of dams, but also with respect to surrounding water defences?

Argentina

Under risk assessment programme (detailed quantifications of probability of failure and consequences) currently underway by ORSEP, there is only one case in which a dam was considered as part of a system. The surrounding water defences against flooding on the regulated river has been considered, only for the consequences' estimation due to overtopping.

Australia

In Australia, dams on a waterway generally have only a single or limited number of dam owners and/or managers. Dams in cascade on a river system are usually analysed bearing in mind impacts from upstream and consequences downstream of the other dams.

Coincident flooding from neighbouring catchments either adding to inflow or outflow from a dam are included in hydrological and dam break analyses.

Canada

A small number of analyses based on formal Systems Engineering approaches have been carried out on river systems by some of the largest dam owners. This is to capture in a static sense system interdependencies over and above that which can be captured using discipline-based deterministic and probabilistic approaches. Other owners of smaller dams such as Alberta Environment and Parks are adopting this approach in a greater or lesser degree.

Czech Republic

No.

France

Yes, the risk analysis includes dam as part of a system. Typically, spillways and bottom outlets civil and electromechanical components with all their control equipment are included in the analysis. For example,

the failure of an upstream dam is considered. Complex hydraulic schemes can include several hydraulic structures which are included in the risk analysis (typically run-off rivers scheme can include 1 or 2 dams, a powerplant, gates, a lock, a channel etc..).

Italy

Risk analysis not applied

The Netherlands

Yes, the risk analyses are based on models that include the whole system. For example, the hydraulic load reduction on levees behind a storm surge barrier is taken into account. The consequences of one water system on another as a result of levee breaches are only included in specific areas where relevant.

Slovakia

Risk analysis not obligatory prescribed

Sri Lanka

As risk analysis is in an initial stage, system wide risk analysis are not carried out, except in certain cascades as explained in 3.1.

United States of America

Federal Energy Regulatory Agency

Most dam safety risk analyses consider dams individually and not integrated as part of an overall system. There are many reasons for this. Individual dams are often part of larger infrastructure systems. Within these watershed systems, risk is attributed to the specific infrastructure that is the source of the risk. This includes due consideration for cascading impacts in the 'downstream' direction. If failure or non-failure of the dam being assessed would result in overtopping and subsequent breach of downstream dams and/or levees, then the risk associated with these cascading failures would be attributed back as a consequence to the dam being assessed. Risks generated by failures of 'upstream' infrastructure are usually not considered at the downstream dam being assessed. If failure of an upstream dam would result in overtopping and breach of the dam being assessed, then increases in the magnitude and frequency of loading caused by failure of the upstream dam would not be included in the risk estimate.

To support inventory prioritization decisions or to communicate the flood risk from multiple flooding sources, there may be a benefit in estimating the risk from a systems perspective in certain situations. These analyses can support improved prioritization decisions within the larger watershed to obtain more efficient and effective risk reduction across the inventory. In these special cases, it may be appropriate to evaluate the cascading impacts of failure in both the 'upstream' and 'downstream' directions.

US Army Corps of Engineers

While many dams are operated as a system, a risk assessment is focused on the individual dam. Hydrologic frequency analyses do take into account upstream dam regulation. Dam breach models will include downstream structures and whether or not those structures are overtopped during breach. Teams will discuss the potential for those downstream facilities to breach, but the probabilities of breach are not determined. Nor is the probability of an upstream dam breach factored into the risk assessment. It is difficult enough to estimate the probability of failure of one dam, let alone joint probabilities of multiple breaches. In the future, risk assessments will take into account downstream coincident flows due to multiple dams operating in the same watershed during an extreme flood event and its effect on consequence assessment.

US Bureau of Reclamation

The basic unit of meaning in Reclamation risk analysis is the individual facility (as defined by the authorization for that project), and risks are tracked at the individual facility level, even when there are multiple dams located in series. The interaction between the dams, and the ability to optimize the overall

risk of the system, would only be considered if one or more of the dams was being modified, in order to help identify a preferred alternative.

State of Colorado

As a regulator of dams, our primary focus for any risk assessment is the safety of the dam. There is some consideration for site security, but water delivery infrastructure not associated with the dam is not part of our regulatory authority. Some larger dam owners that also have expansive water delivery systems, are in the process of utilizing portfolio risk assessment tools in risk framework for prioritization. These activities are also done collaboratively, and Colorado Dam Safety gets benefit from participating in them.

QUESTION 3.3

Does the risk analysis process treat dams or complexes of dams as dynamic systems and apply modern systems engineering concepts and analytic techniques? Are dynamic aspects of system responses accounted for in calculating the probability of dam failure and if they are, how it is being done?

Argentina

For the only case of risk analysis completed (3.2) on a system of several dams, a risk model (loads, probability of failure, consequences) was developed for different scenarios. Floods into the reservoir were obtained from hydrological study; reliability of spillways was estimated by event trees, historical records and expert judgement; hydrographs for different return periods, pool levels and gate performance; probabilities estimations of overtopping modes of failure were obtained through reliability analysis; dam break hydrographs and consequences estimation (loss of lives and economic damage). Failure probabilities by overtopping have been estimated using standardized fragility curves.

SPANCOLD Guidelines on Risk Analysis Applied to Management of Dam Safety have been followed.

Australia

Risk assessments are generally completed on the dam in its current state. Commentary is made on potential impacts to the risk assessment in the future due to deterioration of infrastructure elements (such as Geomembrane liners) or potential changes in downstream consequence due to development / shifting populations. It is part of the dam safety management procedures, particularly intermediate and comprehensive inspections or dam safety reviews, to determine when the conditions at a dam have change and warrant a review of the risk assessment.

Canada

There is a comprehensive risk assessment study where stochastic dynamic simulation has been applied to a river system in Ontario that was intended to capture the static and dynamic performance of the entire system. Stochastic simulation of river systems with multiple dams avoids separation of loadings and system responses in the analysis, which may and often do interact. It also allows to model the full range of system responses instead of commonly used binary response (dam failed; dam did not fail). Capturing this phenomenon is important in multi-dam systems when disturbed operation of some dams may change the probabilistic characterization of hydrologic loadings for other dams.

Czech Republic

No

France

See 3.2. If necessary, yes. Time dependent calculations might be carried out for example to compare the required time for the dam owner to be on site compared to the raise of water level. Dynamics hydraulic simulation of consecutive dams might also be performed when required.

Italy

Risk analysis not applied

The Netherlands

For our storm surge barriers, the full complexity of the system is considered to determine the safety. For this time dependant calculations are made considering the probability of closure, barrier failure, storm duration, overtopping rate, and the allowed storage volume behind the barrier.

Slovakia

There was not made any study about use of risk analysis

Sri Lanka

Modern engineering concepts and analytical techniques are not applied in many organizations in analysing of existing dams. There is a lack of knowledgeable resource persons in these organizations. But major dams under two organizations (Irrigation Department and Mahaweli Authority) who practice risk analysis to certain extent treat dams as dynamic systems.

Risk assessments of 63 major dams were conducted under the World Bank funded “Dam Safety and Water Resources Planning Project” which concluded in 2018

United States of America

Federal Energy Regulatory Agency

US Army Corps of Engineers

No. USACE uses risk analyses/assessments to help identify facilities for which there is increasing justification to reduce or better understand the risk.

US Bureau of Reclamation

No, because that is not what the process is intended for. The purpose of risk analysis is to help identify facilities for which there is increasing justification to reduce or better understand the risk. The PFMs considered as part of this process must be conceptualized to the extent that those involved in the risk analysis understand what is being considered and what they are being asked to estimate. Not every single detail of the failure process needs to be captured in order for the team to develop and understanding of what is driving the risk at the facility.

State of Colorado

No, we are not familiar with these applications of risk assessment in Colorado.

QUESTION 3.4

What methods and analytic techniques are used to determine probability of dam failure?

Argentina

Fragility curves and expert judgement have been used for the estimation of probabilities of dam failure.

Australia

Primarily the "Piping Toolbox" by Fell et al (2008) is used to determine piping / internal erosion risk for earthen embankments and Silva, Lambe and Marr (2008) for slope stability. Where no such procedures exist, probabilities are estimated with reference to databases of knowledge and using guidance such as Barneich et al (1996).

Canada

In the small number of publicly available cases where quantification has been carried out, the approach has relied on physics models of the behaviour of the systems with probability distributions of the physical values of engineering parameters in the model being assigned either based on statistical data where it is available or structured expert opinion of the probable values of the physical parameters in the engineering models. Expert elicitation of the range of probable values of engineering parameters in the physics model takes place when objective parameter data is not available.

A quantitative risk screening tool jointly developed by Hatch, the Ministry of Natural Resources and Forestry and Ontario Power Generation has been used by several dam owners to supplement the PFMA process in the performance of full quantitative risk assessments, to prioritize the portfolio of dams and to develop risk profiles of portfolios.

Other methods and techniques used in risk assessment studies include fault trees, general reliability techniques and statistical models developed using empirical data.

There are no standards or practices for dams that correspond to a Level III Probabilistic Safety Assessment (PSA) as practiced for public safety assessment in the nuclear industry. Further, there are no standards of risk analysis practice for dams that might be equivalent to a PSA Level II for a nuclear power plant.

Czech Republic

Statistics of dam failures and stochastic numerical modelling of dam stability. Expert estimate as well

France

See 3.1. The calculation of probability is mostly done in France by using a semi- quantitative approach with probability classes. Fault trees are modelized with bow-ties diagrams. A deductive approach is used, starting from an UCE (undesired central event) going backward to Initiating Events (IE). All kinds of IE are considered:

- Intrinsic structural issues (Internal erosion, sliding, material ageing, etc.),
- External threats (floods, earthquakes, etc.),
- Equipment dysfunction (gates, transmission, control system),
- Human behavior, organizational issues.

Italy

Risk analysis not applied

The Netherlands

There is a whole range of techniques being used depending on the failure mode, ranging from empirical formulae to advanced probabilistic calculations and finite element methods. Necessary software is made available. The probabilistic calculation is based on a Level III approach.

Slovakia

It depends on expert choice

Sri Lanka

Probability of dam failure is basically analysed considering floods in different probabilistic rainfall.

United States of America

Federal Energy Regulatory Agency

FERC is responsible for the development, dissemination, and interpretation of methodology guidance for use in conducting dam safety risk analyses. As the state of the practice for risk analysis continuously

evolves and improves, the FERC should be contacted for the most current risk analysis guidance. The Best Practices for Dam and Levee Risk Analyses has been developed jointly between the USACE and the BOR for the purpose of summarizing the overall philosophy, methods, and approach to risk analysis for dam safety (BOR/USACE, 2015). The BOR/USACE 'Best Practices' manual is generally maintained and updated on an as needed basis. The current version of the 'Best Practices' manual may be obtained from BOR (refer to web link in references) or from the USACE. Unless otherwise directed by FERC, the risk teams should use the 'Best Practices' manual to guide their efforts in determining the loads, the conditional probability of failure associated with each failure mode, and the consequences associated with each potential failure mode.

The methodology contained in the 'Best Practices' manual provides a suite of scalable analysis approaches that provide information to promote critical thinking and guide a risk analyst's (facilitator or subject matter expert) judgment. These methods are scalable and can be applied with varying degrees of effort (time and cost) to provide the appropriate level of accuracy and rigor required to make credible risk estimates. It is important to understand that every decision does not require a high level of rigor, detail, and accuracy in the risk estimate in order to support a credible decision.

Risk teams and those that are responsible for conducting risk analyses are accountable for understanding the methodology, making and documenting credible and transparent decisions on key input parameters, explaining why the results either do or do not make sense, and adjusting the risk estimate accordingly (USACE, 2014). This will require some judgment and team elicitation to translate the results obtained from the risk methodologies and other likelihood factors to a logical risk estimate. The risk analysis team must apply an understanding of the potential failure modes, key factors, uncertainties, and sensitivities to obtain a risk estimate that they are willing and able to defend with a set of logical arguments.

US Army Corps of Engineers

USACE uses a combination of event tree and fault tree analyses supported by the appropriate engineering analyses for individual failure mechanisms.

US Bureau of Reclamation

Basic probability theory.

State of Colorado

Semi-quantitative and quantitative approaches are used to determine probability. This is based on flood frequency loading understanding, USBR, USACE, and ICOLD best practices for determining likelihoods of initiation, progression, continuation, intervention, and breach associated with internal erosion, overtopping, static slope stability, and seismic failure modes. Currently, the CDSE process establishes a "library" of PFMs, event trees, and worksheets that address these different mechanisms. The primary goal of this library is to establish a consistent PROCESS in evaluating and judging the probability of any of these nodes. All positive and adverse factors are captured in writing for each node of the event tree and the team judges the PFM likelihood and their confidence in that determination.

QUESTION 3.5

What are the relative extents of the use of physics-based models and inductive models of failure and failure consequences processes? For example, are analyses based on largely engineering judgment-based estimates, statistical data or models of physical processes?

Argentina

No ad hoc physical modelling was carried out, although run off computational modelling was carried out in the affected areas. It has been considered within the risk model the probability of failure by overtopping from standardized curve of recognized bibliography.

Expert judgement has been applied to define the degree of damage caused by dam failure or uncontrollable spill on goods and infrastructure.

Australia

The methods described above are mainly based on analysis of statistical data. Other than piping and stability, physics based models are used to determine potential scenarios for varying loadings (i.e. progression of scour to undermine dams in flood, earthquake induced damage to concrete structures, etc.) and judgement use to estimate probabilities of failure from this. The use of probabilistic analyses to generate reliability curves is seldom used.

Canada

The full range of approaches are used depending on the circumstances. Qualitative and judgmental approaches are used at the scoping stage, moving to semi-quantitative methods as the investigation develops to physically based quantitative methods where appropriate. The semi-quantitative approaches usually rely on probabilistic specification of the hazard based on data in conjunction with deterministic response analysis. For the more advanced applications by the larger dam owners, physics models of functions and functional failures using statistical data, material properties obtained from investigations, and expert interpretation of the physical data, including expert estimates of the probability distributions of the physical parameters in the models are the predominant type of analysis. Complex stochastic simulations of the physical functioning of river systems has also been carried out providing failure frequencies that can be applied as the best estimates of failure probabilities.

Czech Republic

Dam break studies (which carries some signs of risk analysis) are usually based on physical process models. The results are often compared to empirical equations and statistics data

France

See 3.4. and 3.6.

Italy

Risk analysis not applied

The Netherlands

The instruments for safety assessment consist of hydraulic boundary conditions and technical guidelines for safety assessment. It includes models to use, which failure-modes to consider, such as overtopping, slope stability, backward erosion, stability of revetments and gate reliability (failure of closing) and formulas to use. See also answer 1.10.

Slovakia

It is not possible to generalize practice without making study

Sri Lanka

Failure modes of existing dams are based on the engineering judgement, mathematical modelling and not by physical modelling. For new designs modelling od spillways being done to decide the engineering parameters.

United States of America

Federal Energy Regulatory Agency

All of the above are used depending on the models and information available.

US Army Corps of Engineers

USACE uses industry-standard methods to calculate hydrologic and seismic loading. USACE uses physics-based analytical tools to calculate probabilities or to anchor subjective probabilities used in the

event tree or fault tree analyses to calculate the probability of failure. USACE uses a simulation-based model founded on empirical life loss estimates from historical dam failures to estimate consequences.

US Bureau of Reclamation

Hydraulic modelling is used exclusively in the preparation of inundation maps for life loss consequence estimation, not as part of the PFM evaluation. For the purposes of the PFM, the breach mechanism would be conceptualized so that the likelihood of breach could be estimated, but the temporal aspects of the breach process would not be considered because there is no sense of time in the basic probability framework. Temporal aspects are considered when developing inundation maps because they can have an impact on the peak discharge. In that context, empirical equations would be used to estimate the breach development time.

State of Colorado

With respect to failure likelihood: Finite element seepage stability models are regularly employed as a basis for understanding gradients, seepage regimes, driving/resisting forces. These models are calibrated through iterative sensitivity analyses, corroboration with piezometers and seepage collection systems, and real world understanding of performance history of dam. These models are used to inform best practices and engineering judgment decisions, particularly for internal erosion (concentrated leakage vs. backward erosion) failure modes. Hydrologic evaluations are tied in using REPS deterministic and probabilistic extreme precipitation estimating tools. Rainfall is transformed to runoff using HEC HMS models to determine spillway adequacy.

With respect to failure consequences: Most evaluations of consequences are based on 2 dimensional dam breach inundation mapping (HEC-RAS 2D). Colorado Dam Safety has been a leader in developing consistent guidelines for dam breach guidelines based on USACE/USBR best practices, and utilizing Census data to correlate inundation boundary to population at risk (Social Vulnerability Index). These models help provide a basis first of all for determining the Population at Risk during a certain failure loading condition, but also aid in understanding travel times, depths, and velocities to help refine actual Loss of Life using USBR Risk Consequence Estimating Methodology.

QUESTION 3.6

Is expert judgment used in order to estimate the probabilities associated with dam safety risk analysis? If it is, what methodology is used for expert opinion elicitation?

Argentina

Expert judgement has been used for the qualitative assessment of the operation and the degree of safety of the electromechanical equipment. The experts have been participated in the failure mode sessions (FMEA) and been interviewed by the risk analysis performers.

Australia

Yes, risk assessments should be completed in a workshop environment with dam engineering and risk professionals. The workshops should review potential failure modes for the dam, the steps to failure using an event tree and probabilities of each step. The decisions made are noted during the workshop as well as any difference of opinions. Where differences of opinions occur, the range of probabilities are tested in a sensitivity analysis.

Canada

Expert judgment is used to various degrees in various ways. At a minimum, the type of mapping of verbal descriptors of probability to numerical values as set out by Whitman in 1984 and modified for dams in 1993 (BC Hydro, 1993). The more serious applications utilize structured approaches such as Cooke's method or the methods set out in the SSHAC methodology. The principles and approaches are set in Risk and Uncertainty in Dam Safety (Hartford, DND and Baecher, GB, 2004, Thomas Telford).

Czech Republic

Sometimes yes. A group of independent experts can be used to have more objective estimates

France

Expert judgement is widely used to estimate the probability class of each Initiating Event (IE). They are usually based on multiple criteria:

- Comprehensive diagnosis, detailed inspections,
- Technical notes and reports (calculation, models, etc.)
- In addition, most consulting firms have internal guidelines based on feedback and experience to help to assess them. These internal guidelines are important to ensure consistency between risk analysis of different dams. It enables to compare the results and to prioritize actions within a portfolio of dams.

Italy

Risk analysis not applied

The Netherlands

Yes, especially as a supplement, for example as input for fault tree analysis or interpretation of results.

Slovakia

I think so, but I have no information about used methodology

Sri Lanka

Yes. On experimental basis a group of experts were appointed recently to inspect the dams and review the risk of dams. There is a proposal to expand this activity by incorporating them into a new organizational structure responsible in national dam safety review.

United States of America

Federal Energy Regulatory Agency

Expert judgment is one of the methods used to estimate probabilities. Expert elicitation follows the methodology provided in Best Practices in Risk Analysis for Dam and Levee Safety (2018) as published by the Bureau of Reclamation and US Army Corps of Engineers.

US Army Corps of Engineers

USACE uses expert opinion elicitation as described in detail in Chapter A-6 from the Best Practices in Dam and Levee Risk Analysis. (https://www.iwrlibrary.us/#/series/Best%20Practices-Manual)

US Bureau of Reclamation

Reclamation uses expert judgment to estimate the conditional probabilities of the response events of a PFM. It is the responsibility of the risk analysis facilitator to ensure that the staff making risk estimates are qualified and reasonably well calibrated. Engineering judgment is converted into subjective probability using a scale of verbal descriptors as a starting point for estimation (except in cases where there is statistical data available that can serve as a starting point). No specific expert elicitation methodology is applied or endorsed.

State of Colorado

Yes, a Colorado Dam Safety facilitator leads the PFMA workshops held with Colorado Dam Safety engineers, dam owners, qualified consultants. The facilitator is responsible for eliciting likelihoods for failure modes from this group in a SQRA approach.

QUESTION 3.7

Explain methods that are used for estimating impacts on affected population

Argentina

In the only case mentioned before (3.2) loss of life and economic consequences were estimated from the

flooded areas defined by computational modelling. USBR-Graham method has been used for estimating loss of life. Reference mortality rates were taken from SUFRI methodology (2010), based on the rates proposed by Graham (1999) and linked to different categories of understanding of severity (depending on levels of emergency communication, coordination among intervening agents, training and existing of emergency action plans).

Australia

Flood modelling to evaluate coincident flooding for selected breach scenarios.

Breach analysis using parametric breach parameters and input to flood modelling

Hydrological modelling for flood and breach scenarios using 1D models to determine depth and velocity data for the downstream inundation area at each building for use with RCEM life loss estimation method or 2D modelling to evaluate the flow data for flood and breach scenarios for use in HEC LifeSim. Most inundation modelling is now completed with 2D hydraulic models.

Estimate PAR for each building.

Use RCEM or HEC LifeSim to estimate Potential Life Loss

Canada

The type of modelling varies with the situation. Approaches range from simple approximations based on 1-D flood models at one end to the spectrum to physically based dynamic simulations using the Life Safety Model. Model types range from simple estimates based on regression models (DeKay and McClelland), empirical models (Graham, DSO-99-06 or RCEM), HEC FIA, HEC LifeSim, Life Safety Model (LSM) – with or without the Loss of Life mode activated. Other approaches within these bounds are also used. In some cases, multiple models such as LSM and HEC LifeSim used together might be applied in a multiple model analysis. The principles of life safety analysis are set out in Risk and Uncertainty in Dam Safety.

Czech Republic

In the process of dam categorization, the given relationships are used from the Methodology, where the fatalities ration is dependent simply on the distance from the dam. In case of broadly used hydrology flood risk analysis, a common relationship is used, where the water speed and depth are the main variables and the number of fatalities is depending on the real information of inhabitants in the flooded area.

France

Dam break modeling is performed to estimate the number of impacted people and properties according to inundation maps:

- For dam failures
- For gate failures or unwanted opening. Simplified analytical methods might be used for small gates. The purpose is to give an order of magnitude of impacted people and properties: 1-10, 10-100, 100-1000 etc.

Italy

Risk analysis not applied

The Netherlands

The impact on the affected population forms the basis for the set standards (see answers above). The water depth and velocity of water level rise determine the number of casualties and material loss. To account for losses of cultural heritage, nature, production and other no- material losses multiplication factors are used. They are such that they could be used in a cost benefit analyses. The casualties and all people who are somehow affected by a flood event are hereto monetarised by 6,7 M Euro and 12000 Euro, respectively.

Slovakia

According to existing law for dam categorization the analysis of the terrain configuration is used, as well as analysis of dam breach and breach wave impacts depending on distance and volume of reservoir are used.

Sri Lanka

The inundation area due to the breaching of the selected dam section were mapped in the DEM after running several models for selected dams. In other cases, GIS maps and primary topographical maps are used to assess the damage to lives, livelihood and environment.

United States of America

Federal Energy Regulatory Agency

In general, FERC uses the methodology to estimate human life loss consequences in accordance with the procedures outlined in the Best Practices in Risk Analysis for Dam and Levee Safety (2018) as published by the Bureau of Reclamation and US Army Corps of Engineers.

US Army Corps of Engineers

Life safety is the focus for managing risk in USACE's portfolio of dams. A scalable approach is utilized for direct life loss starting with empirical methods at the screening level up to agent-based simulation to explicitly model the evacuation process for higher level assessments. Each assessment level provides an estimate of the initial population at risk of being exposed to the hazard and life loss. With simulation methods, a better understanding of risk drivers such as evacuation potential and shelter survivability is achieved. By modelling the evacuation process, USACE can inform potential risk reduction through non-structural measures such as early warning systems.

Indirect life loss is quantitatively estimated using a combination of historic data and downstream population characteristics to inform indirect fatality rates as a percentage of the population at risk. An indirect flood fatality can occur during or after a major flood event, and is typically caused by multiple factors with the flood contributing to unsafe conditions or part of a chain of events that leads to death. Common indirect fatalities include: stress-induced medical conditions (e.g. heart attack, suicide, etc.); exposure while stranded by water; infections or water-borne sicknesses due to contact with water; and lack of medical treatment for chronic conditions or minor but treatable ones.

US Bureau of Reclamation

The life loss consequences of a dam breach are estimated using an empirical method known as RCEM. The method assumes that the fatality rate in a given portion of the inundation area can be estimated as a function of flood severity and the amount of warning received. This relationship was developed based on case history data compiled by Reclamation consequence specialists over the last several decades. The potential range of life loss would be calculated by multiplying the range of fatality rates selected by the risk analysis team by the number of people present at the time of the breach. Considerations such as the potential for successful evacuation would be taken into account when selecting fatality rates or assigning warning categories.

State of Colorado

See response to 3.5, above. USBR guidance for categorizing the consequences into relative orders of magnitude is employed (i.e. Levels 1 to 4, that includes considerations for Level 1 having unlikely potential for loss of life, up to a Level 4 being large population centers 100+ loss of life). Social Vulnerability Index also provides an indication of the Population at Risk's ability to respond to and recover from a dam failure event.

QUESTION 3.8

Explain methods for estimating downstream consequences and assessment of:

- **Damage to property (direct, indirect or both**
- **Damage to the environment**
- **Damage to cultural heritage**
- **Societal impacts**

Argentina

For the aforementioned case, direct and indirect economic consequences damages were estimated (road infrastructure; water and sanitation; agriculture; irrigation; cattle raising; industry; commerce; tourism; education; health; housing; electricity; hydrocarbons and gas). Indirect damage due to the flood was also considered.

A geo-referenced information system GIS was used, where representative variables were included in each item (for example, educational establishments) to identify the effects of different flood scenarios.

Based on GIS data and unit costs, it was possible to estimate the associated costs by items and scenarios in spreadsheets. A damage curve was generated versus maximum flow discharge (by spilling or failure), which was incorporated into the risk analysis model.

Damage to environment, has not been estimated. No protected areas were identified on the affected areas.

Damage to cultural heritage, has not been estimated.

Societal impacts: Damage estimate reaches affected urban and rural areas, infrastructure and production damages. Damages related to social consequences (e.g. deceased) have not been considered.

Australia

A detailed risk assessment requires computer modelling of dam break floods. Current practice is to use a 2-D hydraulic model to calculate depth and velocity of flood waters across the potential inundation area. The depth and velocity is used to determine likely damage to properties and risk to life based on published data.

Damage to environment is generally assessed using a depth x velocity relationship to determine immediate impact and likely long-term impact to the downstream environment. Extent of initial damage and severity of damage to flora and fauna is judged against percentage damage to the species or group. The potential of recovery from the damage is also assessed.

Similar to above for the environment.

Impacts from the loss of services, housing and business are reviewed to determine extent of impact on population. Impacts on health and likely dislocation of populations is also reviewed. The impacts are often reviewed quantitatively against owners' risk criteria and in some cases the tolerability of a failure is made more stringent where significant societal impacts are identified.

Canada

Typically, Depth- Velocity (DV) data from 2-D hydraulic models are used to calculate forces on buildings and infrastructure, and natural features.

Empirical data of toppling of rigid bodies as well as hydrodynamic instability data referenced against theoretical instability models are used for inanimate objects

The DV approach using an adaptation of the Life Safety Model has been applied in one case to estimate the impacts on fish habitat.

Two total cost of environmental losses study have been carried out.

There are no methodologies to determine the damage to local, regional and national economic activity.

There are no methodologies for estimating the intangible social impacts.

Czech Republic

- Damage to property (direct, indirect or both), consequences are calculated from the value of the property and water speed and depths usually.
- Damage to environment, this is individual. In the categorization process according to Methodology used, damages to surface, ground water are evaluated, damages to water supply as well and finally damages to agriculture (soil damage).
- Damage to cultural heritage No methods specifically used.
- Societal impacts No methods specifically used.

Loss of utility – it is missing.

France

Important assets (hospital, schools, public buildings, plants) potentially impacted by the dam are identified.
Downstream consequences on environment, cultural heritage or other societal impacts are generally not highlighted in detail.

Italy

Risk analysis not applied

The Netherlands

Safety assessment and risk assessment as described before.

Slovakia

Explain methods for estimating downstream consequences and assessment of:

- Damage to property (direct, indirect or both),
  Consequences calculation is based on owner information or information from local state water authority about the value (price) of the property and its localization towards the dam.
- Damage to environment,
  In some cases, the results of EIA are used
- Damage to cultural heritage
  No concrete methods are prescribed.
- Societal impacts

No concrete methods are prescribed

Sri Lanka

Use of demographic data and other statistical data available with national and local organization are used to assess the damage to lives, properties such as houses, livestock, cultivation & etc (direct), common properties, livelihood, environment

United States of America

Federal Energy Regulatory Agency

FERC's RIDM Risk Guidelines include the provision to include economic, environmental, and other non-monetary consequences in quantitative risk analyses. No established methodology is provided for these other consequences and will be developed on a case-by-case basis depending on the actual consequences identified for the project.

US Army Corps of Engineers

Direct economic damages are estimated as direct damages to property and benefits foregone. Property damages are estimated for buildings, contents, and vehicles with depth-damage functions and structural stability thresholds. Benefits foregone represent the total estimated value of the benefits not being produced over the period during which the facility is considered out of service. Commonly included benefits foregone includes; lost flood damage reduction, lost recreation, and lost hydropower. Indirect economic damages, which include business interruption and lost market share, are often calculated using a computable general equilibrium model (ECAM) that takes the inputs of reductions in the production factors of the economy (Capital and Labour), and produces changes in the labour force and output of the impacted sectors of the economy for a given county. Environmental, cultural, societal, and other non-monetary impacts are assessed qualitatively for dam safety.

US Bureau of Reclamation

The focus of any consequence assessment would be on the potential for life loss. When economic consequences are considered as part of the decision process, they would be quantified by a staff economist outside of the risk analysis. There are no specific methods used to quantify environmental, cultural, or societal impacts. However, these impacts could be invoked qualitatively as part of the decision process.

State of Colorado

To date, these considerations are in-place but are largely considered qualitative evaluations based on knowledge of dam breach inundation characteristics and local knowledge of downstream conditions. The Loss of life and these consequences in Question 3.8 are ultimately often considered together when trying to bracket the consequence level.

QUESTION 3.9

Assessment of uncertainty aspects of risk analysis – characterization of what is included in the assessment and the outline of assessment methodology

Argentina

For the aforementioned case sensitivity analyses of certain variables were carried out. Fundamentally, sensitivity in hydrological and operational aspects was evaluated. Modelling was carried out for two types of input hydrographs to the reservoirs: a typical one for winter (with strong peak flows) and another for summer (for large water volumes). A sensitivity analysis was performed of the failure probability of electromechanical equipment, which in part was based on expert judgement.

Australia

Generally, risk assessments are completed using 'best estimates'. Uncertainty analyses where distributions are placed on key variables and Monte-Carlo analyses used to determine percentile probabilities of occurrence have generally been found to be too inconclusive for clients. Best estimate results can be judged directly by evaluation criteria to give a single outcome. Where large uncertainties exist in a particular analysis, this is highlighted and the need for further work to define this value compared to the likely impact on the overall risk result. Where the cost of further analyses is unlikely to have any effect on the need for remediation works, the need for analysis is diminished. Where the costs are likely to result in significantly different costs in remediation works, the costs are justified.

Canada

Three types of uncertainty are considered in risk assessments: randomness, also known as aleatory uncertainty, model uncertainty and parameter uncertainties considered to varying degrees depending on the situation. Model uncertainty is addressed using the SSHAC type approach to deal with multiple models.

Parameter uncertainty is typically not addressed but it is compensated to some extent by conducting sensitivity analyses.

Czech Republic

Uncertainty is not included in general, in some specific cases could be, but not known to us.

France

In technical notes or calculations, uncertainty is generally taken into account by performing sensitivity tests on the more important parameters. This analysis is an helpful tool for the expert judgement to conclude. More generally, a semi-quantitative approach is used to estimate the probability classes. Each probability class is relatively wide and includes a range of uncertainty.

Italy

Risk analysis not applied

The Netherlands

At the simple level uncertainty is included in safety factors. In the probabilistic calculations uncertainty is explicitly included in the hydraulic boundary conditions and in several strength functions.

Slovakia

I do not know about use of concrete methods

Sri Lanka

Uncertainties in rainfall are considered but not any other factors. In recently designed high dams earthquake impacts were considered which has a rare possibility.

United States of America

Federal Energy Regulatory Agency

Uncertainty is used to portray variability or a range of values for loads, consequences, conditional response estimates, and risk estimates, rather than a single point estimate for those values.

At the simplest of levels, two main groups of uncertainty exist; these are aleatory (or stochastic) and epistemic (or knowledge-based) uncertainty. The most important distinction between these two types of uncertainty, at a practical level, is that the knowledge-based uncertainty may be reduced by further study, should a reduction in the overall uncertainty in the results from an analysis prove necessary. The aleatory uncertainty, on the other hand, is by definition irreducible.

All risk estimates must give due consideration of uncertainty. This can be accomplished either qualitatively or quantitatively depending on the needs of the risk assessment.

The quantification of risk estimates is dependent on available data and analyses regarding the design, construction, performance and current condition of a dam. It also depends on the identified loads that the dam could be subjected to over its operating life and knowledge about how the downstream population would be affected by a flood resulting from a dam breach. It is acknowledged that the quantification of risk estimates includes a degree of subjectivity regardless of how the estimates are made, and is a function of group dynamics, the experience and associated judgment of group members, models used in the analyses, and the available information for a dam. Thus, uncertainty in the risk estimates is expected. This uncertainty is typically captured by assigning ranges to probability and consequences estimates.

Key areas of uncertainty are to be identified and their potential effect on the risk estimate and resulting decisions presented.

US Army Corps of Engineers

The assessment methodology, in general, consists of the following and is scalable to fit the purpose of the risk assessment: Potential failure mode analysis; Develop event trees for potential failure modes; Develop the loading function for each failure mode carried forward in the assessment; Determine the conditional probability of failure and system response curve for each failure mode carried forward in the assessment; Estimate the consequences associated with each failure mode carried forward in the assessment; Risk estimate calculations for incremental risk and 'non-breach' risk; and Compare the incremental risk to the USACE tolerable risk guidelines for life safety. Numerical estimates of risk and uncertainty are quantified through the use of Monte Carlo simulations. Facilitators typically elicit a range of estimates for each node on an event tree from each expert (i.e. a lowest conceivable value and a highest conceivable value) along with their best estimate as inputs to the Monte Carlo simulation. Semi-quantitative estimates of risk only assume one order of magnitude uncertainty, and a qualitative assessment of the team's confidence is given for each failure mode, the consequences assessed, and an overall confidence in the project risk.

US Bureau of Reclamation

Numerical uncertainty is quantified through the use of Monte Carlo simulation, which allows the AFP distribution to be simulated and its spread characterized in terms of percentiles. This information would be depicted, along with the mean AFP estimates, in the risk portrayal chart (fN chart) shown to decision makers. The potential for the risk estimates to change significantly as a result of new information could result in low confidence and could be used a basis for issuing recommendations to better understand the risk.

State of Colorado

Our system utilizes assessment of confidence. "Strong" confidence indicates that no additional information would change the likelihood assessment (i.e. low uncertainty). "Poor" confidence indicates that key additional information would change the team's likelihood assessment (i.e. high uncertainty). These assessments of confidence also help develop appropriate risk reduction plans that help get appropriate information to increase confidence (reduce uncertainty) in risk assessment.

QUESTION 3.10

Number of risk analyses carried out, feedback of the experience gained, and development perspectives.

Argentina

There is only one case of risk analysis completed, on a system of dams (Cerros Colorados complex at the Neuquen river).

At the moment there are three risk analysis in progress (Alicura, Nihuiles system and Salto Grande – binacional dam Argentina-Uruguay).

The National Dam Safety Regulator ORSEP has a risk analysis and assessment programme for 25 more dams under its jurisdiction, to be carried out in the next five years. Updates and future revisions are also planned.

Australia

Over 100 detailed dam risk assessments including three portfolio risk reviews performed to date as either risk assessor or reviewer. Country wide this would total several hundreds of risk assessments. Since the 2003 ANCOLD Guidelines, risk assessment procedures have generally been standardised and a small pool of independent reviewers has resulted in a general homogenising of information and techniques across the industry.

Canada

Many preliminary risk analyses focused on identification and characterization of hazards and failure modes have been carried out, especially in recent years.

One dam owner has been using semi-quantitative risk analysis involving a mix of probabilistic hazard and deterministic response analysis for over 20 years. Beginning the 1993, the same Owner has carried out

more than 12 detailed quantitative risk analyses using event tree methods on a representative sample of the Owner's portfolio of dams that covered a wide range of dam safety concerns. These studies were subjected to independent peer review by a spectrum of experts in dams engineering and engineering risk that covered the spectrum of opponent and proponents of risk approaches. The purposes of these analyses were to:

- Realise the apparent benefits of the approach,
- Perform detailed exploratory investigations into the scientific integrity, robustness, repeatability and quality of the event tree method as a base methodology for determining that a dam is safe enough.
- Test the limits of dependability of the even tree method applied to a physically based model of the seismic liquefaction failure mode.

One dam owner has carried out detailed dynamic stochastic simulations of two river systems to explore the capability of these methods and to determine the capability, efficiency and effectiveness of these emergent approaches.

FMEA and Fault Tree Analysis has been applied to spillway gate risk and reliability problems. An increasing number of owners are using the PFMA methodology as a decision support and prioritization tool.

A small number of dam owners have introduced consideration of quantitative risk analysis based on subjective and calculated probabilities developed based on empirical correlations and mathematical modeling.

Czech Republic

Not possible to answer, probably no one complete. Only fragments of risk analysis methods are used in the dam categorization process, in the overall dam portfolio rehabilitation prioritization process and in some theoretical works such as Ph.D. theses and so forth.

France

Risk analyses were carried out on more than 470 dams from 2007 to 2015.
They are mandatory for 320 class A dams (every 10 years) and 320 class B dams (every 15 years).

- Risk analysis pointed out lots of dam safety issues. Many (but not all) issues were already known but are now objectively assessed.
- Mitigation actions decided and prioritized.
- Risk analysis is an opportunity to gather all the available documentation.
- An opportunity to share a common judgment.
- An opportunity to develop dam safety culture and practice for dam engineers and dam operators.
- Dam risk analysis is a multi-field exercise. Each contributor can learn a lot from other specialized people in other engineering domain.

Italy

Risk analysis not applied

The Netherlands

From 2017 onwards, safety standards for primary water defences are to be expressed in terms of allowable flooding probabilities. These standards are based on standards for individual (external) risk, and considerations on costs-benefits, group risk and critical infrastructure. Risk analyses have been done for all 235 stretches of primary flood defences. The resulting safety standards for dike stretches will range from 1/300yr flooding probability for areas with low flood risk to 1/30.000yr and occasionally even 1/100.000yr for relatively vulnerable areas (like heavily urbanized/industrialized areas or very deep polders). Approximately 200 different dyke sections have been distinguished.

Slovakia

I do not know these details – a study is needed

Sri Lanka

Under the DSWRP project, from 2009 to 2018 period 63 dam belonging to national and Provincial institutions have been rehabilitated based on the risk assessment done as described earlier. Analytical capacity of technical staff was enhanced through this project. Emergency Action Plans and Operation Manuals were prepared that are being used by the operation staff now.

Most of the Major Dams in cascade are well controlled during flood times to minimize the downstream inundations.

Stability of the dams and reliability of gates were ensured through the rehabilitation program carried out after the risk assessment exercise

United States of America

Federal Energy Regulatory Agency

FERC is just beginning to perform risk analyses for dam safety. Approximately eight pilot studies are currently underway at all levels of risk analysis (screening, semi-quantitative, and quantitative) to evaluate the draft RIDM Risk Guidelines. It is too early in the process to provide meaningful feedback from the pilot

US Army Corps of Engineers

Since 2005, including both dams and levees, USACE has performed over 3,000 risk assessments. The vast majority of these have been semi-quantitative, while slightly more than a 100 have been quantitative. USACE initially employed quantitative analyses for all IES and DSMS, but now reserves fully quantitative risk analyses for only the most complex projects. The biggest trade-off in favor of semi-quantitative methods is usually efficiency and effectiveness in reaching a decision while sacrificing precision and thoroughness that quantitative methods provide.

US Bureau of Reclamation

Since the mid-1990s, Reclamation has performed over 1300 risk analysis on its inventory of 367 high-hazard dams. As a result, over 80 dam safety modifications have been performed under the authorization of the Reclamation Safety of Dams act. Reclamation has found the risk analysis process to be a helpful tool (but not the sole basis for) the identification of dams in need of corrective action. To date, Reclamation has not identified a need to significantly modify the process that it uses or to abandon it in favour of some as-yet untested approach.

State of Colorado

Approximately two dozen risk analyses have been completed. The feedback we have received is that the SQRA tools provide for defensible dam safety decisions. Dam owners have appreciated being part of the process, working collaboratively with regulators. Identified a need to evaluate efficiencies within the SQRA process in order to accomplish more risk analyses in a shorter period of time.

QUESTION 3.11

Are there any formal or informal training or minimum qualification guidelines established for people performing risk analyses?

Argentina

Formal risk analyses are not a common practice in Argentina. Dam safety is under traditional practice (under standard based and generally accepted frameworks). Owners are obliged to accomplish with dams safety requirements set up in the concessions contracts and with regulations dictated by ORSEP. Risk assessments are implicit not explicit. Dam safety is based on standards, factors of safety and expert judgement.

There is no national qualification guidelines established for performing risk analysis. ORSEP risk assessments programme currently underway, described before, is being undertaken following several risk analysis guidelines and references: ICOLD bulletins 130 and 154; SPANCOLD P8, Risk Analysis Applied to Management of Dam Safety (2012); Guidelines on Risk Analysis USBR-USACE Best Practices in Dam and Levee Risk Analysis (2015); HSE, Reducing risks protecting people- HSE`s decision making process, Health and Safety Executive (2001); USBR Dam Safety Public Protection Guidelines (2011); ANCOLD Guidelines on Risk Assessment (2003); D.F. Munger et al. Interim Tolerable Risk Guidelines for USACE dams (2009); others.

Australia

No, clients are required to determine the experience of the proponents tendering for the work. Australia has a small dams industry and most major clients know who the reputable risk assessors are. ANCOLD hold pre-conference workshops and seminars on risk assessment at times to pass on latest methodologies to industry.

Canada

No. In Canada, the practice of Engineering is regulated by the provincially approved licensing organizations and no formal qualification process for risk assessment of dams has been established.

In British Columbia, The Engineering Authority has endorsed a structured approach to risk-informed dam safety. Analysis of Hazards, Failure Modes and Consequences is expected. A structured approach to setting out the logic of the reasoning and judgments is provided in the professional practice guidelines on dam safety reviews. Guidance on risk-informed dam safety improvements follows ICOLD Bulletin 154 and the “Bow-Tie” (Fault Tree/Event Tree) safety management framework.

The Canadian Dam Association has organized workshops on various aspects of risk assessment, which may or may not qualify for Professional Development Hours. In particular, the Canadian Dam Association organises training workshops on Dam Safety Reviews which involve Analysis of Hazards, Failure Modes and Consequences. Individual Owners may arrange training opportunities for their engineers and engineers working on their projects. Informal training where it exists is based on the text books Risk and Uncertainty in Dam Safety (Hartford and Baecher, 1994) and Operational Safety of Dams and Reservoirs (Hartford, Baecher, Zielinski, Patev, Ascilla and Rytters, 2016), relevant ICOLD Bulletins and relevant Canadian and international standards on various aspects of risk analysis (ISO and IEC).

Czech Republic

No

France

- FrenchCold has organized several conferences on dam risk analysis for the past 10 years.
- FrenchCold is currently finalizing a guidebook on the dam risk analysis practice.
- FrenchCold has issued bulletins on feedback of electromechanical equipment and dam operation incident.
- Consulting engineering firms must be officially licensed by the Authorities to be allowed to perform dam risk analysis. The agreement is based on objective criteria defined by an official order including dam safety references.
- Inside these firms there is no formal qualification required for individual people performing risk analysis. They are chosen according to their skills and experience.
- Internal training exists for people performing risk analysis (depends on dam owners and consulting engineering firms)

Italy

Risk analysis not applied

The Netherlands

No formal training is required, but the models to be used can only be used by an engineer. The calculations are performed by engineers who work for the owner of the dam or the consultancy.

Slovakia

As far as I know there are none

Sri Lanka

Formal and informal training sessions were held for a selected group under a recently concluded project funded by World Bank. No guidelines were established for minimum qualifications. However the cadre positions in dam organizations are filled based on government approved recruitment procedure. Even the consultants hired are recruited following an approved procurement procedure.

United States of America

Federal Energy Regulatory Agency

Yes. They are included in Chapter 2 the FERC RIDM Risk Guidelines and provide general guidance regarding the background, experience, training, and other qualifications of key risk analysis team personnel. It is recognized by the FERC that the qualifications presented in Table 2-2 below are lofty and may be difficult to attain in the initial stages of risk analysis in support of RIDM. In special circumstances, FERC may elect to reduce the minimum qualifications of certain key risk personnel described in this section when, in the opinion of the FERC, the qualifications of those individuals will not adversely impact the execution or results of the risk analysis study.

Table 2-2. Guidelines for Minimum Qualifications of Key Risk Analysis Personnel

	Facilitator					Subject Matter Expert	Software Operator	Note Taker/ Recorder
	Level 2 Periodic	Level 3 SQRA	Level 4A QRA	Level 4B QRA	Level 4C QRA			
Dam Safety Experience								
Years of dam safety experience (investigations, studies, designs, construction, etc.)	10	10	15	20	20	10	5	5
Primary author on dam analysis, design, or construction (number of technical papers or significant reports authored)		5	5	7	10	5		
Lead reviewer or member on expert panel/board for dam studies, design, or construction (number of projects)					4			
Lead technical role for one or more technical disciplines for dam analyses (number of projects)		2	2	4	4	5		
Author, presenter, or participant in dam failure or incident case history (number of case histories)		2	3	4	5	1		
Risk Analysis Experience (number of projects)								
Participant as a subject matter expert (SME) for a risk analysis		2	2	4	6			
Primary author of Level 3 risk analysis reports			2					
Primary author of Level 4 risk analysis reports				2	2			
3rd party reviewer/independent review of Level 3 risk analysis reports			2					
3rd party reviewer/independent review of Level 4 risk analysis reports				2	5			
Facilitated level 3 risk analyses			2					
Facilitated level 4A risk analyses				2				
Facilitated level 4B risk analyses					2			
Primary author of a technical publication on dam safety risk analysis					2			

Training*								
Base Courses								
Overview of Risk Analyses	R	R	R	R	R	R	R	R
Best Practices in Dam Safety Risk Analyses		R	R	R	R	R	S	S
Level 2 Risk Analyses	R							
Level 3 Risk Analyses		R	R	R	R	R		
Facilitation			R	R	R	S		
Loadings and Consequences								
Hydrologic Loading		S	S	S	R	R		
Seismic Loading		S	S	S	S	R		
Consequences		S	S	S	R	R		
Failure Modes and Risks								
Internal Erosion Mechanics					S	R		
Internal Erosion Risks					S	R		
Overtopping/Overwash/Erosion of Soil and Rock					S	R		
Seismic Analysis of Concrete Structures and Gates					S	R		
Seismic Analysis of Embankments					S	R		
Operational Risks			S	S	R	R		
Risk Analysis								
Failure Modes and Event Tree Construction			S	R	R		R	
Risk Analysis Software Tools			S	R	R		R	
Portrayal of Risks to Support Decisions			S	R	R			
Other								
Professional License Requirements	PE	PE	PE	PE	PE	PE/PG		
Regularly participates in professional society meetings/conferences/workshops/publications (USSD, ASDSO, or similar)		Yes	Yes, typically a member	Yes, typically a technical committee member	Yes, typically a technical committee member	Yes, typically a member		

R – Strongly Recommended
S – Suggested
*Training courses listed in this table are currently being developed by FERC. A training course schedule will be published and updated by FERC.

US Army Corps of Engineers

USACE has developed an internal Training Plan that identifies training requirements for dam and levee safety program managers and officers and also for individuals that support the dam and levee safety programs. The best training for dam and levee engineers is a combination of education, specialized training courses, and experience.

US Bureau of Reclamation

The basic qualification for being a risk estimator is subject matter expertise. Entry level staff are typically introduced to the setting through participation as a note taker or software operator (for the Monte Carlo simulation). Reclamation encourages its staff to attend the Best Practices in Risk Analysis training that is jointly presented with USACE. However, it is not used as a formal means of qualification or certification. The facilitator, who typically has years of risk analysis experience, is responsible for ensuring that the staff participating are qualified.

State of Colorado

Dam Safety Rules require 5 years engineering experience associated with dams. Engineers within Colorado Dam Safety have all been through PFMA/SQRA training classes. SQRA workshops are facilitated and have at least 2 Colorado Dam Safety representatives present with owner's representatives and their engineers.

FOCUS AREA 4 – RISK EVALUATION

QUESTION 4.1

What are the fundamental principles of establishing risk evaluation principles, criteria or guidelines?

Argentina

Traditional engineering principles are applied under normal regulated dam safety practice. Regulation tends to absolute levels of safety. ALARP principle is not used in Argentina.

Under ORSEP formal risk assessments programme underway, USACE, USBR and ANCOLD guidelines and criteria shall be used, for prioritization and orientation on upgrade dam safety decisions, complementary to traditional practice and expert judgement.

Australia

Within Australia the fundamental principles of risk evaluation and acceptability are the obligation to manage the risks to the safety of people, the common law obligation to manage the impacts of an event on other parties and the acceptability of risks to the community. The legal considerations for Australia are summarised well at :

https://www.damsafety.nsw.gov.au/DSC/Download/Info_Sheets_PDF/General/DSC2E.pdf

Canada

The use of technology-based criteria derived from well-established dam engineering principles and practices represent by far the most common approach to evaluation of risk in dam safety practice in Canada. The approach is risk-informed in principle, as the degree of stringency of the criteria, often reflects the consequences of dam failure.

The Canadian Dam Association has proposed Tolerable Risk Criteria (individual and societal) as a basis for a Dam Owner to enter consultations with their Regulator on a case specific basis. One owner has used these criteria as a basis for determining that the interim risk for one river system pending significant seismic upgrades is tolerable. The same owner reported two other cases where very low values of individual risk ($< 10^{-6}$/yr.) have resulted in situations where interim risk management measures were not required.

Czech Republic

Risk evaluation process is not being done in general. There might be some restricted area for new buildings for example in the active zones around rivers, where the flood is most intensive, but this is not given for the dam break scenarios, only for hydrological floods.

France

Order of 3rd September 2018 amending the order of 12 June 2008 defining the framework for the safety review of dams and specifying the content

Italy

Risk analysis not applied

The Netherlands

You have to meet the standards. See answer 1.10.

Slovakia

No concrete methods are prescribed

Sri Lanka

Consequences of dam incident such as loss of lives, disruption to the livelihood and social fabric, environmental damage are the fundamental principles governing risk evaluation. Stability of the structures under various loading conditions and reliability of appurtenant structures are given due considerations.

United States of America

Federal Energy Regulatory Agency

Per Chapter 3 of the FERC RIDM Risk Guidelines, a number of principles apply to risk assessments (FEMA, 2015). These include:

- Remedial actions should do no harm.
- The goal of remedial dam safety actions is to reduce risk to tolerable levels, including ALARP considerations.
- Some remedial actions may have unintended consequences.
- In order to implement some remedial actions, construction risks may be excessive during certain phases of the work. A remedial action to address a specific potential failure mode can temporarily or permanently increase the probability of another potential failure mode.
- Decisions should be risk-informed, not risk-based.
- Decisions should be based on consideration of the results of a risk analysis as a key input, but other factors, such as the uncertainty and confidence in the risk estimates, should also be considered.
- Decisions should not be based solely on where risk estimates plot on an f-N or F-N chart.
- The decisions made should consider the risk estimates, including the uncertainty and confidence in the risk estimates, the likely outcomes if dam safety actions are completed, and other factors important to the dam owners' mission and regulatory agency's guidelines.

Interim risk reduction measures (IRRMs) should be considered and implemented where needed. While the ultimate goal may be to reduce risks to tolerable levels at a given dam, IRRMs can achieve timely incremental risk reduction, often at a reasonable cost. IRRMs are discussed in Chapter 4 – Risk Management.

Two fundamental principles, from which tolerable risk guidelines are derived, are described as follows in ICOLD (2005):

- Equity. The right of individuals and society to be protected, and the right that the interests of all are treated with fairness, with the goal of placing all members of society on an essentially equal footing in terms of levels of risk that they face.
- Efficiency. Efficiency is the need for society to distribute and use available resources so as to achieve the greatest benefit.

US Army Corps of Engineers

That "Life Safety is Paramount", and it is not appropriate to refer to balancing or trading off public safety with other project benefits. Instead, it is after tolerable risk guidelines are met that other purposes and objectives will be considered. The principle of 'Do No Harm' must underpin all actions intended to reduce dam safety risk. USACE will ensure that USACE dams are designed and operated in a way that during a flood the spillway flow will not, at any time during the event, result in downstream flooding more severe than that which would have been the circumstance had the dam not existed. USACE will ensure that proposed Interim Risk Reduction Measures, emergency or permanent construction, or a temporary or permanent

change in regulation plans will not result in the increased risk of unsatisfactory performance of the dam, adjacent structures, and other basin/system components or operations over existing risk at any time.

US Bureau of Reclamation

That Reclamation should take actions, when necessary, to ensure the safety of those living downstream of its dams. That the risks of an individual Reclamation facility should be low enough to not significantly increase the background risk of death of anyone living downstream.

State of Colorado

Colorado Dam Safety primary goal is to identify risk driving failure modes by a consistent, efficient, and defensible process. Key principle is to engage with all those responsible for dam (owner, regulator, owner's engineer) to complete risk assessment in collaborative, consensus driven environment.

QUESTION 4.2

What entity is responsible for the Risk Evaluation Process? Is it the Responsible Authority, the organization that licenses engineers, the Dam Owner, Consultants, or NGO's such as National Committees of ICOLD?

Argentina

Dam Owners (operators/concessionaires) are responsible for dam safety and risk assessments. Risk assessments are under the traditional engineering practice. Owners must produce periodically dam safety reports for the regulator authority. For the time being, there is no regulation that established obligation by the owner to perform formal risk analysis.

ORSEP risk assessments programme underway is under solely responsibility of the national institution.

Australia

Owners are responsible for the risk evaluation process. However, the regulatory functions to ensure the public interest is adhered to differ between legal jurisdictions and varies between statutory guidelines and legislative requirements. Owners do not licence Engineers, and again, this varies by jurisdiction from a legal qualification requirement in QLD., to Engineers Australia elsewhere.

Canada

The Dam Owner is ultimately responsible for the choice or risk evaluation process and criteria. The deterministic criteria provided in the CDA Dam Safety Guidelines are used by most dam owners. There are a few cases where decisions have been based on the type of risk criterial presented in the CDA Guidelines. However, the Canadian Dam Association assumes no responsibility for the criteria which it states are put forward as a starting point for discussion between the Dam Owner and the Authority.

Czech Republic

Most likely the dam owner

France

It is the administration that has implemented the risk analysis approach and regulations.
- But it is each owner who is responsible to apply it to his dam with the support of a licensed consultant

Italy

Risk analysis not applied

The Netherlands

The Waterboards or Rijkswaterstaat (the Ministry). See also answer 1.6.

Slovakia

At this time there is no directive for the Risk Evaluation Process, but I think it will be the Dam Owner in the future

Sri Lanka

There is no regulatory body to enforce national level risk evaluation process. No licences are required for dam owner organizations as those are government or semi-government organizations.

United States of America

Federal Energy Regulatory Agency

FERC has established the process that must be used in assessing risks (See Chapter 3 of the FERC RIDM Risk Guidelines). It is the responsibility of the dam owner and consultant to follow the process.

US Army Corps of Engineers

As a self-regulating Federal dam owner, USACE is entirely responsible for all aspects of its dam safety program, including risk assessments and evaluations. USACE uses internal teams of risk analysis experts, called cadres, to perform risk assessments in support of studies. Contract support for external subject matter expertise is reserved only for the most complex projects or when insufficient in-house expertise exists. Contract support is also used to provide experts for reviews. A pool of facilitators is centrally managed and facilitators are provided for all phases of risk assessments.

US Bureau of Reclamation

The Reclamation staff writing and peer-reviewing the technical report and decision document it is responsible for comparing the estimated risks to the applicable guidelines and for building the case for (or against) any dam safety action. The Reclamation Risk Cadre (composed of technical staff as well as decision makers) is responsible for ensuring the overall integrity of the risk evaluation process, and that it continues to serve the needs of the organization.

State of Colorado

Colorado Dam Safety (the dam safety regulatory authority for non-federally owned dams in Colorado) has led the Risk Evaluation Process. We are in the process of utilizing FEMA funds to complete consultant led SQRA's for dams. The process includes best practices from USBR and USACE that are refined to suit our State regulatory environment.

QUESTION 4.3

What is the public consultation process for risk evaluation and the bases for determining that the benefits of the dam sufficiently outweigh the risk associated with the dam and its operation?

Argentina

There is no public consultation process that has been carried out for risk evaluations.

Australia

Requirements for this are usually limited to construction process. There is little interaction with the public on dam safety risk (outside generalised flood events) specifically around dams. However, there are several cases where the public has been consulted on the scope of risk reduction works.

Canada

There are no specific requirements, although the Environmental Impact Assessment process which is a regulatory requirement in all Provinces addresses this issue at least indirectly and provides some guidance on assessing the impacts of potential failures.

It is up to the dam owner to justify the project. The determination that the risk associated with the dam and its operation is usually a matter of judgment during the licensing process. In some jurisdictions, the public can access information about the safety of dams through legally binding Freedom of Information requests.

Czech Republic

Not being done.

France

There is no public consultation in the risk analysis process. Public and associations are informed of the results of the risk analysis through a presentation of risk reduction measures and results of safety review in a meeting in the regional office of the State (Prefecture). The non-technical summary of the safety reviews are also theoretically available, and an information is done to the mayor concerned by the dam failure scenarios.

Italy

Risk analysis not applied

The Netherlands

The standards have been approved in National or regional Parliament. The safety assessments have to be reported to Parliament.

Slovakia

No concrete process is prescribed

Sri Lanka

As mentioned in 2.6

United States of America

Federal Energy Regulatory Agency

Risk communication responsibilities and actions are outlined in Chapter 4 of the FERC RIDM Risk Guidelines.

US Army Corps of Engineers

US Bureau of Reclamation

The economic benefits of a project would be quantified by a staff economist in considering whether to abandon or modify a project. As noted in the response to question 2.6, project stakeholders, beneficiaries, Congress, and the Public are engaged when implementing corrective actions at individual dams.

US Army Corps of Engineers

In general, USACE utilizes benefits and costs in three areas to determine if the public benefits outweigh the incremental risks associated with the dam and its operation: economic risk, life risk, and environmental risks. These risks are measured against a defined criteria -- for economic risks we look to see if the contributions to the national economy exceed the costs and for life risk USACE measures the societal and individual life risks and probability of failure and compares them against the tolerable risk guidelines established in policy. Environmental risks are more complicated, as the natural environment has already changed with the construction of a dam and there is no established "test" by which to evaluate the environmental risks associated with a dam and its operation. The closest USACE can come is through the application of federal environmental laws, executive orders, and policies. However, USACE must use professional judgment and the evaluations of the benefits, costs, and impacts when making such a determination.

In addition to the societal and individual life risk limit lines and benefit cost analysis, USACE's study process includes public and stakeholder engagement activities where the agency receives input from the locally impacted communities, which can inform our decision making process, as well as those of the local and state governments with which USACE interacts more regularly.

State of Colorado

We have no public consultation process for risk evaluation. The benefits of water storage in an arid to semi-arid environment are intuitive, we could not support our population and economy without water storage. The benefits of safe water storage will almost always outweigh the risks. Where risks exist that cannot be mitigated immediately, we use the storage restriction to temporarily mitigate undo risks.

QUESTION 4.4

What are the policies on acceptability or tolerability of risk that have been established by government, regulatory agencies or organizations, or that have been proposed by professional associations or non-governmental organizations?

Argentina

There are no policies on acceptability or tolerability of risk established by the government or the regulator. Normal dam safety practice follows ICOLD B 61 criteria. Extreme loading conditions are the focus of traditional dam safety practice. Standards, experience and judgement are applied.

Risk assessments under currently underway ORSEP programme, follows as a reference USBR, USACE and ANCOLD acceptability/tolerability criteria.

Australia

In Australia ANCOLD have led the way in developing Risk Guidelines - The ANCOLD Guidelines on Risk Assessment 2033 is the key reference for the sue of risk assessment in Australia. In Australia, the States are responsible for water and dam safety - in some States there is an independent Regulator in other state the owners self-regulate. The State Regulators have adopted the work of ANCOLD.

Canada

There are no policies on acceptability or tolerability of life safety risks that have been established by government, regulatory agencies or organizations with authority derived from governments (e.g. Provincial Engineering Licensing Organizations). Similarly, there is no professional association or non-governmental organization that has proposed such tolerable life safety risk criteria as a matter of policy. The Canadian Dam Association has proposed tolerable life safety risk criteria to be used as a starting point for discussions between the dam owner and the regulatory authority, without establishing a policy position on the matter. Currently, there is no universal agreement on these proposed thresholds although most practitioners and owners have accepted them as a reasonable starting point.

Czech Republic

Explicitly, only the safety against overtopping (spillway capacity) is given for the large dams by Ordinance, where the flood return period is given according to the dam category and possible/no possible fatalities.

France

Except the minimum criteria set in the order of 6th of August 2018 for certain failure scenarios, the tolerability of scenarios is left to the free appreciation of the owner and his consultant.

Italy

Risk analysis not applied.

The Netherlands

See answer 1.1. The standards in the Water Act are based on the flood risk deemed acceptable for areas protected by the primary flood defences. The standards are based on two principles:

1. Everyone should be able to rely on the same minimum level of protection: the basic level of protection, expressed as local individual risk (LIR) less than 10-5/year.
2. Where the impact of flooding would be very high, a lower probability of flooding is appropriate, based on societal risk and a social cost-benefit analysis (SCBA).

Slovakia

These policies are not based on legislative directions

Sri Lanka

A Dam Safety Regulatory body has been proposed to establish under a leading water resources Ministry. Panel of experts from various disciplines will be appointed to an expert panel.

United States of America

Federal Energy Regulatory Agency

Tolerable risk guidelines and the dam safety case are discussed in Chapter 3 of the FERC RIDM Risk Guidelines. These include:

1. Life safety risk – which includes incremental and non-breach risk within the context of tolerable risk guidelines.
2. Annual probability of failure (APF).
3. Economic considerations – which includes incremental and non-breach consequences.
4. Environment and other non-monetary consequences - which includes incremental and non-breach consequences.

Three types of incremental life safety risk guidelines will be used under the FERC-D2SI tolerable risk guidelines.

1. Individual incremental life safety risk using probability of life loss for the identifiable person or group by location that is most at risk of loss of life due to dam breach.
2. Societal incremental life safety risk expressed in two different ways:
   a. Probability distribution of potential life loss

   b. Average annual life loss (AALL)

The incremental life safety risk is to be evaluated against all three life safety guidelines.

Non-breach life safety risks are also to be evaluated.

Chapter 3 of the FERC RIDM Risk Guidelines has additional discussion of each of above measures. FERC has not developed tolerable risk guidelines for economic or environmental and other non-monetary consequences. However, the FERC will review the information submitted in support of the economic analysis and review each case based on the merits. This information will be used by the FERC, in conjunction with the assessment of life safety risks and the consequences from other factors such as environmental and other non-monetary consequences, in the overall assessment of the tolerability of project risks.

That said, It has been widely recognized that procedures and data available for dam safety risk analysis, while mostly quantitative, do not provide precise numerical results. Therefore, relying solely on the numeric estimates in comparison to hard-line criteria (sometimes referred to as “risk-based” evaluation) would not be appropriate (BOR, 2011). The assessment of risks and the corresponding decisions are generally more

complex than can be portrayed using only the numerical results of a risk analysis. The FERC and other federal dam safety agencies using risk-informed approaches have chosen to use a more "risk-informed" approach where additional information is included to support the assessment and case for proposed actions (or non-action). The intent in the assessment process is to use the entirety of the information available to build and support the case to take a particular action (or to take no action).

Though many concentrated efforts are made during a quantitative risk analysis to achieve high quality, defensible results, the risk estimates themselves are little more than index values. If arrived at in a consistent manner, they are useful in program management as they allow comparisons and rankings between different facilities and promote a general sense of where the risks lie relative to the risk assessment guidelines (BOR, 2011). **It cannot be emphasized enough - these risk guidelines are not intended to be used as rigid decision-making criteria to declare a facility "safe" or "unsafe" based solely on a risk estimate.** Since the numbers are only approximate measures of risk, and since the risk guidelines themselves are not rigid, additional reasoning is essential to justify the risk estimates and the recommended actions. The case is intended to present rationale in a formal and methodical manner to persuade decision-makers to take responsible action (or to justify no action).

The case is a logical set of arguments used to advocate either the position that additional safety-related action is justified, or that no additional safety-related action is justified at any given (current) time (BOR, 2011). The arguments string together key evidence regarding the three basic risk components (i.e. load probability, response probability, and consequences) so as to convince decision-makers that the dam's existing condition and ability to withstand future loading, the risk estimates, and the recommended actions are all coherent. Since uncertainty is inherent in each claim, the arguments should also address whether confidence is high enough for the conclusions to stand on the basis of existing evidence.

The safety case and the identification of risk reduction alternatives are recognized as essential elements in the assessment of tolerable risks. They represent understanding of existing conditions and predicted future behavior stated as objectively as possible. The risk estimates and the case to support them do not in themselves ensure the safety of a facility (BOR, 2011). The case becomes the basis and foundation for risk management. The understanding given to all, from the facility operators, to the owner's engineering and management staff, to the owner's consultants, to the FERC, by a well-constructed supporting case is intended to focus attention on behavioural and technical aspects essential to the facility's integrity so that the facility can be operated and maintained in as safe a manner as possible with the available information.

The case should be clearly presented so that all descriptions and terms are easy to understand by the prime audience, all arguments are cogent and coherently developed, all references are easily accessible, and all conclusions are fully supported and follow logically from the arguments (BOR, 2011).

US Army Corps of Engineers

The Federal Emergency Management Agency in 2015 published P-1025 "Federal Guidelines for Dam Safety Risk Management" in which the risk framework is discussed and devotes a section to discussion of tolerable risk guidelines. The NGO Association of State Dam Safety Officials has promoted webinars and presentations concerning tolerable risk guidelines.

US Bureau of Reclamation

Reclamation does not accept the idea that quantified risks below some specific level are "tolerable" and does not use that terminology in its public protection guidelines. Risk are considered to either be in an area of increasing or decreasing justification to reduce or better understand them. In reaching this conclusion, Reclamation does not rely on the numbers alone, as they are understood to not be exact performance indicators and to be subject to re-estimation given new information. A compelling written case cannot be built without considering additional factors, such as design and construction information, analysis results, field investigations, and the overall condition of the dam (regardless of whether these factors have already been taken into account in the risk estimates). The Reclamation staff writing and peer-reviewing the technical report and decision document are responsible for building the case for or against action.

State of Colorado

Our SQRA process ultimately determines if individual Potential Failure Modes evaluated at a dam are “risk-driving” and warrant actions to reduce the likelihood of failure mode from occurring. Those that are considered risk-driving have an Annual Exceedance Probability more than 10E-5. Since loss of live is always a consequence for high hazard dams, and since loss of life is considered largely intolerable in a regulatory environment, actions to prevent loss of life are generally accepted, provide they are defensible

QUESTION 4.5

What are the criteria or guidelines for risk tolerability/acceptability used to address societal concerns?

Argentina

There are no policies on acceptability or tolerability of risk established by the government or the regulator. Normal dam safety practice follows ICOLD B 61 criteria. Extreme loading conditions are the focus of traditional dam safety practice. Standards, experience and judgement are applied.

Risk assessments under currently underway ORSEP programme, follows as a reference USBR, USACE and ANCOLD acceptability/tolerability criteria.

Australia

The criteria used to address societal concerns are from ANCOLD when above the limit of tolerability. The assessment tool uses potential loss of life vs cumulative risk. If the dam is deemed tolerable, criteria for demonstrating ALARP are up to each individual owner. Discussions over acceptable risk are internal and have a broad requirement to meet common law duty of care.

Canada

There are no criteria in Canada, actual, proposed, or notional for societal concerns that go beyond tolerability of risk to life.

Czech Republic

No criteria

France

None

Italy

Risk analysis not applied

The Netherlands

It is included in the risk assessment through CBA.

Slovakia

No concrete criteria are prescribed

Sri Lanka

Not officially developed yet. But uncertainty created among those living downstream during bad weather conditions are some social concerns taken into account.

United States of America

Federal Energy Regulatory Agency

See Chapter 3 of the FERC RIDM Risk Guidelines. As described in Section 2.2.3 of the FERC RIDM Risk Guidelines, three types of incremental life safety risk guidelines will be used under the FERC-D2SI tolerable risk guidelines.

1. Individual incremental life safety risk using probability of life loss for the identifiable person or group by location that is most at risk of loss of life due to dam breach.

2. Societal incremental life safety risk expressed in two different ways:

- Probability distribution of potential life loss
- Average annual life loss (AALL)

The incremental life safety risk is to be evaluated against the life safety guidelines.

Non-breach life safety risks are also to be evaluated.

These are summarized below.

Individual Incremental Life Safety

The individual incremental life safety risk (IR) to the identifiable person or group by location, that is most at risk, should meet the following and as shown on Figure 1 FERC Individual Incremental Life Safety :

1. For IR ≥ 0.0001 (1E-04) Per Year. IR in this range is unacceptable except in extraordinary circumstances. Risks should be reduced to the tolerable risk reference line (1E-04) regardless of cost considerations and then further until ALARP is satisfied, except in extraordinary circumstances. The justification to take action to reduce or better define the risk increases as the estimates become greater than 0.0001 per year. Extraordinary circumstances will be evaluated by the FERC on a case-by-case basis.
2. For IR < 0.0001 (1E-04) to IR ≥ 0.000001 (1E-06) Per Year. IR in this range will be considered intolerable unless ALARP considerations are satisfied. IR in this range will be considered tolerable provided the other tolerable risk guidelines are met, to include all aspects of the risks listed in Section 3.3.1 and the ALARP considerations are met.
3. For IR < 0.000001 (1E-06) Per Year. IR in this range will be considered tolerable provided the other tolerable risk guidelines are met, to include all aspects of the risks listed in Section 3.3.1 and the ALARP considerations are considered to evaluate potential risk reduction opportunities to further reduce the IR. The justification to take action to reduce or better define the risk diminishes as the estimates become smaller than 0.000001 per year.
4. It is expected that for newly constructed dams, with the opportunity to make use of state of practice designs and technology, this will likely result in lower individual incremental risk when applying the ALARP principle.
5. The probability of individual life loss, which is used in the evaluation of individual incremental life safety risk, is not necessarily the same as the probability of failure that is used in the evaluation of the APF guideline, which is described in Section 3.3.3. The probability of life loss is based on the probability of failure and further takes into consideration the exposure factors to characterize the day-night, seasonal, warning, or other exposure scenarios, and the conditional probability of life loss given exposure to the dam failure flood. The level of detail that is appropriate for use in characterizing exposure factors should be “decision driven.”

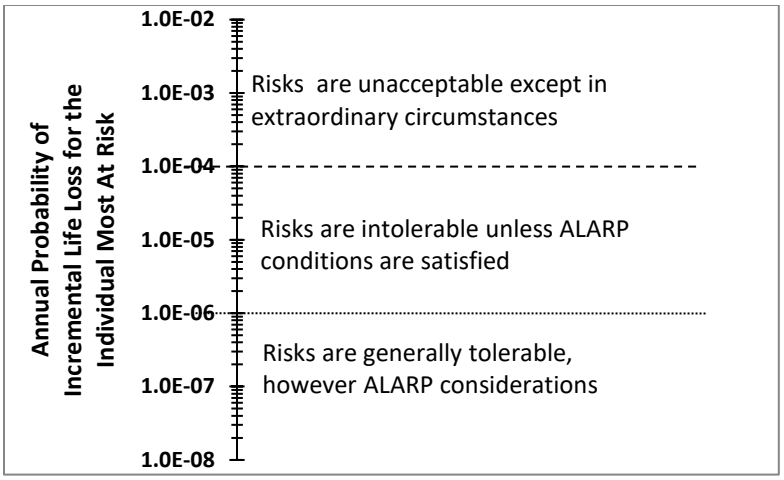

Figure 1 FERC Individual Incremental Life Safety

Societal Incremental Life Safety

Probability Distribution of Potential Incremental Life Loss. The probability distribution of potential incremental risk will be evaluated based on the tolerable risk guideline shown on Figure 2.

Each of the four regions on the F-N chart (Figure 2) has the following attributes:

1. Societal Incremental Risk ≥ 0.001 (1E-03) Lives Per Year. Societal incremental risk above the tolerable risk reference line is unacceptable except in extraordinary circumstances. Risks should be reduced to below the tolerable risk reference line (1E-03) regardless of cost considerations and then further until ALARP is satisfied, except in extraordinary circumstances. The justification (urgency) to take action to reduce or better define the risk increases as the estimates become greater than 0.001 lives per year.

2. Societal Incremental Risk < 0.001 (1E-03) to Societal Incremental Risk ≥ 0.00001 (1E-05) Lives Per Year. Societal incremental risk in this range will be considered intolerable unless ALARP considerations are satisfied. Societal incremental risk in this range will be considered tolerable provided the other risks listed in Section 3.3.1 are considered tolerable, and the ALARP considerations are met. The justification (urgency) to take action to reduce or better define the risk diminishes as the risk estimates approach 0.00001 lives per year.

3. Societal Incremental Risk < 0.00001 (1E-05) Lives Per Year. Societal Incremental Risk in this range will be considered tolerable provided the other risks listed in Section 3.3.1 are considered tolerable, and the ALARP considerations are addressed to evaluate potential risk reduction opportunities to further reduce the incremental risk. The justification to take action to reduce or better define the risk diminishes as the risk estimates become smaller than 0.00001 lives per year.

4. Low Probability – High Consequence Area. If incremental life loss is estimated to equal or exceed 1,000 lives and the annual probability of potential life loss is less than 1 in 1,000,000 (1E-06) for an estimated life loss of in the range of 1000 or greater (low probability – high consequence area of Figure 3-3), the evaluation of the tolerability of risk must be based on a thorough review of the project benefits and risks as described below.

   The qualifier “except in extraordinary circumstances” refers to a situation in which the government, acting on behalf of society, may determine that risks exceeding the tolerable risk may be tolerated based on special benefits that “the dam brings to society at large”. The justification for tolerating such high risks or high consequences is the wider interests of society. Risks, that would normally be unacceptable, can be tolerated on account of the special benefits, which the dam brings to society (ANCOLD, 2003). This is often the result of not having adequate feasible options to further reduce risks.

This is an example of the conflict between the fundamental principles of equity and efficiency. Specifically, the maximum risk level that satisfies equity considerations can be at the expense of reducing efficiency (USACE, 2014). The equity consideration might be relaxed because of special benefits that are deemed to outweigh the increased residual risk. This exception might be made where the incremental potential life loss and economic consequences are large, but where the probability of failure or breach is very low and state-of-the-practice risk management measures have been implemented. For dams in this area on Figure 2, the FERC will look critically at the confidence in the estimate of the incremental risk. Full compliance with essential FERC engineering guidelines will be expected. The adequacy of potential failure modes analysis and risk assessment will be carefully examined. The FERC would reach a decision based on the merits of the case.

For new dams or major modifications, the societal incremental risk should be less than the tolerable risk reference line shown on Figure 2, except in extraordinary circumstances. However, it is expected that new dams, with the opportunity to make use of state of practice designs and technology, will likely result in lower societal incremental risk being considered when applying the ALARP principle.

Average Annual Life Loss (AALL). The AALL associated with the incremental risk will be evaluated based on the tolerable risk guideline shown on Figure 3.

Each of the four regions on the f-$\bar{N}$ chart (Figure 3) has the following attributes:

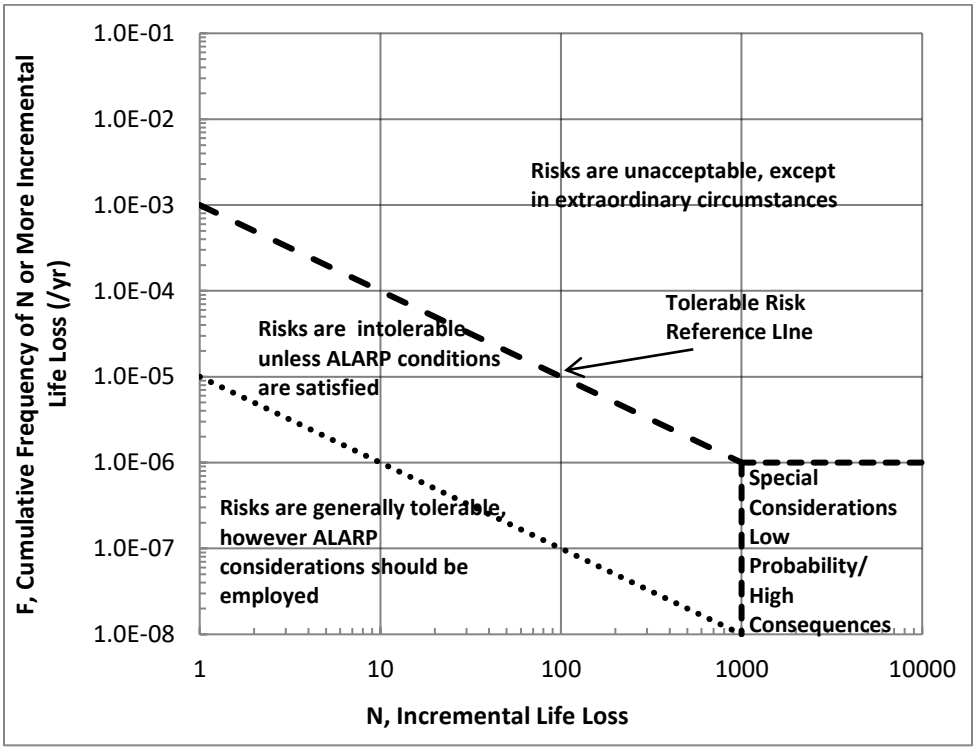

Figure 2 FERC Societal Risk Guideline for Incremental Risk (F-N)

1. AALL ≥ 0.001 (1E-03) Lives Per Year. AALL in this range is unacceptable except in extraordinary circumstances. Risks should be reduced to below the tolerable risk reference line (1E-03) regardless of cost considerations and then further until ALARP is satisfied, except in extraordinary circumstances. The justification (urgency) to take action to reduce or better define the risk increases as the estimates become greater than 0.001 lives per year.
2. AALL < 0.001 (1E-03) to AALL ≥ 0.00001 (1E-05) Lives Per Year. AALL in this range will be considered intolerable unless ALARP considerations are satisfied. AALL in this range will be considered tolerable provided the other risks listed in Section 3.3.1 are considered tolerable, and the

ALARP considerations are met. The justification (urgency) to take action to reduce or better define the risk diminishes as the risk estimates approach 0.00001 lives per year.

3. AALL ≥ 0.001 (1E-03) Lives Per Year. AALL in this range is unacceptable except in extraordinary circumstances. Risks should be reduced to below the tolerable risk reference line (1E-03) regardless of cost considerations and then further until ALARP is satisfied, except in extraordinary circumstances. The justification (urgency) to take action to reduce or better define the risk increases as the estimates become greater than 0.001 lives per year.
4. AALL < 0.001 (1E-03) to AALL ≥ 0.00001 (1E-05) Lives Per Year. AALL in this range will be considered intolerable unless ALARP considerations are satisfied. AALL in this range will be considered tolerable provided the other risks listed in Section 3.3.1 are considered tolerable, and the ALARP considerations are met. The justification (urgency) to take action to reduce or better define the risk diminishes as the risk estimates approach 0.00001 lives per year.
5. AALL < 0.00001 (1E-05) Lives Per Year. AALL in this range will be considered tolerable provided the other risks listed in Section 3.3.1 are considered tolerable, and the ALARP considerations are addressed to evaluate potential risk reduction opportunities to further reduce the AALL. The justification to take action to reduce or better define the risk diminishes as the risk estimates become smaller than 0.00001 lives per year.
6. Low Probability – High Consequence Area. If the incremental life loss is estimated to equal or exceed 1,000 lives and the frequency of dam failure is estimated to less than 1 in 1,000,000 (1E-06) per year, the evaluation of the tolerability of risk must be based on a thorough review of the project benefits and risks as described in Section 3.3.2.2.1.

For new dams or major modifications, the societal incremental risk should be less than the tolerable risk reference line (1E-03) shown on Figure 3-4, except in extraordinary circumstances. However, it is expected that new dams, with the opportunity to make use of state of practice designs and technology, will likely result in lower societal incremental risk being considered when applying the ALARP principle.

Non-Breach Life Safety

The FERC has no explicit risk guideline for non-breach life safety risk.

The estimated non-breach life safety risk is to be plotted on the probability distribution of potential life loss (F-N) chart shown on Figure 4. The diagonal dashed line shown on this F-N plot **does not** have the same meaning as the tolerable risk reference line shown on Figure 2.

Figure 2 is for portraying and communicating the life safety risk associated with the incremental inundation risk in relation to the tolerable risk reference line. Figure 4 provides **a reference line** for communicating the estimated life safety inundation risk for the non-breach inundation scenario and allows comparison of the estimated non-breach life safety risk with the estimated incremental life safety risk.

Use of Figure 4 allows for comparing the estimated non-breach risk with the estimated incremental risk, after risk reduction and risk management measures have been implemented, thus framing and enabling the discussion that life safety inundation risk would continue to exist with a properly functioning dam. Plotting the non-breach risk on a similar plot as various risk reduction alternatives will make the discussion of non-breach risk more meaningful. Such plotting will make it obvious how each risk reduction alternative being considered is estimated to the non-breach risk, and perhaps suggest ways of improving the alternatives to lessen the likelihood of inadvertently increasing this non-breach risk and to improve management of the remaining non-breach risk.

Non-breach life safety risks include those scenarios where the dam operates as designed and intended, but due to high reservoir releases, loss of life may occur due to downstream inundation as a result of those releases. Understanding those conditions when and where loss of life may occur provides opportunities to develop risk reduction management plans or perhaps changes to operational releases and enhanced communication/warning systems with downstream agencies/populations.

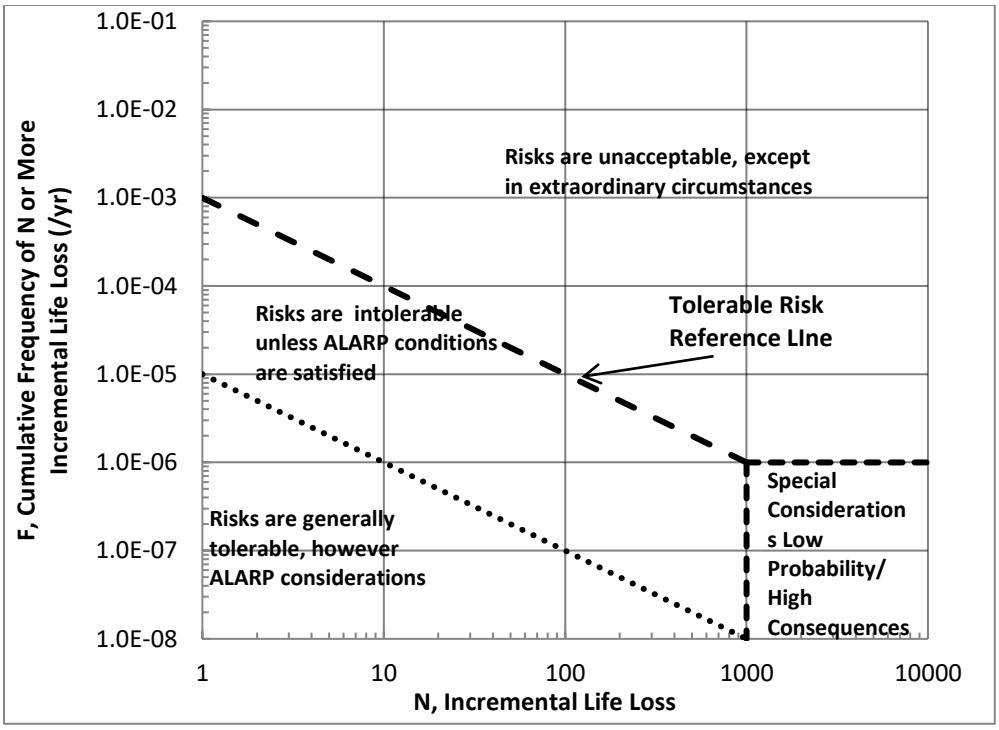

Figure 3 FERC f - $\bar{N}$ Chart for Displaying Average Annual Life Loss for Incremental Risk

Non-breach risk information can also be valuable to downstream communities to assist them in evaluating whether additional community flood risk studies may be warranted.

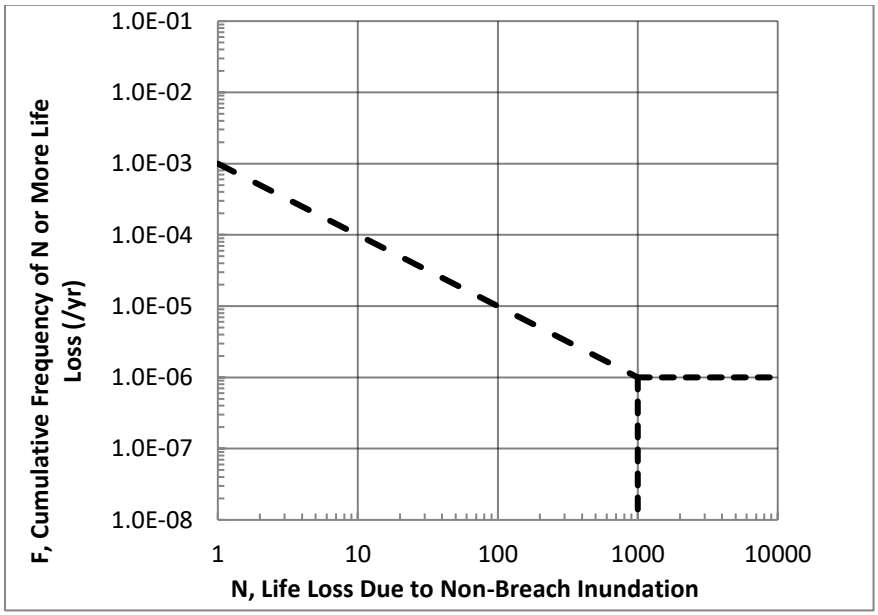

Figure 4 FERC Chart for Plotting Non-breach Life Safety Risk

US Army Corps of Engineers

USACE has borrowed from ICOLD Bulletin 130, Reclamation's Public Protection Guidelines, ANCOLD, and the UK's HSE in formulating its Tolerable Risk Guidelines. The societal risk limit line used on the f-N chart is 0.001 lives/year. USACE defines tolerable risks as the following:

1. risks that society is willing to live with so as to secure certain benefits;

2. risks that society does not regard as negligible or something it might ignore;

3. risks that society is confident are being properly managed by the owner; and

4. risks that the owner keeps under review and reduces still further if and as practicable.

Equity and efficiency are two fundamental principles that were used to derive the tolerable risk guidelines.

US Bureau of Reclamation

Reclamation's basic guideline value is tied to a facility failure rate of 1E-4 per year. However, when there is the realistic potential for life loss in excess of 10, the threshold AFP value is decreased by an order of magnitude for each order of magnitude increase in potential life loss. This portion of the guideline is analogous to the "societal" guideline used by some agencies and corresponds to an expected annualized life loss of 1E-3 per facility. The condition of an fN chart PFM marker plotting above this guideline would generally be associated with increasing justification to reduce or better understand the risks.

State of Colorado

USBR Guidance.

QUESTION 4.6

What are the criteria or guidelines for risk tolerability/acceptability used to address the environmental damage?

Argentina

Under ORSEP risk assessment programme, for the only case completed at the moment, environmental damage was not assessed. For ongoing cases of the programme environmental damage shall be considered. The assessment methodology to be developed will focus on protected areas and shall establish criteria in this aspect.

Australia

There are no specific criteria for risk acceptability/ tolerability for environmental risk but it is qualitatively assessed as part of the risk assessment process.

Canada

No specific criteria but qualitative consideration given based on local and regional importance.

Czech Republic

No criteria

France

None

Italy

Risk analysis not applied

The Netherlands

It is included in the risk assessment through CBA.

Slovakia

No concrete criteria are prescribed

Sri Lanka

Under Environmental Impact Assessments for new developments, the developer has to explain the procedure of safety of dams, once commissioned.

United States of America

Federal Energy Regulatory Agency

A dam failure and loss of the reservoir can impact a number of local, regional, and national non-monetary consequences including, environmental, cultural, and historic resources. Environmental risk is often viewed in terms of the uniqueness of habitat or cultural or other resources that may be destroyed or damaged and the potential for restoring them. Evaluating and quantifying these consequences can be difficult. Assessing the risks associated with these consequences can be even more difficult.
The FERC has no tolerable risk guidelines for these types of risks. In assessing these risks, the FERC will consider the information, analysis, and evidence presented, and will consider the following:

- Significance and magnitude of the consequence and cost and ease of implementation of risk reduction measures
- Effectiveness of risk reduction measures

- Magnitude of risk reduction achievable
- Precedents and other projects where action has been taken or not taken for similar type and magnitude of consequences
- Presence of other intolerable risks

This information will be used by the FERC, in conjunction with the assessment of life safety risks and the consequences from economic considerations, in the overall assessment of the tolerability of project risks.

US Army Corps of Engineers

There are no specific criteria for environmental damage, although judgment would be used when taking environmental damages into consideration when making safety decisions.

US Bureau of Reclamation

There are no specific criteria for environmental damage

State of Colorado

USBR Guidance to qualitatively aggregate dam failure flood impacts.

QUESTION 4.7

What are the criteria or guidelines for risk tolerability/acceptability used to address the damage to cultural heritage?

Argentina

Same answer as before. Cultural heritage was not assessed.

Australia

There are no criteria, but it is considered during design and construction - jurisdictions vary however.

Canada

No specific criteria, but qualitative consideration given based on local and regional importance.

Czech Republic

No criteria

France

None

Italy

Risk analysis not applied

The Netherlands

It is included in the risk assessment through CBA.

Slovakia

No concrete criteria are prescribed

Sri Lanka

In the report mentioned in 4.6 social, cultural and archaeological concerns have to be addressed.

United States of America

Federal Energy Regulatory Agency

FERC has no specific criteria or guideline for damage to cultural heritage. However, other consequences such as these are required to be identified and documented in a risk analysis and will be evaluated in a manner similar to that described above for environmental consequences.

US Army Corps of Engineers

There are no specific criteria for cultural heritage, although judgment would be used when taking this into consideration when making safety decisions.

US Bureau of Reclamation

There are no specific criteria for cultural damage

State of Colorado

QUESTION 4.8

If intangible failure consequences listed in Questions 4.3, 4.4 and 4.5 do not have associated risk tolerability criteria, how the risks related to these consequences are addressed in the risk evaluation process?

Argentina

There are no criteria or guidelines established for address intangible failure consequences. Qualitative measures shall be established in order to address the impact of intangible risks.

Australia

The risks associate with the environment, cultural heritage and societal concerns are qualitatively assessed as part of the risk assessment and often are assessed against corporate risk criteria - for example a medium risk is acceptable with our management but a high or extreme risk would need to be addressed. This process is much more subjective but requires extensive consultation with key stakeholders.

Canada

There are no specific criteria for acceptability/ tolerability for intangible risk, but it is qualitatively assessed as part of the risk assessment process.

Czech Republic

Not able to answer.

France

It is just an inventory of consequences. Their knowledge is already an important step. Moreover, it provides important information for the crisis management.

Italy

Risk analysis not applied

The Netherlands

Cultural and ecological losses, consequences of forced evacuation, loss of life and the effects on society as a whole are included in the CBA and also separately by means of including the group risk.

Slovakia

It depends on the author of evaluation

Sri Lanka

No specific criteria. Consequences are assessed based on judgments of the officers working at the particular dam project.

United States of America

Federal Energy Regulatory Agency

Similar to that described in response to question 4.6 above.

US Army Corps of Engineers

Assessment of consequences is primarily limited to quantifiable property damages and life loss. Other impacts that are identified are assessed qualitatively and this information is included in the decision-making process.

S Bureau of Reclamation

The potential for significant environmental or cultural damage can be used to help build the case for dam safety action.

State of Colorado

By combining in qualitative description of LEVELS of consequences that consider BOTH loss of life and the intangible failure consequences.

QUESTION 4.9

Is any form of benefit-cost calculation performed with the risk assessment to assist in dam safety decision making? Please provide examples.

Argentina

Owners perform different benefit-cost calculations for evaluation of risk reduction measures, upgrade dam safety alternatives and assist dam safety decisions.

In the only case of formal risk assessment completed by ORSEP, several ratios were used:

- Adjusted Cost per Statistical Life Saved (ACSLS)
- Equity Weighted Adjusted Cost per Statistical Life Saved (EAWACSLS)

Australia

Yes. Generally speaking, a form of cost benefit analysis is used to assess ALARP criteria - although this varies by jurisdiction.

Canada

Typically, cost-benefit is just one factor considered in the application of technological risk acceptance criteria.

Czech Republic

Cost-benefit calculations are lately widely made for the small dams build for flood protection. In general, the value of flood protected property by new dam is compared to the price of new dam

France

None

Italy

Risk analysis not applied

The Netherlands

The safety standards are also based on cost-benefit calculation, next to individual- and group risk. All criteria (see answer 3.7) are monetarised.

For all primary dike sections, a factsheet is available showing how the standard is developed. It shows breach locations (if present) and inundation maps. The fact sheets (in Dutch) can be found in: https://www.helpdeskwater.nl/publish/pages/132790/factsheets_compleet19122016.pdf

Slovakia

In principle, cost-benefit calculations are regularly used during the decision-making process (whether flood protection will be implemented or not and how extensive)

Sri Lanka

Cost-benefit calculations are not performed with any risk assessment exercise

United States of America

Federal Energy Regulatory Agency

Yes. ALARP.

US Army Corps of Engineers

USACE does include as part of a study to evaluate risk reduction options the benefit-cost ratio and cost-to-save-statistical-life for the final array of risk management measures. The following example is provided:

	No Action		Action Alternatives [redacted]				
	Existing	FWAC	ALT 9 (F9) [redacted]	ALT 10 (F10)	ALT 11 (F11)	ALT 12 (F12)	Non-Structural
Costs							
Real Estate	N/A		$0	$0	$0	$0	$0
Construction	N/A		$86,624,000	$84,880,000	$37,928,000	$67,740,000	$0
Non-Construction (PED, S&A, EDC)	N/A		$21,541,000	$14,512,000	$12,211,000	$14,512,000	$0
Contingency (%)	N/A		26%	32%	35%	30%	0%
Project First Cost (Current FY)	N/A		$136,288,000	$134,319,000	$70,535,000	$110,295,000	$3,000,000
Operations and Maintenance Costs (Annual)	$3,700,000	$3,700,000	$3,900,000	$4,334,000	$4,334,000	$4,334,000	$3,800,000
Dam Performance							
Annual Probability of Failure (APF)	5.22E-05	8.19E-05	2.90E-06	2.41E-06	1.15E-05	5.92E-06	5.22E-05
Reduction in APF			7.90E-05	7.95E-05	7.04E-05	7.60E-05	2.97E-05
Average Annual Incremental Life Loss (AALL)	2.95E-03	1.08E-02	1.36E-04	1.79E-03	1.88E-03	7.80E-04	9.40E-04
Reduction in AALL			1.07E-02	9.01E-03	8.92E-03	1.00E-02	9.86E-03
Individual Risk	1.05E-05	1.64E-05	5.81E-07	4.82E-07	2.30E-06	1.19E-06	1.05E-05
Benefit Cost Analysis							
Annual Cost of Alternative Risk Management Plan			$5,371,869	$5,731,149	$3,310,668	$4,819,484	$213,844
Annual Benefit of Alternative Risk Management Plan			$26,000	$26,000	$23,000	$25,000	$10,000
Cost-to-Save-a-Statistical-Life			$501,300,520	$633,201,882	$368,572,673	$478,491,431	$20,673,860
Least Cost Rank to Reduce Societal Life Safety Risk			2	4	3	5	1
Benefit Cost Ratio (BCR)			0.005	0.005	0.007	0.005	0.047
Cost Effective at Reducing AALL?			Yes	No	Yes	No	No
Other Factors							
ALARP considerations included?			Most Efficient Plan that Achieves Tolerable Risk Guidelines. No difference in timing of Risk Reduction. Address all Risk Driving PFM's.	Not Efficient	No Difference in timing of Risk Reduction. Does not address all Risk Driving PFM's.	Not Efficient	Does not meet TRG
Degree of Completeness			F09 and F10 are more complete because they address failure modes in reaches 8 & 9, in addition to reaches 4, 5 & 6. F11 and F12 only address reaches 4, 5 & 6. All plans complete because do not rely on external actions to achieve objectives.				Relies on coordination outside current authorities. Does not address failure modes.
Acceptability			High Acceptability				Does not meet TRG
Robustness			F09 and F11 are most Resilient because of centerline cutoff location. F10 and F12 have resiliency issues because of higher pore pressures due to downstream cutoff location. F09 most Robust because addresses all risk driving PFM's. All plans improve resilience of community because non-structural measures reduce consequences of failure. All plans redundant because address both performance and consequence.				Improved community resiliency, low dam resiliency. Not robust or redundant.
Redundancy							
Resilience							
Implementation Duration (PED & Construction)			7	7.5	6.75	6.5	1-3
Do No Harm							
Are risks during construction increased?			No				

US Bureau of Reclamation

As part of a corrective action study, the benefit-cost of an existing project would be quantified by a staff economist in considering whether to abandon or modify the project.

State of Colorado

FEMA – Pre disaster mitigation (PDM) grants rely on cost-benefit analysis. These have been utilized on two recent Colorado Dam Safety dam rehabilitation projects that have received FEMA funding.

QUESTION 4.10

Within your country are you aware of any dam owners who have established their own corporate tolerability of risk guidelines or policies?

Argentina

Owners usually apply different and various corporate policies on tolerability and risk guidelines.

Reliable central maintenance for hydro mechanical equipment (RCM1, RCM2, SAE JA1011 norm or similar methodologies) and periodic systemic qualitative risk analysis by expert judgement are usually applied.

Australia

We are not aware of any that don't use ANCOLD national best practice.

Canada

TransAlta have established criteria based on several factors that provide a risk index that is used for prioritization. Corporations such as Vale and Evolugen have mandated that PFMA's be performed for all their water retaining structures.

Czech Republic

No.

France

All dam owner must have developed a safety policy and a Dam Safety Management System in place. This is proportionate to the dam. The French regulation requires a document called "organization document" and in the safety review a presentation of the safety management system has to be done

Italy

Risk analysis not applied

The Netherlands

No, all owners have to comply with the same standard

Slovakia

No information

Sri Lanka

No.

United States of America

Federal Energy Regulatory Agency

Yes. Bureau of Reclamation and U.S. Army Corps of Engineers.

US Army Corps of Engineers

USACE is an example of an owner-operator that has established its own tolerable risk guidelines and policy on dam safety. The Tennessee Valley Authority (TVA), also a self-regulating Federal dam owner, has established their tolerable risk guidelines and dam safety policy.

US Bureau of Reclamation

Reclamation is an example of an owner-operator that has established its own public protection guidelines.

State of Colorado

Yes, a couple of our larger municipal dam owners.

QUESTION 4.11

Is the principle of As Low as Reasonably Practicable (ALARP) applied and if it is, what is the legal context within which it is applied and how it is used in demonstrating the tolerability of risk?

Argentina

The ALARP principle is not applied in Argentina. Standards and good engineering practice are adhered to, and regulations tend to absolute levels of safety. Dam safety decisions are based on standards, expert judgement and experience.

Australia

It is applied although methods as part of the ANCOLD guidelines. There is a common law requirement for it. What is ALARP has never been tested and it is up to each owner to come to their own defensible position on their individual situation - although there is guidance provided in ANCOLD as a starting point. Consideration of ALARP does not commence until dam safety risk has been reduced below the limit of tolerability.

Canada

ALARP, in the sense intended by the UK Health and Safety Executive, is not applied to any significant degree. As noted above, technological criteria dominate risk-informed dam safety decision-making in Canada.

Czech Republic

This principle is not much known among dam owners and not used.

France

There is no regulation on the ALARP approach. However, in some (very few) safety review approaches of this type have been presented.

Italy

Risk analysis not applied

The Netherlands

No.

Slovakia

ALARP is not officially applied in legal context

Sri Lanka

Not in use.

United States of America

Federal Energy Regulatory Agency

Yes. ALARP is applied in a regulatory context. In making a judgment on whether incremental risks are ALARP, the following factors must be taken into account: the level of incremental risk in relation to the tolerable risk reference line; the cost-effectiveness of the risk reduction measures; the disproportionality of the investment to the benefits associated with a prevented fatality; good practice; societal concerns as revealed by consultation with the community and other stakeholders; and other factors. The specific ALARP considerations to be used are listed below:

1. The cost-effectiveness of the incremental risk reduction measures. Cost-effectiveness of the risk reduction measures and the alternative plans will be used to guide the selection of the measures and plan to be implemented. Reducing the incremental life loss risk to the tolerable risk reference line and below is to be done in a cost effective manner. The adjusted "cost-to-save-a-statistical-life" (aCSSL) is used to evaluate this measure. Chapter 2 - Risk Analysis describes the methodology to compute aCSSL. There is no value of a aCSSL that indicates a threshold for which it can be said that ALARP is satisfied. Instead, the confidence and degree of defensibility with which one can conclude that ALARP has been met increases as the aCSSL increases. In using aCSSL to evaluate competing risk reduction alternatives, the smaller values of aCSSL indicate that a risk reduction alternative is “better value for the money”.
2. The level of incremental risk in relation to the tolerable risk reference line. When the estimated life safety incremental risk has been reduced to the tolerable risk reference line, the ALARP

consideration leads to the question, "How far below that reference line is the level of risk to be reduced?" In evaluating this ALARP factor, the further below the tolerable risk reference line the weaker the rational for further risk reduction efforts.

3. Disproportionality. A disproportionality factor has been used by some agencies (HSE) and organizations (ANCOLD) as a test to assess whether a dam safety investment is grossly disproportionate to the benefits associated with a prevented fatality.

HSE developed a sliding scale of 'proportion factor' that varies with the level of risk. This scale is based on the principles of:

a. The greater the risk, the less weight will be given to the factor of cost
b. The greater the risk, the higher the proportion may be before being considered gross disproportion, but the disproportion must be gross.

The ANCOLD (2003) guidelines are based on HSE, which indicates as generally reasonable, a disproportionality factor of 10 for risks just below the limit of tolerability (tolerable risk reference line) and dropping to approximately 3 for risks just above the broadly acceptable level (two orders of magnitude below the limit of tolerability). It's worth noting here again that the FERC does not define a broadly acceptable level as does ANCOLD. The ANCOLD approach is shown in Tables 1 and 2 that shows the disproportionality ratio of the CSSL to the WTP. The disproportionality ratios in Tables 1 and 2[11]. have been adjusted from the ANCOLD CSSL values using a VSL of approximately $10M/statistical fatality prevented.

Table 1 - ANCOLD Guidance on ALARP Justification for Risks just below the Tolerable Risk Limit (adapted from ANCOLD, 2003)

ALARP Justification Rating	Range of Disproportionality Ratios	
	Greater than or equal to	Less than
Very Strong	Zero	0.5
Strong	1	2
Moderate	2	10
Poor	10	

Table 2 - ANCOLD Guidance on ALARP Justification for Risks just above the Broadly Acceptable Region (adapted from ANCOLD, 2003)

ALARP Justification Rating	Range of Disproportionality Ratios	
	Greater than or equal to	Less than
Very Strong	Zero	0.2
Strong	0.3	1
Moderate	1	3
Poor	3	

The FERC has no requirement for disproportionality. However, the FERC strongly recommends that a disproportionality ratio should be calculated for each risk reduction alternative. The dam owner should use their judgment and consult legal advice, as appropriate, to determine the appropriate disproportionality for each risk reduction alternative. The justification and evidence used to support the disproportionality selected by the dam owner for each risk reduction alternative should be well documented.

4. Good Practice. Good practice includes compliance with the FERC Engineering Guidelines and the Owners Dam Safety Plan. The FERC Engineering Guidelines are the state-of-the-practice for

[11] Tables 1 and 2 refer to the tolerable risk limit and broadly acceptable region, respectively. Based on their original use by HSE, the tolerable risk limit for individual risk may be 1 in 10,000 per year and the broadly acceptable limit may be considered to be 1 in 1,000,000 per year. However, the concepts of broadly acceptable risk and the limit of tolerability do not apply to dams as discussed elsewhere in these guidelines.

design, construction, operation, and maintenance of FERC-regulated dams as documented in current FERC or applicable industry related publications.

The FERC has adopted the following position (modified after NSW (2010)):

- Full compliance with the FERC Engineering Guidelines or good practice of an industry-recognized standard or good practice (where the FERC has no guidance or position) will normally be accepted by FERC as a demonstration of adequate safety in the long-term (not a temporary or short duration condition), provided the standard or good practice was intended to assure safety in the long-term, and
- The FERC will generally accept risks higher than those achieved by the standards or good practice, described in the paragraph above, as adequately safe in the long-term provided the owner can reliably demonstrate that all risks comply with the tolerable risk guidelines, as defined herein, for safety in the long-term.

5. Societal concerns are revealed by consultation with the community and other stakeholders. Societal concerns in terms of community expectations are to be identified, documented, and resolved through public meetings, comment solicitation and response, or by other appropriate measures.

   There is a lack of guidance and precedent for incorporating societal concerns for dam failure risks.

   Societal concerns which should be factored into the assessment of ALARP include (modified from Victoria, 2012):

   - Dams with high to very high consequences (e.g., an identified potential failure mode leading to a potential loss of life of more than 100);
   - A highly vulnerable population at risk (such as a pre-school, nursing home, prison, etc. immediately downstream of a dam);
   - Known and strong interdependence of a dam with critical infrastructure and the provision of essential services (power, water, etc.); and
   - Situations where there is a lack of trust from the community that the risk is being adequately managed, perhaps resulting from an earlier dam safety incident or other significant loss experienced by the community.

   An owner seeking to demonstrate that risks are ALARP is to identify and appropriately evaluate and address societal concerns and is to document the basis for the evaluation. The focus should be about what the societal concerns are and how they are addressed or mitigated. Reduction of risks may or may not be part of the mitigation. Conversely, reducing risks may, in part or in whole, address the societal concerns. In general, the following guidance should be considered:

   - If societal concerns are low, the risks may be tolerable for a risk within the region of tolerability close to the tolerable risk reference line, provided that the other ALARP considerations and other factors so indicate. If societal concerns are high, risks would normally need to be reduced to well below the tolerable risk reference line (at least two orders of magnitude below the tolerable risk reference line).
   - For intermediate societal concerns, intermediate levels could indicate risks are tolerable.

6. There are several other factors that can assist in the assessment of ALARP. These include (from Victoria, 2012):

   - Duration that the risk applies – a greater focus on risk reduction may be prudent for potential failure modes associated with enduring risks compared to shorter term risks, although ANCOLD stresses that this is not necessarily the case. Short duration of risk here is not to be confused with rare events or low failure probability. In principle though, risk is expressed as an intensity (that is, as likelihood of consequences per annum) and intensity is not affected by duration.
   - Availability of risk reduction options – in some situations, for some potential failure modes, it may not be possible to identify additional viable risk reduction options, thus justifying an ALARP determination. Owners will need to be mindful of technological and other developments and review this assessment periodically.

- Creation of new risks – risk reduction can itself be risky. In some cases, reducing dam safety risks cannot be done without creating new and poorly understood risks. In such a situation, evaluation of ALARP may conclude that it is better to leave things as they are.
- Adequacy of the Potential Failure Modes Analysis – the determination of ALARP should be based on no less than a contemporary, thorough, and expert assessment of potential failure modes. Owners will need to remain informed of any changes to the body of knowledge regarding potential failure modes, which may result in new potential failure modes being considered or modifications to event trees associated with existing potential failure modes.
- Consideration of standards-based approaches – satisfaction of contemporary engineering standards may assist with justifying an ALARP determination. Having met standards, there may be additional simple, low-cost risk reduction measures that could also be considered by dam owners and managers to further reduce risk.
- Benchmarking – Very little information is available in the US on benchmarking dam safety risks among dam owners. However, where benchmarking information may be available, in the form of precedents set forth by other dam owners in the available literature, this information could provide helpful information about investment and rate of risk reduction, particularly as risk diminishes over time with increasing investment, and this feedback information could help inform owner investment decisions.

Owners should consider these additional factors, and other factors that may be important in building a case for ALARP.

The evidence provided from the six categories of factors listed above will be used to evaluate ALARP. All else being equal, the first three factors (cost effectiveness, level of risk, and disproportionality) will be weighed more heavily in the ALARP determination. As such, it is incumbent on the dam owner to make sure the documentation and evidence to support the ALARP factors is clearly presented in the risk report and the case is clearly made in the report as to whether ALARP considerations for each potential failure mode are met or not. The use of these factors will be used to inform and not to prescribe the outcomes of an ALARP evaluation.

Some final ALARP remarks:

- Affordability (the capacity of the dam owner to fund improvements) is not a consideration in judging whether risks are ALARP. The FERC will not consider the owner's financial circumstances other than by some possible concessions in the timing of the improvements.

The FERC will review the information submitted in support of ALARP and review each case based on the merits and will advise the dam owner if the risks are or are not considered tolerable. However, it is important to note that although FERC may concur that a risk is considered tolerable, that rendering does not provide a legal decision or imply legal protection of the dam owner.

US Army Corps of Engineers

Although there is no specific legal context, ALARP is addressed within USACE ER 1110-2-1156 "Safety of Dams". The ALARP considerations provide a way to address efficiency aspects in both individual and societal tolerable risk guidelines. The ALARP considerations apply below the tolerable risk limit on the f-N chart. The application of ALARP considerations mean that actions should be taken to reduce risk below the tolerable risk limit until such actions are impracticable or not cost effective. ALARP is an explicit consideration under Reclamation guidelines, 2011, and ANCOLD, 2003, and NSW DSC, 2006 tolerable risk guidelines. Determining that ALARP is satisfied is ultimately a matter of judgment. In making a judgment on whether risks are ALARP, the following factors should be taken into account (adapted from NSW DSC, 2006):

1. The level of risk in relation to the tolerable risk limit;

2. The cost-effectiveness of the risk reduction measures;

3. Any relevant recognized good practice; and

4. Societal concerns as revealed by consultation with the community and other stakeholders.

US Bureau of Reclamation

Under the current (2011) public protection guidelines, ALARP is applicable (1) when a PFM has the potential result in more than 1000 fatalities and (2) in the context of selecting between corrective action alternatives. Because PFMs with the potential to result in over 1000 fatalities are comparatively rare, ALARP has typically been applied within the second context, for example to argue in favor of including features in a modification that, while not strictly necessary to reduce the risks of the targeted PFM, are nonetheless reasonable and prudent. The applicability of ALARP is unique to each project and modification alternative. There is no specific legal context.

State of Colorado

Yes, ALARP principles provide a thorough basis for evaluating risk for dam modifications or new dam construction. Primarily, this has been shown by having multiple iterations of a SQRA completed: pre-design (existing conditions), design workshops to solicit ideas and repair options, final design to ensure ALARP principles were used.

FOCUS AREA 5 – RISK MANAGEMENT

QUESTION 5.1

What is the risk assessment being used for? A portfolio risk assessment undertaken at a screening level is generally only used to identify the priorities for further studies or perhaps some minor interim risk reduction measures, but not used for dam safety decision making?

Argentina

A portfolio risk assessment undertaken at a screening level shall be used to identify priorities for further studies or perhaps some minor interim risk reduction measures, but not used for dam safety decision making.

ORSEP detailed risk assessments shall be used complementary to traditionally dam safety practice, for future dam safety upgrades decisions.

Australia

This varies. Some organizations have a PRA that considers detailed risk and considers this in priority. Other organizations have a much higher-level PRA although the outcome is the same.

Canada

Qualitative and semi-quantitative risk assessments are utilized for most aspects of dam safety management – particularly for prioritization. Technology criteria aimed at achieving a very low level of residual risk normally apply to major augmentations. In one Province a risk screening-type tool based on a mix of reliability methods, fault trees and empirical models is being used in developing portfolio risk profiles and in carrying out preliminary portfolio risk assessments.

A recent example of a semi-quantitative dam safety risk assessment was performed for a remote first nations community in Northern Ontario. These results were accepted by the governments of Ontario and Canada for relocating an entire community or 2,000.

A small number of dam owners have introduced consideration of quantitative risk analysis based on subjective probabilities as a basis for decision-making – normally to proceed with risk reduction measures.

Czech Republic

A simplified portfolio dam risk assessment was made for all large dams recently for the Ministry of Agriculture, to identify the priorities for dam rehabilitation in the future, where also the financial aspect was considered in the way to mitigate maximum of risk for the minimum costs.

France

Risk assessment is used for both:

- For a given dam:
  - Identify main weaknesses and "easy actions" to improve dam safety.
  - Identify dam safety issues, mitigations actions and help to prioritize them.
- For a dam portfolio: provide general dam safety overview to decision makers, prioritize actions

Italy

Risk analysis not applied

The Netherlands

The risk assessment is done by the Ministry and leads to the safety standards (see answer 1.1). Every 12 years safety assessments are performed (see also answer 1.10.)

Slovakia

At present time it is not significantly used

Sri Lanka

Portfolio risk assessment used for prioritizing risk reduction measures within the given budget.

United States of America

Federal Energy Regulatory Agency

From Chapter 2 of the FERC RIDM Risk Guidelines. Risk analyses can be performed for a number of different purposes using a variety of information. The level of detail (and rigor) included in a risk analysis should depend on the confidence that is required to support the purpose of the risk analysis and the decision to be made. To that end, the information and the uncertainty reflected in the risk estimates will also vary. Generally, more detailed risk analyses require more detailed engineering analyses and studies to try to better understand and reduce the uncertainty, when and where possible, and increase the confidence in the risk estimates.

In general, dam safety risk analyses can be divided into four broad categories or levels:

Level 1 - Screening Level Risk Analyses
Level 2 - Periodic Risk Analyses
Level 3 - Semi-Quantitative Risk Analyses (SQRA)
Level 4 - Quantitative Risk Analyses (QRA)

Each level provides a different set of tools and methods that are proportionate in terms of level of effort required, details considered, and confidence in their outcomes. These levels of risk analyses provide a suite of scalable approaches that provide information to promote critical thinking and guide a risk analyst's judgment. The risk analysis methods applied to each level are scalable and can be applied with varying degrees of effort (time, resources, and cost) to provide the appropriate level of accuracy, rigor, and confidence required to make credible risk informed decisions. It is important to understand that every decision does not necessarily require a high level of rigor, detail, and precision in the risk estimate in order to support a credible decision. These risk analysis levels vary in purpose and therefore in the data required, detail, and robustness of analysis, and in uncertainty and confidence in the results. However, in all cases the level of detail should only be what is needed to support the decision(s) that will be informed by the risk analysis. The analysis should be as simple as it can be, but not simpler. Figure 5 shows a general framework for each level of risk analysis.

These levels of risk analysis range from qualitative to quantitative approaches. In either approach a comprehensive identification, written description, discussion, and evaluation of factors that make events more or less likely to occur for each credible potential failure mode are documented. The magnitude of consequences related to a potential failure is also characterized, discussed, and documented.

Qualitative or semi-quantitative risk analyses can be desirable in some cases where it is desired to apply risk analysis principles to the decision making without the time, cost, and data/assessment requirements associated with a quantitative risk assessment; for screening level analyses of an inventory of dams where it is desired to get a quick evaluation of the risks so that risk reduction studies and actions can be prioritized; and for sensitive cases that involve external interested parties that are more likely to understand and accept qualitative assessments rather than detailed numerical analyses (FEMA, 2015).

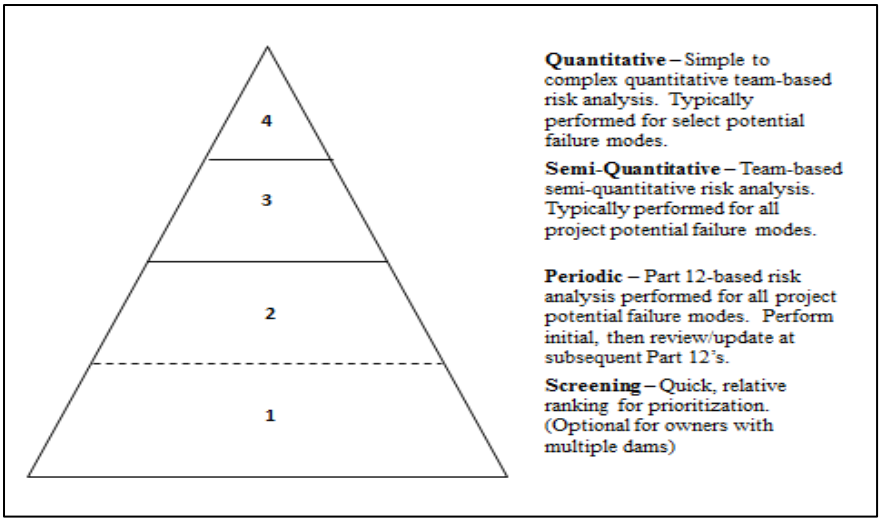

Figure 5 FERC Level of Risk Framework

US Army Corps of Engineers

USACE uses risk assessment to inform decisions on individual structures, examine the system risk effects, and to manage the portfolio of dams and levees owned and operated by USACE. The results of the various types of risk assessment are used to manage that portfolio. There are other ways that risk assessments are used including risk-informed design and evaluating risks taken during construction.

US Bureau of Reclamation

Reclamation utilizes Quantitative Risk Analysis to understand risk associated with individual Potential Failure Modes as well as to understand total risk presented by the facility as a whole. The results of the risk analysis are utilized to build a Dam Safety case for taking actions to better understand risk, to reduce risk, or to take no further action at that time. In general, the results of the QRA are compared to Reclamation's Public Protection Guidelines below:

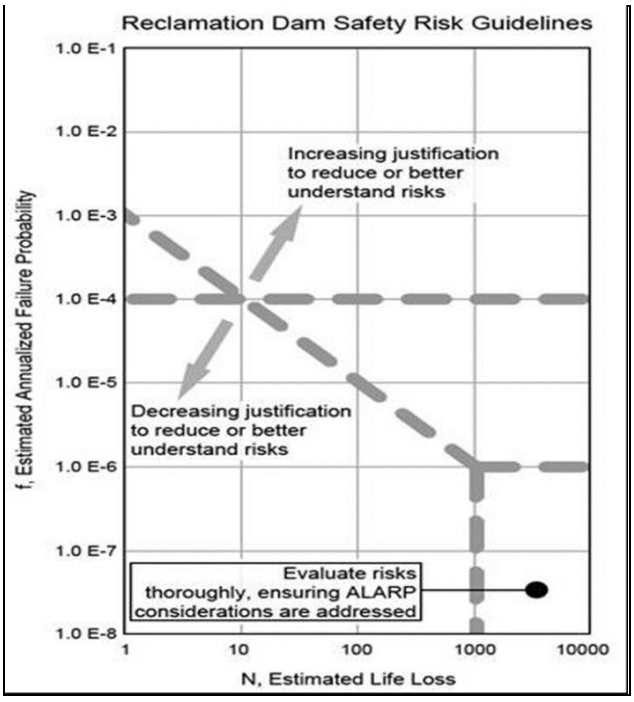

Figure 6 USBR Dam Safety Risk Guidelines

Facility risks are compared to the PPG to help inform whether there is a need to reduce or better understand risks at the facility. This decision is influenced by our uncertainty associated with information utilized estimate risks as well as confidence in the overall confidence in the recommended actions.

Uncertainty:

- When probability estimates are expressed as distributions, Monte Carlo simulation can be used to obtain Annualized Life Loss and AFP distributions (in addition to the mean estimates).
- Total marker crosshairs give a sense of how far the total marker could move if the input estimates change
- Once key sources of uncertainty are identified, actions can be taken to reduce uncertainty

Confidence

- Once it has been demonstrated that there is increasing justification to take risk reduction action, next steps depend on how much confidence there is.
- With high confidence, may make sense to go straight into a corrective action study (CAS).
- For low confidence situations, may be reasonable to first perform additional studies to increase confidence.

It is not enough to say that risk reduction action is justified because the estimated risks are above guidelines. The recommended course of action must be supported by additional arguments.

Other considerations:

- Are the risk estimates reasonable? Consistent with condition of the dam and characteristics of downstream area?
- What is the potential impact of uncertainty? How likely are the estimates to change with additional info or analysis?
- Are the risk estimates consistent with how similar facilities have performed under similar loading?
- Is the design of the dam antiquated compared to the state of the art? Or has the dam been recently modified?
- Level of Study and Available Information (loadings, structural response, consequences)
- Appropriate dam safety actions
- Cost of performing dam safety actions

State of Colorado

See response to 2.1 above.

QUESTION 5.2

How are risk assessment results used in decision making?

Argentina

ORSEP risk assessment programme is fairly new and risk assessment results have not been used up to the moment.

Australia

Assessed assessment will define priority, scope and timing of investment decisions.

Canada

This depends on the context. Most frequently the results are used for prioritization and scheduling of minor and major augmentations. There are a few (3 or 4) cases where semi-quantitative and quantitative risk assessment has been used as a basis for accepting that a dam is safe enough for a long period of time into the future. In one instance, a decision informed by a risk assessment study was reached to relocate an entire remote community of 2,000 persons, in part, as a result of a semi-quantitative risk screening.

Czech Republic

Not used, as the risk assessment is not performed regularly and deeply.

France

In France, there is no formal acceptability criteria of risk analysis.

- Each owner can propose mitigation measures when appropriate based on the risk analysis
- Regulator decision on acceptance or not

Italy

Risk analysis not applied

The Netherlands

If the periodic safety assessment shows that the dam is not up to standard, the owner can request a grant for an upgrade in accordance with The Flood Protection Subsidies Regulation. If more projects request subsidies than funds available in the program, priority is given to the result. The higher the probability of failure, the higher on the list.

Slovakia

At present time it is not significantly used

Sri Lanka

Draw more attention for high risk dams and persuade further studies. More importantly investment decisions by the government is taken based on the results of previously done studies. There is a need to repeat the risk assessment periodically and also to expand the study to the other dams as well

United States of America

Federal Energy Regulatory Agency

Risk information and results are used to make a case for action (or no action). They are risk informed, not risk based. The quantification of risk estimates is dependent on data and analysis regarding the design, construction, and current condition of a dam, as well as the identified loads to which the dam could be subjected to over its operating life. Additional uncertainty is introduced due to limited data and knowledge in the life loss, economic, and environmental consequences. When making a decision regarding future actions, the FERC will consider the risk estimates, the issues most influencing the risks, the sensitivity of the risks to particular inputs, ALARP considerations, and the potential for reducing uncertainty. Uncertainty may be reduced by performing additional actions such as collecting more data, by performing more analysis, or by performing a more detailed analysis of the risks. However, there are occasions when additional efforts may not result in significant reduction in uncertainty. It is important to recognize when this is the case and consider the anticipated value of the additional efforts to reduce uncertainty as a factor in selecting a course of action (BOR, 2011). Sensitivity studies are often useful in evaluating key parameters that additional information would address. These studies could be used to address the following questions:

- If the additional information was collected, what would be the possible range of outcomes?
- How might the risk change over that potential range?
- Could the confidence in the risk estimates increase?

Uncertainty should also be considered in evaluating the performance of risk reduction measures. Each measure will likely not have the same surety in achieving the intended risk reduction.

When significant uncertainties or assumptions related to a lack of data or interpretations of data result in a range of risk estimates, the results may straddle the guideline values with portions of the risk estimates range portrayed both above and below the guidelines. In these cases, the FERC will assess the portion of the risk estimate range that exceeds the guidelines to determine if it is significant enough to warrant further

action or studies. The entire range will be used to assess the need for future actions as well as an aid in setting the priority and urgency for initiating the actions.

US Army Corps of Engineers

Risks are used along with any additional information to inform decisions made by the USACE Dam Safety Officer.

Risks are used along with any additional information to inform decisions made by the USACE Dam Safety Officer.

US Bureau of Reclamation

See above

State of Colorado

See response to 4.4, above with respect to identification of risk driving failure modes. Additionally, see response to 3.9 with respect to identifying actions to increase confidence in assessments.

QUESTION 5.3

What prioritization measures are used as a result of the risk assessment and how are they established and managed?

Argentina

ORSEP risk assessment programme is fairly new and up to the moment prioritization measures has not been applied.

Australia

Prioritization of works and timing - and urgency too. Risk assessment is used for emerging issues to mitigate outside of the annual corporate planning cycle.

Canada

Semi-quantitative risk analysis methods are mostly used for prioritization. One dam owner has developed a standards-based risk assessment scaled to the probability of demand (hazard or operational demand) that mimics the probability of failure equation taking account of the effectiveness of redundant features and interim risk controls

A very small numbers of owners utilise risk based on subjective probability as a basis for prioritization.

Czech Republic

Not being done, except for the case described in 5.1.

France

See answer 5.2

Italy

Risk analysis not applied

The Netherlands

See answer 5.2

Slovakia

At present time it is not significantly used

Sri Lanka

Prioritization of resource allocation for dam safety been done based on risk assessment. Initial Risk assessment would have been done by a generalist engineer. Prioritized items are referred to specialists for further investigations and advice for risk reduction measures.

United States of America

Federal Energy Regulatory Agency

In order to effectively prioritize and implement dam safety actions, information on the cost and duration of the actions and the magnitude of the risk reduction potential is needed. This type of information is necessary to evaluate the efficiency of risk reduction actions and can be used to fine-tune dam safety actions. A record of the baseline (or existing condition) risks, the dam safety case, and updates that resulted from risk reduction activities should be maintained for each dam within an inventory.

For dam owners with large dam inventories, it will be important to prioritize dam safety actions because funding will limit how quickly actions can be completed. If an owner is dealing with a large dam inventory, a risk categorization scheme may be helpful in making initial decisions regarding prioritizing dam safety actions.

The following principles apply to risk management (FEMA, 2015):

1. The objective of a dam owner should be to reduce dam safety risk as effectively and as efficiently as possible.
2. Each dam owner should have a transparent process for establishing priorities and the urgency of completing dam safety actions.
3. Incorporate flexibility in prioritizing work within an inventory, allowing for adjustments in planned work as new, high priority issues are identified.
4. Use a dedicated, established group to review and prioritize proposed dam safety actions within an inventory or when establishing urgency for action at a specific dam.
5. Independent review is critical to the credibility of this process.
6. The urgency of completing dam safety actions should be commensurate with risk.

Prioritization for dam owners with a single dam is not an issue. However, for owners/licensees with multiple dams and those owners/licensees with tens of dams, prioritization is important.

Prioritization of dam safety actions can be done on a facility basis (where total risk is the focal point, and the goal is to reduce total risk to tolerable levels) or on an individual potential failure mode basis (where single potential failure modes are addressed).

For dam owners with a large inventory of dams, it will be important to prioritize dam safety actions because funding and resources will likely limit how quickly actions can be completed. If an owner is dealing with a large inventory, a risk reduction plan will need to be developed to assist in making an initial assessment at prioritizing dam safety actions.

DSRC I dams have a dam safety issue with very high urgency that requires taking immediate and expedited actions to avoid failure. Therefore, DSRC I dams with life-safety risk should be given the highest priority for expedited studies and, if warranted, risk reduction evaluations and designs.

Dams will be prioritized within their DSRC. For example not all DSRC II dams have the same priority.

Priority and urgency are different but should be compatible, thus higher priority dams are normally associated with the more urgent DSRC dams. Prioritization decisions for various studies can have a significant impact on the speed and efficiency of risk reduction for a dam owner's inventory of dams. Therefore, there may be times when a lower risk dam could be prioritized ahead of a dam with a higher risk when it is demonstrated that this action will be more effective and expeditious in reducing the owner's overall inventory risk.

Significant weight should be given to the tolerable risk guidelines, but other ALARP considerations should also be used to provide a more complete basis for prioritization of the queues.

Quantitative considerations include:

1. The level of incremental risk in relation to the tolerable risk reference line. The greater the estimated annual probability of failure and the further the estimated incremental life risk is above the tolerable risk reference line, the greater the urgency to act.
2. The cost-effectiveness of the reduction in the incremental risk (the project with lower overall cost for the same level of risk reduction would be given higher priority). The more cost-effective a risk management plan is in reducing the annual probability of failure and the life-safety risk to and below the tolerable risk reference line, the greater the rationale to select that plan.
3. Net benefits achieved.
4. The magnitude or severity of the economic and environmental impacts.

Qualitative or non-monetary considerations include:

1. Any relevant recognized good practice (FERC Engineering Guidelines) (risk management measures that satisfy all FERC Engineering Guidelines would be given more weight than those that do not).
2. Societal concerns as revealed by consultation with the community and other stakeholders.
3. Impacts on any facilities critical to national security and well-being.
4. The magnitude of impact on community, regional, or national well-being.

To prioritize actions within a DSRC category, consideration should be given to each of the following factors, which should contribute to increasing the priority of actions at a given dam:

1. Both the failure probability (APF) and the average annualized life loss (AALL) exceed the threshold guideline values.
2. The APF or the AALL is driven by a single potential failure mode.
3. The APF or the AALL is driven by a potential failure mode manifesting itself during normal operating conditions.
4. The range of risk estimates is tightly clustered, and the mean and median are similar (for detailed uncertainty analyses only) and/or sensitivity studies instil confidence.
5. Risk reduction or confirmation is relatively easy and inexpensive.

The above factors can also be considered if a dam appears to border two categories. If a dam owner has a small inventory of dams, the above factors alone can be used as the basis for establishing priorities. The initial effort to place the actions in one of the five risk categories would have limited value for small dam inventories.

US Army Corps of Engineers

Results of the risk assessment are used to assign a Dam Safety Action Classification (DSAC) to the dam, which is based upon considerations in the following table:

URGENCY OF ACTION (DSAC)	ACTIONS FOR DAMS IN THIS CLASS***	CHARACTERISTICS OF THIS CLASS
VERY HIGH (1)	Take immediate action to avoid failure. Communicate findings to sponsor, local, state, Federal, Tribal officials, and the public. Implement interim risk reduction measures, including operational restrictions. Ensure the emergency action plan is current and functionally tested for initiating event. Conduct heightened monitoring and evaluation. Expedite investigations to support remediation using all resources and funding necessary. Initiate intensive management and situation reports.	CRITICALLY NEAR FAILURE: Progression toward failure is confirmed to be taking place under normal operations. Dam is almost certain to fail under normal operations to within a few years without intervention. OR EXTREMELY HIGH INCREMENTAL RISK**: Combination of life or economic consequences with likelihood of failure is very high. USACE considers this level of life-risk to be unacceptable except in extraordinary circumstances.
HIGH (2)	Communicate findings to sponsor, local, state, Federal, Tribal officials, and the public. Implement interim risk reduction measures, including operational restrictions as warranted. Ensure the emergency action plan is current and functionally tested for initiating event. Conduct heightened monitoring and evaluation. Expedite confirmation of classification. Give very high priority for investigations to support the need for remediation.	FAILURE INITIATION FORESEEN: For confirmed and unconfirmed dam safety issues, failure could begin during normal operations or be initiated as the consequence of an event. The likelihood of failure from one of these occurrences, prior to remediation, is too high to assure public-safety. OR VERY HIGH INCREMENTAL RISK**: The combination of life or economic consequences with likelihood of failure is high. USACE considers this level of life-risk to be unacceptable except in extraordinary circumstances.
MODERATE (3)	Communicate findings to sponsor, local, state, Federal, Tribal officials, and the public. Implement interim risk reduction measures, including operational restrictions as warranted. Ensure the emergency action plan is current and functionally tested for initiating event. Conduct heightened monitoring and evaluation. Prioritize investigations to support the need for remediation informed by consequences and other factors.	MODERATE TO HIGH INCREMENTAL RISK**: For confirmed and unconfirmed dam safety issues, the combination of life, economic, or environmental consequences with likelihood of failure is moderate. USACE considers this level of life-risk to be unacceptable except in unusual circumstances.
LOW (4)	Communicate findings to sponsor, local, state, Federal, Tribal officials, and the public. Conduct elevated monitoring and evaluation. Give normal priority to investigations to validate classification, but do not plan for risk reduction measures at this time.	LOW INCREMENTAL RISK**: For confirmed and unconfirmed dam safety issues, the combination of life, economic, or environmental consequences with likelihood of failure is low to very low and the dam may not meet all essential USACE guidelines. USACE considers this level of life-risk to be in the range of tolerability but the dam does not meet all essential USACE guidelines.
NORMAL (5)	Continue routine dam safety activities and normal operations, maintenance, monitoring, and evaluation.	VERY LOW INCREMENTAL RISK**: The combination of life, economic, or environmental consequences with likelihood of failure is low to very low and the dam meets all essential USACE guidelines. USACE considers this level of life-safety risk to be tolerable.
*At any time for specific events a dam, from any action class, can become an emergency requiring activation of the emergency plan. ** INCREMENTAL RISK is used to inform the decision on the DSAC assignment; NON-BREACH RISK is not reflected in this table. ***DSAC 1 and 2 dams with no life loss will be referred to the appropriate business line program and are given lower priority in the dam safety program.		

The DSAC for individual facilities is utilized as a means to categorize and prioritize risks and potential actions. Within those categories, the portfolio of dams is prioritized by life safety risks. The risks for facilities are continuously updated as additional studies and analyses are completed.

US Bureau of Reclamation:

Results of the Risk Analysis are utilized to assign a Dam Safety Priority Rating (DSPR) to the Facility. Assignment of DSPR to a facility is based upon considerations in the following table:

Public Protection Guidelines
Interim

Table 1. Bureau of Reclamation Dam Safety Priority Rating (DSPR)

Dam Safety Priority Rating	Characteristics and Prioritization Considerations	Potential Actions
1 – IMMEDIATE PRIORITY An active failure mode is in process or the likelihood of a failure is judged to be extremely high, such that immediate actions are necessary to reduce risk.	TOTAL ANNUALIZED LIFE LOSS OR TOTAL FAILURE PROBABILITY IS EXTREMELY HIGH WITH HIGH CONFIDENCE To assign this category consider if: 1. There is direct evidence that failure is in progress and the dam is almost certain to fail if action is not taken quickly. 2. Both the failure probability and the annualized life loss are extremely high. 3. The annualized life loss or failure probability is driven by a single failure mode. 4. The annualized life loss or failure probability is driven by potential failure modes manifesting during normal operating conditions.	Take immediate action to avoid failure. Implement interim risk reduction measures including operational restrictions, and ensure that emergency action plan is current and functionally tested for initiating event. Conduct heightened monitoring and evaluation. Expedite investigations and designs to support long-term risk reduction. Initiate intensive management and situation reports.
2 – URGENT PRIORITY Potential failure mode(s) are judged to present very serious risks, either due to a very high probability of failure or due to very high annualized life loss, which justify an urgency in actions to reduce risk.	TOTAL ANNUALIZED LIFE LOSS OR TOTAL FAILURE PROBABILITY IS VERY HIGH WITH HIGH CONFIDENCE OR SUSPECTED OF BEING VERY HIGH TO EXTREMELY HIGH WITH LOW TO MODERATE CONFIDENCE To assign this category, as well as prioritize dams within this category, consider if: 5. Both the failure probability and the annualized life loss are very high to extreme. 6. The annualized life loss or failure probability is driven by a single failure mode. 7. The annualized life loss or failure probability is driven by potential failure modes manifesting during normal operating conditions. 8. The range in risk estimates is tightly clustered and the mean and median are similar (for detailed uncertainty analysis only) and/or sensitivity studies instill confidence. 9. Risk reduction or confirmation is relatively easy and inexpensive.	Consider implementing interim risk reduction measures, including operational restrictions as justified, and ensure that emergency action plan is current and functionally tested for initiating event. Conduct heightened monitoring and evaluation if appropriate. Expedite confirmation of rating, as required. Give very high priority for investigations and designs to support remediation, as required.
3 – MODERATE TO HIGH PRIORITY Potential failure mode(s) appear to be dam safety deficiencies that pose a significant risk of failure, and actions are needed to better define risks or to reduce risks.	MODERATE TO HIGH TOTAL ANNUALIZED LIFE LOSS OR TOTAL FAILURE PROBABILITY WITH AT LEAST MODERATE CONFIDENCE To assign this category, as well as prioritize dams within this category, consider if: 10. Both the failure probability and the annualized life loss are moderate to high. 11. The annualized life loss or failure probability is driven by a single failure mode. 12. The annualized life loss or failure probability is driven by potential failure modes manifesting during normal operating conditions. 13. The range in risk estimates is tightly clustered and the mean and median are similar (for detailed uncertainty analysis only) and/or sensitivity studies instill confidence. 14. Risk reduction or confirmation is relatively easy and inexpensive.	Consider whether implementation of interim risk reduction measures is appropriate, which may include ensuring that emergency action plan is current and functionally tested for initiating event; conducting heightened monitoring and evaluation; and in some cases even operational restriction. Prioritize investigations to support justification for remediation and remediation design, as appropriate.
4 – LOW TO MODERATE PRIORITY Potential failure mode(s) appear to indicate a potential concern, but do not indicate a pressing need for action.	LOW TO MODERATE TOTAL ANNUALIZED LIFE LOSS AND TOTAL FAILURE PROBABILITY WITH LOW CONFIDENCE AND THE REALISTIC POTENTIAL TO MOVE THE ESTIMATE INTO "HIGH"; OR MODERATE TO HIGH TOTAL ANNUALIZED LIFE LOSS AND TOTAL FAILURE PROBABILITY WITH LOW CONFIDENCE AND THE REALISTIC POTENTIAL TO MOVE THE ESTIMATE INTO "LOW" To assign this category, as well as prioritize dams within this category, consider if: 15. The failure probability and annualized life loss are near guidelines 16. The likelihood that refinement of risk may change to a different category (a 3 could fall to a 4, or a 4 could rise to a 3)	Ensure routine risk management activities are in place. For those actions for which the case has been built to proceed before the next comprehensive review, take appropriate interim measures and schedule other actions as appropriate. Determine whether action can wait until after the next comprehensive review of the dam and appurtenant structures.
5 – LOW PRIORITY Potential failure mode(s) at the facility do not appear to present significant risks, and there are no apparent dam safety deficiencies.	LOW TOTAL ANNUALIZED LIFE LOSS AND TOTAL FAILURE PROBABILITY WITH MODERATE TO HIGH CONFIDENCE The annualized life loss and failure probability are estimated to be low and are unlikely to change with additional investigations or study.	Continue routine dam safety risk management activities, normal operation, and maintenance.

The DSPR for individual facilities is utilized as a prioritization tool for directing funding to recommended actions. The DSPR for facilities is continuously updated as additional studies and analyses are completed.

State of Colorado

Compliance/action items are established within the final reporting out of the risk assessment process. This includes considerations for improving confidence, addressing actions for highest likelihood failure modes, developing specific monitoring and observation plans tied to these PFMs, and developing/exercising emergency action plans specific to these PFMs.

QUESTION 5.4

Outline of the decision-making process applied to risk reduction

Argentina

Not applied.

Australia

This approach varies slightly across Australian jurisdictions but broadly follows the need to mitigate dams above the ANCOLD L of T and then subsequently to ALARP. Post reduction, monitoring and review through a safety management system to identify emerging risks and to mitigate.

Canada

Practice is largely based on deterministic principles set out in the CDA Dam Safety Guidelines. As noted in 5.2 above, there are a small number of cases where semi-quantitative and quantitative risk assessments have been used as a basis for accepting that a dam is safe enough for a long period of time into the future.

Czech Republic

Not being done, except for the case described in 5.1.

France

See answer 5.2

Italy

Risk analysis not applied

The Netherlands

See answer 5.2

Slovakia

At present time it is not significantly used

Sri Lanka

Since there are no specific guidelines for decision making process, dam owner organizations adopt different types of processes. It starts from the observations made by the field staff (O & M staff and inspecting officers) and reporting to higher officials for advice. In main dam owner organizations, a periodic inspection procedures (by in-house staff) are established. The weekly, monthly or quarterly inspection reports are analyzed and risk is evaluated. Whenever needed specialist's advice are sought for remedial measures.

United States of America

Federal Energy Regulatory Agency

Risk reduction actions can take many forms, from monitoring to engineering studies to immediate corrective actions. These actions can be temporary or permanent. Actions may need to be staged to be both efficient and effective. Interim measures may be required to provide more immediate short-term risk reduction while other risk reduction measures are being investigated and evaluated.

Risk management is the process of problem identification and initiating action to identify, evaluate, select, implement, monitor, and modify actions taken to alter levels of risk. Figure 7 shows the generalized FERC risk management process for dams.

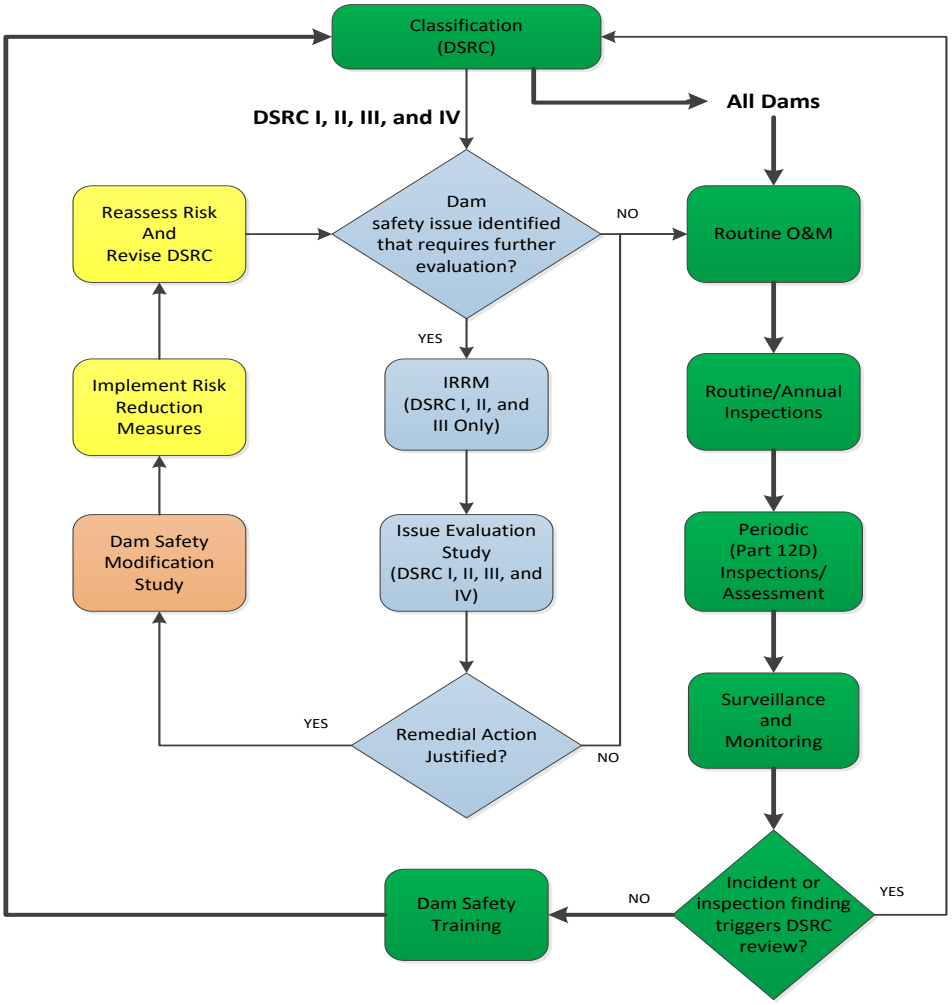

Figure 7 FERC Risk Management Process for Dams.

The decision process associated with dam safety-related actions will depend on the nature of the action under consideration, the consequences of the action in both the short and long term, and the potential for national and international interest and attention. In establishing IRRMPs, life safety is paramount, followed by prevention of catastrophic economic or environmental losses, and other considerations will be last. The process of identifying and evaluating IRRM must be conducted as expeditiously as possible and must be a collaborative effort. A risk analysis may be required as part of the IRRMP to support significant restrictions in project storage and release regulation schedules. However, reservoir restrictions should not be held up or delayed waiting for this risk analysis.

US Army Corps of Engineers US Army Corps of Engineers

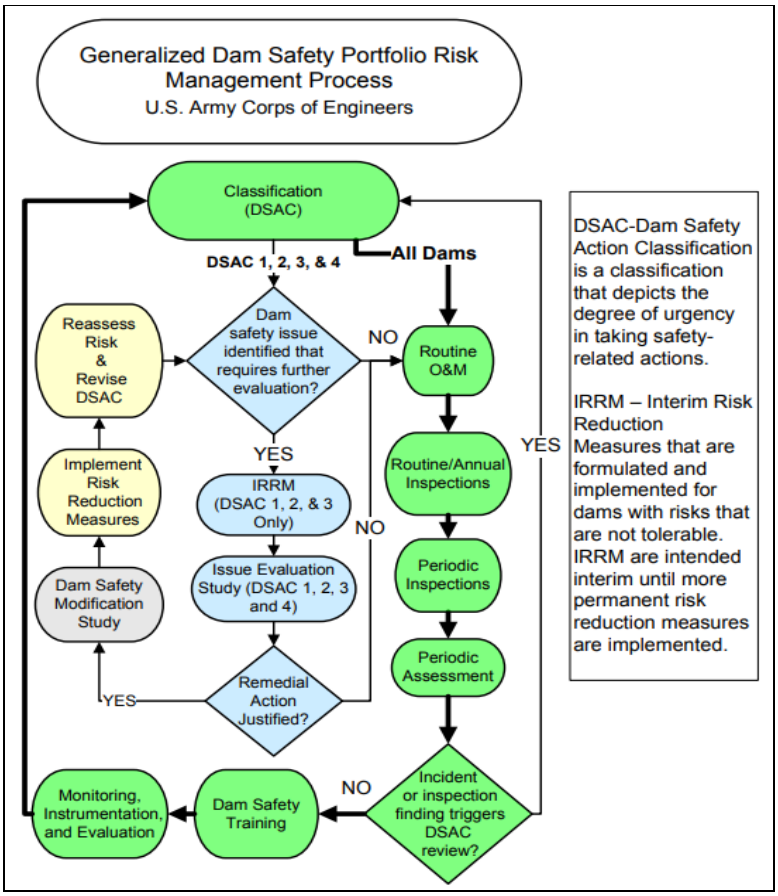

Figure 8 USACE Dam Safety Portfolio Risk Management Process

US Bureau of Reclamation

Reclamation requires a documented decision for all Dam Safety actions (no, action, further studies, develop risk reduction actions, and implement risk reduction actions). These decisions are all vetted through a detailed process that includes peer review, review by a technical advisory team (Dam Safety Advisory Team) and concurrence by designated Dam Safety Decision-makers in the organization. The process also typically includes a review of analyses and decision by an independent Consultant Review Board.

Once the decision is made that risk reduction actions are necessary based upon uncertainty and confidence (as outlined above), Reclamation initiates studies to identify appropriate risk reduction actions (Corrective Action Study).

The CAS identifies:

- A range of potential structural and non-structural risk reduction measures
- Each measure is assessed in terms of effectiveness in achieving risk reduction, cost of the risk reduction measure in terms of capital investment, impacts to project benefits, environmental impacts, etc.
- A recommended risk reduction action is identified at the end of the CAS

Funding for implementation of risk reduction actions continues to be informed the DSPR for the facility, as well as project readiness and availability of funding for construction

State of Colorado

See below, direct example of CDSE decision making table.

Appendix G
Failure Likelihood Category Summary Table, Possible Risk Reduction Actions, and Definitions for Confidence Levels and Consequence Levels

Failure Likelihood Category	*Failure Likelihood Description*[7]	*Possible Actions to Reduce Probability of Failure*	*Possible Actions to Reduce Consequences*
VERY HIGH An active failure mode is in process or likelihood of a failure is judged to be extremely high, such that immediate actions are necessary to reduce risk. *Should be accompanied by a Strong Confidence.	There is direct evidence or substantial indirect evidence to suggest it is occurring and/or is likely to occur (or a flood or an earthquake with an annual exceedance probability more frequent [greater] than 10E-2 would likely cause failure).	Strong Confidence • Immediate draining of reservoir under SEO Authority • Emergency actions to avoid failure • Expedite investigations and designs • Zero Storage with Expedited Compliance Plan to Complete Investigations, Designs, and Construct Repairs, • OR issue Breach Order	• Ensure that emergency action plan is current and functionally tested for initiating event. • Initiate intensive emergency management and situation reports based on continuous monitoring. • Develop early warning system specific to PFM.
HIGH Potential failure mode is judged to present very serious risks, due to high probability of failure, which justifies an urgency in actions to reduce risk.	The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward likely than unlikely (or a flood or an earthquake with an AEP between 10E-4 and 10E-2 would likely cause failure).	Medium to Strong Confidence • SEO Storage Restriction to mitigate PFM. • Strict Deadlines for Compliance Plan to Complete Investigations, Designs, and Construct Repairs. • Conduct Heightened Monitoring specific to PFM. Poor Confidence • Strict Deadline Expedited, high priority Compliance Plan to complete investigations & Studies to increase Confidence in PFM and justify further actions. • Conduct Heightened Monitoring specific to PFM.	• Ensure that emergency action plan is current. • Complete EAP functional exercise for initiating event.
MODERATE Potential failure mode appears to be dam safety deficiency that poses a significant risk of failure, and actions are needed to better define risks or to reduce risks.	The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily towards unlikely than likely (or a flood or an earthquake with [illegible] between 10E-5 and 10E-4	Strong Confidence • Engineering judgment to consider possible storage restriction OR conditional full storage. • Conduct Heightened Monitoring specific to PFM. • Poor to Medium Confidence • Strict Dates for Compliance Plan to complete investigations and analyses to increase	• Ensure that emergency action plan is current and functionally tested for initiating event.

QUESTION 5.5

Outline the decision process for determining that risk reduction measures are not required

Argentina

Not applied.

Australia

Broadly speaking, this is based on a common law assessment that the costs of any upgrade have reached the point of being disproportionate to the risk reduction. This test however is individual to the dam owner as business risk appetite is different. There is a requirement to reach a defensible position.

Canada

No specific methodologies reported. In general, legal, social and cultural considerations will be considered qualitatively in conjunction with the recommendations of the responsible engineer usually on the basis of technological criteria. In cases where the responsible engineer makes a determination that balances cost and risk, the risks will be within the capacity of the owner to absorb and ameliorate any third-party losses.

Czech Republic

Not being done, except for the case described in 5.1.

France

See answer 5.2

Italy

Risk analysis not applied

The Netherlands

There is no such process. Measures are always taken as described in answer 5.2.

Slovakia

Not known for me

Sri Lanka

No specific methodology recommended by any authority. Hence different organizations use their own way of handling these issues depending on the risk, fund available and the competency of the dam safety officers. If in-house experts cannot decide the level of risk involved, advice of competent dam safety experts are organised from other dam owner organizations or through free-lance consultants.

United States of America

Federal Energy Regulatory Agency

Follows the same process as described above.

US Army Corps of Engineers

See also above. If no actions are required, the facility continues to be evaluated through USACE routine risk management processes, known as the “outer loop” in the chart above.

US Bureau of Reclamation

See above. If no actions are required, the facility continues to be evaluated through Reclamation’s routine risk management processes, including annual facility inspections and comprehensive, quantitative re-evaluation of risk at least every 8 years.

State of Colorado

PFMs with less than 10E-5 AEP (Low likelihood) probability AND loss of life less than 10 generally do not warrant specific risk reduction implementation within our guidelines.

FOCUS AREA 6 – RISK COMMUNICATION

QUESTION 6.1

How are risk results communicated internally with dam owner's management and decision makers?

Argentina

Dam risk communication is not made in probabilistic terms. Risk communication is made in qualitative terms. Dam safety activities are regulated under prescriptive norms and tend to absolute levels of safety. Risk awareness and emergency action plans are fundamentals of any risk communication plan.

In the only case completed by ORSEP (detailed formal quantified risk analysis and evaluation), the final report has been sent to the national authority granting the contract. Likewise, the results have been presented to the owner (operator/concessionaire) and to the basin authority.

Australia

This varies but broadly speaking involves clarification of the risks with respect to the Limit of Tolerability.

Canada

This varies with the dam owner. Typically risk communication is carried out in the context of the CDA Dam Safety Guidelines. One dam owner provides a semi-quantitative risk index as a means of communicating risk internally and to interested external parties.

Czech Republic

Not able to answer

France

Each dam owner has its own communication and decision-making process. However, the risk analysis is generally sent to the dam owner including lots of people (managers and technician) within the dam owner organization. Internal presentations are made to present the document and the main results to board members of dam owners.

Italy

No responses

The Netherlands

The safety standards are included in the law. The results of safety assessments are released and published after verification by the national Inspectorate of Environment and Transport.

Slovakia

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Sri Lanka

Each dam organization has their internal communication strategy. Whenever outside technical support is required, the official protocols are followed to communicate with other competent organizations or summon of experts. For special additional funds they have to communicate with financial authorities too.

United States of America

Federal Energy Regulatory Agency

Every dam owner/licensee will have to develop their own internal risk communication strategy and plan. Important risk communication factors are presented in Chapter 4 of the FERC RIDM Risk Guidelines.

US Army Corps of Engineers

The risk assessments are briefed by the risk assessment team to a Dam Senior Oversight Group (DSOG) to review the risk characterization, recommended actions, and the case to support both. DSOG is a national team comprised of HQ leadership and various technical subject matter experts. The DSOG makes recommendations on individual safety decisions and portfolio prioritization to the USACE Dam Safety Officer.

US Bureau of Reclamation

Reclamation owns all dams under our regulatory authority. Risk at each facility is communicated to decision makers through formalized decision documents for all decisions to take or not take additional actions to better understand or reduce risks.

State of Colorado

Colorado Dam Safety involves the owner through all steps of risk assessment process. Engineer's and decision makers are invited to all PFMA workshops and invited to comment on positive and adverse factors associated with failure likelihoods. The goal is for them to observe that this is a transparent, objective approach to assessing dam safety risk and that if there are risk driving PFM's identified, there is sufficient justification for taking action.

QUESTION 6.2

Are the results of risk studies communicated with the stakeholders and the public? If so, how?

Argentina

In terms of social public risk communication, responsibilities are under ORSEP (the national dam safety regulator).

The results of the aforementioned risk assessment study made by ORSEP have been presented in national and international congresses and in technical workshops.

Owners communicate risk results and risk evaluation to some specific stakeholders.

Australia

Formal risk is generally not provided to public although in some jurisdictions is included in information that is publicly accessible - e.g. an annual report. Risk assessments are provided to the Regulator and Government bodies.

Canada

Yes, in the case of reservoir restrictions or major augmentations. These communications are made in terms of press releases, social media, public meetings and consultation processes. Some owners make the safety status of their dams available to the public via the company's public website. Individuals and organizations can request information about the safety of an owner's dams through a Freedom of Information request. In cases where public interest issues are raised in the media, dam owning organizations provide responses through media interviews and other methods of public communication.

Czech Republic

In general results of these studies are not communicated with the public

France

The risk analysis is comprehensively communicated to the Authorities. For the public and other stakeholders, only a non-technical summary is available because lots of information are sensitive and might be considered as confidential. This non-technical summary includes dam description and characteristics and outlines the downstream consequences in case of dam or gate failure. The comprehensive dam risk analysis can however be made available for read only on demand in a specific secured room of the Authorities.

Italy

No responses

The Netherlands

The results of all risk studies are available to the public. There is a website 'overstroomik.nl' where everybody can see what the expected water depth is at any location in case of flooding and what he or she can do.

The Water Act also demands that when a Water Defence is planned to be built or reconstructed a so-called Project Plan Water is necessary to underpin that decision. This Plan describes all effects of the planned activity (including safety, environmental, cultural etc). It is officially published, and stakeholders and the public can comment on it. These comments have to be handled seriously. If not handled satisfactorily stakeholders and public can go to court (Raad van State) to object against the activity.

Slovakia

It could be, but I don't know about that

Sri Lanka

Unless the research reports published in professional forums and available on-line, risk study results are not normally shared with general public, but the emergency action plan be distributed among the relevant stakeholders.

United States of America

Federal Energy Regulatory Agency

That is the responsibility of the dam owner. Additional information is provided in Chapter 4 of the FERC RIDM Risk Guidelines. Licensees should have the philosophy that they will ensure communication regarding potential inundation hazard, consequences, and solutions are open, transparent and understandable to the public. Licensee should document and routinely report the risk communications and management decisions to the FERC.

Communicating risk to the public is the responsibility of the licensee[12]. An open, interactive and ongoing dialogue is critical. Communicating risk is as important as assessing and managing risk. Today's risk communication goes beyond just communicating technical information—it includes recognition of important cultural values and ideas that affect decisions. Social context and culture can influence the beliefs and action for all parties—technical and non-technical. Communicating the ongoing residual risks associated with the most robust dam is as important an activity as is communicating any change to risk because of a change in the dam's status. Research has shown that communicating recommended actions to the public is an effective way to change behaviour. In emergency situations communicating the immediate hazard is important and, in most cases, local authorities will be communicating about the imminent danger.

US Army Corps of Engineers

[12] For those projects in which the licensee is not the owner of the dam and where some other entity, organization, or individual is responsible for the notification or activation of the project's EAP, the licensee shall coordinate with that entity, organization, or individual in communicating the risks from the licensee's facilities.

USACE communicates risks and benefits of dams with stakeholders and the public for our highest risk dams that require immediate action or during flood events. For dams where this communication has taken place, it is typically coordinated first with state and local governments and emergency managers and then USACE works through and with them to reach the at-risk public using both passive communication methods (fact sheets and web pages) as well as more participatory methods (public meetings). USACE is initiating more proactive communications for all risk assessments, not just the highest risk, to aid partners with their own risk management.

US Bureau of Reclamation

Yes. Stakeholders are involved in the facility reviews, risk analyses and informed of all recommended actions and decisions.

State of Colorado

Stakeholders are considered to be the dam owner, see response in 6.1. They are part of the SQRA process and therefore know the risk assessment likelihoods, confidence, and associated actions.

QUESTION 6.3

What are the challenges you have experienced in communicating risk results internally and externally?

Argentina

Communicating risk is a complex task. Risk communication requires specialized attention and experience. Understanding and acceptance by the people have been difficult. Clarity, accuracy and transparency are fundamentals to assure an effective message and adequate response by the recipient. Risk communication strategy needs to focus on understanding how the public perceive risk. Communication programmes need to be carefully and tailor- planned to audiences and concerns. ORSEP has several activities and programmes to communicate dam safety activities and risk awareness, through special meetings, workshops and presentations to schools, the media and stakeholders. Also has an internal plan to communicate risks to the staff, authorities and to the Nation Overall Risk Management System.

Australia

Challenges include: 1) Risk changes constantly, 2) its's not a single point - i.e. has confidence limits that me be several orders of magnitude. 3) Public understanding of risk is poor and often low likelihood events are assumed to never happen. 4) ultimately, risk assessment has components aligned to personal traits of the engineer meaning varied results will occur for the same situations.

Canada

The principal challenge is to make present the characteristics of the risk in a publicly accessible and meaningful way. Risk communication is typically not done in terms of numerical values of risk. When it is done in terms of quantitative estimates, the owner needs to be in a position to respond to a wide range of questions from different perspectives. It has been found that the public can be rather astute in the interpretation of the implications of statements about risk, and owners need to be prepared to deal with a wide range of public understanding of risk, be it qualitative or quantitative.

Social media can be problematic in that misinformation can be communicated widely and quickly that can often be difficult to counteract. Increasingly, the use of social media to communicate factual information to get ahead of the curve is being used as a means to mitigate this problem.

Czech Republic

No specific challenges

France

Risk analysis is a relatively new practice in France (about 10 years). It is a new tool based on a systemic multi-disciplinary approach which takes time to get used to. Lots of communication are required to explain risk analysis principles and results internally and externally. Communicating risk results externally is a sensitive issue. The engineering language is not the general public one. Special care must be paid in the wording to avoid internet buzz and misunderstanding.

Italy

No responses

The Netherlands

The system could be explained well to the public. However, risk awareness with the public is not very high in The Netherlands because of high safety standard.

Slovakia

Still none, but in the near future it will be more and more necessary to defend the construction of dams

Sri Lanka

Sometimes before any official statements, media create unnecessary panic among general public. It is very difficult to correct erroneous reports over dam incidents as the media are reluctant to accept their mistakes. It is not only the formal media channels, but the social media too create panic situations by over-reacting to some situations, especially during bad weather conditions.

Many dams are located in cascade systems and dams along the pathway belong to various organizations. There is a no proper communication system among the organizations and hence the risk of safety is high.

United States of America

Federal Energy Regulatory Agency

There are basically three challenges that must be addressed (USACE, 2014):

1. Knowledge. The audience needs to understand the technical information surrounding the risk assessment. To meet the knowledge challenge, the technical information will have to be presented in a variety of ways.
   - Information materials (pamphlets, fact sheets, and publically releasable reports)
   - Visual representations of risk (graphics, such as simple diagrams, pie charts and conceptual drawings),
   - Face-to-face communication (presentations with vivid projected graphics and handouts),
   - Stakeholder participation (small group discussions with facilitators who are knowledgeable about the risk), and
   - Technology assisted communication (websites and interactive models of risk).
2. Process. The audiences need to feel involved in the risk management process. To meet the process challenges, the audience will have to be included in how the risk is being managed. The audience may be involved in helping to develop the ways the decisions will be made, making the decision or even implementing.
3. Communication Skills. The audience and those who are communicating the risk need to be able to communicate effectively. To meet the communication skills challenge, those who are communicating must have and react to continual feedback regarding how the information is received and may need to meet with smaller groups or even more often.

US Army Corps of Engineers

Internally the agency has multiple missions and areas of expertise for its dams, and staff can become too focused on their area of strength rather than looking at risk holistically. Also, most dams are located a

significant distance from the USACE district office, which can create an information and communication gap between those who work in the district office conducting risk assessments and those on site at the dam, who work to operate and maintain the dam on a day to day basis. Additionally, there can be resistance internally to sharing risk information because people are uncertain about how communities will respond to the new information. Generally internal staff are concerned that they might create unwarranted panic or backlash to risk communication efforts.

Externally people generally want more information than USACE provides. Most of the public wants to know how the risk impacts them individually (i.e. will I get flooded, if so, when and how badly?), where USACE looks at risk on a more societal scale during risk assessments. More commonly still, people want to know what is going to be done to fix the problem. It can often be seen that if USACE is sharing risk with people it means that there is something that USACE can do to "fix it" or remove the risk. This is especially true if USACE is communicating risk to a community for the first time. This topic can be especially challenging both to communicate and to receive when there is not a plan of action to reduce the risk. Internally the agency has multiple missions and areas of expertise for its dams, and staff can become too focused on their area of strength rather than looking at risk holistically. Also, most dams are located a significant distance from the USACE district office, which can create an information and communication gap between those who work in the district office conducting risk assessments and those on site at the dam, who work to operate and maintain the dam on a day to day basis. Additionally, there can be resistance internally to sharing risk information because people are uncertain about how communities will respond to the new information. Generally internal staff are concerned that they might create unwarranted panic or backlash to risk communication efforts.

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US Bureau of Reclamation

Internally: Risk analyses and risk informed decision making is generally well understood by authorized decision-makers and management.

Externally: Communication of risk analyses processes and risk informed decision-making can be difficult for those unfamiliar with the processes. Reclamation encourages stakeholder involvement in risk analyses and other dam safety processes.

State of Colorado

Primary challenge has been communicating results that indicated significant dam safety risk and required action to dam owner leadership who were NOT involved in the PFMA workshops or risk assessment process. As shown above, our goal is to always extend formal invites and enough scheduling in advance so that those high-level individuals from dam owner's organizations can attend and observe/weigh-in.

Security requirements generally associated with critical dam infrastructure present a challenge communicating externally (i.e. public) about real dam safety risks).