



# Guidelines for Submitting Invasive Investigation Plans and Instrumentation Reports

**B.C. Dam Safety Program**



Ministry of  
Water, Land and  
Resource Stewardship

## B.C. Dam Safety Program

**Ministry of Water, Land and Resource Stewardship**

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**Cover photo: Barnes Lake Dam, January 27, 2026**

### **Document Overview:**

The purpose of this guideline is to assist dam owners and qualified professionals in preparing an invasive investigation plan (IIP), instrumentation record (IR) or instrumentation annual plan that meets the expectations for acceptance by the B.C. Dam Safety Program.

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## Acronyms

|              |                                                |
|--------------|------------------------------------------------|
| <b>B.C.</b>  | Province of British Columbia                   |
| <b>CDA</b>   | Canadian Dam Association                       |
| <b>DEP</b>   | Dam Emergency Plan                             |
| <b>DSO</b>   | Dam Safety Officer                             |
| <b>EGBC</b>  | Engineers and Geoscientist B.C.                |
| <b>FERC</b>  | Federal Energy Regulatory Commission           |
| <b>FEMA</b>  | Federal Emergency Management Agency            |
| <b>ICOLD</b> | International Commission on Large Dams         |
| <b>IR</b>    | Instrumentation Record                         |
| <b>IIP</b>   | Invasive Investigation Plan                    |
| <b>IDSMP</b> | Interim Dam Safety Risk Management Plan        |
| <b>OMS</b>   | Operation, Maintenance and Surveillance Manual |
| <b>USACE</b> | U.S. Army Corps of Engineers                   |
| <b>USBR</b>  | U.S. Bureau of Reclamation                     |

## Definitions

|                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Canadian Dam Association (CDA)</b>        | Publishes technical guidelines on dam safety that are considered good established practice.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Dam</b>                                   | As defined in the Dam Safety Regulation, means<br>(a) a barrier constructed for the purpose of enabling the storage or diversion of water diverted from a stream or an aquifer, or both, and<br>(b) other works that are incidental to or necessary for the barrier described in paragraph (a).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Dam Emergency Plan (DEP)</b>              | A document prepared by the dam owner describing the actions to be taken by the owner if there is an emergency at the dam and containing information for use by the local emergency authorities. The plan must be submitted to a dam safety officer (DSO) for acceptance.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Dam Safety Officer (DSO)</b>              | A statutory decision maker designated under the Water Sustainability Act. The DSO has regulatory authority for acceptance of Invasive Investigation Plans (IIP), Instrumentation Records (IR), Instrumentation Annual Reports and other documents.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Engineers and Geoscientists BC (EGBC)</b> | Regulates and governs professional engineers and geoscientists in B.C. EGBC publishes technical and quality management guidelines that are considered good established practice.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Engineer of Record</b>                    | A professional engineer who retains and accepts professional responsibility for the safety of a dam, including evaluating the adequacy of the as-built facility relative to the design in consideration of applicable regulations, criteria and guidelines. The Engineer of Record has continuous involvement with the dam structure and may assist the dam owner in formal inspections, analyses of instrumentation data, maintenance recommendations, assessments, updates to dam documents and provide technical assistance for unusual situations. An Engineer of Record is typically associated with mining dams. Currently, the Dam Safety Regulation does not require water dam owners to retain an Engineer of Record. The term has been defined to distinguish it from the roles of Professional of Record or Design Engineer. |

|                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Established Good Practice</b>                   | As defined in the EGBC's, "Legislated Dam Safety Reviews in B.C. Guideline Version 4.0" (2023) means "the current practices or understanding with respect to dam safety governance, design, construction, operation, closure and or management, expressed in the form of industry-accepted guidelines or technical standards, or as documented lessons learned from recent engineering failures or successful strategies which may not yet be incorporated into codes and standards." |
| <b>Federal Energy Regulatory Commission (FERC)</b> | Publishes technical guidelines on dam safety that are considered good established practice.                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Federal Emergency Management Agency (FEMA)</b>  | Publishes technical guidelines on dam safety that are considered good established practice.                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Heave</b>                                       | Colloquial term used in geotechnical drilling. Describes a condition where saturated soil flows into a drill borehole casing when water pressure in the surrounding soil is higher than in the borehole. This may leave a void in the surrounding soil, leading to internal erosion.                                                                                                                                                                                                  |
| <b>High-Risk</b>                                   | See definition for "risk assessment for determining high-risk professional activities or work".                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Hydraulic Fracturing</b>                        | A condition caused by drilling that may occur in embankment dams, concrete dams and foundations. This occurs when water or air pressure in the borehole is higher than the surrounding material, resulting in a pressure imbalance that could cause the material to crack. In a dam, this may destabilize the structure, initiate internal erosion and potentially cause dam failure.                                                                                                 |
| <b>Instrumentation Record (IR)</b>                 | As defined by the Dam Safety Regulation, a written record describing any proposed installation, modification, replacement or removal of an instrument associated with a dam.                                                                                                                                                                                                                                                                                                          |
| <b>Interim Dam Safety Risk</b>                     | A written plan that details risks associated with invasive activities that may impact on the safe functioning of a dam, and how those risks will be mitigated. The plan should describe hazards created by                                                                                                                                                                                                                                                                            |

|                                                             |                                                                                                                                                                                                                                                                                                                                                    |
|-------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Management Plan (IDSRMP)</b>                             | the work, relevant potential failure modes, methods to mitigate the identified hazards, enhanced surveillance during or after the work, and, if needed, special reservoir operational procedures. An IDSRMP temporarily supplements an Operation, Maintenance and Surveillance (OMS) manual. It must be authenticated by a qualified professional. |
| <b>International Commission on Large Dams (ICOLD)</b>       | Publishes technical guidelines on dam safety that are considered good established practice.                                                                                                                                                                                                                                                        |
| <b>Invasive Investigation</b>                               | Involves drilling, trenching, test pit excavation or other invasive activities within or near a dam. Invasive investigations do not include using a small hand drill to mount signs or instruments to concrete.                                                                                                                                    |
| <b>Invasive Investigation Completion Report</b>             | A report summarizing the factual results of the invasive investigation.                                                                                                                                                                                                                                                                            |
| <b>Invasive Investigation Plan (IIP)</b>                    | Includes 1) a technical plan describing the proposed invasive activities at a dam; and 2) an Interim Dam Safety Risk Management Plan prepared. As required by the Dam Safety Regulation, the IIP must be submitted to and accepted by a dam safety officer before an invasive investigation may begin.                                             |
| <b>Non-Invasive Investigation</b>                           | Investigation of the subsurface material properties of a dam or foundation using surface measurements and empirical relations. Specialized equipment is typically required for these types of investigations. Non-invasive investigation does not require regulatory notification or acceptance.                                                   |
| <b>Operation, Maintenance and Surveillance Manual (OMS)</b> | A manual, prepared by the dam owner, that describes operation, maintenance and surveillance procedures for the dam. An OMS Manual is required by Section 8 of the Dam Safety Regulation.                                                                                                                                                           |

|                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Professional of Record</b>                                                    | An individual qualified professional who is responsible for preparing the IIP, overall supervision of the work, and completion reporting for the work.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Qualified Professional</b>                                                    | A person with experience and training in dam safety, analysis and design, who is registered with Engineers and Geoscientists BC (EGBC).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Risk Assessment for Determining High-Risk Professional Activities or Work</b> | As presented in EGBC's guideline "Documented Independent Reviews for High-Risk Work" (2023), a documented process involving 1) identifying hazards; 2) evaluating the identified hazards based on severity and likelihood of the consequences to determine a risk level; and 3) comparing the determined risk level to risk tolerance criteria (as defined by codes, standards and other requirements). The assessment must be based on determined risk level before mitigation measures are incorporated. A risk assessment must be completed by the Professional of Record prior to the initiation of work or professional activity. Refer to the EGBC's guideline for additional information |
| <b>Sinkhole</b>                                                                  | Surficial expression of a subsurface cavity that has formed in an embankment dam. Internal erosion processes that may cause a sinkhole include concentrated leaks, contact erosion, suffusion or erosion into open joints in the foundation or into a conduit.                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Test Hole</b>                                                                 | A borehole, trench, cone penetration test (CPT), dynamic penetration test (DPT), test pit, concrete core, hand dug hole or hand auger hole.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>U.S. Army Corps of Engineers (USACE)</b>                                      | Publishes technical guidelines on dam safety that are considered good established practice.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>U.S. Bureau of Reclamation (USBR)</b>                                         | Publishes technical guidelines on dam safety that are considered good established practice.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

# 1 Introduction

The guidelines were developed to assist dam owners and qualified professionals in preparing an invasive investigation plan (IIP), instrumentation record (IR) or instrumentation annual plan that meets the expectations for acceptance by the B.C. Dam Safety Program, which has authority to apply the Dam Safety Regulation ('the Regulation') to all regulated dams licenced in B.C. under the Water Sustainability Act (WSA). Specific sections of the Regulation addressed by these guidelines are:

## Section 16 – Invasive Investigations

2)

- b) at least 30 days before the date on which the owner expects the invasive investigation to begin
  - i) prepare a plan, in the form and with the content specified by a dam safety officer, in relation to the invasive investigation, and
  - ii) submit the plan to a dam safety officer for acceptance by the dam safety officer.

## Section 19 – Instrumentation

- 2) An owner of a dam who intends to install, modify, replace or remove instrumentation relating to the dam must submit to a dam safety officer, for acceptance by the dam safety officer,
  - a) a record describing the proposed installation, modification, replacement or removal at least 60 days before the date on which the owner expects the installation, modification, replacement or removal to occur, or
  - b) an annual plan outlining all installations, modifications, replacements and removals of instrumentation proposed for the following year.

## Section 21 – Information and Records to be submitted to dam safety officer

- 2) An owner of a dam must, on request of a dam safety officer, submit to the dam safety officer, in the form, with the content and on or before the date specified by the dam safety officer, the following records relating to an inspection, test or review carried out in relation to a dam:
  - a) A record setting out the results of the inspection, test or review;
  - b) Records setting out the data obtained from any test or measurement taken, and analysis and interpretation of the data, including, but not limited to,
    - i) a record setting out instrumentation readings, and analysis and interpretation of the readings,
    - ii) visual records or observations,
    - iii) drawings,
    - iv) soil, aggregate and concrete test results, and
    - v) any other test results.

The guideline is intended to clarify the acceptable form and content for submissions to a Dam Safety Officer (DSO), before and after the work is completed, related to an IIP. It also addresses instrumentation changes made during an invasive investigation and when a separate Instrumentation Record (IR) or annual plan should be submitted.

Invasive activities that are subject to this guideline include, but are not limited to:

- Drilling, sampling and testing
- Excavating, including trenches, test pits, hand-dug pits, hand augering, et cetera
- Concrete coring
- Installing new subsurface instrumentation, including piezometers, standpipes, inclinometers, shape arrays, thermistors, seismometers, et cetera
- Excavating to install surface instrumentation such as weirs
- Drilling or excavating to decommission instrumentation

Examples of work not considered invasive activities and not subject to this guideline include:

- Using a handheld drill to mount signs or objects to the surface of a concrete dam
- Using an excavator to clear debris or organics from an existing ditch or channel near the dam

- Excavation into the crest or slope of a dam shallower than 0.3 m for the purpose of installing utilities
- Work a considerable distance away from the dam that could not plausibly impact the safety of the dam. Figure 1 provides a “rule of thumb” determination of a safe distance for shallow excavations. A dam owner should confirm the appropriateness with their qualified professional

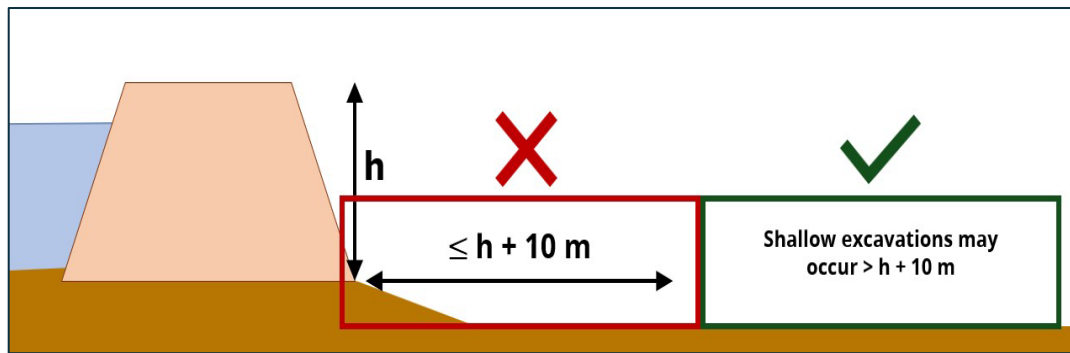


Figure 1: Determination of distance for safe shallow excavations.

If unsure whether your proposed work is considered an invasive activity, contact a DSO for advice.

Plans to alter, improve, replace, decommission or remove a dam are not covered by this guideline. These activities require authorization as per Section 12 or Section 17 of the Regulation. Dam owners and qualified professionals should refer to the B.C. Dam Safety technical guidance documents, “Guidelines for Dam Design and Construction (V.2 2026)” and “Dam Decommissioning Guidelines (V.1 2019)”. For clarity, the following are examples of work could be considered an alteration or improvement to a dam requiring authorization under Section 12 rather than as an invasive activity:

- Excavation and backfilling to remove large vegetation and roots
- Installing seepage control features, including foundation grouting and cutoff wall installation
- Anchoring or stabilization construction
- Removing or decommissioning a dam

## 2 Dam Owner considerations for IIPs

Typically, a dam owner planning an invasive investigation will retain a qualified professional or team of qualified professionals. Alternately, the dam owner may complete the work internally if their staff have appropriate qualifications and training.

After preparation, the IIP is authenticated by the lead Qualified Professional, also referred to as the Professional of Record. The completed IIP is then submitted by the dam owner to a DSO for acceptance. **Unless the regulatory authority has been provided a letter of agency, communication will be directed through the dam owner, not their hired professionals.**

IIPs submitted to a DSO undergo regulatory review, considering the report components listed in the appendices of this document. If satisfied, the DSO will provide written acceptance. B.C. has a professional reliance model, meaning the regulatory authority's review does not serve as a professional technical review. The Professional of Record is expected to submit a document that has undergone technical review following EGBC's "Guide to the Standard for Documented Checks of Engineering and Geoscience Work" (2021) and "Guide to the Standard for Documented Independent Review of High-Risk Professional Activities or Work" (2023).

Invasive investigations in or near to dams can be high-risk activities (see Section 3 below) and should not be undertaken unless the risks are assessed, understood, mitigated to the extent practicable, and justified by the information that will be obtained. The Professional of Record is responsible for determining whether the invasive investigation is considered high-risk work according to EGBC standards.

The regulatory review process will be expediated by providing a complete and clear IIP, with risks and mitigation described in detail. For detailed invasive investigation methodology, the dam owner and qualified professionals may refer to guidance documents produced by the U.S. Army Corps of Engineers (USACE), Federal Energy Regulatory Commission (FERC), the Federal Emergency Management Agency (FEMA), the U.S. Bureau of Reclamation (USBR), International Commission on Large Dams (ICOLD) and other industry recognized design codes, standards and guidelines.

Sections 16, 19 and 21 of the Regulation describe required timelines for written advance notice and submission of plans or other records for acceptance by a DSO. The Dam Safety Program endeavours to process such submissions promptly but cannot guarantee acceptance to meet dam owner work schedules.

Depending on the nature and location of the proposed work, dam owners should be aware that an IIP may be referred to other provincial agencies. For example, work in or about a stream may require WSA authorization from a habitat officer. In addition, an IIP may trigger the province's duty to consult with First Nations whose consultative areas overlap with the work site. Referral and consultation can delay project acceptance and start of work, even if the IIP is submitted within the timelines stipulated by the Regulation.

The dam owner is responsible for compliance with any other regulations that may apply to their proposed work. Qualified Professionals should be able to advise on this.

## **2.1 Ecosystem considerations**

Invasive investigations can disturb both aquatic and terrestrial ecosystems. When creating an Invasive Investigation Plan (IIP), dam owners and their Qualified Professionals need to consider how the planned activities may affect these environments. The review should include impacts related to access to the drilling or test pitting site, significant reductions to reservoir levels, industrial noise on domestic animals and wildlife, et cetera. Depending on the nature and location of the proposed activities, ecosystem considerations may influence changes to access routes, equipment selection, timing of work, and mitigation measures described in the IIP. Dam owners are responsible for ensuring compliance with all applicable environmental requirements, including any permits or conditions associated with work in or around water.

Dam owners and Qualified Environmental Professionals should document potential impacts and explain how they will be avoided, reduced, or mitigated. Early identification of environmental constraints and coordination with appropriate specialists can reduce delays, improve environmental outcomes and support timely regulatory acceptance.

## **2.2 First Nations consultation considerations**

The government of B.C. has a duty to consult First Nations, arising from existing Aboriginal and Treaty Rights affirmed by Section 35 of the Constitution Act (1982) and Section 3 of the Declaration on the Rights of Indigenous Peoples Act (SBC 2019), on projects that could affect asserted or proven Aboriginal rights or treaty rights. The B.C. government is responsible for ensuring adequate and appropriate consultation and accommodation occur and will consult potentially affected First Nations through the decision-making process.

The B.C. government encourages proponents to engage First Nations early in the planning and design phases of their projects, as this provides a general awareness of the project and early opportunities for input by the First Nation and design accommodation by the

proponent. Proponents who engage with First Nations should document their engagement activities, share their consultation record with the provincial government for incorporation into the provincial review and consultation process.

The proponent should consider all aspects of the project and how it may impact First Nations interest including constructing access for drilling and or excavation and environmental consideration of reservoir level drawdowns.

### 3 Risks associated with invasive investigations

Potential hazards associated with drilling into a dam include hydraulic fracturing, internal erosion, artesian conditions, contamination of filters and drainage features, heave and damaging existing pipes or instrumentation. These failure modes may occur immediately or take weeks to months to be visible on the surface. The guiding principle for any activity on a dam should be to **do no harm**.

The following activities, if not well considered with engineering controls, may bring increased risk of unintentional damage to a dam structure:

- 1) Drilling into a dam core of a zoned embankment dam
- 2) Drilling through or near a filter zone, drain zone, or drain pipes. These drilling activities may introduce fines that block and damage the seepage control component of the dam or may create an unfiltered zone where internal erosion processes could initiate
- 3) Trenching or test pitting near the toe of the dam, or near known seepage areas, as this changes the weight on the dam toe, could create artesian conditions or could cause slope destabilization
- 4) Drilling in locations with a high potential for hydraulic fracturing, including:
  - a) Near steep abutments, or abutments with abrupt changes in slope angle
  - b) Adjacent to rock overhangs
  - c) Adjacent to buried structures
  - d) Adjacent to conduits
  - e) Narrow zones of soil backfill placed between the structure and a rock face
  - f) Thin cores that have experienced more settlement than the adjacent shells
  - g) Dams in very narrow valleys
  - h) Areas subject to differential settlement

For these identified activities and locations, invasive investigation or installation of instrumentation may be conducted, but the Professional of Record must also determine if this activity constitutes high-risk work as per EGBC's definition. If the Professional of Record determines the work is high-risk, then they must ensure their plan undergoes an appropriate independent review.

The case studies in Appendix G demonstrate the need for careful planning, as well as the importance of ensuring the team has the right qualifications and experience for the work.

## 4 Regulatory acceptance schedule

Work should be scheduled to allow time for design, planning and regulatory acceptance. As noted in Section 1, the Regulation includes several scheduling requirements for invasive investigations and instrumentation changes:

### **Invasive investigation**

- At least 60 days before the expected start date of the work, a dam owner must provide written notification to the DSO of the proposed program. This notification may be provided through email. Include brief details of the proposed program including the dam's name, type of work, any instrumentation changes, and the name of the Professional of Record who is preparing the IIP
- At least 30 days before the expected start date of the work, the dam owner must submit the IIP to the DSO. This must include the authenticated technical plan
- The IIP should include a technical plan and an Interim Dam Safety Risk Management Plan (IDSRMP). If there are challenges with submitting the IDSRMP at the same time as the technical plan, the dam owner may receive conditional acceptance with a requirement to submit the IDSRMP to a DSO before the work may proceed

### **Instrumentation change**

- At least 60 days prior to making changes to the instrumentation, the dam owner should submit an instrumentation record (IR) to the DSO. This may be sent via email
- If the instrumentation change is part of an invasive investigation, the IR may be included as part of the IIP submission at least 30 days before the expected start date of the work
- Alternately, a dam owner may submit an annual plan outlining all proposed instrumentation changes for the following year. If the instrumentation change is occurring as part of an invasive investigation, an IIP must still be submitted at least 30 days prior to the proposed work

The DSO will provide written acceptance of the IIP, IR or instrumentation annual plan. Work must not begin until written acceptance is received.

## 5 Instrumentation

The Regulation requires a dam owner to install instrumentation necessary to adequately monitor their dam and the area surrounding, or adjacent to the dam. It also requires that prior to installing, modifying, replacing or removing an instrument for a dam, an owner must submit an IR or annual plan describing the proposed changes.

Notification requirements for an instrumentation change may be as follows:

1. Included as part of an invasive activity requiring an IIP to be submitted;
2. Submitted as a stand-alone IR or instrumentation annual plan if no invasive activity is required for installation; or
3. Not required if the change is minor or considered maintenance

Table 1 provides examples of these scenarios.

If a Professional of Record adds instrumentation as part of an invasive investigation, they should clearly communicate the intent of the instrumentation to the dam owner by providing information described in Appendix C.

For instrumentation changes where an IIP is not required, the dam owner may prepare the IR or instrumentation annual plan, or have a qualified professional complete this work. For an IR or instrumentation annual plan the following information should be provided:

1. Dam description, including failure consequence classification
2. Schedule for the work



Photo 1: Solar-powered piezometer used to monitor water pressure inside a dam embankment.



Photo 2: Solar-powered, seismic monitoring station, using a nanometrics broadband monitoring station, for hard rock

3. Information for instrumentation described in Appendix C
4. Drawings as described in Appendix B

The IR or instrumentation annual plan may be provided in an email, letter or report, depending on complexity.

If a new instrument is added, or an instrument is removed, the OMS manual should be revised within one year of work completion.

**Table 1: Instrumentation changes and regulatory processes\***

| Instrumentation change requires Invasive Investigation Plan                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Instrumentation change requires only IR or Annual Plan                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Instrumentation change notification not required.                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>• New boreholes to install piezometers, standpipes, thermistors, inclinometer casing shape arrays, seismometers, geophones, load cells, strain gauges, internal tilt meters, et cetera</li> <li>• New boreholes to decommission or replace existing instruments</li> <li>• Excavations to install seepage weirs, survey monuments, pipes, cables, et cetera that could impact the safety of the dam. This may be determined by a qualified professional or based on:               <ol style="list-style-type: none"> <li>1. Distance from the dam toe is closer than the height of the dam + 10 m (See Figure 1)</li> <li>2. Excavation into the crest or slope of a dam deeper than 0.3 m</li> </ol> </li> </ul> | <ul style="list-style-type: none"> <li>• Installation of seepage weirs, flow meters or turbidity sensors in existing pipes or channels</li> <li>• Installation of new type of instrumentation into an existing downhole casing</li> <li>• Shallow excavations to install seepage weirs, survey monuments, pipes cables, et cetera, that are not expected to impact the safety of the dam. This may be determined by a qualified professional or based on:               <ol style="list-style-type: none"> <li>1. Distance from the dam toe is further than the height of the dam + 10 m (See Figure 1.)</li> <li>2. Excavations into the crest or slope of a dam shallower than 0.3 m</li> </ol> </li> </ul> | <ul style="list-style-type: none"> <li>• Maintenance of existing instrumentation by replacing like-with-like (not invasive)</li> <li>• Installing a weather station</li> <li>• Using a hand drill to mount an instrument on concrete, for example extensometer, crack meter, staff gauge, tilt meter, pendulum system, et cetera. Consideration should be given to the thickness of concrete, depth of hole and rebar as to not compromise the structural integrity of the concrete</li> </ul> |

\*If there are questions on what is required, contact [dam.safety@gov.bc.ca](mailto:dam.safety@gov.bc.ca)

## 6 Engineering considerations for planning an invasive investigation

An invasive investigation to collect the required information should be carefully planned to ensure the data is of high quality and to avoid harm to the dam. The invasive investigation plan (IIP) should be developed in consideration of a review of existing information, dam model, conceptual geological site model, potential failure modes, dam safety risks, preliminary analysis, instrumentation requirements and results from non-invasive measurements. The objective of any plan should be to obtain reliable and representative information while minimizing the invasive activities.

A program should be developed in consideration of EGBC's<sup>1</sup> professional practice guideline "Site Characterization for Dam Foundations in B.C." (2016), the Canadian Dam Association's (CDA) Dam Safety Guidelines and Technical Bulletins, as well as other established good practices. EGBC's guideline provides detailed expectations for developing and describing a site geological model, which may include bedrock and structural geology, surficial geology and geomorphology, geotechnical conditions, hydrogeology and seismotectonic conditions. EGBC's guideline should be read for additional information and context.

### 6.1 Review of existing information

Prior to an invasive investigation, the Professional of Record should have a clear understanding of the dam's history, anticipated dam structure and foundation conditions, and the site geological model. A thorough review of existing information should be undertaken to identify 1) any information gaps that might prove important to the safe execution of the program; and 2) data that should be collected or verified.

At a minimum, if available, the following information should be reviewed in developing an invasive investigation program:

- Original design reports and drawings
- Instrumentation plans, records, and analyses
- Construction records and photographs
- LiDAR data
- Site Surveillance and annual inspection reports
- Geological maps and records for the area

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<sup>1</sup> Document published under EGBC's former name Association of Professional Engineers and Geoscientists BC (APEGBC).

- Dam Safety Review reports
- Issued for record drawings

The existing information review should be considered a process of discovery. As information is reviewed, the initial scope of the invasive investigation requested by the dam owner or proposed by the Professional of Record may need to be adjusted or expanded, so that the program collects the required information and risk to the dam structure is kept as low as reasonably possible. A dam owner should be open to having these conversations with the Professional of Record.

In many cases, preliminary engineering analysis of the structure based on a review of existing information is beneficial. Preliminary analysis assists in identifying risks, failures modes and zones of interest where material properties are sensitive to variation and should be calibrated with in-situ or laboratory testing. A conceptual model can be created from the review of existing information, considering the geometry of the dam, assumed material properties, or by using material strengths based on non-invasive testing methods.

## 6.2 Non-invasive options

Prior to performing an invasive investigation, non-invasive options should first be considered. Non-invasive testing can provide information on the hydraulic conductivity of a dam or foundation, soil density of the dam fill or foundation, concrete density, rebar placement in concrete, approximate locations where changes in dam fill and foundation occur, approximate locations of soft materials, areas of settlement, and can support empirical calculations to estimate material strengths and other properties. Additionally, **non-invasive testing does not require regulatory notification or acceptance.**

Some examples of non-invasive options are:

- Ground penetrating radar (GPR)
- Acoustic emission testing
- Infrared thermography
- Microwaves
- Ultrasonic
- Dye tracers
- Resistivity
- Magnetic and gravity surveys
- Seismic Refraction and or Reflection
- Electrical and electromagnetic surveys
- Multichannel Analysis of Surface Waves (MASW)
- Downhole seismic surveying in existing instrumentation casing



Photo 3: Electromagnetic (EM) mapping reduces unnecessary disturbance to the dam.

- Remote Satellite Sensing, including InSAR and other new emerging technologies

### **6.3 Concrete cores**

Concrete dams present unique challenges, particularly due to embedded services such as electrical conduits, communication lines, water pipes, drains, and existing instrumentation. The Professional of Record is responsible for reviewing all available records and conducting necessary non-invasive investigations before planning any invasive activities for collecting concrete cores.

All concrete core holes should be restored with appropriate cementitious material.

### **6.4 Embankment dams: test holes and backfilling methods**

The Professional of Record should consider the specific dam, site geological model and purpose of the investigation when developing the IIP. For determining the number and location of test holes, the following may need to be considered and documented:

- Variability of fill used in construction
- Expected location and confidence in location, of filters and drains to sample or avoid
- Balancing priorities of installing instruments in a specific location and quality of data at that location
- Dam height and expected depth of influence to confirm competent strata for static, seismic, and post-seismic stability analyses
- Spacing between test holes considering the expected variability in the site geological model and the size of the dam



Photo 4: Drill core samples from a dam foundation.

Different test hole and backfilling methods carry different risks. Each test hole location and type of drilling or excavation technique should be assessed and justified based on the objectives of each hole and associated dam safety risks. Examples of different drilling, excavation and backfilling methods are described in Tables 2 and 3. The Professional of Record must select the appropriate method or combination of methods for the specific site.

**Table 2: Drilling and excavation methods for embankment dams**

| Hazard Potential | Method                         | Considerations for planning                                                                                                                                                                                                                                                                              |
|------------------|--------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Lower</b>     | Hollow stem auger              | <ul style="list-style-type: none"> <li>• Water and or bentonite can be directly added to hole to counteract vertical gradients</li> <li>• Water or drill fluid can be used to offset hydrostatic pressure and avoid “heave”</li> <li>• Raise and lower auger string slowly when fluid in hole</li> </ul> |
|                  | Sonic or Vibratory             | <ul style="list-style-type: none"> <li>• Water or drilling fluid must not be pressurized</li> <li>• Water or drill fluid can be used to offset hydrostatic pressure and avoid “heave”</li> <li>• Consider impact of vibration on in-situ testing quality</li> </ul>                                      |
|                  | Cable tool or Churn            | Chop and drive variation are in the higher hazard potential category                                                                                                                                                                                                                                     |
|                  | Hydro-vacuum                   | Access should be considered as hydro-vacuum equipment is typically on a truck and not track mounted                                                                                                                                                                                                      |
|                  | Excavator or Backhoe           | Size, loading and reach of equipment should be considered                                                                                                                                                                                                                                                |
|                  | Hand exaction or hand auger    | Consider if the hole will be deep enough to collect required data                                                                                                                                                                                                                                        |
| <b>Medium</b>    | Solid stem auger               | Appropriate in some locations. Not appropriate where artesian conditions may occur because of challenges with closing and or sealing hole. Not appropriate in cohesionless soils below the water table as the hole may collapse as the auger is withdrawn                                                |
|                  | Cone Penetration Testing (CPT) | Appropriate in some locations. Consider how the hole will be backfilled                                                                                                                                                                                                                                  |

| Hazard Potential | Method                                        | Considerations for planning                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|------------------|-----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                  | Becker Penetration Tests                      | Appropriate in some locations. Consider air pressure for returning cuttings                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                  | Wireline, Rock coring and or Casing advancers | Size tools and bit to reduce likelihood of clogging                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|                  | Dual rotation or Fluid rotary                 | <ul style="list-style-type: none"> <li>• Volume of water used should be minimized. Specifically direct drillers to use minimal water, as in normal conditions drillers will inject large volumes of water for smoother casing advancement. Frequently dip and or measure the water level to check the expected phreatic surface has not been exceeded</li> <li>• Fluid discharge from bit should be upward, not downward, to reduce clogging and pressure spikes. Open bit methods are not allowed</li> <li>• Raise and lower tools and or heads slowly to reduce pressure spikes</li> <li>• Advance casing ahead of bit to confine fluids</li> <li>• Fluid pressure must be very low and monitored closely. Clear water or air carries higher risk. Use pressure relief valve to cap fluid pressure; and all changes must be gradual</li> </ul> |
| <b>High</b>      | Drill through or Drive casings                | A DSO is unlikely to accept a plan that uses these methods, unless the reason is clearly justified, and the hazards appropriately addressed                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                  | Air rotary                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

Adapted from: FERC 2016, USACE 2023 and USBR 2014, refer to these documents for additional details.

**Table 3: Backfill methods for test holes**

| Preference                          | Backfill Method               | Considerations for planning                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-------------------------------------|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Preferred</b>                    | Grout bentonite mix           | <ul style="list-style-type: none"> <li>Installed with tremie-line placed in bottom of the hole</li> <li>Staged installation may be required</li> <li>Grout should be designed to reach a strength equal or greater than the soil and or bedrock</li> <li>If installing vibrating wire piezometers, consider the maximum pressure based on the weight of the unset grout column</li> </ul>                                                                             |
|                                     | Grout cement mix              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                     | Filter or drain material      | For backfill in specific location if the borehole crosses or is suspected to have encountered these materials                                                                                                                                                                                                                                                                                                                                                         |
|                                     | Concrete or cement            | <ul style="list-style-type: none"> <li>Where concrete cores are collected from a dam</li> <li>At surface for mounting instrumentation covers</li> </ul>                                                                                                                                                                                                                                                                                                               |
|                                     | Sand                          | Around standpipe screen only                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Applicable in some locations</b> | Coated bentonite pellets      | <ul style="list-style-type: none"> <li>Coated chips are a uniform size so less likely to bridge than chips. These may be appropriate in highly permeable layers (rockfill dams, or alluvial deposits), or to seal zones for standpipe screened sections</li> <li>Pellets should be hydrated in layers during placement so the material swells and expands into the voids</li> <li>Measurements during backfill must be made to check and adjust if bridged</li> </ul> |
| <b>Prohibited</b>                   | Drill cuttings                | Not allowed. Likely to bridge and may not provide adequate seal                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                     | Bentonite chips and or powder | <ul style="list-style-type: none"> <li>Bentonite chips are not a uniform size, so are more likely to bridge than coated bentonite pellets</li> <li>Bentonite powder becomes sticky when exposed to water so is likely to bridge</li> </ul>                                                                                                                                                                                                                            |

Adapted from: FERC 2016; USACE 2023 and USBR 2014, refer to these documents for additional details

Back fill procedures for boreholes through a dam foundation or abutments must also follow the B.C. Groundwater Protection Regulation

## 7 Invasive investigation plan

An IIP must clearly justify and define the investigative program. When submitting an IIP to a DSO, the following must be included:

- Technical Plan with attached assurance statement authenticated by the Professional of Record
- Interim Dam Safety Risk Management Plan (IDSRMP) authenticated by a qualified professional familiar with the work and dam operations
- As previously described, the Technical Plan may be submitted first and accepted on condition that the IDSRMP is submitted prior to the work occurring

### 7.1 Technical Plan

The technical plan should clearly justify and define the invasive investigation program. A suggested table of contents for a complete technical plan is provided in Appendix A.

Drawings must be provided as part of the Technical Plan. Appendix B provides expectations for drawings.

#### 7.1.1 Assurance statement

An authenticated assurance statement prepared by the Professional of Record must be attached to the technical plan. The required assurance statement form is provided in Appendix E. If the invasive investigation covers multiple dams on separate reservoirs and the information cannot fit on a single form, please submit multiple forms.

#### 7.1.2 Potential IIP changes

Invasive investigations all carry a degree of uncertainty. Based on observations in one test hole, there may be reasons to add additional test holes, change locations or excavate deeper. These types of changes carry additional risk if not carefully considered, so they should be pre-emptively identified and included as potential options in the Technical Plan.

A DSO **will not** provide acceptance of these types of substantial additions through a phone call. If substantial changes are required, a revised written plan must be provided.

Minor deviations in borehole location are acceptable if approved by the Professional of Record. For example, a borehole location may need to be moved by a few meters due to encountering a boulder. The actual hole locations should be documented in the completion report.

### 7.1.3 Qualifications of team

The Regulation requires:

#### Section 16

- 4) An owner of a dam must ensure that all drilling, trenching, test pit excavations and other invasive activities involved in an invasive investigation are directly supervised by an engineering professional who has qualifications and experience in dam design, construction and analysis.

EGBC's "Guide to the Standard for Direct Supervision" (2023), defines direct supervision as, "The responsibility for the control and conduct of the activities, work or decisions related to the Regulated Practice, that have been Delegated to a subordinate."

The Technical Plan should identify the individual who will be the Professional of Record responsible for directly supervising the entire scope of the invasive investigation, and who will be the on-site field supervisor. The Professional of Record and on-site field supervisor roles may be filled by the same person or separate people. The education, training and experience of the individual(s) should be described to demonstrate they are qualified for the work. The Professional of Record is encouraged to consider the training and qualifications of their on-site field supervisor and may refer to additional guidance on minimum qualifications published by FERC "Guidelines for Drilling in and Near Embankment Dams and Their Foundations" (2016).

A driller must be registered as a Geotechnical and or Environmental Driller and hold a Certificate of Qualification, as required by the B.C. Groundwater Protection Regulation. If this information is not available at the time the IIP is submitted, the DSO may request it as a condition of acceptance.

### 7.1.4 Professional review and high-risk work assessment

Invasive activities in and near dams may adversely impact the dam structure and, in rare cases, can cause an unexpected incident potentially leading to dam failure. An invasive investigation could be considered high-risk work for dams with a consequence classification of High to Extreme<sup>2</sup> due to the potential for loss of life. In high-risk

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<sup>2</sup> See Schedule 1 of the BC Dam Safety Regulation

circumstances, professional registrants must meet the requirements for independent review.

The Professional of Record should substantiate their decision on whether and how to carry out an independent review by using a documented risk assessment, following requirements outlined in the “Guide to Standard on Independent Review of High-Risk Professional Activities and Work” (EGBC, 2023). In making this determination, the Professional of Record should consider the specific dam and work and **not use** the rationale that dam failures rarely occur, so the work is low risk. The outcome of the risk assessment must be documented in the assurance statement attached to the Technical Plan.

## 7.2 Interim Dam Safety Risk Management Plan

An Interim Dam Safety Risk Management Plan (IDSRMP) is a written plan that identifies and addresses potential hazards, and mitigation measures, for work or operational changes occurring at a dam. An IDSRMP is required to be submitted as part of the IIP. Details on information that should be included in an IDSRMP are provided in Appendix D.

The IDSRMP must be authenticated by a qualified professional familiar with the work and dam. This may be the Professional of Record or, for dams with complex operations, an engineer who works for the dam owner. In such cases, it is prudent for the Professional of Record and dam owner’s engineer to discuss the proposed invasive investigation activity and potential failure modes.

## 7.3 Environmental management plan

Although the proposed invasive investigation activities may not constitute a change in and about a stream, invasive investigations commonly occur near a stream and have the potential to cause environmental impacts. Examples of impacts can include the introduction of sediment or contaminants to streams from invasive activities, or the lowering of the reservoir prescribed to mitigate drilling hazards such as artesian conditions. In some instances, construction of roads may be required for the mobilization of drill equipment. For these reasons, an environmental management plan (EMP) should be considered and developed (as required) to ensure appropriate processes are in place to avoid potential impacts. It is expected that proponents comply with the “Terms and Conditions for Construction and Maintenance of Licensed Works” (2017) found in Appendix F.

## 8 Field work for an invasive investigation program

The following must be available at the work site during the work:

- A copy of the IIP including 1) technical plan and 2) IDSRMP
- A copy of the DSO's acceptance letter of the IIP
- A copy of the Dam Emergency Plan (DEP), and
- Any equipment or supplies required in the IDSRMP

A DSO may visit the work site to confirm the work is occurring as planned.

## 9 Invasive investigation completion report

The general purpose of an invasive investigation is to collect data to create a model for engineering analysis of a dam and foundation. Dams have a long lifespan, so the data from an invasive investigation should be documented in a format that can be referenced and understood by a different qualified professional. Having the information in a stand-alone completion report, instead of included in a Dam Safety Review or analysis report, provides clarity for future reference.

Upon completion of an invasive investigation, a dam owner, on request of a dam safety officer, must submit a completion report that includes the following records, as laid out in the Dam Safety Regulation:

- a) a record setting out the results of any in-situ testing carried out during the invasive investigation;
- b) records setting out the data obtained from any test or measurement taken, and analysis and interpretation of the data, including, but not limited to,
  - i) a record setting out instrumentation readings, and analysis and interpretation of the readings,
  - ii) visual records or observations,
  - iii) drawings,
  - iv) soil, aggregate and concrete test results, and
  - v) any other test results

The B.C. Dam Safety Program requests that invasive investigation completion reports identify the version number and summary of changes. The report should be prepared and authenticated by the Professional of Record following EGBC requirements. The authentication page identifies the Professional of Record as well as other contributing author(s), and reviewer(s). Where input is required from multiple professional specialists, each specialist must authenticate the document and state the extent of their responsibility. For example, an invasive investigation completion report may be authenticated by a geotechnical engineer, a hydrogeologist, geophysicist and a Professional of Record who coordinated the other professionals.

An example of information to include in a completion report is summarized in Table 4.

The invasive investigation completion report should be prepared and submitted to the DSO within six months of completion of the field work. Any expected delays for submission should be communicated in advance to the DSO.

**Table 4: Examples of information for an invasive investigation completion report**

| Information                                 | Comments                                                                                                                                                                                                                                                                                                            |
|---------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Dam description</b>                      | Describe dam and identify the failure consequence classification.                                                                                                                                                                                                                                                   |
| <b>Objectives and justification</b>         | Describe the justification and objective for the invasive investigation. Document whether the investigation objectives were achieved and discuss any deviations from the planned scope, including the reasons for those deviations and their significance to the investigation findings.                            |
| <b>Impacts</b>                              | Confirm that the invasive investigation did not adversely affect the integrity, performance, or safety of the dam.                                                                                                                                                                                                  |
| <b>Summary of IIP</b>                       | Provide details on when the work occurred, who supervised the work, equipment used, backfill details, and survey method. Identify if there were limitations or restrictions relevant to data collection.                                                                                                            |
| <b>In-situ testing performed</b>            | Provide factual details so the data may be used by a different qualified professional to perform an analysis. Include information on testing equipment model, dimensions, energy, loading conditions, et cetera.<br>Provide sufficient information to support independent review and interpretation of the results. |
| <b>Laboratory testing</b>                   | Describe testing performed, sample location and results. Provide references to method or standards as appropriate.                                                                                                                                                                                                  |
| <b>Stratigraphy, lithology, or concrete</b> | Industry accepted engineering methods for the interpretation and description of soil, rock and concrete should be used. The classification method or system should be stated, and if a modified method is used additional explanation provided.                                                                     |
| <b>Water level</b>                          | Describe the water level in the reservoir during the work. Water level and or elevation measured in the holes during or after the work.                                                                                                                                                                             |
| <b>Instrumentation</b>                      | Describe instrumentation installed, and calibration details during installation. Where appropriate, provide records of response of nearby instrumentation during the activities.                                                                                                                                    |

| Information            | Comments                                                                                                                                                                                                                                                                                                                                             |
|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Recommendations</b> | Provide recommendations to the dam owner arising from the findings of the invasive investigation program, including recommendations for future monitoring based on installed instrumentation.                                                                                                                                                        |
| <b>Record drawings</b> | See Appendix B. Include section(s) and profile(s) showing a stick-log of the concrete, soil and or bedrock encountered, and interpretation compared to other known, or assumed conditions.                                                                                                                                                           |
| <b>Attachments</b>     | Test hole logs and classification reference sheet.<br>Photographs of the equipment recovered sampled soils, bedrock, and concrete, as well as other features of interest (organic material, debris, et cetera).<br>Instrumentation field calibration records and manufacturer calibration records (as applicable).<br>Field and lab testing results. |

## 10 Changes to Operation Maintenance and Surveillance (OMS) manual

After the work is completed, the dam owner should review and, if necessary, update their OMS manual to reflect any changes resulting from the work. If a revision is required, it should be completed within 12 months of the work.

Updates may include:

- Adding information to the dam description or history indicating that the invasive investigation was performed
- Adding details on any instrumentation installed as outlined in Appendix C
- Incorporating other changes as recommended by the Professional of Record who supervised and reported on the invasive investigation

# 11 References

- B.C. Provincial Government. (2016, amended February 2023). B.C. Dam Safety Regulation.
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- BC Hydro. (March 2018). Engineering Standard: Justification and Risk Mitigation for Drilling or Excavation in Embankment Dams and Their Foundations.
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# Appendix A – IIP technical plan components

The table of contents for an IIP technical plan should include, but is not limited, to the following information:

- 1) Objective and justification
- 2) Schedule
- 3) Dam description, including failure consequence classification
- 4) Existing information review and data gap identification
- 5) Conceptual Model:
  - a) Embankment dam: conceptual model based on construction records, past testing and photographs. Describe material types and expected locations
  - b) Concrete coring: description of concrete pours, rebar, anchoring to foundation and expected strength
  - c) Foundation: conceptual geological site model based on construction records, testing and geological reports. Describe material types and expected locations
  - d) Assumptions should be clearly explained and or justified
- 6) Failure modes relevant to the invasive investigation
- 7) Invasive investigation method including equipment type, backfilling, surveying and proposed in-situ and laboratory testing
- 8) For each test hole:
  - a) Objective
  - b) Equipment access
  - c) Potential hazards and mitigation
  - d) Instrumentation installation (if applicable)
- 9) Instrumentation record, see Appendix C (if applicable)
- 10) Other considerations, such as public safety, environmental considerations, and archaeology
- 11) Invasive investigation team and qualifications
- 12) Attachments
  - a) Assurance Statement
  - b) Drawings

## Appendix B – Drawings

Both plan and cross-sectional drawing(s) should be legible, at a scale appropriate to the size of the dam and labeled to assist interpretation. Drawings should be specific to the dam and proposed work. Cross-sections drawings should be representative of the location(s) of where the test holes will be advanced.

### **Plan drawing(s) should show:**

Plan drawing(s) for areas of planned drilling or excavation should:

- Identify all test hole locations, excavations, in-situ testing, and sampling areas
- Dam features (crest, spillway, low level outlet, all ancillary components)
- Access and restricted areas (if any).
- Areas relevant to the Dam Emergency Plan (DEP) or Interim Dam Safety Risk Management Plan (IDSRMP)
- Buried utilities and through penetrating structures
- Existing instrumentation
- Existing or historical distress features (slumps, fractures, boils, et cetera) and seepage zones

### **Cross-sectional drawing(s) should show:**

Proposed drill holes to include the conceptual dam model consisting of the following information:

- For concrete dams, rebar spacing, existing instrumentation, ancillary components, et cetera
- For embankment dams, zone contacts and materials including core, filters, drains, buried drainage pipes, anticipated phreatic surface level, anticipated foundation soil and or rock types and contacts foundation and or abutment contacts
- Planned instrumentation installation, including depth and planned backfill details (screen, seal, stickup, surface seal, cover, et cetera)

## Appendix C – Instrumentation record

Information known or reasonably available at the time of submission should be provided for a proposed instrumentation change. This should include, as applicable:

- Proposed instrument type and objective
- Parameter to be measured
- Proposed location or area of installation
- Anticipated installation method
- Intended monitoring frequency and
- Criteria that will be used to determine the final location, depth or configuration in the field

It is recognized that some instrumentation details cannot reasonably be determined until subsurface conditions are encountered or sufficient baseline data have been collected. The Professional of Record may make field adjustments that remain consistent with the objectives and risk controls of the accepted plan. This may include installing an instrument at an appropriate or opportunistic depth where actual conditions differ from those anticipated or reliable as-built information is unavailable.

The actual installation details should be documented following the work. These should include, as applicable:

- Instrument type, model and identifier
- Actual location, elevation and installation depth
- Installation and backfilling details
- Calibration information and baseline readings
- Reading, data-download and maintenance requirements
- Data analysis and reporting procedures and
- Normal ranges, warning and alarm thresholds, their technical basis and associated response actions

Information not available at the time of installation should be established within a reasonable period based on the instrument's purpose, the baseline data required and its dam safety significance. Outstanding information, interim monitoring requirements, responsibilities and anticipated completion dates should be identified in the completion report.

Final information should be incorporated into the instrumentation records, record drawings and OMS Manual. The DEP should also be updated where instrumentation thresholds or response actions are relevant to emergency identification or response. The

OMS Manual should normally be updated within 12 months of the work, while information needed for immediate monitoring or emergency response should be communicated to dam operators as soon as practicable.

## Appendix D – IDSRMP components

An Interim Dam Safety Risk Management Plan (IDSRMP) is a written plan for managing temporary dam safety risks associated with work or operational changes at a dam. An IDSRMP identifies the applicable hazards and risks and, where necessary, documents temporary risk controls, operational restrictions, enhanced surveillance and planned response actions.

An IDSRMP is not required where the qualified professional demonstrates in the Invasive Investigation Plan that the work does not require operational changes, enhanced surveillance or temporary response measures, and that the residual risk is as low as reasonably practicable. This may apply, for example, to work in competent concrete or rock at the downstream toe where there is no credible mechanism for the work to adversely affect the safe functioning of the dam. The justification should be proportionate to the nature and risk of the work and should consider the location, investigation method, dam condition, credible failure mechanisms and consequences of an adverse event.

Risk may be managed by avoiding, eliminating, reducing, transferring, monitoring or accepting the residual risk, as appropriate. Mitigation is therefore not required solely for the purpose of demonstrating that a risk has been considered. Where the residual risk is demonstrated to be as low as reasonably practicable and no additional temporary measures are warranted, the qualified professional should document this conclusion and its technical basis in the Invasive Investigation Plan. The dam owner remains responsible for accepting any residual risk associated with the work.

An IDSRMP should be authenticated by a qualified professional familiar with the structure and proposed work. The purpose of an IDSRMP is to focus on concerns related to the structural safety of the dam. Environmental spills or releases should be covered in a separate environmental protection or management plan.

As an example, an IDSRMP could include:

1. Brief description of the work
2. Work schedule and or when the IDSRMP is expected to apply
3. Reservoir level required for the work
4. Risks to the dam that the proposed work may create
5. Mitigation and response measures for the identified risks
6. Enhanced surveillance methods and responsibilities before, during and after the work

7. Contact information for key personnel, including order of contact and specific roles or responsibilities in the context of the work
8. Authentication page identifying who prepared and reviewed the plan. An IDSRMP must be authenticated by a qualified professional

Additional information for an IDSRMP that is specific to invasive investigations may include:

- If drilling fluid will be used, how the drilling fluid will be circulated and tracked to identify losses
- Instruments that will be monitored during the work for unexpected response. Include defined threshold values and action plans for unexpected response changes
- Emergency supplies that will be available on site during the investigation (for example fill material, filter material, grout, backhoe, phone or radio, et cetera)
- Communication methods at the dam site, for example cell reception, other communication equipment required
- If spillway gates will be removed from service during work, describe what storm event the remaining open spillway can safely pass, and plans and timing to return the gates to service

Examples of hazards, risks and mitigation measures for an invasive investigation are summarized in Table D-1. These are general examples and should be adjusted to be specific to the dam type, investigation method, reservoir and project specific risks.

In preparing preventative mitigation measures and response actions, the qualified professional should keep in mind that the observational method may be acceptable for mitigating and responding to hazards. However, if the observational method is used, the expected performance and pre-planned responses to deviations in performance must be clearly documented. The following quotes by Peck<sup>3</sup> should be considered:

“The [observational] method is not without its pitfalls and limitations. It should not be used unless the designer has in mind a plan of action for every unfavourable situation that might be disclosed by the observations. The observations must be reliable, must reveal the significant phenomena, and must be so reported as to encourage prompt action. The possibility of progressive failure may introduce a serious element of uncertainty.”

---

<sup>3</sup> Peck, R.B., “Advantages and Limitations of the Observational Method in Applied Soil Mechanics”, Ninth Rankine Lecture, Geotechnique 19, No. 2 171-187, 1969.

“Potentially the most serious blunder in applying the observational method is the failure to select in advance appropriate courses of action for all foreseeable deviations of the real conditions, as disclosed by the observations from those assumed in the design. If the engineer suddenly realizes that the observations show the job to be heading for trouble against which he has no defense, he must reach crucial decisions under the pressures of the moment. If he is very unlucky he may find that there is no adequate solution at all. Had he originally considered all the possibilities, he would have concluded in advance that if certain unfavourable conditions prevailed he would not be able to carry out the design, and he would not have embarked on a design vulnerable to such conditions.”

**Table 5: IDSRMP examples of hazards, mitigation and response actions for an invasive investigation**

| Examples of Hazards or Risks | Examples of Preventative Measures                                                                                                                                                | Examples of Monitoring Observations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Examples of Response Actions                                                                                                                                                                                                                                                                        |
|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Hydraulic fracturing</b>  | <ul style="list-style-type: none"> <li>• Drill without pressurized fluids</li> <li>• Avoid drilling through core, filter and drains</li> <li>• Minimize fluid density</li> </ul> | <ul style="list-style-type: none"> <li>• Loss of drill fluid circulation</li> <li>• Drop of fluid level in hole</li> <li>• Turbidity observed in seepage near the toe of the dam</li> <li>• Cracks forming on concrete dam or on embankment dam surface</li> <li>• Change in water level in a piezometer</li> <li>• Change in flow rate at the dam toe</li> <li>• Turbidity or drill fluid observed in seepage near dam toe</li> <li>• Air bubbles or turbidity in reservoir</li> <li>• Change in piezometer measurements</li> </ul> | <ul style="list-style-type: none"> <li>• Stop drilling</li> <li>• Seal zone of fluid loss</li> <li>• Increase reading frequency of specific instruments</li> <li>• Buttress dam toe</li> <li>• Specific contingency plan based on dam</li> <li>• Engineering assessment of safety of dam</li> </ul> |

| Examples of Hazards or Risks             | Examples of Preventative Measures                                                                                                                                                                               | Examples of Monitoring Observations                                                                                                                                                                                                      | Examples of Response Actions                                                                                                                                                                                                                                                                                                                                             |
|------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Encountered core, filter or drain</b> | <ul style="list-style-type: none"> <li>• Background review</li> <li>• Survey features of the dam</li> <li>• Confirm hole alignment with downhole surveys</li> </ul>                                             | <ul style="list-style-type: none"> <li>• Change in drill cutting</li> <li>• Sudden loss of fluid</li> <li>• Turbidity or drill fluid observed in seepage near the toe of the dam</li> <li>• Change in piezometer measurements</li> </ul> | <ul style="list-style-type: none"> <li>• Stop drilling, if this was not planned</li> <li>• Determine appropriate repair and or backfill methods depending on observations and dam. Enhanced surveillance measures depending on situation</li> <li>• Buttrussing of dam toe</li> </ul>                                                                                    |
| <b>Heave or formation of sinkholes</b>   | <ul style="list-style-type: none"> <li>• Case hole</li> <li>• Plan for drilling fluid of a specific density to counterbalance expected water pressure</li> <li>• Lower reservoir level prior to work</li> </ul> | <ul style="list-style-type: none"> <li>• Caving and or slough</li> <li>• Heave</li> <li>• Formation of sinkholes</li> <li>• Change in piezometer measurements</li> </ul>                                                                 | <ul style="list-style-type: none"> <li>• Stop drilling</li> <li>• Lower reservoir level</li> <li>• Promptly plan to seal hole and depending on volume displaced, how to fill any voids that were created</li> <li>• Determine appropriate repair and or backfill methods depending on observations and dam</li> <li>• Engineering assessment of safety of dam</li> </ul> |

| Examples of Hazards or Risks              | Examples of Preventative Measures                                                                                                                                                                                                                                                | Examples of Monitoring Observations                                                                                                                                     | Examples of Response Actions                                                                                                                                                                                   |
|-------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Artesian conditions</b>                | <ul style="list-style-type: none"> <li>Plan work and drill outside of potential artesian zones</li> <li>Construct temporary berm platform at toe to drill from</li> <li>Use designed drill fluid</li> <li>Surface Casing</li> <li>Lower reservoir level prior to work</li> </ul> | <ul style="list-style-type: none"> <li>Water level higher than ground surface, or anticipated water level</li> <li>Water flowing from borehole</li> </ul>               | <ul style="list-style-type: none"> <li>Stop drilling</li> <li>Lower reservoir level</li> <li>Packer to seal the zone</li> <li>Tremie grout the hole</li> <li>Use drilling fluid with a high density</li> </ul> |
| <b>Damage to existing instrumentation</b> | <ul style="list-style-type: none"> <li>Plan to avoid existing instruments, casing or cables</li> <li>Locate and or survey pre work utility</li> </ul>                                                                                                                            | <ul style="list-style-type: none"> <li>Instrument stops functioning during work</li> <li>Cables or casing observe in drill cuttings or spoil pile</li> </ul>            | <ul style="list-style-type: none"> <li>Stop work</li> <li>Evaluate if work can continue without instrument</li> <li>Evaluate need for instrument and replacement options</li> </ul>                            |
| <b>Utilities</b>                          | <ul style="list-style-type: none"> <li>Utility locates</li> <li>Hand digging</li> <li>Hydro vacuum</li> </ul>                                                                                                                                                                    | <ul style="list-style-type: none"> <li>Electrical shock</li> <li>Broken pipe pieces</li> <li>Water flowing from borehole where it is not artesian conditions</li> </ul> | <ul style="list-style-type: none"> <li>Stop drilling</li> <li>Contact appropriate utility company to address</li> <li>Determine appropriate repair methods depending on observations and dam</li> </ul>        |

| Examples of Hazards or Risks              | Examples of Preventative Measures                                                                                                                                                                                                                                                  | Examples of Monitoring Observations                                                                                                                                    | Examples of Response Actions                                                                                                                                                                                              |
|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                           |                                                                                                                                                                                                                                                                                    | <ul style="list-style-type: none"> <li>No resistance during drilling, or rods fall</li> </ul>                                                                          |                                                                                                                                                                                                                           |
| <b>Slumping</b>                           | <ul style="list-style-type: none"> <li>Consider weight of equipment and safe access for dam</li> <li>Plan for stress relief and to avoid heave and hydraulic fracture</li> </ul>                                                                                                   | <ul style="list-style-type: none"> <li>Movement of the dam</li> <li>Cracks forming on the dam crest or slope</li> <li>Change in water level in a piezometer</li> </ul> | <ul style="list-style-type: none"> <li>Stop drilling</li> <li>Lower reservoir level</li> <li>Backfill borehole with grout</li> <li>Add buttressing to dam toe</li> <li>Engineering assessment of safety of dam</li> </ul> |
| <b>Rebar encountered</b>                  | <ul style="list-style-type: none"> <li>Plan location of holes based on record drawing</li> <li>Non invasive scans</li> </ul>                                                                                                                                                       | <ul style="list-style-type: none"> <li>Observed in core</li> <li>Change in drill resistance</li> </ul>                                                                 | <ul style="list-style-type: none"> <li>Stop drilling</li> <li>Evaluate repair options based on observations and dam</li> </ul>                                                                                            |
| <b>Spillway gate removed from service</b> | <ul style="list-style-type: none"> <li>Gate removed from service due to interference between drill mast and operation</li> <li>Plan to identify risk of gate being removed</li> <li>Plan work at time of year when there is a low likelihood of spilling being required</li> </ul> | <ul style="list-style-type: none"> <li>Weather forecast or measurements</li> <li>Increase in reservoir level</li> </ul>                                                | <ul style="list-style-type: none"> <li>Plan to delay program if weather conditions are unfavourable</li> <li>Active recall plan to return gate to service</li> </ul>                                                      |

| Examples of Hazards or Risks | Examples of Preventative Measures                                                | Examples of Monitoring Observations                                 | Examples of Response Actions                                                                                                                                                                                                                                              |
|------------------------------|----------------------------------------------------------------------------------|---------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                              | <ul style="list-style-type: none"><li>Plan to monitor weather forecast</li></ul> |                                                                     |                                                                                                                                                                                                                                                                           |
| <b>Earthquake</b>            | <ul style="list-style-type: none"><li>No planning mitigation available</li></ul> | <ul style="list-style-type: none"><li>Ground shaking felt</li></ul> | <ul style="list-style-type: none"><li>Stop work, evacuate dam</li><li>Visually inspect dam from distance</li><li>Read piezometers for change in pressure that could indicate liquefaction has occurred</li><li>If access is safe, backfill hole or buttress dam</li></ul> |

## **Appendix E – Assurance statement**

### B.C. Dam Safety - Invasive investigation plan assurance statement

As the Professional of Record, I have prepared the Invasive Investigation Plan in accordance with the B.C. Dam Safety “Guideline for Submitting Invasive Investigation Plans and Instrumentation Records” and have included a statement of qualifications as an individual or multidiscipline team lead. The proposed work is justified and was developed to minimize the likelihood of damage to the structure(s) identified below.

|                                                                                                                                                                                                    |                                                                           |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Name and title of Professional of Record:                                                                                                                                                          | (Affix professional seal, signature, date, and Permit to Practice number) |
| Company name and address:                                                                                                                                                                          |                                                                           |
| Telephone:                                                                                                                                                                                         |                                                                           |
| Email:                                                                                                                                                                                             |                                                                           |
| (If the Registered Professional is a member of a firm, complete the following.)<br>I am a member of the firm<br>_____<br>(Print name of firm)<br><br>and I sign this letter on behalf of the firm. |                                                                           |

#### Part 1 Dam(s): (list all dams included in IIP)

|                           |  |
|---------------------------|--|
| Dam Owner:                |  |
| Dam Name(s):              |  |
| Provincial Dam Number(s): |  |

|                                    |  |
|------------------------------------|--|
| Dam Consequence Classification(s): |  |
|------------------------------------|--|

**Part 2 High-Risk Work Assessment:**

|                                                                  |                              |                             |
|------------------------------------------------------------------|------------------------------|-----------------------------|
| Did you determine this work to be High-Risk as defined by EGBC?: | Yes <input type="checkbox"/> | No <input type="checkbox"/> |
| If yes, who completed the Independent Review:                    |                              |                             |
| If yes, firm that completed Independent Review:                  |                              |                             |

## **Appendix F – Terms and conditions for construction and maintenance of licensed works**



## Terms and conditions for construction and maintenance of licensed works

This intent of this document is to provide terms and conditions to water licence holders to ensure construction and maintenance of infrastructure is planned, designed and implemented with regard for fish, wildlife, and habitat protection.

Construction activities associated with the installation or maintenance of licenced infrastructure can impact fish and wildlife habitat through the deposit of materials, like sediment, that are deleterious to fish and fish habitats. Proper construction and maintenance of licensed infrastructure can also help minimize impacts to terrestrial species or habitats associated with riparian areas.

You may proceed with the proposed construction or maintenance but must also comply with the following terms and conditions:

1. Any work associated with the proposed changes in and about a stream must not cause stream channel instability or introduce sedimentation into the stream in such a quantity to cause a significant adverse impact to the aquatic ecosystem of the stream
2. During work onsite, erosion and sediment control materials must be available onsite at all times and must be installed if sedimentation is likely to occur into the stream. A contingency plan must be developed outlining the measures to be taken by workers when carrying out any work to control erosion and sediment
3. Any soil removed must be placed in a location that ensures that sediment or debris does not enter the stream
4. Within a work area, water that contains sediment must be pumped to a vegetated area away from the stream where it can seep into the ground, or to a settling pond that is sufficiently far from the stream to allow sediment to settle out before the water returns to the stream
5. The disturbance of stream bank vegetation must not occur or mitigated if it does occur
6. Work must be conducted on, and equipment located and operated from, dry land (no water present) and the worksite must be isolated from flowing water
7. Any equipment used in conducting work must be in good mechanical condition (not leaking fuels, lubricants, anti-freeze, fluids, et cetera) and, when operating in proximity to the wetted perimeter of a stream, the operator must prevent introduction of any sediment, debris or contaminants (for example,

- hydrocarbons, silt) into the stream in such a quantity to cause a significant adverse impact to the aquatic ecosystem
8. All stream flow must be maintained in the stream channel upstream and downstream of the worksite at all times
  9. When work requires de-watering or isolation of the worksite in the stream, a permit for the salvage of fish and wildlife must be obtained prior to commencing work. All required salvage permits must be obtained from [FrontCounterBC](#). Any salvage must be carried out by a qualified environmental professional (such as an R. P. Bio)
  10. Following de-watering or isolation of the worksite, stream flow must be returned to the de-watered or isolated area within the stream in a manner so as to avoid a single sudden rush or erosion of the stream channel and sediment delivery to the stream
  11. The stream channel width must not change as a result of the work.
  12. Any materials, such as riprap or gabion rock, placed within the stream must be clean and not contain substances that could be harmful to fish, wildlife or habitat (for example, acid generating rock, fine erodible materials or treated wood products)
  13. Any areas disturbed as part of the work must be restored as close as possible to their pre-disturbance condition. Any soil exposed at the worksite must be promptly re-vegetated
  14. Subject to section 15 and 16 below, the work must be completed during the "least risk" timing window for the stream in respect of which the changes are proposed. The applicable "least risk" timing window (by region and or by stream) are specified in the following link (see below) and are designed to protect fish, wildlife or habitat known or suspected to be present in the stream. To determine the "least risk" timing window, visit the [Regional terms and conditions and timing windows page](#) and then select the relevant region from the list and then determine the applicable "least risk" timing window for that region and for the stream where the proposed changes will be made. For projects proposed to take place outside these timing windows, please see section 15 and 16 below
  15. In addition to the "least risk" timing windows specified in section 14 above, work may be carried out during the following times provided these requirements are met when the changes are carried out:
    - i. If the stream channel is naturally dry (no flow) or frozen to the bottom at the worksite and the instream work and or activity associated with the

- proposed change will not adversely impact fish, wildlife or habitat (for example, not result in any substance, sediment, debris or other material entering or leaching into the stream that would adversely affect fish, wildlife or their habitat),
- ii. In the construction of a winter crossing, the stream channel is frozen to the bottom at the worksite and related work does not adversely impact the stream channel (including stream bed and banks), or fish, wildlife or habitat, or impede their passage (in both directions) in the stream
16. If your work is proposed outside of the "least risk" timing window (as described in section 14 above), you must retain a qualified environmental professional (such as an R.P. Bio.). The professional will be responsible for providing a written technical rational that assesses and addresses the risks of the proposed changes in and about a stream, including proposing site specific mitigation (for example, an Erosion Control Plan that identifies contingency measures and emergency procedures related to the proposal) and onsite monitoring of their implementation. In proceeding outside the "least risk" timing window in accordance with recommendations by your qualified environmental professional, you must comply with any measures specified by that professional to prevent impacts on the stream channel (including stream bed and banks) or fish, wildlife or their habitat.

In summary, you must meet the terms and conditions described above, as well as any additional terms and conditions specified by the Water Manager or Habitat Officer if any were specified.

Also, for assistance to the public, the government of B.C. has developed clear guidance and or practices, also referred to as best management practices, for working around water. This information, if followed, will help ensure that your project will have minimal impacts on the environment (including related fish, wildlife and habitats) in the stream and stream channel.

Follow the links and website directions (see below) to review the provincial guidance and or practices provided for your proposed works. Please be advised that these documents may contain information which may be the subject of change due to amendments to the federal Fisheries Act and or to related processes by Fisheries and Oceans Canada (DFO). Current up-to-date information on DFO process and legislation can be found at:

<http://www.dfo-mpo.gc.ca/pnw-ppe/index-eng.html>

Final Note: It is the responsibility of persons intending to carry out construction and maintenance of licenced works:

To comply with federal, provincial and municipal enactments, including but not limited to the Fisheries Act (Canada), Wildlife Act (BC) or the Navigation Protection Act (Canada), as well as local government bylaws and regulations, as may be applicable to proposed works or activities;

In cases of demonstrated non-compliance with legal requirements, compliance and enforcement actions may subsequently be undertaken by the Ministry where circumstances warrant.

March 2017

# Appendix G – Case studies

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### Case study – Wilsey Dam

Wilsey Dam is a concrete dam. In December 1992, BC Hydro was installing anchors and drain holes in the dam to improve stability. Work was carried out by an experienced crew with direct supervision by a qualified engineer.

During the drilling of a drain hole, the air-track drill intercepted a sudden water flow estimated at 2000 litres per minute. This flow was encountered at a depth of less than 1m from the downstream face of the dam. The flow created a plume of water approximately 8 to 10 m in height when the drill bit was withdrawn from the hole. The drill bit and steel rods were advanced back into the hole to help stem the flow. The hole was plugged with grout and drilling of the drain hole was continued in the same location. At a depth of 1.2 m, an estimated flow of 3500 L per min was encountered.



Photo 5: Drillhole experiencing artesian flow conditions.

In both cases, the experienced crew was able to stem the flow and grout the hole. The cause of the high-pressure flow was found to be two 254 mm (10 in) diameter steel pipes. That portion of the dam was constructed in 1929, so the pipes were assumed to be 63 years old. The pipes had an orientation nearly perpendicular to the drain hole. Record drawings for the dam were unavailable, and the pipes were not shown on any drawings used in preparing the work.

This case highlights the importance of:

1. Carrying out a desk study to assess risks associated with the invasive investigation. If record drawings are not available, consider reviewing construction notes and photos and or typical construction methodologies from the era of dam construction
2. Identifying the associated risks in advance and developing a mitigation plan
3. Having an experienced work crew directed by a qualified engineer

### Case study – WAC Bennett Dam

In 1986-1987, BC Hydro carried out an exploratory drilling and testing program to determine rock permeability and piezometric pressures within a 10 m thick zone below the dam core and/or bedrock contact. The investigation also tested for the existence of potential seepage paths within the foundation. The drilling plan consisted of twelve near-horizontal holes, laid out to avoid intersecting the core.

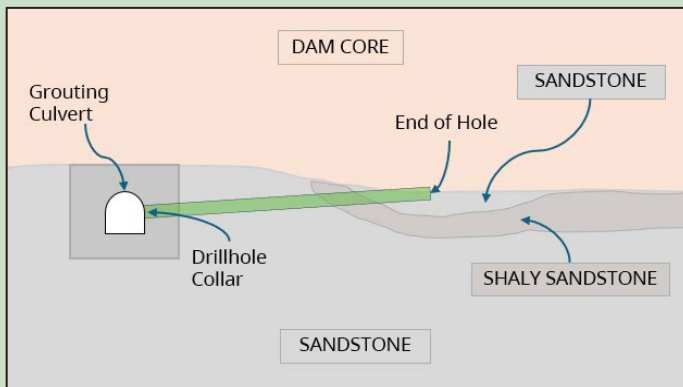


Figure 2: Simplified cross-section of dam and drillhole.

The first hole sagged by  $6^\circ$ , so the second hole orientation was modified by  $+3.5^\circ$  to account for this. Unfortunately, the second hole did not deviate and about 0.4 m of dental concrete was encountered at the impervious core contact. About 2 cubic yards of core material washed out of the hole before it was grouted.

For the remaining holes, Tropari angle tests were conducted at regular intervals to accurately locate the end point of the holes. Accurate geological maps of the as-built foundation surface, with topography, were also compiled and used to construct sections along the drill hole bearings. In this way, drill hole progress could be closely monitored and the hole terminated if the risk of breaking through into core increased.

Later in the program, another drillhole intersected the core but was backfilled with grout more quickly, learning from the earlier lesson. This prevented a washout event like the first time the core was encountered.



Photo 6: Core materials washed out of borehole.

This case highlights the importance of:

1. Carrying out a desk study of available information to pre-assess the risks associated with the invasive investigation
2. Having a plan to address identified risks
3. Ensuring that the methods for implementing and monitoring the invasive investigation are sufficient to mitigate the risk
4. Having experienced crew directed by a qualified engineer

### Case study – Hydraulic fracturing

There are several examples from the U.S. of drilling causing hydraulic fracturing in dams. The following cases are presented by USACE in their regulation ER 1110-1-1807 Drilling and Invasive Activities at Dams and Levees, June 1, 2023.

These photos show the effects of hydraulic fracturing that developed during drilling. The bluish grey horizontal lines show set grout. During installation, the pressure in the grout exceeded the pressure in the surrounding soil causing it to fracture and the grout to flow away from the borehole.

These examples highlight the importance of:

1. Monitoring pressure in a borehole
2. Planning and selecting a drilling and backfilling method to avoid the risk of hydraulic fracturing



Photo 7: Example of hydraulic fracturing at Kentucky Dam.



Photo 8: Example of hydraulic fracturing at Barker Dam.

### Case study – WAC Bennett Dam

In 1996, a tourist reported a 'pothole' on the crest of the WAC Bennett dam. Upon investigation by BC Hydro staff, a construction survey benchmark tube was observed at the base of the cavity. The existence of the buried survey benchmark had not been documented on construction drawings available to the dam surveillance staff.

To investigate the condition of the dam core, a Becker drill was brought to site. After advancing the pipe with very little resistance to a depth of 32 m., the drillhole began to open, resulting in a cavity approximately 2.5 m in diameter and 7 m in depth. A second smaller void associated with another survey benchmark was later discovered.



Photo 9: Sinkhole at WAC Bennett Dam. Prompt action prevented a dam breach. Photo by Ray Stewart.

The cause of the sinkholes was found to be a combination of light compaction around the survey benchmark, proximity to the canyon walls, and the migration of fines. The conditions causing the sinkhole may have developed shortly after first impoundment, however the surface expression did not occur until many years after due to soil arching.

The incident required lowering the reservoir by 2 m, followed by specialized compaction grouting to repair the dam. In total, the investigations and repair cost BC Hydro an estimated \$40 million, not including lost power potential from lowering the reservoir.

This case highlights the importance of:

1. Proper installation of buried instrumentation
2. Risks associated with invasive investigations
3. Importance of developing detailed construction record drawings
4. Awareness of potential unseen hazards around dams

### Case study – Unstable ground

A dam reservoir was lowered so that a test pit excavation for a soil sampling program could proceed. The exposed reservoir slopes dried on surface, but the soils at depth continued to be saturated. Two weeks after dewatering, an excavator tracked across the edge of the reservoir, where it sank and caused an undrained slope failure.



Photo 10: Excavator stuck in upstream slope, causing an undrained slope failure.

Retrieving the machine took a day of coordination between the site team and required the use of three other excavators. The incident had an approximate cost of \$20,000 in lost time and production. Although not a dam safety risk, worker safety and environmental issues could have resulted.

This case highlights the importance of:

1. Proper planning and direction to operators
2. Importance of groundwater monitoring, stability assessments and defining phreatic surface levels prior to work proceeding
3. Importance of having additional equipment available or on call to assist in an emergency