LEGISLATED DAM SAFETY REVIEWS IN BC

APEGBC PROFESSIONAL PRACTICE GUIDELINES

V3.0

Professional Engineers
and Geoscientists of BC

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

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PREFACE

These *Professional Practice Guidelines - Legislated Dam Safety Reviews in BC* were initially commissioned by the British Columbia Ministry of Forests, Lands and Natural Resource Operations. The British Columbia Ministry of Energy and Mines then provided additional assistance so the guidelines would also address dam safety reviews for mining dams. They have been written with the intention of guiding professional practice for legislated dam safety reviews pursuant to *Dam Safety Regulation* 40/2016.

An appropriate standard of care in professional practice, when carrying out legislated dam safety reviews, is common to various types of dams. These guidelines provide the basis for an appropriate professional standard of practice when performing dam safety reviews. These guidelines provide the specific aspects of dam safety reviews relevant to the governing legislation depending upon the purpose of the dam involved.

The objective of the legislation regulating dams in BC is to mitigate the potential loss of life and damage to property and the environment from a dam breach by requiring dam owners to: inspect their dams, undertake proper maintenance, report incidents and take remedial action and ensure that the dams meet current engineering standards by undertaking dam safety reviews. In their on-going effort to achieve these objectives, the two Ministries referenced above have played a leadership role in working with the APEGBC to develop these guidelines for legislated dam safety reviews. The development of these guidelines is consistent with one of the primary objectives of APEGBC which is to establish, maintain and enforce good practice of professionals regulated by APEGBC.

DEFINITIONS

The following definitions are specific to these guidelines. References in the main text to these terms are italicized in the first instance.

Agreement
A contract or terms of engagement, whether formal (written) or informal (verbal or implied), between the client and the Qualified Professional Engineer, or his/her company, for conducting a dam safety review.

APEGBC
The Association of Professional Engineers and Geoscientists of British Columbia.

APEGBC professionals
Professional engineers, professional geoscientists, and licensees who are members or licensees of APEGBC.

Dam Safety Regulation
British Columbia Regulation 40/2016

CDA *Dam Safety Guidelines*
The *Dam Safety Guidelines* published by the Canadian Dam Association in 2007 and revised in 2013 and associated technical bulletins referenced in these guidelines.

Classification
The dam failure consequence classification of a dam as determined by Schedule 1 of the *Dam Safety Regulation* (for water reservoir dams), or Table 2-1 of the CDA *Dam Safety Guidelines* (for dams under the *Mines Act*).

Client
An individual or company who engages a Qualified Professional Engineer to conduct a dam safety review. The client is typically the dam owner or a third party who has been contracted to operate and maintain the dam on behalf of the dam owner. In this instance, the client may be the organization acting on behalf of the dam owner. Multiple holders of water licences and therefore owners are common for small dams. In such cases, it is recommended that the dam safety review be undertaken with the agreement of the joint-owners or their appointed representatives, preferably authorized through a joint works agreement between the owners.

Dam
A barrier constructed across a stream or river, or a barrier constructed off-stream and supplied by a diversion of water from a stream or an aquifer, for the purposes of enabling the storage or diversion of water, and including all works which are incidental to and necessary for the barrier. With respect to water reservoir dams, these guidelines only apply to dams whose size equals or exceeds the size given in Section 2 of the *Dam Safety Regulation* or has a classification of significant, high, very high or extreme.

Such a dam does not include any power production facility or water draw-off facility that is not directly connected to the dam as defined above and does not form an integral part of the barrier across the stream or river.

It also includes retaining structures that exist at mine sites or metallurgical plant sites that retain solids (that may be contaminated) and/or contaminated liquids and are regulated under the *Mines Act*. These retaining structures may include tailing dams and sludge storage dams.

Dam safety analysis
The dam safety analysis is the technical activity within a dam safety review which is carried out to identify the variety of threats to the performance and functional integrity of a dam which ultimately could place various elements at risk (e.g., people, property, the environment). Determination of what is the acceptable level of risk or safety for the various elements which are identified as being at risk is not the role of the Qualified Professional Engineer and is outside the scope of the dam safety analysis.

Dam safety review
A legislated periodic review of the safety assessment of water reservoir dams that have a classification of high, very high or extreme, as defined by the *Dam Safety Regulation*, carried out by a Qualified Professional Engineer in accordance with the requirements of Section 20 or Section 36 (4) of the *Dam Safety Regulation*. Dam safety reviews are also required for tailings storage facilities at least every five years under the *Mines Act* and in accordance with the CDA *Dam Safety Guidelines*.

Dam Safety Review Assurance Statement
The statement for submission, along with the dam safety review report, to the regulatory authority, to fulfill the dam owner's obligations in accordance with Section 20 or Section 36 (4) of the *Dam Safety Regulation*, or Permit Conditions under the *Mines Act*. Two assurance statements are attached as Appendices C1 and C2 to these guidelines.

Dam Safety Review Report
A report prepared by the Qualified Professional Engineer for the client, for submission to the regulatory authority in accordance with Section 20 or Section 36 (4) of the *Dam Safety Regulation*.

Design engineer
The professional engineer who has overall responsibility for the design of the dam, including responsibility for developing and overseeing the site characterization of the dam's foundation. The design engineer signs the site characterization assurance statement required in support of the feasibility study (see Appendix A of *APEGBC Professional Practice Guidelines – Site Characterization for Dam Foundations in BC*; APEGBC 2016). In many projects, the design engineer often transitions into the role of Engineer of Record.

Engineer of Record (EOR)
The professional engineer responsible for assuring that the dam is safe, in that it is designed and constructed in accordance with the current state of practice and applicable regulations, statutes, guidelines, codes, and standards.

Engineers and Geoscientist Act
Engineers and Geoscientist Act, R.S.B.C. 1996, Chapter 116, as amended.

Licensee(s)
A registered licensee in-good-standing with APEGBC which includes limited licensees.

Member(s)
Professional engineer or professional geoscientist. A member of the Association of Professional Engineers and Geoscientists of British Columbia.

Mines Act
Mines Act R.S.B.C., 1996 c. 293 (Updated to 2007).

Ministry
British Columbia Ministry of Forests, Lands and Natural Resource Operations (water reservoir dams) or the British Columbia Ministry of Energy and Mines (mining dams) depending upon the nature of the dam involved.

Owner/Dam owner
A person or legal entity, who with respect to the dam, is any of all of the following: (a) the person or legal entity who holds the current licence or is required to hold a licence for the dam; (b) the person or legal entity who last held a licence for the dam, including a licence that has been suspended, cancelled, abandoned or terminated; (c) if there is no person or legal entity to whom paragraph (a) and (b) above applies, the owner of land on which the dam is located or the person or legal entity who had the dam constructed.

Professional engineer
An engineer who is a member or licensee in good standing with APEGBC and for the purposes of these guidelines is typically registered in the disciplines of structural, civil, geological or mining engineering, which are designated disciplines of professional engineering.

Professional geoscientist
A geoscientist who is registered or licensed member in good standing with APEGBC and typically is registered in the disciplines of geology or environmental geoscience, which are designated disciplines of professional geoscience.

Qualified Professional Engineer
A professional engineer member or licensee in good standing with APEGBC, and for the purposes of these guidelines, is typically registered in the disciplines of structural, civil, geological or mining engineering with the appropriate level of education, training and experience, as defined by these guidelines, to conduct dam safety reviews as described in these guidelines.

Regulatory authority
The regulatory authority is the department within the British Columbia Ministry of Forests, Lands and Natural Resource Operations (freshwater reservoir dams) or the British Columbia Ministry of Energy and Mines (mining dams) depending upon the nature of the dam involved that is tasked with managing the regulatory requirements of dam safety, as enacted by statutes and regulations of British Columbia.

INTRODUCTION

INTRODUCTION TO THE GUIDELINES

Dams in British Columbia may be owned by diverse parties including utilities, mining companies, pulp and paper companies, various levels of government, including first nations or private *owners*. Provincial legislation requires that *dam safety reviews* be carried out by a *professional engineer* "qualified in *dam safety analysis*". *Qualified Professional Engineers* with the appropriate education, training and experience have the technical ability to carry out various forms of dam safety reviews including dam safety analysis. The legislation requires that a Qualified Professional Engineer provides his or her professional opinion regarding the safety status of the dam.

This professional opinion regarding the safety status of the dam has a time limitation pursuant to the *Dam Safety Regulation*. Under such circumstances the dam safety review can be considered to be a "snapshot in time", the validity of which is specified in the *dam safety review report*. Notwithstanding the requirements of the *Dam Safety Regulation* with respect to the interval between reviews, it may be concluded for engineering reasons that the professional opinion is valid for a shorter time.

These guidelines do not consider the impacts of climate change on the safety status of the dam within the period for which the professional opinion is valid. This is because climate change is a time-varying process over decades and centuries, the duration of which is such that significant changes in key design parameters such as the "design flood" as a consequence of climate change will not change during the period of validity of the dam safety review.

The *Canadian Dam Association (CDA) Dam Safety Guidelines*, as well as their associated technical bulletins, and bulletins and guidelines issued by the International Commission on Large Dams (ICOLD 2000, 2005, 2011, 2012a and b) are referenced throughout these guidelines. These documents are resources which provide accepted practices for the determination of the currency and adequacy of the physical performance capacity of a dam and the management of the operational integrity of a dam.

The Ministries and APEGBC assembled a team of specialists from government and the engineering community to prepare these guidelines. The application of these guidelines will result in consistent and comprehensive dam safety review reports being submitted to dam owners and the *regulatory authority*.

Specific objectives of these guidelines are to:

(i) Outline the professional services that should generally be provided by Qualified Professional Engineers conducting dam safety reviews;

(ii) Describe the standard of care a Qualified Professional Engineer should follow in providing professional services in the field of dam safety reviews;

(iii) Specify the tasks that should be performed by a Qualified Professional Engineer to meet an appropriate standard of care when preparing dam safety review reports, and which fulfills the Qualified Professional Engineer's professional obligations under the *Engineers and Geoscientists Act*. These obligations include the Qualified Professional Engineer's primary duty to protect the safety, health and welfare of the public and the environment;

(iv) Describe the roles and responsibilities of the various participants/stakeholders involved in dam safety reviews. The document will assist in delineating the roles and responsibilities of the various participants/stakeholders;

(v) Identify various concepts that can be used in risk informed dam safety decision making;

(vi) Provide consistency in dam safety review reports and other documents prepared by a Qualified Professional Engineer when providing professional services in this field of dam safety reviews; and

(vii) Describe the appropriate knowledge, skill sets and experience that Qualified Professional Engineers providing dam safety review services should have.

1.1 PURPOSE OF THESE GUIDELINES

This document provides guidelines of professional practice for a Qualified Professional Engineer who carries out a dam safety review in response to legislation in BC. Appendix C to these guidelines provides two separate *dam safety review assurance statements* one of which must be submitted, along with a dam safety review report, to a dam owner and the relevant regulatory authority. Appendix C1 contains the Dam Safety Review Assurance Statement for Water Reservoir Dams and is to be submitted in conjunction with the dam safety review report for the purposes of the *Dam Safety Regulation*. Appendix C2 contains the Dam Safety Review Assurance Statement for Mining Dams and is to be submitted with the dam safety reports in response to permit conditions under the *Mines Act*.

These guidelines address typical project organization and responsibilities of the various participants/stakeholders; professional practices that should typically be provided; quality assurance/quality control; and professional registration and education, training and experience.

1.2 ROLE OF APEGBC

These guidelines have been formally adopted by the Council of APEGBC, and form part of APEGBC's ongoing commitment to maintaining the quality of services *members* and *licensees* provide to their clients and the general public. Members and licensees are professionally accountable for their work under the *Engineers and Geoscientists Act*, which is enforced by APEGBC.

A Qualified Professional Engineer must exercise professional judgment when providing professional services; as such, application of these guidelines will vary depending on the circumstances. APEGBC supports the principle that a member should receive fair and adequate compensation for professional services, including services provided to comply with these guidelines. An insufficient fee does not justify services that do not meet the intent of these guidelines. These guidelines may be used to assist in establishing the objectives, type of dam safety reviews, level of service and terms of reference of a Qualified Professional Engineer's *agreement* with the *client*.

By following these guidelines, a Qualified Professional Engineer will fulfill his/her professional obligations, especially with regards to APEGBC Code of Ethics (APEGBC 2012b), Principle 1 (hold paramount the safety, health and welfare of the public, protection of the environment and promote health and safety in the workplace [1]). Failure of a Qualified Professional Engineer to meet the intent of these guidelines could be evidence of unprofessional conduct and lead to disciplinary proceedings by APEGBC.

[1] *APEGBC*'s Code of Ethics is at apeg.bc.ca/APEGBC/media/APEGBC/Governance/APEGBC-Code-of-Ethics.pdf. The Code of Ethics, along with accompanying Guidelines and Commentary, are published in the current (1994) edition of *APEGBC*'s "Guidelines for Professional Excellence".

1.3 INTRODUCTION OF TERMS

For the purpose of these guidelines, a Qualified Professional Engineer is a professional engineer with the appropriate education training and experience to carry out dam safety reviews as described in these guidelines (refer to Section 5). Typically, a Qualified Professional Engineer will be trained and practicing in the discipline of structural, civil, geological, or mining engineering, and have knowledge of the interdependencies between these disciplines relevant to the performance of dams.

The *Engineer of Record* (EOR) is a professional engineer retained by the owner, and is responsible for assuring that the dam is safe, in that it is designed and constructed in accordance with the current state of practice and applicable regulations, statues, guidelines, codes, and standards. The EOR is a requirement for mining dams in BC and may be in place for other dams in BC. If there is an EOR, they should be engaged during the dam safety review process and should review all dam safety review reports.

A dam safety review report is an assessment of the safety status of a dam, based on data, analysis, and professional engineering interpretation in accordance with the generally accepted engineering practices involved in the determination of the currency and adequacy of the physical performance capacity of a dam and the management of the operational integrity of a dam.

Dam safety analysis is a combination of: 1) consideration of hazards, failure modes and failure mechanisms, and 2) consideration of consequences of functional failure of a dam.

1.4 SCOPE OF THE GUIDELINES

These guidelines apply to dam safety review reports prepared in response to the *Dam Safety Regulation* (see Appendix A, this document: Legislative Framework – Water Reservoir Dams). These guidelines also apply to dam safety review reports for mining dams prepared in response to permit conditions under the *Mines Act* (see Appendix B, this document: Mining Dams – Considerations in Dam Safety Reviews)

It is recognized that dam safety reviews may be carried out for purposes other than in response to the above-referenced legislation. Although these guidelines were not intended to address such non-legislated dam safety reviews, some of the information contained in these guidelines may be relevant to the preparation of such non-legislated dam safety review reports.

Furthermore, dam safety reviews, as documented in these guidelines, are not intended to address any occupational health and safety requirements in relation to dams, although where a serious concern is identified, it must be brought to the attention of the dam owner/client.

1.5 APPLICABILITY OF THE GUIDELINES

Notwithstanding the purpose and scope of these guidelines, a Qualified Professional Engineer's decision not to follow one or more aspects of these guidelines does not necessarily mean that he/she has failed to meet his/her professional obligations. Such judgments and decisions depend upon weighing facts and circumstances to determine whether another reasonable and prudent Qualified Professional Engineer, in a similar situation and during the same time frame, would have conducted himself/herself similarly.

Although the client is often the owner of a dam, a dam safety review can also be carried out at the request of the regulatory authority. Following these guidelines, however, does not ensure that the conclusions and recommendations contained within the dam safety review report will be accepted by the regulatory authority.

These guidelines are influenced by current provincial legislation, current case law, advances in knowledge, and evolution of general professional practices in British Columbia. As such, they may require updating from time to time.

1.6 ACKNOWLEDGMENTS

These guidelines were prepared on behalf of APEGBC by a committee of Qualified Professional Engineers and were reviewed by several diverse parties and stakeholders as members of a review task force. The authors and reviewers are listed in Appendix I. The authors thank the reviewers for their constructive suggestions. A review of this document does not necessarily indicate the reviewer and/or his employer endorses everything in the document.

APEGBC thanks the BC Ministry of Forests, Lands and Natural Resource Operations and the BC Ministry of Energy and Mines: they funded the preparation of these guidelines and provided technical and administrative support.

PROJECT ORGANIZATION AND RESPONSIBILITIES

2.1 COMMON FORMS OF PROJECT ORGANIZATION

The dam owner has the responsibility for carrying out dam safety reviews on its dams with certain *classifications* and at the intervals provided in the *Dam Safety Regulation* (for water reservoir dams) or the CDA *Dam Safety Guidelines* (for mining dams required under the *Mines Act*). Dam owners are required to comply with this legislation by having a Qualified Professional Engineer carry out a dam safety review. The Qualified Professional Engineer will prepare a dam safety review report for the dam owner. The dam owner will then submit a copy of the dam safety review report to the regulatory authority for acceptance.

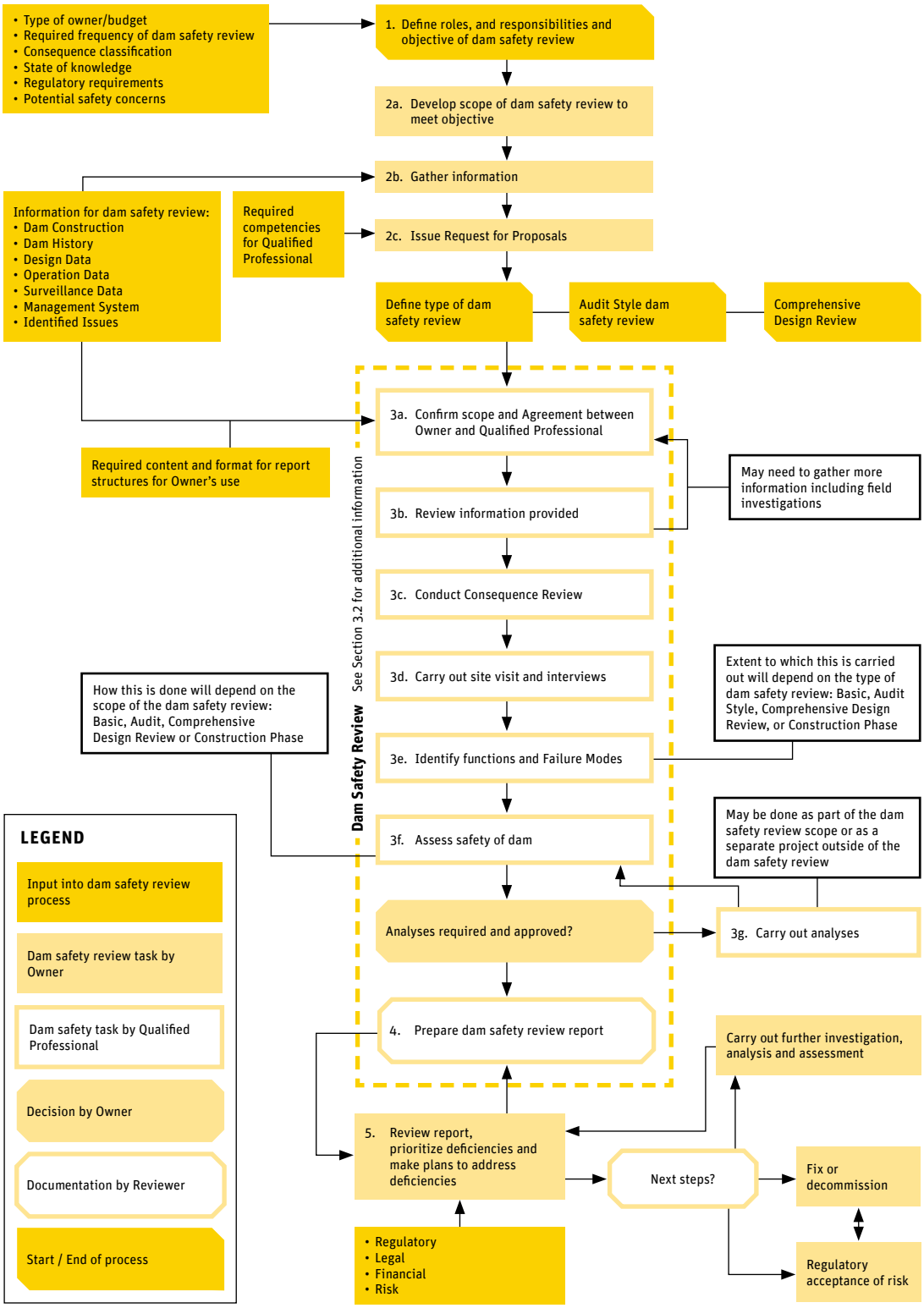
Typically the dam owner, or the operator of the dam on behalf of the dam owner, is the client, and the Qualified Professional Engineer establishes an agreement for professional services with that party. The Qualified Professional Engineer must be aware that his/her dam safety review report will ultimately be reviewed by the regulatory authority.

The client should be aware that the Qualified Professional Engineer may find that the dam is not safely operated, and is then required to make recommendations in the dam safety review report as to the actions that are required to rectify the deficiencies or non-conformances identified. In such a case, the client is required to prepare a plan that identifies and prioritizes any actions required to correct the potential dam safety hazard and submit the plan to the regulatory authority.

The Qualified Professional Engineer should ensure that his/her role, in relation to the client and regulatory authority, is clearly defined. It is possible that a client may not have previously been involved in dam safety, nor previously engaged a Qualified Professional Engineer. In addition, the client may not fully understand or appreciate the level of effort required by the Qualified Professional Engineer to conduct the dam safety review on a particular dam. The amount of data and previous analyses that are available to the Qualified Professional Engineer for conducting the dam safety review may significantly influence the level of service required for the dam safety review. Therefore, the Qualified Professional Engineer should review with the client the typical responsibilities listed below, in order to assist in establishing an appropriate agreement for professional services and to inform the client of the expectation of appropriate and adequate compensation (APEGBC Code of Ethics Principle 5, APEGBC 2012a).

Details of a dam safety review are included in Section 3; however, all parties (client, regulatory authority and Qualified Professional Engineer) should understand that the scope of the dam safety review lies within a larger dam safety management framework. Figure 1 presents a flow chart of the typical activities involved in initiating a dam safety review process and conducting the review, as well as how the dam safety review fits within the dam safety management framework. Some of the activities illustrated might be sequenced slightly differently (e.g., CDA 2016a) without altering the general intent or content of the dam safety review.

Figure 1: Dam Safety Review Process



2.2 RESPONSIBILITIES

Sections 2.2.1 to 2.2.3 describe some of the typical responsibilities of a client, Qualified Professional Engineer, and the regulatory authority. Section 2.2.4 describes some of the typical responsibilities of a Qualified Professional Engineer when asked by the regulatory authority or client to review a dam safety review report prepared by another Qualified Professional Engineer.

2.2.1 The Client/Dam Owner

Prior to the dam safety review, the client should know the current classification of the dam. Dam owners should be aware of the legislative requirements associated with the operation and maintenance of the dam, as set out in the *Dam Safety Regulation* and the *Heath, Safety and Reclamation Code (HSRC)*. In some cases, the client may not be aware of the need to classify the dam in terms of the consequences of failure. In that case, the client should contact the regulatory authority. Further, the dam owner should contact the regulatory authority to clarify any uncertainties about their legislative responsibilities under the *Dam Safety Regulation* or under their permit conditions under the *Mines Act*.

Typically, the client issues a request for proposals to either individual Qualified Professional Engineers or consulting engineering firms who have Qualified Professional Engineers on their staff. In some cases, the client may elect to negotiate directly with a Qualified Professional Engineer or a firm with Qualified Professional Engineers to conduct the dam safety review.

2.2.1.1 Guidance on Preparing Requests for Proposals

Prior to the issue of a request for proposals by the client for Qualified Professional Engineering services for the dam safety review, it is helpful and will likely reduce the cost of professional services if the client is knowledgeable about the dam design and dam safety history, as documented in various sources, which are referenced in Section 3.

The client may not have sufficient knowledge regarding dam safety to judge whether the content of the documents available for the dam safety review contain the relevant information. In this case, it is recommended that the client consult with a Qualified Professional Engineer to determine whether the documents available for the review are relevant or not. Alternatively, all the information available to the client should be provided to the Qualified Professional Engineer who will determine what documentation is relevant and what further documentation, if any, is required.

The Qualified Professional Engineer's scope of services for the dam safety review may vary from dam to dam, depending on the classification of the dam and the records available for the review. For a dam's first dam safety review, the pertinent design records may not be available. In such a case, the scope of services for the dam safety review may include in-depth analyses to provide the level of detail sufficient to demonstrate the safety of the dam structure and that the dam is being safely operated, maintained, and monitored. For the first dam safety review, all the available data should be assembled and supplemented with any investigations and design analyses that have been carried out, as appropriate. After a particular dam's first dam safety review, subsequent dam safety reviews are normally less costly and time-consuming, as the original available data should have been assembled and supplemented by the investigations and analyses carried

out during the first dam safety review. Subsequent dam safety reviews can be structured more as an audit of the previous information and the data generated since the previous dam safety review to determine whether the dam continues to be safely operated. Input from the relevant regulatory authority should be sought at this stage, so that the regulatory authority is supportive of the type of submission being prepared.

The scope of the dam safety review should be described in the request for proposals. The scope of work should be written to reflect the state of knowledge of the design, construction, operation, maintenance, and surveillance of the particular dam. For an old dam that has not had any prior dam safety reviews, the scope of services will be more extensive than for a relatively new dam with extensive recent design and construction documentation. Similarly, the scope of services for the dam safety review of a dam with a straightforward layout on good foundations will be less extensive than the scope of services for the dam safety review of a dam with a complex layout on poor foundations.

The scope of work described in the proposal should assume that the classification of the dam remains unchanged during the dam safety review. If, during the evaluation phase of the dam safety review (see Section 3.2), the Qualified Professional Engineer determines that the classification of the dam should be reviewed and amended, the level of services required to carry out the dam safety review may increase from that originally assumed at the proposal stage, and the agreement between the client and the Qualified Professional Engineer will be adjusted accordingly.

2.2.1.2 Client/Qualified Professional Engineer Involvement

It is recommended that the client select the Qualified Professional Engineer based on his/her qualifications, availability, and local knowledge using a qualifications-based selection process.

Once the client has selected a Qualified Professional Engineer to conduct the dam safety review, the client, with assistance from the Qualified Professional Engineer, should complete a written agreement with the Qualified Professional Engineer to confirm scope of work, schedule and cost estimate for the dam safety review, need for and scope of specialty services, and need for external peer review. It is recommended that such an agreement include a clause that deals with potential disclosure issues due to the Qualified Professional Engineer's obligation under APEGBC Code of Ethics Principle 1 (hold paramount the safety, health and welfare of the public, the protection of the environment, and promote health and safety in the workplace; APEGBC 2012b). See Section 2.2.2 for more information.

The client should be aware that the Qualified Professional Engineer's scope of work and cost estimate may have to be amended during the assessment, depending on the Qualified Professional Engineer's findings and analysis. The cost estimate should be discussed and agreed to with the client prior to the assignment.

During the dam safety review, it is necessary for the client to provide the necessary background information for the Qualified Professional Engineer to conduct the dam safety review, as outlined in Section 3.3, and to provide the required access to the dam and all related facilities to enable the Qualified Professional Engineer to conduct the field work for the dam safety review.

After the dam safety review, it is important that the client reviews the dam safety review report and understands the conclusions and recommendations, and discusses the dam safety review report with the Qualified Professional Engineer. The client is required, upon receipt of the final dam safety review report, to submit it to the regulatory authority.

It is recommended that the agreement between the client and the Qualified Professional Engineer address document-ownership issues, including those related to the Dam Safety Review Assurance Statement and the dam safety review report, and the payment of the Qualified Professional Engineer's outstanding invoices by the client.

2.2.2 The Qualified Professional Engineer

The dam safety review must be carried out by a Qualified Professional Engineer or a multidisciplinary team that includes APEGBC members and that reports to the lead Qualified Professional Engineer. The Qualified Professional Engineer's expected registration, education, training, and experience are detailed in Section 5.0 of these guidelines. The Qualified Professional Engineer is responsible for the final dam safety review report and completes the Dam Safety Review Assurance Statement.

During the development of the agreement with the client, it is recommended that a clause be included in the agreement that deals with potential disclosure issues due to the Qualified Professional Engineer's obligation under APEGBC Code of Ethics Principle 1 (hold paramount the safety, health and welfare of the public, the protection of the environment, and promote health and safety in the workplace; APEGBC 2012b). The following is suggested wording for such a clause:

> "Subject to the following, the Qualified Professional Engineer will keep confidential all information, including documents, correspondence, reports and opinions, unless disclosure is authorized by the client. However, in keeping with APEGBC's Code of Ethics, if the Qualified Professional Engineer discovers or determines that there is a material risk to the environment or the safety, health and welfare of the public or worker safety, he/she shall notify the client as soon as practicable of this information and the need for that information to be disclosed to the appropriate parties within a reasonable time. If the client does not take the necessary steps to notify the appropriate parties within a reasonable amount of time, the Qualified Professional Engineer shall have the right to disclose that information to the appropriate parties in order to fulfil his/her ethical duties and the client hereby authorizes that disclosure."

The Qualified Professional Engineer must comply with the requirements of APEGBC Bylaw 17 (APEGBC 2012a) regarding professional liability insurance.

During the dam safety review, the Qualified Professional Engineer must:

- If necessary, assist the client in obtaining relevant information, such as is referenced in Section 3.0 of these guidelines;
- Make reasonable attempts to obtain from the client and others all relevant information related to the dam safety review;
- Conduct the dam safety review in compliance with applicable legislation and these guidelines, and using guiding principles in the CDA *Dam Safety Guidelines* and associated technical bulletins;
- Notify the client as soon as reasonably possible if specialty services or changes in scope of work are required, and of associated changes to the original cost estimate;

- Determine whether the dam is being safely operated, and determine what actions, if any, are required to make the operations reasonably safe;
- Write the dam safety review report in a reasonably clear, concise, and complete manner;
- Consider whether conclusions and recommendations in the dam safety review report are supported by the appropriate level of analysis and a clear rationale, and that any assumptions made are clearly stated;
- See that summaries of design calculations are provided in support of the technical analysis in the dam safety review report;
- Identify in the dam safety review report any relevant information/materials regarding the dam that are not available and the resulting assumptions made where there is a lack of information;
- Provide a statement in the dam safety review report that the conclusions and recommendations contained in the dam safety review report are valid only for the current operating regime of the dam and the current overall environment of the dam or river system, and include a time limit for the statement of the conclusions and recommendations;
- Have a draft of the dam safety review report undergo APEGBC's quality management procedures (see Section 4.0);
- Submit to the client a signed, sealed, and dated copy of the dam safety review report, and
- Complete a Dam Safety Review Assurance Statement.

After the dam safety review, the Qualified Professional Engineer should respond to questions the client and/or the regulatory authority may have regarding the dam safety review, the dam safety review report, and/or Dam Safety Review Assurance Statement.

The dam safety review may be carried out by a team of APEGBC members led by a Qualified Professional Engineer. In this situation, the lead Qualified Professional Engineer coordinates the work carried out by the other members. Many dams require a multi-disciplinary systems approach to the dam safety review, and it is the responsibility of the lead Qualified Professional Engineer to see that the dam is reviewed as an overall system, that the members with the correct qualifications and experience are engaged on the team, and that the dam safety review is complete and all aspects of dam safety are covered. The lead Qualified Professional Engineer is also responsible for ensuring proper coordination occurs between the various members of the multi-disciplinary team.

If certain professional activities, such as aspects of the field work, are delegated by Qualified Professional Engineers to subordinates—including non-professionals—such delegation of professional activities must occur under the Qualified Professional Engineer's direct supervision (see Section 4.1.3 of these guidelines). The Qualified Professional Engineer assumes full responsibility for all work delegated in accordance with the *Engineers and Geoscientists Act*.

To fulfill APEGBC Code of Ethics Principle 1 (hold paramount the safety, health and welfare of the public, the protection of the environment, and promote health and safety in the workplace), Principle 8 (present clearly to employers and clients the possible consequences if professional decisions or judgments are overruled or disregarded) and Principle 9 (report to APEGBC or other appropriate agencies any hazardous, illegal or unethical professional decisions or practices), the Qualified Professional Engineer must:

- Advise the client in writing of the potential consequences of the client's actions or inactions, and
- Consider whether the situation warrants notifying APEGBC, the dam owner (if different from the client) and/or the regulatory authority of the client's actions or inactions.

The above actions must be taken if a hazardous condition at the dam could possibly result in loss of life and/or other significant negative consequence occurring, or if workplace safety or the environment is potentially jeopardized by the hazardous condition at the dam.

2.2.3 The Engineer of Record

In BC, all mining dams require an EOR, whereas conventional water dams may have an EOR, but are not required to.

The following information on the role of the EOR is intended to apply to mining dams only and is consistent with the documentation prepared by the CDA.

The owner is ultimately responsible for the safety and operation of their dam(s) during construction, operation, and closure. Section 2.3 of the CDA *Dam Safety Guidelines* states that the "owner's policy should clearly demonstrate the organization's commitment to safety management throughout the dam's life cycle". This includes "delegation of responsibility and authority for all dam safety activities". Further "the owner's staff and any consultants or contractors who carry out dam safety activities on behalf of the owner should be aware of the decision making process and who is accountable for that". The dam safety EOR is an integral part of risk management for mining dams.

The EOR is defined as the professional engineer responsible for assuring that the dam is safe, in that it is designed and constructed in accordance with the current state of practice and applicable regulations, statutes, guidelines, codes, and standards. In the case of an older dam, the EOR would assure that the dam was designed to the applicable standards that were in place at the time of the initial dam design and that the dam continues to perform at a satisfactory level.

The EOR provides design continuity and ongoing technical support to the owner with respect to dam safety issues over the life of the dam. The EOR may also provide input to the operating plans and closure design.

The EOR must be clearly identified by the owner and must have accepted the responsibility. Whether the EOR is part of the owner's organization or is contracted externally, he/she must have the authority and independence to ensure that safety assessments and measures are not compromised by operational constraints. Furthermore, in respect to tailings storage facilities, Section 10.1.6 of the *Health, Safety and Reclamation Code for Mines in British Columbia* requires that the EOR notify the manager in writing of any unresolved safety issues that compromise the integrity of a tailings storage facility.

The EOR must have knowledge and experience in the design, construction, performance analysis, and operations of dams, to a level that is commensurate with the consequence classification and complexity of the specific dam or dams under his/her technical authority.

Recommended minimum qualifications include:

- At least 10 years of related engineering experience;
- Knowledge of dam design, construction, operations, and performance evaluation gained through solid experience; this broad knowledge is necessary to appreciate the complex issues of dam safety;
- Current knowledge of applicable regulations and the state of practice, including the

CDA *Dam Safety Guidelines* and other international dam safety guidance;

- Registration and good standing with the professional engineering association where the dam is situated.

If the EOR is a consultant, this individual should be supported by a firm that has dam safety specialists who can provide the necessary support and oversight.

The EOR is separate from the Qualified Professional Engineer who carries out the dam safety reviews. Dam safety reviews should be carried out by an independent third party not previously involved as the EOR for the facility. However, the EOR should be engaged during the dam safety review process and should review all dam safety review reports.

2.2.4 The Regulatory Authority

The regulatory authority is the department within either or both ministries that is tasked with assigning the regulatory requirements of dam safety. For freshwater reservoir dams, this would be the department within the British Columbia government responsible for the status and regulations of the *Dam Safety Regulation* under the *Water Sustainability Act*. Details of the regulatory requirements for water reservoir dams are presented in Appendix A. For mining dams, this would be the department within the British Columbia's government responsible for the status and regulations of the *Mines Act*. Details of the regulatory requirements for mining dams are presented in Appendix B.

In accordance with the *Dam Safety Regulation*, the regulatory authority can accept or reject a classification proposed by the owner (see Section 3 of the *Dam Safety Regulation*). Currently, only dams with high, very high, and extreme classifications require legislated dam safety reviews. Dams with low and significant classifications are not required by the *Dam Safety Regulation* to undergo regularly scheduled legislated dam safety reviews. However, dam owners are required to conduct annual reviews of dams with low and significant classifications in order to confirm the current classification of the dam. Additionally, as per Section 21 (4) of the *Dam Safety Regulation*, a dam safety officer may request additional information and records that he/she deems necessary to evaluate the condition or the hazard potential of the dam and operations, and actions connected with the dam. If the classification changes for any reason—such as increased downstream development—the regulatory authority may review and amend the classification of the dam.

Dams subject to the *Mines Act* require that dam safety reviews be carried out at least every five years.

Before the dam safety review is initiated, the regulatory authority will:

- Inform the client of the current classification of the dam if the client is unaware of the classification;
- Inform the client of the dates by when the dam safety review must completed and the dam safety review report submitted to the regulatory authority; and
- Provide the client with guidelines, if they exist, of the dam owner's responsibilities for the safe management of dams, as defined in the relevant legislation.

After the dam safety review, the regulatory authority will:

- Review the dam safety review report and Dam Safety Review Assurance Statement;
- Accept the dam safety review report or, if the dam safety review report does not comply with the requirements of the relevant legislation, reject the dam safety review report, and
- If necessary, discuss the conclusions and recommendations of the dam safety review report and Dam Safety Review Assurance Statement with the client and Qualified Professional Engineer.

2.2.5 External Review of Dam Safety Review Reports

A Qualified Professional Engineer may be engaged by the regulatory authority to carry out an independent external review of a dam safety review report prepared by another Qualified Professional Engineer. This external review process may be part of the regulatory authority's review of the dam safety review report. A client may also require such an independent external review. These independent external reviews are not the same as an internal or external peer review carried out as a part of the dam safety review quality assurance/quality control activities of the Qualified Professional Engineer prior to submitting the dam safety review report to the client (see Section 4.1.7).

In order for the reviewing Qualified Professional Engineer to carry out an appropriate independent external review, it is helpful if the requesting regulatory authority or client:

- Allows the intent of APEGBC Code of Ethics Principle 7 to be followed – specifically, item (c), which states that a member should not, except in cases where review is usual and anticipated, evaluate the work of a fellow member without the knowledge of, and after communication with, that member where practicable;
- Provides the reviewing Qualified Professional Engineer with a copy of the dam safety review report and Dam Safety Review Assurance Statement, necessary background information, and the reason for the review; and
- Discusses the dam safety review report with the reviewing Qualified Professional Engineer.

The reviewing Qualified Professional Engineer should consider whether there may be a conflict of interest and act accordingly (APEGBC Code of Ethics Principle 4, APEGBC 2012b), conduct himself/herself with fairness, courtesy, and good faith towards colleagues, and provide honest and fair comment (APEGBC Code of Ethics Principle 7).

Following guideline (c) of APEGBC Code of Ethics Principle 7, the reviewing Qualified Professional Engineer must:

- If authorized to do so, inform the Qualified Professional Engineer who prepared the dam safety review report and Dam Safety Review Assurance Statement of the review and the reasons for the independent external review, and document that communication;
- Ask the original Qualified Professional Engineer if the reviewing Qualified Professional Engineer should know about any unreported circumstances that may have limited or qualified the dam safety review, the Dam Safety Review Assurance Statement, and/or the dam safety review report; and
- With the client's authorization, contact the original Qualified Professional Engineer if the results of the independent external review have identified safety or environmental concerns and allow the original Qualified Professional Engineer to comment on the results of the independent external review prior to further action.

The reviewing Qualified Professional Engineer's review should be appropriately documented in a letter or a report. The reviewing Qualified Professional Engineer's signed, sealed, and dated independent external review letter or report should include:

- limitations and qualifications with regards to the review, and
- results and/or recommendations arising from the review.

The reviewing Qualified Professional Engineer should respond to any questions the regulatory authority or client may have with regard to the review letter or report.

Occasionally, a Qualified Professional Engineer is retained to provide a second opinion. This role goes beyond that of an independent external review of the original Qualified Professional Engineer. The second opinion Qualified Professional Engineer must carry out sufficient pre-field work, field work, analysis and comparisons, as required, to accept full responsibility for his/her dam safety review.

GUIDELINES FOR PROFESSIONAL PRACTICE

3.1 GENERAL PRINCIPLES

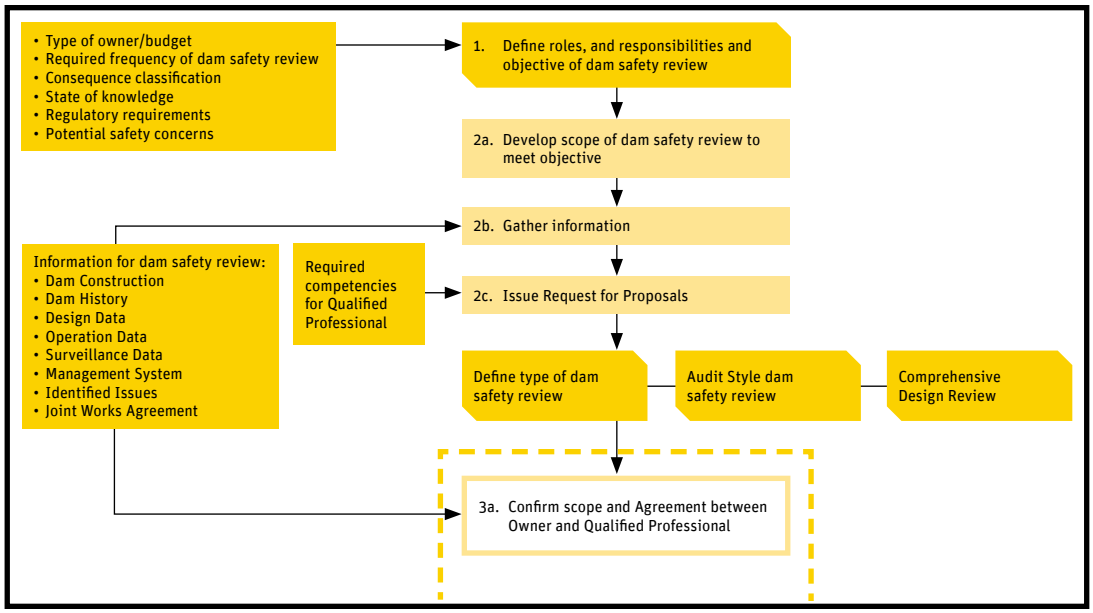
A dam safety review involves a systematic review and evaluation of all aspects of the design, construction, maintenance, operation, processes, and systems affecting a dam's safety, including the dam safety management system. A dam is part of the altered natural environment and, as such, the natural environment will impose hazards on the dam that are beyond the control of the dam owner or dam operator. The hazards and risks are difficult to define and quantify, and the understanding of these hazards and risks often change over time. The knowledge and interpretation of these natural hazards at the time of the original design and construction, and the engineering standards, methods and procedures used for the original design and construction may be significantly different than the current engineering standards, methods and procedures of today. The evaluation of the safety of the dam system for the dam safety review must use the current knowledge and standards for dam engineering.

The level of service required for a dam safety review must be commensurate with the complexity of the dam system and the dam classification. In addition, the level of service required may be dictated by the availability, or lack thereof, of documentation and data to determine whether or not the dam meets current engineering design principles. Regardless of the level of complexity required for the dam safety review, the Qualified Professional Engineer must carry out the dam safety review in sufficient detail so that the conclusions reached and recommendations arising out of the dam safety review can be made with the same level of confidence.

3.2 DAM SAFETY REVIEW PHASES

Each dam safety review will consist of a number of steps or phases that, together, will form the framework of the review. These steps generally need to be carried out in a systematic order to achieve the desired results in a reasonably effective manner. A dam safety review will include a field review of the site, review of all relevant documentation, interviews with site staff, review of incident, maintenance, inspection and other pertinent records, testing of flow discharge equipment (where applicable), and/or review of recent test records. The dam safety review process is based on the appropriate regulations or guidelines adopted by the regulatory authority. The dam safety review is the owner's responsibility and will typically start with the relevant statute requirement and include the following initial items, as depicted in Figure 2.

Figure 2: Steps in Initiating a Dam Safety Review



Reference: T. Oswell, CDA 2012.

In general, the following phases or steps should be carried out to complete a dam safety review. The following information is intended to assist with defining the scope and requirements of the dam safety review. However, it is not exhaustive, and professional judgment is required when adding or subtracting specific steps.

Phase 1 (Review of available information and data):

- It is strongly recommended that a written agreement between the client and the Qualified Professional Engineer be put in place before any work is initiated. This agreement should address, scope of work, objectives, expectations, responsibilities, level of service, schedule, and anticipated extent of the study area, as noted in Section 2.0 of these guidelines;
- The Qualified Professional Engineer must request from the client all available documentation and data for compilation and review, such that all relevant background information on the dam, the river system (if relevant), and the dam management system is considered (Section 3.3). If there is uncertainty whether any documentation is relevant, it is the Qualified Professional Engineer who must make that determination;
- The Qualified Professional Engineer must understand the current dam classification as determined by the regulatory authority and identify performance expectations based on current guidelines, regulations, generally accepted practices, and consideration of changed conditions (Section 3.6);
- The Qualified Professional Engineer must provide an initial facility overview (spatial and functional model of the dam/reservoir system) as it relates to the safety of the dam and other barriers (water or otherwise) in the system (principal functions of components), as shown in Figure 2. This should be reviewed and updated in Phase 3 after a site inspection and further analysis; and

- The Qualified Professional Engineer must review and assess the dam safety management obligations and procedures, including emergency planning, operations and maintenance, surveillance, staff training, documentation, and deficiency tracking, and resolution (Section 3.3).

Phase 2 (Field Review):

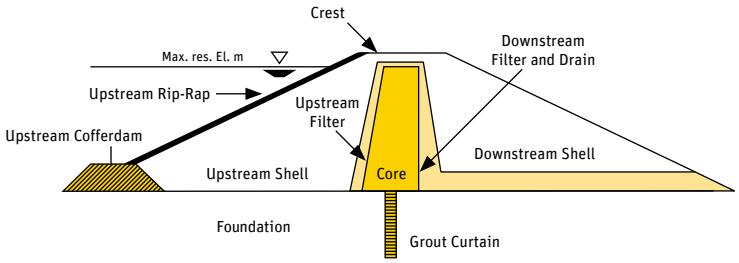
- The Qualified Professional Engineer must carry out field review(s) of the dam, the reservoir (or impoundment), and the catchment areas both upstream and downstream of the reservoir or impoundment to understand the current condition of the dam and appurtenances, the flow control equipment at the dam, water management and flood control structures, the reservoir or impoundment environment, upstream hydrological impacts (logging roads and bridges for example), and development downstream of the dam;
- Preferably during the site visit, the Qualified Professional Engineer will interview (when relevant) the operating personnel who conduct routine inspections, surveillance of the dam, and maintenance of operating systems (e.g., flow control equipment). The Qualified Professional Engineer will review available maintenance records and audit all the documentation that should be onsite, such as the operations, maintenance and surveillance (OMS) manual and the dam emergency plans; and
- If flow control equipment is present, the Qualified Professional Engineer will witness testing of the flow control equipment, or if the flow control equipment is routinely and regularly used, should satisfy himself/herself that the equipment is in good working order by reviewing the operating and maintenance records.

Phase 3 (Evaluation):

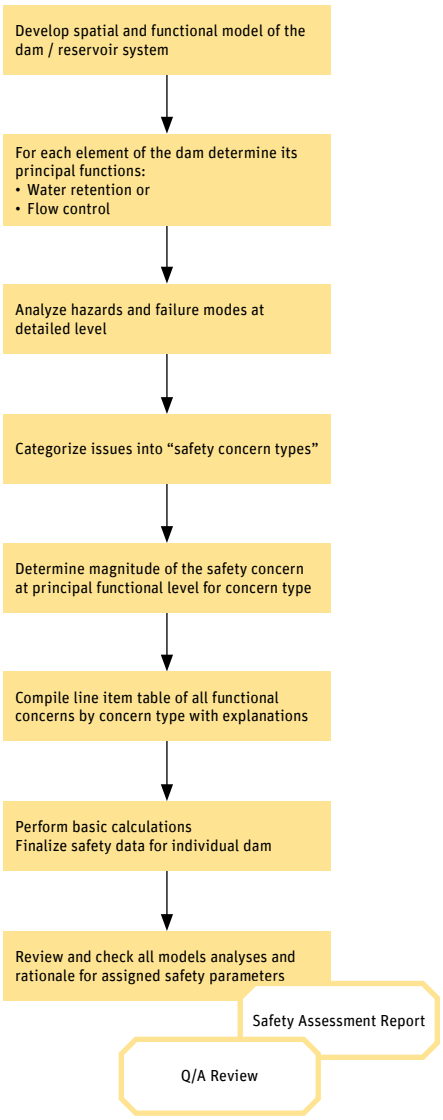
- Following the field review(s), the Qualified Professional Engineer must confirm that the dam classification is appropriate or if it should be reviewed and amended. The Qualified Professional Engineer should state whether there have been changes since the last dam safety review that would warrant change of the classification and provide an explanation in the dam safety review report. If the dam classification should be reviewed and amended, the client and regulatory authority are responsible for confirming that the change in the dam classification is to be carried out. Identification of the required dam safety criteria in relation to the appropriate classification (including considerations of changed conditions, Section 3.6) should be in place prior to the dam safety analysis;
- The Qualified Professional Engineer must then carry out the dam safety analysis for the dam using either the current classification, if it is appropriate, or any new classification, and determine whether the dam meets the dam safety criteria and whether the dam is being operated in a reasonably safe manner. Evaluation of the dam performance should be carried out in relation to the facility condition, applicable internal and external hazards, and applicable failure modes, and may follow the steps of a safety assessment depicted in Figure 3 below;

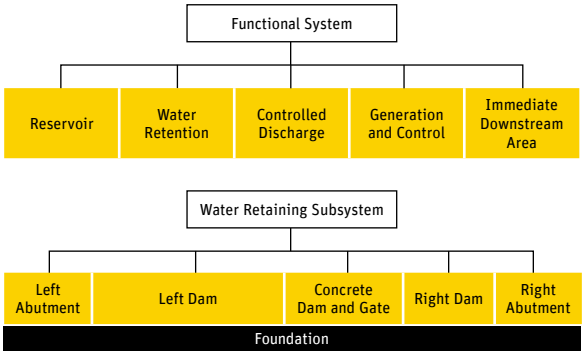
- The Qualified Professional Engineer must then identify and characterize deficiencies in the safe operation of the dam and non-conformance in the dam safety management system and recommend either the actions that should be taken to investigate the deficiencies in more detail or the actions that must be taken to rectify the deficiencies and non-conformance. The Qualified Professional Engineer must also determine the severity of the dam safety concerns;
- The dam safety review report and the Dam Safety Review Assurance Statement must then be prepared by the Qualified Professional Engineer and, after passing the internal quality assurance/quality control process, be submitted to the client; and
- Once the client has reviewed the dam safety review report, the Qualified Professional Engineer should discuss the conclusions and recommendations with the client and provide any clarifications requested by the client.

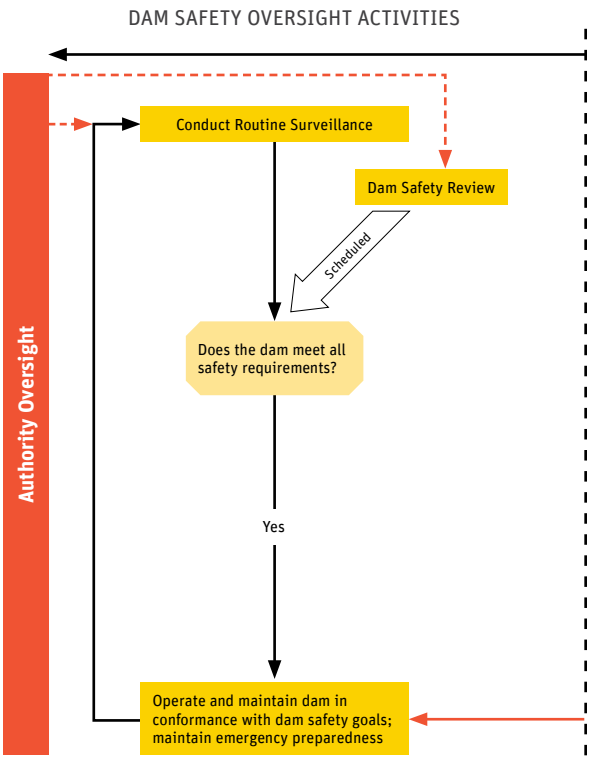
Figure 3: Draft Example Dam Safety Review Process (this particular example is for water reservoir dams but the same fundamental steps apply for mining dams)



SPATIAL MODEL OF EARTH DAM FLOW CONTROL FUNCTION
(steady state condition)







3.3 BACKGROUND INFORMATION

A dam safety review requires an understanding of the site conditions, construction methodology, and practices used for the construction and ongoing monitoring of the dam. A complete set of design and service records provides a reliable basis for evaluations and decisions regarding possible unacceptable performance and potential dam safety improvements. This information will facilitate the dam safety review and must be reviewed as part of the dam safety review; if unavailable, follow-up action may be required and is to be noted in the dam safety review report. Some of this information is listed below; a more complete listing is provided in Appendix D. The relevant documents include:

- Owner and organizational information, such as the owner's dam safety management system, organizational charts and responsibilities; applicable regulations (water license, permits, orders) and operational obligations (laws, regulations obligations and stakeholder agreements)
- Design and construction records, including design documentation, as-built drawings, first reservoir/containment filling data, and original classification
- Annual, routine or special dam safety inspection documents, together with the dam performance and safety history
- Operation of discharge facilities, including operating parameters and procedures, inflow forecasting, summary of critical, maximum and other important levels of stored volume or stored materials, emergency or unusual operations, and other items typically included in the OMS manual.

Particularly with respect to older dams, the Qualified Professional Engineer needs to be cognizant of potential changes of safety criteria, particularly with respect to floods, earthquakes and downstream consequences. Potential updates to the original design criteria may be necessary if the classification has changed. Additional considerations, changed conditions, or increased knowledge may include alteration to discharge capacity (due to conversions of gates, settlement of embankment, or obstructions such as debris or ice, undetected foundation/abutment problems, or construction defects).

The Qualified Professional Engineer must consider the reliability of the background information that is reviewed as part of the dam safety review. If information is known to be available and the Qualified Professional Engineer did not (or was not able to) obtain it, the circumstances, including any information gaps, must be discussed with the client and reported in the dam safety review report.

This section is intended to provide a general outline of the type of background information that must be considered, while also recognizing that the specifics around background information, including what is relevant, will vary depending upon the nature of the dam undergoing a dam safety review. Professional judgment must be used for the analysis and correct interpretation of both primary and indirect sources of information and data. The dam safety review report will state the origin of the data used in the analysis and the assumptions made by the Qualified Professional Engineer.

3.4 FIELD WORK

All dam safety reviews must include a comprehensive field review, testing of discharge facilities (when relevant), checking of site communications, and staff/owner interviews. The field work will generally follow a review of available information and is an important first step in the (Phase 2) field review and evaluation process; the dam safety review will rely to a large extent on the information obtained during the field work. This dam safety review requirement is described in the CDA *Dam Safety Guidelines*.

The extent of the area reviewed will include both upstream reservoir rim areas and downstream areas. Downstream areas may be impacted by inundation by direct flooding or through the triggering of other hazards such as failure of downstream facilities or downstream landslide or debris flow. The Testalinden failure near Oliver, BC, in July 2010 provides a recent example of this hazard and is discussed in more detail in Appendix H.

More information regarding important aspects of the field work, including dam reviews, testing of discharge facilities (if present), and other information relevant to the field work is summarized below and described in Appendix E in greater detail. The information outlines some important issues and areas to be reviewed, although it is the Qualified Professional Engineer's responsibility to identify the pertinent areas to be reviewed and apply the appropriate techniques:

- Visual review(s) – Should focus on functional integrity, hazards, failure modes, and failure mechanisms to provide a qualitative observation-based analysis of the condition of the dam and its surroundings. Testing of discharge facilities (spillways, diversions, decants, and low-level outlets), including of all necessary equipment required for safe discharge of floods, must be in place and well maintained such that they operate reliably. This should include the capability and availability of the operators assigned to the dam to be able to operate, in a timely manner, discharge facilities.
- Debris loading – Episodic debris loading can be critical for many dams and reservoirs in BC, because debris blockage can significantly reduce the discharge capacity of the outlet facilities. The containment of reservoir debris must be managed so that the safety of the dam is not impacted.
- Instrumentation – Review of the dam monitoring system (if present) should be carried out to ascertain its effectiveness in determining the behavior of a dam and its foundation relative to the applied loading conditions and to detect any signs of abnormality.
- Communications – Transmission of data and communication to and from the dam site is also important to dam and worker safety. Vital communications should be tested as part of the dam safety review field work.
- Staff Interviews – This is described in the CDA *Dam Safety Guidelines*.

3.5. DAM SAFETY ANALYSIS (HAZARDS, FAILURE MODES, AND CONSEQUENCES ANALYSES)

3.5.1 General

In general terms, the endeavor of dam safety management has to recognize and accommodate the fact that ageing and normal wear and tear present constant challenges, and that new threats to the safety of the dam sometimes emerge. In this context, the purposes of a dam safety review are to assess if any significant deterioration in the level of safety, which can be estimated in terms of an increased risk position, has occurred since the last dam safety review, and to determine if the overall level of risk is being maintained within limits considered to be tolerable. To exclude risk altogether is impossible—for dams or for any significant hazard.

The dam safety review is intended to provide a snapshot of the condition of the dam and the risks it presents as part of a process of review within the requirements of the regulatory authority, and to identify and measure, so far as possible, new risks, such that necessary improvements in the risk position can be identified. The dam owner can then use the results of the dam safety review to initiate development of any needed designs and repairs, as soon as it is practicable.

3.5.2 Context and Hierarchy of Principles for Dam Safety Reviews

The determination of what the acceptable level of risk or safety is for the various elements that are identified as being at risk is not the role of the Qualified Professional Engineer and is outside the scope of the dam safety analysis. The acceptable level of risk must be established and adopted by the regulatory authority in consultation with the dam owner. However, an assessment of the various elements at risk, through the dam failure consequences classification established by the relevant regulatory authority will guide the Qualified Professional Engineer's dam safety analysis.

The process for analyzing dam safety requires creativity, in that people identify the variety of routes by which an existing dam could reasonably endanger people, property, and the environment. A range of options to address these threats to the performance and functional integrity of the dam can then be identified, from which reasonable alternatives can be identified to protect the safety of the dam. However, the extent to which this process can be applied may also depend on numerous factors outside the scope of the dam safety analysis process. Dam safety analysis is carried out within the context of a dam safety review. However, it cannot be completed without consideration of contextual factors such as those identified in Appendix F (societal, owner, and affected individuals). Against this background is a hierarchy of principles, as outlined in Appendix F.

This hierarchy of principles provides a model for cascading downwards from the broadly based principles of a democratic society through the various constitutive societal arrangements that govern the purposes and the professional practice of dam safety reviews and dam safety analysis.

The hierarchy of principles leads to a comparable hierarchy of purposes and expectations of dam safety reviews, which in turn leads to a hierarchy of types of dam safety reviews. The end result of this principles-based approach is the capacity to provide dam safety reviews with degrees of resolution in proportion to, and appropriate for, the intended purposes of the dam safety reviews.

The following principles-based approach has been developed for performing dam safety analysis. The overarching principle, regardless of the degree of resolution in the analysis, is that the Qualified Professional Engineer should perform the dam safety analysis in a manner that reveals the variety of routes by which a dam can endanger people, property and the environment, thereby enabling the Qualified Professional Engineer to identify the range of options to control these threats to the performance and functional integrity of the dam.

The principles-based approach to dam safety analysis requires:

- An extensive understanding of the dam and associated systems—both in the present and in the foreseeable future—its behaviour in a variety of conditions, as well as experience of failures of other dams and the measures adopted to prevent their recurrence;
- An understanding of how people and organizations affect the safety of the dam;
- Imagination to identify potential failure modes that could arise at the dam or with the people involved in managing safety, and opportunities for prevention, control and mitigation.

The dam safety review should state the extent of the understanding gained during the course of the dam safety review and the degree to which the scope of the dam safety review permitted the analysis of failure modes and the identification of safety measures.

3.5.3 Implementation Principles

The implementation of this principles-based approach as provided above comes from the principles for dam safety management that are commonly adopted in dam safety assessment in Canada, as described in the CDA *Dam Safety Guidelines*. The International Commission on Large Dams provides a complementary set of principles that serve as a basis for the managerial aspects of the dam safety review. The dam safety review can be carried out in terms of these principles, or some other suitable set of principles. If another set of suitable principles are to be followed, they must be clearly referenced, and the basis of their suitability must be documented.

Dams are designed to perform certain functions, and dam safety analysis involves two fundamentally different dimensions of the safe performance of a dam:

- The physical capacity of the dam to withstand applied loads associated with the hazards of the environment at the dam's location (limit of the design envelope); and
- The functional capacity of the dam to safely perform its functions (containment and conveyance).

The engineering principles involved in dam safety analysis and in setting the engineering dimensions of the framework for a dam safety review can be set in terms of the management concept of "loss avoidance". In the context of dams, avoidance of loss typically could range from loss of the dam and its contents to loss of control of the functions of the dam that can be broadly defined in terms of the concepts of containment (of the stored volume and/or stored material (mining dams)) and conveyance (of the flows through and around the dam in a controlled way).

The dam safety analysis process involves consideration of the various relevant engineered and operational safety control measures:

- Prevention of loss of performance capacity or loss of functional capability;
- Control of the deviations from designed performance characteristics; and
- Mitigation of the effects of loss of control of the containment and conveyance functions.

Because dam safety management involves implementing preventative, control, and mitigation measures to various degrees to ensure the functional safety of the dam, the dam safety analysis should reveal the balance across and between these measures and the extent to which functional performance is assured.

Engineering principles that the Qualified Professional Engineer may use to guide the dam safety analysis include:

1. Redundancy – More than one way to achieve the desired performance;
2. Diversity – Different ways to achieve the same function for a dam system;
3. Segregation – Function served from different locations and directions;
4. Defense in depth – Large margins of capacity over demand (in all systems, including redundant systems);
5. Fault tolerance (including human fault tolerance) – A single fault will not cause loss of dam system function; and
6. Fail to a safe condition – If a part of the dam system does fail, it will render the dam to a safe condition.

The dam safety analysis is intended to reveal the extent to which the above engineering principles, or other suitable principles, have been put in place at a dam.

Below is a summary of the important concepts to be followed in implementing this principles-based approach for carrying out dam safety reviews:

- The dam safety review should be framed in the context of generally accepted dam safety management principles. The principles that are selected should be documented, and their application in the dam safety assessment should be explained.
- The dam safety review must identify the performance capacity dimensions and the functional capability dimensions of the dam safety analysis.
- The dam safety review must identify the degree to which preventive, control, and mitigation measures are in place at a dam, and the analysis should determine the adequacy of these measures both individually and collectively as a "safety system".
- The dam safety analysis should identify the degree to which the six established engineering principles described above have been implemented.

3.5.4 Elements of Dam Safety Analysis: Hazards, Failure Modes, Failure Effects, and Consequences

Dam safety analysis involves the analysis of hazards, failure modes, failure effects, and the consequences of functional failures. This includes combinations of hazards and failure modes, as well as analysis of the relationship between hazards and failure modes.

The following summarizes the most important concepts to be considered when carrying out a dam safety analysis:

1. Identify all relevant external and internal hazards or threats, and their combinations that have the potential to interfere with the safe functioning of a dam, the degree of seriousness of each hazard or combination of hazards, and whether or not the hazard condition can be characterized in probabilistic terms.
2. Identify how the hazards may act on a dam, the manner in which a dam responds to the influence of the hazards, and the consequences of functional failure of the dam due to the hazards.
3. Identify all relevant functional failure modes – the dam safety analysis must characterize the manner in which the dam responds to the influence of relevant hazards, and demonstrate how these failure modes can be transformed into physical failure mechanisms.
4. Consider the functionality of the dam as a containment and conveyance system after significant natural events.
5. Consider the possible impacts of other interdependencies between conditions, such as management, procedural and operational factors, on the functionality of the dam after significant natural events.
6. Report the results of the analysis of the relationships between the hazards and failure modes, as well as any interdependencies between hazards and failure modes, in the dam safety review report.
7. The consequences analysis component of the dam safety analysis should be the basis for establishing the classification of a dam, based on the extent of the inundation arising from the failure of one or both of the containment or conveyance functions.
8. The consequences analysis should be structured to provide data on loss of life, environmental and cultural values, infrastructure, and economics, in accordance with the requirements of the regulatory authority.
9. The consequences analysis should state the manner in which the downstream region was modeled and identify the entities and objects considered in the model.
10. The consequences analysis should state the degree of resolution of the analysis.

11. The consequences analysis should state the manner in which the impacts of the flows from the dam were determined, including any dynamic space and time considerations.

Further detail on the considerations that need to be addressed when carrying out a dam safety analysis to satisfy the intent of the above-referenced concepts is provided in Appendix G.

3.5.4.1 External Hazards of Particular Importance in British Columbia

British Columbia's natural environment, climate, and associated natural hazards require that the dam safety review pays particular attention to possible meteorological, geological, environmental, and seismological events. These are generally considered in terms of floods, landslides, and seismic events, although such simple categorization masks the complexity of these hazards, which can act in combination.

The dam safety review should take appropriate account of the nature and complexity of these hazards and should explain how they have been addressed in the dam safety review.

Refer to Appendix H for information on how loadings from natural hazards can be included in a dam safety review, both individually or in combination.

3.5.5 Methods of Dam Safety Review

Because no standardized and generally accepted method of dam safety review exists, the Qualified Professional Engineer should recommend a suitable level of service based on several factors, including but not restricted to:

- Current classification of the dam
- Age of the dam
- Use of the dam
- Type of design and method of construction of the dam
- Previous dam safety management history
- Previous dam safety reviews
- Recent and on-going performance observations and analyses of the dam

The types of dam safety review can be broadly considered to cover a spectrum ranging from an audit-type review to a comprehensive and detailed design and performance review. The Qualified Professional Engineer should recommend an approach to the dam safety review that will cause the result of the dam safety review to be appropriate for its intended purpose. Secondary considerations will involve factors such as what is appropriate for the dam safety management needs and the existing dam safety management arrangements. The Qualified Professional Engineer may need to recommend a phased approach to the dam safety review. This would be appropriate when the actual end use of the dam safety review is to inform a debate in the public domain concerning a matter of significant societal importance, but where the existing dam safety management arrangements may be insufficient to support a dam safety review that would be suitable to inform a public debate.

In many cases, an iterative approach may be appropriate, beginning with an audit-type review with recommendations for subsequent reviews of increasing detail and rigour as considered necessary to meet the end-use objective that includes the relevant regulatory requirements.

The following summarizes the most important concepts for implementing an appropriate methodology when carrying out a dam safety review:

- All aspects of the dam safety review should conform to the current APEGBC guidelines on quality management of engineering services.
- Typically, a dam safety review shall be carried out by one or more Qualified

Professional Engineer(s). Where a team is involved, the lead Qualified Professional Engineer will be the responsible Qualified Professional Engineer. The Qualified Professional Engineer responsible for an audit type review is expected to be sufficiently knowledgeable and experienced to act as the responsible Qualified Professional Engineer for all aspects of a dam safety review.

- The methodology is consistent with the expectations of the regulatory authority.
- The method used for a dam safety review should suit its intended purpose and be in accordance with the results-based contextual factors and principle-based approach described in Section 3.5.2.
- In all cases, and to the extent that is appropriate in terms of established methods of safety assessment, the dam safety review should disclose the evidence developed in the dam safety review and the line of reasoning that connects that evidence to the determination of the safety status of the dam.

3.5.5.1 Audit-Type Dam Safety Review

The audit-type dam safety review is intended to review the currency and adequacy of all safety management arrangements in place for a dam on the basis of a review of documentation, site reviews, interviews with operating staff, and preliminary engineering analysis. The currency dimension of the review focuses on the suitability of all information, systems, and safety controls used, and dam safety management in the context of established dam engineering practices. The adequacy dimension of the review focuses on the extent to which the safety management arrangements that are in place meet or exceed industry norms and the expectations of the regulatory authority.

By definition, there will be a limit to how often an audit-type dam safety review can be carried out for an individual dam unless there has been continual updating of information and upgrading of the dam. However, changes over time will render the audit-type basis for the review out of date or inadequate.

Adoption of an audit-type dam safety review may be appropriate as an interim measure or as a precursor to more detailed forms of dam safety review at the next scheduled formal review.

3.5.5.2 Comprehensive Dam Safety Review

A comprehensive dam safety review comprises all of the elements of an audit-type of dam safety review, but with each element carried out in a more in-depth way by a Qualified Professional Engineer under the direction of the lead Qualified Professional Engineer. In this regard, the review of documentation, site reviews, and interviews with operating staff will be more detailed, and may include a second verification site visit at the dam safety review report preparation stage. The engineering analysis will involve a routine design-basis check of calculations, with subsequent site verification. The regulatory authority expects that the default type of dam safety review that must be carried out by a dam owner under the provision of the *Dam Safety Regulation* is a comprehensive review. An audit-style review will not be accepted unless prior written approval has been provided by the regulatory authority.

3.5.5.3 Detailed Design-Based Multi-Disciplinary Dam Safety Review

A detailed design-based, multi-disciplinary dam safety review is carried out by a team of Qualified Professional Engineers under the guidance and direction of the lead Qualified Professional Engineer who is responsible for the integrity of the review as a whole. A detailed design-based, multi-disciplinary dam safety review is equivalent to a full-scale independent design review of an engineered system. The review of documentation, site reviews, and interviews with operating staff may require several site visits or even a period of residence at the site for the purpose of verifying the integrity of the input data to the analysis.

3.5.5.4 Comprehensive and Detailed Design and Performance Review

A comprehensive and detailed design and performance dam safety review includes a detailed performance analysis of the dam over its operating life, and also considers the attributes of a detailed design-based, multi-disciplinary dam safety review. A dam safety review of this scale and rigour can be expected to take considerable time and be highly resource intensive. In many cases, essential design and performance information may be lacking, thereby necessitating exploratory investigations and detailed sub-studies to assemble sufficient evidence and knowledge on which to base the dam safety review.

3.5.6 Consideration of Safety and Risk

The purpose of the dam safety review is to:

- determine whether the dam is safe, and
- if it is determined that the dam is not safe, to determine what actions are required to make the dam safe.

Additional considerations for environmental safety of mining dams are presented in Appendix B.

Because safety is a relative concept, and because the safety of a dam changes over time in response to changing conditions both internal and external to the dam, the dam safety review can do no more than provide a "snapshot in time" of the safety status of the dam in relative terms.

The safety status of a dam can be determined relative to, and in terms of:

(i) Established dam designs and generally accepted dam safety management measures that are used in the industry

(ii) Conformance to established engineering principles for the design, construction, maintenance, and operation of dams that represent a similar degree of risk.

(iii) If necessary, formal consideration of the tolerability of the risks associated with the dam may be required in the unlikely event that adequate safety cannot be demonstrated in terms of established practices and precedents, and engineering principles. In such an event, the dam safety review should demonstrate the extent to which practices, precedents, and engineering principles can be applied.

In all cases, the determination as to what constitutes "acceptably safe" is not part of the dam safety review process. Rather, with respect to safety determinations that are based on practices, precedents and engineering principles, the onus is on the Qualified Professional Engineer to understand whether the dam conforms to appropriate design, operation, and maintenance norms for a dam. In such cases, the actual determination of the safety status of a dam relative to these norms will be a matter of reasoned judgment by the Qualified Professional Engineer.

In cases where an acceptable level of safety to elements at risk downstream is being considered in the determination of the safety status of the dam, the onus is on the dam owner, in consultation with the regulatory authority, to determine what constitutes an unacceptable degree of risk. Such a determination by the dam owner and the regulatory authority would include considerations of people, property, and the environment downstream of a dam, and the extent to which any risk-informed safety determination should err on the side of safety. Any such determinations should be included in the dam safety review.

3.5.6.1 Consideration of Functional Integrity of a Dam as Part of a System

The various components of a dam are to be considered in their entirety as an overall dam system. How the various components of a dam system interact must be taken into consideration as part of a dam safety review. Please refer to Appendix G for more information on this matter.

3.5.6.2 Consideration of Uncertainty

It is acknowledged that there is a certain level of uncertainty associated with many aspects of dam safety assessments. Please refer to Appendix G for further discussion on this matter.

3.5.6.3 Role of Dam Safety Analysis and Risk in the Dam Safety Review Assurance Statement

The Dam Safety Review Assurance Statement introduces the term "reasonably safe", which, in terms of these guidelines, is intended to mean that the dam owner has implemented all dam safety management measures that 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.

In this regard, it is expected that the dam owner would implement reasonably practicable measures to assure the safety of the dam based on the engineering principles set out in these guidelines. Conformance to the engineering principles described in these guidelines, together with conformance to the principles of the CDA *Dam Safety Guidelines* and generally recognized international practices, and compliance with expectations of the regulatory authority would normally constitute an effective demonstration of the reasonableness of the safety management measures provided in the Dam Safety Review Assurance Statement.

Alternative arrangements of safety management measures to achieve a reasonably safe condition are available to the dam owner should conformance to the engineering principles, accepted norms, and regulatory expectations prove to be impracticable in either the short term or the long term. Under such circumstances, developing a suite of safety management measures to identify that a reasonably safe condition has been achieved can be established by demonstrating conformance to the following:

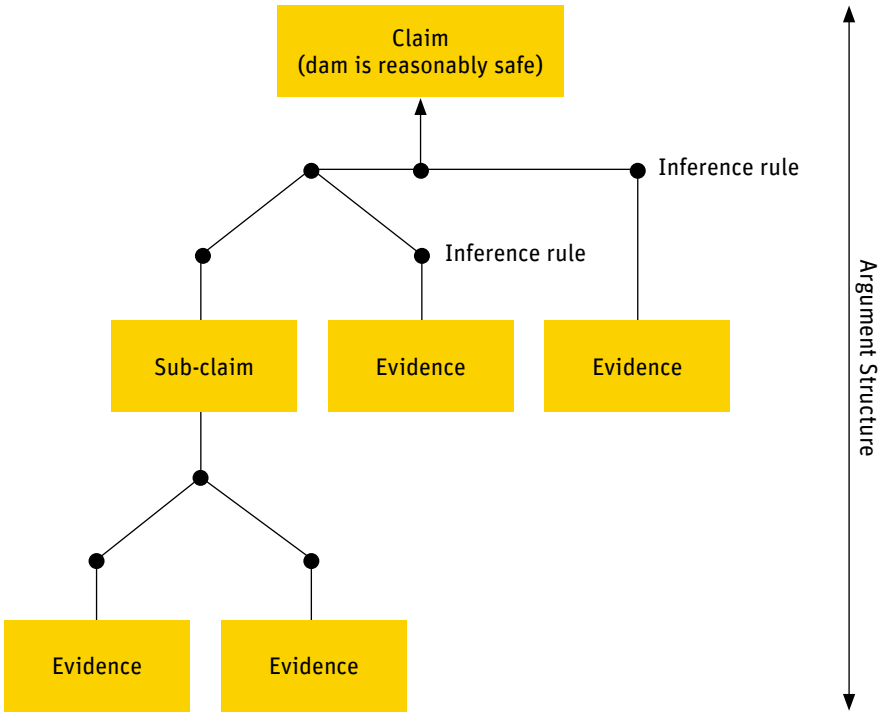
- The engineering principles described in these guidelines (see Section 3.5.3)
- The principles of the CDA *Dam Safety Guidelines*
- Generally recognized international practices
- The expectations of the regulatory authority, and/or
- A set of dam-specific enhanced safety management monitoring, surveillance, and emergency intervention plans agreed to by the regulatory authority.

The achievement of a reasonably safe condition can also be demonstrated in terms of a detailed quantitative risk assessment that has been independently reviewed by recognized experts acceptable to the regulatory authority.

In all of the above, it is not intended that the Qualified Professional Engineer be required to carry out the demonstration that a reasonably safe condition has been established. Rather, it is the responsibility of the Qualified Professional Engineer to verify that such a safety demonstration has been established by the owner.

In discharging his or her professional responsibilities with respect to these guidelines, the Qualified Professional Engineer is expected to provide a clear explanation as to why the assurance that the dam is reasonably safe can be accepted by the dam owner and the regulatory authority. Such demonstration would link the conclusion that the dam is reasonably safe to the supporting evidence by means of lines of reasoning and inference rules that connect the evidence to the conclusion (Figure 4).

Figure 4: Conclusions–Argument–Evidence Structure to support a Dam Safety Review Assurance Statement



A conclusion that a dam is not reasonably safe would be explained in a similar way, whereby the evidence is shown to be inadequate in terms of accepted norms and where logical inferences cannot be made to properly connect the evidence to the conclusion.

3.5.6.4 Risk-Informed Dam-Safety Decisions and Improvements

One purpose of the dam safety review is to enable the dam owner to use the results of the dam safety review to initiate development of designs and repairs to restore the level of safety of the dam as soon as it is practicable.

The following outlines the risk-informed approach to selecting the most appropriate of the available options for improving the safety of a dam. The result of the dam safety review, combined with the result of the dam safety improvements, should then provide key input to the next dam safety review.

In some cases, the minimum level of safety of a dam can be achieved by means of different configuration of containment and conveyance, and different degrees of reliance on preventative, control, and mitigation safety measures. The dam safety review should consider the different configuration of safety arrangements that could be in place at a dam.

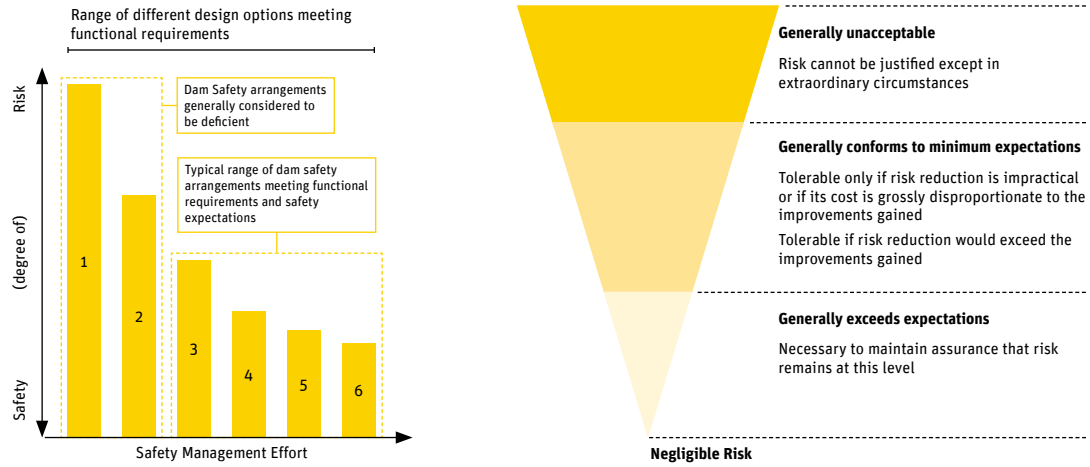
The results of the safety assessment may be represented in various ways, as illustrated in *ICOLD Bulletin 154*, and in the concepts of risk-informed identification of safety engineering solutions. One method of illustrating the various extents to which the fundamental principles of protection, control, and mitigation are represented in the safety arrangements for a dam is by means of the graphical "bow-tie" safety management model (ICOLD *Bulletin 154*). "Bow-tie" models of safety analysis and safety management clearly illustrate the relationship between accepted practices,

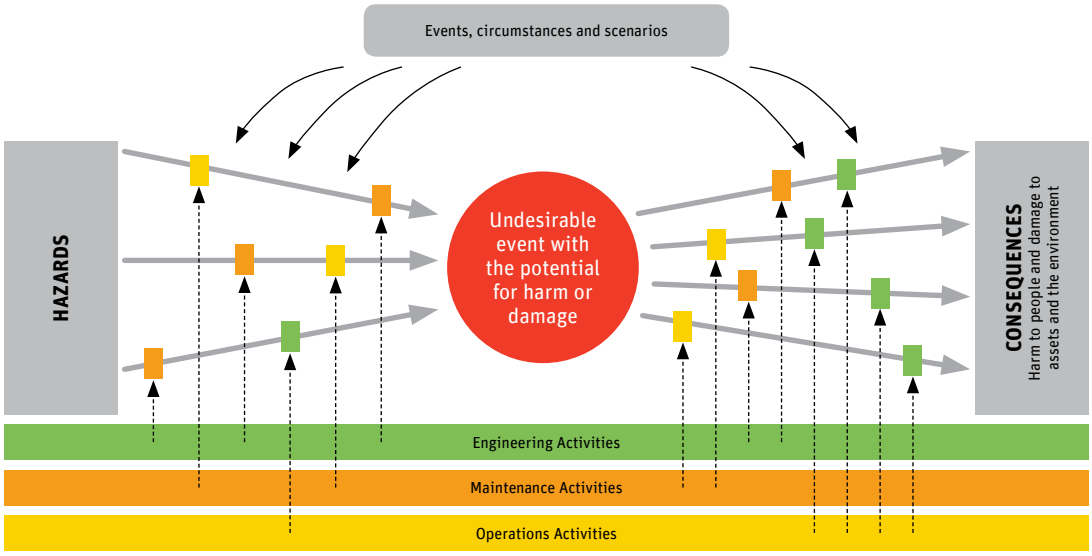
safety assessment, and safety management methods. In particular, the three categories of activities listed above can be found as barriers in this analysis.

Typically, the safety status of the dam that has been the subject of the dam safety review, the "as-is condition", can be represented in terms of the option at the far left (option 1) in Figure 5 (upper diagram). Available options for improvement of safety, some of which may be identified in the dam safety review, can subsequently be developed, and the costs and benefits of the improvements can be illustrated alongside the safety status of the dam as determined in the dam safety review.

The nature, form, and type (preventive, control, mitigative) of the safety improvements that are selected for implementation are illustrated in the "bow-tie" model (Figure 5, lower diagram).

Figure 5: Risk-Informed Dam Safety Improvements (B154, ICOLD 2011)





3.6 CONSIDERATIONS OF CHANGED CONDITIONS

The dam safety review is a snapshot at a particular point in time of whether the dam is being reasonably safely operated using the current best practice for dam safety analysis. Dams are physically located in an ever-changing environment, and downstream developments may also impact the classification of the dam. In addition, the understanding of the natural hazards imposed on the dam is continually evolving, and technical methodologies for dam safety analyses are continually developing as new knowledge is acquired in various aspects of dam safety. Changes beyond the control of the dam owner can include changes in the state of knowledge concerning natural hazards, changes in the operating regime of the dam resulting from new demands for power, water or storage capacity, and changes to the inflow into the reservoir resulting from changes to the operating regime of upstream dams. The condition of the dam itself could also change over time, as the dam ages and the dam material and equipment deteriorate.

The Qualified Professional Engineer cannot foresee and cannot be expected to forecast the impact of potential future changing conditions on the assessment of the safe operation of the dam for a specific dam safety review. The dam safety review should assess the dam in its current state and environment using the current state of practice for dam safety analysis. However, if it is clear during the review process that imminent changes are to be made or are in the process of being made to the dam or to the dam's environment, the Qualified Professional Engineer should assess the impact of these changing conditions on the safe operation of the dam in the immediate future and document these impacts in the dam safety review report. Examples of changing conditions that are planned or actual include changes to downstream development that would possibly change the classification of the dam, or imminent construction of safety improvements to the dam aimed at resolving prior deficiencies.

The dam safety review considers the impacts of climate change on the safety status of the dam at the time of the dam safety review report. However, the period of time of the validity of the dam safety review report is very short in comparison to the multiple decades over which climate change effects materialize.

3.7 DAM SAFETY REVIEW REPORT

Written reports are the means by which the Qualified Professional Engineer communicates the results of his/her dam safety review to the client and, along with the Dam Safety Review Assurance Statement, to the regulatory authority. Report formats vary depending on the complexity of the dam safety review and level of service. The Qualified Professional Engineer should consider reviewing the format and content of the dam safety review report with the client prior to finalizing the report.

While the structure and composition of the report is largely the Qualified Professional Engineer's responsibility, some documentation must be included in the dam safety review report to allow the Qualified Professional Engineer's work to be replicated and made transparent to understanding how he/she arrived at his/her conclusions and recommendations. Typically, a dam safety review report should include the following:

- An executive summary highlighting the key conclusions and recommendations;
- An introduction that defines purpose of the dam safety review and the scope of services of the Qualified Professional Engineer;
- A general description of the dam and related structures, including the general arrangement, design and construction history, recent history of the dam since the previous dam safety review, the assessment of the classification of the dam in the present environment, and descriptions of the flood, seismic reservoir, and slope stability hazards;

- A summary of the findings of the previous dam safety review, if any, and any actions taken since the previous dam safety review to rectify deficiencies and non-conformances;
- The identification of the external and internal hazards and failure modes, and compilation of these hazard and failure mode pairs into a hazards and failure modes matrix;
- A summary of the owner's compliance with the regulatory requirements;
- The details of the assessment of each component of the dam, including the reservoir or impoundment (mining dams), giving a general description of the component, the monitoring and performance of the component over the period since the previous dam safety review, if any, and any deficiencies and non-conformances identified during the assessment of the particular component;
- The details of the assessment of the operations, maintenance, and surveillance practices at the dam, including the assessment of the overall dam safety management system and identification of non-conformances;
- The details of the review of the emergency planning, including documentation and training of personnel and testing of the emergency plans, and identification of any non-conformances;
- Identification of information that was not available;
- The details of all design assumptions;
- A summary of design calculations performed to support the technical analyses;
- The conclusions and recommendation of the dam safety review, including the key findings, a prioritized list of deficiencies and non-conformances, and recommended actions to be taken to correct any hazardous conditions identified during the dam safety review at the dam; and
- The "shelf life" of the dam safety review report (see Section 3.8).

Supporting documents, such as the site visit report, can be included in appendices. Dam safety review reports should be accompanied by drawings, figures, sketches, photographs, other tables, and/or other support information, as required. Graphic information should be consistent with the information in the text.

The dam safety review report should be clearly written, with sufficient detail to allow the client, regulatory authority, and others reviewing the report to understand the methods, information used, and supporting rationale for conclusions and recommendations, without necessarily visiting the dam site.

A peer review of the dam safety review report, prior to its submission to the client, is strongly encouraged as part of the quality assurance/quality control program (refer to Section 4.0).

3.8 LIMITATIONS AND QUALIFICATIONS IN DAM SAFETY REVIEWS

Most consulting firms have their standard limitations that are routinely included in reports. However, for dam safety reviews, a number of other limitations would be unavoidable. The original design and construction, design upgrades, and any other safety assessments done on the dam in the past are likely done by other professionals, and the only evidence of this previous work exists in the form of reports. The Qualified Professional Engineer must review and interpret the data provided in these existing reports in order to form an opinion on the current safety status of the dam. Reliance on work performed by other professionals in the past is therefore used in the dam safety review, and the Qualified

Professional Engineer may wish to include limitations and qualifications in the dam safety review report where he/she has relied on the work done previously by other professionals.

In addition, the determination of the flood and seismic hazards are usually carried out independently of the dam safety review by specialists in the respective fields. This work is highly specialised, and it is usually not possible for the Qualified Professional Engineer to be expected to accept responsibility for the determination of these natural hazards. Therefore, in most cases, the Qualified Professional Engineer must rely on the work done by others to define the natural hazards on the dam, and should qualify the dam safety review report to this regard.

A dam safety review report is not intended to reflect the safety status of the dam for any significant time in the future. The report documents the current safety status of the dam. The client and the Qualified Professional Engineer should attempt to anticipate reasonable changes to the environment in which the dam system is located. These could include such things as possible downstream development and changes that could occur in the condition of the dam over a short period of time in the future, such as deterioration of flow control equipment. In the case of mining dams, such changes may include modifications to the processing plant, expansion of production, or impending closure. The "shelf life" of the dam safety review report is limited, and the report should identify that its currency is only for the dam at the time that the dam safety review was conducted.

Limitations and qualifications, including those associated with background information, assumptions, sources of error, ranges of values, and subjective opinions, should be described clearly in the dam safety review report.

3.9 FOLLOW-UP TO DAM SAFETY REVIEW REPORTS

If deficiencies exist that compromise the safety of the dam, these must be addressed. A dam must not be permitted to remain in a state that imposes unacceptable risk to people or property, or fails to meet required safety criteria. Reducing the risk to tolerable levels may be done either by reducing the consequences or reducing the risk of failure. Where financial constraints do not allow immediate corrective actions, measures such as reduced reservoir or impoundment levels may be implemented until the necessary corrective actions can be undertaken. Other early actions may range from enhanced monitoring, additional instrumentation, or other operational changes. Some findings that typically warrant follow-up are captured in Section 4.0 of the CDA *Dam Safety Guidelines*.

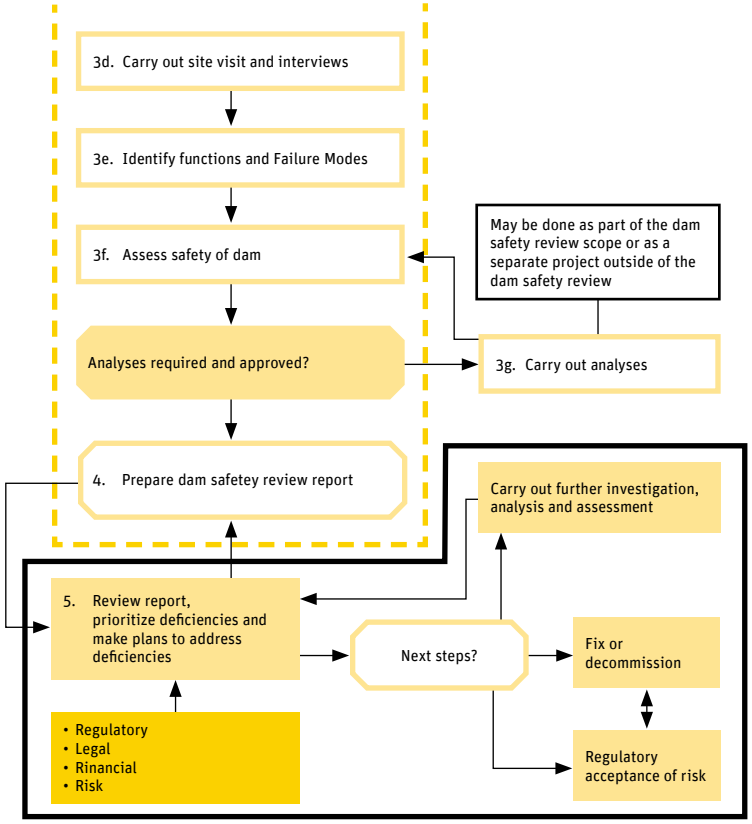
The dam safety review report documents the deficiencies and other dam safety issues found. The dam owner must then prioritize and provide a plan to resolve the deficiencies and issues within the appropriate regulatory, legal, financial, and risk framework. This follow-up may be included as a subsequent phase or separate project, but is not typically included in the scope of a dam safety review. Some of these issues may include:

- Owner's Dam Safety Management System
  - Overall dam safety planning;
  - Prioritization of concerns and decision process;
  - Owner's values and organizational structure;
  - Roles and responsibilities;
  - Mitigating actions – defense of depth, corrective and/or protective measures;
  - Operational and surveillance activities;
  - Emergency preparedness and response.

- Dam Safety Improvements
  - Risk assessment – indication of the threat the dam represents to the public or the environment;
  - Assessment of deficiency and corrective action;
  - Implementation of required upgrades (interim and longer term actions);
  - Operational improvements – advanced drawdown, conservative rule curves, flash board/stoplog removal;
  - Surveillance improvements – increased frequency/situational (enhanced attendance during floods) inspections, additional instrumentation.

Typical follow-up steps to a dam safety review are shown in Figure 6.

Figure 6: Follow-up Steps to a Dam Safety Review



Reference: T. Oswell, CDA 2012.

QUALITY ASSURANCE/QUALITY CONTROL

A Qualified Professional Engineer must apply quality assurance/quality control (QA/QC) during all phases of a dam safety analysis as part of the preparation of a dam safety review report. The assurance statements in Appendix C include confirmation that, in preparing the dam safety review report, the intent of APEGBC's quality management bylaws have been met.

4.1 APEGBC QUALITY MANAGEMENT REQUIREMENTS

Qualified Professional Engineers are required to abide by the quality management requirements of the *Engineers and Geoscientists Act* and Bylaws. In order to meet the intent of the requirements, Qualified Professional Engineers shall establish and maintain documented quality management processes for their practices, which shall include as a minimum;

1. The application of the relevant APEGBC Professional Practice Guidelines – *Engineers and Geoscientists Act*, s.4(1) and Bylaw 11(e)(4)(h)
2. Authentication of professional documents by the application of the APEGBC professional's professional seal – *Engineers and Geoscientists Act*, s.20(9)
3. Direct supervision of delegated professional engineering/geoscience activities – *Engineers and Geoscientists Act*, s.1(1) and 20(9)
4. Retention of complete project documentation – Bylaw 14(b)(1)
5. Regular, documented checks using a written quality control process – Bylaw 14(b)(2)
6. Documented field reviews of engineering/geoscience designs/ recommendations during implementation or construction – Bylaw 14(b)(3)
7. Where applicable, documented independent review of structural designs prior to construction – Bylaw 14(b)(4)

4.1.1 Professional Practice Guidelines

All APEGBC professionals are required to comply with the intent of APEGBC practice guidelines related to the engineering or geoscience work they undertake. One of the three objects of APEGBC, stated in the *Engineers and Geoscientists Act* is "to establish, maintain, and enforce standards for the qualifications and practice of its members and licensees". Practice guidelines are one means by which APEGBC fulfills this obligation.

Bylaw 11(e)4(h) states that registration as a member of the association shall be granted to an applicant who has satisfied all the requirements in the *Engineers and Geoscientists Act* and submitted evidence, in the approved format, satisfactory to the council, that the applicant has demonstrated active and responsible participation in, and sufficiently broad-based competency in, or knowledge of guidelines published by APEGBC and relevant to the practice of the applicant.

When carrying out dam safety reviews, a Qualified Professional Engineer must have sufficient broad-based knowledge of, and experience in, these guidelines.

4.1.2 Use of Seal

All APEGBC professionals are required to seal all professional engineering or professional geoscience documents that have been prepared by them or have been prepared under their direct supervision, and will be delivered to others who will rely on the information contained in the documents.

The Qualified Professional Engineer must apply his/her professional seal to dam safety review reports prepared in his/ her professional capacity or under his/ her direct supervision, and the Qualified Professional Engineer or the lead Qualified

Professional Engineer must apply his/her seal to the Dam Safety Review Assurance Statement. The Qualified Professional Engineer must meet the intent of the *APEGBC Quality Management Guidelines – Use of the APEGBC Seal* (APEGBC 2013d).

Failure to seal engineering or geoscience documents that they prepare and deliver in their professional capacity or have prepared and delivered under their direct supervision in any sector is a breach of the *Engineers and Geoscientists Act*. Please refer to the *APEGBC Quality Management Guideline – Use of the APEGBC Seal* available on the APEGBC website for more information.

4.1.3 Direct Supervision

All APEGBC professionals are required to directly supervise any engineering or geoscience work that they delegate. When working under the direct supervision of an APEGBC professional, unlicensed persons or non-members may assist in performing engineering and geoscience work, but may not assume responsibility for it. APEGBC professionals who are limited licensees may only directly supervise work within the scope of their license.

With regard to direct supervision in dam safety reviews, the Qualified Professional Engineer having overall responsibility must meet the intent of the APEGBC *Quality Management Guidelines – Direct Supervision* (APEGBC 2013f) and should consider:

- The complex nature of the dam being reviewed and the nature of the values at risk;
- Which aspects of the dam safety analysis, and how much of those aspects, may be delegated;
- The training and experience of individuals to whom work is delegated; and
- The amount of instruction, supervision and review of the subordinate that is required.

Field work is one of the most critical aspects of a dam safety analysis. Therefore, careful consideration must be given to delegating field work. Due to the complexities and subtleties of dam safety analysis, direct supervision of field work is difficult, and care must be taken to see that delegated work meets the standard expected of the Qualified Professional Engineer. Such direct supervision could typically take the form of specific instructions on what to observe, check, confirm, test, record, and report back to the Qualified Professional Engineer. The Qualified Professional Engineer should exercise judgment when relying on delegated field observations by conducting a sufficient level of review to be satisfied with the quality and accuracy of those field observations.

4.1.4 Retention of Project Documentation

All APEGBC professionals are required to establish and maintain documented quality management processes that include retaining complete project documentation for a minimum of ten (10) years after the completion of a project or ten (10) years after engineering or geoscience documentation is no longer in use.

These obligations apply to APEGBC professionals in all sectors. Project documentation, in this context, includes documentation related to any ongoing engineering or geoscience work, which may not have a discrete start and end, and may occur in any sector.

Many APEGBC professionals are employed by organizations, which ultimately own the project documentation. APEGBC professionals are considered compliant with this quality management requirement when a complete set of project documentation is retained by the organizations that employ them using means and methods that are consistent with the APEGBC Bylaw and *APEGBC Quality Management Guidelines – Retention of Project Documentation* (APEGBC 2013a).

4.1.5 Documented Checking

All APEGBC professionals are required to undergo documented quality checking and review of engineering and geoscience work appropriate to the risk associated with that work as per the APEGBC *Quality Management Guidelines – Documented Checks of Engineering and Geoscience Work* (APEGBC 2013e).

As a minimum, a dam safety review report must undergo a documented checking and review process before being finalized and delivered to the client and/or the regulatory authority. The documented checking and review process would normally involve an internal review by another Qualified Professional Engineer within the same firm. Where an appropriate internal reviewer is not available, an external reviewer may be engaged or, where this is not practical, it may be appropriate, based on the elements at risk, to have the Qualified Professional Engineer who originally prepared the report check the report at a point removed in time.

Where an internal/external review has been carried out, this must be documented clearly in the dam safety review report. The level of review should be discussed with the client and the relevant regulatory authority, but is based on the professional judgment of the Qualified Professional Engineer. Considerations should include the complexity of the site, the nature of the dam, elements at risk, availability, quality and reliability of background information and field data, and the degree of judgment on which the assessment is based, and the Qualified Professional Engineer's training and experience.

4.1.6 Field Reviews

Field reviews are reviews conducted at the site of the construction or implementation of the engineering or geoscience work by an APEGBC professional or his or her subordinate acting under his or her direct supervision, that the APEGBC professional in his or her professional discretion considers necessary to ascertain whether the construction or implementation of the work substantially complies in all material respects with the engineering or geoscience concepts or intent reflected in the engineering or geoscience documents prepared for the work.

In regards to dam safety review, if the Qualified Professional Engineer makes specific recommendations in the dam safety review report regarding the implementation or construction of remedial engineering works, the Qualified Professional Engineer has an obligation to see that the client is informed in writing that those works must be carried out by or under the direct supervision of a professional engineer. Upon confirmation of this, the Qualified Professional Engineer would place this document in his/her file. If no such confirmation is provided, then the Qualified Professional Engineer must refer to Section 3.7 of the APEGBC *Quality Management Guidelines – Documented Field Reviews During Implementation or Construction* (APEGBC 2013b).

4.1.7 Independent Review

APEGBC Bylaw 14(b)(4) and the APEGBC *Quality Management Guidelines – Documented Independent Review of Structural Designs* (APEGBC 2013c) refers to an independent review in the context of structural engineering and an independent review of the design concept, details, and documentation, based on a qualitative examination of the substantially complete structural design documents that occurs before those documents are issued for construction. It is carried out by an experienced professional engineer or licensee, including limited licensee, licensed to practice structural engineering by APEGBC who has not been involved in preparing the design.

However, an independent review can also refer to an additional level of review beyond the minimum requirements for any project type that may be undertaken for a variety of reasons by an independent APEGBC professional not previously

involved in the project. At the discretion of the APEGBC professional, in consultation with the reviewer(s) involved in the regular checking/review process outlined above, this additional level of review may be deemed appropriate. Alternatively, a regulatory authority or the owner may request an independent external review to support project approval. An independent review may be undertaken by another APEGBC professional employed within the same firm, or an external firm.

In terms of the dam safety review process, the independent review process should be more formal than the checking/review process carried out under Bylaw 14(b)(2). An independent reviewer should submit a signed, sealed, and dated letter or report, to be either included with the dam safety review report or put on file, and should include the following:

- Limitations and qualifications with regard to the independent review; and
- Results of the independent review.

When an independent review is carried out, the professional engineer who signed the dam safety review report remains the Qualified Professional Engineer.

PROFESSIONAL REGISTRATION; EDUCATION, TRAINING AND EXPERIENCE

5.1 PROFESSIONAL REGISTRATION

The following is the professional registration requirements for a Qualified Professional Engineer performing dam safety reviews for dams in BC that are addressed in these guidelines:

> The *Dam Safety Regulation* indicates that dam safety reviews must be carried out by a professional engineer "with qualifications and experienced in dam safety analysis".
>
> The CDA *Dam Safety Guidelines* form the basis for dam safety reviews required by the *Mines Act* permit conditions. The CDA guidelines state that "dam safety reviews should be carried out by, or under the direction of, a registered professional engineer with a background in design, construction, performance analysis, and operation of dams."

A Qualified Professional Engineer, as described above, must be a person registered and in good standing with APEGBC as a professional engineer under the *Engineers and Geoscientists Act*. The Qualified Professional Engineer is typically registered with APEGBC within the discipline of structural, civil, geological, or mining engineering. As the complexity of the dam and site conditions increases, characterization and sound understanding of the hazard and failure mode processes become more critical. Not all professional engineers registered in the disciplines noted above are Qualified Professional Engineers in dam safety reviews. It is the responsibility of the professional engineer to determine whether he/she is qualified by training or experience to undertake and accept responsibility for dam safety reviews for proposed dam and site conditions (APEGBC Code of Ethics Principle 2; APEGBC 2012b) and should meet the intent of the requirements discussed below.

5.2 EDUCATION, TRAINING AND EXPERIENCE

A dam safety review, as described in these guidelines, requires minimum levels of education, training and experience in many overlapping areas of engineering and geoscience. A Qualified Professional Engineer must adhere to APEGBC Code of Ethics Principle 2 (to undertake and accept responsibility for professional assignments only when qualified by training or experience), and, therefore, must evaluate his/her qualifications and possess appropriate education, training and experience consistent with the services provided.

When applying the guidance provided in this section, the level of education, training and experience required for a dam safety review should be commensurate with the complexity of the dam system and the dam classification.

Education, training and experience can vary depending on a Qualified Professional Engineer's background and whether specialty services are being provided. Whether carrying out a dam safety review or providing specialty services, appropriate experience can only be gained by working under the direct supervision of a suitably knowledgeable and experienced Qualified Professional Engineer.

Depending on the size and complexity of the dam and site conditions, dam safety reviews may be carried out by an individual Qualified Professional Engineer or a multidisciplinary team of professionals led by an experienced lead Qualified Professional Engineer. The recommended minimum qualifications for these two positions are discussed here.

Prior to conducting a dam safety review, an individual Qualified Professional Engineer or a lead Qualified Professional Engineer must:

- be knowledgeable in the design, construction, performance analysis, and operations of dams;
- Be knowledgeable about the *Dam Safety Regulation* and applicable legislation;
- In the case of mining dams, be knowledgeable about the regulations applicable to the *Mines Act* and the *Health, Safety and Reclamation Code for Mines in British Columbia;*
- Be knowledgeable about the various technical dam safety guidelines, specifically the CDA *Dam Safety Guidelines* and associated technical bulletins;
- Be knowledgeable about the system approach to dam safety analysis required for the review; and
- Confirm that he/she has the appropriate training and experience to conduct the dam safety review associated with the particular type of dam, complexity of the associated overall dam system of containment of the reservoir, and conveyance of the river flows past the dam, and, if not, involve the required specialists to provide assistance in the relevant areas.

Individual Qualified Professional Engineer

Minimum qualifications for an individual Qualified Professional Engineer carrying out the dam safety review are as follows:

- Current registration with APEGBC as a professional engineer
- Previous involvement with at least three dam safety reviews
- Have at least 15 years of related experience in design, construction, performance evaluation, and/or operation of dams
- Current knowledge of the *Dam Safety Regulation*, CDA *Dam Safety Guidelines*, and other international dam safety standards
- In the case of mining dams, current knowledge of the regulations applicable to the *Mines Act*, the *Health, Safety and Reclamation Code for Mines in British Columbia,* and the CDA *Dam Safety Guidelines*
- Have not participated in the design, construction, or safety management (surveillance, deficiency investigation, capital improvement) of the specific dam in question

Lead Qualified Professional Engineer for a Multidisciplinary Team

Minimum qualifications for a lead Qualified Professional Engineer coordinating a multidisciplinary team of professionals for a dam safety review are as follows:

- Current registration with APEGBC as a professional engineer
- Previous involvement with at least two dam safety reviews as lead technical person or under the direct supervision of a suitably knowledgeable and experienced Qualified Professional Engineer
- Have at least 10 years of related experience in design, construction, performance evaluation, and/or operation of dams
- Current knowledge of the *Dam Safety Regulation*, CDA *Dam Safety Guidelines*, and other international dam safety standards
- In the case of mining dams, current knowledge of the regulations applicable to the *Mines Act*, the *Health, Safety and Reclamation Code for Mines in British Columbia*, and the CDA *Dam Safety Guidelines*
- Not participated in the design, construction, or safety management (surveillance, deficiency investigation, capital improvement) of the specific dam in question.

Under the multidisciplinary team approach, the lead Qualified Professional Engineer may have less experience than an individual Qualified Professional Engineer because he/she is supported by a team of Qualified Professional Engineers and

specialists. However, the lead Qualified Professional Engineer is expected to direct and be involved throughout the dam safety review process.

Qualified Professional Engineers

Minimum qualifications for all Qualified Professional Engineers who carry out dam safety reviews, whether as individuals, as lead Qualified Professional Engineers, or as specialist team members, must have the appropriate education, training, and experience that specifically encompasses the area of expertise required of them. It is the Qualified Professional Engineer's obligation to obtain and document his/her education, training and experience to be able to practice and maintain his/her competency in the field he/she works in.

As previously noted, as the complexity of the dam and site conditions increase, and depending on the location in the province, the minimum qualifications should be supplemented by training and experience in additional subject areas, as required. Specialists may have to be retained to supplement experience in some of these areas and provide the necessary range of disciplines required for the specific dam and site conditions.

The academic training for the above skill sets can be acquired through formal university or college courses, or through continuing professional development. Some overlap in courses may occur, and specific courses may not correlate to specific skill sets.

A Qualified Professional Engineer should also remain current, through continuing professional development, with the evolving topics of dam safety, surveillance, construction, rehabilitation, and other specialized services offered (refer to APEGBC Code of Ethics Principle 6). Continuing professional development can include taking formal courses; attending conferences, workshops, seminars and technical talks; reading new texts and periodicals; searching the web, and participating in field trips.

5.3 SPECIALTY SERVICES

As the complexity of the dam and site conditions increase, so does the need for a multi-disciplinary–team approach to the delivery of a dam safety review. It may be the case that it is neither expected nor reasonable that any given Qualified Professional Engineer has sufficiently broad education and experience to address all of the required components of a dam safety review. Depending on the facility's characteristics—including upstream and downstream conditions—the background of the Qualified Professional Engineer, and the skill sets of the dam safety review team, specialty services may be required: these may include inundation studies, seismic determination and response, concrete technology, or instrumentation.

A specialist who offers specialized services may require specific education, training, and experience in addition to that discussed in Section 5.2. The Qualified Professional Engineer who engages the specialist has a responsibility to confirm that the specialist has the appropriate skills and competencies required to complete the activity he/she is engaged to carry out.

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APPENDIX A: LEGISLATIVE FRAMEWORK – WATER RESERVOIR DAMS

The regulation of water reservoir dams and issuing of water licences in British Columbia is a provincial responsibility. The *Water Sustainability Act* (SBC 2014 c. 15) and the associated regulation, the *Dam Safety Regulation*, are the statute and regulation that govern dam safety in British Columbia.

The dam owner is responsible for carrying out dam safety reviews on their dams for certain classifications and at the intervals provided by the *Dam Safety Regulation*.

Several rivers in British Columbia flow across the international border with the United States. The International Joint Commission was established by the governments of Canada and the US under the *Boundary Waters Treaty,* 1909. The mandate of the commission is to try to prevent or to resolve disputes involving waters in rivers common to both countries. The commission has set up boards to help them carry out their duties. Although the International Joint Commission has no direct mandate to deal with the regulation of dam safety in British Columbia, it sets certain operating parameters of some dams in Canada on the affected rivers. In British Columbia, some of these dams are on the Columbia, Kootenay, and Osoyoos rivers.

The *Columbia River Treaty* was signed by Canada and the US in 1964 and is an international agreement between the two countries to coordinate flood control and to optimize hydroelectric energy production on both sides of the border. In Canada, the dams under the *Columbia River Treaty* are the Mica, Keenleyside, and Duncan dams. The requirements of the treaty dictate the operation of these dams. The *Columbia River Treaty* does not have direct influence on dam safety aspects of these dams beyond the operation of these dams.

When starting a dam safety review, the Qualified Professional Engineer should determine whether the operations of the particular dam are affected by any orders issued by the International Joint Commission or whether the dam falls within the ambit of the *Columbia River Treaty*.

The *Water Sustainability Act* of British Columbia contains little detail affecting dam safety. The *Dam Safety Regulation* specifically addresses the responsibilities of the dam owner for the safe operation of a dam and prescribes documentation requirements, such as OMS manuals and dam emergency plans for the dam. It also prescribes surveillance activities, dam safety reviews, and operational testing of flow control equipment. The *Dam Safety Regulation* includes the determination of the classification of dams based on the consequences of a postulated failure of the dam. The *Dam Safety Regulation* does not contain specific technical details pertaining to dam safety engineering.

The CDA *Dam Safety Guidelines* and associated technical bulletins, provide guiding principles for the management of dams; the technical bulletins suggest methodologies and procedures for use by professional engineers as they carry out dam analyses and safety assessments. The CDA *Dam Safety Guidelines* were developed by CDA working groups that represented a cross section of dam engineering professionals across Canada. The CDA *Dam Safety Guidelines* have no legal status, and the *Dam Safety Regulation* takes precedence. However, the CDA *Dam Safety Guidelines* are considered to be the principal technical document in Canada for conducting dam safety reviews.

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APPENDIX B: MINING DAMS – CONSIDERATIONS IN DAM SAFETY REVIEWS

INTRODUCTION

Mining dams include structures that impound contaminated water and/or tailings or acid-generating waste rock, or water treatment sludge. These dams require additional considerations with respect to dam safety reviews. This appendix identifies the key considerations, including: construction, operations and closure; environmental considerations; and, regulations.

Tailings dams and other mining dams can be evolving structures. This should be taken into account when establishing the appropriate frequency of dam safety reviews. A dam safety review should also be carried out when substantive change in the operation of a mining dam occurs, if significant changes occur downstream, or if applicable regulations change.

The CDA *Dam Safety Guidelines* include a section detailing the information required for completing a formal dam safety review. The technical bulletin *Application of Dam Safety Guidelines to Mining Dams* (CDA 2014) explains how the requirements for a dam safety review, as described in the CDA *Dam Safety Guidelines*, apply to mining dams in the operation phase. In addition, the bulletin addresses aspects of dam safety reviews relevant to closure, including "Closure – Transition Phase," "Closure – Active Care Phase," and "Closure – Passive Care Phase."

The dam safety review for mining dams should be carried out by a Qualified Professional Engineer or multidisciplinary team of professional engineers reporting to the Qualified Professional Engineer who is a registered professional engineer with APEGBC and has the necessary education, training and experience, as detailed in Section 5.0 of these guidelines, with particular experience related to the design, operation, and management of mining dams. In addition, the Qualified Professional Engineer must have current knowledge of the *Health, Safety and Reclamation Code for Mines in British Columbia* and the permit conditions under the *Mines Act* applicable to the dam or dams being reviewed. The Qualified Professional Engineer should also have current knowledge of the CDA *Dam Safety Guidelines*, the associated CDA technical bulletin for mining dams, and other international dam safety standards

The CDA *Dam Safety Guidelines* (and the associated bulletins for mining dams) focuses on the structural failure modes of a dam (sliding, overtopping, internal erosion, etc.). However, other failure modes associated with mining dams occur that are non-structural in nature and are related to environmental protection.

Guidance on tailings dam design, management, operations, maintenance and surveillance, and closure are provided in guidelines developed by the International Commission on Large Dams (ICOLD 2011, 2012) and the Mining Association of Canada (MAC 2011a, 2011b, 2011c).

CONSTRUCTION, OPERATIONS AND CLOSURE

Mining dams are often constructed with a "starter" dam and then raised over the life of the mine to store the waste products. The dams are also subject to ongoing changes during the life of the mine and over the long term for closure conditions. The dam safety review should consider the unique aspects of the facility, which include but are not limited to the considerations listed here:

- Mining dam-design sections vary, from dams constructed almost entirely of tailings to conventional earth/rockfill dams. Some of the unique aspects of mining dam design that should be considered include:
  - Cyclone sand dams – The cyclone sand should be suitable for placement and, if required, compaction. Loose, saturated cyclone sand that is susceptible to liquefaction under seismic loading should not be placed within the dam embankment.
  - Upstream dams – Adequate segregation of the spigotted tailings is required, and underdrains should be provided to control the phreatic surface to mitigate the potential for static liquefaction. Adequate density and/or drainage is required to mitigate the potential for liquefaction under seismic loading.
- Water management systems of tailings facilities are constructed and managed to contain mine-contact (contaminated) water, divert non-contact water, manage water inflows, and recycle water to the process plant. The water balance should be managed to provide storage for operational water and seasonal inflows, while also providing storage for the environmental design flood (EDF) and freeboard.
- The inflow design flood (IDF) should be managed by providing storage within the impoundment or through the construction of temporary spillways to route the flood. Adequate storage capacity is required in the event of failure of diversion structures during the design event. The temporary spillways should have adequate capacity to route the IDF. If decants are used, they should operate according to the design, and adequate capacity for the design flood event should be provided.
- An important design aspect of mining dams is the objective of minimizing long-term liability associated with closure of the facility. Both operating dams and closed dams require dam safety reviews. Some of the unique considerations include:
  - The dam design criteria (flood and seismic) should be appropriately updated to reflect the increased risk of the long-term closure time period, as outlined in the CDA technical Bulletin: *Application of Dam Safety Guidelines to Mining Dams*.
  - The dam design should be amenable to closure, or design measures should be implemented during operations to reduce risks upon closure.
  - The development of new settlements downstream of the dam should be considered, because this could change the dam consequence classification.
  - Long-term geochemical actions that could lead to exceedance of the water-quality design components should be considered.

ENVIRONMENTAL CONSIDERATIONS

Mining dams typically store contaminated water and/or solids. Consequently, the dam safety review needs to appropriately consider if the dam is meeting the environmental objectives of its design. Environmental design criteria should be clearly documented and should include the "allowable" seepage rate, the EDF, and the water-flow and water-quality requirements for any release of surface water. The main components to be assessed in the dam safety review include, but are not limited to:

- The properties of contaminants of potential concern. These could include parameters such as pH, metal and metalloid concentrations, total suspended solids, etc. During mine operations, the concentrations of certain parameters may increase due to recycling of water and input from leached mine rock. Unless considered in the original design, the increase in concentrations may require

additional seepage mitigation or water discharge/treatment facilities.

- The efficiency of seepage mitigation. This could include assessment of the seepage rate and efficiency of seepage-mitigation works, which may include grout curtains, low hydraulic conductivity core zones or impoundment lining, geomembrane or geosynthetic clay liners, seepage-interception ditches or seepage pump-back wells, etc.
- Water releases and risks of water release. Water releases can occur via groundwater or direct discharge. Monitoring of groundwater wells downstream of the facility can indicate potential contaminant migration and may be used to estimate and confirm potential seepage rates. Tracking of parameters that attenuate very little (such as sulphate) provide early indication of seepage effects. Surface water releases must meet site-specific and/or regulatory discharge water-quality criteria, which may also include allowable assimilative capacity of the receiving environment.
- Environmental flood containment. The water balance of the impoundment should be assessed to assure adequate freeboard exists to store the EDF.
- For some facilities, dust can be generated from tailings sand dams, creating a public health and environmental concern. Accordingly, the dam safety review should assess if the dust-mitigation measures are meeting the design objectives.

Environment Canada's *Environmental Code of Practice for Metal Mines* (2009) provides a series of recommended environmental practices pertinent to mining dams throughout the life of a mining dam. The focus of the code of practice document is on metal mines (including uranium). The document can be used to help define the objectives and criteria for mining dams with respect to environmental protection requirements.

REGULATIONS

The dam owner is responsible for the management and safe operation of dams constructed for impoundments on a mine site. Currently, the BC Ministry of Energy and Mines issues permits that provide authorization under the *Mines Act* to construct and operate impoundment and associated dams on mine sites in British Columbia. The permit includes conditions under which the impoundment and dams are to be operated and managed.

The design, construction, and operation of dams on a mine site in British Columbia are currently covered by regulations and requirements under the *Mines Act* (Ref.4) and the *Health, Safety and Reclamation Code for Mines in British Columbia*. Dams on a mine site that require a water licence are also subject to regulations under the *Water Act*.

A Memorandum of Understanding (MOU; Province of British Columbia 2014) specifies the responsibilities between three provincial ministries for the regulation of impoundments and diversion structures at mine sites. Table B-1 lists the individual and joint responsibilities for the various impoundments and dams constructed on a mine site, by provincial ministry. The purpose of the MOU is to define and clarity the roles of the three provincial ministries in the siting, design, construction, operation, maintenance, abandonment, reclamation, and regulation of impoundments and diversions on a mine site in order to protect the public, the environment, and the users of water in the affected watershed.

Table B-1: Regulatory responsibility for impoundments, dams and diversions on a mine site

TYPE OF IMPOUNDMENT	MINISTRY OF ENERGY AND MINES**	MINISTRY OF FORESTS, LANDS AND NATURAL RESOURCE OPERATIONS	JOINT RESPONSIBILITY IF WATER LICENCE REQUIRED
Tailings Storage Facility	✓		✓
Flooded Impoundment	✓		✓
Water Storage Facility		✓	
Sedimentation Control Pond	✓		✓
Sludge Pond	✓		✓
Diversion Dams and Channels		✓	
Impoundment requiring a water licence		✓	

The 2016 *Health, Safety and Reclamation Code for Mines in British Columbia Guidance Document* (HSRC Guidance Document) includes guidance on design standards for tailings storage facilities. Section 10.5.3 requires that "tailings storage and water management facilities and associated dams shall be inspected annually and a report shall be prepared by the EOR (Engineer of Record) in consideration of the HSRC Guidance Document." The requirement for an annual dam safety inspection is in addition to the formal dam safety review that is required at least every five years, as referenced in the HSRC Guidance Document, Section 10.5.4.

All dams require an operation, maintenance, and surveillance manual that specifies the frequency for undertaking formal dam safety reviews. In addition, Section 4.3 of the HSRC Guidance Document requires that an emergency preparedness and response plan for tailings storage facilities be documented, updated annually, and tested on a frequency suitable for its consequence classification for response and recovery from specific incidents.

A dam safety review is required for tailings dams at least every five years, regardless of consequence classification (Section 4.6, HSRC Guidance Document). Tailings storage facilities that do not impound water are also subject to periodic safety reviews. Although the CDA recommends a frequency for conducting dam safety reviews based on the consequence classification, the *Health, Safety and Reclamation Code* requirements must be met for dam.

ENGINEER OF RECORD

Mining dams often evolve over time, with a long and complex design, construction and operational history. Also, frequent changes among the mining company personnel that are responsible for the safety of the dams can occur. In addition, ownership changes can result in changes to staff responsible for dam safety. The concept of EOR is an important consideration for mining dams, because several engineers and engineering firms are often involved in the design and construction of a single mining dam over its life, and it may not be clear who the EOR is for the dam. For each dam, the owner should identify the EOR.

The Qualified Professional Engineer carrying out the dam safety review should consult with the EOR through interviews or participation in workshops.

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APPENDIX C: DAM SAFETY REVIEW ASSURANCE STATEMENTS

C1 - Dam Safety Review Assurance Statement for Dams Regulated under the BC *Dam Safety Regulation*

C2 - Dam Safety Review Assurance Statement for Dams Regulated under the *Mines Act*

APPENDIX C1: DAM SAFETY REVIEW ASSURANCE STATEMENT – WATER RESERVOIR DAMS

Note: This statement is to be read and completed in conjunction with the current *APEGBC Professional Practice Guidelines – Legislated Dam Safety Reviews in British Columbia*, ("APEGBC Guidelines") and is to be provided for dam safety review reports for the purposes of the *Dam Safety Regulation*, BC Reg. 40/2016 as amended. Italicized words are defined in the APEGBC Guidelines.

To: The Owner(s) Date: _____

_____
Name
_____

_____
Address

With reference to the *Dam Safety Regulation*, B.C. Reg. 40/2016 as amended.

For the dam:

UTM (Location): _____

Located at (Description): _____

Name of dam or description: _____

Provincial dam number: _____

Dam function: _____

Owned by: _____

(the "Dam")

Current Dam classification is:

Check one

☐ Low
☐ Significant
☐ High
☐ Very High
☐ Extreme

The undersigned hereby gives assurance that he/she is a Qualified Professional Engineer.

I have signed, sealed and dated the attached dam safety review report on the Dam in accordance with the APEGBC Guidelines. That report must be read in conjunction with this Statement. In preparing that report I have:

Check to the left of applicable items (see Guideline Section 3.2):

____ 1. Collected and reviewed available and relevant background information, documentation and data

____ 2. Understood the current classification for the Dam, including performance expectations

____ 3. Undertaken an initial facility review

____ 4. Reviewed and assessed the Dam safety management obligations and procedures

____ 5. Reviewed the condition of the Dam, reservoir and relevant upstream and downstream portions of the river

____ 6. Interviewed operations and maintenance personnel

____ 7. Reviewed available maintenance records, the Operations, Maintenance and Surveillance (OMS) Manual and the Dam Emergency Plan

____ 8. Confirmed proper functioning of flow control equipment

____ 9. After the above, reassess the consequence classification, including the identification of required dam safety criteria

____ 10. Carried out a dam safety analysis based on the classification in 9. above

____ 11. Evaluated facility performance

____ 12. Identified, characterized and determined the severity of deficiencies in the safe operation of the Dam and non-conformances in dam safety management system

____ 13. Recommended and prioritized actions to be taken in relation to deficiencies and non-conformances

____ 14. Prepared a dam safety review report for submittal to the regulatory authority by the Owner and reviewed the report with the Owner

____ 15. The dam safety review report has been reviewed in meeting the intent of APEGBC Bylaw 14(b)(2)

Based on my dam safety review, the current dam classification is:

Check one

☐ Appropriate

☐ Should be reviewed and amended

I undertook the following type of dam safety review:

Check one

☐ Audit

☐ Comprehensive

☐ Detailed design-based multi-disciplinary

☐ Comprehensive, detailed design and performance

I hereby give my assurance that, based on the attached dam safety review report, at this point in time:

Check one

☐ The Dam is reasonably safe in that the dam safety review did not reveal any unsafe or unacceptable conditions in relation to the design, construction, maintenance and operation of the Dam as set out in the attached dam safety review report

☐ The Dam is reasonably safe but the dam safety review did reveal non-conformances with the *Dam Safety Regulation* as set out in section(s) ____ of the attached dam safety review report.

☐ The Dam is reasonably safe but the dam safety review did reveal deficiencies and non-conformances as set out in section(s) ____ of the attached dam safety review report.

☐ The Dam is not safe in that the dam safety review did reveal deficiencies and/or non-conformances which require urgent action as set out in section(s) ____ of the attached dam safety review report.

_____ _____

Name Date

_____

Signature

_____

Address

_____

Telephone (Affix Professional Seal here)

If the Qualified Professional Engineer is a member of a firm, complete the following:

I am a member of the firm _____

and I sign this letter on behalf of the firm. (Print name of firm)

APPENDIX C2: DAM SAFETY REVIEW ASSURANCE STATEMENT – MINING DAMS

Note: This statement is to be read and completed in conjunction with the current *APEGBC Professional Practice Guidelines – Legislated Dam Safety Reviews in British Columbia,* ("APEGBC Guidelines") and is to be provided for dam safety review reports in accordance with permit conditions and the *Health, Safety and Reclamation Code for Mines in British Columbia* or the *Dam Safety Regulation*, B.C. Reg. 40/2016 as amended (refer to Table B-1 in Appendix B). Italicized words are defined in the APEGBC Guidelines. An assurance statement is required for each dam that is assessed.

To: The Owner(s) Date: _____

_____
Name
_____

_____
Address

With reference to the permit conditions and the *Health, Safety and Reclamation Code for Mines in British Columbia* or the *Dam Safety Regulation*, B.C. Reg. 40/2016 as amended (refer to Table B-1 in Appendix B).

For the *dam*:

UTM (Location): _____

Located at (Description): _____

Name of dam or description: _____

Provincial dam number: _____

Dam function: _____

Owned by: _____

(the "Dam")

Current Dam classification is:

Check one

☐ Low
☐ Significant
☐ High
☐ Very High
☐ Extreme

The undersigned hereby gives assurance that he/she is a Qualified Professional Engineer.

I have signed, sealed and dated the attached dam safety review report for the Dam in accordance with the APEGBC Guidelines. That report must be read in conjunction with this Statement. In preparing that report I have:

Check to the left of applicable items (see Guideline Section 3.2):

____ 1. Collected and reviewed available and relevant background information, documentation and data

____ 2. Reviewed the environmental objectives for the materials stored in the impoundment and related design requirements

____ 3. Understood the current classification for the Dam, including performance expectations

____ 4. Undertaken an initial facility review

____ 5. Reviewed and assessed the Dam safety management obligations and procedures

____ 6. Inspected the condition of the Dam, impoundment area and relevant areas upstream and downstream of the facility

____ 7. Interviewed operations and maintenance personnel

____ 8. Interviewed Engineer of Record

____ 9. Reviewed available maintenance and operating records, the Operations, Maintenance and Surveillance (OMS) Manual and the Dam Emergency Plan

____ 10. Confirmed proper functioning of mine waste and water management systems and environmental control systems

____ 11. After the above, reassessed the consequence classification, including the identification of required dam safety criteria

____ 12. Carried out a dam safety analysis based on the classification in Item 11

____ 13. Evaluated facility performance and conformance with design basis and operating criteria

____ 14. Identified, characterized and determined the magnitude of deficiencies in the safe operation of the dam and non-conformances in the dam safety management system

____ 15. Recommended and prioritized actions to be taken in relation to deficiencies and non-conformances

____ 16. Prepared a dam safety review report for submittal to the regulatory authority by the Owner and reviewed the report with the Owner

____ 17. The dam safety review report has been reviewed in meeting the intent of APEGBC Bylaw 14(b)(2).

Based on my dam safety review, the dam classification is:

Check one

☐ Appropriate

☐ Should be reviewed and amended

I undertook the following type of dam safety review:

Check one

☐ Audit

☐ Comprehensive

☐ Detailed design-based multi-disciplinary

☐ Comprehensive, detailed design and performance

I hereby give my assurance that, based on the attached dam safety review report, at this point in time:

Check one

☐ The dam is reasonably safe in that the dam safety review did not reveal any unsafe or unacceptable conditions in relation to the design, construction, maintenance and operation of the dam as set out in the attached dam safety review report.

☐ The dam is reasonably safe but the dam safety review did reveal non-conformances with the regulatory requirements as set out in section(s) ____ of the attached dam safety review report.

☐ The dam is reasonably safe but the dam safety review did reveal deficiencies and non-conformances as set out in section(s) ____ of the attached dam safety review report.

☐ The dam is not safe in that the dam safety review did reveal deficiencies and/or non-conformances which require urgent action as set out in section(s) ____ of the attached dam safety review report.

.

_____ _____

Name Date

_____

Signature

_____ (Affix Professional Seal here)

Address

_____

Telephone

If the Qualified Professional Engineer is a member of a firm, complete the following:

I am a member of the firm and I _____

sign this letter on behalf of the firm. (Print name of firm)

APPENDIX D: DAM SAFETY REVIEW BACKGROUND INFORMATION

A continuous set of design and service records provides a reliable basis for evaluations and decisions regarding possible unacceptable performance and potential dam safety improvements. This appendix is intended to provide a general outline of the type of background information that should be considered, while recognizing that the specifics around background information—including what is relevant—will vary depending on the nature of the dam undergoing a dam safety review. Careful judgment must be applied for the analysis and interpretation of both primary and indirect sources of information and data. The dam safety review report should state the origin of the data used in the analysis and the assumptions that have been made.

OWNER AND ORGANIZATIONAL INFORMATION

- Owner's dam safety policy/management system;
- Organizational charts and responsibilities;
- Applicable regulations (water license, permits, orders);
- Purpose of structure (key capabilities and as-designed performance objectives);
- Operational obligations (laws, regulations obligations and stakeholder agreements).

DESIGN AND CONSTRUCTION RECORDS

- Design documentation;
  - Pre-design/Conceptual design reports
  - Location and physiography
  - Site Investigations
  - Field and laboratory testing
  - Geologic/hydrogeologic conditions
  - Hydrology
  - Water quality
  - Seismicity
  - Stability of structures
  - Design details (design sections, foundation prep, instrumentation, etc.)
  - Reservoir rim assessment
- As-built drawings;
- Construction and quality control;
- Equipment specifications;
- First reservoir filling data;
- Original consequence classification;
- Functional performance relative to key capabilities and as-designed performance objectives.

ANNUAL AND ROUTINE CLIENT DAM SAFETY INSPECTIONS

- Annual or semi-annual inspection documents;
- Special inspection documents;
- Instrumentation records and documents;
- Checklists (if not included in above);
- Photographs and videos.

OPERATION OF DISCHARGE FACILITIES

- Operations, Surveillance and Maintenance Manual
  - Operating parameters and procedures;
  - Inflow forecasting;
  - Summary of critical, maximum and other important water levels;
  - Emergency or unusual operations;
  - Flow control systems;
  - Testing and maintenance requirements;
  - Surveillance requirements;
  - Instrumentation;

- Site communications;
- Site safety and security.

- Test records (annual, monthly, etc.)
- Inspection records
- Operational records
  - The OMS Manual should be reviewed as part of the dam safety review. It should provide pertinent information for the site review, staff interviews and discharge facilities testing. The OMS Manual is required under the *Dam Safety Regulation* and serves as a vital component of facility documentation. For mining dams the OMS Manual is required under the *Health, Safety and Reclamation Code for Mines in British Columbia (HSRC)*. It should, therefore, be critically reviewed in the office and in the field by the Qualified Professional Engineer and assessed as to whether the document is current (latest revisions, organizational charts, etc.), adequate, and understandable. As importantly, are the instructions in the OMS Manual being followed by operations and site staff (interviews).
  - The OMS Manual should state the classification and complexity of the dam and appurtenant facilities and clearly state the frequency and requirements of inspections, monitoring and testing. It should also include a surveillance plan which considers the dam's consequence, failure modes and performance indicators. The OMS Manual should include:
    - Description of facility, location, access (access restrictions) and dam history;
    - Owner description – Organizational relationship between owner, operator, dam safety and other departments, site staff organization and qualifications;
    - Legal requirements – Government regulations, discharge requirements, downstream interests;
    - As-built drawings and pertinent documentation;
    - Key and critical levels and expected performance;
    - Operating requirements – normal operations and operations during floods and adverse weather conditions, emergencies, discharge restrictions and reservoir evacuation, flood forecasting, ice and debris management;
    - Maintenance requirements – inspections, testing and supporting documentation including operating and maintenance instructions, hydraulic and backup power information. Component requirements, such as, concrete structures, outlets, access routes;
    - Surveillance requirements – routine, periodic and enhanced surveillance plans together with inspection checklists, qualification of staff;
    - Instrumentation – objectives, listings, drawings, calibration requirements, reservoir level redundancy, data management procedures;
    - Site communications – modes, records, maintenance requirements;
    - Emergency preparedness (may be a separate document) – response, training, materials and equipment;
    - Security and public safety.

DAM PERFORMANCE AND SAFETY HISTORY

- Previous dam safety reviews or comprehensive inspection reports;
- Updated inundation studies and mapping;
- Dam Emergency Plan;
- Deficiency investigations;
- Dam safety improvements, repairs or upgrades;
- Updated drawings;
- Updated information (hydrological, seismic, structural, geotechnical).

OTHER OWNER INFORMATION (GENERALLY INCLUDED IN THE OMS MANUAL):

- Site location and access;
- Access restrictions;
- Training/safety aspect for site access (or specific areas);
- Site staff qualifications;
- Site staffing schedule.

OTHER INFORMATION AND DATA SOURCES THAT MAY BE AVAILABLE TO THE QUALIFIED PROFESSIONAL ENGINEER

- Regional Dam Safety Officer or the Dam Safety section in Victoria, B.C., or the geotechnical engineering section of the British Columbia Ministry of Energy and Mines;
- Large and small scale topographic and cadastral maps;
- Maps that show existing and proposed infrastructure, such as, transportation routes, utilities, residential and commercial subdivisions (information from local approving authority);
- Airphotos of different years (historical to present) and scales; high-resolution satellite imagery, and Light Detection and Ranging (LiDAR) images that can be also used for geological and geomorphological mapping and/or topographical mapping;
- Terrain maps, terrain stability maps, bedrock and surficial geology;
- Flood plain mapping and alluvial fan mapping;
- Previous development, including residential and non-residential, and associated infrastructure;
- Seismic data including: seismic hazard maps and reports; ground motion data, seismic site class, and modal magnitude values of the design earthquake.

POTENTIAL UPDATES TO THE ORIGINAL DESIGN CRITERIA (SEE SECTION 3.6) MAY INCLUDE:

- Inflow Design Flood (IDF);
- Maximum Design Earthquake (MDE);
- Water, ice, sediment;
- Uplift and seepage;
- Undetected adverse foundation conditions;
- Construction defects;
- Reservoir and Unexpected conditions;
- Functional availability and reliability objectives;
- Risk-informed performance expectations.

ADDITIONAL CONSIDERATIONS, CHANGED CONDITIONS OR INCREASED KNOWLEDGE MAY INCLUDE:

- Alteration to discharge capacity – due to conversions of gates, settlement of embankment or changes in available free board. Obstructions such as debris, ice, landslides, debris flows or rockfall. Failure to operate due to power, control or overtopping of gates. Inconsistencies and incompatibilities in procedures;
- Foundation/Abutment problems – Undetected geological defects, such as, open fissures, erodible or soluble materials, etc., have led to some notable dam failures including Teton Dam (1976) where core fines were transported in the foundation. Excessive settlements can occur due to hydrogeological changes in the foundation or natural ground may be poorer than considered in design. Potential liquefaction should also be considered;

- Construction defects – Defects that result in conditions not considered in design include inferior materials and poor workmanship, particularly in older dams. Defective joints, inadequate foundation treatment and defective drains have resulted in excessive uplift. Construction interruptions (winter stoppages, etc.) can result in drying or freezing and creation of preferential seepage paths at different levels in the dam. Inadequate compaction at abutments, conduits, and other interfaces. Instrumentation problems associated with inadequate compaction or sealed lead trenches.

TRANSPORTABLE AND ACCESSIBLE PACKAGING OF INFORMATION

It is noted that International Commission on Large Dams (ICOLD) recommends that the management of dam documentation include the preparation and updating at regular intervals of a "briefcase" containing all relevant information, such that it is easily transportable both in digital form and with hard copies of frequently used documents, including:

- Synoptic description of the dam and its appurtenant works;
- Main drawings including layout, excavation, geology, ancillary works, foundation treatment, instrumentation, hydro-electromechanical equipment;
- Description and justification of design options, updated according to adaptations introduced during construction or operation;
- History of the dam since its first impoundment, with a chapter on any issue or item requiring special attention;
- End of construction reports, especially those related to quality control;
- Latest report on instrumentation data analysis and site reviews;
- Note on any eventual large repair works carried out or on hold;
- Maintenance instructions;
- A comprehensive list of references presented by topic (general studies, drawings, monitoring, equipment, etc.);
- Any expert reports;
- Photos and videos during construction and under operation;
- Reservoir bathymetry and hydraulic balance (to be updated each 2 years and after any major hydrological event);
- Executive summary of environmental impact and economical studies;
- Names and phone numbers of persons to be contacted for each specific event.

The “briefcase” should be placed under the specific responsibility of the dam owner and permanently updated particularly for monitoring data analysis, periodic reviews, repair or maintenance works, and bathymetry. The most convenient way for gathering, retrieving and updating dam documentation may be achieved using a geographical information system. It takes, however, a significant effort to build, and is, therefore, only justified at present for very large dams.

> Ensuring the long-term integrity and continuous availability of data and important documents is a critical issue, considering threats associated with fire, power outages, software changes with time, and hardware changes with time. Important considerations include developing and maintaining reliable back-up systems, regularly updating software file systems, and preserving data and important documents in more than one form (paper copies, electronic files, including different types and methods of electronic files, etc.)
>
> — ICOLD B158

REFERENCES

Province of British Columbia. 2016. Water Sustainability Act – Dam Safety Regulation. Available online at: www.bclaws.ca/civix/document/id/complete/statreg/40_2016 [accessed 10/02/2017]

Ministry of Energy, Mines and Petroleum Resources. 2008. Health, Safety and Reclamation Code for Mines in British Columbia. Mining and Minerals Division. Available online at: www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/health-safety/health-safety-and-reclamation-code-for-mines-in-british-columbia [access 10/02/2017]

International Commission on Large Dams. Dam Surveillance Guide. ICOLD Bulletin 158.

APPENDIX E: DAM SAFETY FIELD WORK

DAM REVIEWS

Visual review(s) that are focused on functional integrity, hazards, failure modes, and failure mechanisms constitute an important and necessary component of dam safety review field work by providing a qualitative observation-based analysis of the condition of the structure and its surroundings. Anomalies in the condition and behavior of the structure are most frequently identified by means of visual recognition of features or changes. Because of this, it is beneficial to carry out the dam safety review field review with surveillance staff who can comment on potentially important changes. The dam safety review field review should complement the routine inspections by the owner's staff. The level of detail will depend on the complexity of the site, consequences of failure, past performance, and other parameters.

It is recommended that a checklist be prepared and used, based in part on the surveillance checklist provided in the OMS manual, if this exists, and adapted to the conditions and potential failure modes of the facility. The completed checklist, along with photographs and other information, should be incorporated into the field review report and should describe all relevant site conditions at the time of the field work. The format of the field review report shall include adequate documentation of the inspection to facilitate review and follow-up; typically, the field review report will be provided as an appendix to the dam safety review report. However, if significant dam safety concerns are identified at the time of the field review, the field review report can be used to facilitate early action.

Observations (notes, measurements, checklist entries, photos, or video records) should be documented in a systematic and consistent manner. Review checklists should be comprehensive and include all components to be reviewed, with prompts or notes for follow up. For reference, a generalized outline of a field review checklist developed by the Province of BC can be downloaded from the BC Ministry of the Environment's Water Management Branch website: http://www.env.gov.bc.ca/wsd/public_safety/dam_safety/.

The extent of a field review should be identified beforehand, but at a minimum should include:

- Upstream areas, including reservoir slopes;
- Abutment areas;
- Upstream slopes or faces of the dam, where visible;
- Dam crest;
- Downstream slopes or faces, and toe areas;
- Spillway and stilling basin (includes flow control equipment and power sources);
- Drainage systems and discharge points;
- Areas downstream of the dam site that may be impacted in a breach.

Annotated drawings are useful for record purposes and will facilitate follow-up routine observations by site staff, such that these can then be carried out in a consistent manner, identifying changed conditions. In addition, it is advisable to look at the same feature or anomaly from different perspectives or angles: this can reveal other important aspects that might otherwise go overlooked.

An understanding of the facility, its related potential structural and functional failure modes, and the observed conditions (symptoms or maintenance issues) is an integral part of the dam field review. Besides observing functional performance and observing any visible anomalies, visual reviews should focus mainly on the identification of the processes listed below, their causes, and their consequences, and most importantly, changes that might

be observed for different functions, components or areas of the facility. The processes that should be examined and documented are:

- Seepage – An indicator of adverse conditions. Identification, monitoring and assessment of the quantity and clarity of seepage or change in seepage rate or turbidity, wet areas or change in vegetation pattern.
- Displacements and deformations – Indicators of dam stability. Rate of displacement.
- Cracking – An indicator of stability and impermeability. Extent, new, or change in opening.
- Deterioration – An indicator of erosion, weathering and potential clogging of drainage measures.

(See ICOLD B154 for more information).

Changed conditions will be difficult for the Qualified Professional Engineer to recognize unless he/she is accompanied by the dam owner's staff who carry out the routine or annual inspections. Detailed questions related to the above issues and potential changes will assist.

It is advisable to create separate checklists for these field reviews and tests. In general, the field reviews and tests should be carried out by the personnel familiar with the facilities and their history

TESTING OF DISCHARGE FACILITIES

The dam safety review field work will include review and, if possible, testing of all discharge facilities, such as spillways and low-level outlets. All equipment required for safe discharge of floods must be in place and well maintained, such that it operates reliably. The field review should, in part, ascertain the capability and availability of the operators assigned to the dam to ensure that discharge facilities can be operated in a timely manner. The dam safety review should also consider the facility's normal hours of operation, reaction time, potential rate of reservoir rise under large floods, and access under all weather conditions that may be challenging in many areas of British Columbia. Operator training, operator authority, and staff availability are some of the pertinent questions to be asked on site.

> "Functioning of these outlets and of gated spillways depend primarily (but not only) on the performance of their moving parts, are generally essential for safe dam operation. It is vital for dam safety that these facilities can be operated—opened and closed—under all circumstances whenever needed. It is vital too that the gates remain as they are under all other circumstances. Malfunctioning can lead to disastrous accidents as evident from literature. To ensure that the facilities will operate reliably and safely, an appropriate program for checking and testing them is indispensable.

Testing of gates and valves, together with review of valve chambers, accessible sections of low-level outlets, outlet channels and energy dissipation, should be carried out at a reservoir water level as high as possible. Review of those parts that are under water during normal operation can be carried out by divers with video equipment, when stoplogs are installed, or when/if the reservoir is emptied in the course of flushing out sediments; however, this information should be reviewed as part of the dam safety review.

The normal power supply, as well as the emergency power system, should be used for gate operation. If foreseen, manual operation should also be tested and reviewed onsite. If gates or valves can be operated from remote control centres, the tests should include checks of communication between the control centre and site. Weak points could be identified by analyzing the system and testing it as close to reality as possible.

Reliable power supply is crucial to the safety of most dams, as is access to the control equipment and emergency lighting.

Operation or mis-operation of discharge facilities, including failure to discharge sufficient water and failure to maintain discharge gates, is a hazard to dam safety. It is essential to have adequate operational rules fully documented in the OMS Manual that will result in safe passage of the design flood. Testing of gates periodically or after unusual conditions, such as earthquakes, to ensure jamming has not resulted is crucial, as is power supply and remote control and monitoring, if appropriate. Questions directed to staff regarding this issue should be part of the field work.

DEBRIS MANAGEMENT

Debris management is critical for many dams and reservoirs in British Columbia, because debris blockage can significantly reduce the discharge capacity of outlet facilities. Many areas in British Columbia are situated in heavily forested areas with steep topography and are subject to high winds and high levels of precipitation. In addition, logging activities can result in a significant amount of debris entering the reservoir.

The containment of reservoir debris must be managed so that the safety of the dam is not affected. Dam safety review field reviews should be cognizant of this hazard and include observations and questions to site staff regarding history of debris accumulation at the dam, frequency of debris removal, adequacy of containment booms, potential levels of debris accumulation along the shoreline, and potential for sudden influxes of debris from slides or debris flows under high levels of precipitation. The potential impacts of both floating and submerged debris should be assessed.

INSTRUMENTATION

The dam safety review field work will include field review (discussions with staff) of the dam monitoring system, in order to develop an understanding of the instrumentation and monitoring system, if present. The dam monitoring system should provide for effective monitoring of the behavior of a dam and its foundation subjected to the applied loading conditions in order to detect any signs of abnormality and take action promptly. The analysis of the obtained data also provides insight into and enables better understanding of the dam's behavior.

The main parameters that are usually monitored for embankment and concrete dams, including their foundations, encompass seepage (and turbidity), pore and uplift pressures, displacements, and cracking. Monitoring provides for quantification of these parameters over time, as well as confirmation against readings observed during the field work.

The management of data, including documentation of all procedures beginning with data acquisition and ending in data analysis, interpretation and reporting, is included in the dam safety review under dam safety analysis. However, it is worth reviewing this information onsite with staff familiar with the instrumentation and data trends, as data anomalies may be due to problematic installations that staff are familiar with. Data acquisition, validation, storage, and analysis are important steps in data analysis. The adequacy of the monitoring system—including data acquisition, performance objectives, design and functionality, life expectancy and maintenance requirements—should be addressed in the dam safety review. In order to provide prompt information, instrumentation must be monitored on a regular schedule, and the data must be reduced, plotted and interpreted by qualified staff on a regular basis.

A range of values indicating normal behavior should be established for all instrumentation and procedures for implementing appropriate actions in the event that instrumentation readings fall outside the normal range.

COMMUNICATIONS

Transmission of data and communication to and from the dam site are also important to dam and worker safety. Vital communications should be tested as part of the dam safety review field work. If the lines of communication between site and control centre are redundant (landlines, cell, VHF), all modes should be tested. However, it should be noted that the availability of public networks may be insufficient in the case of extraordinary events, and tests made on a quiet sunny day may not represent emergency situations. Weak points in the system and potential for redundancy should be reviewed.

Communication between persons requires not only reliable communication lines but also updated telephone numbers available when and where they are needed. Safe communication also needs persons who are familiar with the situation and who know exactly what to do. Confirmation with site staff regarding safety and emergency communications should be part of the information obtained from the dam safety review field work.

STAFF INTERVIEWS

Generally, staff interviews are held onsite and in conjunction with the field review work to provide the Qualified Professional Engineer with more information and greater insight into:

- operating and maintenance issues or incidents;
- staff conformance to procedures;
- operating authority under unusual conditions;
- equipment or system issues;
- dam performance;
- the general level of staff training and knowledge;
- staff familiarity with the river system;
- the presence of other dams on the system, the nature of their operations, and any coordination or integration issues;
- any public safety issues, and;
- other stakeholders' interests.

Site staff should have an appropriate level of knowledge and familiarity with:

- the OMS manual
- dam emergency plans
- instrumentation and monitoring protocols
- discharge facilities and operations
- responsibilities
- training

APPENDIX F: SOCIETAL AND REGULATORY PRINCIPLES

The nature, form, and focus of any analysis should be fit for the purpose for which the results will be interpreted and used. While required for regulatory purposes, the results of dam safety reviews have several purposes and are of interest to quite different groups and entities, including: the general public; any members of the public who would be impacted by operational activities at, or failure of, a dam; governments and regulatory authorities; emergency services and responders; dam owners and dam operators; Qualified Professional Engineers and APEGBC; the insurance industry; financing organizations, and; non-governmental organizations, including environmental groups and public interest groups. These interest groups, while expected to have different objectives and alternatives, can be broadly grouped into three categories (with sub-categories as appropriate):

- Societal
  - Laws and regulations (which frame societal expectations)
  - Professional engineering practice and licensing
  - Public protection and emergency management
- Owner and Business
  - Purpose and objects of dam (short, intermediate and long term)
  - Financing and insurance
  - Market and commercial factors
- Affected individuals, groups and non-governmental organizations

Dam safety analysis is set within the context of a dam safety review that is required by *Dam Safety Regulation*, but which cannot be completed without consideration of these contextual factors. Principles for dam safety analysis can be considered to reside within the corpus of principles that define these contextual factors and their relationships.

Against this background, the following Hierarchy of Principles provides a model for cascading downwards from the broadly based principles of a democratic society through the various constitutive societal arrangements that govern the purposes and the professional practice of dam safety reviews and dam safety analysis.

1. Societal and Regulatory Principles
   a. Statutory, Legal and Regulatory Principles
2. Engineering Principles
3. Business Principles
4. Principles of Engineering Practice
   a. Principles of Dam Safety Assessment, Reviews and Management
      i. Principles of Dam Safety Analysis

The basis for this hierarchical principles model is as follows:

> Societal and Regulatory Principles provide the overarching framework to achieve the objectives of government on behalf of its citizens. Safety regulation by government arises in this context with respect to striking a balance between market forces and protection. "Safety regulation entails the regulation of risk to people, property, the environment and the wider social economy that arises from various human and industrial endeavours. It is the nature of risk that, frequently, those who create the risk do not bear its consequences nor its wider costs. So the market does not function properly as a distributive mechanism. The State must intervene to regulate risk. Regulation of risk is about making trade-offs. Trade-offs between different risks; between risks to some individuals

or groups, and risks to others; between costs and benefits. In doing so, the state's regulator has to confront some basic issues: most notably, the need for economic, social and technological progress compared with "zero risk" or "guaranteed safety". The regulator has to assert the propositions that risk is a necessary part of the human condition; that progress often depends both on incurring risk and on learning from failures (that is, accidents); that risk must be controlled but cannot in most circumstances be eliminated; that control of risks must—in the interests of technological development and societal progress—move public opinion from focusing on what is acceptable to what is tolerable; and that 'safe enough' is the goal to be striven for in design, engineering and risk management.

—Bacon 1999

APPENDIX G: ELEMENTS OF DAM SAFETY ANALYSIS

The considerations that need to be addressed when carrying out a dam safety analysis so as to meet the intent of the 11 concepts provided in Section 3.5.4 are discussed in this appendix.

These formal considerations are offered to support a dam safety analysis being carried out in a manner that meets the intent of addressing the hazards/threats to the safe functioning of a dam in an appropriate fashion.

- Hazards – Include both external hazards and internal hazards due to the dam and its operation.
  - External hazards include natural hazards, including meteorological, seismic, and landslide and debris disturbances; and human agency (terrorism, vandalism etc.) that are "external" to the dam and the actions of which are outside the control of the dam owner.
  - Internal hazards are within the control of the owner through the design, construction, maintenance, operational, and functional fault management of the dam.
- Failure modes – Specifically, the various ways that dam failure processes manifest themselves.
- Failure effects (as opposed to failure consequences) – Refer to the end physical state of the dam during and after the operation of the failure mechanism.
- Consequences of functional failure of the dam.

HAZARDS

Hazards can be considered to be external to the dam and reservoir system or internal to the system.

- External hazards (outside the control of the dam owner) – Hazards such as floods, earthquakes, reservoir environment hazards, and human agency.
- Internal hazards (within the control of the dam owner) – Hazards such as design errors; construction flaws, maintenance arrangements, operating procedures, etc.

The natural hazard environment of British Columbia is exceptionally challenging, and significant differences exist between operating environments of dams across the province.

External hazard type

- Meteorological events
  - Floods, intense rain events (causing local erosion, landslides, etc.), temperature extremes, and the effects of ice, lightning strikes, and wind storms.
- Seismic events
  - Natural and those caused by economic activity such as mining, fracking, or even reservoir-induced seismicity. The fact that areas without active seismicity can be disturbed by distant earthquakes should not be ignored.
- Reservoir environment
  - Includes all reservoir-rim features that pose a threat, including upstream dams, slopes around the reservoir, overhead off spillways, etc.
  - Reservoir environment also includes any deleterious substances or burrowing or other animals that can affect the physical performance of the dam.

- Terrorist attacks and vandalism
  - Includes vandalism and sabotage by groups ranging from local disaffected individuals to domestic or international terrorism.

Internal hazard type

- Errors and omissions in the design of the dam and water conveyance structures including inadequate consideration of the performance of the reservoir rim and upstream dams.
- Construction errors or design compromises to accommodate natural or imposed deviations from the design assumptions.
- Maintenance procedure errors where maintenance requirements are not fully defined at the design stage.
- Errors and omissions in the development and maintenance of operating rules or means of verifying adequate operation (e.g., infrastructure problems with water level recorders).

The internal hazard types are further subdivided into "sources":

Internal hazard type sources

- Water barrier: All elements retaining or interfacing with the body of water, including the main dam, any concrete spillway structure with water retaining functions, saddle dams, etc.
  - Spillway gates that function as water retaining subsystems form part of the water barrier.
- Hydraulic structures: All water conveyance structures required to direct water around or through the dam in a controlled way.
  - Typically, spillway structure, low-level outlet structure, and power water passages (canals and penstocks etc.)
- Mechanical and electrical sub-systems: All mechanical and electrical equipment and machinery required to control the reservoir level.
  - This will typically include all mechanical and electrical subsystems and controls at the dam site and, in the case of remotely controlled dams, the remote control centre. The definition of the system boundary will include the boundary around the control systems.
- Infrastructure and plans: The term "infrastructure" may be used to describe all physical infrastructure and equipment necessary for the collection of data and information required to verify the performance adequacy of the dam. The term "plans" is used to describe all of the "non-physical" dam safety activities necessary to support dam safety, including the design, construction maintenance, and implementation of all operating and safety procedures that form part of the engineering design of the dam and safety system.
  - The "infrastructure" will include all instruments and its physical supports. It will also include access roads, audits, portals, etc., required for siting and reading the instruments.
  - The "plans" will include all of the engineering design of all operating orders, maintenance strategies and plans, surveillance procedures, and the emergency plans—all of which form part of the engineering design. "Plans" also includes all forecasts, such as inflow forecasting.
  - In general, if some form of additional infrastructure or a plan (especially if human activity is involved) is required to ensure adequate performance of the water barrier, the hydraulic structures or the mechanical/electrical system with respect to any failure mode or functional failure characteristic, then infrastructure/plans will form a hazard/failure mode pair.

FAILURE MODES

A failure mode describes how element or component failures must occur to cause loss of the sub-system or system function—specifically, the containment and conveyance functions. In this regard, failure modes are not unique features of the dam, but are artefacts of how the functions of the dam are determined in design and represented and modelled in the dam safety analysis.

Containment failure mode categories

Two general containment failure mode categories can be described for dams and while these categories are often too general for definitive analysis of the safety of a dam, they provide a basis for structuring the analysis and for explaining the results of the analysis. At a very general level, there are two containment failure modes, dam overtopping and dam collapse.

Overtopping failure mode: Inadequate freeboard leading to the flow of water over the crest of the dam in a manner not intended or provided for in the design, construction, maintenance, and operation of the dam.

Collapse failure mode: Inadequate internal resistance to the hydraulic forces applied to the dam, foundations, and abutments while being hydraulically operated in accordance with the design intent.

Conveyance failure modes

Typically, conveyance failure modes are numerous, more obscure and less well defined than the containment failure modes of a dam, and they typically involve the materialization of internal hazards, including management and procedural hazards.

Conveyance failure mode – Loss of control of the flows through and around the dam.

Combinations of Hazards and Failure Modes

It is now recognized that dam safety analysis that considers natural hazards such as floods and earthquakes separately is non-conservative from a safety perspective. This is particularly the case if the sole focus of the dam safety analysis is restricted to the traditional consideration of only the Probable Maximum Flood and/or the Maximum Credible (Maximum Design) Earthquake taken in isolation.

The results of the hazards and failure modes identification process may be represented in various ways. One such way is to graphically represent all of the safety management measures in place at a dam in graphical form, such as in a "fault tree" diagram[2] or in the form of the fault tree representation (such as Hazards and Failure Modes matrix form presented on the BC Government Dam Safety website).

[2] ICOLD, B154 (2012)

CONSEQUENCES OF FUNCTIONAL FAILURE OF A DAM

The *Dam Safety Regulation* includes a five-tier dam failure consequence classification scheme for dams which aligns the consequence classification of British Columbia dams with the CDA *Dam Safety Guidelines*, thus ensuring British Columbia's dam safety requirements are consistent with the CDA guidelines.

The consequences of functional failure of a dam will typically be different for the containment and conveyance functions. Because the functions are not independent of each other, loss of the conveyance function may result in loss of the containment function with the same ultimate loss.

Dam failure consequence analysis involves developing a model of the reservoir, its operations and the region downstream of the dam, and then analyzing the effects of deviations in the water conveyance functions of the reservoir operations model.

The complexity of the model and the extent of the modelling endeavour will vary from one situation to the next, depending on the extent of the dam breach inundation and the demographics and land use of the area affected by the flood. The system boundary may be limited to the extent of the inundation, or it might be larger if wider environmental, social and economic issues are considered.

As is the case with analysis of functional failure, the level of the modelling effort will also depend on the degree of resolution required by the dam safety analysis, as determined at the outset of the dam safety review. In keeping with the iterative nature of the dam safety analysis process, it is generally appropriate to begin with a relatively coarse representation of the downstream area, and move to more refined modelling techniques as the need arises.

Typically, functional failure consequences of interest will include:

- Threats to public safety
- Environmental degradation
- Infrastructure and property damage and losses
- Socio-economic impacts, including political and public perception issues,
- Owner's reputation and financial integrity.

Because of the broad range of considerations involved, consequence analysis is a multidisciplinary endeavour that has many analytical components outside the realm of engineering. Typically, the engineering analysis pertains to modelling:

- Reservoir operation
- Formation of the breach in the dam
- Characteristics of the dam breach flooding, and
- Damage state and magnitude of the loss in the affected areas downstream.

From an analysis perspective, dam breach consequences can be broadly considered to fit into two main categories:

- Direct consequences attributable to contact with the flood waters, and
- Indirect consequences that arise as a result of the direct consequences.

Typically, direct consequences, which are the focus of this chapter, are divided into three categories:

- Life safety;
- Economic and financial; and,
- Environmental impact.

The following boundaries apply to this categorization (model):

- Public safety, including life safety considerations that apply to loss of life, physical injuries and emotional trauma caused by direct contact with flood waters.
- Economic losses pertain to all third-party economic impacts, whereas financial losses pertain solely to the dam owner.

- Environmental degradation refers to environmental losses that occur during the flood event, with collateral losses of habitat that impact migratory species being considered as indirect losses.

Typically, the physical entities and objects considered include:

- People, buildings
- Structures and infrastructure
- Animals, fish, and wildlife species
- Habitat objects such as trees, landscapes, etc.

The analysis should state the considerations involved in considering the dynamics of releases from dams and reservoirs, flows, and the interaction with affected entities and objects. Specific details with respect to the interactions between people and flows should be provided.

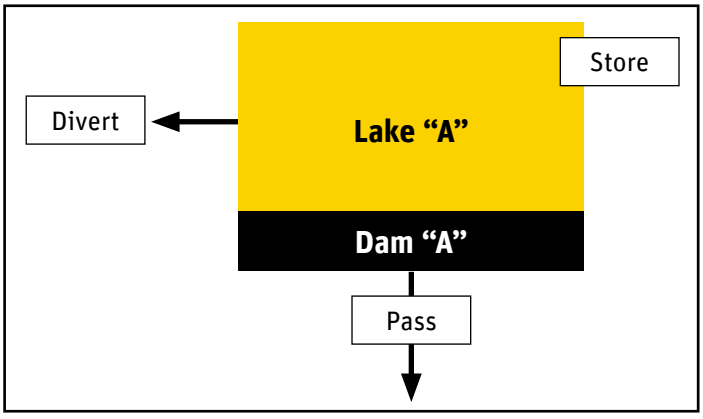
CONSIDERATION OF FUNCTIONAL INTEGRITY OF A DAM AS PART OF A SYSTEM

In recent years, it has become clear that it is necessary to consider the contributions that operational disturbances present as a hazard to a dam that should be taken into account in a dam safety review. Essentially the dam/reservoir/production unit system transforms inflows into the reservoir from rainfall and runoff that are often considered as being random natural processes, into controlled outflows, while delivering goods and services that are of benefit to society.

The dam safety review draws conclusions as to the structural performance of the dam to withstand the forces that are applied to it and the resilience of the dam to maintain the structural support and integrity required for the functions of the dam and reservoir. The functional performance and resilience pertain to the various processes, products and services that the dam is intended to provide. Specifically, the dam is intended to retain the stored volume and to pass all flows through and around the dam in a controlled manner. In simple terms, the dam has containment and conveyance functions in support of one or more hydraulic processes. The conveyance functions can be further subdivided into diversion flows for productive purposes such as power production or irrigation, and release flows where by the water is passed directly from upstream to downstream for safety, environmental or social purposes. The range of the volumes of water to be stored as divided into "live storage" and "dead storage", the rate of change of storage, the rate at which water is diverted and the rate at which water is passed directly downstream are all interrelated and must be considered throughout the dam safety analysis process.

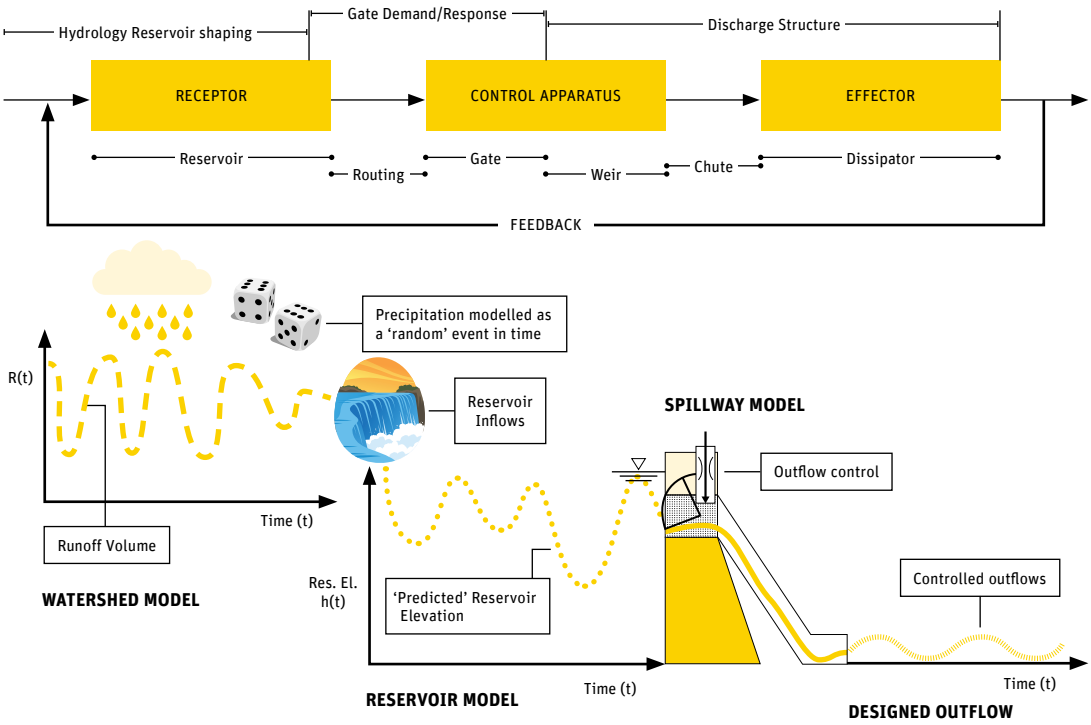
The dam, when considered in these general terms performs up to three fundamental functions; water storage (store) for future use, water passage (pass) to fulfill immediate downstream demands including the vitally important safety function, and, water diversion (Divert) for alternative productive purposes (Figure 7).

Figure 7: Fundamental Functions of the System



The engineering of dams and reservoirs involves designing a system to transform essentially random inflows into controlled outflows passed either by means of diversion of flows for production purposes or for passage around the dam to satisfy downstream production needs. In schematic terms this process can be illustrated as in Figure 8. Analysis of the performance of these functions is central to the dam safety analysis.

Figure 8: Containment of Inflows and Controlled Conveyance of Flows



CONSIDERATION OF UNCERTAINTY

Uncertainty pervades all aspects of dam safety analysis, and the Qualified Professional Engineer should include a statement in the practice analysis of the uncertainties that are identified in the dam safety review. The uncertainties are of two kinds; inherent randomness otherwise known as aleatory uncertainty; and knowledge or epistemic uncertainty. The dam safety review would be expected to identify the relative contributions of these two types of uncertainty to the total uncertainty, and to identify opportunities to reduce the total uncertainty by means of scientific advances or investigations to eliminate gaps in knowledge.

One implication of the effects of uncertainty is that a dam might be determined not to be reasonably safe because of the prevalence of knowledge (epistemic) uncertainty that can be reduced by means of accepted methods such as monitoring or surveillance. However, the nature of uncertainty is such that the Qualified Professional Engineer might deem a dam to be reasonably safe with the condition that certain uncertainties are reduced within a reasonable period of time. Such consideration is required to avoid declaring a dam that is actually reasonably safe to not being reasonably safe simply because sufficient corroborating evidence is not available.

A comprehensive treatment of uncertainty in dam safety analysis is provided in the authoritative text book *Risk and Uncertainty in Dam Safety* (Hartford and Baecher 2004).

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APPENDIX H: NATURAL HAZARD CONSIDERATIONS IN DAM SAFETY REVIEWS

INTRODUCTION

Natural hazards, external to the dam itself, impose the most significant loadings on the dam structure and associated facilities. This introductory section will define these natural hazards and suggest how they should be included into a dam safety review both individually or in combination.

HYDROLOGICAL LOADINGS

The principal loadings on a dam are hydrological and can be defined by performance criteria; the ability of the dam to retain the reservoir and the ability of the flow control equipment at the dam to pass the river flow. The external natural hazards associated with the hydrological loadings on the dam are the river flows and floods resulting from precipitation, snow melt and run-off in the catchment area, ice loadings and siltation.

The Qualified Professional Engineer should verify the currency and adequacy of the hydrological loading, commensurate with the complexity of the dam system and the classification of the dam. The technical bulletin, *Hydraulic Considerations for Dam Safety* (2007), which is associated with the 2007 CDA *Dam Safety Guidelines*, provides a summary of the state of practice in Canada and the Qualified Professional Engineer should give considerations to these guidelines for the evaluation of the hydrological loading on the dam.

The estimation of extreme events, such as flood, is often derived from statistical analyses of historic recorded data. These estimations do not take the possibility of climate change into account. Climate change may increase the frequency of high river flows and may increase the magnitude of extreme floods. Climate change is generally considered to be the change in weather patterns in the future, predicting changes over the next 50 to 100 years. However, the dam safety review considers the safety status of the dam at the present time. Therefore, the dam safety review does not need to take into account estimates of how climate change may affect the frequency of high river flows and the magnitude of extreme floods. The potential impact of siltation should be assessed.

SEISMIC LOADINGS

British Columbia is situated adjacent to a destructive tectonic plate margin and has experienced significant earthquakes in the past. The seismic hazard varies considerably across the province. In the regions of high seismicity, the seismic hazard may be the governing loading condition of the structure and foundation of the dam. Failure of a dam caused by seismic ground motion may be sudden and catastrophic and therefore the determination of the seismic hazard for the dam is often critical in the assessment of the safety of the dam.

The seismic hazard parameters and uniform hazard spectra generated for the *National Building Code of Canada* represents the median hazard values and are not site-specific. This data has been developed mainly for major urban areas and as a result may be conservative for remote sites. As the mean hazard values are recommended for use in typical seismic hazard computations for dam safety engineering, the seismic hazard parameters derived from the national building code should not be used for dam safety reviews. However, the use of seismic hazard parameters derived from the national building code could be used

for a screening level analysis provided appropriate correction factors are applied and that the limitations of the use of these approximate parameters are recognized.

The Qualified Professional Engineer should verify the currency and adequacy of the seismic loading, commensurate with the complexity of the dam system and the classification of the dam. The technical bulletin, *Seismic Hazard Considerations for Dam Safety* (2007), which is associated with the 2007 CDA *Dam Safety Guidelines*, provides a summary of the state of practice in Canada and the Qualified Professional Engineer should give considerations to these guidelines for the evaluation of the seismic loading on the dam.

LANDSLIDE LOADINGS

Throughout the world, there is a significant history of catastrophic landslides into reservoirs and natural lakes. In Vaiont, Italy (1963), more than 2,000 people were killed and many injured when a landslide of some 270 million m3 generated a wave 125 m over the dam, causing destruction for 10 miles downstream. Other examples include Loen, Norway, with loss of life of 61 people and Chungar, Peru, with an estimated loss of life of 400 to 600 people. A recent British Columbia example that highlights the complexity of all areas in the vicinity of the reservoir and dam is the June 13, 2010, debris flow initiated on Testalinden Creek, by overflow failure of a small earth dam. The event involved an estimated volume of 240,000 to 260,000 m3 of material, impacted an area of about 23.6 ha, and resulted in extensive property damage[3].

Reservoir rim hazards include overtopping waves, direct impacts and significant indirect impacts to the dam and appurtenant structures may cause failure or severe damage to the dam itself as well as upstream and downstream areas. If these natural hazards exist, the Qualified Professional Engineer must evaluate these hazards to the same degree as floods and earthquakes and under all anticipated loading conditions (seismic, high infiltration, rapid drawdown, and load combinations) to see if induced waves and/or other effects pose an unacceptable risk to the public, dam or its appurtenant structures.

The terrain adjacent to reservoirs, particularly in mountainous regions of British Columbia, can be very steep and susceptible to large landslides, avalanches, rockfalls and debris flows. In addition, in seismically active areas such as British Columbia, earthquakes can destabilize slopes leading to landslides, liquefaction and major slope displacements. Slope movements or other instabilities such as glacier collapse or major rockfalls are frequent phenomena which can occur with or without the presence of a dam/reservoir. The phenomena may become more frequent as a result of shoreline erosion and hydrogeological changes, due to the presence of a reservoir. Additionally, upstream dams, natural barriers, debris and ice may also present significant hazards. The critical areas of the reservoir circumference require careful observation to identify these hazards and slopes which could become unstable in time. Reservoir ice and debris can also create hazardous situations depending on the amount, thickness of these materials on the reservoir and characteristics of the facility[4]. Ice or debris jamming, blockage and impact loading in spillways and on gates are hazards the Qualified Professional Engineer should be aware of and account for.

[3] *EBA 2010/11*
[4] CDA07, Hydrotechnical Considerations

The process of investigation and managing slope instability issues is a logical sequence of technical evaluation and risk management including[5]:

- Identifying actual and potential slope instabilities or other potential hazards (through airphoto analysis, mapping, and other field techniques);
- Carrying out field investigations;
- Establishing geologic, hydrogeologic and geotechnical database;
- Developing and reviewing conceptual slope models;
- Assessing stability (potential, mode, post failure conditions);
- Determining hydraulic effects;
- Assessing potential consequences.

Most dam safety reviews are carried out during the operational phase of the facility and practical steps that will minimize or mitigate the risks of reservoir hazards may be limited, but do include:

- Ensure management recognition of the potential consequences of these hazards and the risks they impose; ensure sufficient effort has gone into the identification/ evaluation process;
- Maintain and continue engineering assessments of identified hazards and issues;
- Review slope models after any unusual loadings (high precipitation, earthquake or rapid drawdown);
- Establish an on-going monitoring, performance reviews and dam safety review program.

[5] *ICOLD B124 (2000)*

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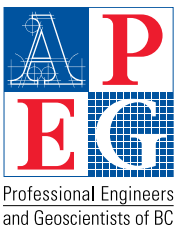

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