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Dam Safety Review and Risk Assessment of Ashburnham Creek Dam

Presented To:

CVRD

Dated: March 2019

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Ecora's General Conditions are provided in Appendix H of this report.

Executive Summary

Cowichan Valley Regional District (CVRD) engaged Ecora Engineering & Resource Group Ltd. (Ecora) to undertake a comprehensive Dam Safety Review (DSR) and risk assessment of the Ashburnham Creek Dam located just south of Honeymoon Bay, BC on the southern shore of Cowichan Lake. Ashburnham Creek Dam is approximately 6.2 m high and 25.3 m long according to the MFLNRORD dam database. There is an 11.62 m long concrete spillway located at the left side of the dam crest with a crest elevation 1.32 m below the dam crest, as identified during the site reconnaissance completed by Ecora on April 17, 2018. The dam crest was measured at 0.61 m wide, the upstream face is vertical, and the downstream face is sloped slightly offset from vertical at an approximate angle of 15°. The full length of the dam including the spillway and abutments was estimated to be 24.8 m. A summary of key dam and reservoir attributes is included in Table i below.

Table i Summary of Key Dam Attributes

Ashburnham Creek Dam		
Provincial Dam File Number:	D730128-00	
Stream Name:	Ashburnham Creek	
Current Consequences Classification:	Significant	
Dam Type:	Concrete Gravity	
Location:	Latitude: 48°48’24” N	Longitude: 124°11’01” W
Height:	6.2 m	
Length:	24.8 m	
Spillway Length:	11.6 m	
Crest Width:	0.61 m	
Spillway Capacity:	34.5 m^3/s	
Live/Dead Storage:	2,030 m^3	
Potential Storage:	470 m^3 (2,500 m^3 Total)	
Drainage Area:	6.04 km^2	
Peak of Inflow Design Flood (IDF):	60.2 m^3/s – 75.4 m^3/s (Significant – 100-year to 1,000-year flood)	
Peak Outflow During IDF:	60.2 m^3/s – 75.4 m^3/s (Significant – 100-year to 1,000-year flood)	

The DSR was undertaken in general accordance with the requirements of the BC Water Sustainability Act including all amendments up to BC Reg. 301/2016 (December 7, 2016), the BC Dam Safety Regulation BC Reg. 40/2016 (February 29, 2016), the Association of Professional Engineers and Geoscientists of BC (APEGBC) Professional Practice Guidelines – Legislated Dam Safety Reviews in BC V3.0 (October 2016), and the Canadian Dam Association (CDA) Dam Safety Guidelines (DSG) 2007 (2013 Edition).

The scope of the DSR included the following tasks:

- Background review;
- Site reconnaissance;
- Review of consequences classification;
- Dam assessment, including wall stability and seepage;
- Hydrotechnical analysis including dam break analysis, flood routing and hydraulics;
- Review of any existing Operation, Maintenance & Surveillance Manual, Dam Emergency Plans (Emergency Response Plan and/or Emergency Preparedness Plan), and/or public safety management strategies;

- Risk assessment as per the NDMP framework;
- Assessment of compliance with CDA design criteria; and,
- Development of conclusions and recommendations.

Key outcomes from the engineering analyses are summarized in Table ii below.

Table ii Summary of Results from Engineering Analyses

Does the dam meet CDA design criteria?	Yes/No	Comments
Is the current consequences classification appropriate for this dam in accordance with the BC Dam Safety Regulation BC Reg. 40/2016?	Yes	See Section 6
Do the strength and/or characteristics of the dam foundation materials provide sufficient resistance to liquefaction or softening during seismic (cyclic) loading due to application of the EDGM?	Yes	See Section 8.6
Does the dam meet minimum CDA sliding stability criteria for all loading conditions?	No	See Section 8.4
Does the position of the force resultant meet CDA minimum criteria for all loading conditions?	No	See Section 8.4
Are maximum stresses (normal, perpendicular) within the limits of CDA acceptance criteria?	Yes	See Section 8.4
Does the dam meet CDA minimum static global stability criteria?	No	See Section 8.4
Does the dam meet CDA minimum pseudo-static global stability criteria?	No	See Section 8.4
Does the dam meet CDA minimum post-earthquake global stability criteria?	No	See Section 8.4
Do the characteristics of the dam foundation materials provide sufficient resistance and/or control of seepage to prevent internal erosion?	Yes	See Section 8.7
Does the spillway have sufficient capacity to safely pass the inflow design flood (IDF)?	Yes	See Section 9.5
Does the dam meet CDA freeboard requirements including the effects of wind and wave action?	Yes	See Section 9.5

Based on the results of the site reconnaissance, analyses and assessment of the dam, a number of observations, conclusions and recommendations were developed as summarized in Table iii below. Priorities (Low, Medium, High or Very High) are given in parentheses. Low, Medium, High and Very High priority recommendations should be addressed within 5, 3, 1 and 0.5 year(s) respectively.

Dam Safety Review of Ashburnham Creek Dam — Observations, Conclusions and Recommendations

Task	Observations & Conclusions	Recommendations
Background Review	▪ Limited background information is available for this dam which does not include record drawings for the dam structure. ▪ The dam was constructed in 1947 by a logging company. ▪ The reservoir has filled with sediment, possibly as a result of logging roads washing out in upstream areas on two occasions.	▪ As no record drawings are available for the dam structure, a detailed topographical survey of the dam embankment, abutments, outlet and spillway channel should be commissioned to verify existing dam geometry, confirm critical dam elevations and to assist in any future engineering assessments (High).
Site Reconnaissance	▪ The reservoir was completely filled with sediment up to the spillway crest at the time of the site reconnaissance. ▪ Extensive organic growth (moss) was noted throughout the surface of the structure. ▪ A build-up of oxidation residue appeared to be staining the mossy growth on the concrete surface on the downstream side of the dam and therefore it is suspected that the reinforcing steel has corroded. ▪ Signs of erosion and weathering were noted on the upstream side of the west wing wall.	▪ There are no recommendations in this area of the review.
Consequence Classification Review	▪ The dam breach inundation mapping indicates that a total area of 0.33 km^2 would be flooded in the event of a dam breach during a 100-year event, potentially impacting Gordon River Road and South Shore Road. ▪ Dam breach analysis and inundation mapping results confirmed that the consequences classification for Ashburnham Creek Dam should be maintained as “Significant”. The CDA guidelines recommend an Inflow Design Flood (IDF) for a “Significant” consequence dam to be between the 100-year and the 1,000-year event.	▪ There are no recommendations in this area of the review.
Failure Mode Assessment	▪ The plausible failure modes of the dam are; overtopping as the spillway may not have sufficient capacity to pass the IDF, deformation and deterioration due to age and sliding/overturning from the design flood or seismic forces.	▪ There are no recommendations in this area of the review.
Geotechnical and Structural Assessment	▪ Results of the stability assessment indicate that the dam does not meet CDA criteria for normal, flood, earthquake and post-earthquake load combinations under the current sediment loading. ▪ Even with removal of the sediment loading, the dam still does not meet the CDA criteria for normal, earthquake and post-earthquake load combinations. ▪ The results indicate that the dam is unstable upon application of the EDGM for a “Significant” consequence classification. ▪ Even upon removal of the sediment loading, the dam is only stable up to an applied EDGM between the 1/100-year and 1/475 year seismic events which corresponds to a NDMP likelihood rating of 3. ▪ The allowable bearing capacity of the foundation is adequate to resist the maximum compressive stress for normal, flood, earthquake and post-earthquake loading conditions. ▪ The dam foundation is considered to have a very low susceptibility to liquefaction and post-seismic deformation when subject to strong ground motion. ▪ The dam foundation is considered to have an extremely low susceptibility to piping failure.	▪ CVRD should commission a design study to address the major deficiencies in the Ashburnham Creek Dam, namely to increase its resistance to sliding and overturning to meet CDA stability criteria. It is envisioned this would result in a recommendation to either remediate or decommission the existing dam. Remediation of the dam would likely include the design of a reinforced concrete toe buttress solution to increase the stability of the gravity wall (Very High). ▪ If it is chosen to remediate the existing dam, it is recommended that sediment retained by the dam be removed, a debris barrier constructed upstream of the dam to contain debris and areas of concrete deterioration, particularly in vicinity of cold joints, be addressed.
Hydrotechnical Assessment	▪ The peak inflow to Ashburnham Creek Dam during the IDF associated with the recommended “Significant” consequences classification is between 60.2 m^3/s (100-year flood) and 75.4 m^3/s (1,000-year flood). Because of the absence of significant storage, peak outflows are the same as peak inflows. ▪ The capacity of the spillway is estimated to be 34.5 m^3/s. ▪ The flood routing exercise determined that during the IDF event the dam crest will be overtopped. Given that Ashburnham Creek Dam is a concrete gravity dam, it should be able to resist overtopping without serious damage.	▪ Extra spillway capacity should be added to the dam to allow for passage of the IDF event or the dam should be strengthened so that the dam would be able to resist forces generated by an overtopping event during the IDF (High).
Dam Safety Management	▪ No Operation, Maintenance and Surveillance (OMS) Manual or Dam Emergency Plan (DEP) is currently in place for Ashburnham Creek Dam.	▪ An Operation, Maintenance and Surveillance Manual and a Dam Emergency Plan need to be prepared for Ashburnham Creek Dam (High). ▪ The dam should either be decommissioned or rehabilitated to meet design loading criteria (High).
Risk Assessment	▪ Even upon removal of the sediment loading, the dam is only stable up to an applied EDGM between the 1/100-year and 1/475 year seismic events which corresponds to a NDMP likelihood of 3. ▪ A preliminary estimate of reconstruction costs as a result of a dam breach is between $300,000 and $3 million based on the scope of the infrastructure impacted.	▪ Should the CVRD wish to proceed with a NDMP funding application to remediate or replace Ashburnham Creek Dam they should undertake a more detailed cost estimate of infrastructure that would be impacted in the event of a dam breach (High).

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Acronyms and Abbreviations

AEP	Annual Exceedance Probability
APEGBC	Association of Professional Engineers and Geoscientists of British Columbia
BC	British Columbia
CDA	Canadian Dam Association
CFEM	Canadian Foundation Engineering Manual
CN	Curve Number
CVRD	Cowichan Valley Regional District
DBE	Dam Breach Elevation
DEP	Dam Emergency Plan
DSG	Dam Safety Guidelines, Canadian Dam Association 2007
DSR	Dam Safety Review
EDGM	Earthquake Design Ground Motion
EPP	Emergency Preparedness Plan
ERP	Emergency Response Plan
FEA	Finite Element Analysis
FERC	Federal Energy Regulatory Commission
FoS	Factor of Safety
FSR	Forestry Service Road
GPS	Global Positioning System
GSC	Geological Survey of Canada
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HFMM	Hazard Failure Modes Matrix
ICOLD	International Congress on Large Dams
IDF	Inflow Design Flood
LOL	Loss of Life
MFLNRORD	Ministry of Forests, Lands, Natural Resource Operations & Rural Development
MSC	Meteorological Service of Canada
NAD	North American Datum
NBCC	National Building Code of Canada
NDMP	National Disaster Mitigation Program

OMS	Operations, Maintenance and Surveillance
PAR	Population at Risk
PGA	Peak Ground Acceleration
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PSP	Public Safety Plan
PVC	Polyvinyl Chloride
RAIT	Risk Assessment Information Template
RFP	Request for Proposal
Sa(T)	Spectral Accelerations
SCS	Soil Conservation Service
TRIM	Terrain Resource Information Management
UBC	University of British Columbia
US	United States
USBR	United States Bureau of Reclamation
UTM	Universal Transverse Mercator

1. Introduction

1.1 General

The Cowichan Valley Regional District (CVRD) engaged Ecora Engineering & Resource Group Ltd. (Ecora) to undertake a comprehensive Dam Safety Review (DSR) and risk assessment of the Ashburnham Creek Dam located just south of Honeymoon Bay, BC located on the south shore of Cowichan Lake.

The dam is currently not in active use.

This report presents the technical findings of the Ashburnham Creek Dam DSR and it is understood that this is the first comprehensive DSR of this facility.

A DSR is considered to be a “snapshot in time” and the observations, conclusions, and recommendations provided in this report are deemed to be valid until the next scheduled DSR, which should be conducted in 10 years (2028) for the Ashburnham Creek Dam. However, if conditions (e.g. loading, reservoir level, etc.) change, the results of this DSR may no longer be considered valid and/or current, and a reassessment may be required.

Ashburnham Creek Dam is catalogued in the BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development (MFLNRORD) Dam Safety Section, Dam File No. D730128-00. The BC MFLNRORD has currently assigned the dam a consequence classification rating of “Significant” in terms of the BC Dam Safety Regulation (BC Reg. 40/2016), and the Canadian Dam Association (CDA) DSR Guidelines 2007 (2013 Edition).

The DSR was undertaken in general accordance with the requirements of the BC Water Sustainability Act including all amendments up to BC Reg. 301/2016 (December 7, 2016), the BC Dam Safety Regulation BC Reg. 40/2016 (February 29, 2016), The Association of Professional Engineers and Geoscientists of BC (APEGBC) Professional Practice Guidelines – Legislated Dam Safety Reviews in BC V3.0 (October 2016), and the Canadian Dam Association (CDA) Dam Safety Guidelines (DSG) 2007 (2013 Edition).

The objective of the BC Dam Safety Regulation (BC Reg. 40/2016) is to mitigate loss of life and damage to property and the environment from a dam breach. This Regulation requires dam owners to:

- Operate the dam in a safe manner in accordance with any terms and conditions;
- Inspect their dams;
- Undertake proper maintenance;
- Report incidents and take remedial action; and
- Undertake periodic Dam Safety Reviews.

The risk assessment of the Ashburnham Creek Dam was undertaken in general accordance with the National Disaster Mitigation Program (NDMP) framework.

1.2 Dam Description and Access

Ashburnham Creek Dam is a cast-in-place concrete gravity dam situated along Ashburnham Creek approximately 1.2 km upstream (southwest) of South Shore Road in Honeymoon Bay, along the southwest shoreline of Cowichan Lake, at Map Grid (NAD 83) co-ordinates E413092, N5406646 (Zone 10). The dam is oriented northwest to southeast and is situated in a shallow northeast to southwest trending valley. The dam impounds approximately 1360 m³ of water at the spillway level, with a watershed area of approximately 6.04 km² upstream of the dam.

Ashburnham Creek Dam is approximately 6.2 m high and 25.3 m long according to the MFLNRORD dam database. There is an 11.62 m long concrete spillway located at the left side of the dam crest with a crest elevation 1.32 m below the dam crest, as identified during the site reconnaissance completed by Ecora on April 17, 2018. The dam crest was measured at 0.61 m wide, the upstream face is vertical, and the downstream face is sloped slightly offset from vertical at an approximate angle of 15°. The full length of the dam including the spillway and abutments was estimated to be 24.8 m.

Water passing through the dam is primarily discharged by the spillway at the right side of the dam. Stored water can also be discharged via an inlet controlled low level outlet pipe of unknown diameter and material located at the right portion of the dam, which discharges to a 200 mm diameter PVC watermain which can act as a water supply for Honeymoon Bay. There is an abandoned 250 mm steel outlet pipe, wooden stave pipe and a lower screened inlet in addition to the intake structure which to our understanding is not currently being operated. Control of the discharge provided be a gate valve on the steel outlet pipe.

Access to the dam is provided by a gravel access road off Gordon River Road on the south side of Honeymoon Bay. A map showing the location of the dam and a primary access route from Duncan, BC and a secondary access from Port Renfrew, BC is shown on Figure 1.2.

1.3 Operation, Maintenance and Surveillance

Operations at Ashburnham Creek Dam are regulated under one conditional water licence summarized in Table 1.3 below.

Table 1.3 Summary of Water Licences on Ashburnham Creek

Licence Type	Licence Number	Purpose	Quantity	Licence Holder
Conditional	C130538	Storage – Non-Power	3,080 m^3	CVRD

Copies of the water license can be found at http://a100.gov.bc.ca/pub/wtrwhse/water_licences.input

It is understood that there previously existed a conditional water licence (C130537) for the purpose of waterworks (local authority) at a maximum diversion of 318,000 m^3/year from Ashburnham Creek. The point of diversion under this licence has recently been amended to two groundwater wells as per the decision letter and updated licence (C500782) issued by the MFLNRORD dated December 12, 2018.

It is understood that operation and maintenance of the Ashburnham Creek Dam is overseen by the CVRD. From discussions with the CVRD, it is understood that surveillance (inspection) of the dam is generally undertaken monthly, weather permitting, however it is not documented. Formal annual inspections are carried out using the MFLNRORD dam site surveillance template.

2. Scope of Work

2.1 Comprehensive Dam Safety Review

Ecora's scope of work for the DSR was developed in accordance with the requirements of the CDA Dam Safety Guidelines 2007 (2013 Edition). In summary, the study included the following tasks:

- Background review;

- Site reconnaissance;
- Review of consequences classification;
- Geotechnical assessment, including seepage analyses, piping potential and considerations for liquefaction and post-earthquake deformation;
- Structural stability assessment including calculation of the position of the resultant force, normal stresses, and calculated sliding factors;
- Hydrotechnical analysis including hydrological analysis, dam break analysis, flood routing and hydraulics;
- Review of any existing Operation, Maintenance & Surveillance Manual;
- Review of any existing Dam Emergency Plans (Emergency Response Plan and/or Emergency Preparedness Plan);
- Review of any public safety management strategies;
- Risk assessment as per the NDMP framework;
- Assessment of compliance with CDA design criteria; and,
- Development of conclusions and recommendations.

The results of each task are detailed in the following sections.

2.2 NDMP Risk Assessment

The NDMP Risk Assessment Information Template (RAIT) provides a likelihood rating scale for a specific hazard event and the likelihood that this event will occur based on conditions expected over a certain timeframe (Table 2.2). As the consequences of a dam failure (break) are the same, the event for this assessment is defined as any embankment overtopping, internal erosion, slope instability and/or earthquake induced condition(s) that causes failure of Ashburnham Creek Dam. The NDMP RAIT is discussed in more detail in Section 11.

Table 2.2 Likelihood Rating Scale

Likelihood Rating	Definition
5	The event is expected and may be triggered by conditions expected over a 30-year period.
4	The event is expected and may be triggered by conditions expected over a period of 30 – 50-year period
3	The event is expected and may be triggered by conditions expected over a period of 50 – 500-year period
2	The event is expected and may be triggered by conditions expected over a period of 500 – 5,000-year period
1	The event is possible and may be triggered by conditions exceeding a period of 5,000 years

3. Background Review

3.1 Sources of Information

The following sources of background information were reviewed during the DSR:

- Historical aerial photographs;
- Readily available published sources of geological data;
- Past Dam Safety Reviews, inspections and other reports;
- Discussions with CVRD staff familiar with the site; and
- MFLNRORD Dam Safety Branch files.

A detailed list of the various documents reviewed from these sources is provided in Appendix A.

3.2 Design, Construction and Modification

It is understood that Ashburnham Creek Dam was initially constructed in 1947 as a 6 m high cast-in-place concrete gravity structure designed by Swan, Rhodes and Wooster. The original water licence was held by Western Forest Industries Ltd. for both waterworks and industrial purposes. In 1990 the water licences were held by the Honeymoon Bay Improvement District with the CVRD assuming responsibility of the dam in 1994.

A major debris slide and washout of a Forest Service Road approximately 600 m upstream of the dam occurred in 1992, possibly as a result of logging activities in the upper portion of the watershed. This event, as well as the ongoing erosion of logging roads and the collapse of a bridge structure in 1994, resulted in complete filling of the reservoir with gravel and debris. This has resulted in issues with potable water supply and concerns regarding possible depletion of fish stock in the creek as a result of the high turbidity.

Since the construction of the dam in 1947, Ashburnham Creek Dam has undergone no known major modifications however a presence of a cold joint at the right abutment indicates that the right side of the dam was raised either shortly after construction or sometime later. According to the Golder Associates inspection report dated 2001, an undated drawing was reviewed showing outlet piping improvements made on the right abutment including a 1.8 m high retaining wall.

It is our understanding that no design or record drawings of the dam are available.

3.3 Historical Aerial Photographs

A review was conducted of available historical aerial photographs of the Ashburnham Creek area held by the Geography Department of the University of British Columbia (UBC) as summarized in Table 3.3 below.

Table 3.3 Summary of Reviewed Aerial Photographs of the Ashburnham Creek Dam Area

Year	Aerial Photo No.	Type
1946	BC246: 95	Black and White
1957	BC2088: 80-81	Black and White
1962	BC5044: 132-133	Black and White

1968	BC7109: 216	Black and White
1972	BC7410: 206	Black and White
1975	BC7791: 113-114	Black and White
1980	BC80078: 164-165	Black and White
1987	BC87024: 42-43	Black and White
2007	ME07460C: 445-446	Colour

The review of the available historical aerial photographs included the historical condition of the dam and reservoir side slopes, noting the following:

- Major logging activity was observed above Honeymoon Bay with clear cutting observed in 1946 and moving up into the catchment between 1946 and 1957. Many logging roads were developed during this time. Logging activity continues to this day;
- Access road toward the dam is present in 1946 one year prior to construction. Dam is first visible in 1957;
- The sawmill historically in Honeymoon Bay was redeveloped between 1987 and 2007; and
- Background identified that sediment in dam is from logging roads washing out in the upper watershed. Signs of slope instability were noted in the vicinity of some of these roads within the photos reviewed.

A review of historical aerial imagery on Google Earth shows that periodic clearing and the development of access roads has occurred in areas upstream of the dam between 2005 and 2016.

3.4 Geological Setting

The Geological Survey of Canada (GSC) 1:50,000,000 scale map “Geological Map of Canada” indicates that Ashburnham Creek Dam is close to the boundary of two bedrock units, namely;

- Massive amygdaloidal and pillowed basalt to andesite flows, dacite to rhyolite massive or laminated lava, green and maroon tuff, feldspar crystal tuff, breccia, tuffaceous sandstone, argillite, pebble conglomerate and minor limestone; and
- Boulder, cobble and pebble conglomerate, coarse to fine sandstone, siltstone, shale, coal.

The bedrock geology of the site is presented on Figure 3.4.

3.5 Seismicity

The GSC has developed a new probabilistic (5th Generation) seismic hazard model (Halchuk, Adams and Allen, 2015) that forms the basis of the seismic design provisions of the 2015 National Building Code of Canada (NBCC, 2015).

Based on the surficial geology of the area, which indicates shallow bedrock, the site classification for seismic response for the Ashburnham Creek Dam is considered to be Site Class C (very dense soil and soft rock). Peak Ground Accelerations (PGA) and Spectral Accelerations (Sa(T)) for a reference “Site Class C” (very dense soil and soft rock) can be obtained from Earthquakes Canada for various return periods, with the reference values for the Ashburnham Creek Dam summarized in Table 3.5.a below.

Table 3.5.a Site Class C Design PGA and Sa for Ashburnham Creek Dam, Honeymoon Bay, BC

Annual Exceedance Probability (AEP)	PGA (g)	Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)
1/100 year	0.105	0.244	0.200	0.096	0.051
1/475 year	0.269	0.616	0.543	0.286	0.159
1/1,000 year	0.385	0.867	0.794	0.448	0.262
1/2,475 year	0.550	1.228	1.155	0.704	0.427

For seismic hazards with very low probabilities (i.e. return periods greater than 2,475 years) the GSC recommends plotting the annual probability versus acceleration of the 1/475 year and 1/2,475 year values on a log-log scale and extrapolating the line to the required return period. Extrapolated site “Class C” PGA and Sa(T) reference values for the Ashburnham Creek Dam are summarized in Table 3.5.b.

Table 3.5.b Extrapolated Site Class C Design PGA and Sa for Ashburnham Creek Dam, Honeymoon Bay, BC

Annual Exceedance Probability (AEP)	PGA (g)	Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)
1/5,000 year	0.739	1.639	1.581	1.020	0.641
1/10,000 year	0.996	2.187	2.167	1.486	0.968

With respect to selection of earthquake design magnitudes the CDA Technical Bulletin, Seismic Hazard Considerations for Dam Safety recommends utilising the greatest of the mean magnitude, modal magnitude or the 84th percentile of the total magnitude contributions when considering multiple seismogenic probabilistic seismic hazards.

The relative contribution of the earthquake sources to the seismic hazard in terms of distance and magnitude can be obtained by deaggregation of the seismic hazard result. The deaggregation data for the NBCC 2015 design model has been obtained from Earthquakes Canada, which provides the mean and modal magnitude of the seismic hazard for the Ashburnham Creek Dam for the 1/2,475 year event as summarized in Table 3.5.c below.

Table 3.5.c Design Earthquake Magnitudes for Ashburnham Creek Dam, Honeymoon Bay, BC

Magnitude Contributions	PGA	Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)
Mean	7.98	7.88	8.13	8.51	8.66
Modal	8.95	8.95	8.95	8.95	8.95
84th Percentile	9.05	9.00	9.05	9.05	9.05

3.6 Existing Drawings

As discussed in Section 3.2, in our understanding no design or record drawings of the dam are available for review.

3.7 Instrumentation

No instrumentation is currently installed on Ashburnham Creek Dam.

3.8 Previous Dam Safety Reviews

It is understood that this DSR is the first for this facility so no previous DSR is available for review.

3.9 Other Reports

A review was undertaken of other available reports associated with the dam (listed in Appendix A) including a dam inspection report prepared by Golder Associates (2001).

Key points from Ecora's review of the 2001 dam inspection report are as follows:

- The site inspection was undertaken to verify the dam was functioning as intended and was in accordance with the Provincial Dam Safety Guidelines;
- At the time of the inspection, no deflection or significant cracking was observed along the dam crest, minor cracking, localized deterioration of concrete and carbonate leaching were observed. It was concluded that in general the dam and spillway appeared to be in good condition;
- It was recommended that the downstream face, toe and abutment contacts be carefully examined during a "no-flow" period to confirm the condition of the structure;
- Accumulation of sediment and wood debris from higher mountain slopes was considered likely to continue with a risk of debris loading affecting the stability of the structure. It was recommended that if the dam was to remain in place, stability be reviewed under the following load conditions:
  - full sediment loading (static and liquefaction);
  - seismic loading;
  - ice loading; and,
  - uplift if cracking is anticipated under the above-mentioned loading conditions.
- It was recommended that a debris boom be designed and constructed upstream of the spillway;
- Deactivation of Forest Service Roads was suggested as mitigation against further debris; and
- It was recommended that Operation, Maintenance and Surveillance Plans be implemented for the dam including an annual review and site reconnaissance of the watershed area and emergency preparedness procedures.

4. Site Reconnaissance

4.1 General

Ecora conducted a site reconnaissance of the Ashburnham Creek Dam on two occasions, as part of the Request for Proposal (RFP) on January 17, 2018 and as part of a scheduled site inspection on March 29, 2018. Ecora's site representatives in March were Michael J. Laws, P.Eng, Caleb Pomeroy, P.Eng., Dr. Adrian Chantler, P.Eng. and Bram Hobuti, P.Eng.

The site reconnaissance comprised three components, namely:

- A visual inspection of the exposed section of the dam and tour of some of the area in the vicinity of Ashburnham Creek;

- Measurement of the concrete wall rebound using a Schmidt hammer at a number of locations; and
- Staff interviews.

A summary of the site reconnaissance notes is provided as Appendix B. A summary of key dam dimensions measured during the site reconnaissance is provided in Figure 4.1.

4.2 Visual Inspection

Ecora inspected the concrete gravity dam structure including the spillway, cold joints, height of sediment on the upstream side of the dam, and outlet (creek downstream) of the dam. Photographs 1 through 18 show the Ashburnham Creek Dam at the time of site visits. The observations made through this inspection are presented in the Photo Log following the text of this report.

Key observations from the site inspection are as follows:

- The reservoir is completely full of debris and sediment (Photo 2);
- The access road and a stairway are on the right side (looking downstream) of the dam. Path down to the dam has significant vegetation (Photo 6);
- The low-level outlet is located at the right side of the dam. Significant moss growth (Photo 9);
- The wall width is approximately 610 mm at the dam crest, the upstream wall face is vertical, and the downstream wall face has a back slope of approximately 15° (Photo 12);
- The reservoir level at the time of both site visits was above the spillway elevation (Photo 12);
- There was a cold joint located on the right wall with efflorescence (recent and old) observed (Photos 13 & 14);
- The dam foundation consists of bedrock with possible colluvium at the left abutment (Photo 15); and
- The spillway is approximately 11.6 m long at an elevation of approximately 1.32 m below the dam crest elevation on the left portion of the dam (Photo 15);

4.3 Structural Observations

During the visual non-destructive structural assessment of the dam the following key observations were made:

- Signs of erosion and weathering were noted on the upstream side of the west (right) wing wall about 300 mm above the water line at the time of the site visit (Photo 3).
- Extensive organic growth (moss) was noted throughout the surface of the concrete structure, which has caused the concrete paste near the surface to deteriorate and reduced visibility of exposed concrete over the majority of the surfaces of the concrete wing walls (Photo 11).
- A build-up of oxidization residue appeared to be staining the mossy growth on the concrete surface of the downstream side of the west abutment, therefore it is suspected the reinforcing steel has corroded (Photo 14).

Schmidt hammer rebound values were measured on the concrete at a number of locations including the old dam wall, the new wall, wing wall and left abutment. It is noted that the new and old dam wall is considered to be the sections of wall above and below the cold joint on the right side of the dam. The measured rebound values corresponded to compression strengths of between 18 MPa and 37 MPa with an average of 25 MPa. It should be noted that given the extent of exposed aggregate at the concrete surface (due to erosion of the concrete paste) and the variability of the values, the rebound values are not considered to have provided an accurate representation of the overall concrete compressive strength. To better understand the in-situ concrete compressive strength, core samples would need to be taken.

4.4 Staff Interviews

Following completion of the site reconnaissance, an interview with David Parker (CVRD) was carried out regarding the operation, maintenance and surveillance of the dam.

Key points from this discussion are as follows:

- Surveillance (inspection) of the dam is undertaken predominantly by the CVRD, monthly, weather permitting.

5. Dam Break Analysis

The consequences classification of a dam depends on the incremental consequences of a dam failure, and this can be the result of overtopping, a piping failure, or an earthquake for example. A dam break analysis, including characterization of a hypothetical dam breach, flood wave routing and inundation mapping, was carried out as part of this review.

Failure times of concrete gravity dams are estimated to be between 6 and 18 minutes (Federal Energy Regulatory Commission, 2015), therefore the characterization of the dam breach and initial flood hydrograph was conducted by assuming a catastrophic failure over the course of 6 minutes during a period of high inflow. Further, FERC recommends that the average breach width of concrete gravity dams consist of one or more monoliths with an average breach width of less than half the length of the dam. However, documentation from FERC further states that higher breach widths should be considered if the dam is overtopped for a long period of time. In the case of Ashburnham Creek Dam, it is assumed that the dam consists of one monolith and that the dam would continue to be overtopped until the end of the runoff event.

The characterization of the dam breach and initial flood hydrograph was conducted by assuming that the dam would fail at the peak flow during a 100-year inflow event. Due to the limited size of the reservoir it was conservatively assumed that the contents of the reservoir would be fully discharged within the 6-minute failure period and that the sediment filling the reservoir would be fully mobilized.

This mode of dam failure was selected to be both conservative and take into consideration that the water storage capacity of the dam is severally limited by the trapped sediment. It is anticipated that full mobilization of the sediment would be difficult under normal flow conditions and thus a breach during a period of high inflow would be most appropriate.

The dam breach parameters are given in Table 5.0.a

Table 5.0.a Summary of Dam Breach Parameters

Dam Breach Parameter	Value
Type of Dam:	Concrete Gravity
Peak Inflow to Reservoir (100-year event):	60.2 m^3/s

Dam Breach Parameter	Value
Water Elevation at Dam Breach:	1.27 m above spillway
Volume of Dam Breach:	2,030 m^3
Reservoir Surface Area:	1,500 m^2
Width of Crest:	0.61 m
Length of Dam Crest:	35 m
Time at Which Failure Occurs:	8.7 h after start of event
Peak Breach Flow:	5.64 m^3/s

The resulting dam breach hydrograph was routed using a 2-dimensional volume conservation flood routing model, FLO-2D, with the flood wave simulation run for 24 hours. The mud and sediment transportation module within FLO-2D was utilized for this breach. This involved the inclusion of a sediment load equivalent to the storage capacity of the reservoir within the dam breach hydrograph. In order to be conservative, it was assumed that the breach and subsequent discharge of sediment took place during the peak of the 100-year storm. Topographical inputs for the model were developed from available LIDAR data obtained by CVRD.

It should be noted that in the FLO-2D model, the ground surface is represented by a grid. The grid size utilized for this project is 3 m × 3 m. This is considered adequate to represent the rough terrain that accounts for the majority of the study area. Sudden changes in topographic relief, such as channels, roads and river dykes, may not be accurately characterized as elevation variations are averaged out within a grid area and therefore some localised variation in flow depths from those modelled is anticipated.

The model assumed that any hydraulic structures such as culverts were blocked by debris picked up by the flood wave and therefore their effect on routing the flood wave was ignored.

Changes in the Manning's roughness coefficients in the FLO-2D model due to variations in the flood wave depth, velocity and flow regime are automatically calculated by assigning a limiting Froude number. The Froude number represents the relationship between the kinematic flow forces, gravitational forces and the threshold between subcritical and supercritical flow. Limiting Froude numbers assigned to the grid cells in the analysis are based on the suggested values summarized in Table 5.0.b for various terrain characteristics.

Table 5.0.b Suggested Limiting Froude (Fr) Numbers[1.]

Terrain Characteristics	Flat or Mild Slope (large rivers and floodplains)	Steep Slope (alluvial fans and watersheds)
Channels	0.4 – 0.6	0.7 – 1.05
Overland	0.5 – 0.8	0.7 – 1.5
Streets	0.9 – 1.2	1.1 – 1.5

[1.] From FLO-2D Reference Manual, September 1996.

Figure 5.0a presents the results of the flood extents and maximum depth of flooding, indicating a total inundation area of 0.33 km^2. The flow travels along Ashburnham Creek for approximately 1.7 km where it enters Cowichan Lake.

Figure 5.0b shows the delay time between the initial dam breach and the time at which flooding reaches a depth of 0.6 m. It is noted that time period is in reference to the start of the flood event and that the dam breach takes place 8.7 hrs into the flood event.

Areas of interest impacted by the dam breach and flooding are summarized below.

- Transportation Infrastructure:
  - Gordon River Road; and

  - South Shore Road.
- Residences:
  - None.
- Other Potential Impacts:
  - Lily Beach Park.

Flood hazard maps are presented on Figure 5.0c, using the method of Garcia et al. (2003 and 2005). The flood hazard level at a specific location is a function of flood intensity (flow depth and velocity) and probability. The map uses three colours to define high (red), medium (orange) and low (yellow) hazard levels. Definitions of each flood hazard level are provided in the legend of the map and in Table 5.0.c below.

Table 5.0.c Definition of Water Flood Intensity

Flood Intensity	Maximum Depth “h” (m)		Product of Maximum Depth “h” Times Maximum Velocity “v” (m^2/s)
High	h > 1.5 m	OR	v h > 1.5 m^2/s
Medium	0.5 m < h < 1.5 m	OR	0.5 m^2/s < v h < 1.5 m^2/s
Low	H < 0.5 m	AND	V h < 0.5 m^2/s

6. Consequences Classification

6.1 General

A consequences classification system has been developed by the Canadian Dam Association (CDA, 2007) to categorize the consequences of dam failure in terms of potential loss of life; environmental and cultural losses; and infrastructure and economic losses. The consequences classification of a dam should be selected using the highest rating based on these types of loss. Note that the consequences are incremental to those that would have occurred in the same event without failure of the dam. The CDA (2007) defines incremental consequence of failure as:

“The incremental consequences of failure are defined as the total damage from an event with dam failure minus the damage that would have resulted from the same event had the dam not failed”.

The consequences categories are applied to establish guidelines for some of the design parameters for a dam, such as the Inflow Design Flood (IDF) and the Earthquake Design Ground Motion (EDGM), and the standard of care expected of owners. The BC Dam Safety Regulation and the CDA guidleines describe five consequence categories: “Low”, “Significant”, “High”, “Very High” and “Extreme”.

The BC Dam Safety Regulation 40/2016 (February 29, 2016), and the 2007 CDA Dam Safety Review Guidelines (2013 Edition), provide consequences classification criteria as well as suggested design flood and earthquake levels as a function of dam consequence classification as reproduced as Table 6.1 below. It is noted that the BC Dam Safety Regulation was amended in 2011 so that consequence classifications are now in alignment with those provided in the 2007 CDA guidelines and care must be taken in the interpretation of engineering reports dated prior to November 2011.

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Table 6.1 BC Regulation 40/2016 & CDA Consequences Classification Criteria and Design Earthquake and Flood

Dam Classification from BC Reg. 40/2016 & CDA 2007	Population at Risk (BC Reg. 40/2016)	Loss of Life (BC Reg. 40/2016)	Infrastructure and Economics (BC Reg. 40/2016)	Environmental and Cultural Losses (BC Reg. 40/2016)	Annual Exceedance Probability Level	
					EQ Design Ground Motion (CDA 2007)	Inflow Design Flood (CDA 2007)
Extreme	Permanent[3]	>100	Extremely high economic losses affecting critical infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to residential areas	Major loss or deterioration of: a) critical fisheries habitat or critical wildlife habitat, b) rare or endangered species, c) unique landscapes, or d) sites having significant cultural value, and restoration or compensation in kind is impossible.	1/10,000	PMF
Very High	Permanent[3]	10-100	Very high economic losses affecting important infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to residential areas	Significant loss or deterioration of: a) critical fisheries habitat or critical wildlife habitat, b) rare or endangered species, c) unique landscapes, or d) sites having significant cultural value, and restoration or compensation in kind is possible but impractical	½ between 1/2,475 and 1,10,000	⅔ between 1/1000 year and PMF
High	Permanent[3]	1-10	High economic losses affecting infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to scattered residential buildings	Significant loss or deterioration of: a) important fisheries habitat or important wildlife habitat, b) rare or endangered species, c) unique landscapes, or d) sites having significant cultural value, and restoration or compensation in kind is highly possible	1/2,475	⅓ between 1/1000 year and PMF

Dam Classification from BC Reg. 40/2016 & CDA 2007	Population at Risk (BC Reg. 40/2016)	Loss of Life (BC Reg. 40/2016)	Infrastructure and Economics (BC Reg. 40/2016)	Environmental and Cultural Losses (BC Reg. 40/2016)	Annual Exceedance Probability Level	
					EQ Design Ground Motion (CDA 2007)	Inflow Design Flood (CDA 2007)
Significant	Temporary Only[2]	Low potential for multiple loss of life	Low economic losses affecting limited infrastructure and residential buildings, public transportation or services or commercial facilities, or some destruction of or damage to locations used occasionally and irregularly for temporary purposes	No significant loss or deterioration of: a) important fisheries habitat or important wildlife habitat, b) rare or endangered species, c) unique landscapes, or d) sites having significant cultural value, and restoration or compensation in kind is highly possible	1/1,000	Between 1/100 and 1/1000 year
Low	None[1]	0	Minimal economic losses mostly limited to the dam owner's property, with virtually no pre-existing potential for development within the dam inundation zone	Minimal short-term loss or deterioration and no long-term loss or deterioration of: a) fisheries habitat or wildlife habitat, b) rare or endangered species, c) unique landscapes, or d) sites having significant cultural value	1/475	1/100 year

1. There is no Identifiable Population at Risk
2. People are only occasionally and irregularly in the dam-breach inundation Zone, for example stopping temporarily, passing through on transportation routes or participating in recreational activities.
3. The population at risk is ordinarily or regularly located in the dam-breach inundation zone, whether to live, work or recreate

The BC MFLNRORD has currently assigned the dam a consequence classification rating of “Signficant” in terms of the BC Dam Safety Regulation. The “Significant” classification suggests that, in the event of a dam failure, no permanent population would be at risk, or there could be significant loss or deterioration of important fish, or wildlife habitat, or high economic losses affecting infrastructure, public transportation and commercial facilities.

6.2 Consequences Classification Review

6.2.1 General

Based on the results of the dam break analysis and flood inundation mapping, a review of the consequences classification criteria for the Ashburnham Creek Dam was conducted as per the CDA 2007 Dam Safety Guidelines considering each of the following loss criteria:

- Loss of life;
- Environmental and cultural losses; and
- Infrastructure and economics.

6.2.2 Loss of Life

No dwellings were identified within the High Hazard area and therefore no permanent population is considered to be at risk in the event of dam failure. It is anticipated that loss of life could occur due to the presence of a transitory population in the inundation zone. The breach would therefore only affect a temporary population and corresponds to a consequences classification of “Significant”.

6.2.3 Environmental and Cultural Losses

Reference to the BC Ministry of Environment, BC Species and Ecosystems Explorer indicates that there are known instances of Red and Blue listed species in the area around Honeymoon Bay, namely the Cowichan Lake Lamprey. It is anticipated, however, that there would be minimal impact on these species as a direct result of a dam breach. No significant difference in hazard rating was noted when comparing the scenarios in which the dam routed the flow and when the dam failed during a 100-year event. This suggests that no significant loss or deterioration of habitat or rare or endangered species would occur as a result of a dam breach and therefore this would equate to a consequence rating of “Significant”.

6.2.4 Infrastructure and Economic Losses

The primary infrastructure that is expected to be impacted is the creek crossings at South Shore Road and Gordon River Road. Surface flooding is expected in areas outside of the creek which may experience minor impacts. It is noted that residential buildings within the flood inundation zone are all within the low hazard area and thus are not expected to experience significant damage.

Neither the BC Dam Safety Regulation 40/2016 nor the 2007 CDA Dam Safety Review Guidelines (2013 Edition) provides guidance with respect to the monetary value of infrastructure and economic losses associated with each consequences classification. Therefore, reference has been made to the Ontario Ministry of Natural Resources Technical Bulletin on Classification and Inflow Design Flood Criteria (August 2011) that provides suggested monetary values for economic losses. Table 6.2 below includes the estimated property losses from the technical bulletin for each equivalent CDA consequences classification.

Table 6.2 Property Loss Criteria based on Consequence Classification

Consequences Classification Rating	Economic Losses
Low	Not exceeding $300,000
Significant	Not exceeding $3 million
High	Not exceeding $30 million
Very High & Extreme	In excess of $30 million

The flood wave also has the ability to overwhelm the downstream stream crossings as they would need to convey normal flood waters, discharge from the reservoir, debris and any silt eroded from the reservoir in this scenario. It is further anticipated that these culverts wouldn't be able to pass the flow from this combined effect as the stream is unlikely to have sufficient hydraulic capacity for the 100-year event.

The combination of damage to the stream crossings and the disruption that it would cause likely represent damages greater than $300,000 but less than $3 million. The damages are expected to represent low economic losses affecting infrastructure and services and thus would correspond to a consequences classification of "Significant".

6.3 Conclusions

Based on the assessment of the three loss criteria summarized in the sections above, it is recommended that the consequences classification rating of Ashburnham Creek Dam remain as "Significant". For a dam with a consequences classification of "Significant", the Inflow Design Flood (IDF) is required to be between the 100-year and the 1,000-year event and design seismic hazard is required to be the 1,000-year event, according to the CDA DSR Guidelines 2007 (2013 Edition).

7. Failure Modes Assessment

Static failure of concrete dams can be generally divided into two broad categories, namely:

- Sliding Failure; and,
- Overturning Failure.

The dam's ability to resist sliding and overturning can be compromised by concrete deterioration and distress. Marginal static stability with respect to sliding, overturning and concrete distress may lead to instability under dynamic loading due to additional loads caused by the inertial effects of the dam and reservoir. The dam foundations may also undergo a loss of strength when subjected to dynamic loading.

Although sliding and overturning stability govern the design of concrete dams, most historical problems are associated with the dam foundations. The foundation of a concrete dam must be capable of resisting the applied forces without overstressing the dam or the foundation itself. The horizontal component of the loads acting on the dam tends to make the dam slide in a downstream direction, which results in shear stresses in the dam and along the base of the dam. These stresses may induce concrete shear failure on horizontal planes within the dam, at the base or along the concrete-rock contact, or within the rock foundation. Uplift forces induced by seepage pressure, in combination with the horizontal forces, tend to overturn the dam, which in turn may cause overstressing and crushing of the rock along the downstream toe of the dam. Increased hydrostatic pressures within the foundation stratum and potential seepage paths may result in piping failure of the foundation due to the filling of the reservoir.

Some static concrete dam failures and incidents, as compiled by the US Congress on Large Dams (USCOLD) are summarised in Table 7.0 below.

Table 7.0 Summary of Causes of Static Concrete Dam Failures

Cause	Failures		Incidents		Total	
	No.	%	No.	%	No.	%
Overtopping	6	31.6	3	15.8	9	23.7
Flow Erosion	3	15.8	0	0	3	7.9
Foundation Leakage, Piping	5	26.3	6	31.6	11	28.9
Sliding	2	10.5	0	0	2	5.3
Deformation & Deterioration	0	0	8	42.1	8	21.1
Other Causes e.g. Faulty Construction, Gate Failure	1	5.3	2	10.5	5	13.1

A modified version of the MFLNRORD Hazards and Failure Modes Matrix (HFMM) was utilized in assessing the plausible failure modes for Ashburnham Creek Dam as presented in Appendix C. The likelihood of each hazard and associated failure mode being applicable to Ashburnham Creek Dam was assessed as either, high, moderate or low as represented by red, orange and green cells respectively in the matrix. It can be noted that the unmodified version uses ratings of applicable versus non-applicable in place of low, medium or high.

For the Ashburnham Creek Dam, the following failure modes are considered to be plausible:

- **Overtopping** – The water level of the dam during both site visits was above the spillway elevation and the sediment has reduced the storage capacity of the dam;
- **Deformation & Deterioration** – Given the age of the dam it is possible that the upstream concrete wall may have undergone some deterioration; and,
- **Sliding / Overturning Failure** – It is possible that the gravity wall may become unstable when subjected to the design flood/seismic forces, particularly considering the present debris loading.

8. Geotechnical and Structural Assessment

8.1 General

The current assessment is based on the results of the measurements and observations made during the site reconnaissance, available data on the existing dam, published geological data and Ecora's engineering judgement, rather than a detailed survey and intrusive geotechnical assessment (e.g. drilling, sampling, testing, etc.) and should therefore be considered preliminary in nature. The objective of this approach is to identify potential issues so that any detailed assessment can be tailored to that particular issue.

The following subjects will be discussed in this Section:

- Seepage through the foundation;
- Sliding failure;
- Overturning failure;
- Bearing capacity of the foundation;
- Liquefaction of the foundation and post-seismic deformation; and

- Potential for piping through the foundation.

8.2 Material Parameters Estimation

8.2.1 Concrete Gravity Wall

The following assumptions were adopted in the dam stability assessment for the concrete gravity wall:

- Concrete unit weight: 24 kN/m^3;
- Concrete compressive strength: 25 MPa (from Schmidt hammer readings, Section 4.3); and
- Concrete is non-porous.

8.2.2 Geotechnical Parameters

Geotechnical parameters for the dam foundation have been estimated using a combination of field observations and published data for similar material types.

Based on our site observations and review of published data for similar material types, the following geotechnical parameters as summarized in Table 8.2 were utilized in the various analyses. It is noteworthy that based on site observations, it is considered likely that the gravity wall is founded on bedrock, however there are no design drawings or geotechnical data to verify this conclusion.

Table 8.2 Summary of Geotechnical Parameters Used in the Dam Assessment

Material	Geotechnical Parameters			
	c' (kPa)	ϕ' (°)	γ (kN/m^3)	k_{sat} (m/s)
Bedrock[1,2]	0	55	25	1x10^{-9}

1 Strength parameters based on RocLab analysis of the rock type assumed for a low stress range, conservatively ignoring cohesion.

2 Saturated hydraulic conductivity (k_{sat}) based on lower bound value for fractured igneous and metamorphic rocks, Figure 5.4 of Wyllie & Mah (2004).

c' = Effective Cohesion Intercept

ϕ = Effective Friction Angle

γ = Unit Weight

k_{sat} = Saturated Hydraulic Conductivity

8.3 Seepage Through Foundation

At the time of the site reconnaissance there were no obvious seepage flows noted along the dam toe, however water was overtopping the spillway, which made it difficult to verify this.

A steady state seepage analysis was undertaken utilising the built-in Finite Element Analysis (FEA) module within the RocScience Slide v8.017 software. The seepage analysis considered the reservoir level at the spillway elevation which is consistent with observations during the site reconnaissance. The geometry of the dam has been estimated from measurements obtained during the site reconnaissance. Note that the seepage analysis does not consider flow from concentrated sources such as along the low-level outlet conduit or cracks in the concrete wall or along the base of the gravity wall.

The rate of toe seepage calculated for the dam is summarized in Table 8.3 below. It should be noted that the analyses were undertaken at the dam’s maximum height and reduced seepage rates are anticipated where the dam height is less.

Table 8.3 Estimated Rate of Toe Seepage for the Ashburnham Creek Dam

Reservoir Level	Calculated Toe Seepage	Figure No.
At spillway elevation	<0.001 m^3/m/day	8.3

The flow field from the steady state analysis of the dam is provided on Figure 8.3.

8.4 Structural Stability Review

8.4.1 Acceptance Criteria

The CDA Dam Safety Guidelines (2007) provide acceptance criteria for the structural stability of concrete gravity dams including the position of the resultant force for rotational modes of failure, the allowable normal compression strength and minimum factors of safety for resistance to sliding for concrete gravity dams as reproduced in Table 8.4.a below.

Table 8.4.a Acceptance Criteria for Concrete Gravity Dams

Loading combination	Position of resultant force (percentage of base in compression)	Normal compression stress[1]	Sliding safety factor		
			Friction only	Friction and cohesion[2]	
				With tests	Without tests
Usual	Preferably within the kern (middle third of the base: 100% compression); however, for existing dams, it may be acceptable to allow a small percentage of the base to be under 0 compression if all other acceptance criteria are met[3]	<0.3 x f_c’	≥1.5	≥2.0	≥3.0
Unusual	75% of the base in compression and all other acceptance criteria must be met	<0.5 x f_c’	≥1.3	≥1.5	≥2.0
Extreme flood	Within the base and all other acceptance criteria must be met	<0.5 x f_c’	≥1.1	≥1.1	≥1.3
Extreme earthquake	Within the base, except where an instantaneous occurrence of resultant outside the base may be acceptable	<0.9 x f_c’	Refer to Note 4.		
Post-earthquake	Within the base	<0.5 x f_c’	≥1.1[5]	Refer to Note 6.	

1 Where f_c’ = compressive strength of concrete.

2 Given the significant impact a very small amount of cohesion can have on the shear resistance of small and medium-sized dams, the use of a cohesive bind this level of safety factor should be used with extreme caution.

3 It is very important to verify that all possible failure modes have been addressed under a potential cracked base scenario.

4 The earthquake load case is used to establish the post-earthquake condition of the dam.

5 If the post-earthquake analysis indicates a need for remedial action, this condition should not be allowed to remain for any length of time. Remedial action should be carried out as soon as possible such that factors of safety are increased to the level of the pre-earthquake conditions.

6 Shear resistance based on friction and cohesion needs to be considered carefully, since the analysis surface may not remain in compression throughout the earthquake but may result in cracking, which will change the resistance parameters.

8.4.2 Methodology

The stability review of the gravity wall was undertaken utilizing the software program CADAM v.1.4.3. CADAM is based on the gravity method using rigid body equilibrium and beam theory to perform stress analyses, compute crack lengths and factors of safety for the static and seismic stability of concrete gravity dams.

The geometry of the dam has been estimated from measurements obtained during the site reconnaissance and scaled from site photos. As there are no design drawings or geotechnical data available for the dam wall, the stability analysis conservatively does not consider foundation embedment or shear key contribution to sliding resistance.

The stability analysis considers load conditions at the maximum height of the dam. The operating reservoir level was assumed to be at the spillway elevation (consistent with observations during the site reconnaissance) and the flood elevation consistent with the IDF. The height of sediment against the upstream face of the wall measured on site (at approximately the spillway elevation) was used in the analysis assuming active earth pressures, an effective saturated unit weight of 10 kN/m^3 and a friction angle of 33º to calculate the sediment load.

Due to the assumed low permeability of the bedrock foundation and estimated seepage rate (Section 8.3), uplift pressures beneath the foundation are considered negligible and are therefore not included in the stability analysis with the exception of the post-earthquake load case which assumes a crack has been formed during the earthquake event creating a seepage path and the build up of hydrostatic pressures beneath the dam equal to the hydrostatic head at the upstream and downstream faces.

Pseudo-static stability calculations are based on the 1/1,000 year AEP earthquake design ground motion (EDGM) for a “Significant” consequence dam as recommended by the CDA technical bulletin for Seismic Hazard Consideration for Dam Safety (2007).

For the purpose of providing a high-level stability analysis and considering the absence of information available on construction of the dam wall, a simplified analysis has been undertaken which does not include the observed cold joint.

8.4.3 Load Combinations

The following load combinations were considered to assess the stability of Ashburnham Creek Dam:

- Usual Load Combination: Dead + Operating Hydrostatic + Sediment Load
- Flood Combination: Dead + IDF Hydrostatic + Sediment Load
- Earthquake Combination: Dead + Operating Hydrostatic + Sediment Load + Seismic Load
- Post-Earthquake Combination: Dead + Operating Hydrostatic + Sediment Load + Hydrostatic Uplift

Ice load conditions have not been considered due to the location of the dam.

8.4.4 Results

The results of the stability analyses for the current condition of the dam and for the case where sediment loading is removed are summarized in Table 8.4.b and 8.4.c respectively, with the CADAM reports provided in Appendix D.

Table 8.4.b Factors of Safety for Stability of the Ashburnham Creek Dam – Current Condition

Load Combination	Sliding		Overturning		Position of Resultant		Maximum Normal Stress (kPa)
	CDA Min. FoS	Calculated Min. FoS	CDA Min. FoS	Calculated Min. FoS	CDA Limit	Position (% of joint)	
Static stability, operating level	≥1.5	1.8	≥1.2	1.5	Middle 1/3	77.7	253.9
Static stability, flood[1]	≥1.1	1.3	≥1.1	0.9	Within base	104.2	369.7
Pseudo-static stability[2]	≥1.0	0.9	≥1.0	0.6	Within base	136.2	523.7
Post-earthquake[3]	≥1.1	0.5	≥1.1	0.8	Within base	148.0	165.1

Table 8.4.c Factors of Safety for Stability of the Ashburnham Creek Dam – Sediment Loading Removed

Load Combination	Sliding		Overturning		Position of Resultant		Maximum Normal Stress (kPa)
	CDA Min. FoS	Calculated Min. FoS	CDA Min. FoS	Calculated Min. FoS	CDA Limit	Position (% of joint)	
Static stability, operating level	≥1.5	2.4	≥1.2	2.0	Middle 1/3	67.6	174.8
Static stability, flood[1]	≥1.1	1.5	≥1.1	1.1	Within base	94.4	1028.5
Pseudo-static stability[2]	≥1.0	1.0	≥1.0	0.7	Within base	126.1	472.4
Post-earthquake[3]	≥1.1	0.7	≥1.1	0.9	Within base	112.4	113.8

1 Does not consider the effect of debris impact during a debris flood which is considered a potential risk for Ashburnham Creek Dam.

2 The earthquake load case is used to establish the post-earthquake condition of the dam.

3 The post-earthquake case assumes a crack has been formed creating a seepage path and the build up of hydrostatic pressures beneath the dam equal to the hydrostatic head at the upstream and downstream faces.

The results indicate that the sliding factor meets or exceeds the minimum CDA criteria under the normal and flood load combinations, however does not meet CDA criteria for the post-earthquake load combination for both the current condition and upon removal of the sediment loading.

The position of the resultant does not meet CDA criteria for all of the load combinations considered under the current sediment loading conditions. For the case that the sediment loading is removed, the position of the resultant meets criteria for the flood load combination, however does not meet CDA criteria for the normal, earthquake and post-earthquake load combinations.

The maximum normal compression stress at the dam foundation is within the CDA acceptance criteria for the normal, earthquake and post-earthquake load combinations for both cases analyzed.

The results indicate that the dam is unstable upon application of the EDGM for a “Significant” consequence classification. Even upon removal of the sediment loading, the dam is only stable up to an applied EDGM between the 1/100 year and 1/475 year seismic events which corresponds to a NDMP likelihood rating of 3.

8.5 Gravity Wall Foundation Review

Based on the site observations and the anticipated geological conditions for the site, an allowable bearing capacity of 3 MPa is assumed for the gravity wall foundation as per Table 9.3 of the Canadian Foundation Engineering

Manual (CFEM, 2006). The allowable bearing capacity of 3 MPa exceeds the maximum compressive stress for each of the load combinations considered in the structural stability review as presented in Table 8.4.b.

8.6 Liquefaction and Post-Seismic Deformation

Based on site observations, the dam is assumed to be founded on bedrock and is therefore considered to have a very low susceptibility to liquefaction and post-seismic deformation when subject to strong ground motion.

8.7 Internal Erosion (Piping)

8.7.1 Internal Erosion Mechanisms

The process of internal erosion through a dam foundation may be broadly divided into four phases, namely:

- Initiation of erosion;
- Continuation of erosion;
- Progression to form a pipe or occasionally cause surface instability (sloughing); and,
- Initiation of a breach.

Erosion can be initiated by four mechanisms, namely:

- Concentrated leaks. Concentrated leaks occur where there is an opening in the foundation through which preferential seepage occurs, with the sides of the opening enlarging through continual erosion by the leaking water. Such concentrated leaks may occur through a crack caused by differential settlement during construction of the dam or its operation, hydraulic fracturing due to low stresses around conduits or the upper parts of the dam due to differential settlement, or through desiccation at high levels of fill. Concentrated leaks can also occur due to collapse settlement of poorly compacted fill around conduits and adjacent to walls. They may also occur due to the action of animals burrowing into levees and small dams and tree roots rotting in dams and forming seepage conduits.
- Backward erosion. Backward erosion piping occurs where critically high hydraulic gradients at the toe of a dam erode particles upwards and internal erosion develops backwards below the dam through small erosion conduits and flow velocity can transport the eroded particles. The presence of backward piping erosion is often exhibited by the manifestation of sand boils at the downstream side of the dam.
- Contact erosion. Contact erosion occurs when a coarse soil such as a gravel is in contact with a fine soil and flow parallel to the contact in the coarse soil erodes the fine soil.
- Suffusion. Suffusion occurs when water flows through widely graded or gap graded (internally unstable) non-plastic soils, with the small particles of soil transported by the seepage flow through the pores of the coarse particles. Poorly graded soils such as non-plastic glacial tills are more vulnerable to suffusion. Suffusion results in an increase in permeability, greater seepage velocities, and potentially higher hydraulic gradients, potentially accelerating the rate of suffusion.

Segregation of broadly or gap graded non-plastic soils during dam construction may create layers which are internally unstable even though the average grading of the soil is internally stable.

8.7.2 Piping Potential

As it is assumed that Ashburnham Creek Dam is founded on bedrock, it is considered to have an extremely low susceptibility to piping failure.

8.8 Debris Flow, Debris Flood and Flood Hazard Assessment

Debris flow, debris flood and flood hazard were studied for the Ashburnham Creek watershed and assessed using the Melton ratio (Wilford et al., 2004). The Melton ratio was developed to determine whether a stream is likely to be subject to a debris flow, debris flood or a flooding hazard. Debris flows and debris floods represent a significant risk to the dam as debris carried by either a debris flow or debris flood could be sufficient to damage the dam.

It is noted that the dam has in the past acted as a barrier to debris coming down the watershed, however as the reservoir is now completely full of debris it is unlikely impede the passage of additional debris.

Debris flows are very rapid to extremely rapid flows of fully saturated non-plastic (PI < 5% in sand and finer fractions) debris in steep channels (Hungr et al., 2001) that have considerable momentum and high destructive potential with peak discharges of up to 40 times calculated clear water flows. Key characteristics of debris flows include the presence of an established channel or regular confined path and a certain degree of rough sorting that tends to bring the largest clasts close to the flow surface producing inversive grading. Geomorphological indications of channels susceptible to debris flow generation include signs of scour along the gully and the presence of a well-defined depositional cone or fan built up by a number of separate events along the same path.

Debris floods are characterized as sediment-charged flood events with sediment concentrations between 20% and 47% by volume (Hungr et al., 2001) and peak discharges of up to 2 times the calculated flows. Debris floods may be triggered by extreme precipitation events, or by the blockage (and subsequent release) of creek flows impounded by landslides or debris flows entering the creek channel further upstream.

The Melton Ratio is calculated by the equation below:

Melton Ratio = Watershed relief (km)/$\sqrt{}$(Watershed Area (km^2))

Watershed relief is the difference in elevation between the top and bottom of the watershed.

Table 8.8 shows the typical ranges of the ratio associated with each hazard type.

Table 8.8 Typical Hazard for Melton Ratios

Hazard	Melton Ratio
Flood	< 0.3 for all watershed lengths
Debris Flood	0.3 to 0.6 for all watershed lengths > 0.6 for watershed lengths ≥ 2.7 km
Debris Flow	> 0.6 for watershed lengths < 2.7 km

Note that creeks classified as subject to debris flows may also be subject to floods and debris floods. Those that are subject to debris floods may also be subject to floods but aren't typically subject to debris flows. Those that are classified as subject to floods are typically not subject to debris floods or debris flows.

The Melton ratio calculated for Ashburnham Creek was 0.32. Plotted against an approximate watershed length of 5.1 km indicates that the catchment sits within the debris flood criteria as seen in Figure 8.8. This indicates that the catchment could be susceptible to debris floods but likely not debris flows. This would indicate that flow volumes could be up to two times greater than those calculated in the hydrotechnical assessment.

9. Hydrotechnical Assessment

The following sections provide a description of the study watershed, a review of available climatic and hydrometric data, and a summary of the method used to develop the Inflow Design Flood (IDF).

9.1 Watershed

Ashburnham Creek Dam is at an elevation of approximately 230 m and has a drainage area of 6.04 km² based on existing community watershed boundaries. The inflows to the reservoir are rainfall and snowmelt within the catchment area. The median basin elevation of the Ashburnham Creek watershed is estimated to be 510 m with a maximum basin elevation of 1020 m. The catchment area is forested land that is subject to logging. This causes tree canopy and vegetative cover to vary from year to year which impacts times of concentration and runoff coefficients. The Ashburnham Creek Dam basin is shown on Figure 9.1.

9.2 Climatic and Snow Course Data

There are several climate stations operated by the Meteorological Service of Canada (MSC) within the study region. Some of these stations have climatic data useful in determining the climate conditions at the project site by virtue of their proximity to the site, elevation and length of record. Details are summarized in Table 9.2.a and station locations are shown on Figure 9.2.

Table 9.2.a Regional Climate Stations

Station Name	Station No.	Elevation (m)	Period of Record	Data Type	Rainfall IDF* Curve	Distance to Site (km)
Cowichan Lake Forestry	1012040	177	1981 – 2010	Daily	No	4.1
Lake Cowichan	1012055	171	1983 – 2002	Daily	Yes	10.2
Nanaimo A	1025370	28	1985 – 2012	Hourly	Yes	35.4
North Cowichan	1015628	45	1982 – 2005	Daily	Yes	33.9
Port Alberni A	1036206	2	1969 – 1993	Hourly	Yes	68.7
Port Renfrew	1016335	10	1973 – 1982	Daily	Yes	26.2
Shawinigan Lake	1017230	159	1981 – 2010	Daily	No	44.7
Victoria Gonzales HTS	1018610	69	1925 – 1988	Hourly	Yes	76.8
Victoria Intl A	1018621	19	1965 – 2013	Hourly	Yes	58.1

*Intensity – Duration – Frequency data

The stations Cowichan Lake Forestry, Shawnigan Lake, Victoria Intl A, Victoria Gonzales HTS, Port Renfrew and Port Alberni A were included only for the purposes of determining a temperature versus elevation relationship.

According to the 1981 to 2010 Climate Normals data on the Environment Canada website, the mean annual precipitation at the Lake Cowichan Station, which is East of Ashburnham Creek Dam, is 2,047.5 mm (1,975.6 mm rainfall and 72.0 cm snowfall depth). Rainfall occurs throughout the year with 80% during the cooler half of the year (October to March). Snowfall mainly occurs in winter (November to March). Mean daily temperatures range from -2.5°C in December to 18.1°C in August.

The 24-hour rainfall totals for various return periods for the Lake Cowichan, North Cowichan and Nanaimo A stations were obtained from the MSC and are shown in Table 9.2.b. The 500-year, 1000-year and 5000-year 24-hour rainfall totals were obtained by extrapolation and adjusted to apply to the project site based on the elevation-rainfall relationship for the climate stations in Table 9.2.a.

Table 9.2.b 24-Hour Rainfall for Various Return Periods at Regional Climate Stations

Return Period (Years)	24-Hour Rainfall Total (mm)		
	Lake Cowichan	North Cowichan	Nanaimo A
2	93.6	57.8	55.5
5	110.7	70.8	69.7
10	122.1	79.4	79.0
25	136.4	90.3	90.9
30	138.9	92.2	92.9
50	147.1	98.4	99.7
100	157.6	106.5	108.4
500	184.5	126.9	130.6
1000	195.8	135.5	139.9
5000	221.9	155.3	161.5

The River Forecast Centre of the BC Ministry of Environment has a number of snow course and snow pillow sites available on Vancouver Island. The station closest to the project site, by distance and elevation, is the Jump Creek snow pillow station (at an elevation of 1160 m) located north of Cowichan Lake. The information for this automatic snow pillow station is presented in Table 9.2.c.

Table 9.2.c Regional Snow Pillow Station

Station Name	Station No.	Elevation	Period of Record	Distance to Site
Jump Creek Snow Pillow Station	3B23P	1160 m	1995-2011	20.7 km

The average snow water equivalents for the period of record at the Jump Creek snow pillow station are summarized in Table 9.2.d.

Table 9.2.d Average Snowpack Data for Jump Creek Snow Pillow

Month	Snow Water Equivalent (mm)
Jan	580.6
Feb	836.1
Mar	1070.2
Apr	1257.5
May	1015.6
June	308.5

The data shows that the peak average snow water equivalent (1257.5 mm) occurs in April. Note that this station is approximately 900 m higher than Ashburnham Creek Dam and 600 m higher than the median basin elevation, so use of this data is considered conservative.

9.3 Hydrometric Data

There is no long-term streamflow data available within the Ashburnham Creek watershed. Regional hydrometric data was obtained from the Water Survey of Canada to characterize the hydrology of the study area. The regional hydrometric stations used in this study are listed in Table 9.3 with station locations presented on Figure 9.3.

Table 9.3 Regional Hydrometric Stations

Station ID	Station Name	Drainage Area (km²)	Period of Record	Status
08HA072	Cottonwood Creek Headwaters	3.81	1998 – 2018	Active
08HA070	Harris Creek Near Lake Cowichan	28.0	1997 – 2018	Active

9.4 Determination of Inflow Design Flood

9.4.1 General

Based on a review of dam consequences classification discussed in Sections 6.2 and 6.3, Ashburnham Creek Dam should be classified as a “Significant” consequence dam in accordance with the 2007 Canadian Dam Association (CDA) Dam Safety Guidelines (2013 Edition). The CDA guideline for an Inflow Design Flood (IDF) for a “Significant” consequence dam is between the 100-year and the 1,000-year event. For the study watershed, peak runoffs are generated either by major rainstorms alone or by rain-on-snow events.

9.4.2 Determination of the 100-Year and the 1,000-Year Flood

Two methods were used to determine the 100-year and the 1000-year flood: a rainfall-runoff approach and a regional analysis. The rainfall-runoff approach refers to the development of a hydrologic model to determine the runoff hydrograph at the site, using precipitation, snowmelt and catchment characteristics as inputs. The regional analysis involves frequency analyses of regional hydrometric data and determination of the relationship between peak discharge and drainage area. The following paragraphs provide more details and present the results of the two approaches.

Rainfall-Runoff Approach

The 100-year and 1000-year 24-hour rainfall totals were calculated using a regression analysis from available 24-hour rainfall data at the Lake Cowichan, North Cowichan and Nanaimo A stations. The elevations and the magnitude of the 100-year and 1000-year rainfall events are included in Table 9.4.a.

Table 9.4.a 1000-Year 24-Hour Rainfall

Station Name	Elevation (m)	100-Year 24-Hour Rainfall (mm)	1000-Year 24-Hour Rainfall (mm)
Lake Cowichan	171	157.6	195.8
North Cowichan	45	106.5	135.5
Nanaimo A	28	108.4	139.9

A relationship between 1000-year 24-hour rainfall and elevation was developed using the above results to calculate the corresponding rainfall in the catchment area of the dam. This was repeated for the 100-year rainfall. The calculated 100-year and 1000-year 24-hour rainfall at the site were estimated to be 283 mm and 340mm.

To take into account the snowmelt occurring during a rain-on-snow event, the following equation was applied (Gray, 1973):

For heavily forested regions (60 – 100%)

$M = (0.074 + 0.007*P)*(Ta - 32) + 0.05$

where

M = snowmelt (in/day);

P = precipitation (in); and

Ta = temperature (°F).

For the 1000-year flood, the 1000-year 24-hour rainfall and the average daily temperature from January to March were used in estimating the daily snowmelt rate. The average value of the mean daily temperature (4.02°C) in Ashburnham Creek Dam catchment was calculated by defining a relationship for average temperature based on elevation for the above referenced climate stations and using that relationship to estimate the temperature at the Ashburnham Creek Dam median catchment elevation. The average daily snowmelt during a 1000-year rainfall event was determined to be 32.1 mm/day. This daily snowmelt is considered reasonable when compared to the Jump Creek snow pillow station data because there would be enough snow to supply the calculated amount of snowmelt. The combination of the 1,000-year 24-hour precipitation and snowmelt amounts to 372.0 mm. Using the same methodology, the 100-year average daily snowmelt during a 100-year rainfall event was determined to be 29.2 mm/day which combines with the rainfall to total 311.8 mm.

The hydrologic model used in the runoff analysis was HEC-HMS version 4.0, developed by the U.S. Army Corps of Engineers. The US Soil Conservation Service (SCS) unit hydrograph method was applied to determine the runoff hydrograph from the 100-year and 1000-year 24-hour rainfall combined with the average daily snowmelt rate. The SCS Type Ia distribution was selected to define the distribution of rainfall over 24 hours. The average daily snowmelt was evenly distributed and combined with the rainfall for the storm of interest. In general, the Ashburnham Creek catchment area consists of heavily forested area in good condition with intermittent logging activities taking place within the catchment. Soil Type B, representing soil with a well and moderately well drained infiltration rate, was chosen for the study area. Antecedent moisture condition III (saturated conditions) was assumed. A curve number (CN) of 79 was estimated for the catchment area. Slopes, elevations and channel lengths were taken from GIS maps to estimate the time of concentration for the catchment.

The peak inflow to Ashburnham Creek Dam during the 1000-year return period flood was estimated to be 75.4 m^3/s. Similarly, the 100-year flood event was calculated as 60.2 m^3/s

Regional Analysis

A regional hydrological analysis was carried out to provide an alternative estimate of the 1000-year flood inflow to Ashburnham Creek Dam. Flood frequency analyses were conducted for the selected regional hydrometric stations using the HYFRAN software Version 2.2. Four different frequency distributions: Gumbel, the Three Parameter Lognormal, Weibull and the Log Pearson Type III distributions, were applied to the data. The maximum instantaneous flows were plotted against drainage area and a logarithmic regression equation was fitted to obtain the 1000-yr flows for each selected hydrometric station. The peak flow estimates for three return periods at the project site are tabulated in Table 9.4.b.

Table 9.4.b Regional Analysis Peak Flood Estimates

Return Period (Years)	Flood Estimate (m^3/s)
10	32.4
30	38.7
50	41.5
100	45.1
200	48.5

Return Period (Years)	Flood Estimate (m³/s)
500	53.0
1000	56.2
5000	63.6

100-year and 1,000-year Flood

The 100-year and the 1,000-year peak flood estimates obtained from the regional analysis are lower than that from the hydrologic model. However, most of the available regional stations with data sets extensive enough for statistical analysis are from larger watersheds than that of Ashburnham Creek. As larger watersheds have a greatly reduced peaking factor and significantly larger time of concentration, it is likely that this method underestimates flooding within the watershed. Also, the data sets have too short a record period for accurate statistical assessment of a 1000-year event. The HEC-HMS hydrologic model was based on site specific conditions such as soil type and local climate data, making this method preferred as well as conservative. Therefore, the 100-year and the 1,000-year peak inflows to Ashburnham Creek were determined as 60.2 m^3/s and 75.4 m^3/s, respectively.

9.4.3 Inflow Design Flood

The rainfall-runoff method is considered appropriate for developing the IDF for Ashburnham Creek as it accounts for site specific conditions such as soil type and local climate data.

As indicated earlier, the 100-year and the 1,000-year flood event were determined to be 60.2 m^3/s and 75.4 m^3/s, respectively. The CDA guidelines recommend that the IDF for a “Significant” consequence dam should be between the 100-year and the 1000-year floods (CDA, 2007). The hydrographs for the two floods are shown on Figure 9.4.

9.5 Flood Routing and Freeboard Determination

A hydrological model was developed to simulate water levels in Ashburnham Creek reservoir and determine the peak outflow during the IDF. The following sections provide a summary of the methodology and results of this analysis.

9.5.1 Volume-Elevation Relationship

The original Area-Elevation-Storage relationship is illustrated in Figure 9.5a. The current volume-area-elevation relationship for Ashburnham Creek dam was estimated using measurements at the time of the field reconnaissance as the reservoir is completely full of sediment leaving no water storage capacity.

9.5.2 Rating Curve

The spillway is approximately 11.6 m long and 1.32 m high. The rating curve for the spillway was estimated based on the following equation for broad crested weir flow (Smith, 1995):

$Q = CLH^{1.5}$

Where:

Q = Discharge (m^3/s);

C = Discharge coefficient, for a broad crested weir;

L = Effective spillway crest length (m); and

H = Head above spillway crest (m).

The 24.8 m crest length of the dam includes 11.6 m for the spillway, 2.9 m for a slightly elevated section to the left side of the spillway and 10.3 m for the right wall section. Water will primarily route through the spillway during a flood, however the crest will also act as a weir if the flood overtops the dam crest. The rating curve developed for the Ashburnham Creek Dam spillway is shown on Figure 9.5b. The capacity of the spillway, to the dam crest, is 34.5 m³/s.

9.5.3 Flood Routing Results

The flood routing was performed using the HEC-HMS model, which includes a routing component for flows through reservoirs. The starting water surface elevation was assumed to be at the spillway crest elevation. As the reservoir is full of sediment the low level outlet is ineffective for discharging any water. The results of the HEC-HMS flood routing during the IDF corresponding to the “Significant” classification as well as other flows as per the NDMP framework are summarized in Table 9.5. Figure 9.5c represents the results of the flood routing graphically. Note that in this figure the inflow and outflow hydrographs are coincident, due to the lack of storage, and there is no attenuation of peak flows.

Table 9.5 Results of Flood Routing

Return Period (y)	Spillway Weir Crest Elevation (m)	Initial Lake Level (m)	Peak Lake Level (m)	Peak Storage (m³)	Peak Inflow (m³/s)	Peak Outflow (m³/s)	Dam Crest Elevation (m)	Available Freeboard (m)
30	0.00	0.00	1.67	1,000	52.8	52.8	1.32	-0.3
50	0.00	0.00	1.72	1,100	56.1	56.1	1.32	-0.4
100	0.00	0.00	1.78	1,200	60.2	60.2	1.32	-0.5
500	0.00	0.00	1.94	1,400	70.9	70.9	1.32	-0.6
1000	0.00	0.00	2.00	1,500	75.4	75.4	1.32	-0.7
5000	0.00	0.00	2.14	1,700	85.7	85.7	1.32	-0.8

The results above indicate that for the “Significant” consequence storm there is overtopping of the dam during the inflow design flood.. The reservoir level response to the IDF is plotted in Figure 9.5d. Peak outflows would be the same as the peak inflows, between 60.2 m³/s for a 100-year storm and 75.4 m³/s for a 1,000-year storm.

9.5.4 Freeboard Assessment

The flood routing exercise described above determined that there would be overtopping of the dam crest by 0.5 m during a 100-year event and overtopping of the dam crest by 0.7 m during a 1,000-year event. In other words, the spillway cannot pass a 100-year event or not a 1,000-year event. However, as Ashburnham Creek Dam is a concrete gravity dam, it should be able to resist overtopping without serious damage. The CDA Guidelines (2007) indicate that concrete dams may be permitted to have the freeboard requirement reduced or overtopping may be allowed provided that the integrity of the dam, its abutments and any ancillary structures is not compromised.

Wind and wave analyses were not undertaken for this dam as the concrete structure is considered non-erodible and thus should be able to resist wave overtopping without serious damage to the main water barrier.

10. Dam Safety Management System

10.1 General

Dam safety management can be generally described in terms of five components (CDA Guidelines 2007):

- Owner commitment to safety;
- Regular inspections and Dam Safety Reviews with proper documentation and follow up;
- Implementation of effective Operations, Maintenance and Surveillance (OMS) practices;
- Preparation of effective Emergency Preparedness Plan; and
- Management of Public Safety.

A general schematic of a dam safety management system is presented in Figure 10.1. Ecora has assessed the dam safety management system in place for the Ashburnham Creek Dam and the results of this assessment are presented in this section.

10.2 Operation, Maintenance and Surveillance Manual

An Operation, Maintenance and Surveillance (OMS) Manual is a means to provide both experienced and new staff with the information they need to support the safe operation of a dam (CDA 2007). It is Ecora's understanding that currently Ashburnham Creek Dam does not have an Operation, Maintenance and Surveillance Manual.

10.3 Dam Emergency Plan

The objective of a Dam Emergency Plan (DEP) is to establish a formal internal document that operators of a dam should follow in the event of an emergency at the dam. The DEP outlines the key emergency response roles and responsibilities, in order of priority, as well as the required notifications and contact information. The DEP also provides basic information that allows for the planning and coordination by municipalities, Royal Canadian Mounted Police, Provincial agencies, utility owners, transportation companies and other parties that would be affected by a major flood (CDA 2007). The DEP is intended to combine the requirements of both the Emergency Response Plan (ERP) and Emergency Preparedness Plan (EPP) based on the BC Dam Safety Regulation (40/2016).

It is Ecora's understanding that currently Ashburnham Creek Dam does not have a DEP.

10.4 Public Safety Management

The CDA released Guidelines for Public Safety around Dams in 2011. Public safety around dams is an emerging topic in the dam safety community around the world, which in Canada is led by the CDA.

Dam owners are responsible for managing the public safety risks caused by a dam, as far upstream and downstream as the owner has property rights. Beyond the property the dam owner may have additional responsibilities to assess specific locations where the hazards are known by the owner to result directly from the dam or its operation and to inform the public and other affected property owners of these hazards. In most jurisdictions in Canada, due diligence is the test that the dam owner has taken reasonable and prudent precautions to protect the public. The implementation of a Public Safety Plan (PSP), records of decisions made, and activities performed to manage public safety at the dam, provide evidence of due diligence (CDA 2011).

During Ecora’s inspection of Ashburnham Creek Dam it was noted that there is limited restriction on public interaction with the dam. Currently there is no PSP in place for this facility and one should be developed.

10.5 Dam Safety Expectations Assessment

10.5.1 General

The British Columbia Ministry of Forests, Lands, Natural Resource Operations & Rural Development (MFLNRORD) has developed a sample check sheet of Dam Safety Expectations, Deficiencies and Priorities (May 2010) which is based on the BC Hydro Hazards and Failure Modes Matrix and the 2007 CDA Guidelines. A dam safety expectations assessment has been undertaken for Ashburnham Creek Dam using the sample check sheet prepared by the MFLNRORD as presented in Appendix E.

The Dam Safety Expectations are divided into five categories:

- Dam Safety Management System
- Operation, Maintenance and Surveillance
- Emergency Preparedness
- Dam Safety Review
- Dam Safety Analysis

A brief summary of the results of the Dam Safety Expectations is discussed below.

10.5.2 Dam Safety Analysis

There are two actual deficiencies and one non-conformance, namely:

- No engineering drawings of the dam structure were available. Limited inspection and operational records are available.
- Catchment may be susceptible to development of debris floods and thus the dam may not be adequately protected.
- Dam does not meet all CDA stability requirements for sliding and overturning.

10.5.3 Operation, Maintenance and Surveillance

There is one actual deficiency and 15 non-conformances in this section.

- Flow control equipment is not tested and is unlikely to be capable of operating as required due the sediment in the reservoir.
- All non-conformances could be addressed with the completion of an OMS Plan that includes detailed operating procedures, testing records and surveillance documentation.

10.5.4 Emergency Preparedness

There are no deficiencies and 10 non-conformances in this category which can be addressed by documenting training and by the completion of a DEP.

10.5.5 Dam Safety Review

There are no deficiencies and non-conformances in this category. By commissioning this Dam Safety Review, the Cowichan Valley Regional District conforms to the dam safety expectations for this category.

10.5.6 Dam Safety Management

There are no deficiencies and seven non-conformances in this category, all of which could be addressed by completion of an OMS Manual and a DEP.

11. Risk Assessment

11.1 General

As part of this DSR, the NDMP Risk Assessment Information Template (RAIT) was completed in accordance with NDMP and has been included as Appendix F. The assessment process allows stakeholders to identify and prioritize the risks that are likely to create the most disruption to them. The assessment also helps decision-makers to identify and describe hazards and assess impacts and consequences based upon the vulnerability or exposure of the local area, or its functions to that hazard.

The risk assessment approach aims to understand the likely impacts of a range of emergency scenarios upon community assets, values and functions. As such, risk assessments provide an opportunity for multiple impacts and consequences to be considered enabling collaborative risk treatment plans and emergency management measures to be described.

The outputs of the assessment process can be used to better inform emergency management planning and priority setting, introduce risk action plans, and ensure that communities are aware of, and better informed about, hazards and the associated risks that may affect them.

11.2 Risk Assessment Information

Descriptions of the risk ranking, and definitions associated with the five-point scale used to define the impacts are presented below. The impact risk rating definitions are based on qualitative and quantitative elements referenced from a diverse array of risk and resilience methodologies and external risk management models.

People and Societal Impacts

It is a priority at the municipal, provincial and federal levels to protect the health and safety of Canadians. Impacts on people are considered pertinent in the assessment process given that natural hazards can result in significant societal disruptions such as evacuations and relocations as well as injuries, immediate deaths, and deaths resulting from unattended injuries or displacement. As such, the following impact criteria will be assessed on a 1 to 5 scale:

- number of fatalities;

- ability for local healthcare resources to address injuries; and,
- number of individuals displaced and duration of displacement.

Environmental Impacts

A priority for municipal, provincial and federal governments is to protect Canada's natural environment for current and future generations. As such, environmental impacts were included in the assessment to measure the risk event in relation to the degree of damage and predicted scope of clean-up and restoration needed following an event. The definitions consider the direct and indirect environmental impacts within the defined geographic area on a 1 to 5 scale, and include an assessment of air quality, water quality and availability (exclusive to on land and in-ground water), and various other nature indicators.

Local Economic Impacts

There may be impacts on the local economy that are the result of a risk event occurring. Local economic impacts attempt to capture the value of damages or losses to local economically productive assets, as well as disruptions to the normal functioning of the community/region's local economic system. The definitions consider the local economic impacts within the defined geographic area on a 1 to 5 scale and should consider direct and indirect economic losses (i.e. productivity losses, capital losses, operating costs, financial institutions and other financial losses).

Local Infrastructure Impacts

There are several local infrastructure components, as per a variety of risk assessment and management sources and guidelines that are fundamental to the viability and sustainability of a community/region. Those components that appear most pertinent to assess impacts resulting from natural hazards, such as floods, include: energy and utilities; information and communication technology; transportation; health, food and water; and safety and security. At a minimum, an assessment of the aforementioned components must be completed, defined on a 1 to 5 scale, and should consider both direct and indirect impacts.

Public Sensitivity Impacts

Public sensitivity was included as an impact criterion given that credibility of governments is founded on the public's trust that all levels of government will respond effectively to a disaster event. The definitions consider the impacts on public visibility on a 1 to 5 scale and include an assessment of public perception of government institutions, and trust and confidence in public institutions.

11.3 Risk Assessment Summary

From the impact categories considered, the following principal impacts were noted:

- The primary risk event is the breach of Ashburnham Creek Dam due to structural failure caused by hydrostatic pressures generated by a 1 in 100-year flood event.
- In the event of a dam breach, consequences could include the following:
  - Damage to creek crossings at Gordon River Road and South Shore Road;
  - Lily Beach Park; and
  - Minor flooding around Ashburnham Creek.

11.4 Confidence Levels

The risk assessment process requires confidence levels to be defined, particularly since confidence levels can vary considerable depending on the availability of quality data, availability of relevant expertise to feed the risk assessment process, and the existing Canadian body of knowledge associated with specific natural hazards and natural disaster events.

Confidence levels have been defined using letters ranging from A to E, where ‘A’ is the highest confidence level and ‘E’ is the lowest. This approach was taken to ensure all applicants can determine the confidence in their risk assessment in a simplified, straightforward manner, which also ensures that a more consistent representation of confidence levels is being determined across all submissions.

The level of confidence for this assessment is considered to be “C”, based on the level of assessment completed to date.

12. Observations and Conclusions

The conclusions reached during the DSR of Ashburnham Creek Dam are presented as follows for each area of review:

12.1 Background Review

- Limited background information is available for this dam which does not include record drawings for the dam structure.
- The dam was constructed in 1947 by a logging company.
- The reservoir has filled with sediment, possibly as a result of logging roads washing out in upstream areas on two occasions.

12.2 Site Reconnaissance

- The reservoir was completely filled with sediment up to the spillway crest at the time of the site reconnaissance.
- Extensive organic growth (moss) was noted throughout the surface of the structure.
- A build-up of oxidation residue appeared to be staining the mossy growth on the concrete surface on the downstream side of the dam and therefore it is suspected that the reinforcing steel has corroded.
- Signs of erosion and weathering were noted on the upstream side of the west wing wall.

12.3 Consequence Classification Review

- The dam breach inundation mapping indicates that a total area of 0.33 km^2 would be flooded in the event of a dam breach during a 100-year event, potentially impacting Gordon River Road and South Shore Road.

- Dam breach analysis and inundation mapping results confirmed that the consequences classification for Ashburnham Creek Dam should be maintained as “Significant”. The CDA guidelines recommend an Inflow Design Flood (IDF) for a “Significant” consequence dam to be between the 100-year and the 1,000-year event.

12.4 Failure Mode Assessment

- The plausible failure modes of the dam are; overtopping as the spillway may not have sufficient capacity to pass the IDF, deformation and deterioration due to age and sliding/overturning from the design flood or seismic forces.

12.5 Geotechnical and Structural Assessment

- Results of the stability assessment indicate that the dam does not meet CDA criteria for normal, flood, earthquake and post-earthquake load combinations under the current sediment loading.
- Even with removal of the sediment loading, the dam still does not meet the CDA criteria for normal, earthquake and post-earthquake load combinations.
- The results indicate that the dam is unstable upon application of the EDGM for a “Significant” consequence classification.
- Even upon removal of the sediment loading, the dam is only stable up to an applied EDGM between the 1/100-year and 1/475 year seismic events which corresponds to a NDMP likelihood rating of 3.
- The allowable bearing capacity of the foundation is adequate to resist the maximum compressive stress for normal, flood, earthquake and post-earthquake loading conditions.
- The dam foundation is considered to have a very low susceptibility to liquefaction and post-seismic deformation when subject to strong ground motion.
- The dam foundation is considered to have an extremely low susceptibility to piping failure.

12.6 Hydrotechnical Assessment

- The peak inflow to Ashburnham Creek Dam during the IDF associated with the recommended “Significant” consequences classification is between 60.2 m^3/s (100-year flood) and 75.4 m^3/s (1,000-year flood). Because of the absence of significant storage, peak outflows are the same as peak inflows.
- The capacity of the spillway is estimated to be 34.5 m^3/s.
- The flood routing exercise determined that during the IDF event the dam crest will be overtopped. Given that Ashburnham Creek Dam is a concrete gravity dam, it should be able to resist overtopping without serious damage.

12.7 Dam Safety Management

- No Operation, Maintenance and Surveillance (OMS) Manual or Dam Emergency Plan (DEP) is currently in place for Ashburnham Creek Dam.

12.8 Risk Assessment

- Even upon removal of the sediment loading, the dam is only stable up to an applied EDGM between the 1/100-year and 1/475 year seismic events which corresponds to a NDMP likelihood of 3.
- A preliminary estimate of reconstruction costs as a result of a dam breach is between $300,000 and $3 million based on the scope of the infrastructure impacted.

13. Recommendations

The recommendations that have been developed during this DSR of Ashburnham Creek Dam are presented as follows for each area of review. Priorities (Low, Medium, High or Very High) are given in parentheses. Low, medium, high and very high priority recommendations should be addressed within 5, 3, 1 and 0.5 year(s) respectively.

13.1 Background Review

- As no record drawings are available for the dam structure, a detailed topographical survey of the dam embankment, abutments, outlet and spillway channel should be commissioned to verify existing dam geometry, confirm critical dam elevations and to assist in any future engineering assessments (High).

13.2 Site Reconnaissance

- There are no recommendations in this area of the review.

13.3 Consequence Classification

- There are no recommendations in this area of the review.

13.4 Failure Mode Assessment

- There are no recommendations in this area of the review.

13.5 Geotechnical and Structural Assessment

- CVRD should commission a design study to address the major deficiencies in the Ashburnham Creek Dam, namely to increase its resistance to sliding and overturning to meet CDA stability criteria. It is envisioned this would result in a recommendation to either remediate or decommission the existing dam. Remediation of the dam would likely include the design of a reinforced concrete toe buttress solution to increase the stability of the gravity wall (Very High).

- If it is chosen to remediate the existing dam, it is recommended that sediment retained by the dam be removed, a debris barrier constructed upstream of the dam to contain debris and areas of concrete deterioration, particularly in vicinity of cold joints, be addressed.

13.6 Hydrotechnical Assessment

- Extra spillway capacity should be added to the dam to allow for passage of the IDF event or the dam should be strengthened so that the dam would be able to resist forces generated by an overtopping event during the IDF (High).

13.7 Dam Safety Management

- An Operation, Maintenance and Surveillance Manual and a Dam Emergency Plan need to be prepared for Ashburnham Creek Dam (High).
- The dam should either be decommissioned or rehabilitated to meet design loading criteria (High).

13.8 Risk Assessment

- Should the CVRD wish to proceed with a NDMP funding application to remediate or replace Ashburnham Creek Dam they should undertake a more detailed cost estimate of infrastructure that would be impacted in the event of a dam breach (High).

14. Dam Safety Review Assurance Statement

In accordance with the Association of Professional Engineers and Geoscientists of BC (APEGBC) Professional Practice Guidelines – Legislated Dam Safety Reviews in BC V3.0 (October 2016) we have completed a Dam Safety Review Assurance Statement, which is presented in Appendix G.

References

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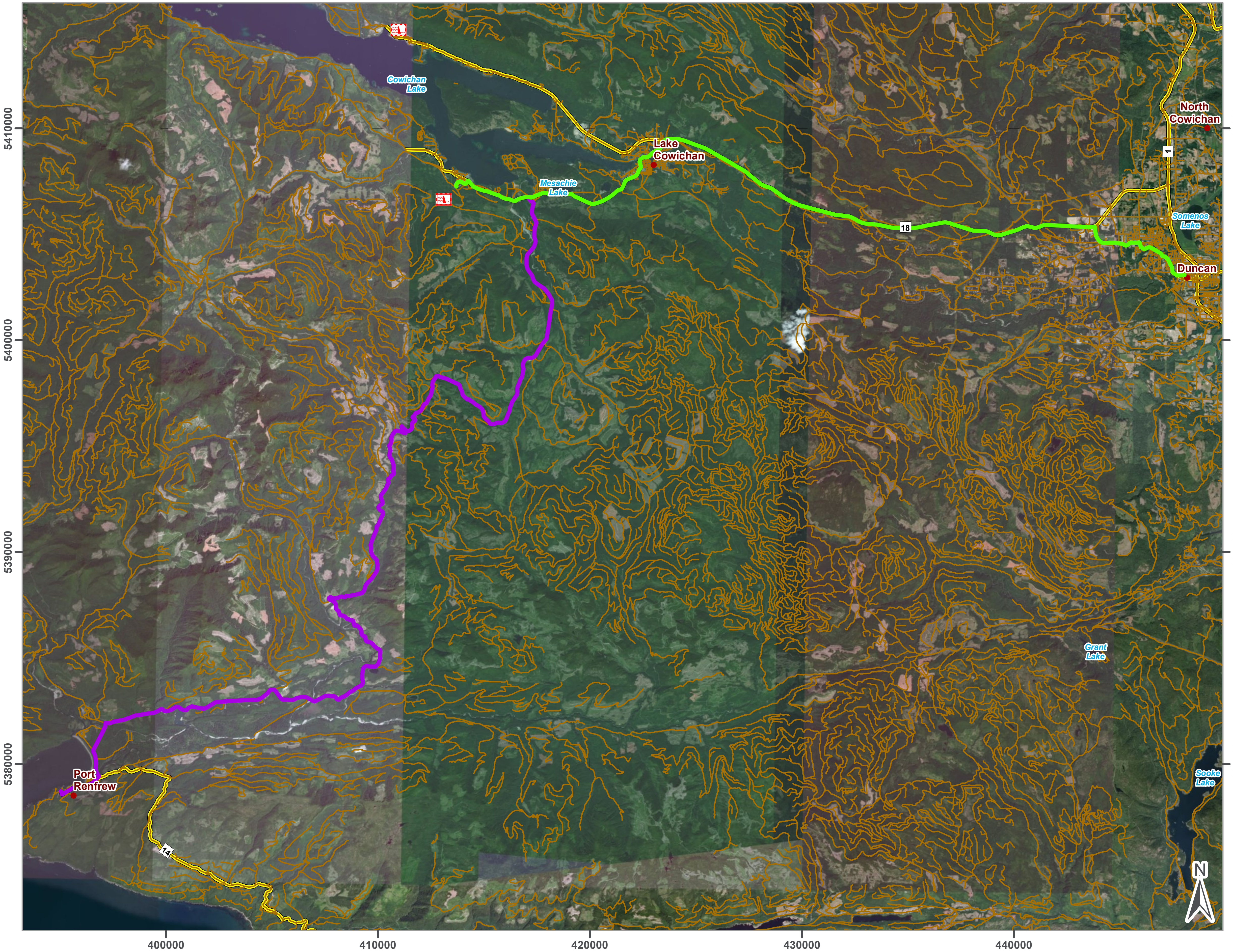
Figures

SITE LOCATION & ACCESS ROUTE

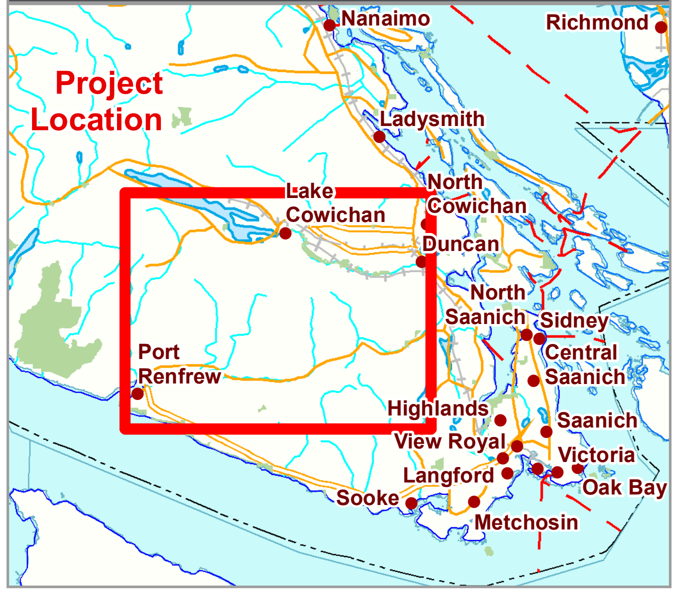


DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM HONEYMOON BAY, BC

Legend

- ⊡ Ashburnham Creek Dam
- ● Cities
- — Digital Atlas Roads
- ═ Highways
- — Primary Access (36 min,
- — Secondary Access (1hr 15 min,

LOCATION MAP



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0 5 10 KM

Project No.: GK-18-020-CVD
Client: Cowichan Valley
Regional District
NAD 1983 UTM Zone 10N

Date: 2019/02/12
Drawn: MT Check: AG

Figure 1.2

BEDROCK GEOLOGY

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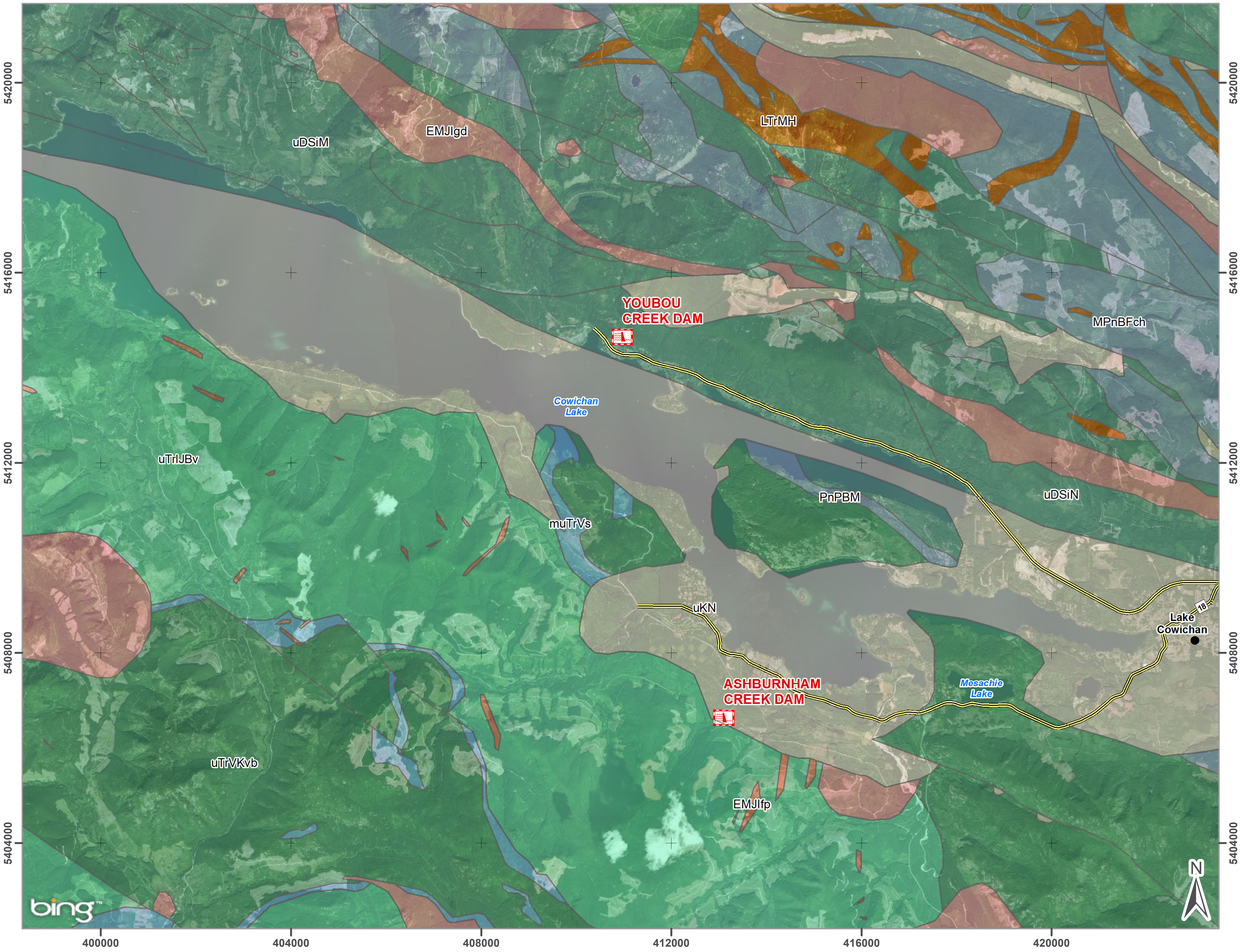
DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM HONEYMOON BAY, BC



Legend

● Cities

Dam Locations

Highways

Streams

Bedrock Geology

EMJIfp - Feldspar porphyry, hornblende porphyry, augite porphyry, dacite, basalt (92B, C, F).

EMJIgd - Granodiorite, quartz diorite, quartz monzonite, diorite, agmatite, feldspar porphyry, minor gabbro and aplite (170 - 185 Ma).

LTrMH - Gabbro, diabase, feldspar diabase, glomeroporphyritic diabase and gabbro, minor diorite (215 - 230 Ma). Coeval with Karmutsen Formation.

MPnBFch - Ribbon chert, cherty tuff, graphitic argillite, thinly bedded intercalated sandstone-siltstone-argillite, volcanic sandstone and conglomerate, interbedded argillite and crinoidal limestone, massive and pillowed basalt with intercalated cherty sed

PnPBM - Massive crinoidal limestone, bedded calcirudite and calcarenite, chert, cherty argillite and siltstone, marble (Upper Pennsylvanian to Lower Permian) (92B, C, F)

muTrVs - Undifferentiated Parson Bay and Quatsino formations (92B, C, F).

uDSiM - Thickly bedded tuffite and lithic tuffite, breccia, tuff, feldspar and quartz-feldspar crystal tuff, lapilli tuff, rhyolite, dacite, laminated tuff, jasper, chert, hematite-chert iron formation (92B, C, F).

uDSiN - Pyroxene-feldspar phyric agglomerate, breccia, lapilli tuff, massive and pillowed flows, massive tuffite, laminated tuff, jasper and chert (92B, C, F)

uKN - Boulder, cobble and pebble conglomerate, coarse to fine sandstone, siltstone, shale, coal (Santonian to Maastrichtian).). Includes BENSON, COMOX, HASLAM, EXTENSION, PENDER, PROTECTION, EAST WELLINGTON, TRENT RIVER, CEDAR DISTRICT, DE COURCY, DE

uTrVKvb - Basalt pillowed flows, pillow breccia, hyaloclastite tuff and breccia, massive amygdaloidal flows, minor tuffs, interflow sediment and limestone lenses (Carnian).

uTrIJBv - Massive amygdaloidal and pillowed basalt to andesite flows, dacite to rhyolite massive or laminated lava, green and maroon tuff, feldspar crystal tuff, breccia, tuffaceous sandstone, argillite, pebble conglomerate and minor limestone (Sinemurian t

1:80,000

0 1 2 3 4 km

Project No.: GK-18-020-CVD
Client: Cowichan Valley
Regional District
NAD 1983 UTM Zone 10N

Date: 2018/11/02
Drawn: MT Check: AG

Figure 3.4

Notes:
Photos taken on March 4, 2018.

DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM

Estimated Dimensions of Ashburnham Creek Dam

Project No. GK-18-020-CVD
Client: Cowichan Valley Regional District
Office: Kelowna
Scale: NTS
Date: JAN 10, 2019
DWN: AG CHK: MJL

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Figure 4.1

EXTENT OF INUNDATION & MAXIMUM FLOW DEPTH

DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM HONEYMOON BAY, BC

Legend

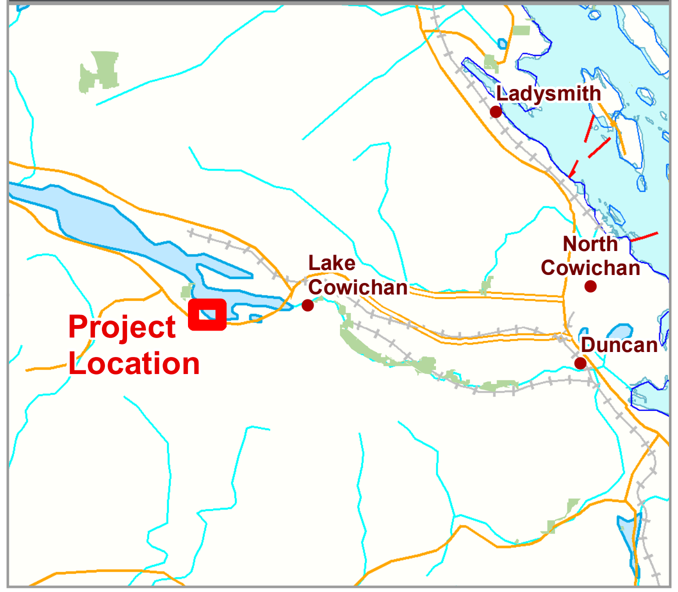
▨	Ashburnham Creek Dam
—	Digital Atlas Roads
═	Highways

Maximum Flow Depth (m)

🟦	0.000 - 0.250
🟦	0.251 - 0.500
🟩	0.501 - 0.750
🟨	0.751 - 1.000
🟨	1.001 - 2.000
🟧	2.001 - 4.000
🟧	4.001 - 6.000
🟥	6.001 - 10.000

Total Area of Inundation = 0.33 km^2

LOCATION MAP



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Project No.: GK-18-020-CVD
Date: 2019/02/12
Client: Cowichan Valley Regional District
Drawn: MT Check: AG
NAD 1983 UTM Zone 10N

Figure 5.0a

TIME (HRS) FOR 0.6m FLOW DEPTH

DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM HONEYMOON BAY, BC

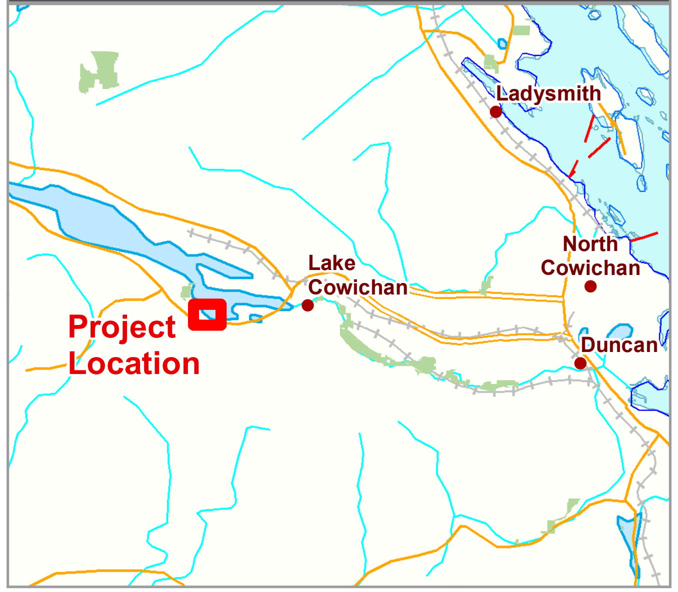
Legend

- Ashburnham Creek Dam
- Digital Atlas Roads
- Highways

Time (hrs) for 0.6m Flow Depth

- 🟦 0.100 - 1.000
- 🟩 1.001 - 3.000
- 🟩 3.001 - 5.000
- 🟨 5.001 - 10.000
- 🟧 10.001 - 15.000
- 🟧 15.001 - 20.000
- 🟥 20.001 - 24.000

LOCATION MAP



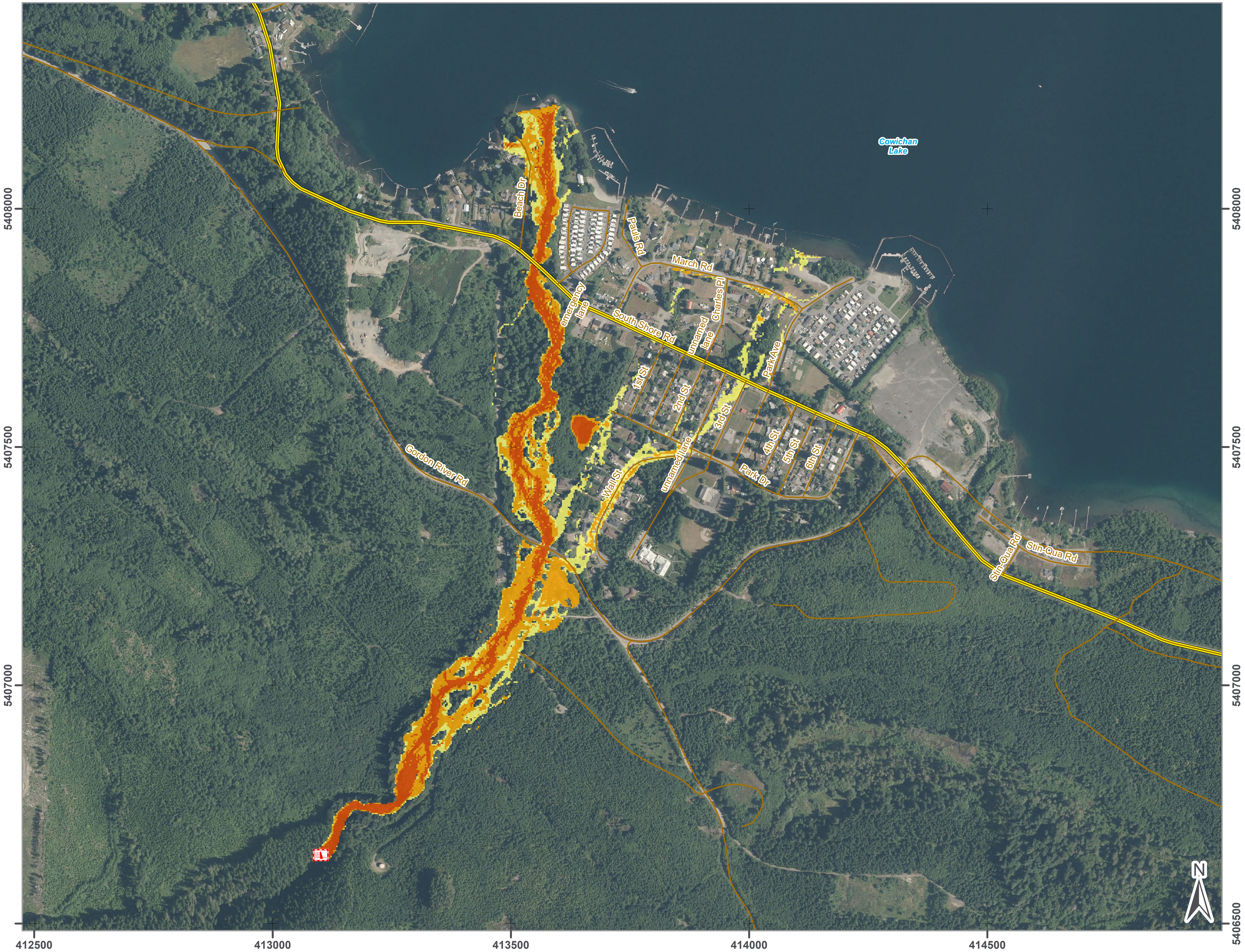
1:8,000

0 250 500 Meters

Project No.: GK-18-020-CVD
Date: 2019/02/12
Client: Cowichan Valley Regional District
Drawn: MT Check: AG
NAD 1983 UTM Zone 10N

Figure 5.0b

FLOOD HAZARD RATING



DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM HONEYMOON BAY, BC

Legend

Ashburnham Creek Dam

Digital Atlas Roads

Highways

Flood Hazard Rating and Total Area of Flooding Downstream of Dam Spillway Point

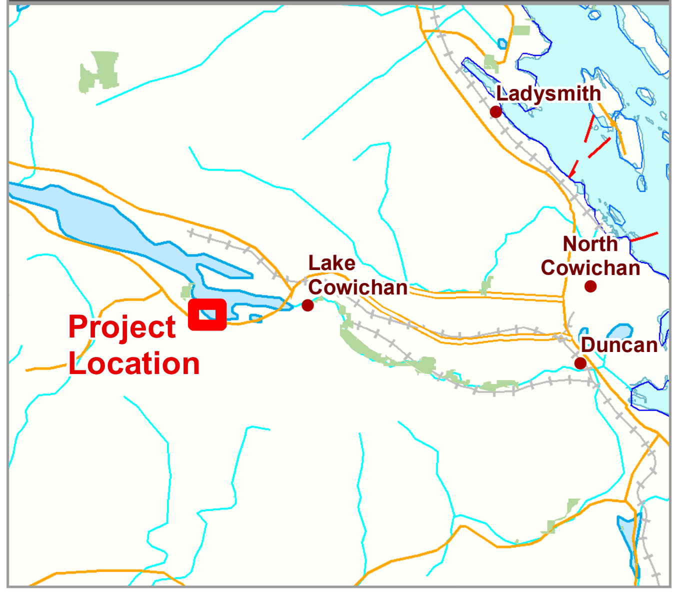
🟨 Low (0.043km ^{2})

🟧 Medium (0.056 km ^{2})

🟥 High (0.041 km ^{2})

Hazard Level	Description
High	Persons are in danger both inside and outside of buildings. Structures are at risk of being destroyed.
Medium	Persons are in danger outside of buildings. Structures may suffer damage and possible destruction depending on construction characteristics.
Low	Danger to persons is low or non-existent. Buildings may suffer little structural damage, however may undergo significant non-structural damage to interiors.
Reference: Garcia, et al., 2003, 2005	

LOCATION MAP



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0 250 500 Meters

Project No.: GK-18-020-CVD

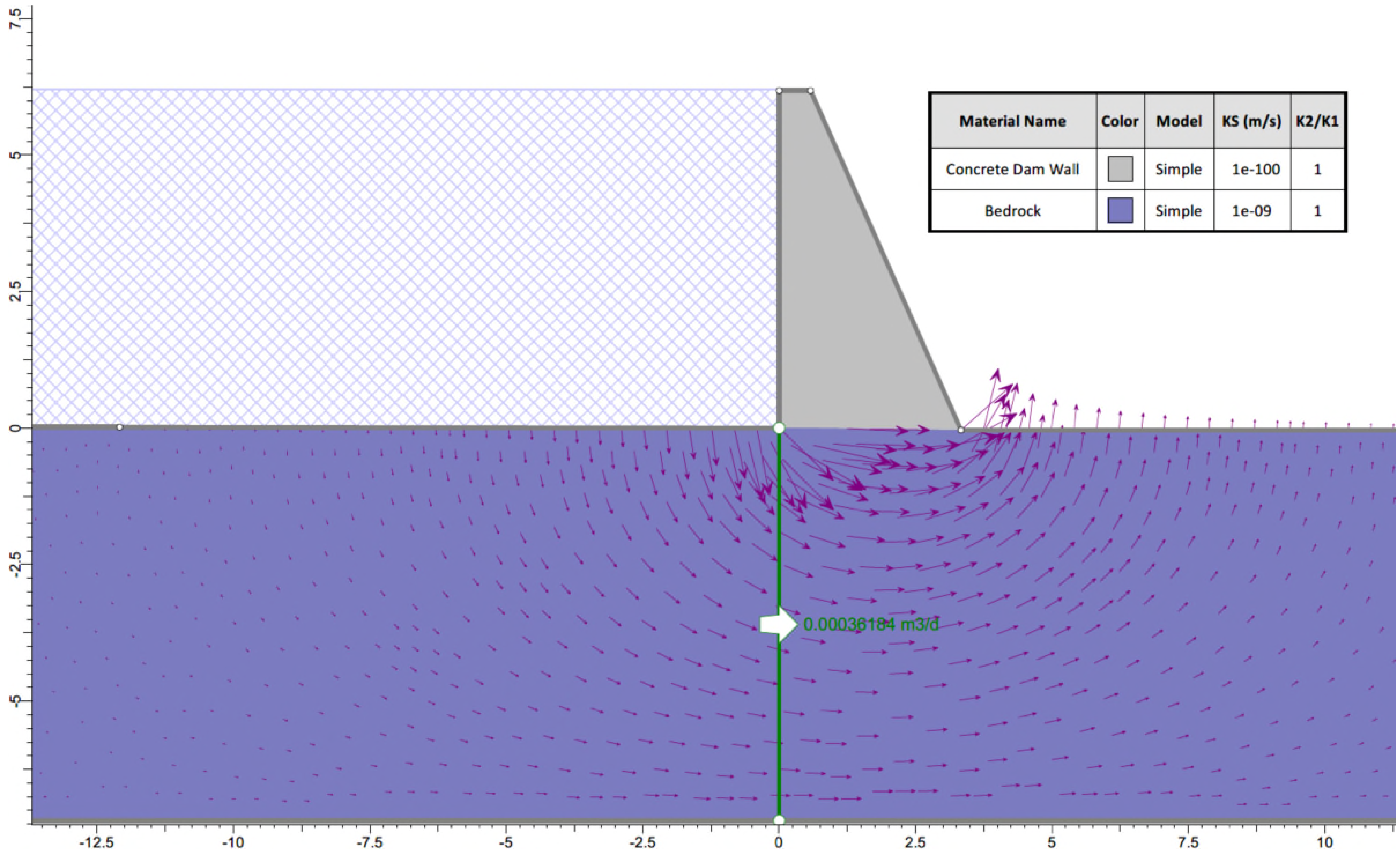
Client: Cowichan Valley Regional District

NAD 1983 UTM Zone 10N

Date: 2019/02/12

Drawn: MT Check: AG

Figure 5.0c



Material Name	Color	Model	KS (m/s)	K2/K1
Concrete Dam Wall	⬜	Simple	1e-100	1
Bedrock	🟪	Simple	1e-09	1

Notes:

DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM

Steady State Seepage Analysis: Reservoir Level at Spillway Elevation

Project No.	GK-18-020-CVD
Client:	Cowichan Valley Regional District
Office:	Kelowna
Scale:	NTS
Date:	November 23, 2018
DWN:	CE CHK: MJL

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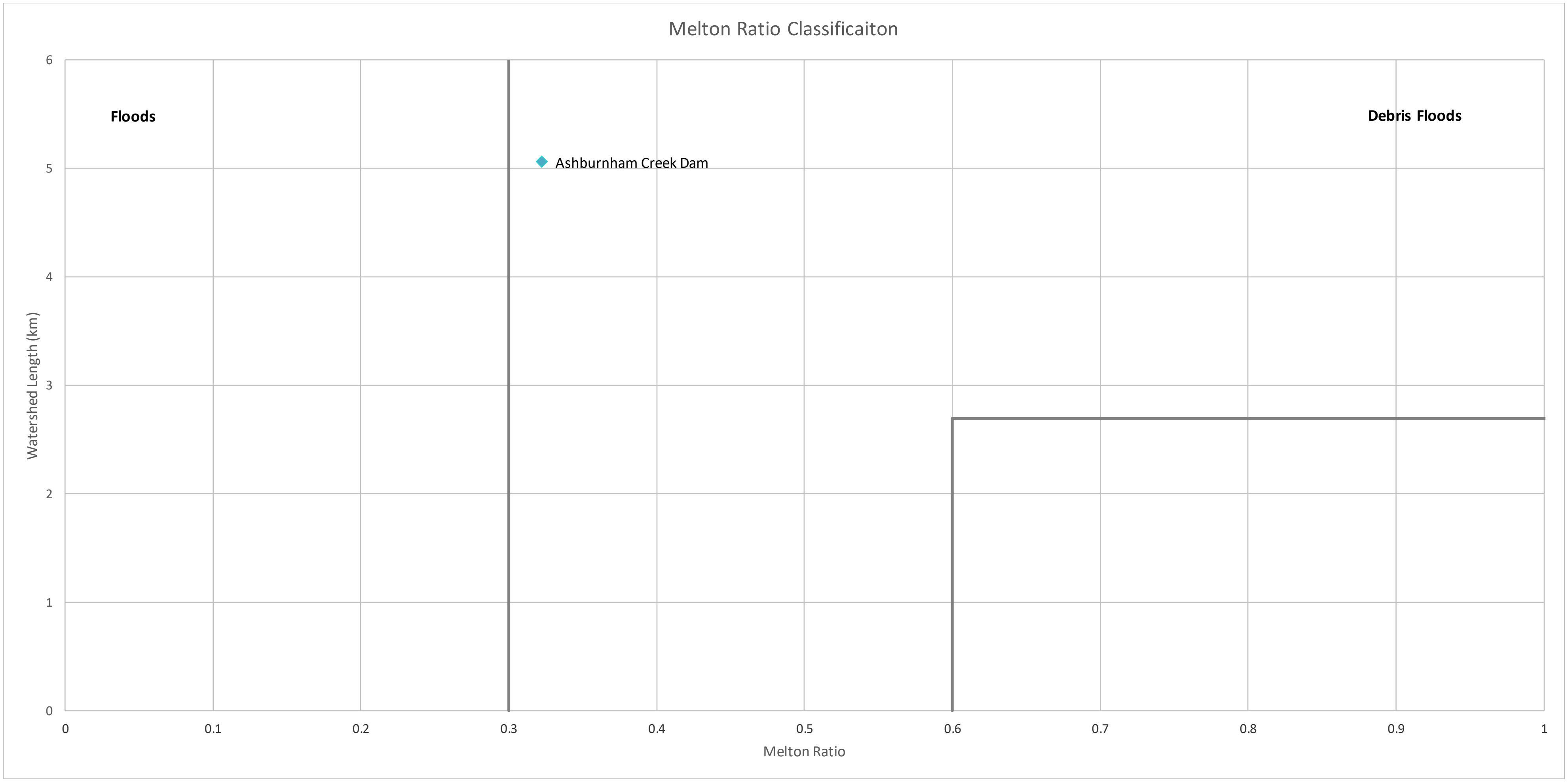
Figure 8.3



Notes:

DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM

Melton Ratio of Ashburnham Creek

Project No.	GK-18-020-CVD
Client:	Cowichan Valley Regional District
Office:	Kelowna
Scale:	NTS
Date:	JAN 14, 2019
DWN:	AG CHK: AGC

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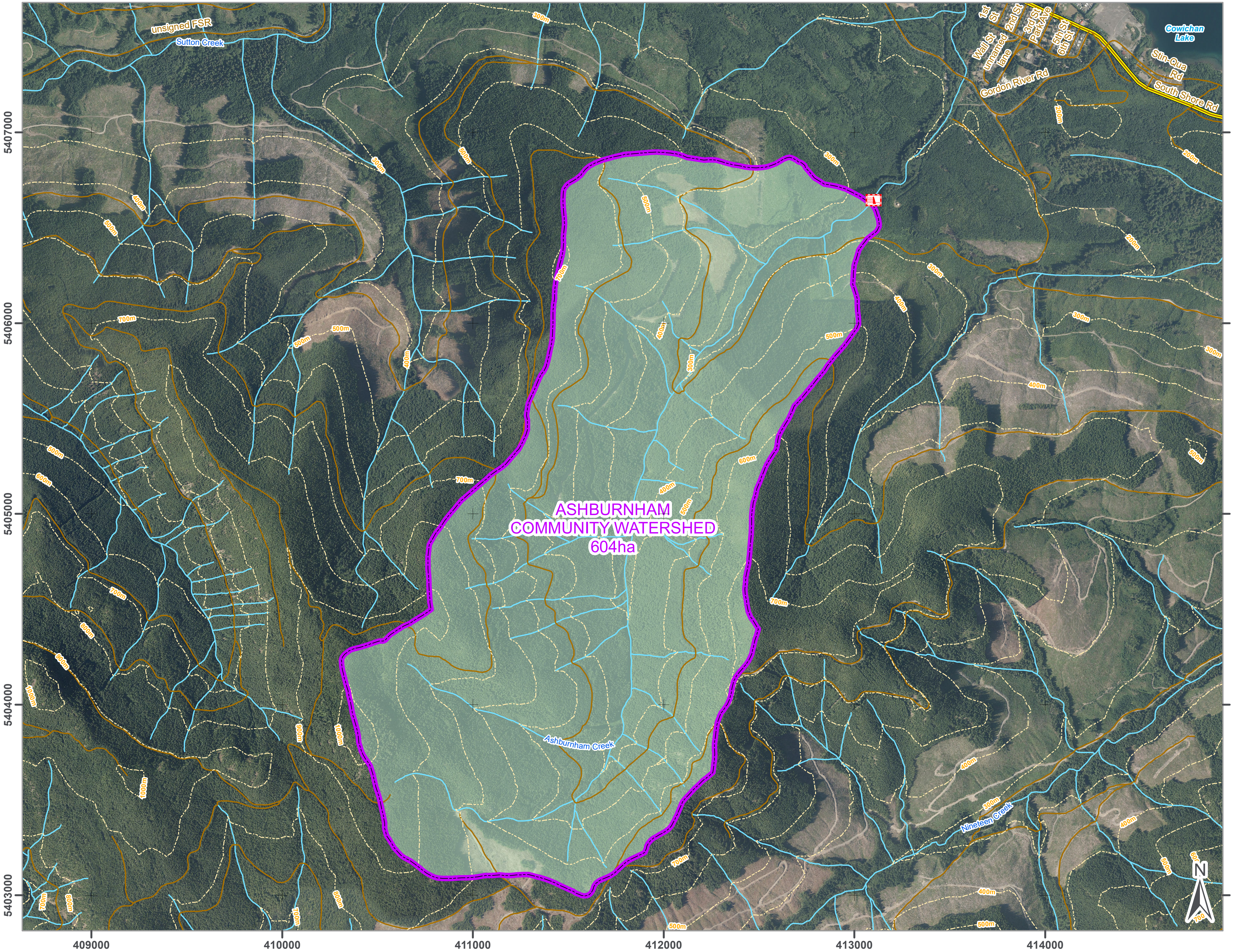
Figure 8.8

ASHBURNHAM CREEK WATERSHED

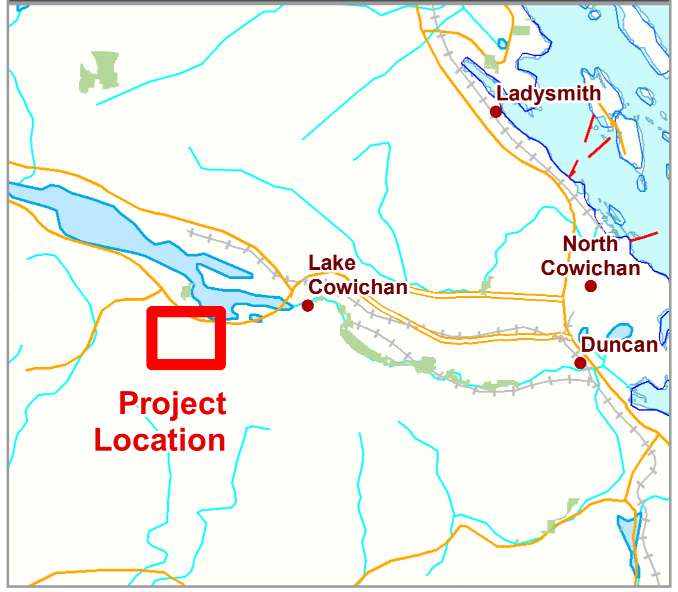


DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM HONEYMOON BAY, BC

Legend

- Ashburnham Creek Dam
- 100m TRIM Contours
- Fresh Water Atlas Streams
- Digital Atlas Roads
- Highways
- Ashburnham Community Watershed

LOCATION MAP



1:20,000

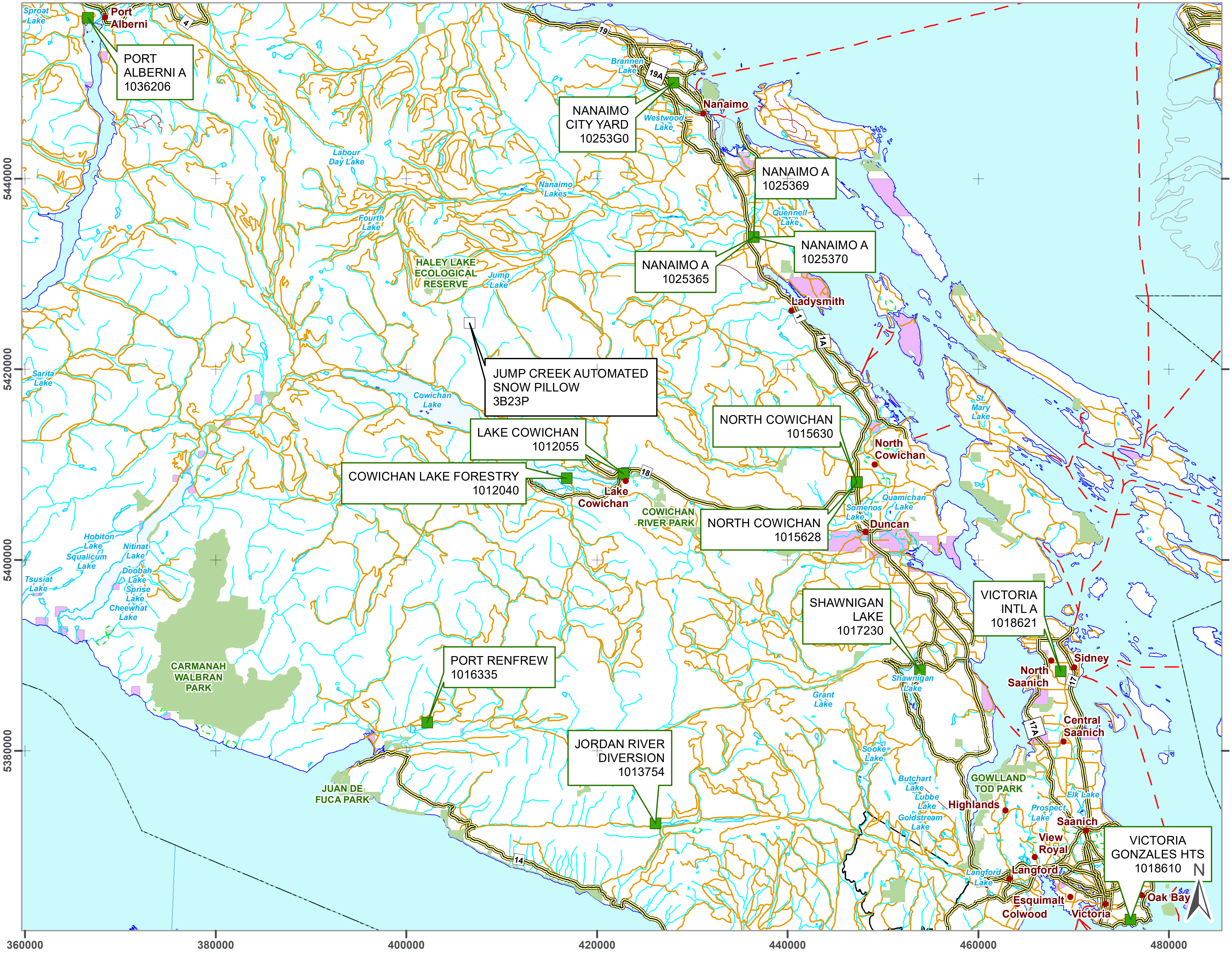
0 0.5 1 KM

Project No.: GK-18-020-CVD
Client: Cowichan Valley Regional District
NAD 1983 UTM Zone 10N

Date: 2018/07/04
Drawn: MT Check: AG

Figure 9.1

CLIMATE AND AUTOMATED SNOW PILLOW STATIONS

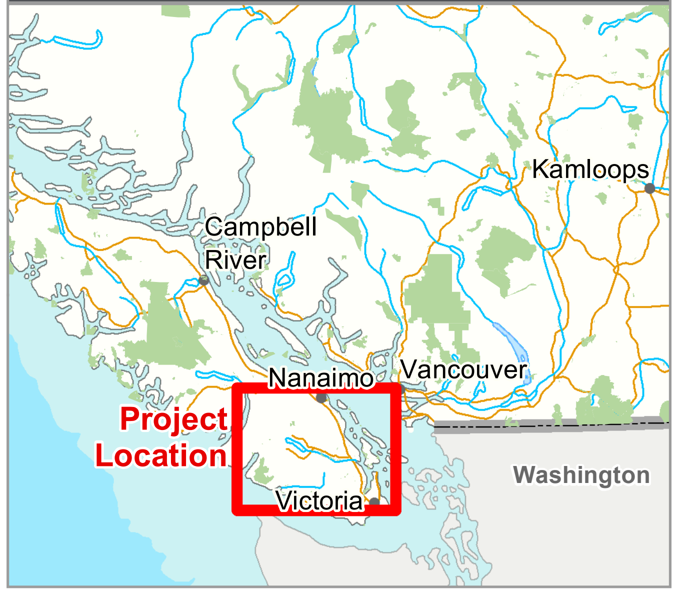


DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM HONEYMOON BAY, BC

Legend

- ● Cities
- 🟩 Climate Station (Environment and Climate Change Canada)
- ☐ Automated Snow Pillow Station (British Columbia)
- Highways
- Streams
- Ferry Route
- Roads
- Trail
- Bridge
- Reserves
- Parks

LOCATION MAP



1:400,000

0 5 10 15 20 km

Project No.: GK-18-020-CVD
Client: Cowichan Valley Regional District
NAD 1983 UTM Zone 10N

Date: 2018/11/19
Drawn: MT Check: AG

Figure 9.2

HYDROMETRIC STATIONS

DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM HONEYMOON BAY, BC

Legend

- ● Cities
- 🟦 Hydrometric Station (Water Survey of Canada)
- ═ Highways
- — Streams
- – – Ferry Route
- — Roads
- — Trail
- — Bridge
- 🟪 Reserves
- 🟩 Parks

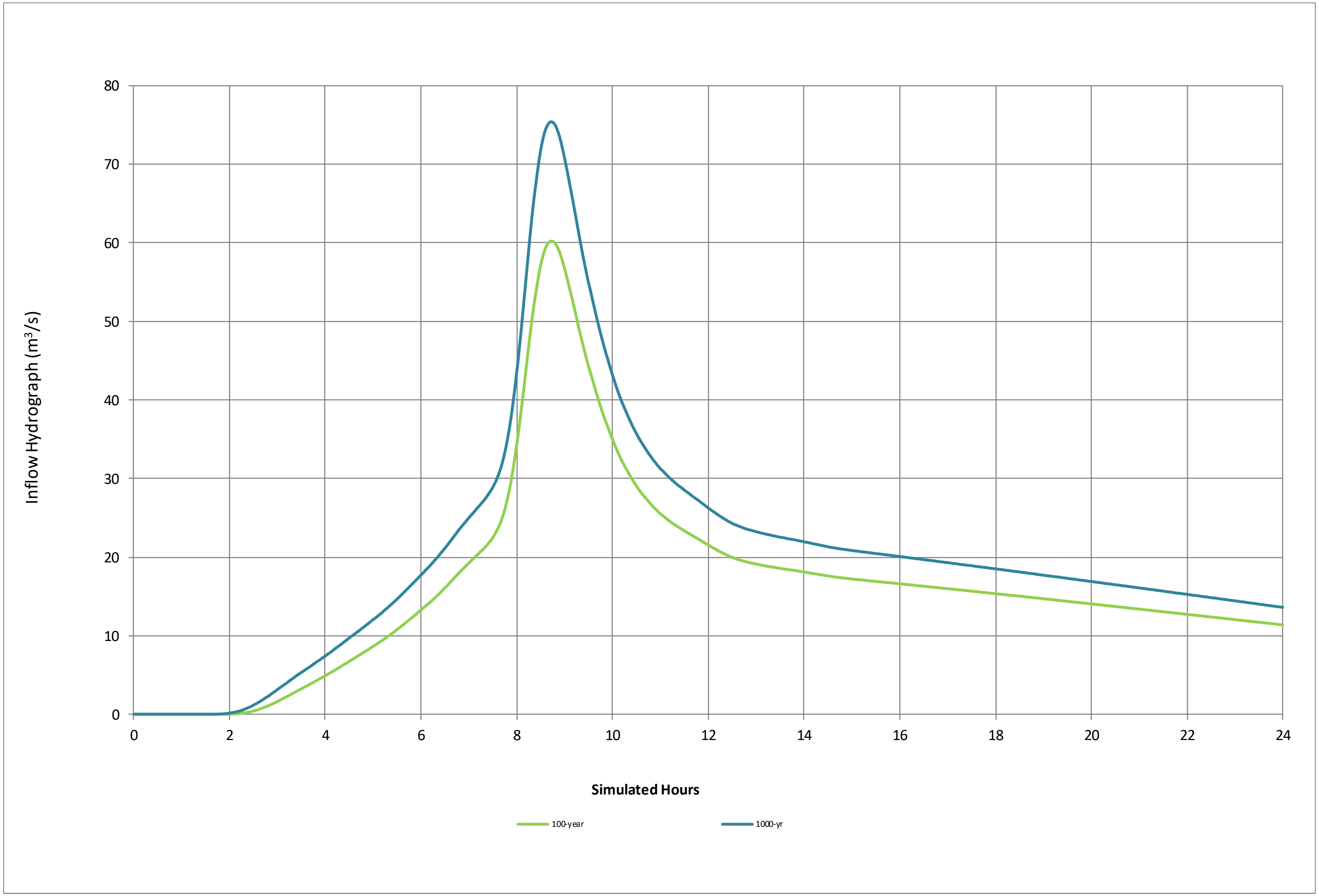
LOCATION MAP

1:370,000

0 5 10 15 20 km

Project No.: GK-18-020-CVD
Date: 2018/11/02
Client: Cowichan Valley Regional District
Drawn: MT Check: AG
NAD 1983 UTM Zone 10N

Figure 9.3



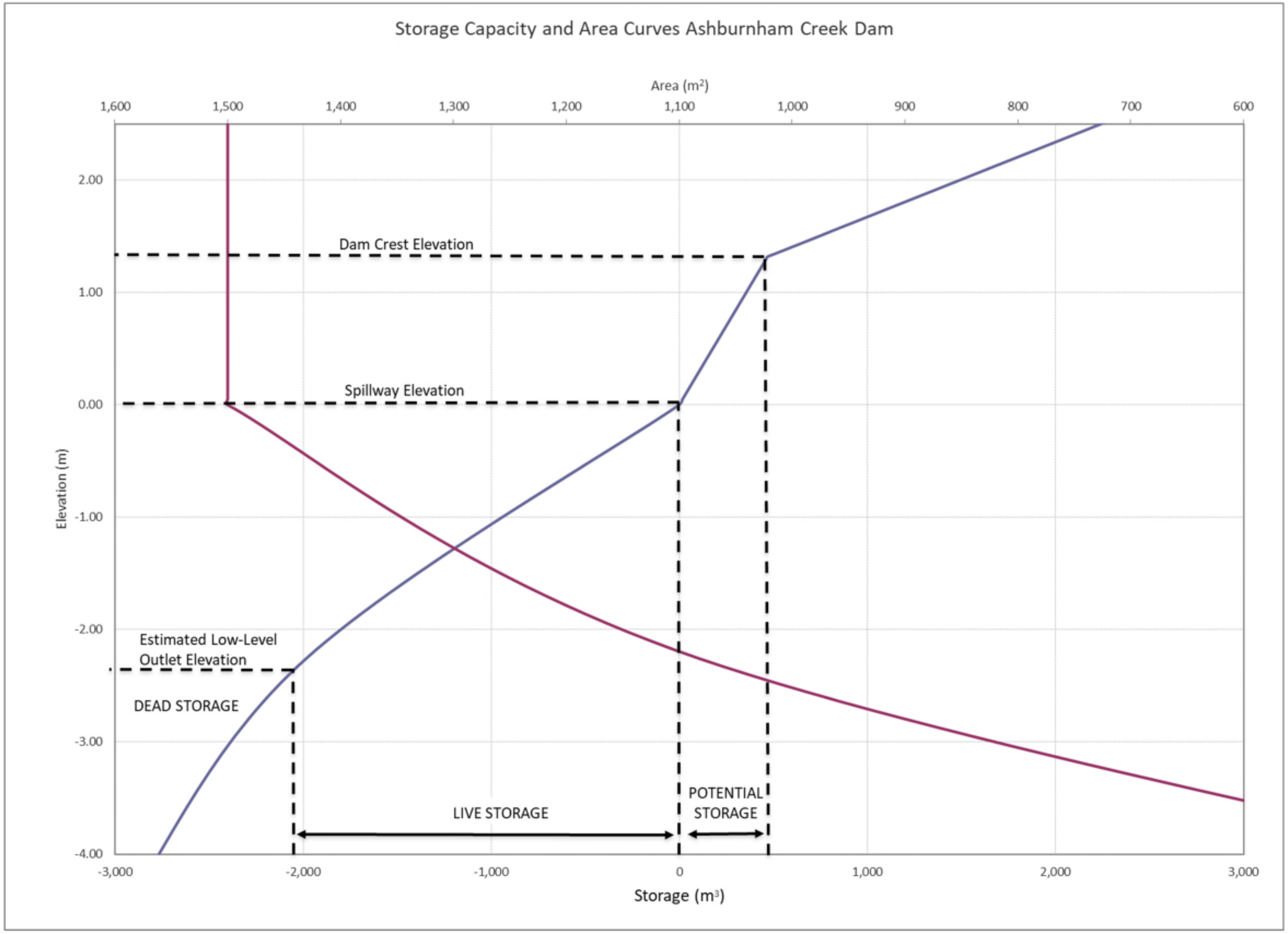
Notes:

DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM

Inflow Design Flood Hydrographs

Project No. GK-18-020-CVD
Client: Cowichan Valley Regional District
Office: Kelowna
Scale: NTS
Date: JAN 14, 2019
DWN: AG CHK: AGC

Figure 9.4



Notes:

DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM

Area Elevation Storage Curves

Project No.	GK-18-020-CVD
Client:	Cowichan Valley Regional District
Office:	Kelowna
Scale:	NTS
Date:	JAN 14, 2019
DWN:	AG CHK: AGC

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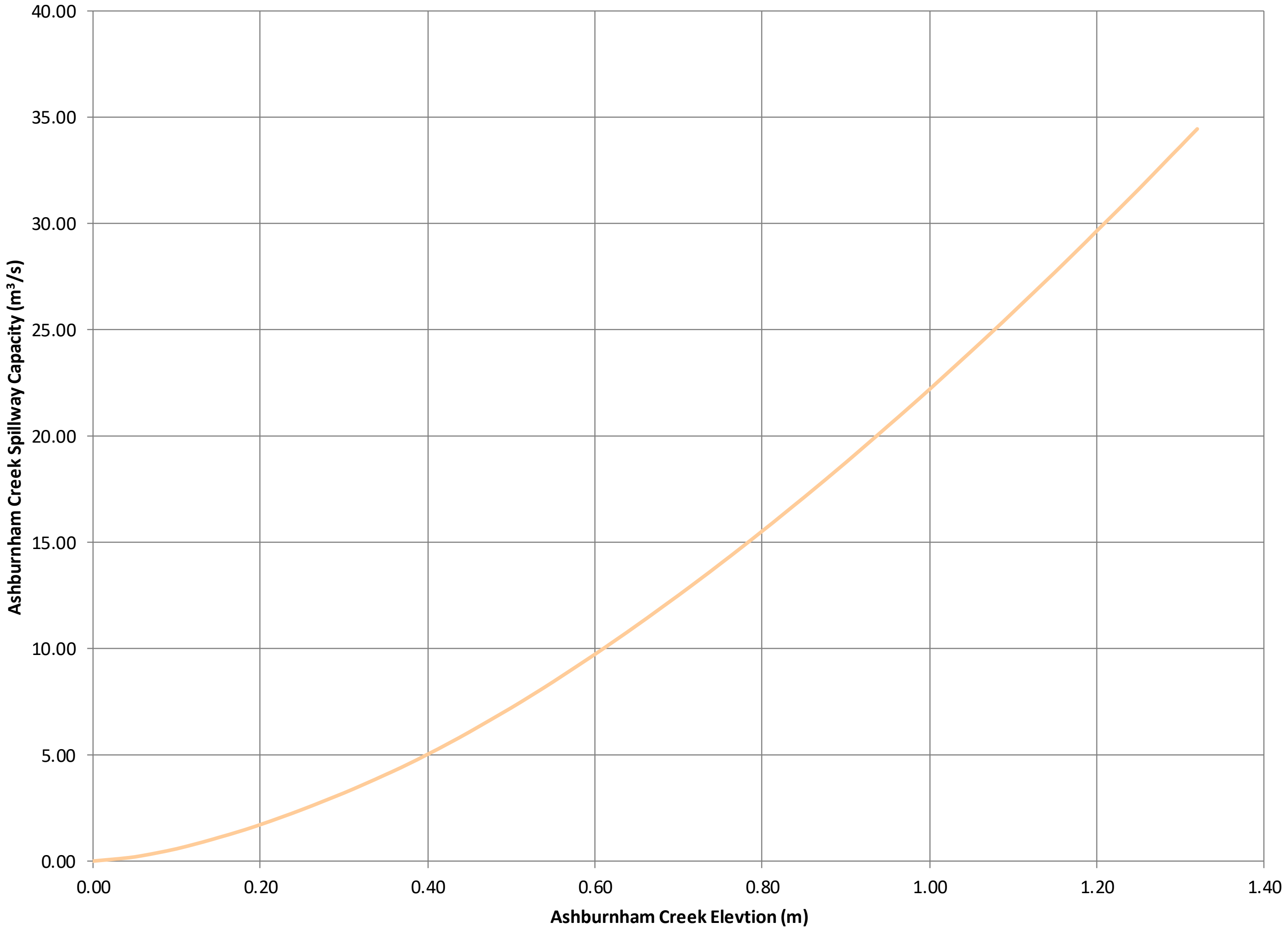
Figure 9.5a



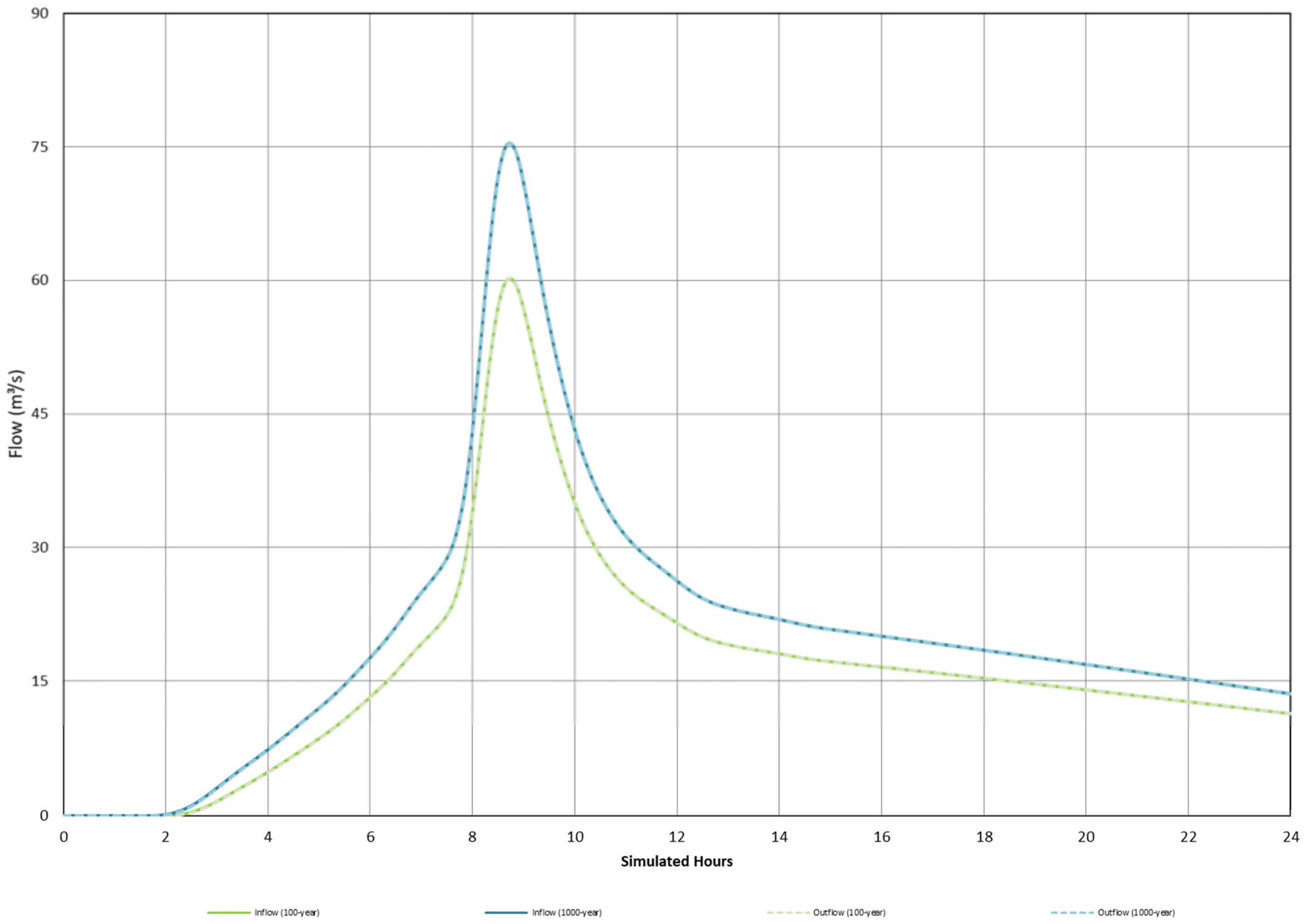
Notes:

DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM

Spillway Rating Curve

Project No. GK-18-020-CVD
Client: Cowichan Valley Regional District
Office: Kelowna
Scale: NTS
Date: JAN 14, 2019
DWN: AG CHK: AG

Figure 9.5b



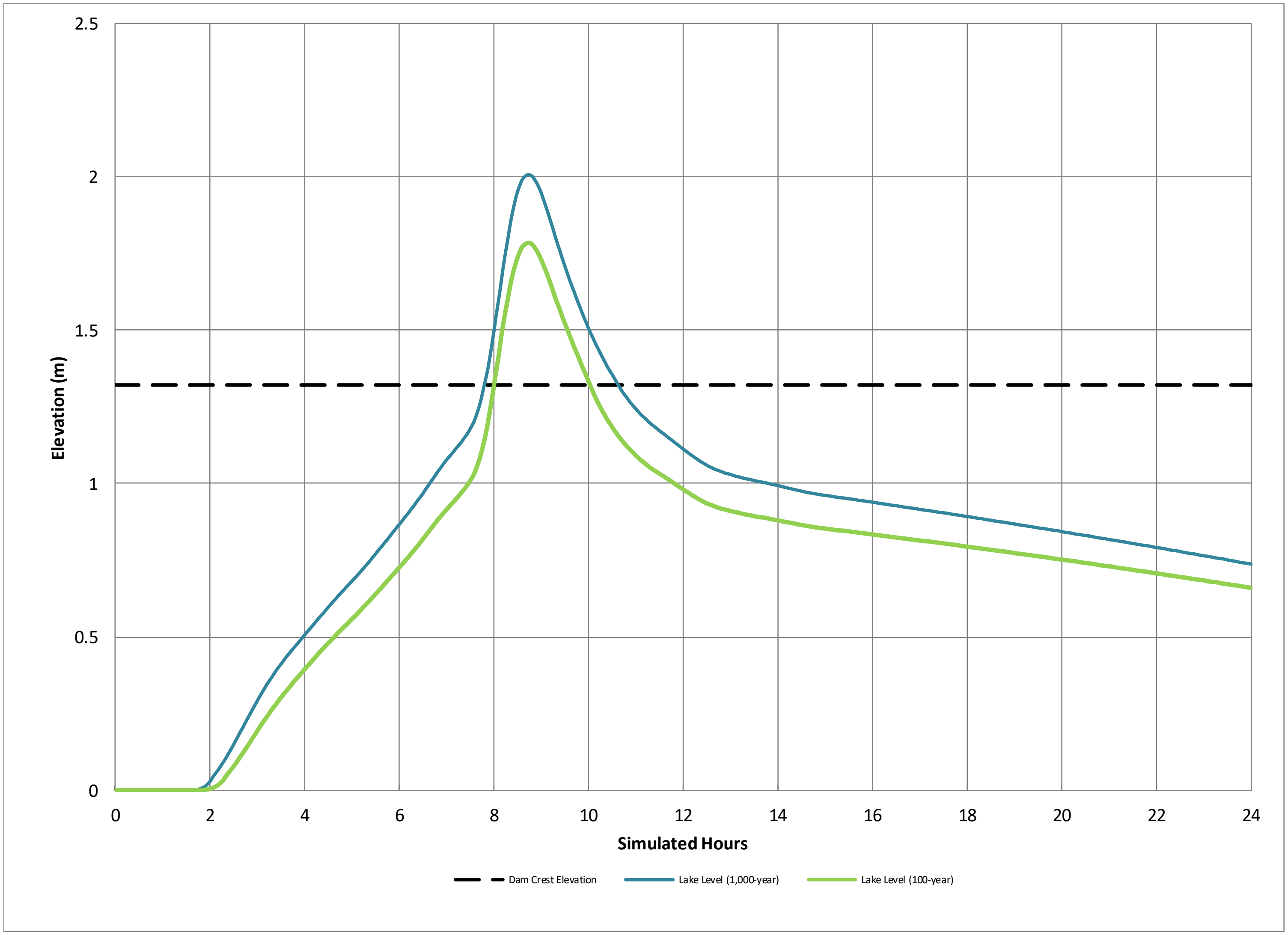
Notes:

DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM

Flood Routing Hydrographs

Project No.	GK-18-020-CVD
Client:	Cowichan Valley Regional District
Office:	Kelowna
Scale:	NTS
Date:	JAN 14, 2019
DWN:	AG CHK: AGC

Figure 9.5c



Notes:

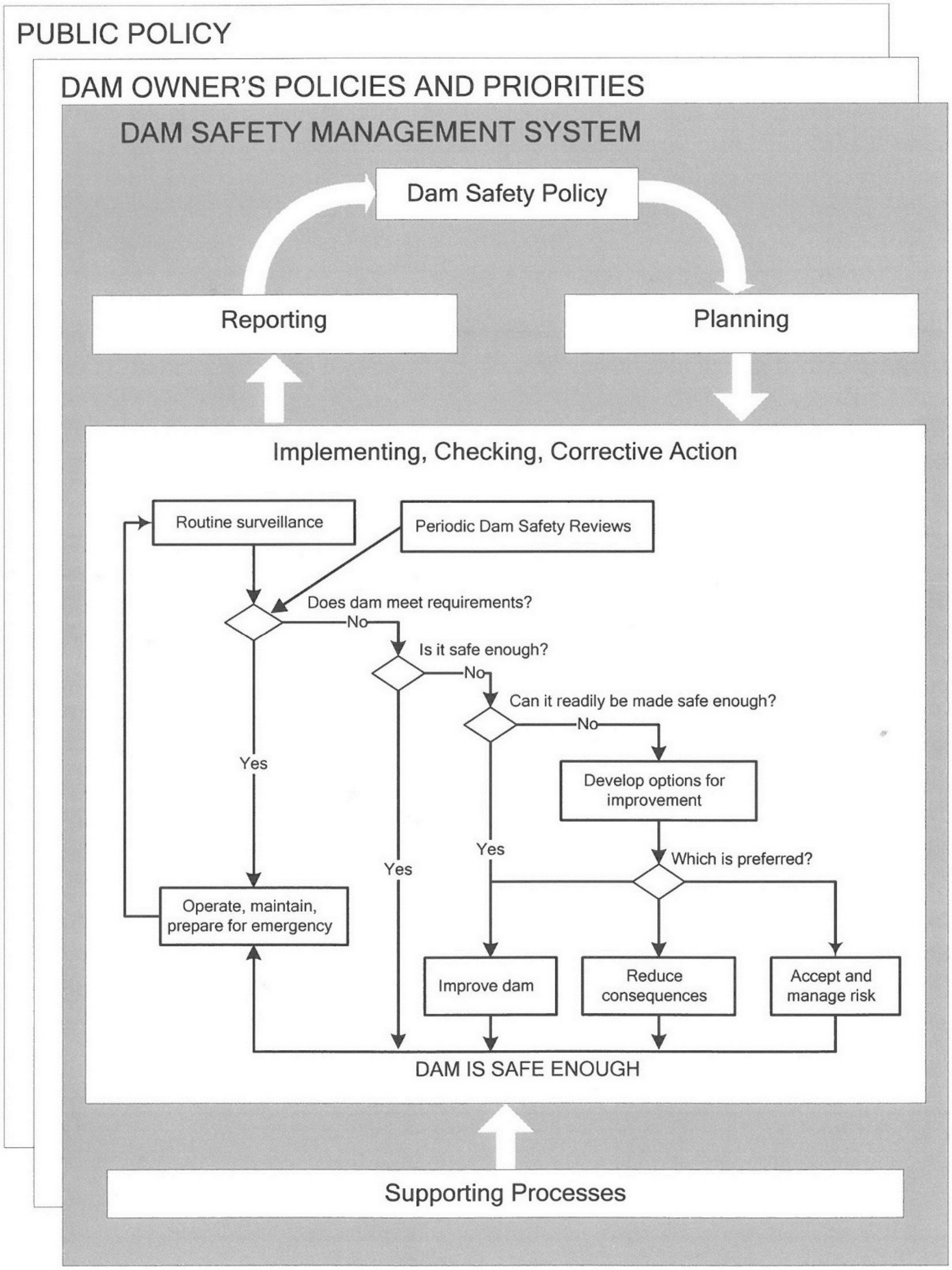
DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM

Reservoir Flood Levels

Project No.	GK-18-020-CVD
Client:	Cowichan Valley Regional District
Office:	Kelowna
Scale:	NTS
Date:	JAN 14, 2019
DWN:	AG CHK: AGC

ecora™

Figure 9.5d



Notes:
Adapted from Figure 1-1 of Canadian Dam Association Dam Safety Guidelines 2007 (2013 Edition).

DAM SAFETY REVIEW AND RISK ASSESSMENT OF ASHBURNHAM CREEK DAM

Dam Safety Management System

Project No. GK-18-020-CVD
Client: Cowichan Valley Regional District
Office: Kelowna
Scale: NTS
Date: September 19, 2018
DWN: CE CHK: MJL

ecora

Figure 10.1

Photographs

Photo 1	Channel/reservoir upstream of the dam.
Photo 2	Dam upstream face as viewed from right abutment.
Photo 3	Right wingwall viewed from upstream. Erosion and weathering noted.
Photo 4	Dam downstream channel as viewed from upstream side.
Photo 5	Right abutment and staircase used for access.
Photo 6	Access path at right side of the dam.
Photo 7	Downstream wingwall below spillway.
Photo 8	Downstream wingwall and area of downstream discharge of smaller channel.
Photo 9	Low level outlet valve located on the right abutment.
Photo 10	Small discharge channel on the right side of the dam.
Photo 11	Moss growing on dam reducing visibility.
Photo 12	Main spillway as viewed from the right side of the dam.
Photo 13	Cold joint at the right side of the dam between headwall and sloped part of the structure. Looking towards abutment.
Photo 14	Cold joint at the right side of the dam between headwall and sloped part of the structure. Looking towards spillway.
Photo 15	Downstream face as viewed from downstream.
Photo 16	Right side of the structure including wingwall as viewed from downstream.
Photo 17	Spillway channels viewed from wingwall. Outlet in center is blocked.
Photo 18	Downstream channel viewed from dam structure.

Photo 1 **Channel/reservoir upstream of the dam.**

Photo 2 **Dam upstream face as viewed from right abutment.**

Photo 3 **Right wingwall viewed from upstream. Erosion and weathering noted.**

Photo 4 **Dam downstream channel as viewed from upstream side.**

Photo 5 Right abutment and staircase used for access.

Photo 6 Access path at right side of the dam.

Photo 7 Downstream wingwall below spillway.

Photo 8 Downstream wingwall and area of downstream discharge of smaller channel.

Photo 9 Low level outlet valve located on the right abutment.

Photo 10 Small discharge channel on the right side of the dam.

Photo 11 **Moss growing on dam reducing visibility.**

Photo 12 **Main spillway as viewed from the right side of the dam.**

Photo 13 **Cold joint at the right side of the dam between headwall and sloped part of the structure. Looking towards abutment.**

Photo 14 **Cold joint at the right side of the dam between headwall and sloped part of the structure. Looking towards spillway.**

Photo 15 Downstream face as viewed from downstream.

Photo 16 Right side of the structure including wingwall as viewed from downstream.

Photo 17 Spillway channels viewed from wingwall. Outlet in center is blocked.

Photo 18 Downstream channel viewed from dam structure.

Appendix A

Background Information Reviewed

Background Review

- April 2015 – Electoral Area Services Committee Meeting of May 19, 2015 Committee Report – Cowichan Valley Regional District
- February 2015 – Land Title Search Results
- Date Unknown – Water Licences, Statutory Right-of-Way and Water System Summary
- November 2003 – Land Title Act Form C
- July 1994 – Land Title Act Form C
- June 1988 – Land Title Act Form 17 Application
- February 2001 – Inspection of Ashburnham Dam – Golder Associates Ltd.
- October 1996 – Honeymoon Bay Dam on Ashurnham Creek (letter) – BC Ministry of Environment, Lands and Parks
- April 1994 – Ashburnham Creek Watershed (letter) – Cowichan Valley Regional District
- September 1993 – Ashburnham Cr. – Gravel Removal From Behind Water Supply Dam – Government of Canada Fisheries and Oceans
- Date Unknown – Water Licences Report
- July 2013 – Recreational Fisheries Conservation Partnerships Program Application Form – Fisheries and Oceans Canada

Appendix B

Dam Inspection Notes

Table B Site Inspection Observations of the Ashburnham Creek Dam

General Description of Dam			
Date:	March 29, 2018	Attendees:	Michael J. Laws, P.Eng. (Ecora), Caleb Pomeroy, P.Eng. (Ecora), Dr. Adrian Chantler, P.Eng. (Ecora), Bram Hobuti, P.Eng. (Ecora), David Parker (CVRD)
Weather:	Cloudy	Location:	Cowichan Valley Regional District
Length:	35 m	Outlet type:	250 mm Steel Outlet Pipe
Max. Height:	6 m	Sluice gate:	Gate Valve
Crest Elevation:	N/A	Spillway:	25 m
Crest Width:	610 mm	Spillway Height:	1.32 m
Water Level:	Just above spillway	Downstream Slope Angle:	N/A
Appurtenances:	Spillway, Low Level Outlet Pipe	Upstream Slope Angle:	Vertical
Location	**Observations**		
Reservoir	Reservoir is completely backfilled with sediment		
Downstream	Fallen trees in the channel, a log is wedged in the downstream channel resting against the dam		
Structure	Vegetation, primarily moss, growing all over the structure		
Structure	Metal components on the dam are showing corrosion. Includes low level outlet pipe.		
Left Abutment	Black pipe located to the left of the dam. Runs from upstream and ends to the right of the spillway.		
Right Abutment	Right wall has raised section with cold joint, efflorescence at cold joint new and old		
Right Abutment	Weathering of concrete noted on upstream face		
Right Abutment	Access is provided from a staircase coming down from the access road. Staircase is covered in moss with other vegetation around it.		
Right Abutment	Metal slide gate located at the right abutment. Acts as an outlet below the spillway		
Foundation	Foundation is on bedrock, could be same colluvium at abutment		

Appendix C

Hazards and Failure Modes Analysis

Table C: Hazards and Failure Modes Analysis (HFMM)

Global Failure Modes		Element And/Or Element Function	Most Basic Functional Failure Characteristics	External Hazards				Internal Hazards (Design, Construction, Maintenance, Operation)			
				Meteorological	Seismic	Reservoir Environment	Human and/or Animal Activities	Water barrier	Hydraulic Structure.	Mechanical/Electrical	Infrastructure & Plans
DAM COLLAPSE BY OVERTOPPING (erosion or overturning)	Water elevation too high	Inadequate installed discharge capacity	Meteorological inflow > buffer + outflow capacity	Could a meteorological event cause the inflow to be greater than the outflow capacity and lead to dam overtopping / failure due to insufficient installed discharge capacity?	Could a seismic event cause a meteorological event and cause the dam to be overtopped/fail from a reduced discharge capacity (channels, chutes)?	Could the reservoir environment (landslide? debris?) cause a meteorological event leading to the dam to be overtopped/fail because of insufficient installed discharge capacity?	Could human and/or animal activities cause a meteorological event that leads to the dam being overtopped/fail due to insufficient installed discharge capacity?	Could design or construction of the water barrier cause a meteorological event leading to dam overtopping / failure due to insufficient installed discharge capacity?	Could design or construction of the hydraulic structure cause a meteorological inflow greater than the buffer + outflow capacity and cause the dam to be overtopped/fail?	Could the design or construction of the mechanical/electrical systems cause a meteorological inflow greater than the buffer + outflow capacity and lead to the dam being overtopped/fail due to insufficient installed discharge capacity?	Could inadequate infrastructure and plans cause a meteorological inflow greater than the buffer + outflow capacity and lead to the dam being overtopped/fail due to insufficient installed discharge capacity?
		Inadequate available discharge capacity	Inadequate reservoir operation (rules not followed)	Could the dam be overtopped/fail during a meteorological event if the operating rules are not followed?	Could a seismic event create a condition that prevents the operating rules from being followed, leading to the dam being overtopped/fail?	Could the reservoir environment cause the operating rules to not be followed leading to the dam being overtopped/fail?	Could human and/or animal activities cause the operating rules to not be followed leading to the dam being overtopped/fail?	Could design or construction of the water barrier cause the operating rules to not be followed and cause the dam to be overtopped/fail?	Could the design or construction of the hydraulic structure cause the operating rules to not be followed and lead to dam collapse by overtopping?	Could the design or construction of the mechanical/electrical systems cause the operating rules to not be followed leading to dam overtopping/failure?	Could inadequate infrastructure and plans cause inadequate reservoir operation leading to dam collapse by overtopping?
			Random functional failure on demand	Could the dam be overtopped/fail during a meteorological event if there is a random functional failure of spilling capability?	Could a seismic event cause a random functional failure of spilling capability leading to the dam be overtopped/failed?	Could the reservoir environment cause random functional failure on demand of discharge capability and lead to the dam being overtopped/fail?	Could human and/or animal activities cause random functional failure of spilling capability causing the dam to be overtopped/fail?	Could design or construction of the water barrier cause a random functional failure of spilling capability and cause the dam be overtopped/fail?	Could the design or construction of the hydraulic structure cause random functional failure of spilling capability and lead to the dam being overtopped/fail due to inadequate available discharge capacity?	Could the design or construction of the mechanical/electrical systems cause a random functional failure on demand leading to dam collapse by overtopping?	Could inadequate infrastructure and plans cause random functional failure on demand leading to dam collapse by overtopping?
			Discharge capability not maintained or retained	Could the dam be overtopped/fail during a meteorological event if the discharge capacity is not maintained?	Could a seismic event cause the discharge capacity to be damaged causing the dam to be overtopped/fail?	Could the reservoir environment cause loss of the discharge capability leading to the dam being overtopped/fail?	Could human and/or animal activities cause loss of discharge capability and cause the dam to be overtopped/fail?	Could design or construction of the water barrier cause the discharge capability to be not maintained/retained and cause the dam to be overtopped/fail?	Could the design or construction of the hydraulic structure cause loss of the discharge capability and lead to the dam being overtopped/fail due to inadequate available discharge capacity?	Could the design or construction of the mechanical/electrical systems cause the discharge capability to be not maintained / retained leading to dam collapse by overtopping?	Could inadequate infrastructure and plans cause discharge capacity to not be maintained or retained leading to dam collapse by overtopping?
		Inadequate freeboard	Excessive elevation due to landslide or U/S dam	Could the dam be overtopped/fail during a meteorological event due to a reservoir landslide or upstream dam failure?	Could a seismic event cause the dam to be overtopped/fail by a reservoir landslide or upstream dam failure?	Could the reservoir environment cause excessive elevation of the reservoir leading to the dam being overtopped/fail?	Could human and/or animal activities cause a landslide or upstream dam failure leading to the dam being overtopped/fail?	Could design or construction of the water barrier cause a reservoir landslide or upstream dam failure and cause the dam to be overtopped/fail?	Could the design or construction of the hydraulic structure cause excessive elevation due to a landslide or upstream dam failure leading to the dam being overtopped/fail due to inadequate freeboard?	Could the design or construction of the mechanical/electrical systems cause excessive elevation due to landslide or upstream dam failure leading to dam collapse by overtopping?	Could inadequate infrastructure and/or plans cause the dam to fail due to a reservoir landslide or upstream dam failure?
			Wind-wave dissipation inadequate	Is freeboard and wind wave dissipation adequate to prevent overtopping/failure during a meteorological event?	Could a seismic event cause the dam to be overtopped/fail due to inadequate freeboard and wind wave dissipation?	Is freeboard and wind wave dissipation adequate to prevent overtopping/failure from failure of features in the reservoir environment?	Could human and/or animal activities cause inadequate freeboard and wind wave dissipation leading to dam overtopping/failure?	Could design or construction of the water barrier cause inadequate freeboard and wind wave dissipation and cause overtopping/failure?	Could the design or construction of the hydraulic structure cause inadequate wind-wave dissipation leading to dam collapse by overtopping?	Could the design or construction of the mechanical/electrical systems cause inadequate wind-wave dissipation leading to dam collapse by overtopping?	Could inadequate infrastructure and plans cause inadequate wind-wave dissipation leading to dam collapse by overtopping?
	Management System Failure	Safeguards fail to provide timely detection and correction	Operation, maintenance and surveillance fail to detect/prevent hydraulic adequacy	Could a meteorological event prevent the Dam Safety Engineers activities (based on OMS requirements, see column L) from detecting/prevent hydraulic inadequacy leading to dam overtopping/failure?	Could a seismic event prevent the Dam Safety Engineers activities (based on OMS requirements, see column L) from detecting/preventing hydraulic inadequacy leading to overtopping/failure of the dam?	Could the reservoir environment prevent Dam Safety activities (based on OMS requirements, see column L) from detecting/preventing hydraulic inadequacy leading to dam overtopping/failure?	Could human and/or animal activities cause the OMS activities to not detect/prevent hydraulic inadequacy leading to dam overtopping/failure?	Could inadequate operation, maintenance and surveillance fail to detect / prevent hydraulic adequacy and lead to failure of the water barrier?	Could inadequate operation, maintenance and surveillance fail to detect / prevent hydraulic adequacy and lead to failure of the hydraulic structure?	Could inadequate operation, maintenance and surveillance fail to detect / prevent failure of the mechanical/electrical system leading to dam collapse by overtopping?	Could inadequate operation, maintenance and surveillance of the infrastructure and plans cause the OMS activities to not detect /prevent hydraulic inadequacy before leading to overtopping/failure of dam?
DAM COLLAPSE BY LOSS OF STRENGTH (External orinternal structural failure and weakening)			Operation, maintenance and surveillance fail to detect poor dam performance	Could the meteorological event prevent the OMS rules from being implemented by the DS Engineer leading to dam collapse by loss of strength?	Could a seismic event cause the OMS rules to not be followed leading to collapse by loss of strength during a seismic event?	Could the reservoir environment cause the OMS rules to not be followed leading to dam collapse by loss of strength?	Could human and/or animal activities cause OMS activities to not be followed leading to dam collapse by loss of strength?	Could inadequate operation, maintenance and surveillance fail to prevent poor dam performance and lead to dam collapse by loss of strength?	Could inadequate operation, maintenance and surveillance of the hydraulic structure fail to prevent poor dam performance and lead to dam collapse by loss of strength?	Could inadequate operation, maintenance and surveillance of the mechanical/electrical systems fail to prevent poor dam performance and lead to dam collapse by loss of strength?	Could inadequate surveillance and management of the infrastructure and plans cause the OMS activities to not detect /prevent dam collapse by loss of strength?
	Crest elevation too low	Stability under applied loads	Mass movement (external stability:- displacement, tilting, seismic resistance)	Could loss of strength and static instability occur during a meteorological event and cause dam collapse?	Could a seismic event cause mass external instability and cause dam collapse?	Could the reservoir environment cause external instability of the dam leading to dam collapse?	Could human and/or animal activities cause external instability of the dam and cause dam collapse?	Could design or construction of the water barrier cause external instability and lead to dam collapse?	Could the design or construction of the hydraulic structure cause external instability leading to dam collapse by loss of strength?	Could the design or construction of the mechanical/electrical systems cause external instability leading dam collapse by loss of strength?	Could inadequate infrastructure and plans cause external instability leading to dam collapse by loss of strength?
			Loss of support (foundation or abutment failure)	Could reduction/lack of support in foundation or abutments during a meteorological event cause dam collapse?	Could a seismic event cause reduction/lack of support in foundation or abutments leading to dam collapse?	Could the reservoir environment (debris, ice, landslides) cause foundation or abutment failure leading to dam collapse?	Could human and/or animal activities cause reduction/lack of support in foundation or abutments and cause dam collapse?	Could design or construction of the water barrier cause reduction/lack of support in foundation or abutments and cause dam collapse?	Could the design or construction of the hydraulic structure cause reduction/lack of support in foundation or abutments and lead to dam collapse by loss of strength?	Could the design or construction of the mechanical/electrical systems cause a reduction/lack of support in foundation or abutments leading to dam collapse by loss of strength?	Could inadequate infrastructure and plans cause reduction/lack of support in foundation or abutments leading to dam collapse by loss of strength?
		Watertightness	Seepage around interfaces (abutments, foundation, water stops)	Could seepage around interfaces/abutments/foundation during meteorological event reduce watertightness sufficient to cause dam collapse?	Could a seismic event cause seepage around interfaces / abutments / foundation reduce watertightness sufficient to cause dam collapse?	Could the reservoir environment (debris, ice, landslides) cause seepage around interfaces/abutments/foundation and reduce watertightness sufficient to cause dam collapse?	Could human and/or animal activities seepage around interfaces / abutments / foundation and reduce watertightness sufficient to cause dam collapse?	Could design or construction of the water barrier cause seepage around interfaces / abutments / foundation and reduce watertightness sufficient to cause dam collapse?	Could the design or construction of the hydraulic structure cause seepage around interfaces/ abutments/ foundation leading to dam collapse by loss of strength?	Could the design or construction of the mechanical/electrical systems cause seepage around interfaces/ abutments/ foundation leading to dam collapse by loss of strength?	Could inadequate infrastructure and plans cause seepage around interfaces/ abutments/ foundation and reduce watertightness sufficient to cause dam collapse by loss of strength?
			Through dam seepage control failure (filters, drains, pumps)	Could through -dam seepage (filters/drains/pumps, internal instability) during a meteorological event reduce watertightness and cause dam collapse?	Could a seismic event cause through dam seepage (filters/drains/pumps) to fail and reduce watertightness and cause dam collapse?	Could the reservoir environment (landslides, ice, debris) cause through dam seepage control be lost (filters/drains/pumps) and reduce watertightness and cause dam collapse?	Could human and/or animal activities cause failure of through dam seepage (filters / drains / pumps) control and reduce watertightness and cause dam collapse?	Could design or construction of the water barrier cause through dam seepage (filters / drains / pumps) and reduce watertightness and cause dam collapse?	Could the design or construction of the hydraulic structure cause through dam seepage control failure (filters/ drains/ pumps) and lead to dam collapse by loss of strength?	Could the design or construction of the mechanical/electrical systems cause through dam seepage (filters/ drains/ pumps) and reduce watertightness and cause dam collapse?	Could inadequate infrastructure and plans cause through dam seepage (filters/ drains/ pumps) and cause dam collapse by loss of strength?
		Durability/cracking	Structural weakening (internal erosion, AAR, crushing, gradual strength loss)	Could structural weakening (internal erosion, crushing, cracking, strength loss) caused by a meteorological event cause dam collapse?	Could a seismic event cause internal structural weakening (internal erosion, crushing, cracking, strength loss) and cause dam collapse?	Could the reservoir environment (landslides, ice, debris) cause internal structural weakening (internal erosion, crushing, cracking, strength loss) and lead to dam collapse?	Could human and/or animal activities cause internal structural weakening (internal erosion, crushing, cracking, strength loss) and cause dam collapse?	Could design or construction of the water barrier cause internal structural weakening (internal erosion, crushing, cracking, strength loss) and cause dam collapse?	Could the design or construction of the hydraulic structure cause internal structural weakening (internal erosion, crushing, cracking, strength loss) leading to dam collapse?	Could the design or construction of the mechanical/electrical systems cause internal structural weakening (internal erosion, crushing, cracking, strength loss) leading to dam collapse by loss of strength?	Could inadequate infrastructure and plans cause internal structural weakening (internal erosion, crushing, cracking, strength loss) and cause dam collapse by loss of strength?
			Instantaneous change of state (static liquefaction, hydraulic fracture, seismic cracking)	Could instantaneous change of state occur (Liquefaction, hydraulic fracture) caused by a meteorological event cause dam collapse?	Could a seismic event cause instantaneous change of state to occur (Liquefaction, hydraulic fracture) leading to dam collapse?	Could the reservoir environment (landslides, ice, debris) cause instantaneous change of state to occur (liquefaction, hydraulic fracture) and cause dam collapse?	Could human and/or animal activities cause instantaneous change of state to occur (Liquefaction, hydraulic fracture) and cause dam collapse?	Could design or construction of the water barrier cause instantaneous change of state occur (Liquefaction, hydraulic fracture) and cause dam collapse?	Could the design or construction of the hydraulic structure cause instantaneous change of state to occur (Liquefaction, hydraulic fracture) leading to dam collapse?	Could the design or construction of the mechanical/electrical systems cause instantaneous change of state to occur (Liquefaction, hydraulic fracture) leading to dam collapse by loss of strength?	Could inadequate infrastructure and plans cause instantaneous change of state occur (Liquefaction, hydraulic fracture) and cause dam collapse by loss of strength?

Appendix D

CADAM Stability Results

CADAM - Results report

by Martin Leclerc, M. Ing., Research Engineer
NSERC / Hydro-Quebec / Alcan Industrial Chair on Structural Safety of Concrete Dams
École Polytechnique de Montréal, Canada

General Information:

Project:	Ashburnham Creek Dam DSR
Dam:	Ashburnham Creek Dam
Owner:	CVRD
Dam location:	Honeymoon Bay, BC
Project engineer:	
Analysis performed by:	CE
Date:	11/23/2018

Load Combination Factors:

	Usual	Flood	Seismic #1	Seismic #2	Post-seismic #1
Self-weight	1.0000	1.0000	1.0000		1.0000
Hydrostatic (upstream)	1.0000	1.0000	1.0000		1.0000
Hydrostatic (downstream)	1.0000	1.0000	1.0000		1.0000
Uplift pressures					1.0000
Silts	1.0000	1.0000	1.0000		1.0000
Ice					
post-tensioning					
Applied forces					
Floating debris					
Seismic (horizontal)			1.0000		
Seismic (vertical)					

Combination Required Safety Factors:

	Usual	Flood	Seismic #1	Seismic #2	Post-seismic #1
Peak sliding factor	1.5000	1.1000	1.0000	1.0000	1.1000
Residual sliding factor	1.5000	1.1000	1.0000	1.0000	1.1000
Overturning factor	1.2000	1.1000	1.0000	1.0000	1.1000
Uplifting factor	1.2000	1.1000	1.0000	1.0000	1.1000

Combination allowable stresses:

	Usual	Flood	Seismic #1	Seismic #2	Post-seismic #1
Tension (% of ft)	0.0	0.0	90.0	90.0	0.0
Compression (% of f'c)	30.0	50.0	0.0	0.0	50.0

Usual Combination (Stresses):

Joint		Cracking		Normal stresses		Allowable normal stress		Shear stresses			
ID	U/S elevation (m)	Upstream (%) of joint	Downstream (%) of joint	Upstream (kPa)	Downstream (kPa)	Tension (kPa)	Compression (kPa)	Upstream (kPa)	Maximum (kPa)	Maximum at (% of joint)	Downstream (kPa)
1	Base joint	33.18573		0.000	-253.904	0.000	-7500.000				

Usual Combination (Stability):

Joint		**Safety factors**					**Resultants over ligament**				**Final uplift**	**Rock wedge**
ID	**U/S elevation** (m)	**Sliding**		**Overturning**		**Uplifting**	**Normal** (kN)	**Shear** (kN)	**Moment** (kN·m)	**Position** % of joint	**Normal** (kN)	**Resistance** (kN)
		Peak	Residual	toward U/S	toward D/S							
1	Base joint	1.82788	1.82788	> 100	1.51033	> 100	-313.84	245.21	129.3	77.72857	149.86	0.000
	Required:	1.500	1.500	1.200	1.200	1.200						

Flood Combination (Stresses):

Joint		Cracking		Normal stresses		Allowable normal stress		Shear stresses over the ligament			
ID	**U/S elevation** (m)	**Upstream** (%) of joint	**Downstream** (%) of joint	**Upstream** (kPa)	**Downstream** (kPa)	**Tension** (kPa)	**Compression** (kPa)	**Upstream** (kPa)	**Maximum** (kPa)	**Maximum at** (% of joint)	**Downstream** (kPa)
1	Base joint	100.00000		195.813	-369.705	0.000	-12500.000				

Flood Combination (Stability):

Joint		**Safety factors**					**Resultants over ligament**				**Final uplift**	**Rock wedge**
ID	**U/S elevation**	**Sliding**		**Overturning**		**Uplifting**	**Normal**	**Shear**	**Moment**	**Position**	**Uplift**	**Resistance**
	(m)	Peak	Residual	toward U/S	toward D/S		(kN)	(kN)	(kN·m)	% of joint	(kN)	(kN)
1	Base joint	1.29978	1.29978	> 100	0.94062	> 100	-321.70	353.47	645.2	104.20221	289.65	0.000
	Required:	1.100	1.100	1.100	1.100	1.100						

Seismic #1 Combination - Peak accelerations analysis (Stresses):

Joint		Cracking		Normal stresses		Allowable normal stress		Shear stresses over the ligament			
ID	U/S elevation (m)	Upstream (%) of joint	Downstream (%) of joint	Upstream (kPa)	Downstream (kPa)	Tension (kPa)	Compression (kPa)	Upstream (kPa)	Maximum (kPa)	Maximum at (% of joint)	Downstream (kPa)
1	Base joint	100.00000		354.045	-523.689	0.000	0.000				

Seismic #1 Combination - Peak accelerations analysis (Stability):

Joint		Safety factors					Resultants over ligament				Final uplift	Rock wedge
ID	U/S elevation (m)	Sliding		Overturning		Uplifting	Normal (kN)	Shear (kN)	Moment (kN·m)	Position % of joint	Uplift (kN)	Resistance (kN)
		Peak	Residual	toward U/S	toward D/S							
1	Base joint	*0.85336*	*0.85336*	*> 100*	*0.64528*	*> 100*	-313.84	525.23	1001.3	136.23284	149.86	0.000
	Required:	*1.000*	*1.000*	*1.000*	*1.000*	*1.000*						

Post-Seismic Combination (Stresses):

Joint		Cracking		Normal stresses		Allowable normal stress		Shear stresses over the ligament			
ID	U/S elevation (m)	Upstream (%) of joint	Downstream (%) of joint	Upstream (kPa)	Downstream (kPa)	Tension (kPa)	Compression (kPa)	Upstream (kPa)	Maximum (kPa)	Maximum at (% of joint)	Downstream (kPa)
1	1	100.00000		117.120	-165.120	0.000	-12500.000				

Post-Seismic Combination (Stability):

Joint		Safety factors					Resultants over ligament				Final uplift	Rock wedge
ID	U/S elevation (m)	Sliding		Overturning		Uplifting	Normal (kN)	Shear (kN)	Moment (kN·m)	Position % of joint	Uplift (kN)	Resistance (kN)
		Peak	Residual	toward U/S	toward D/S							
1	Base joint	0.51719	0.51719	2.16800	0.82915	1.39459	-88.80	245.21	322.0	147.99959	225.04	0.000
		1.100	1.100	1.100	1.100	1.100						

CADAM - Results report

by Martin Leclerc, M. Ing., Research Engineer
NSERC / Hydro-Quebec / Alcan Industrial Chair on Structural Safety of Concrete Dams
École Polytechnique de Montréal, Canada

General Information:

Project:	Ashburnham Creek Dam DSR
Dam:	Ashburnham Creek Dam
Owner:	CVRD
Dam location:	Honeymoon Bay, BC
Project engineer:	
Analysis performed by:	CE
Date:	11/23/2018

Load Combination Factors:

	Usual	Flood	Seismic #1	Seismic #2	Post-seismic #1
Self-weight	1.0000	1.0000	1.0000		1.0000
Hydrostatic (upstream)	1.0000	1.0000	1.0000		1.0000
Hydrostatic (downstream)	1.0000	1.0000	1.0000		1.0000
Uplift pressures					1.0000
Silts					
Ice					
post-tensioning					
Applied forces					
Floating debris					
Seismic (horizontal)			1.0000		
Seismic (vertical)					

Combination Required Safety Factors:

	Usual	Flood	Seismic #1	Seismic #2	Post-seismic #1
Peak sliding factor	1.5000	1.1000	1.0000	1.0000	1.1000
Residual sliding factor	1.5000	1.1000	1.0000	1.0000	1.1000
Overturning factor	1.2000	1.1000	1.0000	1.0000	1.1000
Uplifting factor	1.2000	1.1000	1.0000	1.0000	1.1000

Combination allowable stresses:

	Usual	Flood	Seismic #1	Seismic #2	Post-seismic #1
Tension (% of ft)	0.0	0.0	90.0	90.0	0.0
Compression (% of f'c)	30.0	50.0	0.0	0.0	50.0

Usual Combination (Stresses):

Joint		Cracking		Normal stresses		Allowable normal stress		Shear stresses			
ID	**U/S elevation** (m)	**Upstream** (%) of joint	**Downstream** (%) of joint	**Upstream** (kPa)	**Downstream** (kPa)	**Tension** (kPa)	**Compression** (kPa)	**Upstream** (kPa)	**Maximum** (kPa)	**Maximum at** (% of joint)	**Downstream** (kPa)
1	Base joint	2.93320		0.000	-174.770	0.000	-7500.000				

Usual Combination (Stability):

Joint		Safety factors					Resultants over ligament				Final uplift	Rock wedge
ID	U/S elevation	Sliding		Overturning		Uplifting	Normal	Shear	Moment	Position	Normal	Resistance
	(m)	Peak	Residual	toward U/S	toward D/S		(kN)	(kN)	(kN·m)	% of joint	(kN)	(kN)
1	Base joint	2.37718	2.37718	> 100	1.96420	> 100	-313.84	188.55	187.9	67.64439	115.82	0.000
	Required:	1.500	1.500	1.200	1.200	1.200						

Flood Combination (Stresses):

Joint		Cracking		Normal stresses		Allowable normal stress		Shear stresses over the ligament			
ID	**U/S elevation** (m)	**Upstream** (%) of joint	**Downstream** (%) of joint	**Upstream** (kPa)	**Downstream** (kPa)	**Tension** (kPa)	**Compression** (kPa)	**Upstream** (kPa)	**Maximum** (kPa)	**Maximum at** (% of joint)	**Downstream** (kPa)
1	Base joint	83.09310		-0.003	-1028.521	0.000	-12500.000				

Flood Combination (Stability):

Joint		Safety factors					Resultants over ligament				Final uplift	Rock wedge
ID	U/S elevation	Sliding		Overturning		Uplifting	Normal	Shear	Moment	Position	Uplift	Resistance
	(m)	Peak	Residual	toward U/S	toward D/S		(kN)	(kN)	(kN·m)	% of joint	(kN)	(kN)
1	Base joint	1.54790	1.54790	> 100	1.09249	> 100	-321.70	296.81	33.5	94.36435	265.16	0.000
	Required:	1.100	1.100	1.100	1.100	1.100						

Seismic #1 Combination - Peak accelerations analysis (Stresses):

Joint		Cracking		Normal stresses		Allowable normal stress		Shear stresses over the ligament			
ID	U/S elevation (m)	Upstream (%) of joint	Downstream (%) of joint	Upstream (kPa)	Downstream (kPa)	Tension (kPa)	Compression (kPa)	Upstream (kPa)	Maximum (kPa)	Maximum at (% of joint)	Downstream (kPa)
1	Base joint	100.00000		302.723	-472.367	0.000	0.000				

Seismic #1 Combination - Peak accelerations analysis (Stability):

Joint		**Safety factors**					**Resultants over ligament**				**Final uplift**	**Rock wedge**
ID	**U/S elevation** (m)	**Sliding**		**Overturning**		**Uplifting**	**Normal** (kN)	**Shear** (kN)	**Moment** (kN·m)	**Position** % of joint	**Uplift** (kN)	**Resistance** (kN)
		Peak	Residual	toward U/S	toward D/S							
1	Base joint	*0.95655*	*0.95655*	*> 100*	*0.71596*	*> 100*	-313.84	468.57	884.2	126.14866	115.82	0.000
	Required:	*1.000*	*1.000*	*1.000*	*1.000*	*1.000*						

Post-Seismic Combination (Stresses):

Joint		Cracking		Normal stresses		Allowable normal stress		Shear stresses over the ligament			
ID	U/S elevation (m)	Upstream (%) of joint	Downstream (%) of joint	Upstream (kPa)	Downstream (kPa)	Tension (kPa)	Compression (kPa)	Upstream (kPa)	Maximum (kPa)	Maximum at (% of joint)	Downstream (kPa)
1	1	100.00000		65.798	-113.798	0.000	-12500.000				

Post-Seismic Combination (Stability):

Joint		Safety factors					Resultants over ligament				Final uplift	Rock wedge
ID	**U/S elevation**	**Sliding**		**Overturning**		**Uplifting**	**Normal**	**Shear**	**Moment**	**Position**	**Uplift**	**Resistance**
	(m)	Peak	Residual	toward U/S	toward D/S		(kN)	(kN)	(kN·m)	% of joint	(kN)	(kN)
1	Base joint	0.67261	0.67261	1.88673	0.94962	1.39459	-88.80	188.55	204.9	112.35962	225.04	0.000
		1.100	1.100	1.100	1.100	1.100						

Appendix E

Check Sheets for Dam Safety Expectations, Deficiencies and Priorities

Check Sheets for Dam Safety Expectations Deficiencies and Priorities

Deficiencies and non-conformances identified during the Dam Safety Review have been evaluated in accordance with the sample check sheet for Dam Safety Expectations Deficiencies and Priorities developed by BC MoE (May 2010). Deficiencies are classified into Actual Deficiencies and Potential Deficiencies and there is a variety of non-conformances. These classifications are described as follows.

Definitions of Deficiencies and Non-Conformances

1. Deficiencies
    a. Actual – An unacceptable dam performance condition has been confirmed, based on the CDA Guidelines, or other specified safety standard. Identification of an actual deficiency generally leads to an appropriate corrective action or directly to a capital improvement project:
        i. (An) Normal Load – Load which is expected to occur during the life of a dam.
        ii. (Au) Unlikely Load – Load which could occur under unusual load (large earthquake or flood).
    b. Potential – There is a reason to expect that an unacceptable condition might exist, but has not been confirmed. Identification of a potential deficiency generally leads to a Deficiency Investigation:
        i. (Pn) Normal Load – Load which is expected to occur during the life of a dam.
        ii. (Pu) Unlikely Load – Load which could occur under unusual load (large earthquake or flood).
        iii. (Pq) Quick – Potential deficiency that cannot be confirmed but can be readily eliminated by a specific action.
        iv. (Pd) Difficult - Potential deficiency that is difficult or impossible to prove or disprove.
2. Non-Conformances

    Established procedures, systems and instructions are not being followed, or, they are inadequate or inappropriate and should be revised:

    a. Operational (NCo), Maintenance (NCm), Surveillance (NCs).
    b. Information (NCi) – information is insufficient to confirm adequacy of dam or physical infrastructure for dam safety.
    c. Other Procedures (NCp) – other procedures, to be specified.

Table E2: Dam Safety Expectations for the Ashburnham Creek Dam

	Dam Safety Expectations	Yes	N/A	No	Deficiencies		Non-Conformances	Comments
					Actual	Potential		
1.0	**Dam Safety Analysis**							
1.1	Records relevant to dam safety are available including design documents, historical instrument readings, inspection and testing reports, operational records and investigation results.			X			NCi	No engineering drawings of the dam structure were available. Limited inspection and operational records are available.
1.2	Hazards external and internal to the dam have been defined.	X						Undertaken as part of this DSR
1.3	The potential failure modes for the dam and the initial conditions downstream from the dam have been identified.	X						Undertaken as part of this DSR
1.4	Inundation study adequate to determine consequence classification. Flood and “sunny day” scenarios assessed.	X						Undertaken as part of this DSR
1.5	The Dam is classified appropriately in terms of the consequences of failure including life, environmental, cultural and third-party economic losses	X						Undertaken as part of this DSR
1.6	All other components of the water barrier (retaining walls, saddle dams, spillways, road embankments) are included in the dam safety management process.	X						
1.7	The EDGM selected reflects current seismic understanding.	X						
1.8	The IDF is based on appropriate hydrological analyses.	X						
1.9	The dam is safely capable of passing flows as required for all applicable loading conditions (normal, winter, earthquake, and flood).	X						IDF is between the 100-year and the 1,000-year flood. Dam is capable of passing the 100-year without overtopping but will overtop the right abutment during a 1,000-year event.
1.10	The dam has adequate freeboard for all applicable operating conditions (normal, winter, earthquake, and flood).	X						Reservoir size and the tree cover around the reservoir will limit wind-wave generation. Dam is constructed out of concrete and will resist erosion from overtopping.
1.11	The dam safety analyses (stability & hydrological) use current information and standards of practice.	X						
1.12	The approach and exit channels of discharge facilities are adequately protected against erosion and free of any obstructions that could adversely affect the discharge capacity of the facilities.			X	Au			Catchment may be susceptible to development of debris floods and thus the dam may not be adequately protected.
1.13	The dams, abutments and foundations are not subject to unacceptable deformation or overstressing.			X	Au			Dam does not meet all CDA stability requirements for sliding an overturning.
1.14	Adequate filter and drainage facilities are provided to intercept and control the maximum anticipated seepage and to prevent internal erosion.		X					
1.15	Hydraulic gradients in the dams, abutments, foundations and along embedded structures are sufficiently low to prevent piping and instability.	X						Dam is constructed out of concrete and thus should not be susceptible to internal erosion.
1.16	Slopes of an embankment have adequate protection against erosion, seepage, traffic, frost and burrowing animals		X					
1.17	Stability of reservoir slopes are evaluated under all conditions and unacceptable risk to public safety, the dam or its appurtenant structures is identified.	X						
1.18	The need for reservoir evacuation or emergency drawdown capability as a dam safety risk control measure has been assessed.	X						
2.0	**Operation, Maintenance and Surveillance**							
2.1	Responsibilities and authorities are clearly delegated within the organization for all dam safety activities.			X			NCo	An OMS Manual needs to be prepared for Ashburnham Creek Dam.
2.2	Requirements for the safe operation, maintenance and surveillance of the dam are documented with sufficient information in accordance with the impacts of operation and the consequences of dam failure.			X			NCo	An OMS Manual needs to be prepared for Ashburnham Creek Dam.
2.3	The OMS Manual is reviewed and updated periodically: when major changes to the structure, flow control equipment, operating conditions or company organizational structure and responsibilities have occurred.			X			NCo	An OMS Manual needs to be prepared for Ashburnham Creek Dam.
2.4	Documented operating procedures for the dam and flow control equipment under normal, unusual and emergency conditions exist, are consistent with the OMS Manual and are followed.			X			NCo	An OMS Manual needs to be prepared for Ashburnham Creek Dam.
	Operation							
2.5	Critical discharge facilities are able to operate under all expected conditions.	X						
a.	Flow control equipment is tested and is capable of operating as required.			X	Au			Flow control equipment is not tested and is unlikely to be capable of operating as required due the sediment in the reservoir.

	Dam Safety Expectations	Yes	N/A	No	Deficiencies		Non-Conformances	Comments
					Actual	Potential		
b.	Normal and standby power sources, as well as local and remote controls, are tested.		X					
c.	Testing is on a defined schedule and test results are documented and reviewed.			X			NCo	No official testing records were provided.
d.	Management of debris and ice is carried out to ensure operability of discharge facilities.			X			NCo	No official records were available documenting debris removal.
2.6	Operating procedures take into account:							
a.	Outflow from upstream dams		X					
b.	Reservoir levels and rates of drawdown		X					Sediment in the reservoir limits the ability to control reservoir level or discharge.
c.	Reservoir control and discharge during an emergency		X					Sediment in the reservoir limits the ability to control reservoir level or discharge.
d.	Reliable flood forecasting information	X						
e.	Operator safety			X			NCo	No safe work procedures were available for review.
	Maintenance							
2.7	The particular maintenance needs of critical components or subsystems, such as flow control systems, power supply, backup power, civil structures, drainage, public safety and security measures and communications and other infrastructure are identified.			X			NCm	Assumed to be a non-conformance as no supporting documentation provided.
2.8	Maintenance procedures are documented and followed to ensure that the dam remains in a safe and operational condition.			X			NCm	Assumed to be a non-conformance as no supporting documentation provided.
2.9	Maintenance activities are prioritized and carried out with due consideration to the consequences of failure, public safety and security.			X			NCm	Assumed to be a non-conformance as no supporting documentation provided.
	Surveillance							
2.10	Documented surveillance procedures for the dam and reservoir are followed to provide early identification and to allow for timely mitigation of conditions that might affect dam safety.			X			NCm	Assumed to be a non-conformance as no supporting documentation provided.
2.11	The surveillance program provides regular monitoring of dam performance, as follows:							
a.	Actual and expected performances are compared to identify deviations.			X			NCm	Assumed to be a non-conformance as no supporting documentation provided.
b.	Analysis of changes in performance, deviation from expected performance or the development of hazardous conditions.	X						
c.	Reservoir operations are confirmed to be in compliance with dam safety requirements.	X						
d.	Confirmation that adequate maintenance is being carried out.			X			NCm	Assumed to be a non-conformance as no supporting documentation provided.
2.12	The surveillance program has adequate quality assurance to maintain the integrity of data, inspection information, dam safety recommendations, training and response to unusual conditions.	X						
2.13	The frequency of inspection and monitoring activities reflects the consequences of failure, dam condition and past performance, rapidity of development of potential failure modes, access constraints due to weather or the season, regulatory requirements and security needs.	X						
2.14	Special inspections are undertaken following unusual events (if no unusual events then acknowledge that requirement to do so is documented in OMS).	X						
2.15	Training is provided so that inspectors understand the importance of their role, the value of good documentation, and the means to carry out their responsibilities effectively.			X			NCm	Assumed to be a non-conformance as no supporting documentation provided.
2.16	Qualifications and training records of all individuals with responsibilities for dam safety activities are available and maintained.			X			NCm	Assumed to be a non-conformance as no supporting documentation provided.
2.17	Procedures document how often instruments are read and by whom, where the instrument readings will be stored, how they will be processed, how they will be analyzed, what threshold values or limits are acceptable for triggering follow-up actions, what the follow-up actions should be and what instrument maintenance and calibration are necessary.		X					No instrumentation on Ashburnham Creek Dam
3.0	**Emergency Preparedness**							
3.1	An emergency management process is in place for the dam including emergency response procedures and emergency preparedness plans with a level of detail that is commensurate with the consequences of failure.			X			NCp	A Dam Emergency Plan (DEP) needs to be prepared for Ashburnham Creek Dam

Dam Safety Expectations		Yes	N/A	No	Deficiencies		Non-Conformances	Comments
					Actual	Potential		
3.2	The emergency response procedures outline the steps that the operations staff is to follow in the event of an emergency at the dam.			X			NCp	A Dam Emergency Plan (DEP) needs to be prepared for Ashburnham Creek Dam
3.3	Documentation clearly states, in order of priority, the key roles and responsibilities, as well as the required notifications and contact information.			X			NCp	A Dam Emergency Plan (DEP) needs to be prepared for Ashburnham Creek Dam
3.4	The emergency response procedures cover the full range of flood management planning, normal operating procedures and surveillance procedures.			X			NCp	A Dam Emergency Plan (DEP) needs to be prepared for Ashburnham Creek Dam
3.5	The emergency management process ensures that effective emergency preparedness procedures are in place for use by external response agencies with responsibilities for public safety within the floodplain.			X			NCp	A Dam Emergency Plan (DEP) needs to be prepared for Ashburnham Creek Dam
3.6	Roles and responsibilities of the dam owner and response agencies are defined.			X			NCp	A Dam Emergency Plan (DEP) needs to be prepared for Ashburnham Creek Dam
3.7	Inundation maps and critical flood information are appropriate and are available to downstream response agencies.			X			NCp	Inundation maps included in this report should be incorporated into a DEP and provided to the downstream response agencies.
3.8	Exercises are carried out regularly to test the emergency procedures.			X			NCp	No documentation of training exercises is available.
3.9	Staff are adequately trained in the emergency procedures.			X			NCp	No documentation of training is available.
3.10	Emergency plans are updated regularly and updated pages are distributed to all plan holders in a controlled manner.			X			NCp	A Dam Emergency Plan (DEP) needs to be prepared for Ashburnham Creek Dam.
4.0	**Dam Safety Review**							
4.1	A safety review of the dam ("Dam Safety Review") is carried out periodically based on the consequences of failure.	X						The CVRD commissioned this dam safety review. This is the first comprehensive dam safety review of this structure.
5.0	**Dam Safety Management System**							
5.1	The dam safety management system for the dam is in place incorporating:							
a.	Policies			X			NCo	An OMS Manual needs to be prepared for Ashburnham Creek Dam.
b.	Responsibilities			X			NCo	An OMS Manual needs to be prepared for Ashburnham Creek Dam.
c.	Plans and procedures including OMS, public safety and security			X			NCo	An OMS Manual needs to be prepared for Ashburnham Creek Dam.
d.	Documentation			X			NCo	Documentation of inspections and other documentation is limited.
e.	Training and review			X			NCo	An OMS Manual needs to be prepared for Ashburnham Creek Dam.
f.	Prioritization and correction of deficiencies and non-conformances	X						Prioritization of deficiencies are provided in this dam safety review.
g.	Supporting infrastructure	X						
5.2	Deficiencies are: documented, reviewed, and resolved in a timely manner. Decisions are justified and documented.			X			NCo	Prioritization of deficiencies are provided in this dam safety review.
5.3	Applicable regulations are met.			X			NCo	An OMS Manual & DEP needs to be prepared for Ashburnham Creek Dam.

Appendix F

NDMP Risk Assessment Information Template

National Disaster Mitigation Program (NDMP)
Risk Assessment Information Template

Risk Event Details			
Start and End Date	Provide the start and end dates of the selected event, based on historical data.	Start Date: 05/11/2018	End Date: Ongoing
Severity of the Risk Event	Provide details about the risk, including: • Speed of onset and duration of event; • Level and type of damaged caused; • Insurable and non-insurable losses; and • Other details, as appropriate.	A comprehensive Dam Safety Review and Risk Assessment was undertaken of the Ashburnham Creek Dam in 2018 to meet the CVRD's obligations as a water licensee under the BC Dam Safety Regulations. The dam safety review includes a dam breach analysis, flood routing, inundation mapping and assessment of the performance of the dam structure to resist failure under normal and extreme loads. This includes assessment of various meteorological and seismic hazards. Flood routing inundation mapping indicates that hazardous flow conditions downstream of the dam would occur within an hour of the initiation of the event. The results of the dam safety review and risk assessment indicated that the following infrastructure is at risk in the event of a dam breach during a 100-year inflow event. 1. Gordon River Road 2. South Shore Road 3. Lily Beach Park	
Response During the Risk Event	Provide details on how the defined geographic area continued its essential operations while responding to the event.	N/A	
Recovery Method for the Risk Event	Provide details on how the defined geographic area recovered.	Recovery is anticipated to include the investigation, design and construction of a replacement dam structure that would meet the performance criteria contained within the BC Dam Safety Regulations, Canadian Dam Association (CDA) Dam Safety Guidelines and technical bulletins.	

Recovery Costs Related to the Risk Event	Provide details on the costs, in dollars, associated with implementing recovery strategies following the event.	Dam reconstruction and restoration roads: $1,000,000 Potential additional costs
Recovery Time Related to the Risk Event	Provide details on the recovery time needed to return to normal operations following the event.	Unknown

Risk Event Identification and Overview	
Provide a qualitative description of the defined geographic area, including: • Watershed/community/region name(s); • Province/Territory; • Area type (i.e., city, township, watershed, organization, etc.); • Population size; • Population variances (e.g., significant change in population between summer and winter months); • Main economic areas of interest; • Special consideration areas (e.g., historical, cultural and natural resource areas); and an • Estimate of the annual operating budget of the area.	Ashburnham Creek Watershed Honeymoon Bay, British Columbia Vancouver Island Region Area type: Watershed Population Size: 561 Population Variance: Unknown Main Economic Interests: Forestry, Tourism Special Consideration: Lily Beach Park Estimate of Annual Operating Budget: Unknown
Methodolgies, processes and analyses	
Provide the year in which the following processes/analyses were last completed and state the methodology(ies) used: • Hazard identification; • Vulnerability analysis; • Likelihood assessment; • Impact assessment; • Risk assessment; • Resiliency assessment; and/or • Climate change impact and/or adaptation assessment. *Note: It is recognized that many of the processes/analyses mentioned above may be included within one methodology.*	Analysis completed during the 2018 Comprehensive Dam Safety Review and Risk Assessment of the Ashburnham Creek Dam, prepared by Ecora Engineering & Resource Group Ltd. Report includes: Dam stability analysis, dam breach assessment, dam hydrotechnical assessment Hazards, vulnerability, likelihood, impact, risk are assigned as a result of the analysis

Hazard Mapping	
To complete this section: • Obtain a map of the area that clearly indicates general land uses, neighbourhoods, landmarks, etc. For clarity throughout this exercise, it may be beneficial to omit any non-essential information from the map intended for use. Controlled photographs (e.g. aerial photography) can be used in place of or in addition to existing maps to avoid the cost of producing new maps. • Place a grid over the maps/photographs of the area and assign row and column identifiers. This will help identify the specific area(s) that may be impacted, as well as additional information on the characteristics within and affecting the area. • Identify where and how flood hazards may affect the defined geographic area. • Identify the mapped areas that are most likely to be impacted by the identified flood hazard. Map(s)/photograph(s) can also be used, where appropriate, to visually represent the information/prioritization being provided as part of this template.	
Hazard identification and prioritization	
List known or likely flood hazards to the defined geographic area in order of proposed priority. For example: (1) dyke breach overland flooding; (2) urban storm surge flooding ; and so on.	1. Dam breach of Ashburnham Creek Dam and overland flooding
Provide a rationale for each prioritization and the key information sources supporting this rationale.	1. The 2018 Comprehensive Dam Safety Review and Risk Assessment of the Ashburnham Creek Dam indicated that the dam in its current form does not meet the performance criteria contained within the BC Dam Safety Regulations, Canadian Dam Association Dam Safety Guidelines and Technical Bulletins and is at risk of structural failure due to sliding and overturning. 2018 Comprehensive Dam Safety Review and Risk Assessment of Ashburnham Creek Dam, prepared by Ecora Engineering & Resource Group Ltd.
Risk Event Title	
Identify the name/title of the risk. An example of a risk event name or title is: "A one-in-one hundred year flood following an extreme rain event."	Dam breach and overland flooding due to a 1 in 100-year flood event
Type of Flood Hazard	

Identify the type of flood hazard being described (e.g., riverine flooding, coastal inundation, urban run-off, etc.)	Riverine flooding and associated bank erosion. Failure and overtopping of hydraulic structures.
Secondary hazards	
Describe any secondary effects resulting from the risk event (e.g., flooding that occurs following a hurricane).	Erosion and bank instabilities downstream of the dam failure due to elevated flows. Failure of road embankments where hydraulic structures are overwhelmed by breach flows.
Primary and secondary organizations for response	
Identify the primary organization(s) with a mandate related to a key element of a natural disaster emergency, and any supporting organization(s) that provide general or specialized assistance in response to a natural disaster emergency.	The Cowichan Valley Regional District and the BC Ministry of Transportation & Infrastructure and Emergency Management BC would be the primary organizations with a mandate to respond to a natural disaster emergency at the subject site.

Risk Event Description	
Description of risk event, including risk statement and cause(s) of the event	
Provide a baseline description of the risk event, including: • Risk statement; • Context of the risk event; • Nature and scale of the risk event; • Lead-up to the risk event, including underlying cause and trigger/stimulus of the risk event; and • Any factors that could affect future events. *Note: The description entered here must be plausible in that factual information would support such a risk event.*	The risk event is the breach of Ashburnham Creek Dam. This can be caused by a flood event, an earthquake or further deterioration of the concrete structure. In the event of a breach during a 100-year inflow event damage to public infrastructure would occur including damage to Gordon River Road, South Shore Road and Lily Beach Park. The event would most likely occur in the spring freshet period when there is the greatest potential for significant flows in the creek.

Location	
Provide details regarding the area impacted by the risk event such as: • Province(s)/territory(ies); • Region(s) or watershed(s); • Municipality(ies); • Community(ies); and so on.	Ashburnham Creek Dam is located on the south shore of Cowichan Lake on Vancouver Island in Southwest British Columbia. The creek passes through the western side of the community of Honeymoon Bay. A dam breach during a 100-year event has the potential to disrupt transportation traveling between the southeast and southwest side of Cowichan Lake.
Natural environment considerations	
Document relevant physical or environmental characteristics of the defined geographic area.	The Ashburnham Creek watershed is heavily forested around the creek, frequent logging activity has been noted in the upper catchment. Elevation of the catchment varies from approximately 230 m near the dam to 1020 in the upper catchment.
Meteorological conditions	
Identify the relevant meteorological conditions that may influence the outcome of the risk event.	Relevant meteorological conditions may include: - High snowpack in the Ashburnham Creek watershed - High temperatures as snow thaws - Extreme rainfall - Extreme rain on snow

Seasonal conditions	
Identify the relevant seasonal changes that may influence the outcome of the risk assessment of a particular risk event.	Relevant seasonal conditions may include: - Extreme precipitation - Wood debris in the dam spillway - Changing watershed conditions due to wildfire, logging and other factors
Nature and vulnerability	
Document key elements related to the affected population, including: • Population density; • Vulnerable populations (identify these on the hazard map from step 7); • Degree of urbanization; • Key local infrastructure in the defined geographic area; • Economic and political considerations; and • Other elements, as deemed pertinent to the defined geographic area.	Population density of Honeymoon Bay: 140.3 people per square km. Hazardous area is identified on hazard maps included with the 2018 Comprehensive Dam Safety Review and Risk Assessment completed by Ecora. Areas around the creek is mostly rural with development only exist along the shore of Cowichan Lake below the dam. Key local infrastructure: 1. Gordon River Road 2. South Shore Road 3. Lily Beach Park Economic and political considerations: A dam breach will impact local roads and parks.

Asset inventory	
Identify the asset inventory of the defined geographic area, including: • Critical assets; • Cultural or historical assets; • Commercial assets; and • Other area assets, as applicable to the defined geographic area. Key asset-related information should also be provided, including: • Location on the hazard map (from step 7); • Size; • Structure replacement cost; • Content value; • Displacement costs; • Importance rating and rationale; • Vulnerability rating and reason; and • Average daily cost to operate. A total estimated value of physical assets in the area should also be provided.	Key local assets that are within the flow area include: 1. Gordon River Road 2. South Shore Road Possible further damage from overland flooding through Honeymoon Bay. No detailed cost estimate has taken place, however the total impact cost is estimated to be below $3 million
Other assumptions, variability and/or relevant information	
Identify any assumptions made in describing the risk event; define details regarding any areas of uncertainty or unpredictability around the risk event; and supply any supplemental information, as applicable.	A breach of the dam can be caused by a number of scenarios and thus it is difficult to say which scenario would be the first that causes dam failure. As per the Canadian Dam Association (CDA) guidelines the most conservative scenario was considered. Dam breach analysis assumed a sudden failure of the dam during a 100-year inflow event. Some variation between the modeled breach and a real breach may exist due to variation in terrain that may not entirely captured in the digital terrain model
Existing Risk Treatment Measures	
Identify existing risk treatment measures that are currently in place within the defined geographic area to mitigate the risk event, and describe the sufficiency of these risk treatment measures.	It is anticipated that the bridges downstream at Gordon River Road and South Shore Road would likely be sized for the 100-year event however debris washed down and limiting stream capacity could may the bridges susceptible to failure during a breach.

Likelihood Assessment

Return Period

Identify the time period during which the risk event might occur. For example, the risk event described is expected to occur once every X number of years. Applicants are asked to provide the X value for the risk event.	1 in 100-year

Period of interest

Applicants are asked to determine and identify the likelihood rating (i.e. period of interest) for the risk event described by using the likelihood rating scale within the table below.

Likelihood Rating	Definition	
5	The event is expected and may be triggered by conditions expected over a 30 year period.	3
4	The event is expected and may be triggered by conditions expected over a 30 - 50 year period.	
3	The event is expected and may be triggered by conditions expected over a 50 - 500 year period.	
2	The event is expected and may be triggered by conditions expected over a 500 - 5000 year period.	
1	The event is possible and may be triggered by conditions exceeding a period of 5000 years.	

Provide any other relevant information, notes or comments relating to the likelihood assessment, as applicable.	For the purpose of this study a 1 in 100-year event has been considered. The 1 in 100-year condition was considered as the inflow design flood for the dam corresponds to this event, further the dam was noted to be susceptible to overturning during flood conditions.

Impacts/Consequences Assessment

There are 12 impacts categories within 5 impact classes rated on a scale of 1 (least impacts) to 5 (greatest impact). Conduct an assessment of the impacts associated with the risk event, and assign one risk rating for each category. Additional information may be provided for each of the categories in the supplemental fields provided.

A) People and societal impacts

	Risk Rating	Definition	Assigned risk rating
Fatalities	5	Could result in more than 50 fatalities	2
	4	Could result in 10 - 49 fatalities	
	3	Could result in 5 - 9 fatalities	
	2	Could result in 1 - 4 fatalities	
	1	Not likely to result in fatalities	
Supplemental information (optional)	No permanent population at risk (PAR) was identified in the inundation area however transient population could find themselves in a hazardous location		
Injuries	5	Injuries, illness and/or psychological disablements cannot be addressed by local, regional, or provincial/territorial healthcare resources; federal support or intervention is required	2
	4	Injuries, illnesses and/or psychological disablements cannot be addressed by local or regional healthcare resources; provincial/territorial healthcare support or intervention is required.	
	3	Injuries, illnesses and/or psychological disablements cannot be addressed by local or regional healthcare resources additional healthcare support or intervention is required from other regions, and supplementary support could be required from the province/territory	
	2	Injuries, illnesses and/or psychological disablements cannot be addressed by local resources through local facilities; healthcare support is required from other areas such as an adjacent area(ies)/municipality(ies) within the region	
	1	Any injuries, illnesses, and/or psychological disablements can be addressed by local resources through local facilities; available resources can meet the demand for care	
Supplemental information (optional)	Closest hospital to impacted area is the Cowichan District Hospital approximately 44 km away		

		Risk Rating	Definition	Assigned risk rating
Displacement	Percentage of displaced individuals	5	> 15% of total local population	1
		4	10 - 14.9% of total local population	
		3	5 - 9.9% of total local population	
		2	2 - 4.9% of total local population	
		1	0 - 1.9% of total local population	
	Duration of displacement	5	> 26 weeks (6 months)	4
		4	4 weeks - 26 weeks (6 months)	
		3	1 week - 4 weeks	
		2	72 hours - 168 hours (1 week)	
		1	Less than 72 hours	
Supplemental information (optional)		Primary impact will be to a temporary population. The duration of displacement could be a number of weeks as road access is restored		
B) Environmental impacts				
		5	> 75% of flora or fauna impacted or 1 or more ecosystems significantly impaired; Air quality has significantly deteriorated; Water quality is significantly lower than normal or water level is > 3 meters above highest natural level; Soil quality or quantity is significantly lower (i.e., significant soil loss, evidence of lethal soil contamination) than normal; > 15% of local area is affected	2
		4	40 - 74.9% of flora or fauna impacted or 1 or more ecosystems considerably impaired; Air quality has considerably deteriorated; Water quality is considerably lower than normal or water level is 2 - 2.9 meters above highest natural level; Soil quality or quantity is moderately lower than normal; 10 - 14.9% of local area is affected	
		3	10 - 39.9% of flora or fauna impacted or 1 1 or more ecosystems moderately impaired; Air quality has moderately deteriorated; Water quality is moderately lower than normal or water level is 1 - 2 meters above highest natural level; Soil quality is moderately lower than normal; 6 - 9.9 % of area affected	

	2	< 10 % of flora or fauna impacted or little or no impact to any ecosystems; Little to no impact to air quality and/or soil quality or quantity; Water quality is slightly lower than normal, or water level is less than 0.9 meters above highest natural level and increased for less than 24 hours; 3 - 5.9 % of local area is affected	
	1	Little to no impact to flora or fauna, any ecosystems, air quality, water quality or quantity, or to soil quality or quantity; 0 - 2.9 % of local area is affected	
Supplemental information (optional)	Elevated water levels are expected for a period of less than 24 hours as the flood wave moves downstream		

C) Local economic impacts

	Risk Rating	Definition	Assigned risk rating
	5	> 15 % of local economy impacted	5
	4	10 - 14.9 % of local economy impacted	
	3	6 - 9.9 % of local economy impacted	
	2	3 - 5.9 % of local economy impacted	
	1	0 - 2.9 % of local economy impacted	
Supplemental information (optional)	Access to the west will be restricted		

D) Local infrastructure impacts

	Risk Rating	Definition	Assigned risk rating
Transportation	5	Local activity stopped for more than 72 hours; > 20% of local population affected; lost access to local area and/or delivery of crucial service or product; or having an international level impact	1
	4	Local activity stopped for 48 - 71 hours; 10 - 19.9% of local population affected; significantly reduced access to local area and/or delivery of crucial service or product; or having a national level impact	
	3	Local activity stopped for 25 - 47 hours; 5 - 9.9% of local population affected; moderately reduced access to local area and/or delivery of crucial service or product; or having a provincial/territorial level impact	
	2	Local activity stopped for 13 - 24 hours; 2 - 4.9% of local population affected; minor reduction in access to local area and/or delivery of crucial service or product; or having a regional level impact	
	1	Local activity stopped for 0 - 12 hours; 0 - 1.9% of local population affected; little to no reduction in access to local area and/or delivery of crucial service or product	
Supplemental information (optional)			
Energy and Utilities	5	Duration of impacts > 72 hours; > 20% of local population without service or product; or having an international level impact	5
	4	Duration of impact 48 - 71 hours; 10 - 19.9% of local population without service or product; or having a national impact	
	3	Duration of impact 25 - 47 hours; 5 - 9.9% of local population without service or product; or having a provincial/territorial level impact	
	2	Duration of impact 13 - 24 hours; 2 - 4.9% of local population without service or product; or having a regional level impact	
	1	Local activity stopped for 0 - 12 hours; 0 - 1.9% of local population affected; little to no reduction in access to local area and/or delivery of crucial service or product	

Supplemental information (optional)			
Information and Communications Technology	5	Service unavailable for > 72 hours; > 20 % of local population without service; or having an international level impact	1
	4	Service unavailable for 48 - 71 hours; 10 - 19.9 % of local population without service; or having a national level impact	
	3	Service unavailable for 25 - 47 hours; 5 - 9.9 % of local population without service; or having a provincial/territorial level impact	
	2	Service unavailable for 13 - 24 hours; 2 - 4.9 % of local population without service; or having a regional level impact	
	1	Service unavailable for 0 - 12 hours; 0 - 1.9 % of local population without service	
Supplemental information (optional)			
Health, Food, and Water	5	Inability to access potable water, food, sanitation services, or healthcare services for > 72 hours; non - essential services cancelled; > 20 % of local population impacted; or having an international level impact	1
	4	Inability to access potable water, food, sanitation services, or healthcare services for 48 - 72 hours; major delays for nonessential services; 10 - 19.9 % of local population impacted; or having a national level impact	
	3	Inability to access potable water, food, sanitation services, or healthcare services for 25 - 48 hours; moderate delays for nonessential services; 5 - 9.9 % of local population impacted; or having a provincial/territorial level impact	
	2	Inability to access potable water, food, sanitation services, or healthcare services for 13 - 24 hours; minor delays for nonessential; 2 - 4.9 % of local population impacted; or having a regional level impact	
	1	Inability to access potable water, food, sanitation services, or healthcare services for 0 - 12 hours; 0 - 1.9 % of local population impacted	

Supplemental information (optional)			
Safety and Security	5	> 20 % of local population impacted; loss of intelligence or defence assets or systems for > 72 hours; or having an international level impact	2
	4	10 - 19.9 % of local population impacted; loss of intelligence or defence assets or systems for 48 – 71 hours; or having a national level impact	
	3	5 - 9.9 % of local population impacted; loss of intelligence or defence assets or systems for 25 – 47 hours; or having a provincial/territorial level impact	
	2	2 - 4.9 % of local population impacted; loss of intelligence or defence assets or systems for 13 – 24 hours; or having a regional level impact	
	1	0 - 1.9 % of local population impacted; loss of intelligence or defence assets or systems for 0 – 12 hours	
Supplemental information (optional)			

E) Public sensitivity impacts			
	Risk Rating	Definition	Assigned risk rating
	5	Sustained, long term loss in reputation/public perception of public institutions and/or sustained, long term loss of trust and confidence in public institutions; or having an international level impact	2
	4	Significant loss in reputation/public perception of public institutions and/or significant loss of trust and confidence in public institutions; significant resistance; or having a national level impact	
	3	Some loss in reputation/public perception of public institutions and/or some loss of trust and confidence in public institutions; escalating resistance	
	2	Isolated/minor, recoverable set - back in reputation, public perception, trust, and/or confidence of public institutions	
	1	No impact on reputation, public perception, trust, and/or confidence of public institutions	
Supplemental information (optional)			

Confidence Assessment

Based on the table below, indicate the level of confidence regarding the information entered in the risk assessment information template in the "Confidence Level Assigned" column. Confidence levels are language - based and range from A to E (A=most confident to E=least confident).

Confidence Level	Definition	Confidence Level Assigned
A	Very high degree of confidence Risk assessment used to inform the risk assessment information template was evidence - based on a thorough knowledge of the natural hazard risk event; leveraged a significant quantity of high - quality data that was quantitative and qualitative in nature; leveraged a wide variety of data and information including from historical records, geospatial and other information sources; and the risk assessment and analysis processes were completed by a multidisciplinary team with subject matter experts (i.e., a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences) Assessment of impacts considered a significant number of existing/known mitigation measures	
B	High degree of confidence Risk assessment used to inform the risk assessment information template was evidence - based on a thorough knowledge of the natural hazard risk event; leveraged a significant quantity of data that was quantitative and qualitative in nature; leveraged a wide variety of data and information including from historical records, geospatial and other information sources; and the risk assessment and analysis processes were completed by a multidisciplinary team with some subject matter expertise (i.e., a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences) Assessment of impacts considered a significant number of potential mitigation measures	

C	Moderate confidence Risk assessment used to inform the risk assessment information template was moderately evidence - based from a considerable amount of knowledge of the natural hazard risk event; leveraged a considerable quantity of data that was quantitative and/or qualitative in nature; leveraged a considerable amount of data and information including from historical records, geospatial and other information sources; and the risk assessment and analysis processes were completed by a moderately sized multidisciplinary team, incorporating some subject matter experts (i.e., a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences) Assessment of impacts considered a large number of potential mitigation measures	C
D	Low confidence Risk assessment used to inform the risk assessment information template was based on a relatively small amount of knowledge of the natural hazard risk event; leveraged a relatively small quantity of quantitative and/or qualitative data that was largely historical in nature; may have leveraged some geospatial information or information from other sources (i.e., databases, key risk and resilience methodologies); and the risk assessment and analysis processes were completed by a small team that may or may not have incorporated subject matter experts (i.e., did not include a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences). Assessment of impacts considered a relatively small number of potential mitigation measures	
E	Very low confidence Risk assessment used to inform the risk assessment information template was not evidence - based; leveraged a small quantity of information and/or data relating to the natural risk hazard and risk event; primary qualitative information used with little to no quantitative data or information; and the risk assessment and analysis processes were completed by an individual or small group of individuals little subject matter expertise (i.e., did not include a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences). Assessment of impacts did not consider existing or potential mitigation measures	

Rationale for level of confidence

Provide the rationale for the selected confidence level, including any references or sources to support the level assigned.	The risk assessment considered multiple risk events including the probabilistic (5th Generation) seismic hazard model developed by the Geological Survey of Canada (GSC) (Halchuk, Adams and Allen, 2015) that forms the basis of the seismic design provisions of the 2015 National Building Code of Canada (NBCC, 2015). Only one mitigation measure was considered as rehabilitation of the existing dam structure is the most logical option.

Key Information Sources	
Identify all supporting documentation and information sources for qualitative and quantitative data used to identify risk events, develop the risk event description, and assess impacts and likelihood. This ensures credibility and validity of risk information presented as well as enables referencing back to decision points at any point in time. Clearly identify unclassified and classified information.	Comprehensive Dam Safety Review and Risk Assessment of Ashburnham Creek Dam, prepared by Ecora Engineering & Resource Group Ltd. in draft form from 2018. Unclassified.
Description of the risk analysis team	
List and describe the type and level of experience of each individual who was involved with the completion of the risk assessment and risk analysis used to inform the information contained within this risk assessment information template.	Michael J. Laws, P.Eng. Senior Geotechnical & Dam Safety Engineer Dr. Adrian Chantler, P.Eng. Senior Hydrotechnical Engineer

Appendix G

Dam Safety Assurance Statement

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

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

To: The Owner(s)

Date: March 19, 2019

Cowichan Valley Regional District
Name
175 Ingram Street
Duncan, BC V9L 1N8
Address

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

For the dam:

UTM (Location): E413092, N5406646 (Zone 10)

Located at (Description): Gordon River Road, Honeymoon Bay, BC

Name of dam or description: Ashburnham Creek Dam

Provincial dam number: D730128-00

Dam function: Storage – Non-Power

Owned by: Cowichan Valley Regional District

(the "Dam")

Current Dam classification is:

Check one

☐ Low
☑ Significant
☐ High
☐ Very High
☐ Extreme

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

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

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

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

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

✓ 3. Undertaken an initial facility review

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

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

✓ 6. Interviewed operations and maintenance personnel

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

✓ 8. Confirmed proper functioning of flow control equipment

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

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

✓ 11. Evaluated facility performance

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

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

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

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

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

Check one

☑ Appropriate

☐ Should be reviewed and amended

I undertook the following type of dam safety review:

Check one

☐ Audit

☑ Comprehensive

☐ Detailed design-based multi-disciplinary

☐ Comprehensive, detailed design and performance

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

Check one

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

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

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

☑ The Dam is not safe in that the dam safety review did reveal deficiencies and/or non-conformances which require urgent action as set out in section(s) ____ of the attached dam safety review report.
10.5, 12 & 13

Michael J. Laws, P.Eng.
Name

March 19, 2019
Date

Signature

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
M. J. LAWS
36691

579 Lawrence Avenue, Kelowna, BC V1Y 6L8
Address

250.469.9757
Telephone

(Affix Professional Seal here)

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

I am a member of the firm Ecora Engineering & Resource Group Ltd.
and I sign this letter on behalf of the firm. (Print name of firm)

Appendix H

Statement of General Conditions – Geotechnical

Statement of General Conditions — Geotechnical

Standard of Care

Ecora Engineering and Resource Group Ltd. (Ecora) has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practicing under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this report. No other warranty, expressed or implied is made.

Basis and Use of the Report

This report and the recommendations contained in it are intended for the sole use of Ecora's Client. Ecora does not accept any responsibility for the accuracy of any of the data, the analyses or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than Ecora's Client unless otherwise authorized in writing by Ecora. Any unauthorized use of the report is at the sole risk of the user. In order to properly understand the suggestions, recommendations and opinions expressed herein, reference must be made to the whole of the report. We cannot be responsible for use by any party of portions of the report without reference to the whole report.

This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of Ecora. Additional copies of the report, if required, may be obtained upon request.

Alternate Report Format

Where Ecora submits both electronic file and hard copy versions of reports, drawings and other project-related documents, only the signed and/or sealed versions shall be considered final and legally binding. The original signed and/or sealed version archived by Ecora shall be deemed to be the original for the Project. Both electronic file and hard copy versions of Ecora's deliverables shall not, under any circumstances, no matter who owns or uses them, be altered by any party except Ecora.

Soil, Rock and Groundwater Conditions

Classification and identification of soils, rocks and geological units have been based upon commonly accepted systems and methods employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Classification and identification of the type and condition of these materials or units involves judgment, and boundaries between different soil, rock or geologic types or units may be transitional rather than abrupt. Accordingly, Ecora does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities such as traffic, excavation, groundwater level lowering, pile driving, blasting on the site or on adjacent sites. Excavation may expose the soils to climatic elements such as freeze/thaw and wet /dry cycles and/or mechanical disturbance which can cause severe deterioration. Unless otherwise indicated the soil must be protected from these changes during construction.

Environmental and Regulatory Issues

The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report. The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.

Sample Disposal

Ecora will dispose all soil and rock samples for 30 days following issue of this report. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded.

Construction Services

During construction, Ecora should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not materially differ from those interpreted conditions considered in the preparation of Ecora's report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in Ecora's report. Adequate field review, observation and testing during construction are necessary for Ecora to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, Ecora's responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

Job Site Safety

Ecora is responsible only for the activities of our employees on the jobsite. The presence of Ecora's personnel on the site shall not be construed in any way to relieve the Client or any contractors on site from their responsibilities for site safety. The Client acknowledges that he, his representatives, contractors or others retain control of the site and that Ecora never occupy a position of control of the site. The Client undertakes to inform Ecora of all hazardous conditions, or other relevant conditions of which the Client is aware. The Client also recognizes that our activities may uncover previously unknown hazardous conditions or materials and that such a discovery may result in the necessity to undertake emergency procedures to protect our employees as well as the public at large and the environment in general.

Changed Conditions and Drainage

Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that Ecora be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that Ecora be employed to visit the site with sufficient frequency to detect if conditions have changed significantly. Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. Ecora takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the system.

Services of Sub consultants and Contractors

The conduct of engineering and environmental studies frequently requires hiring the services of individuals and companies with special expertise and/or services which we do not provide. Ecora may arrange the hiring of these services as a convenience to our Clients. As these services are for the Client's benefit, the Client agrees to hold the Company harmless and to indemnify and defend Ecora from and against all claims arising through such hiring's to the extent that the Client would incur had he hired those services directly. This includes responsibility for payment for services rendered and pursuit of damages for errors, omissions or negligence by those parties in carrying out their work. In particular, these conditions apply to the use of drilling, excavation and laboratory testing services.