# SITE CHARACTERIZATION FOR DAM FOUNDATIONS IN BC

## APEGBC PROFESSIONAL PRACTICE GUIDELINES

V1.2

Professional Engineers and Geoscientists of BC

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V1.2 October, 2016

# PREFACE

*The Professional Practice Guidelines – Site Characterization for Dam Foundations in BC* have been developed in response to Recommendation 6 in the *Report on Mount Polley Tailings Storage Facility Breach* prepared by the Independent Expert Engineering Investigation and Review Panel (Panel Report). On August 4, 2014, a 40-metre-high section of the Mount Polley tailings dam failed along a weak soil layer in the dam's foundation, releasing over 20 million cubic metres of tailings and process water ("Mount Polley incident"). The Province of British Columbia appointed the Independent Expert Engineering Investigation and Review Panel ("Review Panel") to assess the failure and provide recommendations for improved practice.

Recommendation 6 of the Panel Report reads as follows:

> 6. To improve professional practice
>
> Encourage the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) to develop guidelines that would lead to improved site characterization for tailings dams with respect to the geological, geomorphological, hydrogeological and possibly seismotectonic characteristics.

The Panel Report also noted that the development of these professional practice guidelines is one of the best applicable practices that should be implemented.

*The Professional Practice Guidelines – Site Characterization for Dam Foundations in BC* have been developed in response to Recommendation 6.

The Mount Polley incident demonstrated that when a dam's foundation is not sufficiently characterized or accounted for in the design, failure can result. The nature of the Mount Polley incident is relevant to a range of other types of dams, such as water reservoir dams and other types of storage dams (e.g., storage facilities used at oil and gas exploration or production facilities and sewerage facilities). It follows that the application of an appropriate standard of practice when carrying out site characterization for foundations is equally important for all types of dams, and fundamental to their safe construction and ongoing operation. Consequently, these guidelines have been developed to be applicable to all types of dams and, where appropriate, the differences between dam types have been noted.

The application of the appropriate standard of practice when carrying out site characterization for dam foundations is fundamental to the safe construction and ongoing operation of *any type of dam*. On this basis, the appropriate standard of practice identified in these guidelines has been developed so the guidelines apply to *all* dam types.

In the context of improving professional practice involving dam-related activities, these guidelines will complement the existing *APEGBC Professional Practice Guidelines – Legislated Dam Safety Reviews in BC*, which also applies to dams in the mining industry and to water storage dams.

The development of these guidelines is consistent with one of the primary objectives of APEGBC, which is to establish, maintain, and enforce standards for the professional practice of practitioners regulated by APEGBC.

These guidelines apply to site characterization for dam foundations during the various phases of development, from conceptual through to design, construction, design updates, and closure.

These guidelines have been written for the information of APEGBC professionals, statutory decision-makers, regulators, dam owners (including utilities, mining companies, municipalities, farmers, and others), First Nations, the public at large, and a range of other stakeholders who might be involved in, or have an interest in, carrying out site characterization for dam foundations in British Columbia. These guidelines provide a common level of expectation for these various stakeholders with respect to the level of effort, due diligence, and standard of practice to be followed when carrying out the site characterization.

These guidelines outline the appropriate standard of practice at the time they were prepared. However, this is a living document that is to be revised and updated, as required, in the future, to reflect the developing state of practice.

Although these guidelines are applicable to dams in British Columbia, the guidance provided can also be considered by APEGBC professionals while working in other jurisdictions in Canada or any other global jurisdiction.

# DEFINITIONS

The explanations of the terms below are specific to these guidelines. All of these terms are italicized the first time they appear in the text.

**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.

**Assurance Statement**
The Design Engineer Site Characterization Assurance Statement, Appendix A-1 of these guidelines.

***British Columbia Dam Safety Regulation***
*British Columbia Regulation 44/2000*, including revised amendments B.C. Reg. 108/2011 (June 2011) and B.C. Reg. 163/2011 (September 2011).

**Client**
An individual or company that engages an APEGBC professional to carry out work related to the design, inspection, or review of a dam. The client is typically the dam owner. The client might also be a third party that has been contracted to operate and maintain the dam on behalf of the dam owner. Multiple holders of water licences, and therefore multiple owners, are common for small dams.

**Consequence classification**
The dam failure consequence classification of a dam as determined by Schedule 1 of the *British Columbia Dam Safety Regulation* (for water dams) or Table 2-1 of the *Canadian Dam Association Dam Safety Guidelines* (for dams under the Mines Act).

**Dam**
A structure that allows storage of water or saturated solids.

**Design Engineer**
The professional engineer having overall responsibility for the design of the dam, which includes responsibility for developing and overseeing the site characterization of the dam's foundation. The Design Engineer signs the Design Engineer's Site Characterization Assurance Statement (see Appendix A-1 of these guidelines) required in support of the feasibility study. The Design Engineer would normally transition into the Engineer of Record.

***Engineers and Geoscientists Act***
*Engineers and Geoscientists Act*, RSBC 1996, Chapter 116, as amended.

**Engineer of Record**
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.

**Field reviews**
Reviews of the work at a dam site or, where applicable, at fabrication sites where components are fabricated for use at the dam site, considered necessary by an APEGBC professional in his/her professional discretion to ascertain whether the work substantially complies in all material respects with the documents that he/she has prepared.

**Geologic Strength Index**
A system for estimating the reduction in rock mass strength for different geological conditions as identified by field observations.

**InSAR**
A radar technique used in geodesy and remote sensing.

**Lidar**
A surveying technology that measures distance by illuminating a target with a laser light.

***Mines Act***
*Mines Act*, RSBC 1996, c. 293 (updated to 2007).

**Owner / dam owner**

A person or legal entity that, with respect to a dam, is any or all of the following:

1. The person or legal entity that holds the current licence or is required to hold the licence for the dam
2. The person or legal entity that last held a licence for the dam, including a licence that has been suspended, cancelled, abandoned, or terminated
3. If there is no person or legal entity to whom paragraph (1) or (2) above applies, the owner of the land on which the dam is located or the person or legal entity that had the dam constructed.

**Phases**
Phases of the project are design, construction, operation, decommissioning, and closure (in the case of tailings dams).

**Professional engineer**
An engineer who is a member or licensee in good standing with APEGBC and, in relation to dam foundation work, is typically registered in one of the following disciplines: geological engineering, mining engineering, or civil engineering, all of which are designated disciplines of professional engineering.

**Professional geoscientist**
A geoscientist who is a member or licensee in good standing with APEGBC and, in relation to dam foundation work, is typically registered in the discipline of geology or of environmental geoscience, each of which is a designated discipline of professional geoscience.

**Regulatory authority**
The regulatory authority tasked with managing the regulatory requirements of a dam project, as decreed by statutes and regulations of British Columbia. Regulatory authorities may include the Ministry of Energy and Mines; Ministry of Environment; Ministry of Forests, Lands and Natural Resource Operations; Parks Canada Agency; Canadian Nuclear Safety Commission; or International Joint Commission.

**Site characterization**
The process of defining a dam's subsurface conditions with respect to geology, geomorphology, and hydrogeology. Site characterization involves data collection, field investigations, and interpretation.

**Site characterization program**
The combination of activities that are undertaken to define a dam's subsurface conditions (e.g., field mapping, drilling, geophysics, testing).

**Site characterization report**
A report produced by the Design Engineer that documents the site characterization data and the interpretation of the data.

**Site geological model**
A model that includes the bedrock and surficial geology, with integration of geomorphology, geotechnical and hydrogeological conditions, and relevant seismotectonic characteristics.

**Stages**
Stages of project design are as follows: scoping-level, pre-feasibility, feasibility and detailed design.

**Supporting registered professional (SRP)**
An APEGBC professional engineer, professional geoscientist, or licensee engaged by the Design Engineer to carry out professional activities related to the site characterization of the dam foundation.

# ABBREVIATIONS USED IN THESE GUIDELINES

| | |
|---|---|
| **APEGBC** | Association of Professional Engineers and Geoscientists of British Columbia |
| **ASTM** | American Society for Testing and Materials |
| **DSCR** | dam site characterization report |
| **FMEA** | failure modes and effects analysis |
| **InSAR** | interferometric synthetic aperture radar |
| **lidar** | light detection and ranging |
| **SGM** | site geological model |
| **SRP** | supporting registered professional |

# INTRODUCTION

## 1.1 INTRODUCTION TO THESE GUIDELINES

The foundation of a *dam* is a critical structural component and requires special attention. A dam foundation has a twofold function: (1) structural stability (to provide stability and sufficient stiffness to limit deformations to within acceptable behaviour patterns under the weight of the dam and the forces acting on it and to maintain this integrity under the conditions that exist and/or can be expected to develop over time); and (2) seepage control (to control seepage with respect to flow quantity and quality, uplift pressures, and erosive stresses). If one of these functions is not sufficiently addressed, the dam's performance may be impaired to the point that the dam is unsafe.

The foundation conditions at a site are also a determining factor in the selection of the type of dam; *site characterization* is therefore important for the design of the dam and its safe operation. In the context of dam safety, the design and supporting *site characterization program* are important "critical controls" – elements that reduce risks. Accordingly, the site characterization program could be considered a "critical control" for dam safety and should be treated as such.

Whereas the dam itself is "engineered" and quality control can be exercised through design and construction specifications, the foundation conditions are "natural" and are subject to the inherent heterogeneities and potentially complex conditions between investigated locations. Because it is impractical to achieve a full definition of the geologic domain in a dam's foundation, the challenge is to keep the uncertainties within acceptable limits and to balance the uncertainties with design provisions. This balance is part of the ongoing review of cost/benefit considerations of incremental investigations.

It should always be assumed that a given site is both geologically and geomorphologically complex. Therefore, the site characterization program should be carried out to confirm either that the site is one of those rare locations that is not complex and that conditions and parameters are understood, or that the program has appropriately assessed the site's complexity and variability, allowing determination of representative conditions and parameters.

Tailings dams have unique characteristics that are different from those of water dams and industrial dams, as discussed in Section 2.1. The most significant differences are the staging of tailings dam construction over the life of the mine (steady state is typically reached only at mine closure or when an alternative tailings storage facility is commissioned for an operation), the impoundment of both tailings solids and mine process/contact water, and the fact that the dam will be required in perpetuity. These conditions provide for a unique set of considerations that must be addressed where tailings dams are involved.

The role of the *Design Engineer*, as described in these guidelines, is to develop a site characterization program that considers the geological complexity, the dam design, and factors influencing the program. The Design Engineer is responsible for assuring that adequate and appropriate site characterization has been carried out for the dam's foundations, and commonly transitions into the *Engineer of Record*.

## 1.2 BACKGROUND TO THESE GUIDELINES

The investigation carried out by the Chief Inspector of Mines into the Mount Polley incident ("Chief Inspector's Report") concluded that the incident occurred because the dam's embankment failed as a result of an unidentified weak soil layer (upper glaciolacustrine unit) in the foundation of the dam. Insufficient freeboard relative to the embankment deformation then led to a dam breach.

The main findings of the Chief Inspector's Report with respect to site characterization of the dam foundation included:

* The spacing between deep sampled drill holes in the dam foundation was over 400 metres, which was considered to be too far apart for the nature of the site's geology and geomorphology.
* The depth of drilling (typically less than 10 metres) was not enough to characterize the foundation for the height of the dam (40 metres) and the nature of the foundation materials.
* The drilling and sampling methodology for the one deep drill hole located in the breach area was not adequate for characterization of the soils (rotary diamond drill hole with observation of cuttings).
* The geological model for the site did not recognize the more than three stages of glaciation and the complexity of the surficial geology.

The Chief Inspector's Report identified additional factors that did not appear to have been adequately characterized, although they may not have contributed directly to the incident:

* The foundation bedrock beneath the breach included high-plastic, low-strength mudstone, which could influence stability at higher dam heights.
* The undrained strength response of the foundation glaciolacustrine layers was not clearly identified in the design reports.
* Artesian pressures in the foundational glaciofluvial soils were not explicitly recognized or accounted for in stability analyses.

## 1.3 PURPOSE AND OBJECTIVES OF THESE GUIDELINES

The *Professional Practice Guidelines – Site Characterization for Dam Foundations in BC* have been developed in response to Recommendation 6 of the Independent Expert Engineering Investigation and Review Panel's *Report on Mount Polley Tailings Storage Facility Breach*. The purpose of these guidelines is to identify an appropriate standard of professional practice for site characterization. This standard of practice provides a framework for adequate site characterization for dam foundations, to improve dam safety and ensure that incidents such as the one at Mount Polley will not be repeated.

These guidelines provide direction on good practice for site characterization and on the level of detail required.

The guidelines are intended to lead to a common level of expectation for Association of Professional Engineers and Geoscientists of British Columbia (*APEGBC*) professionals, *owners*, regulatory authorities, First Nations, and other stakeholders. For First Nations, this common level of expectation should include issues related to Aboriginal title, rights, and traditional land use being reviewed with the relevant authorities and stakeholders. This review is normally undertaken by the owner(s) during the project's scoping stage.

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[1]*APEGBC*'s Code of Ethics is at https://www.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.*

These guidelines should be considered within the context of guidance provided by the Canadian Dam Association and the Mining Association of Canada with respect to dams.

The specific objectives of these guidelines are to:

1. Describe the types of dams that these guidelines apply to, the *stages* of dam design, and the *phases* of a dam project/life
2. Describe the roles and responsibilities of the various participants and stakeholders, including regulatory authorities, that are involved in the site characterization for dam foundations
3. Outline the professional services to be provided by APEGBC professionals in conducting site characterization for dams in British Columbia
4. Describe the standard of practice to be followed by APEGBC professionals in providing professional services related to conducting site characterization for dams in British Columbia. The standard of practice is set in the context of the complexity of the site, dam design, and other factors.
5. Specify the tasks and the technical components to be considered by APEGBC professionals in order to meet an appropriate standard of practice and the intent of these guidelines while fulfilling APEGBC professionals' obligations under the *Engineers and Geoscientists Act*. These obligations include a primary duty to protect the safety, health, and welfare of the public and the environment.
6. Describe the quality management practices to be followed by APEGBC professionals in carrying out site characterization, in order to meet their professional obligations
7. Provide consistency in site characterization and reporting
8. Describe the appropriate knowledge, skill sets, and experience that APEGBC professionals must have when providing professional services related to site characterization

These guidelines provide a framework for the standard of practice to be applied to site characterization of foundation conditions for dams in British Columbia. They are an important tool for managing the uncertainties associated with the outcome of a site characterization program.

In particular, Section 4.6 of these guidelines outlines the documentation outcomes of a site characterization. These include a *site characterization* report and *Site Characterization Assurance Statement* that are to be submitted to the *dam owner* and the *regulatory authority*, if applicable, by the Design Engineer and supporting APEGBC professionals.

A Site Characterization Assurance Statement is required at the feasibility and detailed design stages of a project, as described in Section 2.2.2. A Site Characterization Assurance Statement provides a standardized statement confirming that the objectives of the site characterization program have been met in obtaining an appropriate understanding of the following five site characterization components and that the level of investigation carried out was sufficient:

- Bedrock and structural geology
- Surficial geology and geomorphology
- Geotechnical conditions
- Hydrogeology
- Seismotectonic conditions

These characterization components are addressed in Section 4.4. A template for the Site Characterization Assurance Statement is included in Appendix A-1.

## 1.4 ROLE OF APEGBC

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

An APEGBC professional must exercise professional judgment when providing professional services; as a result, application of these guidelines will vary depending on the circumstances. APEGBC supports the principle that, in order to comply with the standard of practice provided in these guidelines, the Design Engineer responsible for carrying out the site characterization of the dam foundation should be provided with appropriate financial, human, and technical services. These guidelines should be used to assist in establishing the objectives, type of dam site characterization, level of service, and terms of reference for an APEGBC professional's scope of work and agreement with the client.

By following these guidelines, APEGBC professionals will fulfill their professional obligations, especially with regard to APEGBC's 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" 1). Failure of an APEGBC professional to meet the intent of these guidelines could be evidence of unprofessional conduct and lead to disciplinary proceedings by APEGBC.

## 1.5 SCOPE OF THE GUIDELINES

These guidelines apply to site characterization conducted for dam foundations regulated under the *British Columbia Dam Safety Regulation* and/or permit conditions under the *Mines Act* and other relevant provincial or federal legislation. These guidelines apply to all stages of design, as described in Section 2.2.

Dam site characterization may be carried out for dams other than those regulated under the legislation referenced above. The information contained in these guidelines is likely relevant to dam site characterization for the construction of dams that are not regulated by legislation in British Columbia.

Furthermore, dam site characterization methods documented in these guidelines are not intended to address any occupational health and safety requirements in relation to the site characterization activities to be carried out. However, where a serious concern is identified, it must be brought to the attention of the constructor / dam owner / client.

## 1.6 APPLICABILITY OF THESE GUIDELINES AND APEGBC

These guidelines provide guidance on professional practice for APEGBC professionals carrying out site characterization assessments for dams in British Columbia. These dams may be owned by diverse parties, including utilities, mining companies, pulp and paper companies, companies working in the oil and gas sector, various levels of government, First Nations, or private owners. The application of these guidelines provides a consistent and comprehensive standard of professional practice to be applied to site characterization for dams in British Columbia.

An APEGBC professional'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

1).APEGBC's Code of Ethics is at https://www.apeg.bc.ca/APEGBC/media/APEGBC/Governance/APEGBC-Code-of-Ethics.pdf. The Code of Ethics, along with accompanying guidelines and commentary, is published in the current (1994) edition of APEGBC's *Guidelines for Professional Excellence.*

professional obligations. Such judgments and decisions depend on considering the facts and circumstances for a specific site to determine whether another reasonable and prudent APEGBC professional, in a similar situation and during the same time frame, would have conducted himself or herself similarly.

These guidelines outline the appropriate standard of practice at the time they were prepared; this is a living document that is to be revised and updated, as required, to reflect the developing state of practice. These guidelines are influenced by current provincial legislation, advances in knowledge, and the evolution of general professional practices in British Columbia.

With respect to the use of these guidelines in other jurisdictions in Canada (provinces and territories) or internationally, the practitioner wishing to apply them in another jurisdiction should confirm this with the relevant regulatory body. APEGBC supports the development of a common standard of care in professional practice in the carrying out of professional engineering/geoscience activities across Canada and, as practical, internationally. This includes site characterization for dam foundations.

## 1.7 ACKNOWLEDGMENTS

These guidelines were prepared on behalf of APEGBC by a committee of APEGBC professionals and were reviewed by several individuals as members of a review task force. The authors and reviewers are listed in Appendix C. The authors thank the reviewers for their constructive suggestions. A review of this document does not necessarily indicate that reviewers and/or their employer / agency / affiliated association endorse everything in these guidelines.

APEGBC thanks the BC Ministry of Energy and Mines and BC Ministry of Forests, Lands and Natural Resource Operations for providing technical support in the preparation of these guidelines. APEGBC also thanks the Canadian Dam Association, Mining Association of British Columbia, and BC First Nations Energy & Mining Council for providing support and peer review of these guidelines.

# CONTEXT FOR SITE CHARACTERIZATION FOR DAM FOUNDATIONS

## 2.1 TYPES OF DAMS

These guidelines are intended for dams that are constructed for any one of a variety of purposes ranging from, for example, small water storage dams for irrigation to very high dams for hydroelectric power generation and mine tailings storage. In addition, dam ownership and uses can vary widely. Table 2-1 summarizes three general dam types and purposes—water dam, industrial dam, and tailings dam—and the key differences between them.

Earth or rockfill dams (embankment dams) can be constructed for each of the types shown in Table 2-1. Concrete dams are often constructed for water dams and industrial dams, but rarely for tailings dams.

**Table 2-1. Characteristics of Water Dams, Industrial Dams, and Tailings Dams**

| Characteristic | Water Dam | Industrial Dam | Tailings Dam |
|---|---|---|---|
| **Purpose and stored material** | Water supply; hydroelectric; flood control; water and stream diversions; run-of-river hydroelectric; recreational; land improvement | Storage of process and waste water, sludge, and sediment | Storage of tailings solids and process/ mine contact water |
| **Operating life** | Typically designated as 100 years, but "as long as required by society" | As long as the industrial operation remains (can be multiple decades) | As long as the mine remains operating (can be multiple decades) |
| **Construction period** | Usually 1 to 5 years | Usually less than 1 year | Initial starter dam, then staged over the operating life (can be multiple decades) |
| **Closure** | Facility may be decommissioned, with the dam removed or breached | Often decommissioned and/or covered | Commonly a perpetual closure period. If there is water retention, then the dam may have to be treated the same way as it was during operation.<br><br>Modifications to the dam may allow redesign to become a "landform." |
| **Continuity of engineering** | Typically one engineering firm for design and construction | Varies and can change frequently during operating life | Varies: engineering firm may change during the operating life and most certainly will change over the closure period |
| **Owner** | Public utilities and municipalities; individual landowners | Mining, forestry, and oil and gas companies; municipalities | Mining companies and government |
| **Consequences of failure** | Water inundation | Release of water and/or sludge that has been affected by the process | Water inundation and tailings solids debris flow |
| **Dam section** | Usually a consistent section; upgrades, including raising and downstream berms, are possible | Usually a consistent section | Can vary and evolve during the development of the facility |

### Special Considerations for Tailings Dams

The three dam types shown in Table 2-1 perform different functions, and each type has unique characteristics. For example, tailings dams have three unique characteristics:

- The progressive raising of the dam during the operating life of the mine results in ongoing changes to the stability of the dam.
- Unlike most water retention dams, which can be breached at the end of their intended life, a tailings dam is required in perpetuity, although its function may change according to the water retention characteristics on closure.
- The storage of mine tailings and process water increases the potential environmental consequences associated with seepage, water release, or dam failure. Industrial dams may also have additional public safety and environmental concerns.

Considerations for tailings dams include the following:

- Tailings dams are fundamentally different from other types of dams in that they are typically raised successively over time as a mine develops. As a result, the static loading conditions are continually changing, and stability and seepage considerations therefore also continue to change.
- The progressive dam raises typically involve additional site characterization and detailed designs for the stages and/or dam modifications over time.
- Most, or at least a significant portion, of a dam is constructed over the operating life of a mine, which in some cases can be multiple decades. As a result, changes can be expected in the Design Engineer, potentially in the ownership, and even in regulatory requirements over this extended time frame. Transitions between the responsible parties can represent a challenge and must be carefully planned and implemented to maintain the integrity of institutional knowledge, including the site characterization studies.
- Permitting requirements for a tailings dam may be tailored to the periodic raises that may occur over the life of the facility or to a specific dam elevation, which may change. As a result, the regulatory review process may also be subject to changing regulatory requirements over time.
- The nature of tailings solids and process water may limit the allowable quantity of seepage water to the receiving environment, which places additional emphasis on the need for hydrogeological assessment.
- As noted above, tailings dams cannot be removed on closure. As a result, they have to be maintained in perpetuity and engineered to function as a dam in that manner or engineered to be able to transition to performing as a natural landform while maintaining physical and chemical containment for the tailings.

## 2.2 LIFE PHASES AND DESIGN STAGES OF DAMS

### 2.2.1 Life Phases

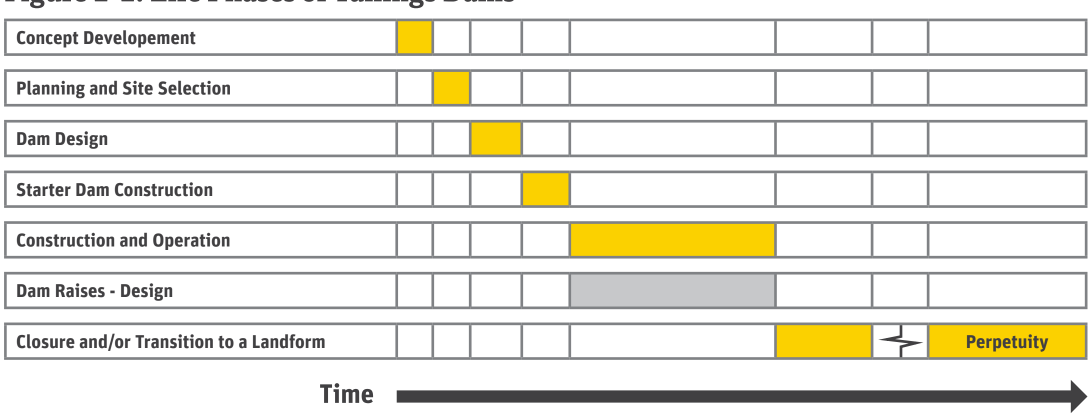
There can be several life phases for a dam, as follows:

- Concept development— the general location, configuration, and type of dam is considered
- Planning and site selection—involves a comprehensive review of potential sites and dam configurations
- Design of the dam
- Construction of the dam— for a tailings dam, this would be the starter dam
- Operation—for a water dam or industrial dam, operation involves first filling the reservoir, and after that, ongoing operation; for a tailings dam, construction typically occurs in stages during the operational life of the dam
- Closure—for many dams can include breaching or removal of the dam (decommissioning); however, for many tailings dams, the dams may have to remain in perpetuity, unless they can be closed as a natural landform; tailings dams requiring storage of water for permanent submergence of reactive tailings must function as both tailings and water retention structures in perpetuity

Figure 2-1 shows a generalized timeline for water or industrial dams, which starts with concept development and ends with breaching or removal of the dam. Figure 2-2 is a similar timeline for a tailings dam that cannot be transitioned to a "landform" after mine operations cease and may require treatment as a dam in perpetuity.

**Figure 2-1. Life Phases of Conventional Dams (Water or Industrial Dams)**


**Figure 2-2. Life Phases of Tailings Dams**



### 2.2.2 DESIGN STAGES

There are typically a number of stages of design for a dam, and different conventions are used for naming and defining them. Table 2-2 presents the naming conventions that are used in these guidelines and, for comparison, provides examples of naming conventions used by others.

The design stages and life phases of a water dam and an industrial dam are the same.

**Table 2-2. Naming Conventions for Typical Design Stages**

| Terms Used in These Guidelines | Other Common Terms | |
|---|---|---|
| Scoping-level design | Conceptual design | Preliminary economic assessment |
| Pre-feasibility design | Feasibility design | Preliminary design |
| Feasibility design | Preliminary design | Basic engineering design |
| Detailed design | Detailed design | Final engineering design |

As shown in Table 2-2, design stages for dams typically include:

- **Scoping-level design** – this design stage develops the initial concept for the dam, including site selection and possible options for the dam configuration, location, size, and so on. The study typically focuses on identifying major features that could have a bearing on the dam siting, configuration, and operation. Major cost items and risks are identified. In some cases, the scope level may advance far enough to decide on the site and location for the dam. Cost estimates are typically developed to an accuracy of +/– 50% or greater and should be consistent with the owner's needs. The key objective of this stage is to determine whether the project should move forward.
- **Pre-feasibility design** – this stage typically considers multiple options and possibly multiple sites for the dam. The preferred site and location for the dam will typically be defined during this stage. The site characterization program is undertaken to provide information for the advancement of the dam concepts and should identify the preferred configuration of the dam. Cost estimates for the dam construction are typically developed to an accuracy of +/– 25% to 35% and should be consistent with the owner's needs.

- **Feasibility design** – this stage advances the design to support a +/– 15% to 25% cost estimate, consistent with the owner's needs. The feasibility design for the dam may also be required to support financing, environmental assessments, and other regulatory requirements for approval of the project.
- **Detailed design (tender stage)** – this stage occurs just prior to construction and is when the scope of work, specifications, and construction drawings are prepared. It is typically used to support a +/– 10% to 15% cost estimate, consistent with the owner's needs. Additional regulatory approvals may be required after the detailed design has been completed and prior to construction commencing. It may also be necessary to conduct additional site characterization to support aspects of the detailed design.

For smaller projects, the design stages are often combined (e.g., scoping and pre-feasibility are combined, followed by the feasibility design and detailed design stages).

Section 4.1 provides information on the typical site characterization activities for each design stage. During construction and operation, conditions may develop that had not been anticipated during the feasibility and detailed design stages, and additional site investigations and/or modifications to the design and construction plans may be required.

For a new tailings dam, the dam design and site characterization at the feasibility stage should be based on the planned ultimate configuration of the dam, with consideration of the future construction sequencing and raises. A detailed design will typically be prepared for the starter dam and/or the permitted dam elevation. Additional detailed design updates throughout the operation life phase are typically required for each successive raise of the tailings dam for construction control and, in some cases, to meet permit requirements. To support the design of the raises, additional site characterization may be required.

For many mining projects, as the mine develops there is an increase in the tailings quantity above the originally planned amount, which requires an increase in the size of the tailings storage facility. There may also be modifications to the mine plan that require a reduction in the size of the facility or other modifications, such as a new spillway. These design modifications may move directly into the feasibility stage required to support amendments to the previously granted regulatory approvals, and in this case would be followed by detailed design to support additional permitting and the construction. There will typically be additional site characterization activities to support these design modifications.

The design of a dam depends on site characterization at any phase of the dam's life. Therefore, these guidelines for site characterization are organized, in large part, by design stage.

# ROLES AND RESPONSIBILITIES

This section describes the roles and responsibilities of the parties that are involved in a dam site characterization program.

## 3.1 OWNER

The owner is responsible for assigning a Design Engineer who will take responsibility for the dam site characterization. On rare occasions, the owner may have an internal team with a Design Engineer as part of the team. However, in many cases and almost always for tailings dams, the owner requires the services of an external professional (consulting firm) to carry out the design, which includes the site characterization.

The use of external professionals (consultants) typically starts during the scoping or pre-feasibility study, and a contractual arrangement to be used throughout the design stages may be established. The arrangement is most often established through a request for proposals process that allows an owner to assess the relative merits and core competencies of the candidates and, as appropriate, their proposed supporting APEGBC professionals. Typically, the request for proposals is for some portion of the design, of which the site characterization program is a component.

Other typical roles and responsibilities of the owner include the following:

- Provides safe work guidelines
- Establishes the general objectives for the project
- Documents who the Design Engineer is
- Instructs the Design Engineer to develop a work plan specific to the envisioned investigation works
- Interacts with First Nations and other stakeholders as required to communicate the extent of the site characterization program
- Obtains authorization for investigations to proceed on the property
- Finances the investigations
- Obtains, or assigns responsibility to the Design Engineer to obtain, clearances for underground infrastructure, road closures, working near power lines, and so on
- Participates in the development of the site characterization scope and monitoring during the execution of the program
- Provides relevant documentation to the Design Engineer
- Obtains, or assigns responsibility to the Design Engineer to obtain, regulatory approvals for site characterization activities that require such approvals
- In the event of a change in ownership, provides for an effective transfer of information related to the investigation program, including previous investigations
- Establishes contracts with firms undertaking the site characterization programs directly, or instructs the Design Engineer to act in this capacity
- Reviews changes that the Design Engineer recommends for consideration during the site characterization program and acts accordingly

For tailings dams, where construction and design services commonly are required over decades, changes in the Design Engineer are common. During the engagement process, provisions for full transference of salient information from previous design and investigation work need to be ensured, and the transfer should be formally documented. Furthermore, through all stages of the project, the owner should document the identity of the Design Engineer for the relevant regulatory authorities and stakeholders.

## 3.2 DESIGN ENGINEER

A Design Engineer must be identified who will be responsible for the design of the dam and for overall oversight, development, and execution of the site characterization program. The Design Engineer is typically an external professional (consultant) but may also be someone within the owner's organization.

The Design Engineer, through interaction with the owner, will establish the overall objectives and scope of the site characterization program. The Design Engineer will lead the program (actively in the field) and/or provide oversight of the program to determine whether the objectives of the investigation with respect to the design requirements are being met. The Design Engineer is responsible for ensuring that the site investigation program is sufficient to support the design stage for the dam. However, portions of that responsibility may be officially transferred to a supporting APEGBC professional (as described in Section 3.3).

The fieldwork for the site characterization program may be supervised by the Design Engineer or may be undertaken by an individual or individuals with sufficient experience as a qualified engineer, geologist, or technician, under the direction supervision of the Design Engineer. Supporting APEGBC professionals may also be engaged to provide specialist support in key technical areas.

The contracted entities that conduct the site characterization activities (e.g., reconnaissance, pitting, soundings, drilling, geophysics, surveying) may be contracted directly to the owner or, as directed by the owner, to the Design Engineer.

The Design Engineer must be a *professional engineer* experienced in dam design and site characterization programs. It is expected that the Design Engineer will understand the benefits, limitations, and risks of each of the investigation methods being considered for the site characterization program. (The education and training requirements for the Design Engineer are addressed in Section 6.2.)

Other typical roles and responsibilities of the Design Engineer include the following:

- In consultation with the owner, develops the site characterization program, consistent with project objectives
- Takes on responsibility for the site characterization program
- As requested by the owner, may take on specific roles that are normally carried out by the owner
- Develops a safe work plan that is submitted to the owner for approval
- Develops scope of work and methodology for the site characterization program that is submitted to the owner for approval
- Leads and/or monitors the implementation of the program
- Reports to the owner on progress and deviations from the plan
- Supervises the supporting APEGBC professionals who may be involved in support of the program
- If required by the owner, establishes contracts with firms undertaking the site characterization program
- Confirms with the owner that regulatory approvals and clearances for powerlines, roads, and so on have been obtained
- Reviews the results of the site characterization program as they are obtained from the field and identifies modifications that may be required to meet the objectives of the program
- Documents limitations on site access due to regulatory, land-ownership, or other factors
- Prepares reports describing the site characterization program results and implications for the design of the dam

- With the owner, develops a database and document control system that will allow the results of site characterizations programs to be properly catalogued
- Prepares the Site Characterization Assurance Statement(s)

## 3.3 SUPPORTING REGISTERED APEGBC PROFESSIONAL

A Design Engineer may require supplementary supporting professional engineering or professional geoscience services for a particular professional activity or component or sub-component of a professional activity related to the site characterization program in support of the design and construction of a dam. This would be provided by an APEGBC-registered *supporting registered professional (SRP)*. The SRP carries out duties for the site characterization as assigned by the Design Engineer (e.g., geological, geophysical, geotechnical, geochemical, hydrogeological, hydrological studies).

In instances where supporting professional engineering or professional geoscience services are required, site characterization assurance statements should be obtained by the Design Engineer from the SRP. All of the SRPs engaged to carry out professional activities related to the site characterization of the dam foundation must submit site characterization assurance statements that the professional activity that they are responsible for has been carried out in a manner that meets the intent of these guidelines and good professional practice.

The use of SRPs is appropriate for the site characterization program because the Design Engineer should draw on the experience and knowledge of professionals who specialize in the required disciplines when undertaking a site characterization program. SRPs include:

- Geologists
- Geomorphologists
- Geophysicists
- Geotechnical engineers
- Geochemists
- Hydrogeologists
- Hydrologists
- Seismologists

For a small site characterization program without complexity, the Design Engineer may draw on published information that has been prepared by such specialists. For a large program or a complex site, the Design Engineer must involve specialized professionals as required. Additional specialists may also be required to address land and water use issues, such as anthropologists, archaeologists, and biologists.

## 3.4 REVIEWERS

Both internal and external reviewers may be used for a site characterization program (see Sections 4.3 and 4.4). Specialist technical experts may be used in areas where the Design Engineer requires a higher level of investigation and assessment to support the design. An owner might also request that an external review of the designs be conducted, or the regulatory authority may have requirements regarding external review.

A site characterization program should include a review process as part of the APEGBC professional's quality assurance program. This review process is often provided by another APEGBC professional within the firm that employs the Design Engineer. In addition to this review, different types of external review of the site characterization program may be undertaken. These include:

- External peer review, whereby a specialist external to the owner's company and the Design Engineer's company is invited by the owner to conduct a review of the site characterization program. Such a review may be done during the development of the site characterization program, after it is completed, or as part of a review of the overall dam design. The review would consider, for example, the appropriateness of the investigation tools and methods, location, quality control programs during the work, findings, and interpretations. This would typically occur at the feasibility design stage or later.

- Review boards can be established by the owner to review the design and performance of a dam—in particular, a tailings dam or large water dam. A review of the site characterization program should be included in the review board's scope.

## 3.5 REGULATORY AUTHORITY

The regulatory authority may be involved in the site characterization to review applications for permits to support the site characterization program (e.g., water crossings, working near water, or working near sensitive habitat). As required, the regulatory authority can work with the Design Engineer and owner to address constraints with respect to obtaining adequate site access for specified site investigation contractors and associated equipment and to manage potential environmental effects of the work.

## 3.6 OTHER PARTIES

Table 3-1 shows the roles of other parties that may be involved in a site characterization program.

**Table 3-1. Roles of Other Parties Involved in a Site Characterization Program**

| Party | Role |
|---|---|
| **Field team supervising the site characterization program** | • Reports to the Design Engineer on progress and deviations from the plan<br>• Prepares documents describing the site characterization program that can be used in the reports being prepared by the Design Engineer |
| **Site investigation contractors/firms (e.g., drilling, geophysics, laboratory)** | • Undertake work in accordance with the work plan developed by the Design Engineer<br>• Advise the Design Engineer of challenges that may be encountered, as well as opportunities to obtain information in a more effective manner |
| **Communities of interest** | • Participate in community meetings or similar communication vehicles and in the permitting review process |
| **First Nations** | • Participate in consultation for possible site investigation on traditional lands |

# GUIDELINES FOR PROFESSIONAL PRACTICE

This section of these guidelines provides guidance on the standard of practice and due diligence associated with carrying out a site characterization for a dam, given the complexity of the site, the scale of the project, the life phase of the project, and the design stage (see Section 2.2). This section reinforces the requirement that a systematic assessment be carried out and describes what is involved in doing so from a professional practice perspective.

Section 4.1 provides an overview of a site characterization program, including a general description of the activities that should be undertaken for each design stage. Section 4.2 describes the elements that should be considered in a work plan for a site characterization program. Section 4.3 introduces the Site Characterization Assurance Statement. Section 4.4 provides details on the subject areas that should be investigated during the site characterization program (e.g., geology, hydrogeology); it describes "what" should be done, and not so much "how" it should be done. (References are provided for the "how.") Sections 4.5 to 4.7 describe other aspects of site characterization, including reporting.

The Design Engineer has overall responsibility for the site characterization program, including integration of the components described in this section.

## 4.1 OVERVIEW OF SITE CHARACTERIZATION

### 4.1.1 Site Characterization Activities

Characterization of the dam foundation most commonly begins during the scoping-level site selection studies. Figure 4-1 shows the typical activities that are undertaken during the site characterization.

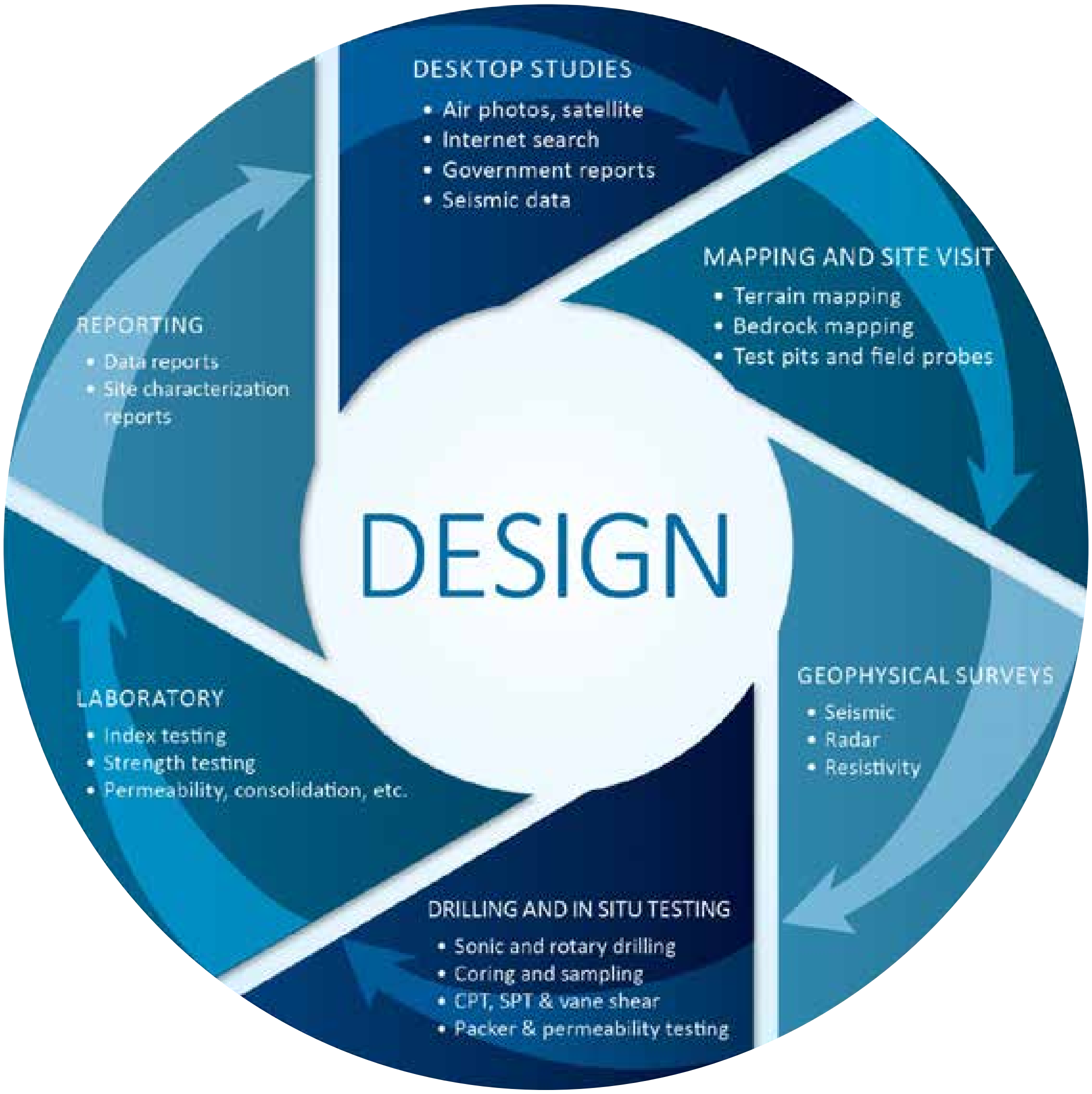
During scoping-level design, the concept for the dam may be partially or completely developed, and some level of site characterization work is required. The concept for the dam could require changes as a result of the site characterization, and these developments are often iterative processes. The questions that are asked about the site's geological, geomorphological, geotechnical, hydrogeological, and environmental characteristics are a function of the concept for the dam and the anticipated foundation conditions.

As the dam design develops through the pre-feasibility, feasibility, and detailed design stages, the site characterization will typically become increasingly detailed. It is typical to have ongoing site characterization work associated with each of these project stages, and for it to become more intensive as the project proceeds.

Site characterization is not a one-time event (as shown in Figure 4-1) and, in fact, continues from design into construction, operation, and closure. In addition, technologies for site characterization continue to evolve over time. Monitoring is used during construction and operation to confirm expected conditions and, if changes are observed, additional site characterization and design may be required.

For a water-retaining dam, site characterization activities are most active during planning and design; however, additional site characterization should take place when surveillance and monitoring indicate changing conditions or provide better knowledge. For tailings dams, the site characterization will continue through the years of construction and operation as the dam is raised.

**Figure 4-1. Typical Site Characterization Activities to Support Design**




**Notes:** CPT = cone penetration test; SPT = standard penetration test.

A range of APEGBC professionals may participate in site characterization for a dam foundation. They may include technical specialists such as structural geologists, Quaternary geologists, and geomorphologists. The requirements for various APEGBC professionals are determined by the scale and complexity of the dam. Other specialists, such as anthropologists and archaeologists, may be required to address land and water use issues.

Section 2.2.2 describes the design stages for a dam and how the site characterization program fits into those design stages. Table 4-1 outlines the typical site characterization activities for each of the design stages.

**Table 4-1. Typical Site Characterization Activities by Design Stage**

| Design Stage | General Objectives of Design Stage | Typical Site Characterization Activities |
|---|---|---|
| **Scoping-level design** | Develop options for siting and dam configuration | Work is primarily based on existing information and table-top evaluations, but it typically includes a site visit for general reconnaissance of site conditions and mapping. Site geologic and other public information is used to develop an initial characterization of the potential site foundation conditions. |
| **Pre-feasibility design** | Compare options to select the preferred site and design for the dam | Work typically includes terrain and bedrock mapping, some site-specific intrusive investigations, *lidar*, test pits, and geophysics. |
| **Feasibility design** | Support financing and environmental assessment estimates | Work includes a wide range of investigation methods, including intrusive investigations, in situ testing, geophysics, and laboratory testing. Extent of site investigations is increased to the level required for the complexity of the site. |
| **Detailed design** | Issue for construction drawings and specifications<br>Address permitting requirements | It may be necessary to conduct additional site characterization to support aspects of the detailed design. |

For a new tailings dam, the design stages and site characterization activities will be similar to those shown in Table 4-1. For a tailings dam that is being raised in accordance with an existing approved design, additional site characterization may be required to check that the design basis that was used during the feasibility design stage remains valid and determine whether or not modifications need to be made to the design to accommodate information gained during construction and operation. For a tailings dam that is being raised beyond an existing approved design, the site characterization activities are similar to those described above for the pre-feasibility, feasibility, and detailed design stages, depending on the extent of the raise.

As far as is practical, if the potential tailings facility is near areas of exploration interest, it may be possible to integrate geotechnical investigations with the exploration holes that are being advanced for the mine. Regardless, any tailings facility should have some economic geological evaluation to confirm mineral value. If mineral exploration work can potentially be integrated into the dam site investigation for dams to be built at the site, it is essential the Design Engineer ensure that the exploration personnel are sufficiently trained to obtain the information expected to come from that program.

Permitting for fieldwork locations and access to sensitive areas can be a challenge. As the dam design advances through successively detailed stages, from pre-feasibility to detailed design, the need for more intensive site characterization typically increases. Permitting requirements (e.g., to clear a site of archaeology, to cut a tree to work in and near a stream) affect timelines, budgets, access to critical sites, and, ultimately, the quality of site characterization. Good site investigations cannot be conducted if they are impeded by competing constraints, such as limited access when more intensive site investigations are needed. For example, if it is impractical to get appropriate drilling equipment into a site until construction is underway, an appropriately detailed stratigraphic record to detect potentially thin, isolated, and shear-strength-deficient stratigraphic units cannot be produced. Planning, foresight, and early permit applications can minimize the potential for this to occur.

If the regulatory process is at odds with sufficient site characterization, it is the Design Engineer's responsibility to make that clear and to and to state his or her concerns about deficiencies in the supporting investigation work accordingly for the design stage involved. Further, it is important for the regulatory authority to understand its role in the site investigation process and how that role can influence the effectiveness of the program.

#### 4.1.2 Site Geological Model

The general objective of site characterization is to develop a clear, three-dimensional understanding of a dam's foundation. As noted above, site characterization begins with a broad appreciation of the site with respect to the overall landscape and geology in the region, then progresses with more site-specific information and details until a sufficient three-dimensional picture of the dam's foundation conditions has been developed. The degree of refinement of the three-dimensional picture is commensurate with the nature of the dam to be constructed.

Depending on the nature of the dam, the format of the three-dimensional picture can range from basic plan views and cross-sections to a fully integrated three-dimensional model containing the available information. In these guidelines, this three-dimensional picture, based on an understanding of the geological and geomorphological processes, is referred to as the *site geological model* (SGM).

- The SGM has several components, including:
- Bedrock and structural geology
- Surficial geology and geomorphology
- Geotechnical conditions
- Hydrogeology
- Seismotectonic conditions

These components are addressed in detail in Section 4.4.

## 4.2 WORK PLAN FOR SITE CHARACTERIZATION PROGRAM

For each design stage, the Design Engineer should develop a work plan that describes the information that is available, the objectives of the site characterization program, and the methodology to be undertaken to meet those objectives (including the activities noted in Figure 4-1). The program work plan developed by the Design Engineer is to be reviewed according to the Design Engineer's applicable quality control procedures.

The work plan should take into account the considerations listed below.

**General**

- The general planned configuration of the dam or modification, including the areal extent, height, seepage control requirements, and so on – These aspects set the context for the investigation program. At the early design stages, this will be in general terms, but in later design stages, it will become better defined.
- Purpose of the dam (water control, tailings disposal, or other)
- Anticipated design loads of the dam during construction and operation
- Design basis and design criteria – In the early design stages, these will be general, but they will be better defined in later stages.
- Background to the site characterization investigation program, including known existing information and nature of such information, to set the context of the program and the objectives of the program
- Documentation that is expected to be produced
- Budget and schedule
- Health, safety, and environmental protection plan
- Potential risks associated with the program
- How the results are to be integrated into the SGM

**Investigation Programs**

- Description of locations for the site characterization investigations (field mapping, geophysics, subsurface exploration, and other), including the reasoning behind establishing the locations – This should also include anticipated depths for subsurface explorations and instrumentation.
- Plans for access to the required locations
- Description of investigation methodologies to be employed
- Quality control program
- Permitting requirements
- Location of underground utilities and infrastructure that need to be protected from damage during an intrusive investigation
- Location of above-ground power lines that could limit access for some drilling and excavation equipment
- Method of soil classification (such as Unified Soil Classification System) and technical standards and/or guidelines to be used for investigation and testing (such as American Society for Testing of Materials [ASTM] International)
- Method for logging the investigations
- Method for naming the investigation locations so that they can easily be tracked in a database over many years
- Laboratory testing plan (which may be modified as the investigation program proceeds)
- Plan to survey the investigation locations in terms of laying them out and then locating them after completed

"Data worth" is an important consideration in developing the work plan for site characterization (Freeze *et al*. 1992): "Data worth is established by comparing the cost of data collection and interpretation against the expected value that the data provides." This can also be considered the value of risk reduction. The decision to collect further data must therefore be weighed against the cost of the data collection and the value of that data in improving the performance of a dam, including improved stability of a structure and improved control of seepage losses. The information can also be evaluated by comparing the risks prior to the data collection with the remaining risks after incorporating the expected value of the additional data into the analyses. Reducing the uncertainties through data collection will add value to a project.

## 4.3 SITE CHARACTERIZATION ASSURANCE STATEMENT

The Design Engineer must provide a Site Characterization Assur ance Statement based on the dam site characterization, stating that the Design Engineer is an APEGBC professional; the dam site characterization report was completed in accordance with these guidelines; and either the dam site characterization report is reasonably comprehensive and supports the design of the dam, or the dam site characterization report is not sufficiently comprehensive and additional investigation is required. The Design Engineers Site Characterization Assurance Statement supports the feasibility design and the detailed design stages.

Leading up to the feasibility design stage, there are a wide range of variables, configurations, sites, and so on, that are considered when undertaking a site characterization program. It is the Design Engineer's judgment, in concert with the owner's requirements, the regulatory authority's requirements, and input from First Nations and other stakeholders, that determines the requirements for these earlier design stages.

However, for the feasibility design stage, where the design has to be advanced sufficiently to demonstrate that the dam can safely be constructed and to support regulatory requirements for permitting, the site characterization has to be thorough enough to support the design. While these guidelines provide information that is applicable to all design stages, a Site Characterization Assurance Statement is required only for the feasibility design and detailed design stages.

As noted in Section 3.2, the Design Engineer may require supporting APEGBC professional services for a particular professional activity or component related to the site characterization program. These services would be provided by an APEGBC-registered supporting registered professional (SRP).

All of the SRPs engaged to carry out professional activities related to the site characterization of the dam foundation must submit separate assurance statements to the Design Engineer in the form set out in Appendix A-2 of these guidelines. The SRP Assurance Statement declares that the professional activity and the supporting documents prepared by the SRP have been carried out and produced in a manner that meets the objectives of these guidelines and reflects good professional practice. The Design Engineer will review the SRP assurance statements as part of his/her acceptance and sign off on the Site Characterization Assurance Statement.

## 4.4 SITE CHARACTERIZATION COMPONENTS

A preliminary site geological model (SGM) is developed on the basis of published reports, aerial photographs / lidar, site reconnaissance, and so on, and it informs planning for the site investigation. Much of the larger-scale information, such as satellite images, aerial photographs, and regional and smaller-scale geological and topographical maps, is publicly available. There may also be published papers about the area, as well as research reports. If there are any other development projects or mines in the area, it is possible that other site characterization reports for the area may be available.

The SGM should focus not just on the dam and the impoundment but also on the surrounding region. The preliminary SGM should also provide some initial idea as to the degree of variability expected, which then informs the conduct and sequence of the site investigation. An iterative process ensues.

### 4.4.1 Bedrock Geology

Bedrock in BC varies from strong massive intrusive rocks to weak hydrothermally altered volcanic rocks and fissile sedimentary sequences. Weak rock can adversely affect siting conditions, and landslides could affect a dam or impoundment. Existing bedrock geologic information will provide valuable input to the initial SGM, which can then be used for considerations such as drilling density. Publications related to bedrock geology are available from the Geological Survey of Canada and the BC Geological Survey, and full references are listed in Appendix B to these guidelines (Bibliography).

Table 4-2 lists documents that are particularly relevant. The information provided by these sources may be too limited for siting considerations but is vital for regional overview. For tailings and other mine-related dams, more detailed information about local bedrock geology should be available from the mining company, as a result of extensive drilling and ground traverses that would have also identified outcrop locations. However, the objectives of the mining company's investigation would have been more focused on proving the ore deposit and not necessarily on geotechnical characteristics. At least some fieldwork will be required to proof the bedrock map and the SGM.

**Table 4-2. Key Information Sources for Bedrock Geology**

| Reference | Items of Interest |
|---|---|
| **GEOSCAN—Natural Resources Canada (Earth Sciences Sector) publications database.** | Geological Survey of Canada publications, including maps |
| **BC Geological Survey publications.** | BC Geological Survey publications |
| **Geologic Maps of BC.** | Geologic maps of BC |
| **Geological Survey of Canada maps.** | Geological Survey of Canada maps |

A bedrock mapping program should emphasize features that affect the geotechnical properties of the rocks: faults, fractures, joints, and types of weathering. A competent bedrock mapper with experience with structural geology should do the mapping and evaluation, likely in conjunction with a geotechnical specialist. Having a good understanding of the regional tectonic history of the area from previous studies will assist in the mapping of structural features.

Faults are problematic because rocks adjacent to the fault can be highly fractured, and the fault itself could contain fault gouge (finely crushed rock), both of which serve to lower the *Geologic Strength Index*. Other potential planes of weakness, such as joints and bedding, should be measured and evaluated with respect to continuity, daylighting, general foundation conditions, and overall joint fabric orientations of major joint sets. Stress relief from isostatic rebound after glaciation causes unloading and can also affect jointing patterns. Glaciotectonic considerations are discussed in Section 4.4.2.

Although remote sensing is generally of less utility in bedrock mapping than in surficial mapping, satellite images, aerial photographs, and especially lidar images are useful for locating structural elements such as lineaments. Ground-based lidar and photogrammetry can be useful for discontinuity analysis if suitable outcrops exist.

To support the SGM, geophysics and drilling must be considered. The drilling program and ongoing site observations will be used to improve the SGM in an iterative manner. Surface geophysics, as discussed in Section 4.4.2, may be useful. The selection of appropriate drilling equipment, such as triple-tube diamond drilling with oriented core, should be considered.

Groundwater well databases should also be consulted to provide input to the hydrogeological component of the SGM (discussed further in Section 4.4.4).

Special care is required in areas of calcareous rock because of the possibility of karst features. Dissolution can cause cavities that provide conduits for groundwater and may collapse. Although calcareous rocks occur throughout BC, they are most common on Vancouver Island and in the Rocky Mountains. Geophysical surveys may be considered to determine whether larger cavities exist in the area. A related issue is old underground workings that can have similar issues of collapse and groundwater diversion.

For a mining project, the mining company will have an understanding of the local bedrock geology, gained from its exploration drilling and mapping. However, as mentioned above, geological work associated with mine development is typically more focused on identifying and confirming the ore-body characteristics, with potentially limited information gathered about the geotechnical characteristics of the bedrock and surficial (non-consolidated) material. There is commonly little information on the stratigraphy of the surficial material. The mining company's drilling program and mapping programs should therefore be used to improve the SGM in an iterative manner, once the initial SGM has been created.

For a greenfield non-mining dam project, there may be little drill-hole information available prior to commencing the site characterization program, but records of nearby groundwater wells and examination of rock exposures in the area can assist in the development of the preliminary SGM.

### 4.4.2 Surficial Geology

Glacial stratigraphy and history of an area can have important implications for the terrain mapping and the presence of subsurface and rare sediment types.[2] BC has a glacial history that spans the Quaternary period (Clague and Ward 2011). The Pleistocene epoch is characterized by periods of cooler temperatures during which glaciers covered large portions of the northern hemisphere. These periods are termed glaciations. Periods of warm or warmer-than-present temperatures are termed interglaciations. Due to differential preservation caused by erosion and burial, sediments from the last glacial cycle dominate the record. Care must be taken when assessing the surficial geology, however, as sediments from older glaciations and interglaciations can exist in the subsurface in areas of BC, and these can affect siting considerations and the design of the site characterization program. Of particular concern are buried organic-bearing soils (paleosols), advance or retreat glaciolacustrine sediments, and glaciomarine sediments.

The availability of information on the Quaternary history and terrain maps is variable across BC. While some publications discuss BC as a whole, most are more regional and local in nature. See Appendix B and Table 4-3 for a list of relevant publications. If no local surficial geologic history has been developed, it will have to be constructed for the area under consideration. This work should be done by someone with experience and training in Quaternary geology and terrain analysis.

It is important to be able to view the surface expression of the area for the Quaternary history and for the terrain and geomorphic analysis. There are three main choices: aerial photographs, satellite imagery, and *lidar*. Interferometric synthetic aperture radar (*InSAR*) also has potential for certain applications. Another relatively inexpensive possibility is the use of unmanned aerial vehicles or drones to create a three-dimensional image of a small area using photogrammetry software. Aerial photograph flight lines can be viewed through Google Earth and then ordered through the Internet.

**Table 4-3. Key Information Sources for Surficial Geology**

| Reference | Items of Interest |
|---|---|
| **Clague and Ward. 2011. Pleistocene Glaciation of British Columbia.** | Overview of Quaternary history of BC. Contains numerous references |
| **Fulton. 1991. A Conceptual Model for the Growth and Decay of the Cordilleran Ice Sheet.** | Summary of the style of glaciation and deglaciation in the Canadian Cordillera |
| **Fookes *et al.* 2015. Geomodels in Engineering Geology: An Introduction.** | Engineering geology, geologic environments, geophysics, ground investigations |

2). The Mount Polley incident highlighted the importance of understanding the glacial stratigraphy and carrying out site characterization studies commensurate with the complexity of the site.

Light detection and ranging (lidar), satellite data, and InSAR are usually available only from private companies. Aerial photographs are black and white or colour images taken from an airplane. Satellite data can be useful for recent changes/ events (e.g., roads, landslides) but cannot be viewed in stereo. As well, resolution can be lacking on satellite images for the type of detailed work required. Light detection and ranging, if available, is the best option. Processing allows the stripping off of the vegetation to get a "bare earth" image. The detail provided by lidar is the best of the three options, but the acquisition and processing can be expensive. There are both ground-based and aerial-based lidar systems.

It is important to develop a regional glacial history through examination and interpretation of the glacial and non-glacial sediments and the literature. An understanding of the nature of glaciation and deglaciation of the Cordilleran Ice Sheet (Fulton 1991), the regional stratigraphic framework (e.g., Ryder *et al.* 1991), the potential antiquity of sediments (e.g., Nichol *et al.* 2015), and the potential complexity of sediments (Ward and Thomson 2004) is vital for anticipating the types and ranges of sediments that may be present. This knowledge, combined with examining natural exposures and drilling, should allow for the appropriate determination of the local glacial history. Although there may be insufficient exposures at the actual site, the Quaternary history can be reconstructed by examining exposures in the vicinity of the dam site. These can be identified through aerial photographs, lidar, and so on, and then combined with the site drilling information.

A drilling method that results in undisturbed samples and continuous core that can be examined for sedimentary structures is preferred. Obviously, sediment types that are susceptible to lateral shearing are of concern; these include fine-grained alluvial, lacustrine, glaciolacustrine, glaciomarine, marine, peat, and organic-rich paleosols. An understanding of the lateral variability of these environments is vital. A good example is glaciolacustrine, which, although commonly thought just to be rhythmically bedded clay and silt, may contain ice-contact glaciolacustrine sediments that can have sand, gravel, and diamicton (that can look like a till) interstratified at various scales and expressing rapid lateral variability. If the site is close to the present coastline, or to historic coastlines, care must be taken to determine whether glaciomarine sediments are possible, based on the geologic history and elevation of marine limit (McCuaig and Roberts 2006). Quick clays, or sensitive clays, may be present and are prone to landslides if disturbed (e.g., Geertsema and Torrance 2005).

As glaciers moved over the landscape, they not only eroded and deposited sediments, but they may also have sheared, folded, and fractured sediments and bedrock. This glaciotectonism can form thrust sheets that could repeat units, complicating the stratigraphy recorded in drill holes. The faults themselves can also form planes of weakness and/or conduits for groundwater.

Terrain mapping must be carried out for all sites. It is a way of portraying the landscape of surficial materials, surface expression, and geomorphological processes, such as landslides, snow avalanches, and gullying. Terrain mapping provides information on topography and slope steepness, texture, porosity, permeability, moisture content, thickness, and present-day geomorphic processes. It portrays the landscape as a mosaic of irregularly shaped areas that are referred to as terrain units or polygons. It has a flexible (open) legend, in contrast to the closed legend of a surficial geology map. An open legend provides the most information because the mapper selects the symbols that most represent the particular conditions in a given polygon. Each polygon therefore ends up with unique polygon descriptors; however, untrained users can have difficulty interpreting the map.

Production of applied terrain maps, such as terrain stability, terrain hazard and risk, sediment erosion potential and delivery, and earthquake hazard maps, may be required for siting. These maps all have a specialized terrain base where the polygons are subdivided on the basis of the end product. The polygons are then interpreted for the final objective of the map; for example, terrain stability classes are added. A general terrain map base cannot be used for creating applied maps, and the mappers doing this work require specialized training.

In areas of steep relief (especially in close association with glaciers), avalanches and all types of landslides should be considered during dam site characterization. These geohazards must be recognized and mitigated as part of the design and development plan. Recognition should be part of the terrain-mapping portion of the assessment. For example, snow avalanches are common in areas of high relief and significant snowfall, and they may be recognized by vertical swaths that contain low trees such as alder, birch, and willow—but no conifers—below steep terrain that has few if any trees.

Permafrost is ground that stays below 0°C year-round. It occurs in many alpine areas and in northeastern BC (Smith 2011). Disturbance of the surficial organic layer in permafrost terrain results in melting and degradation of the terrain. If there is a high content of frozen soil and ice, the potential for degradation (melting) can be significant. If permafrost is suspected in the area, the objectives of the drilling program must include its characterization and distribution.

Surface geophysics (also referred to as geophysical surveys) can play an important role in defining the surficial geology and bedrock geology and in identifying anomalies and spatial continuity of foundation materials.

Geophysical surveys have the following benefits:

- They are non-intrusive and have limited impact on the site conditions.
- They provide a continual spatial quantification of potential ground conditions.
- They can identify anomalous areas that can be targeted with a drilling program.
- They can identify bedrock contacts and support better definition of the extent of the site investigation program, including depth and spacing of drill holes.

Typical geophysical surveys include, for example:

- Seismic refraction/reflection – measures velocity and can be used to identify bedrock and groundwater levels and indicate the density of materials
- Electrical and electromagnetic surveys measuring resistivity/conductance – can be used to identify saturated and/or clay rich materials
- Ground-penetrating radar – can be used in shallow investigations to identify permafrost or anomalies in layering and materials
- Magnetic and gravity surveys – may be useful in identifying low-strength rock or natural or human-made cavities

However, geophysical surveys do not provide quantitative information in all situations and should be used in conjunction with ground proofing and calibration with known information.

### 4.4.3 Geotechnical

The objective of the geotechnical component of the site characterization program is to develop parameters that can be used in the dam design. The geotechnical component may include, for example, investigations related to stability, deformation, settlement, seismic response, seepage, and piping potential.

Geotechnical characterization of the bedrock foundations should assess the spatial distribution of the lithological rock units, as well as the orientation and distribution of the main joint sets within each lithological unit. Additionally, it is important to identify major geological structural features, such as faults, shears, and intrusive dykes. The strength of bedrock will be influenced by its structure (e.g., unfavourably dipping sedimentary rock), degree of weathering, degree of fracturing (rock quality designation, joints, and faults), rock hardness, and the Geologic Strength Index. The hydraulic conductivity of bedrock is typically controlled by the degree of fracturing and rock quality. The stress state of the rock should consider the potential for valley rebound and regional stresses. For high dams, the deformation properties of the rock may be determined with geophysical methods and correlations with rock strength and rock properties.

Geotechnical characterization of the foundation soils should delineate representative geotechnical units. The geotechnical units would consider, for example, the surficial geologic history and geotechnical properties. Index testing of soils is used for general characterization and generally includes, for example, moisture contents, grain size, Atterberg limits, and density and pocket penetration shear strength indices. Undisturbed samples of cohesive soils are required for strength and consolidation testing. Strength testing should consider drained and undrained strength response and peak and residual/large strain strength, as well as the stress state of the soils and the stress conditions that will be imposed by the dam. Deformation properties of the materials should consider the stress history; pre-consolidation stress state; degree of over-consolidation; and coefficients of compression, recompression, and consolidation. In determining the potential for liquefaction of the materials during static or dynamic loading, the degree of saturation, density, stress state, and drainage properties should be considered.

In considering the SGM, the site investigation program should focus on obtaining representative geotechnical properties for each of the identified geotechnical units in the dam foundation. A range of methods are available for conducting intrusive investigations, such as test pits, drill holes, standard penetration tests, and cone penetration tests. These methods include obtaining disturbed and undisturbed samples, conducting in situ testing, downhole examination, and instrument installation. They are described in many sources, a selection of which is included in Appendix B. Particularly relevant references are indicated in Table 4-4. The Design Engineer is responsible for determining the most appropriate methods for the dam and site being considered.

**Table 4-4. Key Information Sources for Geotechnical Field and Laboratory Work**

| Reference | Items of Interest |
|---|---|
| **Fell *et al.* 2005. Geotechnical Engineering of Dams.** | Chapters 1–7, covering geology, site investigations, geotechnical properties, and clay properties |
| **International Commission on Large Dams. 2005. ICOLD Bulletin 129, Dam Foundations: Geologic Considerations, Investigation Methods, Treatment, Monitoring.** | Foundation investigations and case histories |
| **Federal Energy Regulatory Commission. Various dates. Engineering Guidelines for the Evaluation of Hydropower Projects.** | Chapter V: Geotechnical Investigations and Studies (Dams, Dam Sites or Appurtenant Structures) |
| **US Army Corps of Engineers. 2004. Engineering and Design: General Design and Construction Considerations for Earth and Rock-Fill Dams.** | Chapter 3: Field and Laboratory Testing |
| **US Army Corps of Engineers. 1995. Engineering and Design: Geophysical Exploration for Engineering and Environmental Investigations.** | Geophysical Exploration for Engineering and Environmental Investigations |
| **US Army Corps of Engineers. 2001. Engineering and Design: Geotechnical Investigations.** | Geotechnical Investigations |
| **US Department of the Interior, Bureau of Reclamation. 2012. Design Standards No. 13: Embankment Dams.** | Chapter 12: Foundations and Earth Materials Investigation, Phase 4. |
| **US Department of the Interior, Bureau of Reclamation. 1987. Design of Small Dams, 3rd edition.** | Chapter 5: Foundations and Construction Materials |

For the feasibility design stage and the detailed design stage, a detailed work plan should be developed for the geotechnical site investigation program that clearly describes the basis for the work plan, the drill hole spacing and depth, and so on. This work plan should be included in the dam site characterization report to document how the geotechnical site investigation program was developed. Site characterization programs (including the laboratory testing and instrumentation aspects) are typically modified during the execution of the program to address conditions that are encountered in the field that are different from what was expected (e.g., access challenges, poor weather, unexpected results).

Other considerations with respect to developing the geotechnical parameters include, for example:

- Clay mineralogy and potential for dispersive soils
- Potential effects of glacial rebound/ drag – damage to fabric, reduction of strength, change of orientation
- Hydrogeological properties (as discussed in Section 4.4.4)
- Permafrost and ground temperatures and the potential for thermal influences from the dam and reservoir/ impoundment
- For dams in the mining industry, the mine plan (underground workings below a dam, or an open pit near a dam)
- Effect of other subsurface activities that could affect a dam design

As noted in Section 4.4.2, surficial geophysical methods (or geophysical surveys) can be used to provide spatial coverage that, in concert with intrusive investigations, can supplement the SGM. These surveys may precede the geotechnical investigation, or additional surveys may be done to address specific areas in parallel with the geotechnical site investigation. Downhole geophysics may also be employed to obtain additional information on the properties of the soil and rock units.

Some general guidance for intrusive geotechnical site investigations includes the following:

- The depth of the geotechnical investigation should be to the expected height of the final dam or to a depth sufficient to confirm competent strata for the proposed dam. Deeper investigations may be required if conditions at depth could influence the design and function of the dam.
- The spacing between investigative locations along the proposed dam axis should be determined within the context of the variability of the foundation conditions and height of the dam. Spacing could, for example, range from a few metres apart for complex foundation conditions to 100 metres for sites with simple foundation conditions.
- The investigations should be strategically located to cover the areal extent of the dam structure and the anticipated stratigraphy.
- The number of investigative locations must be sufficient to support representative profiles along the dam axis and representative design cross-sections (upstream to downstream) along the dam alignment. The number of investigative locations must be sufficient to adequately characterize all the different soil and bedrock units that are present in the proposed dam foundation.
- Undisturbed sampling of cohesive soils should be conducted to obtain samples for laboratory testing.
- Appropriate in situ testing should be considered to establish and confirm in situ properties.

Laboratory testing is assigned based on field observations, and the results of laboratory testing can be an important input in the design of further field investigations. This interaction is an important part of the refinement of the site characterization throughout the development of increasingly detailed site characterization and refinements of the dam design.

Instrumentation (e.g., standpipes, piezometers, slope indicators, thermistors) is an important component of a site characterization program. Instrumentation will ordinarily be installed during the foundation site characterization program and also during the construction of the dam.

Site characterization programs (including the lab testing and instrumentation aspects) are typically modified during the execution of the program to address conditions that are encountered in the field that are different from what was anticipated. The work plan for the site characterization program should include a process for managing these modifications that will allow for response during the execution of the program. The owner must be advised to set aside a budget contingency allowance to respond effectively to these modifications (typically 20% to 50%). The contingency allowance will vary by design stage.

#### 4.4.4 Hydrogeology

Hydrogeological assessments are carried out to support both the engineering design and the environmental permitting of dams. The understanding of the bedrock and surficial geology and the geotechnical conditions is intimately related to, and complementary to, the development of the hydrogeological component of the SGM. Hydrogeological assessments are therefore commonly integrated with the bedrock, surficial geology, and geotechnical investigations.

The hydrogeological assessment is used to develop a conceptual hydrogeological model, which is developed within the framework of, and is complementary to, the SGM. The SGM, however, typically extends from within the reservoir/impoundment area to downstream from the dam. The interpretation of site data defines the foundation conditions and associated groundwater occurrence. Factors influencing groundwater levels, quality, flows, and seepage are also described in the SGM. Prediction of seepage through the dam foundation and from the reservoir/impoundment area is used to support design of seepage control, conveyance, collection, and mitigation systems, and the assessment of potential downstream impacts on the receiving environment. Prediction of seepage is also used to support design of filters and piping controls and to assess the potential for artesian uplift pressures within the dam foundation.

Appendix B includes references for hydrogeological investigations, and Table 4-5 lists references that are particularly relevant.

**Table 4-5. Key Information Sources for Hydrogeology**

| Reference | Items of Interest |
|---|---|
| **BC Ministry of Environment. Water Protection and Sustainability Branch. 2012. Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Activities.** | Modelling for contaminant transport assessment |
| **BC Ministry of Environment. 2012. Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators.** | Monitoring guidelines |
| **Province of British Columbia. 2014. *Water Sustainability Act.*** | Entire document |
| **Province of British Columbia. 2004. *Water Act—Ground Water Protection Regulation.*** | Entire document |

The hydrogeological components of site characterization typically include the following:

- Distribution and significance of hydrogeologic units (aquifers, aquitards, and aquicludes) associated with bedrock and overburden
- Hydraulic characteristics (hydraulic conductivity, anisotropy, transmissivity, storage characteristics) of bedrock and overburden, including structural features (e.g., faults)
- Groundwater levels, flow directions, and groundwater gradients
- Groundwater quality and factors that may influence that quality, including temporal and seasonal variability (e.g., response to freshet)
- Groundwater quality with respect to baseline quality and geochemistry of groundwater water types
- Groundwater–surface water interconnectivity (e.g., baseflow), and recharge and discharge mechanisms and locations
- Location and characteristics of nearby groundwater receptors (e.g., groundwater-fed wetlands/springs), users (e.g., existing wells), and existing infrastructure that may influence groundwater (e.g., sources of contamination)
- Hydraulic gradients indicating flow direction

Investigative methods used as part of hydrogeological characterizations include:

- Site walk/fly overs and mapping
- Overburden/bedrock drilling and logging (the methodology should be selected with consideration to site conditions, testing requirements, and access)

- Installation of monitoring and pumping wells, and monitoring instrumentation
- "Point" hydraulic tests (e.g., packer and slug tests)
- Pumping tests (which measure aquifer response to pumping)
- Unsaturated zone testing (e.g., double ring infiltrometer testing, permeameter testing)
- Groundwater level measurement (including instrumented), surface water flow gauging and groundwater/surface water quality sampling
- Geophysical surveys (downhole and regional)

Hydrogeological site investigations are often performed in conjunction with exploration, geological, geotechnical, and other investigations (e.g., surface water) to reduce costs and maximize data acquisition.

The conceptual hydrogeological sub-model of the SGM should include:

- Details of the SGM extents/boundaries) and how these were selected
- Baseline geochemical conditions, if groundwater quality is a potential issue
- A simple visual representation of the groundwater system (e.g., cross-sections, "cartoon"-type figures, zone maps for recharge/discharge)
- A description of key hydrostratigraphic units and processes influencing groundwater
- Quantitative components – a groundwater flow balance, ranges of hydraulic data for key overburden/bedrock units
- Details of how dam development may affect the groundwater system

Baseline hydrogeological conditions are established for comparison as the dam project proceeds into construction and operation. The hydrogeology information is used in seepage analyses, in concert with assumptions made about the dam materials, to develop estimates of the seepage patterns that will be present through the dam and dam foundation when the dam is in operation.

### 4.4.5 Site Characterization of Seismotectonic Conditions

The objective of the seismotectonic assessment is to develop an understanding of the regional tectonic conditions at the dam site and to carry out site characterization studies to develop parameters that can be used to support a seismic hazard assessment for the site. These parameters would include the design ground-motion events/parameters and the foundation response parameters that will be used for the seismic response assessment for the dam, foundations, and reservoir or impoundment slopes.

Appendix B contains references for seismic investigations, and Table 4-6 lists references that are particularly relevant.

**Table 4-6. Key Information Sources for Seismotectonics**

| Reference | Items of Interest |
|---|---|
| **Natural Resources Canada. Seismic Hazard Maps and Seismic Hazard Calculator.** | For location in question |
| **Canadian Dam Association. 2007. Seismic Hazard Considerations for Dam Safety.** | Overview of seismic hazard assessment |
| **Idriss and Archuleta. 2007. Evaluation of Earthquake Ground Motions.** | Section 3: Geologic and Seismologic Considerations |
| **American Society of Civil Engineers. 2005. Minimum Design Loads for Buildings and Other Structures.** | Chapter 20: Site Classification Procedure for Seismic Design<br>Chapter 21: Site-Specific Ground Motion Procedures for Seismic Design |

Seismic hazard analysis considers two approaches, the probabilistic (determines events for various annual exceedance probabilities) and the deterministic (determines seismic hazard due to identified faults), and consideration of both may be important for dam design.

Assessment of the seismotectonic setting should consider the regional area (up to a 500-kilometre radius) and include the following considerations:

- Plate tectonic setting with respect to potential subduction zones and tectonostratigraphic terranes that may have associated active faults
- Regional faults identified in geologic and seismic hazard maps and from aerial photograph, satellite, and lidar imagery
- Evidence of potential Holocene fault movements (e.g., scarps displacing glacial or recent soil deposits)
- Human-induced seismicity (e.g., hydrofracking, gas/oil extraction subsidence, mine operational blasting)

Seismic hazard evaluation in Canada continues to be developed in support of the *National Building Code of Canada 2015* (Canadian Commission on Building and Fire Codes 2015). Improvements to the seismic hazard assessment incorporate ongoing refinement of our understanding of the seismic source zones and developments in both probabilistic and deterministic influences on the hazard classification. Seismic hazard maps and a seismic hazard calculator (for the specific location) are available online via http://www.earthquakescanada.nrcan.gc.ca/index-en.php (Natural Resources Canada; see Appendix B). Use of these sources provides a preliminary estimate of the seismic hazard up to the 1:2500 ground motion annual exceedance level and is appropriate in cases of firm ground conditions (i.e., non-liquefiable or non-strain softening) for low-, medium-, or high-consequence dams.

For very-high-consequence and extreme-consequence dams and for sites with complex geological conditions, it is appropriate to carry out site-specific probabilistic and/or deterministic hazard evaluations. The probabilistic evaluations allow for determination of parameters for various exceedance probabilities, whereas the deterministic assessment is typically used in simple but rare cases where the concept of a maximum credible earthquake that could be generated by one or more known faults can be used.

The determination of earthquake ground motions generally assumes “firm ground” or “rock” conditions, which would be an input to the analytical model for the dam that would consider the foundation soil and rock conditions. Consequently, an understanding of the foundation conditions is an important consideration in seismic analysis. The depth of soils under the dam and the shear wave velocity of the soils are important inputs to that analysis and must be determined. Low-strain shear wave (see Chapter 21, American Society of Civil Engineers 2005) velocities can be determined from field measurements using downhole or linear seismic surveys or from similar soils in the site vicinity. Non-linear or linear shear stress-strain relationships and unit weights can be selected on the basis of laboratory tests or published relationships for similar soils. The uncertainties in the soil properties must be estimated. Where very deep soil profiles make the determination of the model impractical, adjustments to the seismic hazard assessment need to be made to accommodate that uncertainty.

The seismotectonic components of the site characterization study are typically used to support a more detailed seismic hazard assessment, which would include both the probabilistic and deterministic hazard assessment.

## 4.5 EVOLVING UNDERSTANDING OF PROJECT AND SITE CONDITIONS

Site characterization for a dam foundation is an ongoing process that yields a better and better understanding of the site as the project proceeds through design stages. This gradual increase in understanding can develop with additional site investigations, observations from construction and monitoring, and additional studies such as geohazard assessment and a refined assessment of Quaternary geology. In addition, as the design of the dam proceeds, the relative influence and importance of specific site conditions—for example, the influence of foundation soil behaviour under dynamic loading conditions, and changes in allowable seepage release—to different dam components will evolve, as will site characterization technologies.

Other changes may also influence the requirements for understanding of the site conditions. For example, an increase in land or water use downstream from the dam may increase the consequence of failure or impose limitations on seepage or on dam footprint in the case of expanding dam height or requirements for flatter slopes. Natural geohazard events such as landslides or debris flows could influence the dam foundation or the dam.

The Design Engineer should continue to monitor the ongoing information and understanding of the site characterization and consider the effect of the most up-to-date understanding on dam design, through all stages of a project. As the results of additional site investigations, observations, and monitoring continue to inform the Design Engineer, and as data are collected from ongoing recommended site investigations or studies, the data need to be incorporated into ongoing updates to the dam site characterization report.

For tailings dams that are developed over a long period of time, consideration should be given to updating the design record and dam site characterization report (discussed in Section 4.6) at appropriate intervals to ensure that the evolving understanding of the site is integrated into the evolving design of the dam.

## 4.6 DAM SITE CHARACTERIZATION AND DATA RECORD REPORTS

Reports will be prepared to document the ongoing site characterization data (the data record report, discussed in Section 4.6.2) and the interpretation of the data (dam site characterization report, discussed in Section 4.6.1).

### 4.6.1 Dam Site Characterization Report

A dam site characterization report (DSCR) must be produced by the Design Engineer to allow his/her work to be replicable and to make it transparent for report reviewers, so they can understand how the APEGBC professionals involved arrived at their conclusions.

The DSCR may be a stand-alone report or form part of a dam design report. There may be several DSCRs issued for a dam project as the design and site characterization evolve.

The purpose of the DSCR is to present the data and relevant supporting information used by the Design Engineer (e.g., empirical correlation, reference reports) and document his/her interpretation of them. Representative geological and hydrogeological plans and cross-sections should be developed to communicate the extent of site investigation data, geological and geotechnical units, and groundwater conditions. The report should also include summaries of physiographic, climatic, and hydrological conditions that provide context for the site characterization. The interpretation of the data is intimately integrated with the design of the project, and the report therefore needs to be considered within the context of the design.

The DSCR should summarize the objectives of the site investigation plan and document the outcomes. All data and reports must be documented and kept on file, in accordance with APEGBC quality management bylaws.

Internal peer review must be carried out in accordance with APEGBC quality management bylaws. External peer review specialists should be considered for specialist technical areas where the Design Engineer or the SRPs may not have the appropriate level of experience. The use of an independent technical review board should be considered for projects with greater potential consequences and/or complexity.

### 4.6.2 Data Record Report

The data record report may be a separate document or an appendix to the DSCR or the dam design report. The data record report must include all relevant data acquired or produced as part of the site characterization (e.g., mapping, results of site investigations and laboratory testing). The data record report should summarize the extent of the site characterization studies, with appropriate summaries to guide reviewers. Interpretation of data should be kept at a "high level," with a focus on areas relevant to the data collection and veracity of data.

### 4.6.3 Limitations and Qualifications—Dam Site Characterization Report

The DSCR must include a section on limitations and qualifications. Site investigations and site characterizations provide a snapshot in time at various stages of the design of the project. A degree of professional judgment is required to understand site conditions and some natural events, such as ancient landslides, that may not be readily interpreted. As the project proceeds, additional information on the site conditions is produced, and understanding grows, through ongoing studies, construction observations, monitoring observations, and so on. Additionally, the dam design can change in response to site characterization results, economic conditions, dam height changes, and other factors. Consequently, it is important for the Design Engineer to document the limitations and qualifications of the DSCR, as described in Section 4.7.3. The Design Engineer's signing of the Site Characterization Assurance Statement is limited to the stage of the project at the time of signing (i.e., it is time-variable) and should include reference to the limitations and qualifications identified in the DSCR.

The DSCR should identify limitations or qualifications relevant to the assessment (e.g., areas of uncertainty and requirements for further investigation, context with respect to spatial limitations and dam height). Qualifications with respect to assumptions and reliance on existing or third-party reports should also be documented.

The DSCR should document the minimum requirements for additional site characterization studies. As the project proceeds, the owner must document completion of the recommended work or provide written assurance that the recommendations have been amended or that their implementation can be appropriately delayed, as approved by the Design Engineer. When transitioning from one Design Engineer to another, the new Design Engineer will be required to provide that approval.

**Data Record Report**

The data record report must identify significant limitations or qualifications relevant to data collection (e.g., access to project area and drill pads, drilling or sampling problems, equipment reliability, budget or scope limitations, laboratory data quality).

### 4.6.4 Reviewing and Updating the DSCR

Follow-up to the DSCR will normally be required at various stages of the project. Follow-up could be required in response to the execution of recommendations, or in response to a Site Characterization Assurance Statement that indicates that the level of site characterization is not appropriate or identifies areas of risk. Follow-up could also be triggered by advancement to the next stage of the project or in recognition of other factors discussed in Section 4.7. A review of the DSCR will also be triggered by an unusual event, such as excessive slope deformation, or in response to a major earthquake.

Advancement to the next stage of the project could require more-detailed investigations or additional laboratory testing to confirm empirical relationships that may have been used previously. Areas of identified risk could also warrant additional appropriate site characterization to reduce the level of risk. The Design Engineer must review the DSCR at each project stage and at appropriate intervals during construction and operations. Site visits and review of construction and monitoring data are important components of these ongoing DSCR reviews.

The data record report and the SGM should continue to be populated with new data. Existing and new data may be stored in a database or electronic files that contain all site characterization data and associated reports. The new data will include data developed during construction of the dam when the foundation conditions are exposed, or additional information developed through instrumentation and performance.

The DSCR will be updated either with highlighted revisions to the original report or with DSCR amendment reports. Updates to the DSCR will include a Site Characterization Assurance Statement that documents the areas of change and the current status of the relevant provincial legislation as it relates to the use of APEGBC professionals in carrying out this type of work.

## 4.7 OTHER SITE CHARACTERIZATION CONSIDERATIONS

### 4.7.1 First Nations and Communities of Interest

Site characterization activities may be initiated in the early stages of the potential development of a dam and, consequently, the owner's discussions with the relevant First Nations and communities of interest may also take place at an early stage. The Design Engineer will confirm with the owner that the site characterization activities have been discussed with the relevant First Nations and communities of interest.

### 4.7.2 Hydrology and Climate

Both hydrology and climate influence the surficial geology, hydrogeology, and geotechnical conditions around the dam foundation, as well as the dam's sizing and design requirements. For example, the influences of hydrology and climate are apparent in the geological deposition of materials, as well as on groundwater conditions:

- Precipitation can lead to erosional deposition of soils, and infiltration of precipitation can lead to slope instability and colluvial processes.
- Freeze/thaw cycles over time can lead to erosion and colluvial processes.
- Historic extreme hydrological events in mountainous terrain may lead to deposition of significant debris-flow deposits over time. Depending on the energy of the debris flows and the origin of the soils, the deposits may vary considerably, from loose silty soils to dense granular soils.

The dam site characterization report (DSCR) should therefore include summaries of these conditions and their effect on the dam.

Hydrology is a key component of the hydrogeology site characterization, because the amount of precipitation and the climatic cycle influence the rate of infiltration into the ground and, additionally, could introduce artesian pressures in both confined and unconfined pervious layers in the foundation of the dam.

The presence of permafrost and permafrost-influenced soils and bedrock is directly influenced by the temperature, both past and future. Thermal-induced influences on the foundation can lead to changes in the permafrost, which may affect the dam's foundation soils and bedrock.

#### 4.7.3 Risk Management and Uncertainty in Site Characterization

As noted in Section 1.1, site characterization is a "critical control" for the safe design and operation of a dam. Identification of risk and uncertainty is an important component of site characterization and directly influences the intensity of site investigations and the level of detail required to understand the site conditions. When undertaking a site characterization program, the key risk factors to consider include:

- Complexity of the site conditions – that is, multiple periods of glaciation and interglacial depositions, variability in clay origin and strength, spatially diverse conditions, artesian pressures. The Design Engineer must start with the assumption that the geologic conditions at the site are complex and could present risks to the dam.
- The *consequence classification* of the dam as determined by BC and Canadian dam safety regulations/guidelines
- The consequences to the owner of not properly characterizing the different geologic units
- Site access issues (e.g., high water levels, landowner issues)
- Climate changes that were not planned for in the development of the program
- Equipment issues, such as breakdowns
- Inadequate tools to address findings as they develop

These factors, as well as others defined by the Design Engineer and owner, must be considered throughout all design stages and in each step of a site characterization program.

Risk assessments are routinely carried out at numerous stages of a project. For example, for mining dams, the *Mining Association of Canada Guidelines* recommends carrying out risk assessment at all phases of a mining project. The failure modes and effects analysis (FMEA) is an industry-accepted methodology for identifying risks and developing risk management plans. The FMEA is a semi-quantitative, practical tool for identifying potential risks, and an FMEA risk workshop would typically include key APEGBC professionals involved as specialists in the site characterization and dam design. An FMEA carried out for the feasibility design stage of a project could identify potential risks associated with the foundation, and the risk assessment must be updated throughout the life of the project to reflect ongoing changes.

Risk assessment can be integrated within the framework of a site characterization program with, for example, identification of critical failure modes that include the foundation soils or rock. These potential failure modes can then be examined with respect to the adequacy of the information being collected to appropriately assess the risk.

On completion of the site characterization program, there will still be uncertainty associated with the foundation conditions. The Design Engineer must identify where those uncertainties are and plan to deal with them in the design, construction, and operation of the dam—for example, through additional investigations, instrumentation, and contingency plans.

# 5.0 PROFESSIONAL PRACTICE—QUALITY ASSURANCE/QUALITY CONTROL

An APEGBC professional must carry out quality assurance / quality control during all phases of site characterization for a dam foundation. This includes the preparation of a data record report and dam site characterization report (DSCR).

## 5.1 APEGBC Quality Management Requirements

APEGBC professionals are obligated to abide by the quality management requirements set out in the APEGBC Bylaws. In order to meet the intent of those requirements, APEGBC professionals must establish and maintain documented quality management processes for their practices, including as a minimum:

- The application of the relevant APEGBC Professional Practice *Guidelines*, the *Engineers and Geoscientists Act*, s. 4(1) and Bylaw 11(e)(4)(h):
  - When carrying out site characterization for dam foundations, an APEGBC professional must have sufficient broad-based knowledge of and competence in applying these guidelines.
- Retention of complete project documentation—Bylaw 14(b)(1):
  - When carrying out site characterization for dam foundations, an APEGBC professional must comply with the *APEGBC Quality Management Guidelines – Retention of Project Documentation*.
- Regular, documented checks using a written quality control process—Bylaw 14(b)(2):
  - When carrying out site characterization for dam foundations, an APEGBC professional must comply with the *APEGBC Quality Management Guidelines – Documented Checks of Engineering and Geoscience Work*.
- Documented field reviews of engineering/geoscience designs/recommendations during implementation or construction—Bylaw 14(b)(3):
  - When carrying out site characterization for dam foundations, an APEGBC professional must comply with the *APEGBC Quality Management Guidelines – Documented Field Reviews During Implementation or Construction*. For example, if the Design Engineer makes specific technical recommendations related to the site characterization of the dam's foundation, which can include the carrying out of engineering/geoscience investigations, the Design Engineer must be able to demonstrate that he/she carried out field reviews or that field reviews were carried out under his/her direct supervision. Field reviews are required to ensure that the documentation prepared by the Design Engineer supporting his/her technical recommendations are followed in a matter which is consistent with his/her recommendations.

Authentication of professional documents by the application of the APEGBC professional's professional seal—*Engineers and Geoscientists Act*, s. 20(9):

- The Design Engineer must apply his/her professional seal to the data record report and the DSCR prepared in his/her professional capacity or under his/her direct supervision and the Design Engineer must apply his/her seal to the Site Characterization Assurance Statement. The APEGBC professional must meet the intent of the *APEGBC Quality Management Guidelines – Use of the APEGBC Seal*.

- Professional engineering/geoscience activities can only be delegated to subordinates under direct supervision—*Engineers and Geoscientists Act,* s. 1(1) and 20(9):
    - If certain aspects of the dam site characterization, such as field reviews, are delegated to non-professionals or other subordinate engineers/geoscientists, they must be carried out under direct supervision of the APEGBC professional. Where such delegation occurs it must be carried out in a fashion which meets the intent of the APEGBC Quality *Management Guidelines – Use of the APEGBC Seal*. The APEGBC professional assumes full responsibility for all work so delegated.

### 5.2 Direct Supervision

Section 1(1) of the *Engineers and Geoscientists Act* states that direct supervision means taking responsibility for the control and conduct of the engineering or geoscience work of a subordinate. With regard to direct supervision of delegated responsibilities, the APEGBC professional having overall responsibility should consider:

- The complex nature of the dam site characterization and the nature of the values/elements at risk
- Which aspects of the dam site characterization can be delegated and how much of those aspects can be delegated
- The training and experience of individuals to whom work is delegated
- The amount of instruction, supervision, and review of the subordinate required

Field review work is one of the most critical aspects of dam site characterization. This is especially the case in the geotechnical investigations being carried out and laboratory tests and analysis resulting from the geotechnical investigation. Therefore, careful consideration must be given to delegating field review work. Because of the complexities and subtleties of dam site characterization, direct supervision of field review work is difficult, and care must be taken to see that delegated work meets the standard expected of the APEGBC professional. Direct supervision could typically take the form of specific instructions on what to observe, check, confirm, test, record, and report back to the APEGBC professional. The APEGBC professional must exercise judgment when relying on delegated field review observations by conducting a sufficient level of review to be satisfied with the quality and accuracy of those observations.

### 5.3 Internal Checking and Review

As referenced in Section 4.6.1 of these guidelines and consistent with the requirements of APEGBC Quality Management Bylaw 14(b)(2), as a minimum, a DSCR must undergo a documented checking and review process before being finalized and delivered. This process would normally involve an internal review by another APEGBC professional within the same firm. Where an appropriate internal reviewer is not available, an external reviewer (i.e., outside the firm) must be engaged. Where an internal or external review has been carried out, this must be documented in the DSCR. The level of review is to be based on the professional judgment of the APEGBC professional (the reviewer). Considerations should include the complexity of the site and of the underlying geological conditions; the consequence classification and the nature of the dam; loading conditions; elements at risk; availability, quality, and reliability of background information and geotechnical data; the degree of judgment on which the dam site characterization is based; and the APEGBC professional's training and experience.

### 5.4 External Review

An external review is an additional level of review beyond the minimum requirements of APEGBC Bylaw 14(b)(2) 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 Design Engineer, 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 external review may be undertaken by another APEGBC professional employed by another firm, independent from the firm that carried out the initial DSCR for the dam's foundation.

An independent external review process should be more formal than the checking/review process carried out under Bylaw 14(b)(2). An independent external reviewer should submit a signed, sealed, and dated letter or report, to be either included with the DSCR or included in the Design Engineer's file. The letter or report should include the limitations and qualifications with regard to the independent external review and the results of the independent external review.

When an independent external review is carried out, the APEGBC professional who sealed the DSCR remains the designer of record (Design Engineer) for the dam site characterization.

The independent external review discussed above is not the same as an independent review or advisory service provided by an APEGBC professional who is retained by the regulatory authority or sometimes by the client.

# 6.0 PROFESSIONAL REGISTRATION, EDUCATION, TRAINING, AND EXPERIENCE

## 6.1 Professional Registration

It is the responsibility of the professional engineer or *professional geoscientist* to determine whether he/she is qualified by training and/or experience to undertake and accept responsibility for the carrying out of site characterization for dams in British Columbia (APEGBC Code of Ethics Principle 2).

With regard to the distinction between professional engineering and professional geoscience, the following is an excerpt under Principle 2 of the Code of Ethics guidelines (APEGBC 1994, amended in 1997):

> The professions are distinct and registration in one does not give a member the right to practice in the other; however, the Association recognizes that there is some overlap of the practices of engineering and geoscience.
>
> Nothing in this principle authorizes a professional engineer to carry on an activity within the area of professional geoscience which goes beyond the practice of professional engineering and nothing in this principle authorizes a professional geoscientist to carry on an activity within the area of professional engineering which goes beyond the practice of professional geoscience.

On this basis, the APEGBC professional who leads site characterization for a dam requires registration with APEGBC as a professional engineer.

The Design Engineer must be registered and in good standing with APEGBC as a professional engineer under the *Engineers and Geoscientists Act*.

A professional engineer acting as a Design Engineer for dams in British Columbia is typically registered with APEGBC within the discipline of civil, geological, or mining engineering.

The Design Engineer can take professional responsibility only for design and field review activities related to the design and construction of the dam that are consistent with his/her training and experience. This would include responsibility for development and oversight of the site characterization of the dam's foundation. As such, a Design Engineer may require supplementary supporting professional engineering and/or professional geoscience services for a particular professional activity, or component or sub-component of a professional activity, related to the design and construction of the dam, including aspects related to the development and oversight of the dam site characterization. The APEGBC professional acting in such a supporting capacity is engaged as a supporting registered professional (SRP). It is the responsibility of the professional engineer acting as the Design Engineer to determine which professional activities he/she can take personal responsibility for as well as those professional activities that will require the services of an SRP with the relevant training and experience.

The APEGBC professional who investigates or interprets complex geological conditions, geomorphic processes, and geochronology in support of dam site characterization is typically registered with APEGBC as a professional geoscientist in the discipline of geology or environmental geoscience, or as a professional engineer in the discipline of geological or geotechnical engineering.

A professional geoscientist is typically registered with APEGBC in the discipline of geology, environmental geoscience, or geophysics.

## 6.2 Education, Training, and Experience

The professional engineer acting as the Design Engineer having overall responsibility for the design of a dam, which includes responsibility for developing and overseeing the site characterization of the dam's foundation, as described in these guidelines, requires minimum levels of education, training, and experience in many overlapping areas of engineering and geoscience. The Design 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 must possess the appropriate education, training, and experience to provide the services.

The level of education, training, and experience required of a professional engineer acting as a Design Engineer should be commensurate with the complexity of a dam, the dam site, and the dam's consequence classification. The qualifications of the Design Engineer should be supplemented by training and experience in additional subject areas, depending on the dam's consequence classification and as required by any increased complexity of a dam and its site conditions.

The recommended qualifications that an individual must hold prior to acting in the capacity of Design Engineer include the following:

- Be currently registered as a professional engineer with APEGBC
- Have previous extensive involvement with the design of at least two dams of similar nature and complexity (e.g., if a concrete dam, then of that nature)
- Have at least 10 years of experience related to the design of dams, including responsibility for developing and overseeing the site characterization of dam foundations
- For water dams, have current knowledge of industry best practices in the assessment, design, and construction of dam foundations for water reservoir dams, the *British Columbia Dam Safety Regulation*, *Canadian Dam Association Dam Safety Guidelines*, and international dam safety guidelines
- For tailings dams, have current knowledge of industry best practices in the assessment, design, and construction of dam foundations for tailings dams, the regulations applicable to the *Mines Act* and the *Health, Safety and Reclamation Code for Mines in British Columbia*, the guidelines provided by the Mining Association of Canada, and, if relevant, portions of the *Canadian Dam Association Dam Safety Guidelines* that may apply to tailings dams
- When a multidisciplinary team approach is utilized, the Design Engineer is also required to have extensive experience in coordinating the work of a variety of SRPs. In such instances, the Design Engineer would be required to identify:
    - All of the types of professional activities for which SRPs need to be engaged
    - The engineering/geoscience and other disciplines required, as well as the background, experience, and expertise required of individual SRPs in order to carry out a particular professional activity (that is, determine that each SRP has the appropriate skills and competencies required to complete the activity he/she is engaged to carry out)
- Be knowledgeable about site characterization for dams and the design, construction, and operation of dams

- Confirm that he/she has the appropriate training and experience to oversee the dam site characterization for the particular type of dam, complexity of the site, and associated overall system of containment for the reservoir; if not, involve the required specialists to provide assistance in the relevant areas

The level of experience required for a Design Engineer, as identified above, can only be obtained by working under the direct supervision of a suitably knowledgeable and experienced professional engineer.

Supporting registered professionals acting as specialists in a particular field of practice offering specialized services (e.g., seismic determination and response) usually require specialized education, training, and experience in addition to the recommended qualifications to act in the capacity of Design Engineer (discussed above).

In addition to the above-listed qualifications, the relevant technical skill sets can be acquired through formal university or college courses, or through continuing professional development. There may be some overlap in courses, and specific courses may not correlate to specific technical skill sets.

An APEGBC professional acting in the capacity of a Design Engineer or an SRP must also remain current, through continuing professional development, with evolving topics related to their field of practice as it relates to the design of dams (see 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.

# APPENDIX A-1: DESIGN ENGINEER'S SITE CHARACTERIZATION ASSURANCE STATEMENT

To: The Owner(s) Date: ______________________

Name: ______________________________________________

Address: ____________________________________________

____________________________________________________

For the dam:

UTM (Location): ______________________________________

Located at (Description): ______________________________

Name of dam or description: ____________________________

Provincial dam number: ________________________________

Dam function: _______________________________________

Current *project stage* is:

Check one

☐ Feasibility design
☐ Detailed design
☐ Construction/operations

The undersigned hereby gives assurance that he/she is a qualified APEGBC-registered professional and is a professional engineer and is the **Design Engineer** for the dam project identified above.

I have signed, sealed, and dated the attached dam site characterization report in accordance with the *APEGBC Professional Practice Guidelines – Site Characterization for Dam Foundations in BC*. The report must be read in conjunction with this Assurance Statement.

### In preparing the dam site characterization report, I have completed the following activities:

(Check the applicable items)

| Completed by the Design Engineer | Activity |
|---|---|
| | Collected and reviewed available and relevant background information, documentation, and data |
| | Visited the site and reviewed the conditions in the field that may be relevant for site characterization |
| | Developed and executed a site characterization program that provides information to support the design of the dam, subject to the qualifications noted |
| | Reviewed previous site characterization studies and data and updated the dam site characterization assessment report to include all data and, where appropriate, revised interpretations of data |
| | Assessed potential areas of risk identified during site characterization programs to date and, as far as is practical, addressed the risks |
| | Evaluated the level of complexity of the site and documented how it was assessed and supported by the site characterization program(s) |
| | Reviewed and accepted all assurance statements submitted by the supporting registered professionals (SRPs) |
| | Prepared a data record report |
| | Prepared the dam site characterization report, which interprets the site conditions |

### In preparing the dam site characterization report, I have completed the following activities or reviewed and accepted such activities completed by a supporting registered professional (SRP):

(Check the applicable items)

| Completed by the Design Engineer | Completed by the SRP, and reviewed and accepted by the Design Engineer | Activity |
|---|---|---|
| | | Assessed the surficial and bedrock geological models to confirm that they adequately support the understanding of the spatial variability of the geotechnical properties of the foundation materials |
| | | Carried out sufficient in situ and laboratory testing to quantify the geotechnical properties of the foundation materials |
| | | Assessed the strength properties of the foundation materials with consideration of stress state and response to loadings |
| | | Assessed the hydrogeological properties of the foundation materials with consideration of potential hydraulic gradients, artesian pressures, and seepage flow paths |
| | | Assessed the seismotectonic conditions to provide a basis for the seismic hazard analysis of the dam |
| | | Evaluated the level of complexity of the site and documented how it was assessed and supported by the site characterization program(s) |
| | | Reviewed and accepted all assurance statements submitted by the supporting registered professionals (SRPs) |
| | | Prepared a data record report |
| | | Prepared the dam site characterization report, which interprets the site conditions |

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

Check one

- ☐ The dam site characterization report is reasonably comprehensive and supports the design of the dam.
- ☐ The dam site characterization report is not sufficiently comprehensive to support the design of the dam, in that the dam site characterization report identifies areas of potential concern that require additional investigation as set out in section(s) ______ of the attached dam site characterization report

Name: (print) ________________________________

Signature:________________________________ Date:________________________________

Address: ________________________________

________________________________

________________________________ (Affix professional seal here)

Telephone: ________________________________

Email: ________________________________

(If the APEGBC professional is a member of a firm, complete the following)

I am a member of the firm ________________________________
(Print name of firm)

and I sign this letter on behalf of the firm.

# APPENDIX A-2: SUPPORTING REGISTERED PROFESSIONAL'S ASSURANCE STATEMENT OF PROFESSIONAL SERVICES

To: The Design Engineer Date: ______________________

Name: (print) ____________________________________________________

Address: (print) __________________________________________________

______________________________________________________________

For the dam:

UTM (Location): ____________________________________________________

Located at (Description): ____________________________________________

Name of dam or description: __________________________________________

Dam function: ______________________________________________________

Owned by: _________________________________________________________

Current project stage is:

Check one

- ☐ Feasibility design
- ☐ Detailed design
- ☐ Construction/operations

This is to advise that the undersigned is a **supporting registered professional** (SRP) retained by ____________________to carry out supporting professional services for the dam.

I undertook supporting professional services in the following:

(Check applicable sections)

- ☐ Bedrock/structural geology
- ☐ Surficial geology
- ☐ Geotechnical investigations
- ☐ Hydrogeology
- ☐ Seismotectonic investigations
- ☐ Other

The undersigned hereby gives assurance that the ______________________________________________

______________________________________________________________________________

______________________________(Insert here the specific professional services carried out) and the documents prepared by this supporting registered professional for the project have been carried out in a manner that meets the intent of the applicable APEGBC guidelines and good professional practice.

These professional services are described, and the results of them reported on in the documents prepared by me, or under my direct supervision, which bear my professional seal.

(With respect to field reviews, initial the following statements, as applicable. Leave blank those that are not applicable.)

________ Field review(s) are not applicable

________ Field review(s) are applicable:

    ________ I have performed field review(s) for the services identified above.

    ________ Field review(s) have been performed by______________________________.

I confirm that I have communicated and liaised as required with the appropriate APEGBC professionals for the purposes of my services.

I hereby give my assurance that I am an APEGBC-registered professional.

Name: (print) ____________________________________

Signature:____________________________________ Date:____________________________________

Address: ____________________________________

____________________________________

____________________________________ (Affix professional seal here)

Telephone: ____________________________________

Email: ____________________________________

(If the APEGBC professional is a member of a firm, complete the following)

I am a member of the firm ______________________________________________
(Print name of firm)

and I sign this letter on behalf of the firm.

# APPENDIX B: BIBLIOGRAPHY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# APPENDIX C: AUTHORS AND REVIEWERS

**Primary Authors**

Harvey N. McLeod, MSc., P.Eng., P.Geo., Klohn Crippen Berger Ltd. (Canadian Dam Association, International Commission on Large Dams)

Peter Mitchell, P.Eng., FEC, APEGBC

Andy Small, P.Eng., AMEC Foster Wheeler, Environment & Infrastructure (Canadian Dam Association)

Lindsay Steele, P.Geo., APEGBC

Dirk Van Zyl, P.Eng., Ph.D., University of British Columbia

Brent Ward, P.Geo., Ph.D., Simon Fraser University

**Review Task Force**

Stephen Rigbey, MASc., P.Eng., BC Hydro

Li Yan, Ph.D., P.Eng., BC Hydro

Michael Davies, Ph.D., P.Eng., P.Geo., Mining Association of British Columbia

Heather Narynski, P.Eng., BC Ministry of Energy and Mines

Kyle Terry, P.Geo., BC Ministry of Environment

Tony Fogarassy, M.Sc., LL.M., First Nations Energy and Mining Council

Mike Noseworthy, P.Geo., Eng.L., BC Ministry of Forest, Lands and Natural Resource Operations

Andy Small, P.Eng., AMEC Foster Wheeler, Environment & Infrastructure (Canadian Dam Association)

**Legal Review**

Robert W. Hunter, LLB, Bull Housser

**Editorial Review**

Merrie-Ellen Wilcox, West Coast Editorial Associates LLP

Margaret Shaw, M.Sc.

Monique Keiran, APEGBC

Professional Engineers and Geoscientists of BC
THE ASSOCIATION OF PROFESSIONAL ENGINEERS AND GEOSCIENTISTS OF BRITISH COLUMBIA
200 – 4010 Regent Street, Burnaby, British Columbia V5C 6N2
T: 604.430.8035 F: 604.430.8085 E: apeginfo@apeg.bc.ca APEG.BC.CA