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Dam Safety Review and Risk Assessment of Shawnigan Lake Weir

Presented To: CVRD

Dated: March 2019

Ecora File No.: GK-18-020-CVD

ENGINEERS & GEOSCIENTISTS BRITISH COLUMBIA

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Presented To:

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

Prepared by:

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

2019-03-19

Michael J. Laws, P.Eng. — Date
Senior Geotechnical & Dam Safety Engineer
michael.laws@ecora.ca

Prepared by:

2019-03-19

Andrew Gain, E.I.T. — Date
Junior Geotechnical/ Hydrotechnical Engineer
andrew.gain@ecora.ca

Prepared by:

2019-03-19

Chelsea Evans, B.E. (Hons) Civil — Date
Geotechnical Consultant
chelsea.evans@ecora.ca

Prepared by:

PROFESSIONAL PROVINCE OF B. A. HOBUTI # 41534 BRITISH COLUMBIA ENGINEER

MAR 19 2019

Bram Hobuti, P.Eng. — Date
Structural Engineer
bram.hobuti@ecora.ca

Reviewed by:

PROFESSIONAL PROVINCE OF A. G. CHANTLER BRITISH COLUMBIA ENGINEER

2019-03-19

Dr. Adrian Chantler, P.Eng. — Date
Senior Hydrotechnical Consultant
adrian.chantler@ecora.ca

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

Executive Summary

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 Shawnigan Lake Weir located just north of Shawnigan Lake, BC.

Shawnigan Lake Weir was constructed in 2006 to replace the original timber weir located approximately five metres upstream and that it functions as a control for outflows from Shawnigan Lake. The weir was funded by the Mill Bay Waterworks District, Shawnigan Village Waterworks and CVRD Shawnigan Lake North Water System, designed by John Braybrooks Engineering and constructed by Bercon Construction Ltd.

A summary of key dam and reservoir attributes are included in Table i below.

Table i Summary of Key Dam Attributes

Shawnigan Lake Weir		
Provincial Dam File Number:	D730200-00	
Stream Name:	Shawnigan Creek	
Current Consequences Classification:	Significant (Recommended: High)	
Dam Type:	Concrete Weir	
Location:	Latitude: 48°39’35” N	Longitude: 123°37’44” W
Height:	3.2 m	
Length:	16 m	
Spillway Capacity:	26.4 m^3/s	
Live Storage Capacity:	6,270,000 m^3	
Potential Storage Volume:	10,200,000 m^3	
Reservoir Surface Area:	570,000 m^2	
Watershed Area:	69.7 km^2	
Peak of Inflow Design Flood (IDF):	227 m^3/s – 298 m^3/s (Significant, 100-y to 1,000-y flood)	408 m^3/s (High)
Peak Outflow During IDF:	20.6 m^3/s – 37.2 m^3/s (Significant, 100-y to 1,000-y flood)	49.3 m^3/s (High)

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;
- Geotechnical assessment, including seepage and liquefaction analyses and global stability checks under static and seismic loading conditions, piping potential and considerations for deformation of foundation soils;
- 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 hydraulic analysis;
- Mechanical and electrical review;
- Review of any Operation, Maintenance & Surveillance Manuals (OMS);
- Review of any existing Dam Emergency Plans (DEP);
- 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.

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

Table ii Summary of Results from Engineering Analyses

Does the dam meet the applicable CDA design criteria?	Yes/No	Comments
Is the current consequences classification considered appropriate for this dam in accordance with the BC Dam Safety Regulation, BC Reg. 40/2016?	No	See Section 6.0
Does 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?	Yes	See Section 8.4
Does the position of the force resultant meet CDA minimum criteria for all loading conditions?	Yes	See Section 8.4
Are maximum stresses (normal, perpendicular) within the limits of CDA acceptance criteria?	Yes	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)?	No	See Section 9.5
Does the dam meet CDA freeboard requirements including the effects of wind and wave action?	No	See Section 9.5

Based on the results of the investigation, 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.

Table iii Dam Safety Review of Shawnigan Lake Dam — Observations, Conclusions and Recommendations

Task	Observations & Conclusions	Recommendations
Background Review	▪ The dam was constructed in 2006 and replaced the original timber structure. No major modifications have been made since construction.	▪ There are no recommendations in this area of the review.
Site Reconnaissance	▪ The inlet channel has a log boom at the outlet of Shawnigan Lake. ▪ The upstream and downstream channels are heavily vegetated. ▪ There are limited security features, with no security alarm or remote monitoring of the dam.	▪ There are no recommendations in this area of the review.
Consequences Classification Review	▪ The dam breach inundation mapping indicates that a total area of approximately 1.03 km^2 would be flooded in the event of a dam breach that takes place during a 100-year storm event. Homes are expected to be affected indicating that there would be population at risk. ▪ Dam breach analysis and inundation mapping results confirmed that Shawnigan Lake Weir should have a consequences classification of “High”. The CDA guidelines recommend an inflow design flood (IDF) for a “High” consequences dam should be 1/3 of the way between a 1,000-year flood and a Probable Maximum Flood (PMF).	▪ Based on the estimated potential loss of life within the dam breach flood inundation area it is recommended that the consequences classification of Shawnigan Lake Weir be increased from “Significant” to “High”. However, any decision to modify the consequences classification rating must be confirmed by the BC MFLNRORD Dam Safety Section (Very High).
Failure Mode Assessment	▪ The plausible failure modes of the dam are; overtopping, as the spillway may become blocked with debris, and overturning, as a result of 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 meets or exceeds the minimum CDA criteria for the normal, flood, earthquake and post-earthquake load combinations. ▪ 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.	▪ There are no recommendations in this area of the review.
Hydrotechnical Assessment	▪ The peak inflow to Shawnigan Lake Weir during the IDF associated with the recommended “High” consequences classification is 408 m^3/s which represents the value that is $1/3^{rd}$ between the 1,000-year flood and the PMF. ▪ The peak inflow to Shawnigan Lake Weir for the current IDF corresponding to a “Significant” consequences classification is between 227 m^3/s (100-year) and 298 m^3/s (1,000-year). ▪ The overshot gate does not have sufficient hydraulic capacity to pass the IDF associated with the “High” consequences classification. ▪ The capacity of the overshot gate is 26.4 m^3/s. The flood routing exercise determined that during the IDF event the dam crest will be overtopped. Given that Shawnigan Lake Weir is concrete it should be able to resist overtopping without serious damage, the abutment wing walls are above the flood elevation and the gate can be operated during the IDF.	▪ Extra spilling capacity should be added to allow for passage of the IDF event. Allowing water to flow around the gate structure, over the north and south abutment aprons, may be appropriate provided measures be taken to ensure that nothing on these aprons would be damaged during a high inflow event and should be further assessed. Additional erosion protection may be necessary (High).
Mechanical and Electrical Review	▪ The dam flow control equipment, which includes a manually controlled overshot gate and gate hoist assembly are in good working condition. Operation of the gate was not observed at the time of the site reconnaissance, however an interview with CVRD staff indicated that the gate had recently been operated and was in good working condition. ▪ Stoplogs and a stoplog frame are available in case of a mechanical failure.	▪ There are no recommendations in this area of the review.
Dam Safety Management	▪ No Operation, Maintenance and Surveillance Manual and no Dam Emergency Plan have been prepared for Shawnigan Lake Weir.	▪ An Operation, Maintenance and Surveillance Manual and a Dam Emergency Plan need to be prepared for Shawnigan Lake Weir (High). ▪ As public interactions with the structure may take place a Public Safety Plan (PSP) should be developed and implemented (High).
Risk Assessment	▪ Damage from a mechanical failure during the peak of a 100-year flood is expected to impact several properties, impact road crossings and impact the Southern Vancouver Island Railway. It is noted however that the likelihood of this event is considered to be low as it requires a random functional failure during the peak of the 100-year flood event.	▪ There are no recommendations in this area of the review.

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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 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
RAIT	Risk Assessment Information Template
Sa(T)	Spectral Accelerations
SCS	Soil Conservation Service
TRIM	Terrain Resource Information Management
UBC	University of British Columbia
US	United States
USCOLD	United States Congress of Large Dams
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 Shawnigan Lake Weir located just north of Shawnigan Lake, BC.

The dam functions as a control for outflows from Shawnigan Lake.

This report presents the technical findings of the Shawnigan Lake Weir 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 Shawnigan Lake Weir. 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.

Shawnigan Lake Weir is catalogued in the BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development (MFLNRORD) Dam Safety Section, Dam File No. D730200-00. The BC MFLNRORD has currently assigned the dam a consequences 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 Shawnigan Lake Weir was undertaken in general accordance with the National Disaster Mitigation Program (NDMP) framework.

1.2 Dam Description and Access

Shawnigan Lake Weir is a gate-controlled weir located along an outlet creek approximately 300 m from the north end of Shawnigan Lake. The weir is located at Map Grid (NAD 83) co-ordinates E453693, N5389834 (Zone 10) and is orientated north to south. The weir impounds approximately 6,300,000 m^3 at the elevation of 116.30 m, with a total watershed area of approximately 69.7 km^2 upstream of the dam.

According to the MFLNRORD dam database Shawnigan Lake Weir is 3.2 m high and 16 m in length. The overshot gate which acts as a weir operates between the minimum and maximum elevations of 115.10 m and 116.30 m respectively and has a length of approximately 6.1 m. The structure is constructed of reinforced concrete with abutments/aprons on either side constructed with a top elevation of 117.00 m. An elevated walkway is located above the main structure to access the main lifting mechanism located at elevation of 119.00 m.

The weir can be accessed from either the right (north) or left (south) abutments of the dam. The directions if travelling via Highway 1 from Duncan are as follows. From Highway 1 turn right onto Cobble Hill Road and follow for 2.6 km. Cobble Hill Road runs into Shawnigan Lake Road while diverging to the left. Continue onto Shawnigan Lake Road and travel an additional 4.1 km to Malta Road. Turn right onto Malta Road. An access gate is located on the left approximately 150 m from the intersection of Malta Road and Shawnigan Lake Road.

Alternatively, the dam can be accessed from the south from Victoria by travelling north on Highway 1 and turning left at Shawnigan Lake Road and travelling 14.1 km north. Within this section Shawnigan Lake Road will briefly diverge to follow the lake shore and one should continue onto Stowood Road which will meet up with Shawnigan Lake Road after 700 m. Turn right to stay on Shawnigan Lake Road at the intersection of Renfrew Road and Shawnigan Lake Road at the north end of Shawnigan Lake. After travelling 350 m, turn left onto Malta Road. The access gate is located on the left, approximately 150 m from the intersection of Malta Road and Shawnigan Lake Road.

Access routes to Shawnigan Lake Weir are shown in Figure 1.2.

1.3 Operation, Maintenance and Surveillance

Operations at the Shawnigan Lake Weir are regulated under several conditional water licences summarized in Table 1.3. The water licences in the table only include licences that involve stream storage.

Table 1.3 Summary of Water Licences on Shawnigan Lake

Licence Type	Licence Number	Purpose	Quantity (m^3/year)	Licence Holder
Conditional	C106569	Stream Storage: Non-Power & Waterworks: Local Provider	1,272,951.36	Cowichan Valley Regional District
Conditional	C116151	Stream Storage: Non-Power & Waterworks: Local Provider	858,502.08	Lidstech Holdings Ltd.
Conditional	C117976	Stream Storage: Non-Power & Waterworks: Local Provider	730,220.16	Mill Bay Waterworks District
Conditional	C120414	Stream Storage: Non-Power & Waterworks: Local Provider	20,352.42	Shawnigan Lake Recreation Association
Conditional	C125528	Stream Storage: Non-Power & Waterworks: Local Provider	6,151.77	British Columbia Conference Property Development Council of the United Church of Canada

Copies of individual water licenses can be found at http://a100.gov.bc.ca/pub/wtrwhse/water_licences.input. An application for stream storage is listed within the database which is not included in this table.

It is understood that the operation and maintenance of the Shawnigan Lake Weir is managed through a joint works agreement by a management committee composed of representatives from three of the licence holders. The management committee from time to time may appoint a person or firm to operate the weir. At the time of the DSR, operation and maintenance was being overseen by Mill Bay Waterworks District.

From discussions with the CVRD it is understood that surveillance (inspection) of the dam is generally undertaken weekly, 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 embankment stability and seepage;
- Hydrotechnical analysis including 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 Principles; 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 risk 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 cause failure of Shawnigan Lake Weir. The NDMP RAIT is discussed in more detail in Section 12.

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 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 – 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:

- Historic aerial photographs;
- Readily available published sources of geological data;
- Past Dam Safety Reviews, inspections and other reports; 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 Shawnigan Lake Weir was constructed in 2006 to replace the original timber weir located approximately five metres upstream and that it functions as a control for outflows from Shawnigan Lake. The weir was funded by the Mill Bay Waterworks district, Shawnigan Village Waterworks and CVRD Shawnigan Lake North Water System, designed by John Braybrooks Engineering and constructed by Bercon Construction Ltd.

To our understanding there have been no major modifications made to the dam since its construction in 2006. The available design and record drawings of the dam are reproduced in Appendix B.

3.3 Historical Aerial Photographs

A review was conducted of available historical aerial photographs of the Shawnigan Lake 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 Shawnigan Lake Area

Year	Aerial Photo No.	Type
2005	ME05442C: 113-107, 54-49	Colour
1998	30BCC98034:165-159, 140-145, 27-29	Colour
1993	30BCC93026:116-111, 133-135, 137-139, 153-156	Black and White
1987	30BCC606:203-208, 141-150, 83-90, 118-114	Black and White

Year	Aerial Photo No.	Type
1980	15BC80078:91-94, 84-81, 70-72	Black and White
1975	BC7764:107-103, 57-61	Black and White
1968	BC7081:201-206, 208	Black and White
1968	BC7080:179-184	Black and White
1962	BC5057:36-33, 14-15	Black and White
1957	BC2087:37-34	Black and White
1951	BC1235:65-62	Black and White
1950	BC1053:93-95	Black and White
1946	BC243:62-65, 88-86	Black and White
1946	BC244:10-13	Black and White
1937	A5644:31-27	Black and White
1937	A5645:61-64, 69-66	Black and White
1937	A5775:6-8	Black and White

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

- Development, roads and the railway exist around the dam prior to 1937, further development takes place between 1937 and the modern day;
- Logging activity is noted in the area around Shawnigan Lake prior to 1937. Activity continues to the modern day;
- A structure located at the outlet of Shawnigan Lake was observed in photos taken in 1937. Function is likely the same as a log boom;
- Significant change in the geometry of the outlet from Shawnigan Lake noted between 1937 and 1946. A section of beach before the bridge at Renfrew Road has been either removed or eroded. Structure in previous comment replaced with a larger boom structure;
- Malta Road to the immediate north of the dam is constructed between 1962 and 1968; and
- No obvious signs of slope instability were noted at the sides of the reservoir.

A review of historical aerial imagery on Google Earth shows that periodic clearing and the development of access roads has occurred in areas of dense forest on the side slopes of the lake between 2004 and 2018. Tree cover around the weir limits the visibility of the structure.

3.4 Geological Setting

The Geological Survey of Canada (GSC) 1:50,000,000 scale map “Geological Map of Canada” indicates that the site is underlain by 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. The bedrock geology for 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 Shawnigan Lake Weir 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. The reference values for Shawnigan Lake Weir are summarized in Table 3.5.a below.

Table 3.5.a Site Class C Design PGA and Sa for Shawnigan Lake Weir, Shawnigan Lake, BC

Annual Exceedance Probability (AEP)	PGA (g)	Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)
1/100 year	0.124	0.288	0.236	0.112	0.058
1/475 year	0.287	0.655	0.575	0.301	0.166
1/1,000 year	0.391	0.889	0.800	0.442	0.254
1/2,475 year	0.541	1.227	1.122	0.657	0.391

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 Shawnigan Lake Weir are summarized in Table 3.5.b.

Table 3.5.b Extrapolated Site Class C Design PGA and Sa for Shawnigan Lake Weir, Shawnigan Lake, BC

Annual Exceedance Probability (AEP)	PGA (g)	Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)
1/5,000 year	0.704	1.602	1.483	0.911	0.564
1/10,000 year	0.917	2.083	1.960	1.263	0.807

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 Shawnigan Lake Dam for the 1/2,475 year event, as summarized in Table 3.5.c below.

Table 3.5.c Design Earthquake Magnitudes for Shawnigan Lake Weir, Shawnigan Lake, BC

Magnitude Contributions	PGA	Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)
Mean	7.49	7.45	7.76	8.20	8.44
Modal	8.95	7.45	8.95	8.95	8.95
84th Percentile	8.95	8.95	8.95	9.05	9.05

3.6 Existing Drawings

A review of the existing documentation for the Shawnigan Lake Weir indicates that there are a series of drawings available for the weir constructed in 2006, namely:

- 2005 – Proposed Shawnigan Creek Weir, Dwg No. 202-00, 202-01, 202-02, 202-03, Revision B As-Built, February 1, 2007, John Braybrooks Engineering.

There are also several series of historical drawings available for the original timber weir, namely:

- 1979 – Shawnigan Lake Reservoir Plan of Reservoir, Dwg No. 4984-8, Sheet 1 of 1.
- 1979 – Shawnigan Lake Reservoir Plan of Reservoir, Dwg No. 4984-8A, Sheets 1 to 3.
- 1981 – Shawnigan Lake Reservoir Plan and Elevation of Dam Including Profile and Cross-Sections of Outlet Channel, Dwg No. 4984-8B, Sheet 1 of 1.
- 1994 – Shawnigan Lake Reservoir Outlet Channel Plan and Profile, Dwg No. 4984-8C, Sheet 1 of 1.

All existing drawings for Shawnigan Lake Weir are presented in Appendix B.

3.7 Instrumentation

Currently the only instrumentation installed on Shawnigan Lake Weir is a leveling gauge located on the left abutment side wall.

3.8 Previous Dam Safety Reviews

It is our understanding that this DSR is the first for this facility and as such no previous DSR is available for review.

4. Site Reconnaissance

4.1 General

Ecora has conducted a site reconnaissance of the Shawnigan Lake Weir as part of a scheduled site inspection on March 28, 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;
- A tour of some of the area in the vicinity of Shawnigan Lake; and
- Staff interviews.

A summary of the site reconnaissance notes is provided as Appendix C.

4.2 Visual Inspection

Ecora inspected the crest, downstream face, spillway structure, downstream toe, and outlet (creek downstream) of the dam. Photographs 1 through 20 show the Shawnigan Lake Weir and the area around the weir at the time of the site visit undertaken on March 28, 2018. 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 weir structure is located downstream of the outlet of the lake;
- Residential properties are located in close proximity to the structure (Photo 4);
- The weir incorporates a fishway on the left side of the structure (Photo 5);
- The flywheel on the gate hoist is locked in place with a lock and chain (Photo 9);
- The hoist can be accessed by a walkway on the right side of the dam and by a ladder on the left side of the dam (Photos 17 & 18);
- Riprap has been placed on the downstream sides of the structure (Photo 19); and
- Some erosion at downstream end, no displacement of riprap noted.

4.3 Structural Observations

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

- Grout pad under gate motor supports showed signs of cracking on the compression side of the support legs (downstream side) (Photo 10).
- Steel guardrail pipe connections showed signs of mild corrosion. Pipe sections were noted to be hot-dip galvanized and the connection pieces were mechanically galvanized, which have less corrosion resistance (Photo 12).
- Organic growth (moss) was noted on the concrete along the downstream concrete wing walls (Photo 14).

No further signs of structural distress or abnormal cracking, movement, or loading were noted at time of site assessment.

4.4 Staff Interviews

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

Key points from this discussion are as follows:

- Log boom on lake, debris can pass over the boom has been a historical issue; and
- Surveillance (inspection) of the dam is undertaken by the CVRD weekly, 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.

The characterization of the dam breach and initial flood hydrograph was conducted by assuming a failure of the gate while it is at its highest operating position during a 100-year flood. While it is noted that it would be unlikely for the gate to be fully closed during a 100-year flood this breach scenario would result in the most conservative dam breach that can be reasonably be expected. For the purpose of this study it is assumed that the gate fails during the peak inflow. A flood hydrograph was developed by routing the flood through the dam using a broad-crested weir equation, taking into consideration that the gate would collapse during the peak inflow.

A summary of the overall dam breach parameters is provided in Table 5.0.a.

Table 5.0.a Summary of Dam Breach Parameters

Shawnigan Lake Weir	
Type of Dam:	Gate controlled concrete weir
Peak Inflow to Reservoir:	226.9 m^3/s
Dam Breach Elevation:	116.73 m
Final Breach Elevation:	115.10 m
Volume of Reservoir Between Breach Elevations:	8,672,000 m^3
Reservoir Surface Elevation at Breach Elevation:	5,562,000 m^2
Length of Gate:	6.1 m
Peak Flow During Breach:	40.8 m^3/s

The resulting dam breach hydrographs were routed using a 2-dimensional volume conservation flood routing model, FLO-2D, with the flood wave simulation run for 24 hours. Topographical inputs for the model were developed from the BC Terrain Resource Information Management (TRIM) Program data, supplemented by LIDAR data provided by the CVRD. It is noted that the LIDAR is largely focused on the western extents of the catchment with major gaps around Mill Bay, which were filled in with TRIM data.

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 5 m × 5 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.

Figures 5.0a-d present the results of the flood extents and maximum depth of flooding, indicating a total inundation area of 1.03 km^2. The flow travels along Shawnigan Creek for approximately 10.1 km where it enters the Saanich Inlet at Mill Bay.

Figures 5.0e-h show the delay time between the initial dam breach and the time at which flooding reaches a depth of 0.6 m.

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

- Transportation Infrastructure:
  - Southern Vancouver Island Railway (610 m & 1.2 km downstream);
  - Hartl Road (1.0 km downstream);
  - Shawnigan Lake Road (2.3 km downstream);
  - Shinrock Road/Stein Way (3.7 km downstream);
  - Cameron Taggart Road (4.9 km downstream); and
  - Campbell Road (5.8 km downstream);
- Residences Located on:
  - Stein Way;
  - Cool Brook Place; and
  - Shawnigan Lake – Mill Bay Road.
- Other Potential Impacts:
  - Loss of the ability to control the level of Shawnigan Lake.

Flood hazard maps are presented on Figures 5.0i-l, 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 Definitions 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 consequences 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”.

These 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 CDA describe five dam failure consequences classifications: “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 consequences classification as reproduced as Table 6.1 below. It is noted that the BC Dam Safety Regulation was amended in 2011 so that consequences 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) (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 consequences classification rating of “Significant” in terms of the BC Dam Safety Regulation (BC Reg. BC Reg. 40/2016). 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 Shawnigan Lake Weir 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

There are several factors that affect the severity of the loss of life consequence, such as depth of flow, velocity and advance warning time within the inundated area.

However, the most important factor in estimating the loss of life (LOL) that would result from dam failure is determining when dam failure warnings would be initiated. The United States Bureau of Reclamation (USBR) has compiled data on dam failure warning times from US dam failures that have occurred since 1960, as well as other notable global dam failures as summarized in Table 6.2.a below.

Table 6.2.a Guidance for Estimating when Dam Failure Warning would be Initiated (Dam Type: Earthfill Dam)

Cause of Failure	Special Considerations	Time of Failure	When Would Dam Failure Warning be Initiated	
			Many Observers at Dam	No Observers at Dam
Overtopping	Drainage area of dam less than 260 km²	Day	0.25 h before dam failure	0.25 h after floodwater reaches populated area
	Drainage area of dam less than 260 km²	Night	0.25 h after dam failure	1 h after floodwater reaches populated area
	Drainage area of dam more than 260 km²	Day	2 h before dam failure	1 h before dam failure
	Drainage area of dam more than 260 km²	Night	1 to 2 h before dam failure	0 to 1 h before dam failure
Piping (full reservoir, normal weather)		Day	1 h before dam failure	0.25 h after floodwater reaches populated area
		Night	0.5 h after dam failure	1.0 h after floodwater reaches populated area
Seismic	Immediate Failure	Day	0.25 h after dam failure	0.25 h after floodwater reaches populated area
		Night	0.5 h after dam failure	1.0 h after floodwater reaches populated area
	Delayed Failure	Day	2 h before dam failure	0.5 h before floodwater reaches populated area
		Night	2 h before dam failure	0.5 h before floodwater reaches populated area

Brown and Graham (1988) developed a series of empirical equations for estimating loss of life due to dam failure from analysis of major dam failures and flash floods. Their study concluded that loss of life is much greater in those areas that receive little warning time compared to those areas that receive 90 minutes or more of warning, and three empirical equations were developed as a function of warning time as summarized in Table 6.2.b below.

Table 6.2.b Loss of Life Empirical Equations

Warning Time	Estimated Loss of Life (LOL)
Less than 15 minutes	LOL = 0.5 x PAR
When warning time is between 15 and 90 minutes	LOL = $PAR^{0.6}$
Greater than 90 minutes	LOL = 0.0002 x PAR

PAR = Population at Risk.

Residences close to the flood wave that were identified on Figures 5.0i-l were evaluated to determine whether the residence would be at risk as part of a dam breach. From analysing these figures, it was determined that five residences are located in an area of high hazard and could be impacted in this breach scenario. A second scenario was run to allow for comparison between the result of the 100-year flood without failure to determine the incremental loss. This second scenario impacted three out of the five residences previously identified. The remaining two residences were found to be in areas of medium hazard rather than high hazard, indicating that these two residences would likely have only minor damage during a 100-year flood but would experience significant damage during the breach scenario. The two properties are located 3.4 and 7.7 km downstream.

Reference to the 2016 Census completed by Statistics Canada indicates an average household size of 2.6 people in the area around Shawnigan Lake. Combining this number with the estimated number of residences impacted by the breach results with a population at risk (PAR) of 5.

Warning time for residences impacted by a breach of Shawnigan Lake Weir is expected to be greater than 90 minutes as the dam exists in a populated area and reference to the time to 0.6 m flood depth figures indicate that the flow will take at least five hours to reach the residences of concern.

Using the corresponding loss of life (LOL) equation it is possible to determine the estimated LOL would be below one person, however, it is noted that a permanent population would be considered to be at risk. Impacting a permanent population would equate to a consequences classification of “High” as per the LOL criteria.

6.2.3 Environmental and Cultural Losses

It is understood that several fish species are present in Shawnigan Lake and in Shawnigan Creek. It is anticipated that in the event of a breach the lake would be drawn down by up to just over a metre which wouldn’t represent a large impact given the size of Shawnigan Lake. Further, reference to the background information indicates that the downstream area already has significant obstacles, such as falls, that limit fish habitat. This suggests that potential loss of minor restorable habitat could occur in the event of a dam breach equating to a consequences classification rating of “Significant” based on environment losses.

6.2.4 Infrastructure and Economic Losses

Notable infrastructure within the downstream flood inundation zones includes multiple residential lots along each side of Shawnigan Creek, multiple road and driveway crossings and the Southern Vancouver Island Railway. It is noted that damage to residential lots is expected to include damage to out buildings, driveway access and other small features on the properties. The flood wave will pass under Highway 1 and it is anticipated that the bridge will have enough hydraulic capacity to pass the flow given the elevation of the bridge deck above the creek.

Neither the BC Dam Safety Regulation 40/2016 (February 29, 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), which provides suggested monetary values for economic loses. Table 6.2.c includes the estimated property losses from the technical bulletin for each consequences classification in equivalent CDA clssification rating.

Table 6.2.c Property Loss Criteria based on Consequences 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

1. 2011 Dollars

The principle impacts from the dam breach would include two railway crossings and seven road crossings likely containing utilities over the length of Shawnigan Creek. Considering this in addition to other impacts, it is likely that the damage from a dam breach would be more than $3 million but less than $30 million. Damage resulting from a gate failure at Shawnigan Lake Weir is anticipated to involve high economic losses affecting infrastructure, some residential buildings, public transportation or services. This would correspond to a consequences classification of “High” as per the BC Dam Safety Regulation (BC Reg. 40/2016).

6.3 Conclusions

Based on the assessment of the three loss criteria summarized in the above sections, it is recommended that the consequences classification rating of Shawnigan Lake Weir be increased to “High”.

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.

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 Hazard and Failures Modes Matrix (HFMM) was utilized in assessing the plausible failure modes for Shawnigan Lake Weir as presented in Appendix D. The likelihood of each hazard and associated failure mode being applicable to Shawnigan Lake Weir 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 Shawnigan Lake Weir, the following failure modes are considered to be plausible:

- **Overtopping** – It is possible that the dam may not have adequate freeboard for passage of the IDF.
- **Overturning Failure** – It is possible that the gravity wall may become unstable when subjected to the design seismic forces.

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 30 MPa; 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. Construction photographs of Shawnigan Lake Weir show the main slab was founded on fresh to slightly weathered basalt with closely spaced to moderately closely spaced joints.

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)
Basalt[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 weir at this time, which would have 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 considers the cross-section immediately to the right of the gate hoist assembly through the north apron slab which is considered the critical section for seepage. The weir geometry was taken from available as-built drawings. Section D-D, Dwg No. 202-01 of the as-built drawings shows upstream and downstream concrete cut-off walls (approximately 200 mm thick) were constructed as part of the north apron slab. The operating reservoir level was assumed to be consistent with that observed at the time of the site reconnaissance which was estimated at 116.4 m. It is noted that the gate was fully raised to elevation 116.3 m during the site reconnaissance. Note that the seepage analysis does not consider flow from concentrated sources such as along cracks in the concrete wall or along the base slab.

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 Shawnigan Lake Weir

Reservoir Level	Calculated Toe Seepage	Figure No.
116.40 m	<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	Sliding safety factor: Friction and cohesion[2] With tests	Sliding safety factor: Friction and cohesion[2] 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 shear resistance of small and medium-sized dams, the use of a cohesive bond in calculating the sliding 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 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 stability analysis conservatively assumes the overshot gate is in its closed position and ignores contribution from the downstream portion of the apron slab due to its limited thickness (≤0.2 m). The geometry of the dam has been taken from the available as-built drawings and the section considered is through the centreline of the overshot gate. The dead load considers the load of the base slab, operating bridge, overshot gate and the body of water on top of the base slab, behind the overshot gate. Because the analysis considers a simplified cross-section, a vertical mass acting at the centre of the base slab has been applied to counteract the mass of what the analysis assumes to be a continuous cross-section in order to represent the average dead load per metre. Zero tensile strength was assumed for the base joint.

The operating reservoir level was assumed to be consistent with that observed at the time of the site reconnaissance of 116.4 m elevation and the flood elevation is consistent with the IDF. The analysis conservatively assumes a downstream water elevation equal to the downstream channel invert level for both operating and flood reservoir levels. No floating debris or silt build-up has been assumed in the analysis of the structure.

Hydrostatic uplift pressures used in the analysis to check global stability conservatively ignores the cut-offs and considers a triangular hydrostatic pressure distribution with 100% of headwater at the upstream face and 100% of tailwater at the downstream face as per the FERC guidelines. For the post-earthquake combination, the hydrostatic pressure equal to 100% of headwater was applied across the entire width of the base slab, which represents a condition where the cut-off at the upstream face is ineffective and the downstream cut-off is 100% effective.

Pseudo-static stability calculations are based on the 1/1,000 year and 1/2,475 year AEP earthquake design ground motion (EDGM) corresponding to “Significant” and “High” consequences classifications respectively, as per the CDA technical bulletin for Seismic Hazard Consideration for Dam Safety (2007).

8.4.3 Load Combinations

The following load combinations were considered to assess the stability of Shawnigan Lake Weir:

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

Ice load conditions have not been considered as this is considered a non-applicable loading condition due to the location of the dam.

8.4.4 Results

The results of the static and pseudo-static CADAM analyses are summarized in Table 8.4.b and Table 8.4.c respectively with the complete CADAM output results provided in Appendix E.

Table 8.4.b Factors of Safety for Static Stability of the Shawnigan Lake Weir

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)	
Usual load	≥1.5	8.5	≥1.2	2.9	Middle 1/3	57.9	41.8
Flood[1]	≥1.1	3.9	≥1.1	1.9	Within base	64.8	59.4
Post-earthquake[2]	≥1.1	6.2	≥1.1	2.1	Within base	54.7	26.6

1 Does not consider the effect of debris impact during a debris flood which is considered a potential risk for Shawnigan Lake Weir.

2 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.

Table 8.4.c Factors of Safety for Pseudo-Static Stability of the Shawnigan Lake Weir

Consequences Classification	AEP EDGM	Calculated Minimum FoS		Position of Resultant		Maximum Normal Stress (kPa)
		Sliding	Overturning	CDA Limit	Position (% of joint)	
Significant	1/1,000	2.0	1.7	Within base	73.2	73.2
High	1/2,475	1.5	1.5	Within base	79.1	90.3

1 As per the CDA guidelines, the earthquake load case is used to establish the post-earthquake condition of the dam.

The results indicate that the sliding factor, position of the resultant and the maximum normal stress meet the CDA acceptance criteria for the normal, flood, earthquake and post-earthquake load combinations.

8.5 Gravity Wall Foundation Review

Based on the site observations and the construction photos which indicate that the dam is founded on fresh to slightly weathered basalt, 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 (state) for each of the load combinations considered in the structural stability review as presented in Table 8.4.b and Table 8.4.c.

8.6 Liquefaction and Post-Seismic Deformation

The dam is 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 the 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. 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 Shawnigan Lake Weir is founded on bedrock, it is considered to have an extremely low susceptibility to piping failure.

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

Shawnigan Lake Weir is located approximately 350 m north of the outlet of Shawnigan Lake and is situated at an elevation of 115.1 m. The drainage area is approximately 69.7 km^2 (6965 ha). The inflows to the reservoir are rainfall and snowmelt within the catchment area. The median basin elevation of the Shawnigan Lake watershed is estimated to be approximately 210 m with a maximum basin elevation of 600 m. The reservoir is surrounded by forested land that is subject to logging causing tree canopy and vegetative cover to vary from year to year, which can cause increased times of concentration and higher runoff coefficients. The boundary of the Shawnigan Lake Weir drainage basin is shown on Figure 9.1.

9.2 Climatic and Snow Course Data

A number of climate stations operated by the Meteorological Service of Canada (MSC) are located within the study region. In view of their proximity to the project site, elevation, and length of record, the stations listed in Table 9.2.a were considered to have climatic data that was useful in determining the climate conditions at the project site. 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)
Victoria Intl A	1018621	19	1965 – 2013	Daily	Yes	14.7
North Cowichan	1015628	45	1982 – 2005	Daily	Yes	18.9
Lake Cowichan	1012055	171	1983 – 2002	Daily	Yes	36.3
Shawnigan Lake	1017230	159	1981 – 2010	Daily	No	1.3

*Intensity – Duration – Frequency data

According to the 1981 to 2010 Climate Normals data on the Environment Canada website, the mean annual precipitation at the Shawnigan Lake Station, which is South of Shawnigan Lake Weir, is 1250.0 mm (1182.0 mm rainfall and 67.9 cm snowfall depth). Rainfall occurs throughout the year with 79% taking place between the months of October and March. Snowfall mainly occurs in winter (November to March). Mean daily temperatures range from 3.1°C in December to 17.9°C in August. The rainfall intensity frequency data for the Victotia Intl A, North Cowichan, and Lake Cowichan stations are shown in Table 9.2.b and the 24-hour rainfall totals for various return periods were obtained from IDF curves available through the MSC. 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 regional climate stations in Table 9.2.a. The data for the 24-hour events coupled with return periods are provided in Table 9.2.b.

Table 9.2.b Rainfall Intensity Frequency Data at Regional Climate Stations

Return Period (Years)	24-Hour Rainfall Total (mm)		
	Victoria Intl A	North Cowichan	Lake Cowichan
2	53.9	57.8	93.6
5	71.0	70.8	110.7
10	82.3	79.4	122.1
25	96.6	90.3	136.4
30	99.0	92.2	138.9
50	107.3	98.5	147.2
100	117.7	106.5	157.6
500	144.5	126.9	184.5

Return Period (Years)	24-Hour Rainfall Total (mm)		
	Victoria Intl A	North Cowichan	Lake Cowichan
1000	155.7	135.5	195.8
5000	181.7	155.3	221.9

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 and its location is shown on Figure 9.2.

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	59.1 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 1050 m higher than Shawnigan Lake Weir, so use of this data is considered conservative.

9.3 Hydrometric Data

There is no long-term streamflow data available within the Shawnigan Lake 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 and station locations are shown on Figure 9.3.

Table 9.3 Regional Hydrometric Stations

Station ID	Station Name	Drainage Area (km²)	Period of Record	Status
08HA016	Bings Creek Near the Mouth	15.5	1961 – 2018	Active
08HA001	Chemainus River Near Westholme	355	1912 – 2018	Active
08HB002	Englishman River Near Parksville	319	1913 – 2018	Active
08HA003	Koksilah River at Cowichan Station	209	1912 – 2018	Active
08HB032	Millstone River at Nanaimo	86.2	1961 – 2018	Active
08HA011	Cowichan River Near Duncan	826	1912 – 2018	Active

9.4 Determination of Inflow Design Flood

9.4.1 General

Based on the review of dam consequences classification in Sections 6.2 and 6.3, Shawnigan Lake Weir should be classified as a “High” consequences 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 “High” consequences dam is 1/3 between the 1,000-year and the Probable Maximum Flood (PMF). 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 1,000-Year Flood

Two methods were used to determine the 1,000-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 and snowmelt as inputs. The regional analysis involves frequency analyses of regional hydrometric data and determination of the relationship between peak discharge and size of drainage area. The following paragraphs further illustrate the methodology and present the results of the two approaches.

Rainfall-Runoff Approach

The 1,000-yr 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 1,000-year rainfall events are included in Table 9.4.a.

Table 9.4.a 1,000-Year 24-Hour Rainfall

Station Name	Elevation (m)	1,000-Year 24-Hour Rainfall (mm)
Victoria Intl A	19	118
North Cowichan	45	107
Lake Cowichan	171	158

A relationship between 1,000-year 24-hour rainfall and elevation was developed using the above results to calculate the corresponding rainfall at the median elevation of the Shawnigan Lake Weir drainage basin. The calculated elevation adjusted 1,000-year 24-hour rainfall on the catchment was estimated to be 207 mm.

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 1,000-year flood, the 1,000-year 24-hour rainfall and the average daily temperature from January to March was used in estimating the daily snowmelt rate. The average value of the mean daily temperature (4.5°C) at Shawnigan Lake Weir was determined by using historical temperatures recorded at the Shawnigan Lake climatic station located approximately 1.43 km away. The average daily snowmelt during a 1,000-year rainfall event was determined to be 28.4 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 235 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 1,000-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 Shawnigan Lake catchment area consists of heavily forested area in good condition with intermittent logging activities taking place within the upper reaches of the catchment. Residential development is also present around the perimeter of the lake. 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 Shawnigan Lake Weir during the 1,000-year return period flood was estimated to be 298 m³/s.

Regional Analysis

A regional hydrological analysis was carried out to provide an alternative estimate of the 1,000-year flood inflow to Shawnigan Lake Weir. 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 1,000-yr flows for each selected hydrometric station. The peak flow estimates for various 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 (m³/s)
10	75.1
30	86.7
50	92.0
100	97.9
200	104
500	112
1000	117
5000	130

1,000-year Flood

The 1,000-year peak flood estimate obtained from the regional analysis is 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 Shawnigan Lake Weir. 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 mostly have too short of period of records for accurate statistical assessment of a 1,000-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 1,000-year peak inflow to Shawnigan Lake Weir was determined as 298 m³/s.

9.4.3 Determination of the Probable Maximum Flood

The probable maximum flood (PMF) was assumed to be the result of the probable maximum precipitation (PMP) combined with snowmelt.

The rainfall-runoff approach was used in determining the probable maximum flood for the Shawnigan Lake Weir. The 24-hour probable maximum precipitation was estimated using the Hershfield method described in the Rainfall Frequency Atlas for Canada (Hogg and Carr, 1985).

$K_{M24} = 19 \times 10^{-0.000965\, X_{24}}$

$X_{PMP} = X_{24} + K_{M24} \times S$

where

K_{M24} = frequency factor for a 24-hour duration rainfall;

X_{24} = mean annual 24-hour extreme rainfall (mm);

X_{PMP} = PMP for a 24-hour duration (mm); and

S = standard deviation for a 24-hour duration rainfall (mm).

The 24-hour PMP determined by this method is 379 mm.

The hydrologic model, HEC-HMS was used to estimate the probable maximum flood. The 24-hour PMP was distributed using the SCS Type Ia rainfall distribution, which included a daily snowmelt rate of 38.3 mm/day, for combining with the 24-hour PMP. The PMF for Shawnigan Lake Weir was determined to be 629 m^3/s.

The PMF estimator for British Columbia (Abrahamson, 2010) was further used as a rough check for the results of the hydrologic model. The following equation for Vancouver Island was applied:

$Q_{PMF} = 17.795 \times A^{0.8156}$

where

Q = probable maximum flood (m^3/s); and

A = area of the watershed (km^2).

The PMF determined using the PMF estimator for British Columbia is approximately 567 m^3/s. However, the PMF estimator is based on very few data points and considerable variability can occur based on the physical characteristics of the catchment. The PMF estimator is not considered to be particularly accurate for this application. Therefore, the hydrologic model result was considered to be more representative and the PMF for Shawnigan Lake is estimated to be 629 m^3/s.

9.4.4 Inflow Design Flood

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

As indicated earlier, the 1000-year flood event and the PMF were determined to be 298 m^3/s and 629 m^3/s, respectively. The CDA guidelines recommend that the IDF for a “High” consequences dam should be 1/3rd between the 1000-year and the PMF (CDA, 2007).

The peak inflow to Shawnigan Lake Weir during the IDF was determined to be 408 m^3/s. The hydrographs for calculated return periods are shown on Figure 9.4.

9.5 Flood Routing and Freeboard Determination

A hydrological model was developed to simulate water levels in Shawnigan Lake 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 volume-area-elevation relationship for Shawnigan Lake was determined utilizing lake bathymetry of Shawnigan Lake completed for the BC Ministry of Environment dated March 1979. Based on this information, Shawnigan Lake has a live storage capacity of 6,270,000 m^3 between the elevations of 115.1 m and 116.3 m. In addition, the structure has a potential storage capacity 10,200,000 m^3 measured between the elevations of 115.1 m and 117.0 m. The lake surface area at the minimum weir crest is estimated at 5,070,000 m^2. The minimum weir crest level is at an elevation of 115.1 m and the maximum is at 116.3 m. The area-elevation-storage relationship is illustrated in Figure 9.5a.

9.5.2 Rating Curve

The as-built drawings for the weir indicate that the gate is 6.1 m in length. The rating curve for the weir was estimated based on the following equation (Smith, 1995):

For broad crested weir flow:

$Q = CLH^{1.5}$

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 concrete dam crest will act also as a weir if the flood overtops the main gated channel. The rating curve developed for the Shawnigan Lake weir is shown on Figure 9.5b. The capacity of the weir in the open position as measured to the dam crest, 117.0 m, is 26.4 m^3/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. Two scenarios for flood routing were considered, namely, with the gate in the open and closed positions. The starting water surface elevation was assumed to be at the weir crest elevation of 115.1 m. The results of the HEC-HMS flood routing during the IDF corresponding to the "High" classification as well as other design flows are summarized in Table 9.5.a and Table 9.5.b. Table 9.5.a is for the gate in the open position and Table 9.5.b is for the gate in the closed position. Figures 9.5c and 9.5d represent the results of the flood routing graphically.

Table 9.5.a Results of Flood Routing for Gate in Open Position

Consequences Classification/ Return Period	Weir Crest (Gate) Elevation (m)	Initial Lake Level (m)	Peak Lake Level (m)	Peak Storage (1000 m³)	Peak Inflow (m³/s)	Peak Outflow (m³/s)	Dam Crest Elevation (m)	Available Freeboard (m)
30-year	115.10	115.10	116.52	7,460	193	16.8	117.00	0.5
50-year	115.10	115.10	116.61	7,950	208	18.4	117.00	0.4
100-year	115.10	115.10	116.72	8,560	227	20.6	117.00	0.3
500-year	115.10	115.10	117.00	10,150	277	26.4	117.00	0.0
1000-year	115.10	115.10	117.12	10,810	298	37.2	117.00	-0.1
5000-year	115.10	115.10	117.38	12,320	348	37.2	117.00	-0.4
High (1/3rd between 1000-year and PMF)	115.10	115.10	117.67	14,060	408	49.3	117.00	-0.7
Very High (2/3rd between 1000-year and PMF	115.10	115.10	118.18	17,100	518	74.4	117.00	-1.2
Extreme (PMF)	115.10	115.10	118.64	20,000	629	101	117.00	-1.6

Table 9.5.b Results of Flood Routing for Gate in Closed Position

Consequences Classification/ Return Period	Weir Crest (Gate) Elevation (m)	Initial Lake Level (m)	Peak Lake Level (m)	Peak Storage (1000 m³)	Peak Inflow (m³/s)	Peak Outflow (m³/s)	Dam Crest Elevation (m)	Available Freeboard (m)
30-year	116.30	116.30	117.57	7,360	193	21.0	117.00	-0.6
50-year	116.30	116.30	117.64	7,810	208	23.6	117.00	-0.6
100-year	116.30	116.30	117.73	8,380	227	27.0	117.00	-0.7
500-year	116.30	116.30	117.95	9,830	277	36.5	117.00	-0.9
1000-year	116.30	116.30	118.04	10,426	298	40.9	117.00	-1.0
5000-year	116.30	116.30	118.26	11,780	348	52.2	117.00	-1.3
High (1/3rd between 1000-year and PMF)	116.30	116.30	118.53	13,350	408	66.5	117.00	-1.5
Very High (2/3rd between 1000-year and PMF	116.30	116.30	118.98	16,110	518	95.4	117.00	-2.0
Extreme (PMF)	116.30	116.30	119.40	18,760	629	124	117.00	-2.4

The results above indicate that for the “High” consequences inflow design flood there is no overtopping of the dam. The lake level response from the IDF for the open and closed scenarios are shown in Figures 9.5e and 9.5f. Peak outflows would reach 66.5 m³/s during the “High” consequences IDF. Note that the “Significant”, “Very High” and “Extreme” results are included for comparison only, as it is considered that “High” is the appropriate classification.

9.5.4 Freeboard Assessment

The flood routing exercise described above determined that during a 1,000-year event the dam crest will be overtopped. It is noted that while the north and south abutments will be overtopped water would continue to flow through the structure at an elevation below that of the walkway (Elevation 118.80 m) and below that of the left-wing wall (Elevation 117.77 m) when the gate is open.

Wind and wave analysis were not undertaken for Shawnigan Lake Weir as the concrete structure is considered non-erodible and thus not susceptible to erosion in the event of overtopping. In addition, the enclosed nature of the weir location will also limit the ability for the structure to be affected by waves, as waves from the lake are anticipated to dissipate within the creek channel before reaching the weir.

The CDA Guidelines (2007) indicate that concrete dams may be permitted to have the freeboard requirement reduced or overtopping permitted provided that the integrity of the dam, its abutments and any ancillary structures is not compromised. In the event of overtopping of the lower concrete platform, access to the control structure will be maintained under all conditions assuming the gate is in the open position. If the gate is in the closed position it is possible that access to the control structure may be hindered in the “Very High” event.

10. Mechanical and Electrical Review

The following section provides a summary of the inspection completed to review the mechanical flow control equipment for Shawnigan Lake Weir. It is our understanding that there are no electrical components to review.

10.1 General

Mechanical and electrical components on any dam must be maintained in such condition that allows the operator to be able to discharge or retain water on demand and to allow for safe operation under normal or abnormal conditions. The intent of this review was to review any changes in loading conditions between the weir construction in 2006 and this current DSR and their impact on the safe operation of Shawnigan Lake Weir.

The current review for Shawnigan Lake Weir is based on information available from data and observations made during site reconnaissance, discussions with the operator, available background information and Ecora’s engineering judgement. Mechanical components of the dam include:

- An overshot gate – 6.10 m wide, 1.52 m high;
- A gate hoist assembly comprising a flywheel (for manual operation of the weir gate); and,
- Stoplogs and stoplog frame.

The overshot gate for Shawnigan Lake Weir is operated manually by a gate hoist and frame assembly comprising a flywheel and two steel cables, one connected to each end of the gate. The gate hoist flywheel is located on the access bridge at the northern end of the gate and is locked by a chain and padlock. Stoplogs and a stoplog frame are available in the case of a mechanical failure.

10.2 Inspections and Maintenance

As mentioned earlier, it is understood that surveillance (inspection) of the dam is generally undertaken weekly, weather permitting. Maintenance on the dam equipment should follow procedures specified in operating manuals supplied by equipment manufacturers. Critical spare parts should be kept in inventory to allow for quick maintenance in the event of an equipment failure.

Dam operators should have contingency plans to be used in the event mechanical equipment malfunctions or fails. The updated Operation, Maintenance and Surveillance Plan (OMS) and the Dam Emergency Plan (DEP) outline contingency plans for the operation of key equipment and procedures to follow during an emergency. Key information includes:

- Operation of the dam during a mechanical equipment failure;

- Procedure on addressing a damaged overshot gate (stoplog installation procedure); and,
- Operation of the dam during an emergency.

These plans identify potential problems that could occur during an unforeseen event, operation and testing and are included in the updated Operation, Maintenance and Surveillance Plan (OMS) and the Dam Emergency Plan (DEP).

Simple maintenance items such as greasing bearings and general up-keep should be completed by the person or firm appointed by the management committee. Maintenance and surveillance records should be circulated to the management committee and kept as supporting documents for reporting to the Province.

10.3 Flow Control Equipment

10.3.1 Testing

All flow control that is required for the dam to pass the inflow design flood should be periodically tested. The testing program should demonstrate that the equipment is in good working order and confirm the equipment can pass the required flows.

As per the CDA Technical Bulletin on Flow Control for Dam Safety (2007), there are two categories of flow control test:

- A functional test is intended to verify that flow control equipment is in operable condition. The test is a documented operation of the device under normal operating condition. For regularly used equipment it could be part of normal operation. For rarely used equipment it would be a specific test. This type of test often is done annually.
- A full flow test should be done periodically. It may, for example, be part of the Dam Safety Review and done on a 5, 7- or 10-year schedule. The test is intended to verify the design capability of equipment. It is a full flow test where a gate, log sluice or valve would be fully opened so that the device and its auxiliary equipment operate close to their design loads.

As the discharge from Shawnigan Lake Weir is controlled exclusively through the use of an overshot gate, the flow control is in effect tested regularly as part of regular operation fulfilling the requirements of the functional test. Ecora representatives did not observe gate operation at the time of the site reconnaissance, however anecdotal evidence from an interview with CVRD staff indicated that the gate had recently been operated and was in good working condition.

As per the CDA Technical Bulletin on Flow Control for Dam Safety (2007), an equipment testing program should include the following elements:

- Testing and operation activities should be documented and reported to the dam owner.
- Testing and flows through the waterways should be conducted in accordance with all safety and environmental regulations and standards.
- Any observed equipment test failures and deficiencies should be documented, evaluated and corrected as specified in the OMS manual.
- Testing should be incorporated into training programs for both normal and emergency situations.

- Contingency plans should be available to manage unplanned events that could occur during testing. These should be provided in the OMS manual and DEP.

10.3.2 Safety

Operation and maintenance of flow control equipment should be able to be done in a manner that ensures both operator and public safety. To that end, flow control equipment is located on the restricted access elevated walkway with the flywheel locked by a chain and padlock. The upper walkway is elevated to help isolate operating equipment from high water levels. Access to the elevated walkway from the right abutment is provided by stairs and access from the left abutment is provided by ladder rungs on the dam structure. Railings are in place on all walkways. Video surveillance is not available at the dam.

10.3.3 Current Condition

It is our understanding that there have been no major modifications to the weir structure and that the overshot gate and gate hoist assembly have operated since the completion of construction in 2006.

Some minor corrosion of the steel cables and the paint of the gate hoist frame, and cracking of the concrete where the gate hoist frame is bolted to the access bridge was noted during the site reconnaissance, however overall the weir appeared to be in good condition.

11. Dam Safety Management System

11.1 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 Operation, 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 11.1. Ecora has assessed the dam safety management system in place for the Shawnigan Lake Dam and the results of this assessment are presented in this section.

11.2 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 Shawnigan Lake Weir does not have an Operation, Maintenance and Surveillance Manual.

11.3 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 Shawnigan Lake Weir does not have a DEP.

11.4 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 Shawnigan Lake Weir 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 given that Shawnigan Lake is utilised recreationally, public interaction with the dam is anticipated and therefore a PSP should be developed for this facility.

11.5 Dam Safety Expectations Assessment

11.5.1 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 Shawnigan Lake Weir using the sample check sheet prepared by the MFLNRORD as presented in Appendix F.

The Dam Safety Expectations are divided into five categories:

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

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

11.5.2 Dam Safety Analysis

There are two actual deficiencies, namely:

- The capacity of the overshot gate in the structure will be exceeded during the IDF
- The aprons/abutments on the left and right side of the gate bay will be overtopped during the IDF event

11.5.3 Operation, Maintenance and Surveillance

There are no deficiencies in this category.

There are seventeen non-conformances in this category, eight of which could be resolved by preparing an OMS Manual and DEP for this facility. The remaining non-conformances can be resolved by improving or maintaining documentation of training, maintenance and testing of equipment.

11.5.4 Emergency Preparedness

There are ten non-conformances in this category which all could be resolved by preparing an OMS Manual and DEP for this facility and undertaking an emergency exercise and training of staff involved.

11.5.5 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.

11.5.6 Dam Safety Management System

There are seven non-conformances, all of which could be addressed by preparing an OMS Manual and DEP for this facility.

12. Risk Assessment

12.1 General

As part of the DSR, the NDMP Risk Assessment Information Template (RAIT) was completed by Ecora in accordance with NDMP and has been attached in Appendix G. 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.

12.2 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 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.

12.3 Risk Assessment Summary

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

- The primary risk event is a breach of Shawnigan Lake Weir due to a mechanical issue that results with the sudden opening of the gate during a 100-year flood event.
- In the event of a dam breach, significant damage to public infrastructure would occur including damage to the following:
  - Southern Vancouver Island Railway.
  - Several road crossings including:
    - Hartl Road;
    - Shawnigan Lake Road;
    - Shinrock Road;
    - Cameron Taggart Road; and
    - Campbell Road;
  - Some damage to residential properties.
- The event would most likely occur during the winter months when the lake levels are at their highest.

The likelihood of this scenario is considered to be low as it requires the gate to be left in the closed position prior to a 100-year inflow event and for the gate to fail during the peak of this event.

12.4 Confidence Levels

The risk assessment process requires confidence levels to be defined, particularly since confidence levels can vary considerable depending on the quality of available data, availability of relevant expertise to inform 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 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.

13. Observations and Conclusions

The conclusions reached during the DSR of Shawnigan Lake Weir are presented as follows for each area of review:

13.1 Background Review

- The dam was constructed in 2006 and replaced the original timber structure. No major modifications have been made since construction.

13.2 Site Reconnaissance

- The inlet channel has a log boom at the outlet of Shawnigan Lake.
- The upstream and downstream channels are heavily vegetated.
- There are limited security features, with no security alarm or remote monitoring of the dam.

13.3 Consequences Classification Review

- The dam breach inundation mapping indicates that a total area of approximately 1.03 km^2 would be flooded in the event of a dam breach that takes place during a 100-year storm event. Homes are expected to be affected indicating that there would be population at risk.
- Dam breach analysis and inundation mapping results confirmed that Shawnigan Lake Weir should have a consequences classification of “High”. The CDA guidelines recommend an inflow design flood (IDF) for a “High” consequences dam should be 1/3 of the way between a 1,000-year flood and a Probable Maximum Flood (PMF).

13.4 Failure Mode Assessment

- The plausible failure modes of the dam are; overtopping, as the spillway may become blocked with debris, and overturning, as a result of the design flood or seismic forces.

13.5 Geotechnical and Structural Assessment

- Results of the stability assessment indicate that the dam meets or exceeds the minimum CDA criteria for the normal, flood, earthquake and post-earthquake load combinations.
- 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.

13.6 Hydrotechnical Assessment

- The peak inflow to Shawnigan Lake Weir during the IDF associated with the recommended “High” consequences classification is 408 m^3/s which represents the value that is 1/3rd between the 1,000-year flood and the PMF.
- The peak inflow to Shawnigan Lake Weir for the current IDF corresponding to a “Significant” consequences classification is between 227 m^3/s (100-year) and 298 m^3/s (1,000-year).
- The overshot gate does not have sufficient hydraulic capacity to pass the IDF associated with the “High” consequences classification.
- The capacity of the overshot gate is 26.4 m^3/s. The flood routing exercise determined that during the IDF event the dam crest will be overtopped. Given that Shawnigan Lake Weir is concrete it should be able to resist overtopping without serious damage, the abutment wing walls are above the flood elevation and the gate can be operated during the IDF.

13.7 Mechanical and Electrical Review

- The dam flow control equipment, which includes a manually controlled overshot gate and gate hoist assembly are in good working condition. Operation of the gate was not observed at the time of the site reconnaissance, however an interview with CVRD staff indicated that the gate had recently been operated and was in good working condition.
- Stoplogs and a stoplog frame are available in case of a mechanical failure.

13.8 Dam Safety Management

- No Operation, Maintenance and Surveillance Manual and no Dam Emergency Plan have been prepared for Shawnigan Lake Weir.

13.9 Risk Assessment

- Damage from a mechanical failure during the peak of a 100-year flood is expected to impact several properties, impact road crossings and impact the Southern Vancouver Island Railway. It is noted however that the likelihood of this event is considered to be low as it requires a random functional failure during the peak of the 100-year flood event.

14. Recommendations

The recommendations that have been developed during this DSR of Shawnigan Lake Weir 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.

14.1 Background Review

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

14.2 Site Reconnaissance

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

14.3 Consequences Classification

- Based on the estimated potential loss of life within the dam breach flood inundation area it is recommended that the consequences classification of Shawnigan Lake Weir be increased from “Significant” to “High”. However, any decision to modify the consequences classification rating must be confirmed by the BC MFLNRORD Dam Safety Section (Very High).

14.4 Failure Mode Assessment

- There are no recommendations in this area of review.

14.5 Geotechnical and Structural Assessment

- There are no recommendations in this area of review.

14.6 Hydrotechnical Assessment

- Extra spilling capacity should be added to allow for passage of the IDF event. Allowing water to flow around the gate structure, over the north and south abutment aprons, may be appropriate provided measures be taken to ensure that nothing on these aprons would be damaged during a high inflow event and should be further assessed. Additional erosion protection may be necessary (High).

14.7 Mechanical and Electrical Review

- There are no recommendations in this area of review.

14.8 Dam Safety Management

- An Operation, Maintenance and Surveillance Manual and a Dam Emergency Plan need to be prepared for Shawnigan Lake Weir (High).
- As public interactions with the structure may take place a Public Safety Plan (PSP) should be developed and implemented (High).

14.9 Risk Assessment

- There are no recommendations in this area of review.

15. Dam Safety Review Assurance Statement

In accordance 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 H.

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Figures

SITE LOCATION & ACCESS ROUTE

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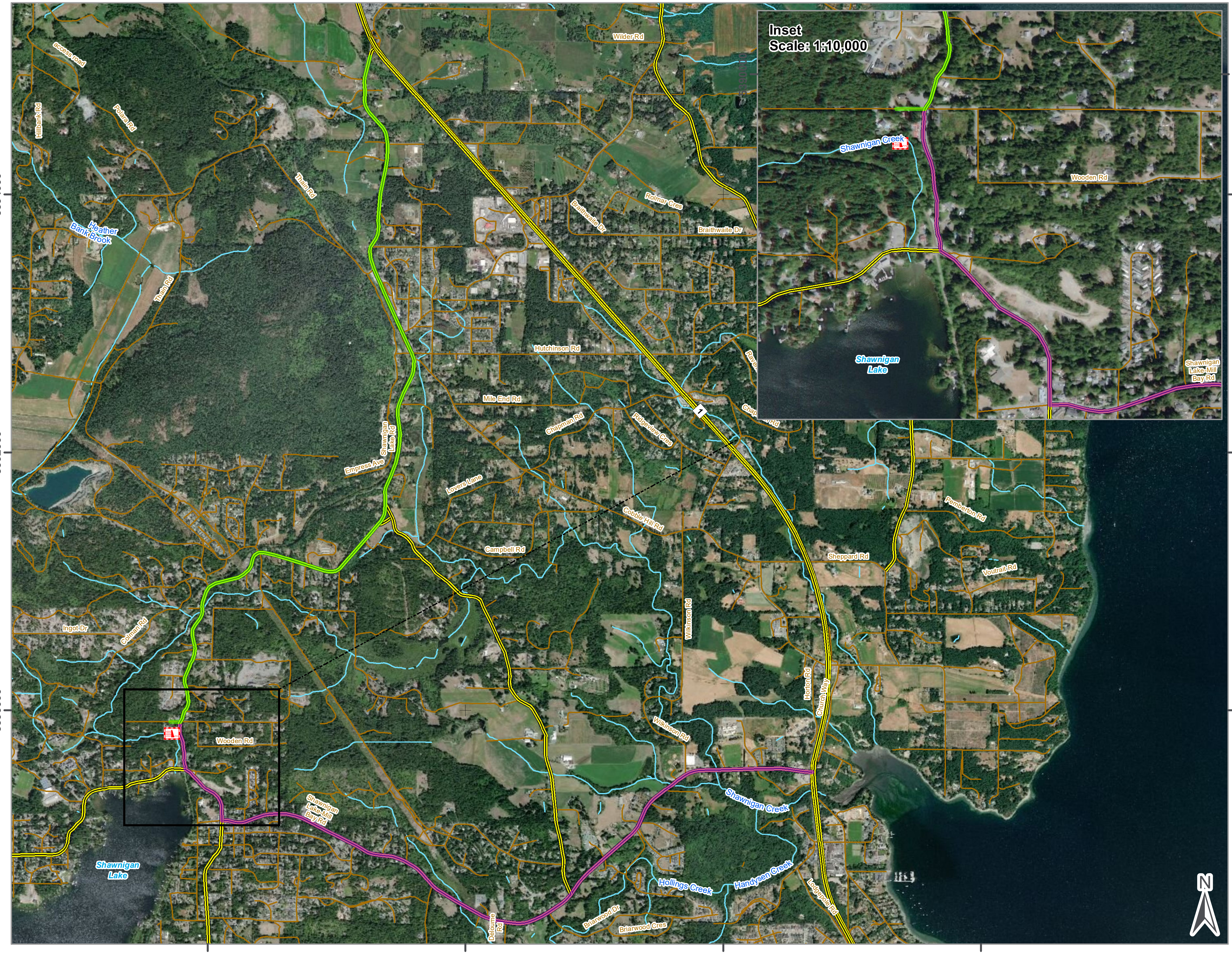
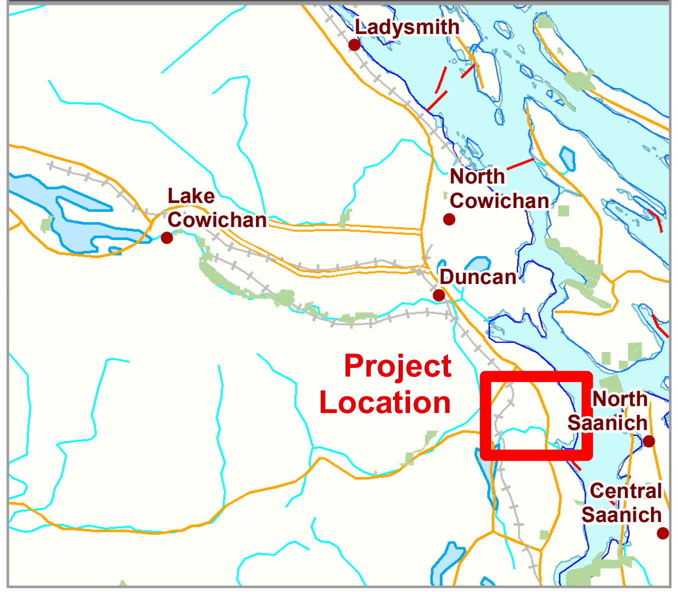


DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

Legend

- Shawnigan Lake Weir (1900 Malta Road)
- Fresh Water Atlas Streams
- Digital Atlas Roads
- Highways
- Primary Access (9 min, 6.8km) - From 3965 Cobble Hill Road
- Secondary Access (9 min, 6.4km) - From 855 Shawnigan-Mill Bay Road

LOCATION MAP



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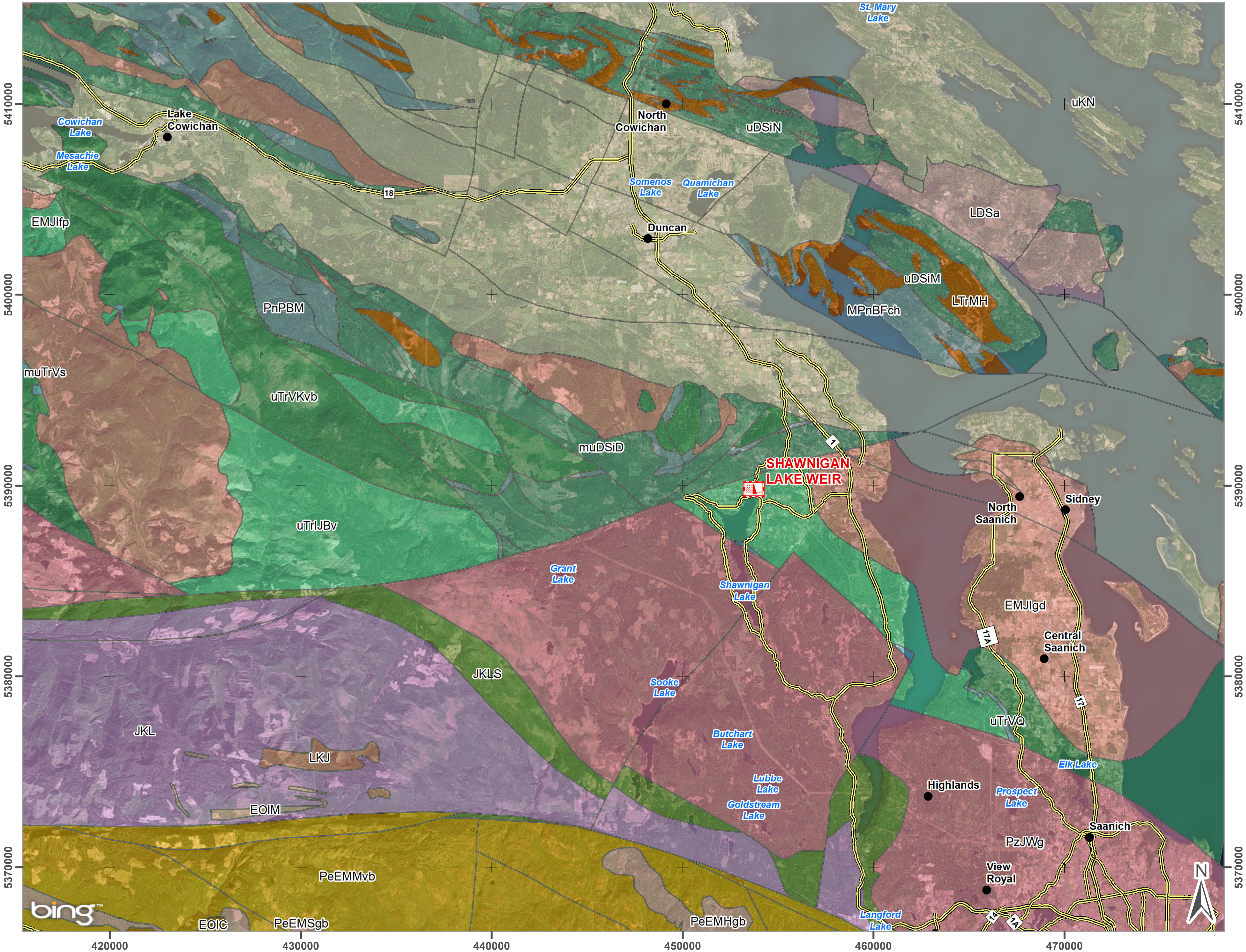
0 1 2 KM

Project No.: GK-18-020-CVD
Date: 2019/02/27
Client: Cowichan Valley Regional District
Drawn: MT Check: AG
NAD 1983 UTM Zone 10N

Figure 1.2

BEDROCK GEOLOGY



DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, 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).
- EOIC
- EOIM - Quartz diorite, feldspar-hornblende dacite porphyry (includes volcanic breccias of the Mount Washington area) (42 - 32 Ma) (92F, L).
- JKL - Slate, phyllite, quartz-biotite schist, quartz-feldspar-garnet-biotite schist, metagreywacke, meta-arkose, minor interbedded metavolcanics (92B, C).
- JKLS - Metabasalt, metarhyolite, chlorite schist, ribbon chert, cherty argillite (92B, C).
- LDSa - Granodiorite, feldspar porphyry, quartz-feldspar porphyry, coeval with McLaughlin Ridge Formation (365 -360 Ma) (92B).
- LKJ
- 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
- PeEMHgb
- PeEMMvb
- PeEMSgb
- PnPBM - Massive crinoidal limestone, bedded calcirudite and calcarenite, chert, cherty argillite and siltstone, marble (Upper Pennsylvanian to Lower Permian) (92B, C, F)
- PzJWg - Quartz diorite, tonalite, hornblende-plagioclase gneiss, quartz-feldspar gneiss, amphibolite, diorite, agmatite, gabbro, marble and metasediments. Includes the WARK-COLQUITZ COMPLEX (92B, C, F, E, L):
- muDSiD - Pillowed and massive basalt flows, monolithic basalt breccia and pillow breccia, chert, jasper and cherty tuff, felsic tuffs, massive dacite and rhyolite, magnetite-hematite-chert iron formation (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).
- uTrVQ - Thick bedded, grey to black, micritic and stylolitic limestone, medium to thin bedded limestone and calcareous siltstone, minor oolitic and bioclastic limestone, garnet-epidote-diopside skarn. (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

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0 2.5 5 7.5 10 km

Project No.: GK-18-020-CVD	Date: 2019/01/31
Client: Cowichan Valley Regional District	Drawn: TJM Check: AG
NAD 1983 UTM Zone 10N	**Figure 3.4**

EXTENT OF INUNDATION & MAXIMUM FLOW DEPTH

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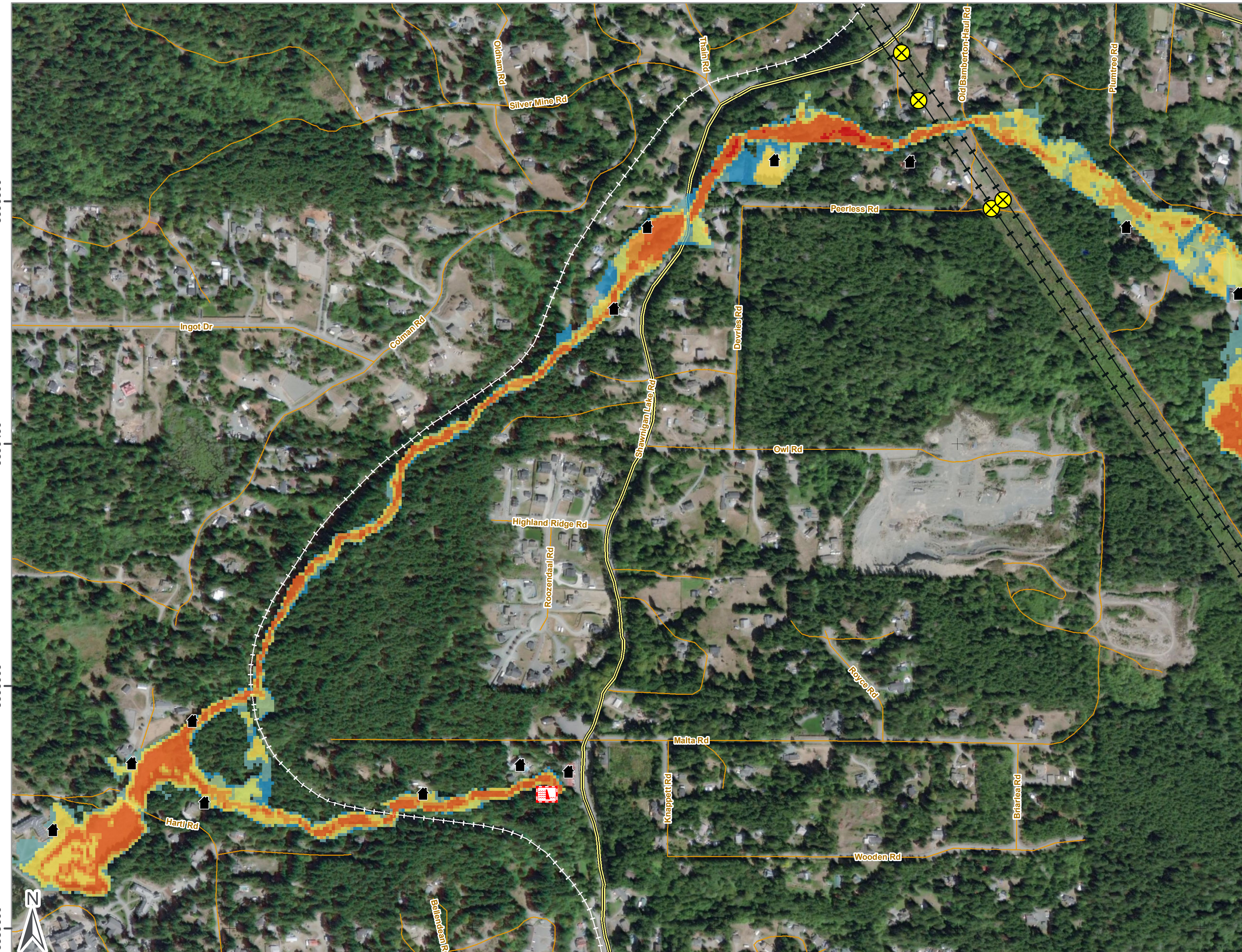


DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

Legend

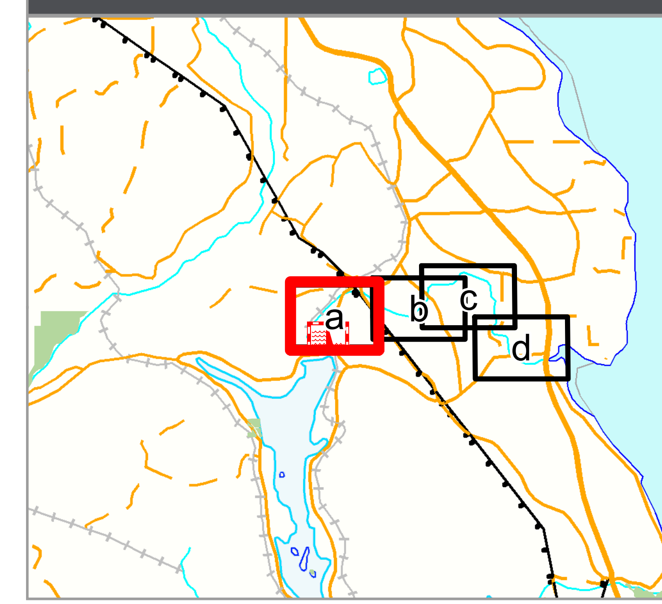
- Shawnigan Lake Weir Location
- Houses
- Transmission Towers
- Highways
- Digital Atlas Roads
- Transmission Lines
- Railways

Maximum Flow Depth (m)

- 0.000 - 0.250
- 0.251 - 0.500
- 0.501 - 0.750
- 0.751 - 1.000
- 1.001 - 1.500
- 1.501 - 2.000
- 2.001 - 5.000
- 5.001 - 9.000

Total Area of Inundation = 1.03km^2

LOCATION MAP



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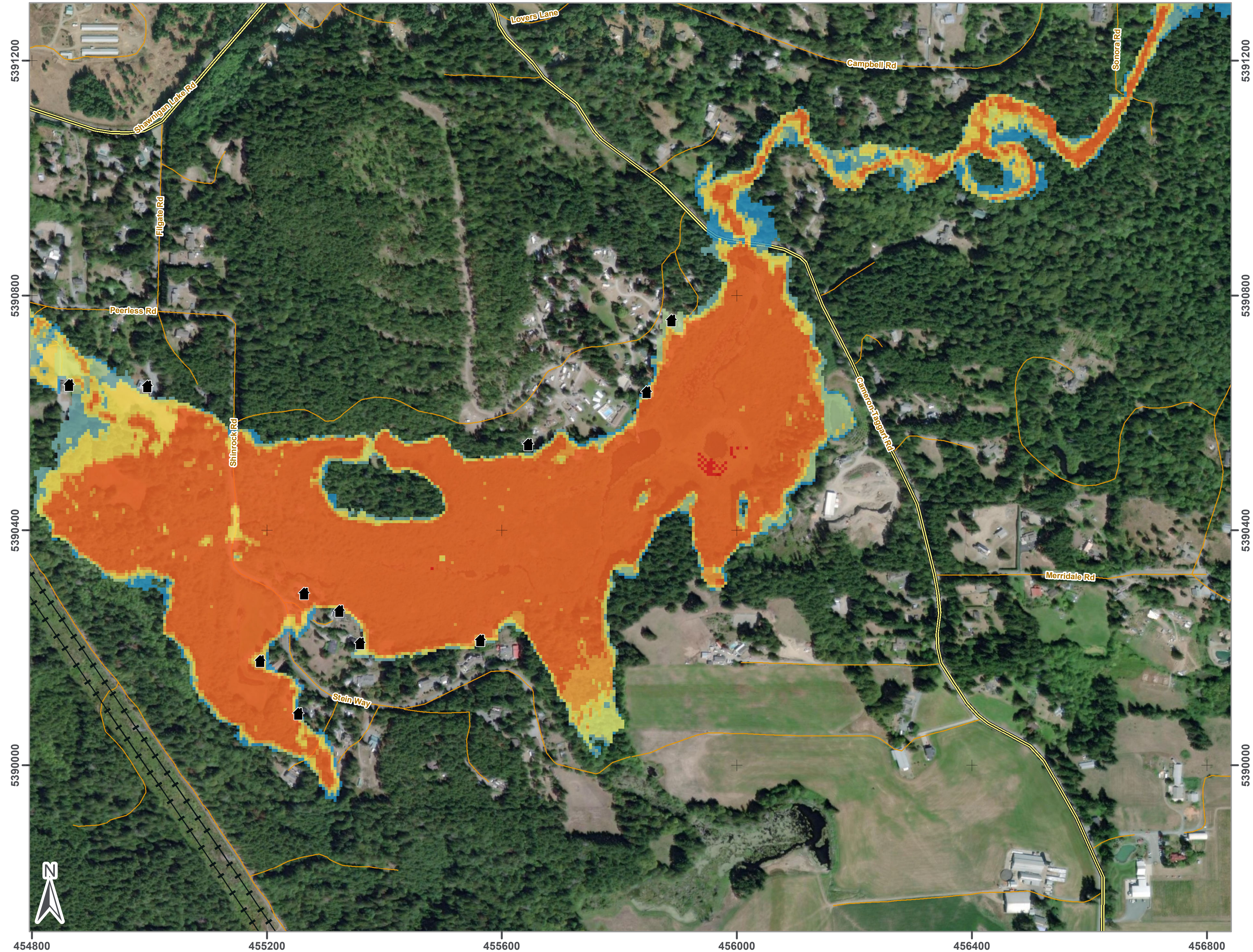
0 200 400 Meters

Project No.: GK-18-020-CVD
Date: 2019/01/28
Client: Cowichan Valley Regional District
Drawn: MT Check: BF
NAD 1983 UTM Zone 10N

Figure 7.0a

EXTENT OF INUNDATION & MAXIMUM FLOW DEPTH



DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

Legend

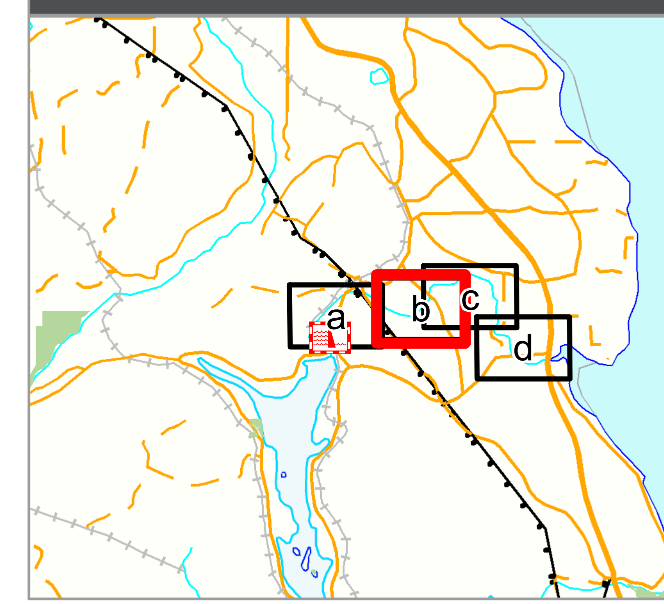
- Shawnigan Lake Weir Location
- Houses
- Transmission Towers
- Highways
- Digital Atlas Roads
- Transmission Lines
- Railways

Maximum Flow Depth (m)

- 0.000 - 0.250
- 0.251 - 0.500
- 0.501 - 0.750
- 0.751 - 1.000
- 1.001 - 1.500
- 1.501 - 2.000
- 2.001 - 5.000
- 5.001 - 9.000

Total Area of Inundation = 1.03km²

LOCATION MAP



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0 200 400 Meters

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

Date: 2019/01/28
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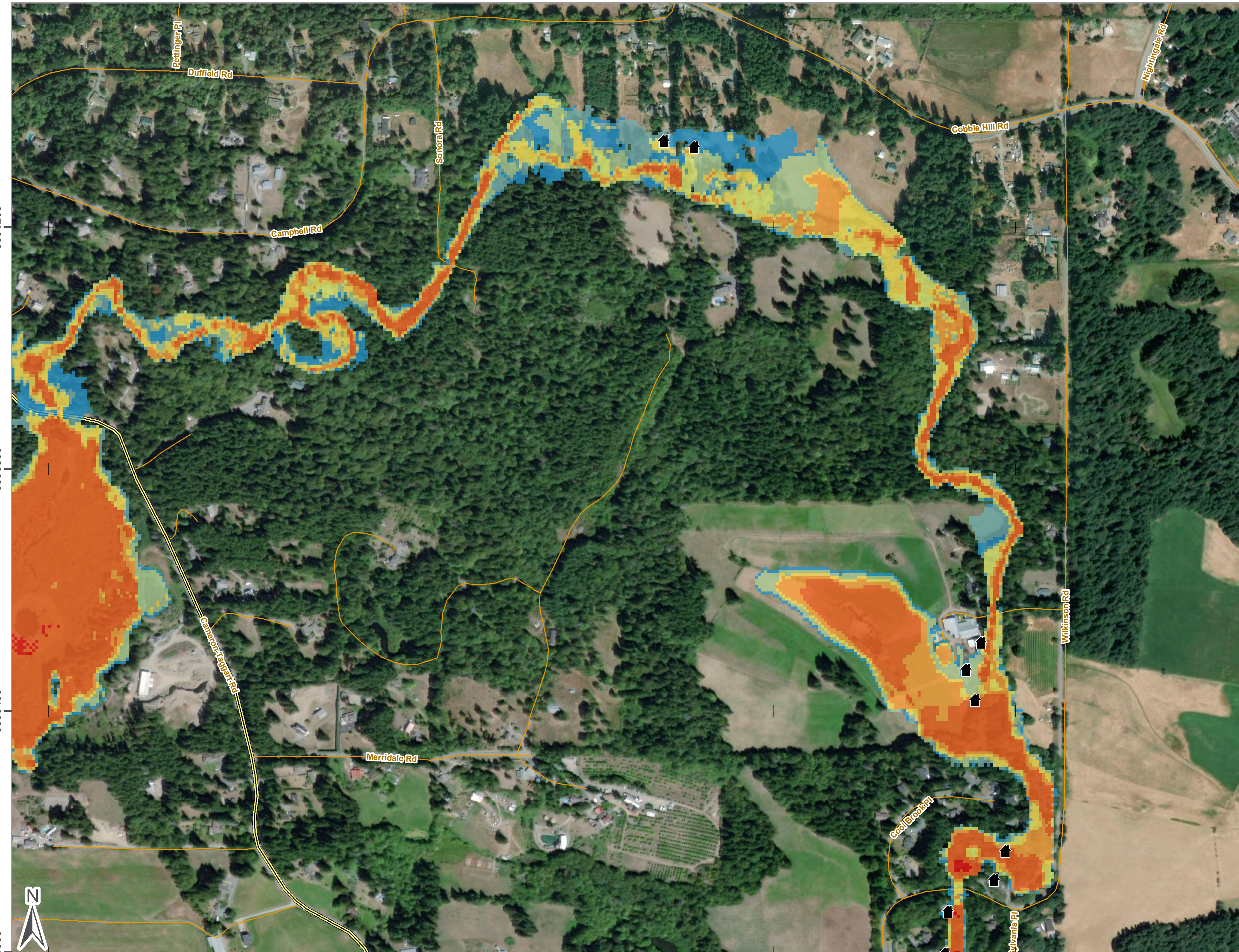
Figure 7.0b

EXTENT OF INUNDATION & MAXIMUM FLOW DEPTH



DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

Legend

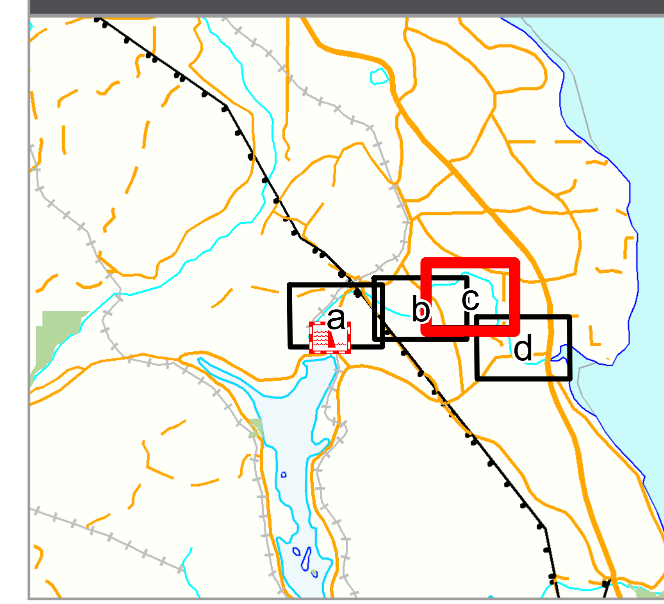
- Shawnigan Lake Weir Location
- Houses
- Transmission Towers
- Highways
- Digital Atlas Roads
- Transmission Lines
- Railways

Maximum Flow Depth (m)

- 0.000 - 0.250
- 0.251 - 0.500
- 0.501 - 0.750
- 0.751 - 1.000
- 1.001 - 1.500
- 1.501 - 2.000
- 2.001 - 5.000
- 5.001 - 9.000

Total Area of Inundation = 1.03km^2

LOCATION MAP



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0 200 400 Meters

Project No.: GK-18-020-CVD
Date: 2019/01/28
Client: Cowichan Valley Regional District
Drawn: MT Check: BF
NAD 1983 UTM Zone 10N

Figure 7.0c

EXTENT OF INUNDATION & MAXIMUM FLOW DEPTH

ecora

DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

Legend

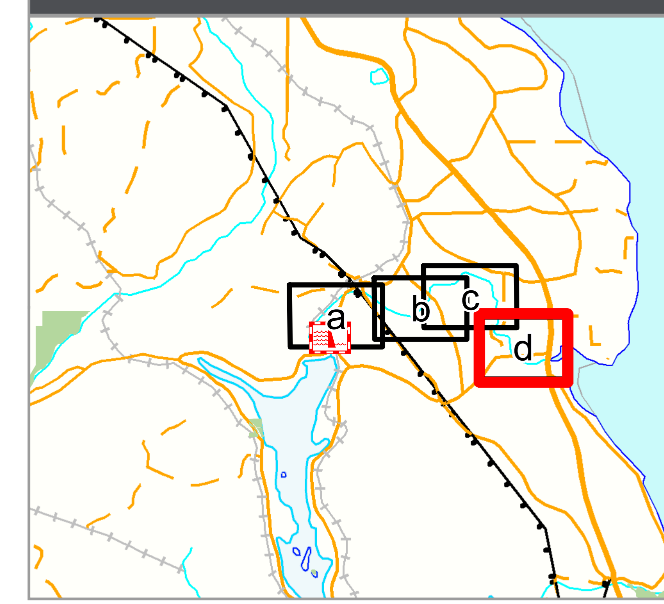
- Shawnigan Lake Weir Location
- Houses
- Transmission Towers
- Highways
- Digital Atlas Roads
- Transmission Lines
- Railways

Maximum Flow Depth (m)

- 0.000 - 0.250
- 0.251 - 0.500
- 0.501 - 0.750
- 0.751 - 1.000
- 1.001 - 1.500
- 1.501 - 2.000
- 2.001 - 5.000
- 5.001 - 9.000

Total Area of Inundation = 1.03km^2

LOCATION MAP



1:6,500

0 200 400 Meters

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

Date: 2019/01/28
Drawn: MT Check: BF

Figure 7.0d

TIME (HRS) FOR 0.6m FLOW DEPTH

ecora

DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

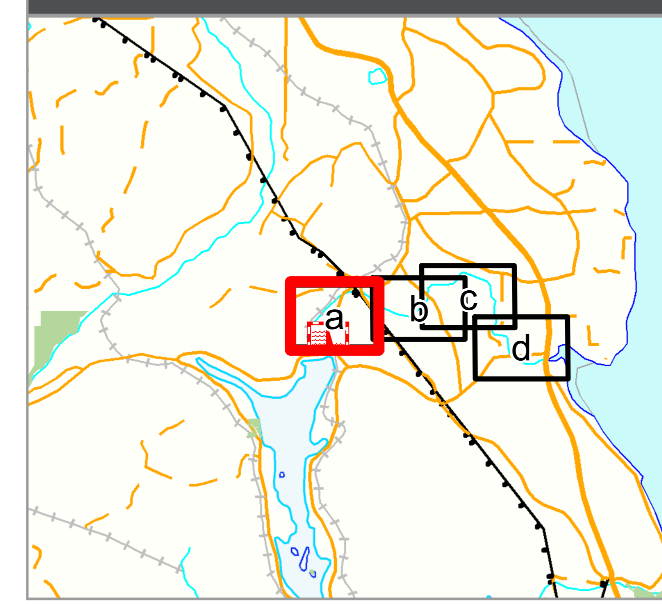
Legend

- Shawnigan Lake Weir Location
- Houses
- Transmission Towers
- Highways
- Digital Atlas Roads
- Transmission Lines
- Railways

Time (hrs) for 0.6m Flow Depth

- 0.001 - 1.000
- 1.001 - 2.000
- 2.001 - 3.000
- 3.001 - 4.000
- 4.001 - 5.000
- 5.001 - 10.000
- 10.001 - 15.000
- 15.001 - 20.000
- 20.001 - 25.000

LOCATION MAP



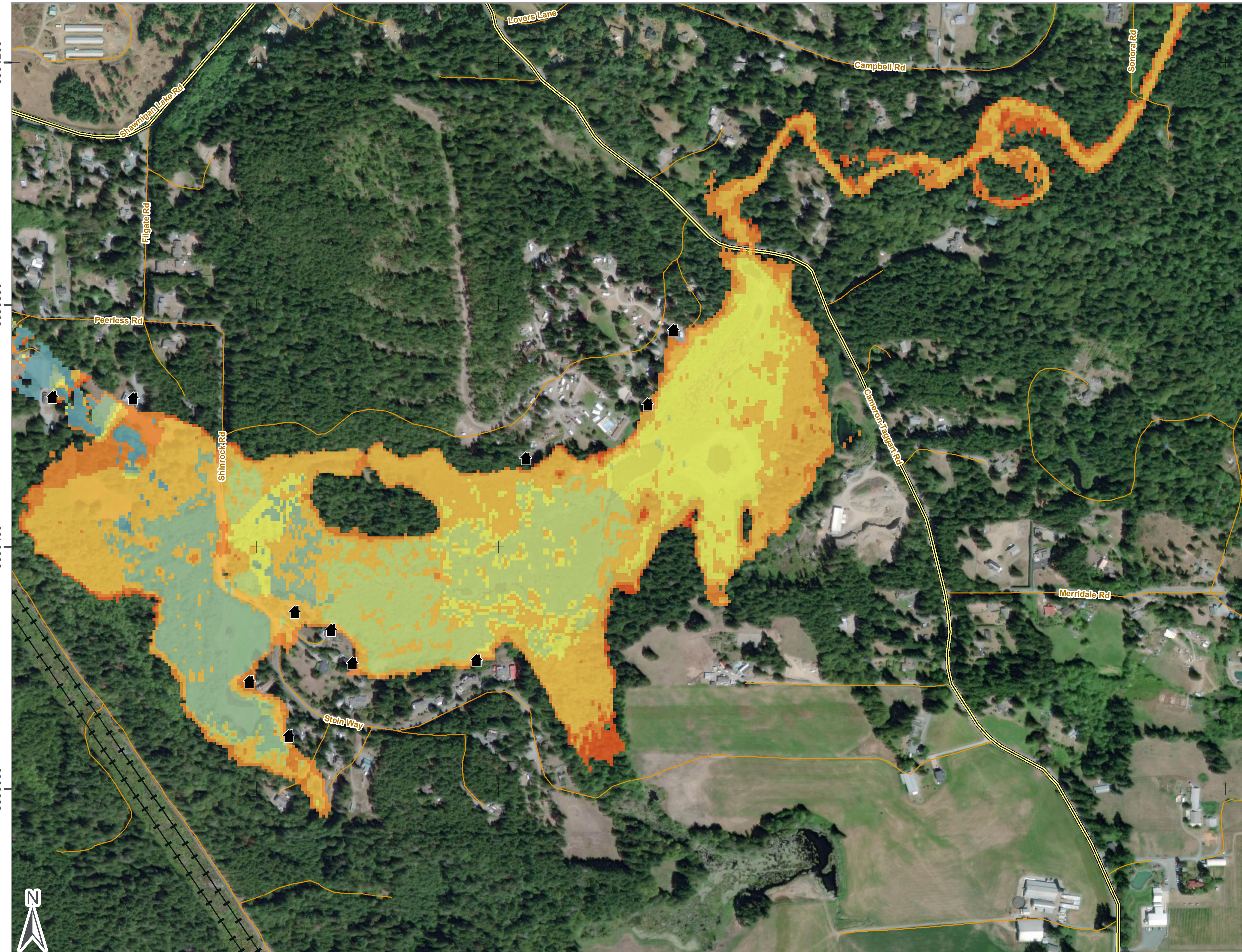
1:6,500

Meters: 0 200 400

Project No.: GK-18-020-CVD
Date: 2019/01/28
Client: Cowichan Valley Regional District
Drawn: MT Check: BF
NAD 1983 UTM Zone 10N

Figure 6.0a

TIME (HRS) FOR 0.6m FLOW DEPTH



DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

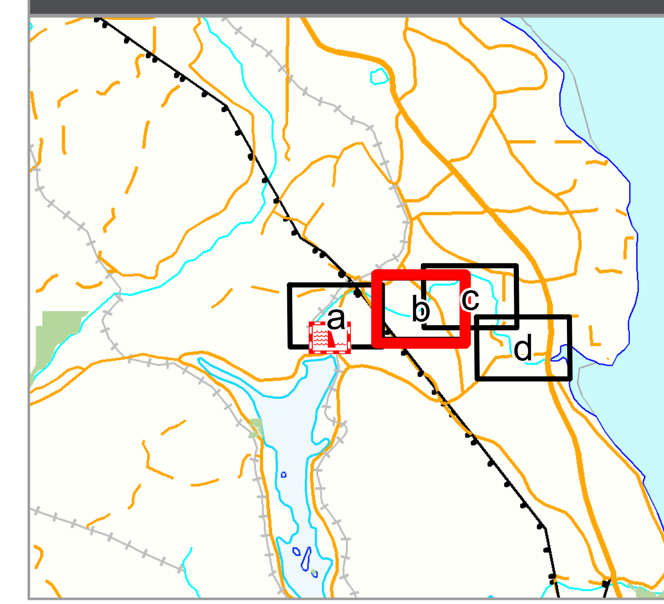
Legend

- Shawnigan Lake Weir Location
- Houses
- Transmission Towers
- Highways
- Digital Atlas Roads
- Transmission Lines
- Railways

Time (hrs) for 0.6m Flow Depth

- 0.001 - 1.000
- 1.001 - 2.000
- 2.001 - 3.000
- 3.001 - 4.000
- 4.001 - 5.000
- 5.001 - 10.000
- 10.001 - 15.000
- 15.001 - 20.000
- 20.001 - 25.000

LOCATION MAP



1:6,500

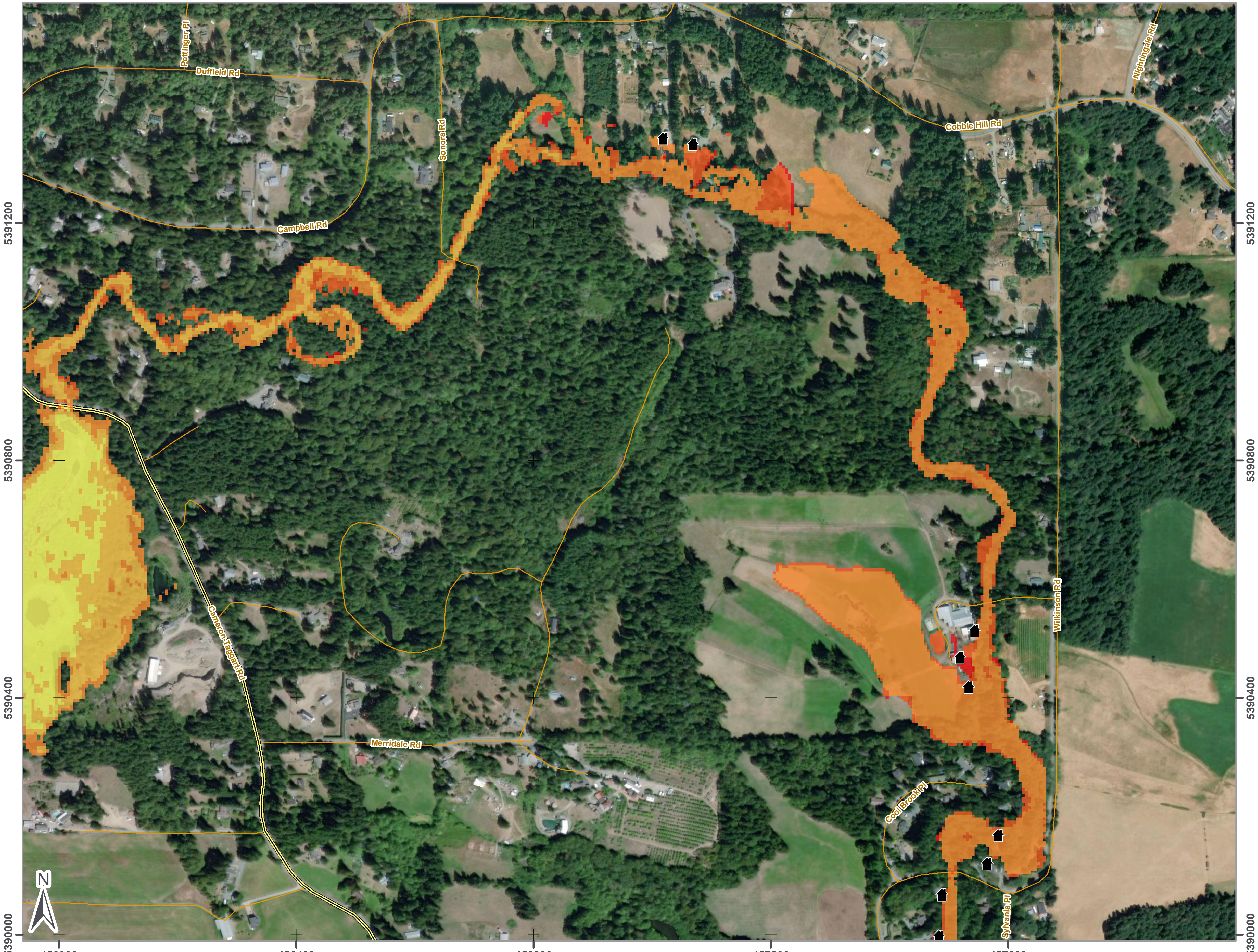
0 200 400 Meters

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

Date: 2019/01/28
Drawn: MT Check: BF

Figure 6.0b

TIME (HRS) FOR 0.6m FLOW DEPTH



DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

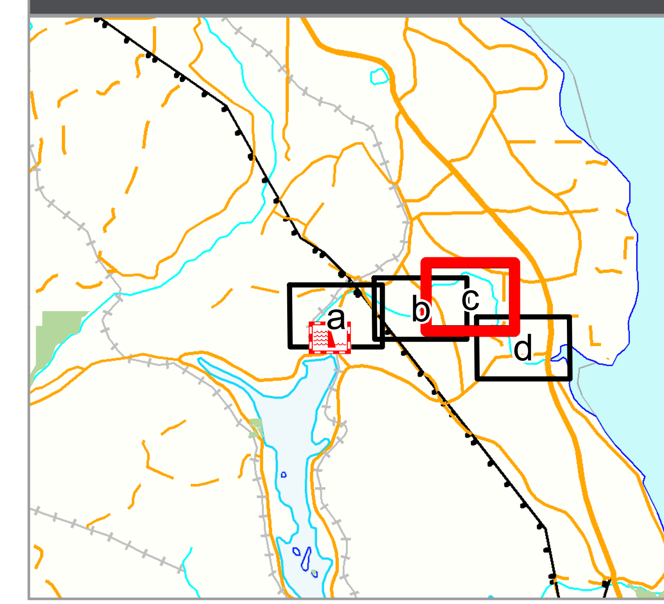
Legend

- Shawnigan Lake Weir Location
- Houses
- Transmission Towers
- Highways
- Digital Atlas Roads
- Transmission Lines
- Railways

Time (hrs) for 0.6m Flow Depth

- 0.001 - 1.000
- 1.001 - 2.000
- 2.001 - 3.000
- 3.001 - 4.000
- 4.001 - 5.000
- 5.001 - 10.000
- 10.001 - 15.000
- 15.001 - 20.000
- 20.001 - 25.000

LOCATION MAP



1:6,500

0 200 400 Meters

Project No.: GK-18-020-CVD

Client: Cowichan Valley Regional District

NAD 1983 UTM Zone 10N

Date: 2019/01/28

Drawn: MT Check: BF

Figure 6.0c

TIME (HRS) FOR 0.6m FLOW DEPTH

ecora

DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

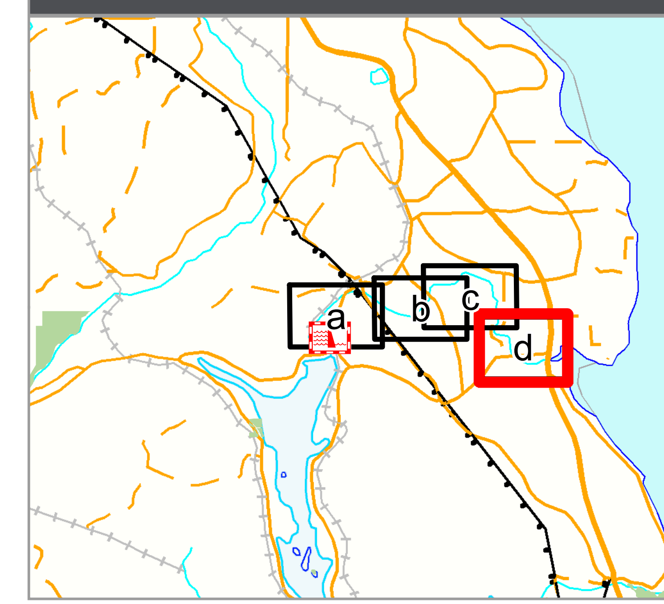
Legend

- Shawnigan Lake Weir Location
- Houses
- Transmission Towers
- Highways
- Digital Atlas Roads
- Transmission Lines
- Railways

Time (hrs) for 0.6m Flow Depth

- 0.001 - 1.000
- 1.001 - 2.000
- 2.001 - 3.000
- 3.001 - 4.000
- 4.001 - 5.000
- 5.001 - 10.000
- 10.001 - 15.000
- 15.001 - 20.000
- 20.001 - 25.000

LOCATION MAP



1:6,500

0 200 400 Meters

Project No.: GK-18-020-CVD

Date: 2019/01/28

Client: Cowichan Valley Regional District

Drawn: MT Check: BF

NAD 1983 UTM Zone 10N

Figure 6.0d

FLOOD HAZARD RATING

ecora™

DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

Legend

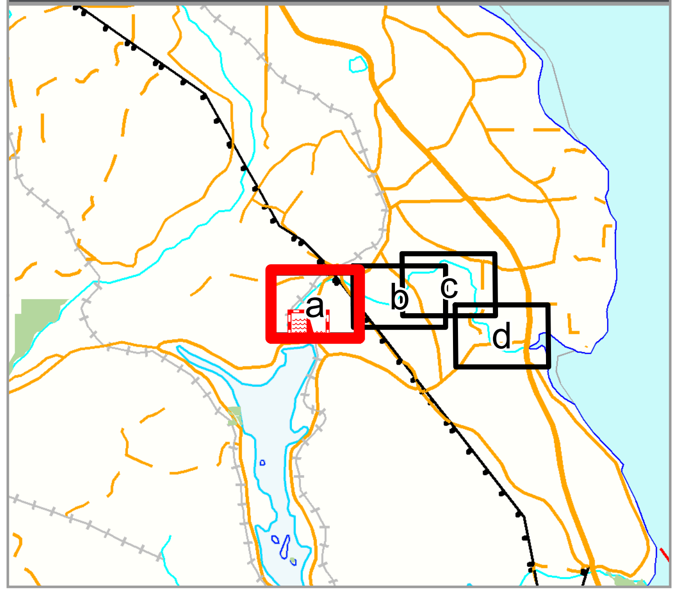
- Shawnigan Lake Weir Location
- Houses
- Transmission Towers
- Transmission Lines
- Highways
- Digital Atlas Roads
- Railways

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

Low (0.044 km²) Medium (0.240 km²) High (0.650 km²)

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



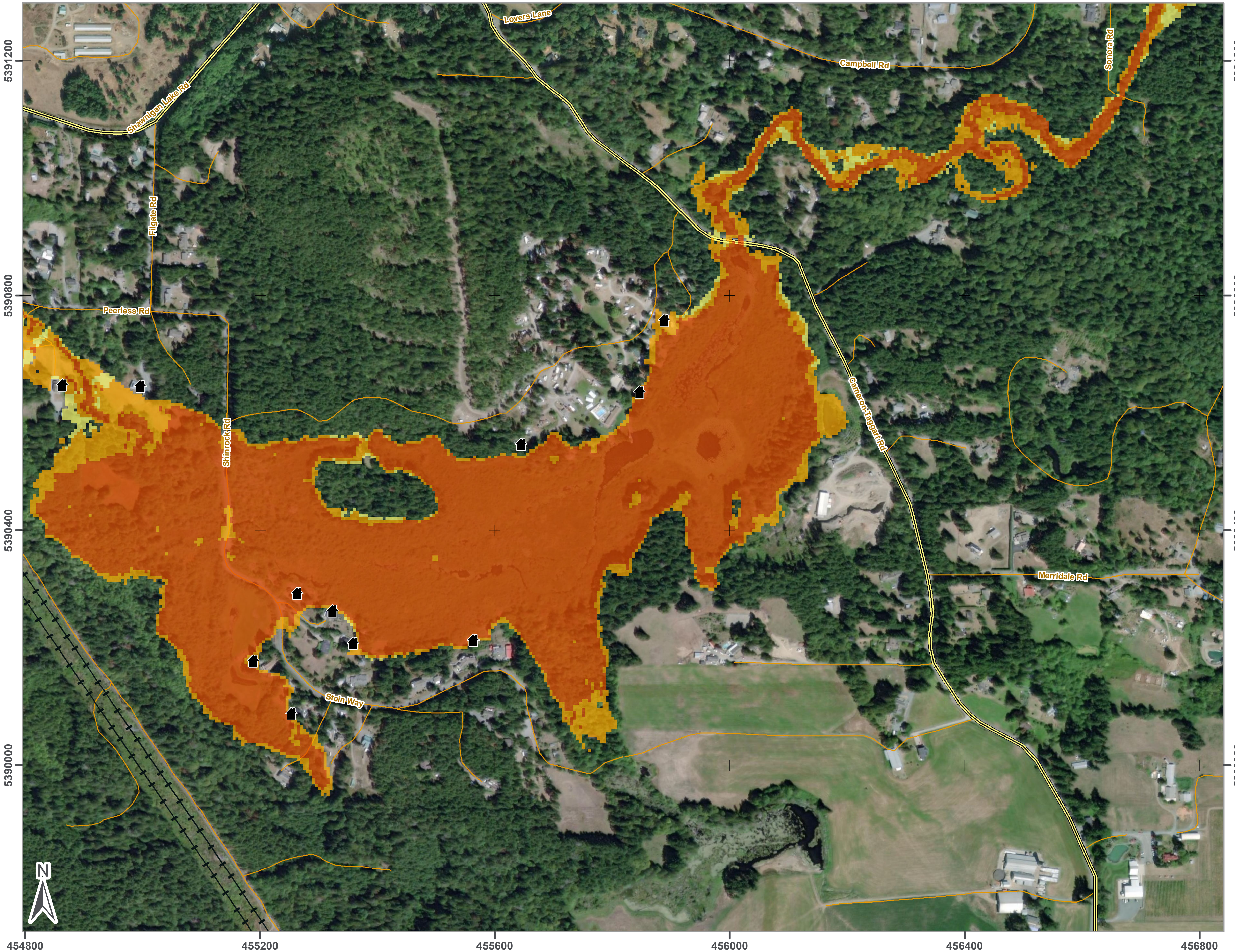
1:6,500

0 200 400 Meters

Project No.: GK-18-020-CVD
Date: 2019/01/28
Client: Cowichan Valley Regional District
Drawn: MT Check: BF
NAD 1983 UTM Zone 10N

Figure 5.0a

FLOOD HAZARD RATING



DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

Legend

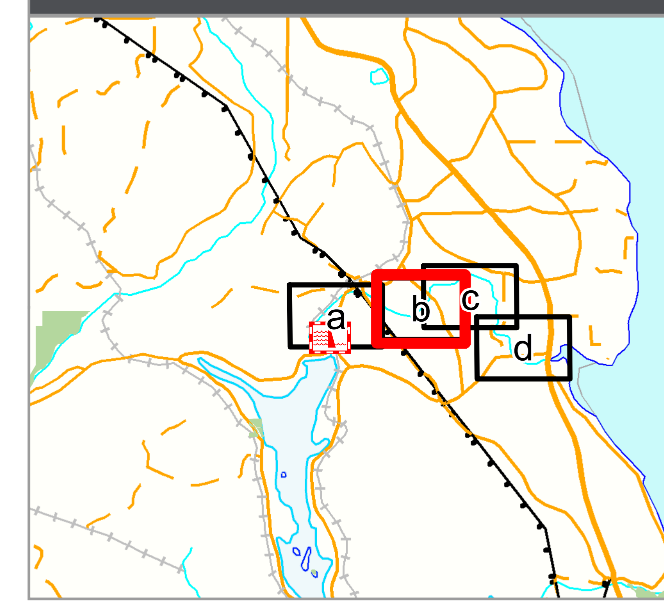
- Shawnigan Lake Weir Location
- Houses
- Transmission Towers
- Transmission Lines
- Highways
- Digital Atlas Roads
- Railways

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

- Low (0.044 km²)
- Medium (0.240 km²)
- High (0.650 km²)

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



1:6,500

0 200 400 Meters

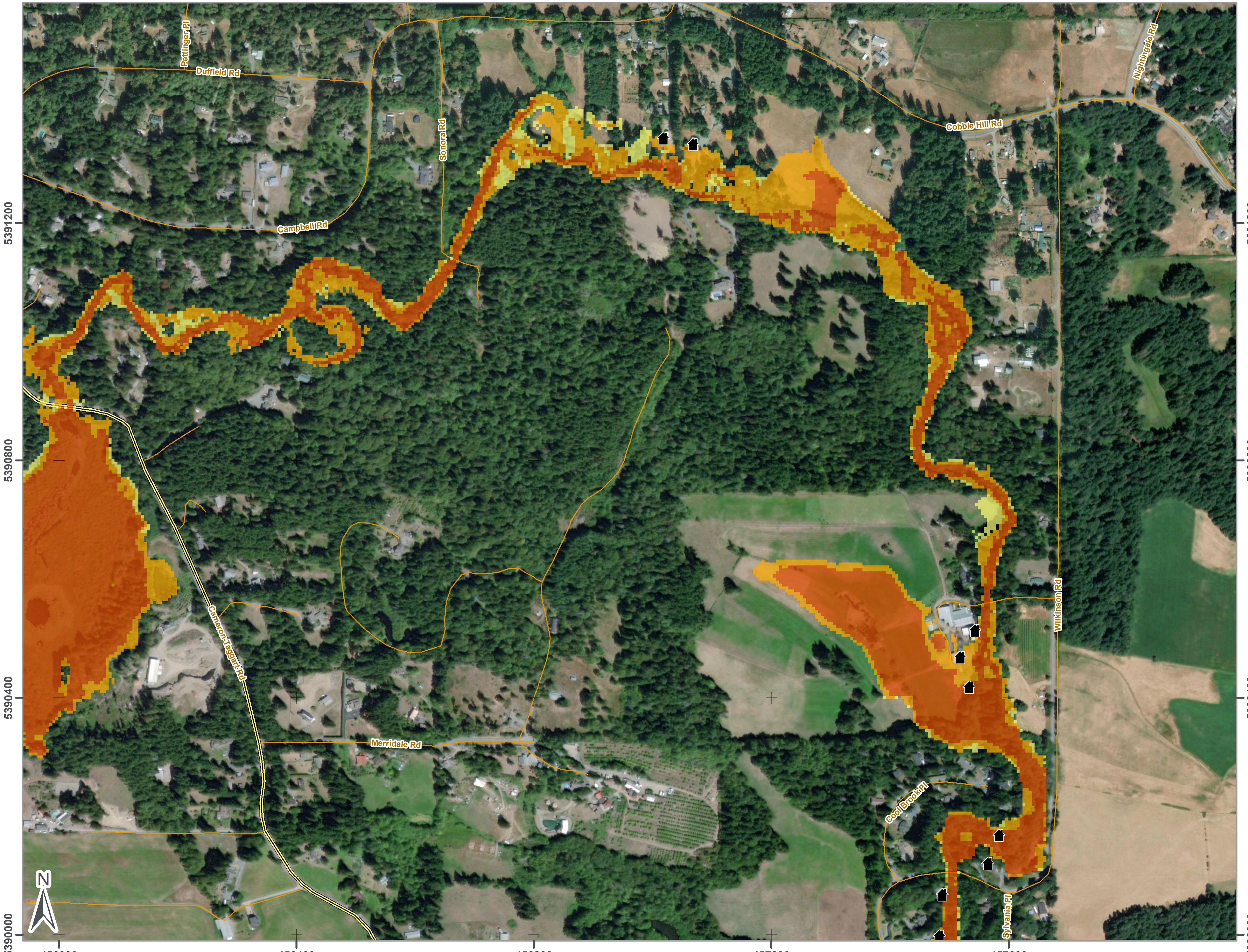
Project No.: GK-18-020-CVD
Client: Cowichan Valley Regional District
NAD 1983 UTM Zone 10N

Date: 2019/01/28
Drawn: MT Check: BF

Figure 5.0b

FLOOD HAZARD RATING

ecora



DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

Legend

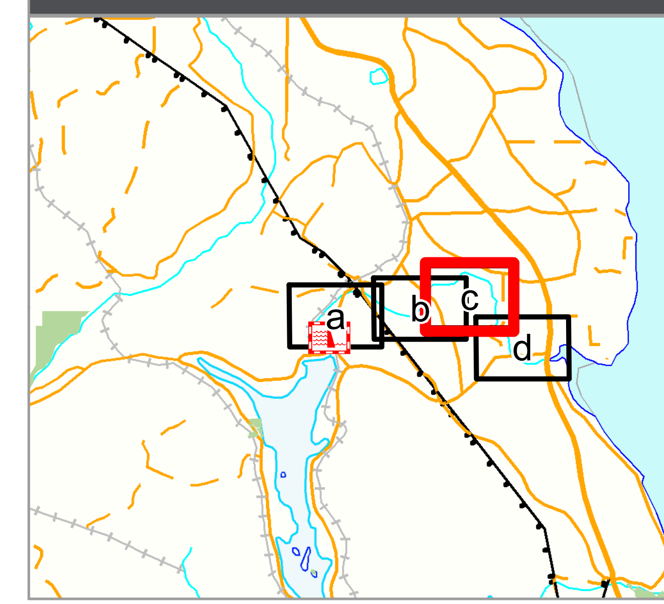
- Shawnigan Lake Weir Location
- Houses
- Transmission Towers
- Transmission Lines
- Highways
- Digital Atlas Roads
- Railways

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

- Low (0.044 km²)
- Medium (0.240 km²)
- High (0.650 km²)

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



1:6,500

0 200 400 Meters

Project No.: GK-18-020-CVD

Client: Cowichan Valley Regional District

NAD 1983 UTM Zone 10N

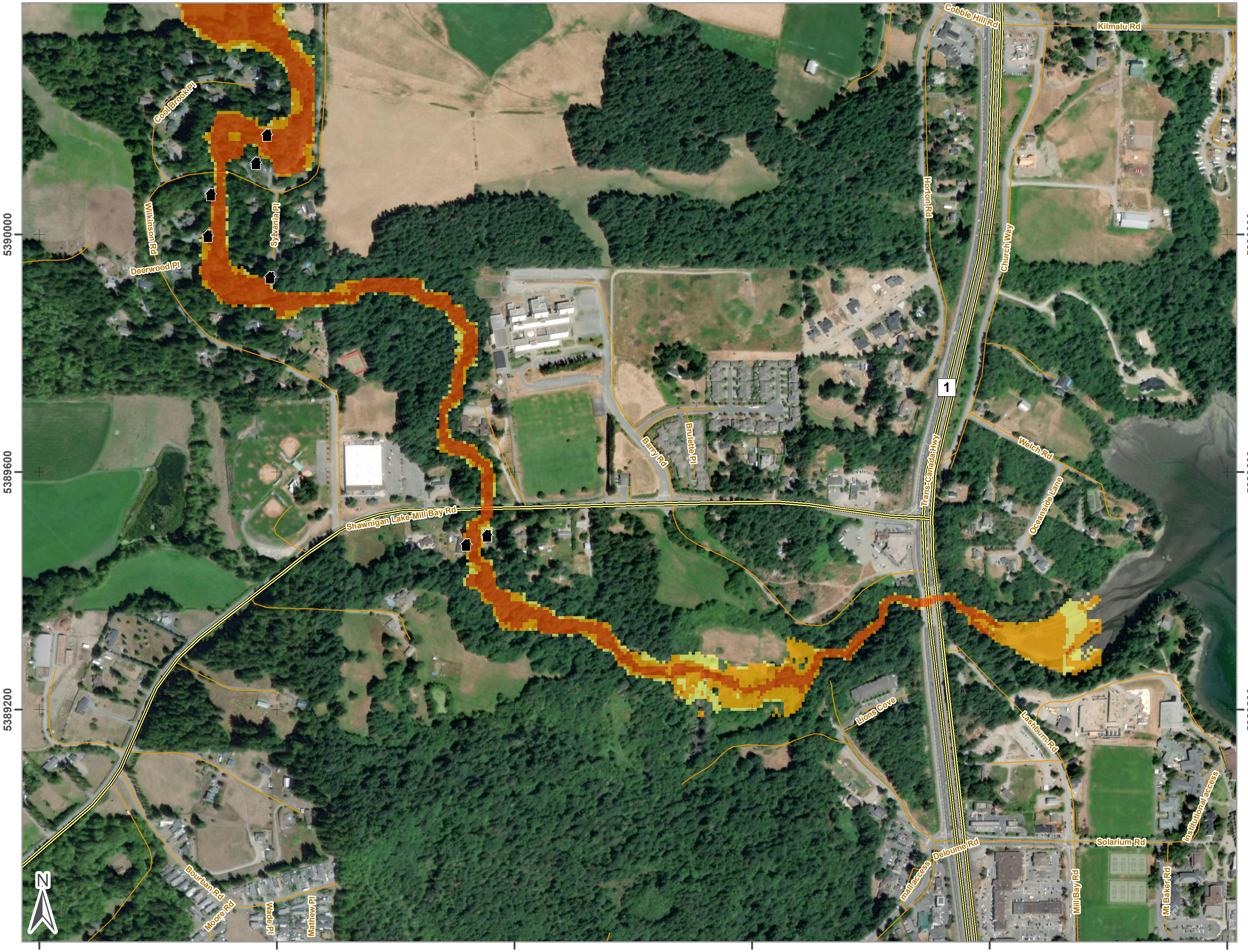
Date: 2019/01/28

Drawn: MT Check: BF

Figure 5.0c

FLOOD HAZARD RATING

ecora



DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

Legend

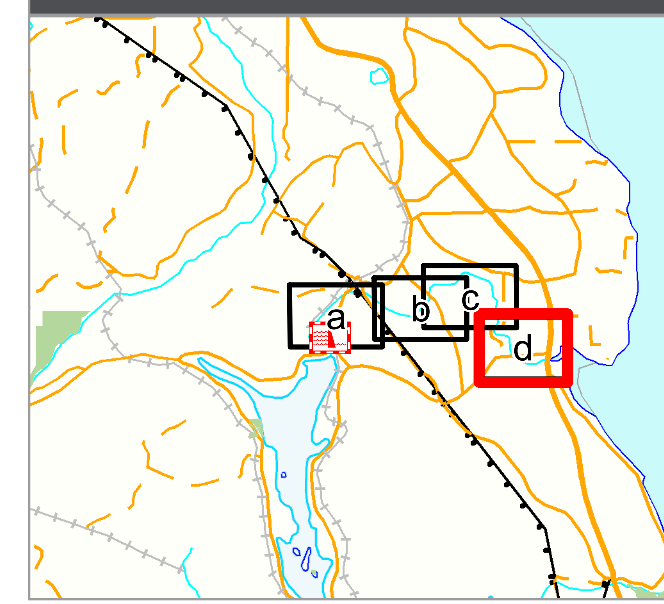
- Shawnigan Lake Weir Location
- Houses
- Transmission Towers
- Transmission Lines
- Highways
- Digital Atlas Roads
- Railways

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

Low (0.044 km²) Medium (0.240 km²) High (0.650 km²)

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

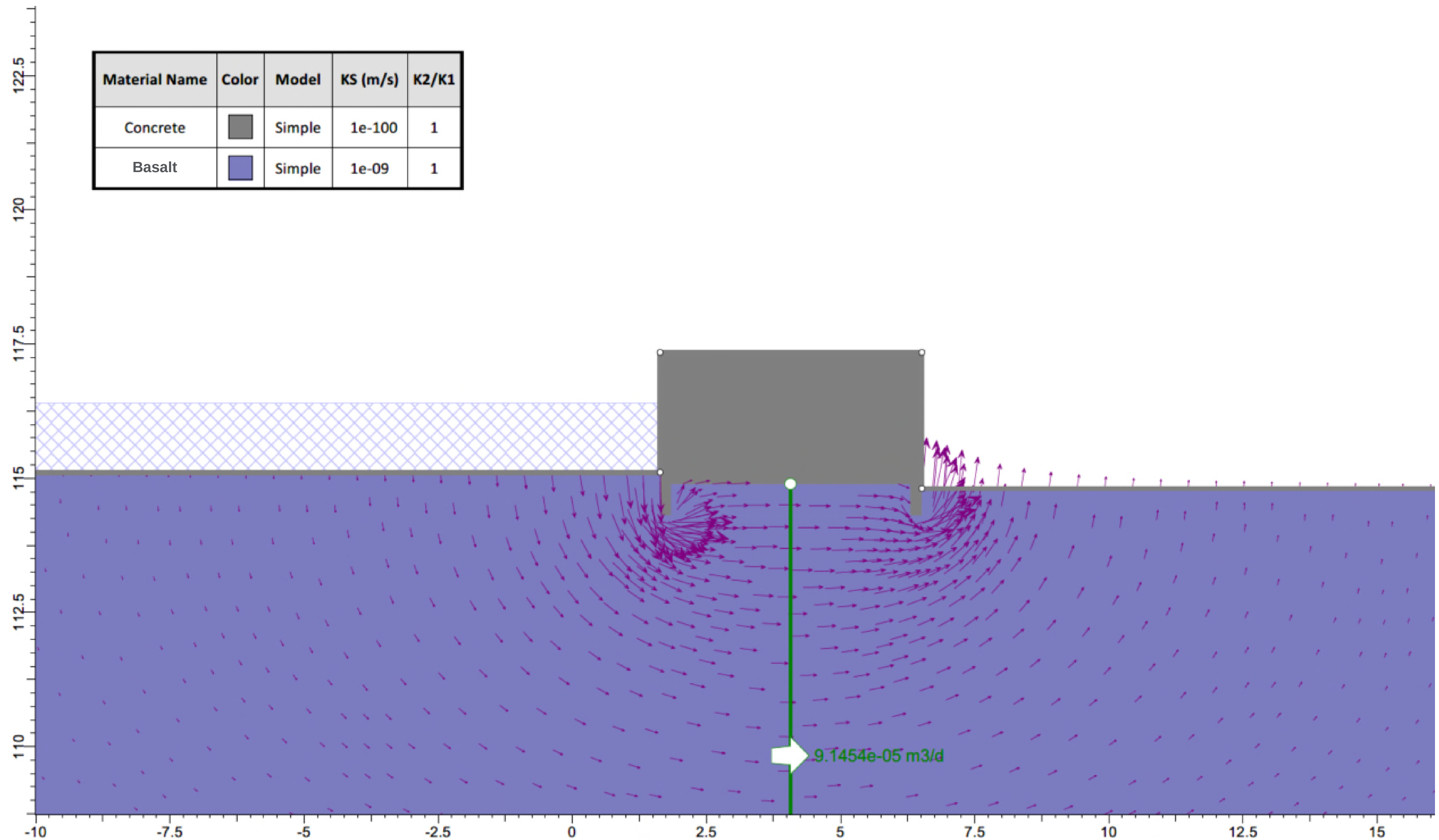


1:6,500

0 200 400 Meters

Project No.: GK-18-020-CVD
Date: 2019/01/28
Client: Cowichan Valley Regional District
Drawn: MT Check: BF
NAD 1983 UTM Zone 10N

Figure 5.0d



Material Name	Color	Model	KS (m/s)	K2/K1
Concrete		Simple	1e-100	1
Basalt		Simple	1e-09	1

Notes:

DAM SAFETY REVIEW & RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR

Steady State Seepage Analysis: Reservoir Level at 116.4 m Elevation

Project No. GK-18-020-CVD
Client: Cowichan Valley Regional District
Office: Kelowna
Scale: NTS
Date: November 26, 2018
DWN: CE CHK: MJL

Figure 8.3

SHAWNIGAN LAKE WATERSHED

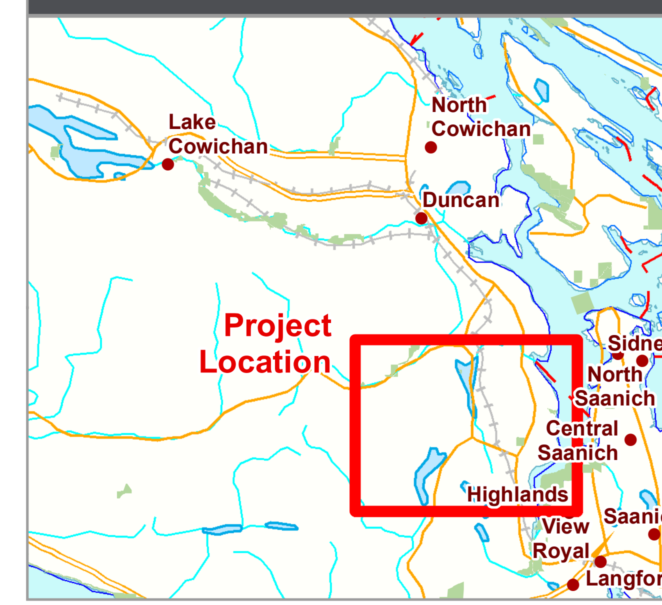
ecora

DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

Legend

- Shawnigan Lake Weir
- 100m TRIM Contours
- Fresh Water Atlas Streams
- Highways
- Shawnigan Community Watershed

LOCATION MAP



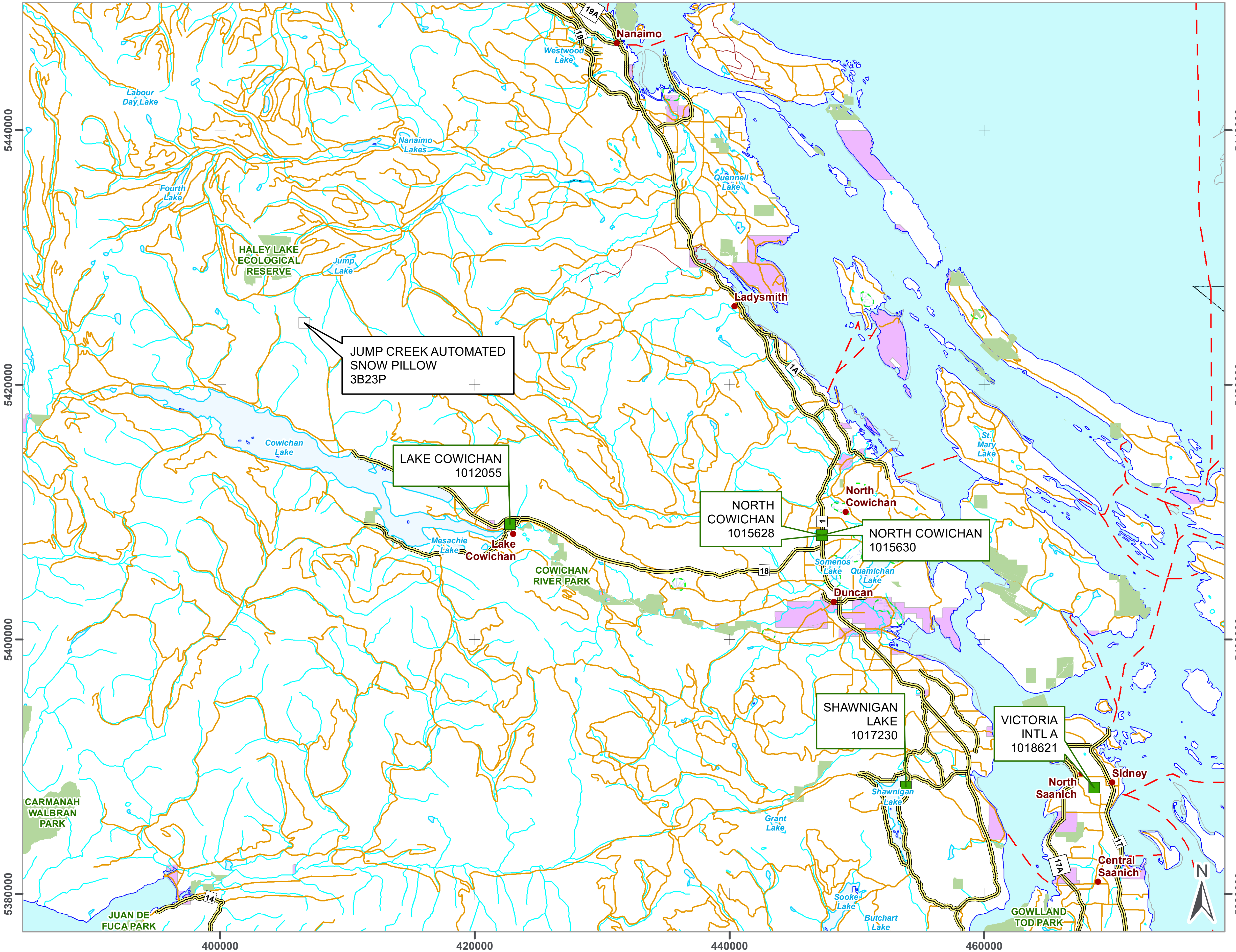
1:70,000

0 2.5 5 KM

Project No.: GK-18-020-CVD
Date: 2018/07/05
Client: Cowichan Valley Regional District
Drawn: MT Check: AG
NAD 1983 UTM Zone 10N

Figure 9.1

CLIMATE AND AUTOMATED SNOW PILLOW STATIONS

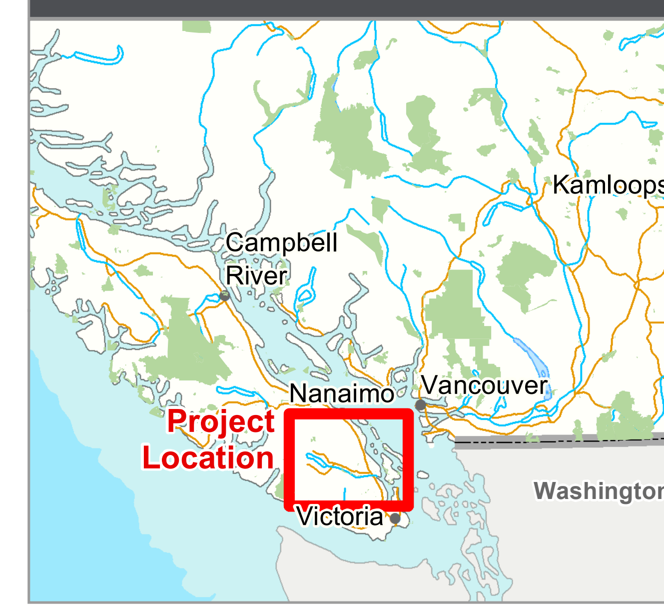


DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

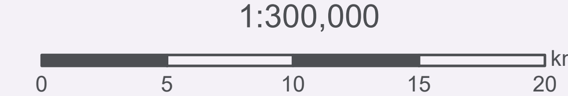
Legend

- 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



1:300,000

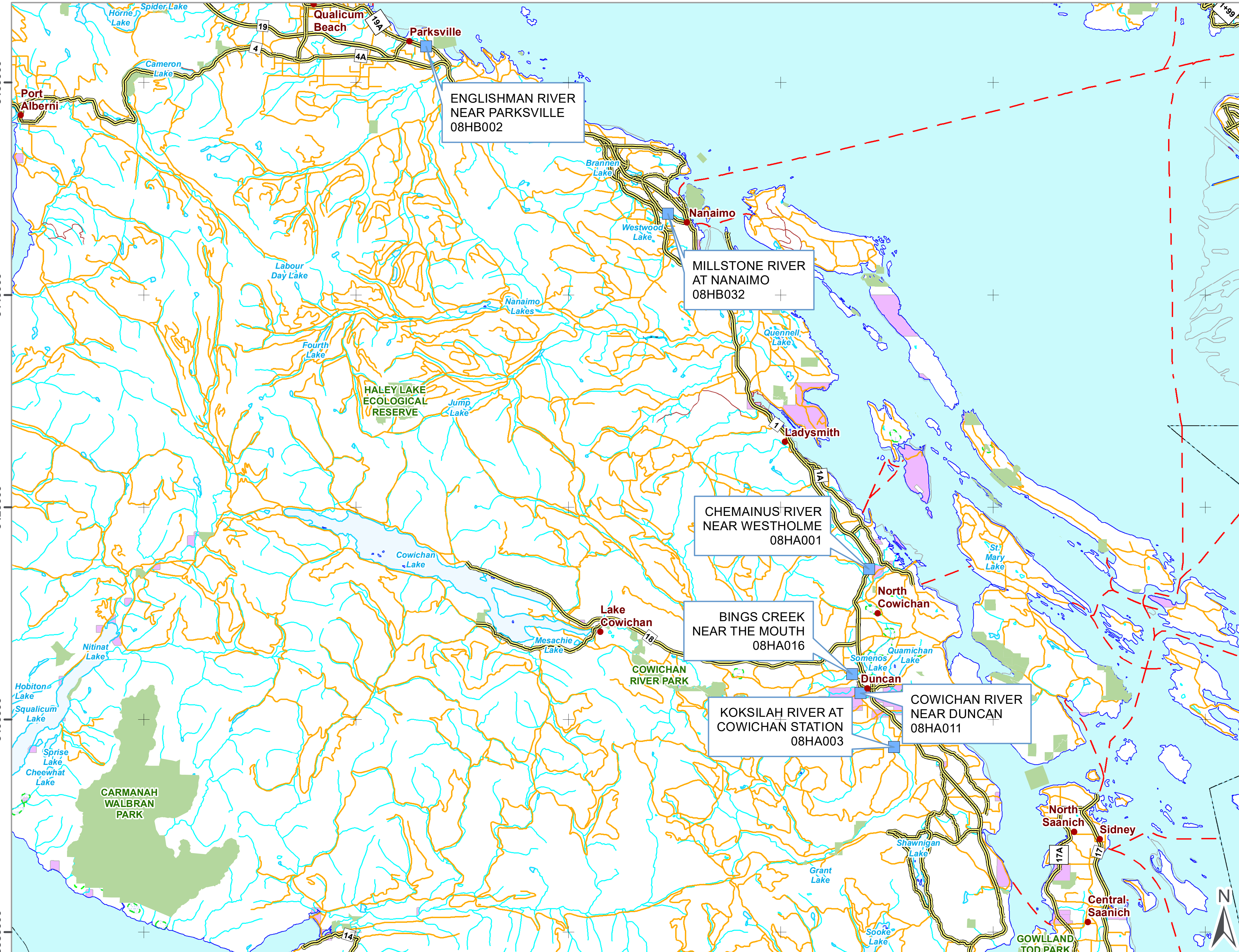


Project No.: GK-18-020-CVD
Client: Cowichan Valley Regional District
NAD 1983 UTM Zone 10N

Date: 2019/01/08
Drawn: MT Check: AG

Figure 9.2

HYDROMETRIC STATIONS

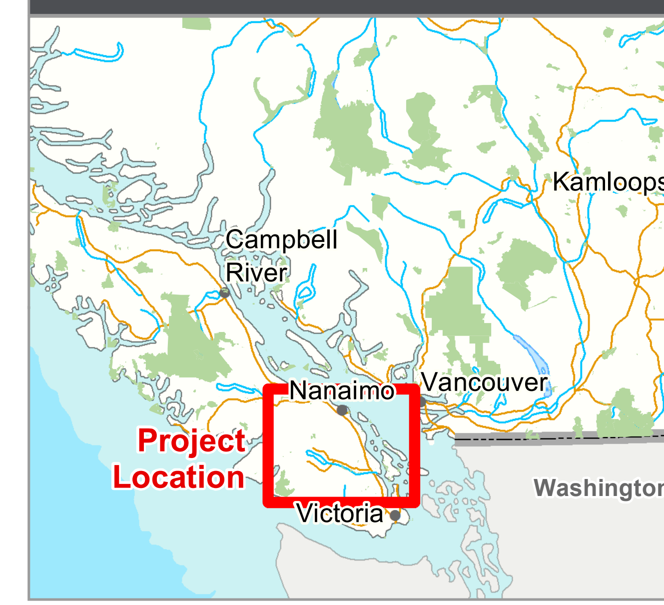


DAM SAFETY REVIEW RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR SHAWNIGAN LAKE, BC

Legend

- Cities
- Hydrometric Station (Water Survey of Canada)
- Highways
- Streams
- Ferry Route
- Roads
- Trail
- Bridge
- Reserves
- Parks

LOCATION MAP

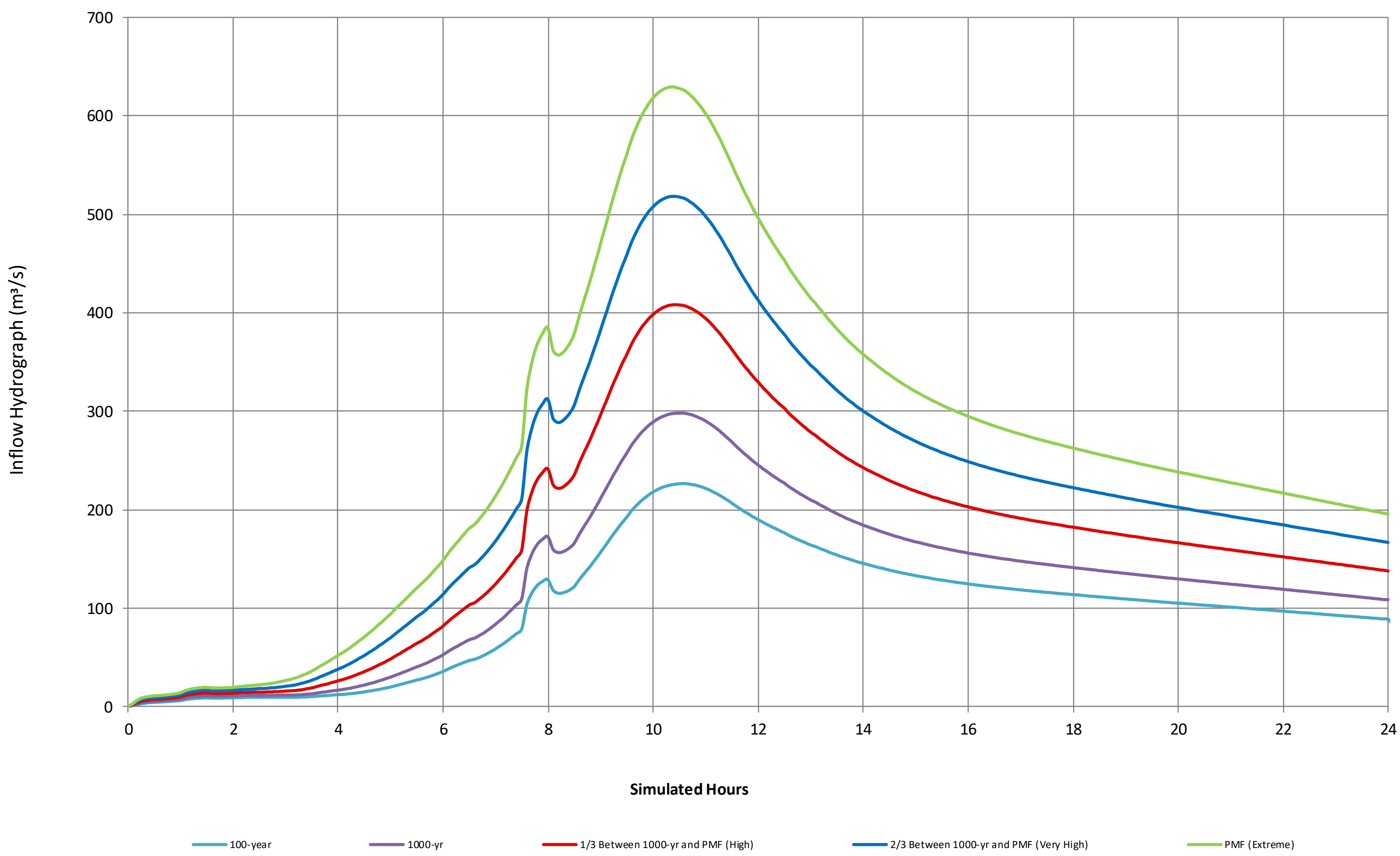


1:370,000

0 5 10 15 20 km

Project No.: GK-18-020-CVD
Date: 2018/09/13
Client: Cowichan Valley Regional District
Drawn: MT Check: AG
NAD 1983 UTM Zone 10N

Figure 9.3



Notes:

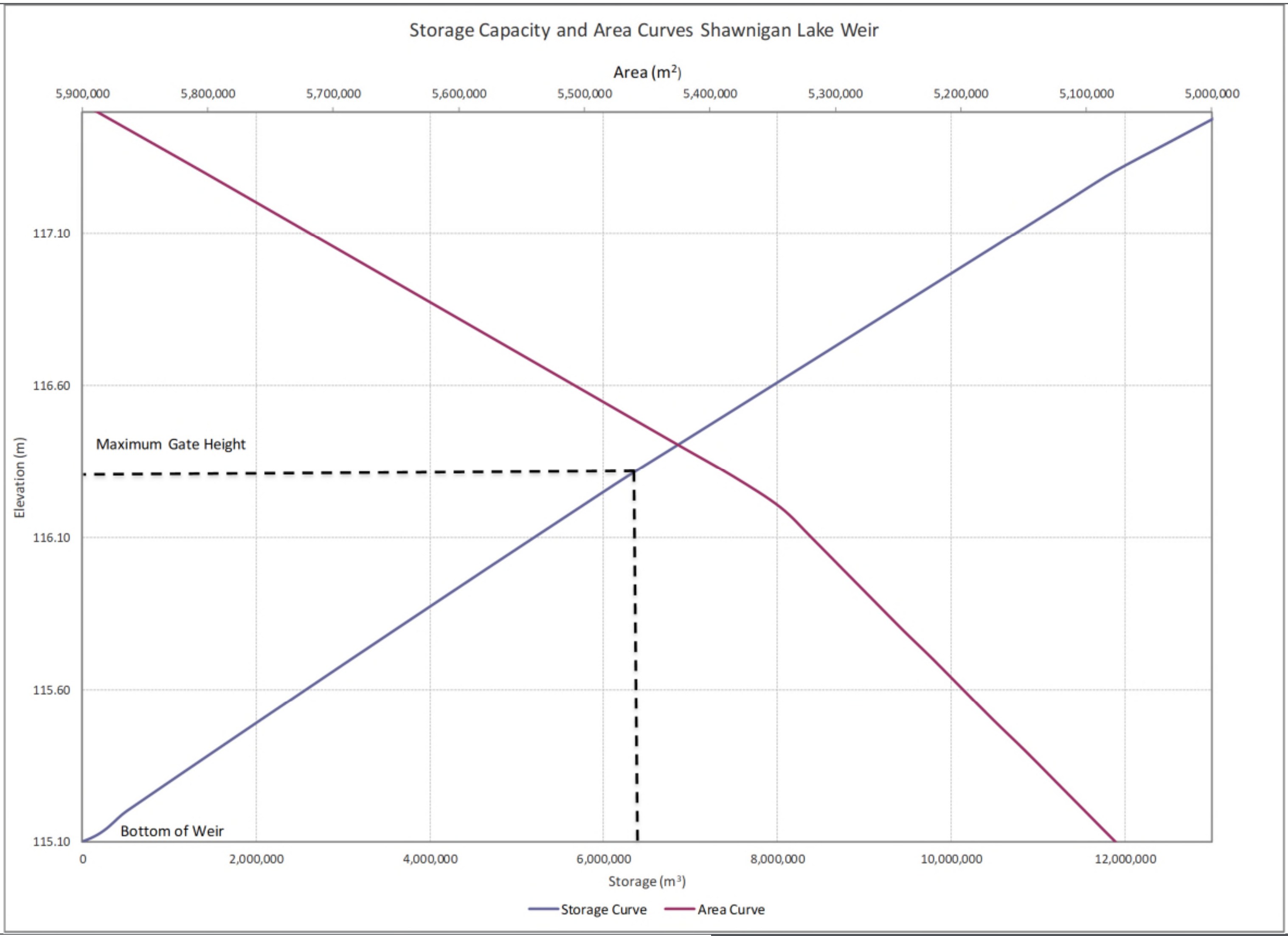
DAM SAFETY REVIEW AND RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR

Inflow Design Flood Hydrographs

Project No. GK-18-020-CVD
Client: Cowichan Valley Regional District
Office: Kelowna
Scale: NTS
Date: OCT 31, 2018
DWN: AG CHK: MJL

ecora

Figure 9.4



Notes:

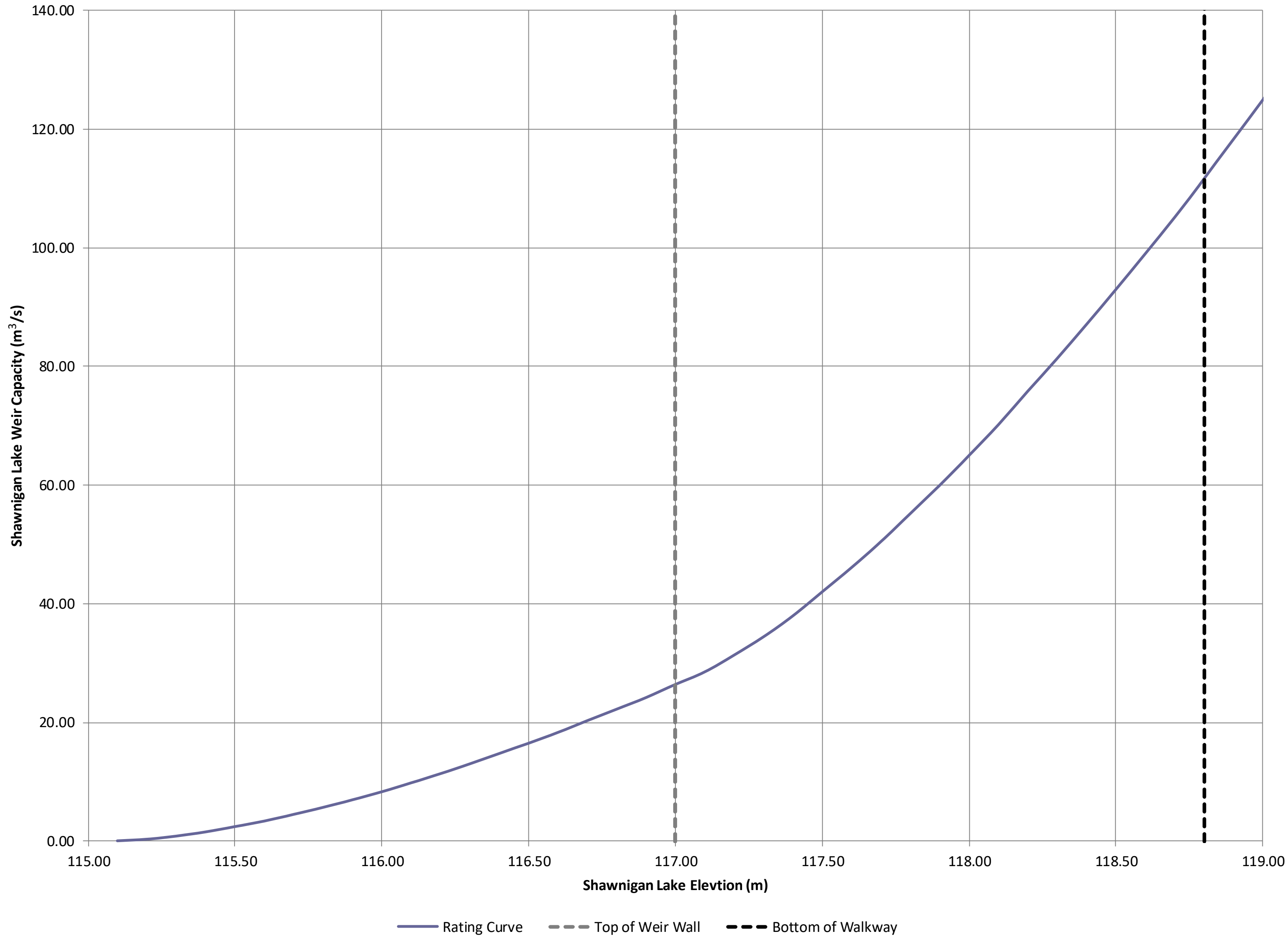
DAM SAFETY REVIEW AND RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR

Storage Elevation Area Curves

Project No.	GK-18-020-CVD
Client:	Cowichan Valley Regional District
Office:	Kelowna
Scale:	NTS
Date:	OCT 31, 2018
DWN:	AG CHK: AGC

ecora™

Figure 9.5a



Notes:

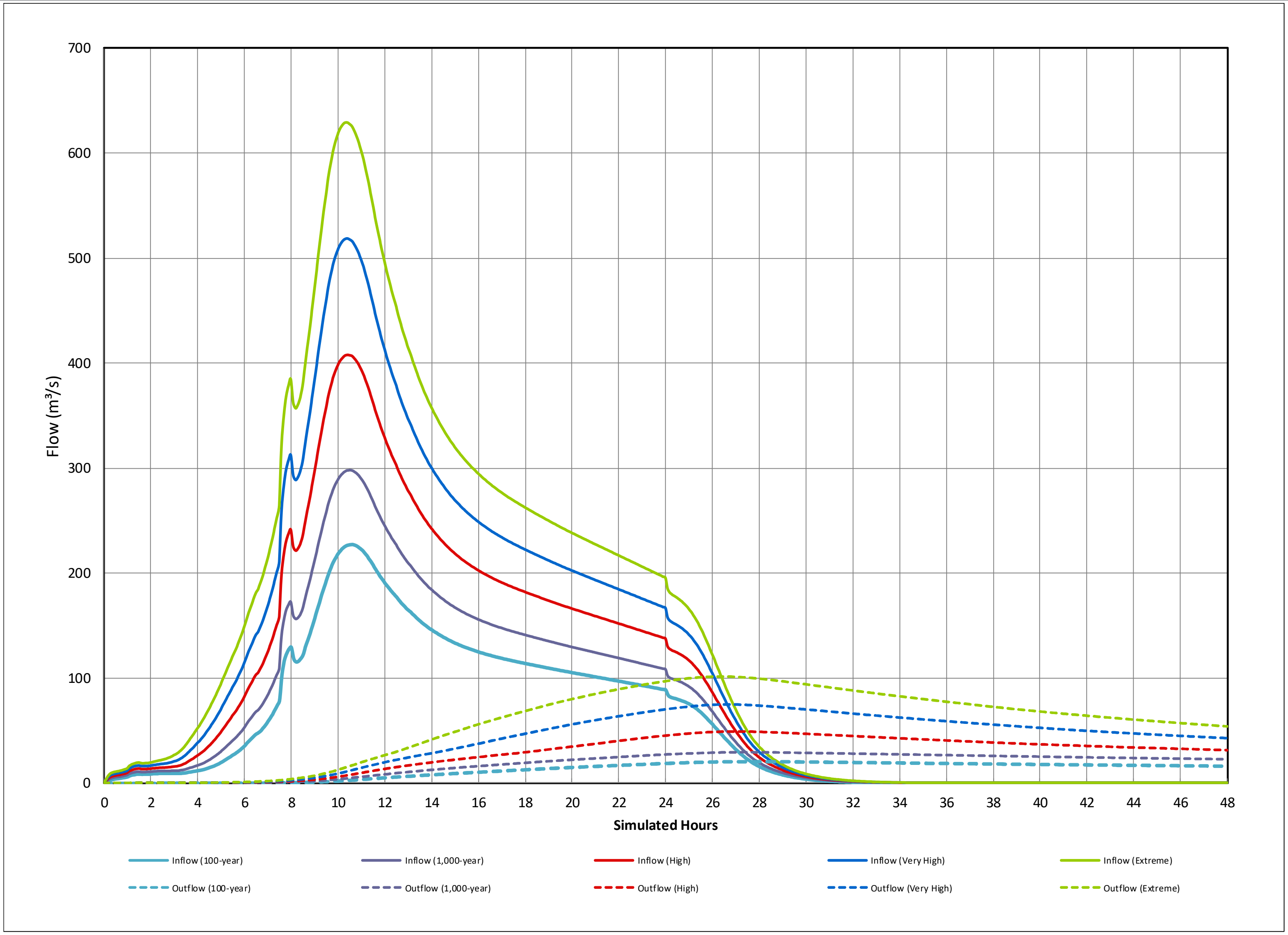
DAM SAFETY REVIEW AND RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR

Spillway Rating Curve

Project No.	GK-18-020-CVD
Client:	Cowichan Valley Regional District
Office:	Kelowna
Scale:	NTS
Date:	OCT 31, 2018
DWN:	AG CHK: AGC

ecora

Figure 9.5b



Notes:

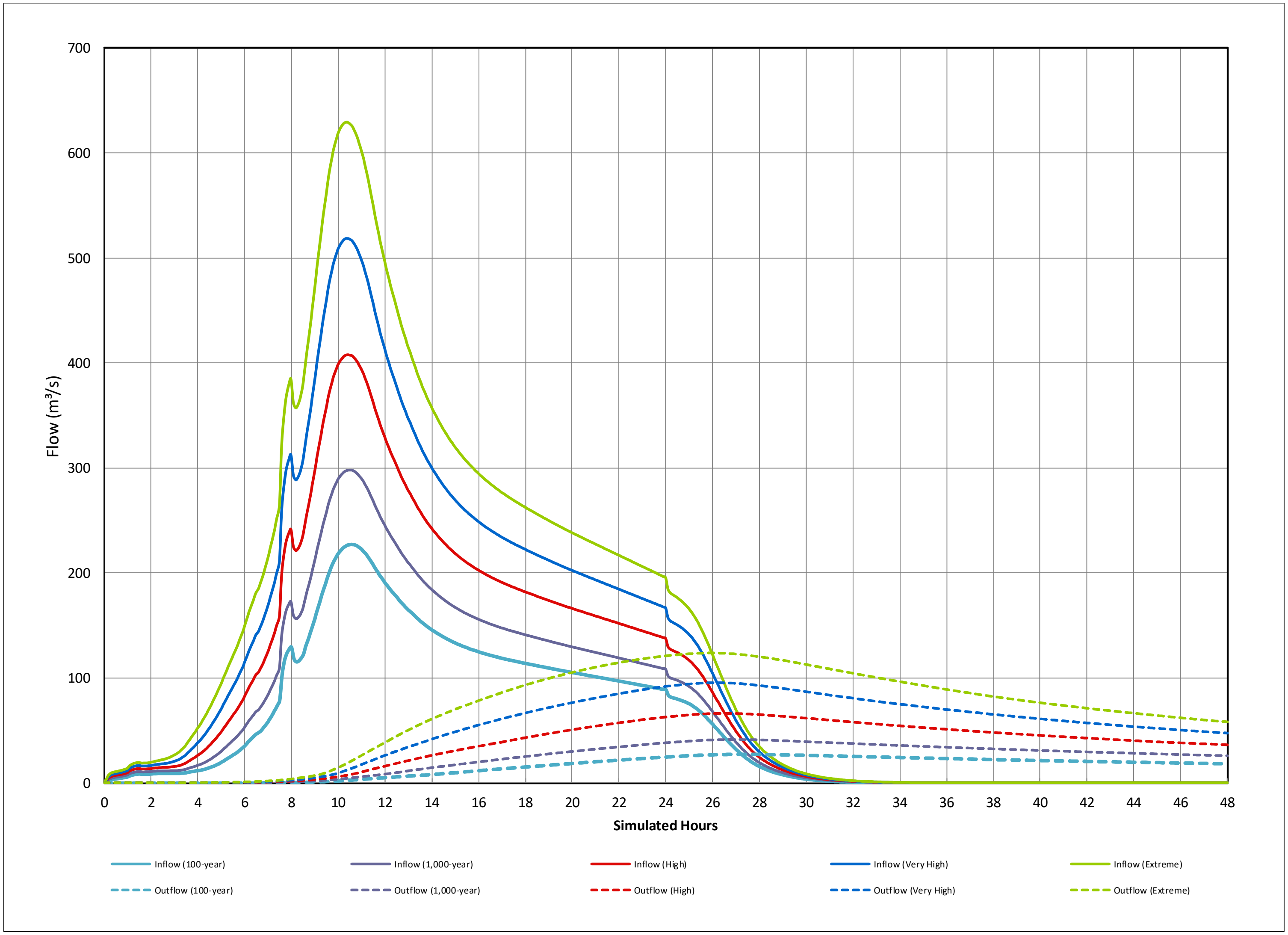
DAM SAFETY REVIEW AND RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR

Flood Routing Hydrographs (Gate Open)

Project No. GK-18-020-CVD
Client: Cowichan Valley Regional District
Office: Kelowna
Scale: NTS
Date: OCT 31, 2018
DWN: AG CHK: AGC

ecora

Figure 9.5c



Notes:

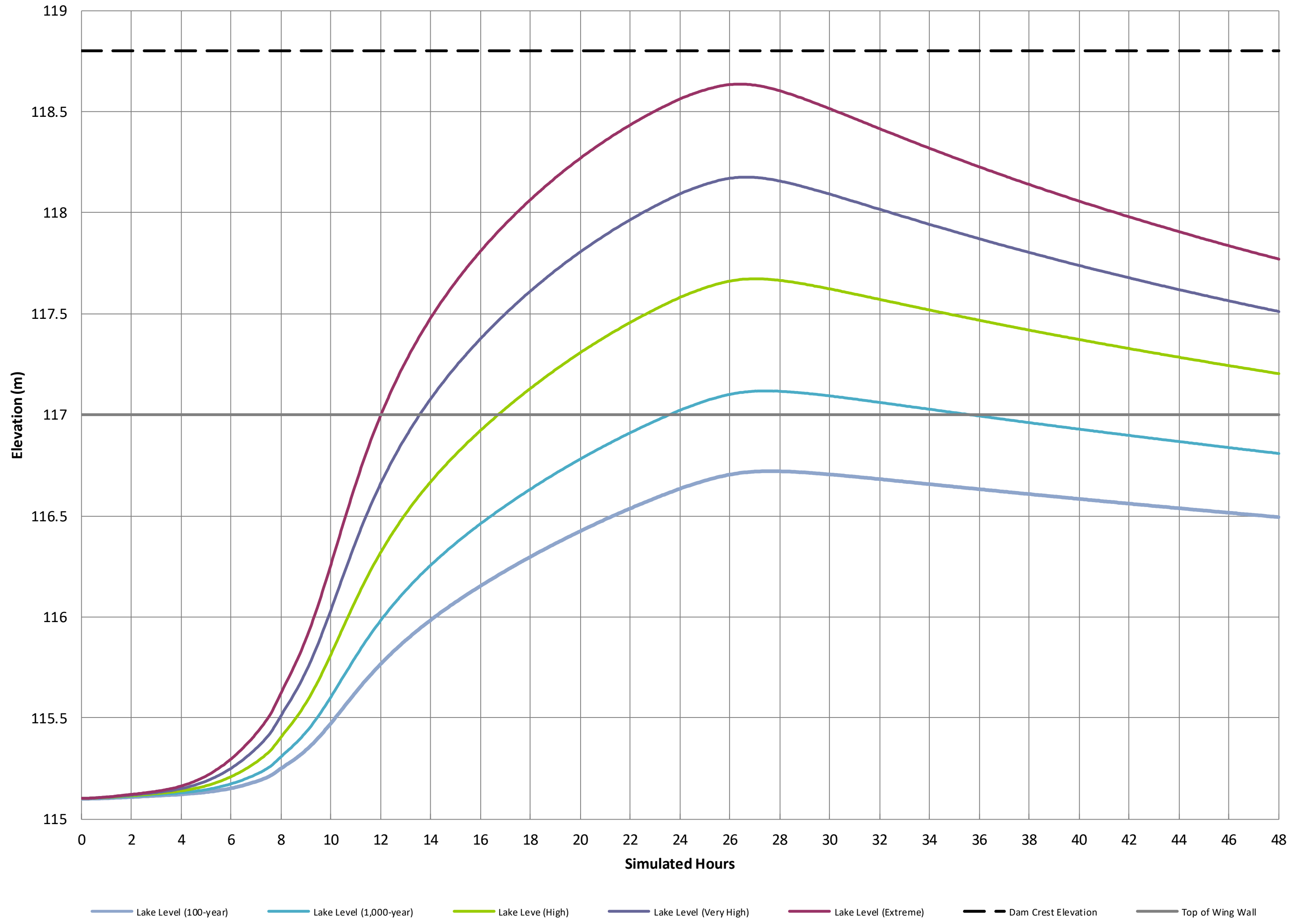
DAM SAFETY REVIEW AND RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR

Flood Routing Hydrographs (Gate Closed)

Project No. GK-18-020-CVD
Client: Cowichan Valley Regional District
Office: Kelowna
Scale: NTS
Date: OCT 31, 2018
DWN: AG CHK: AGC

ecora

Figure 9.5c



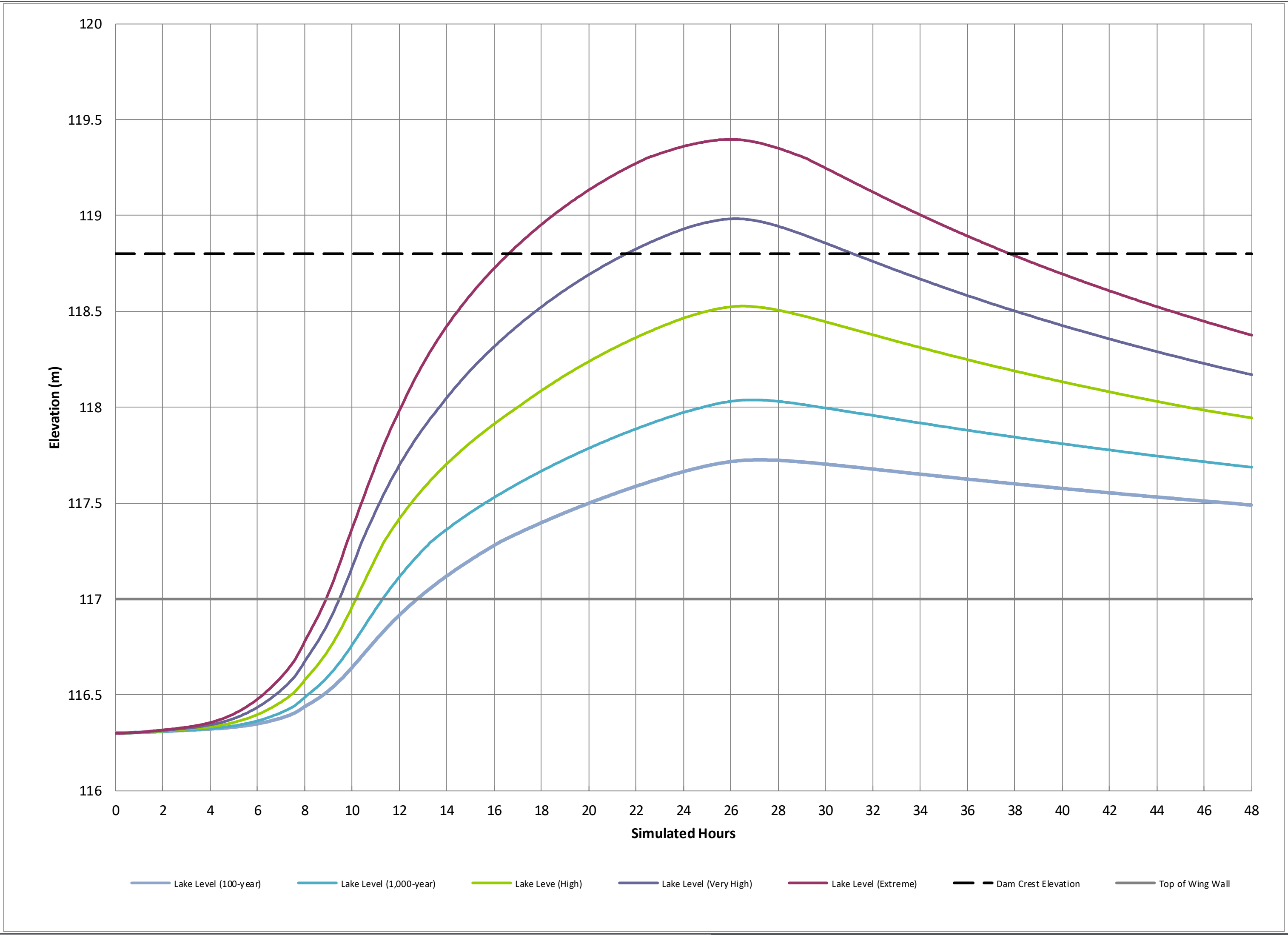
Notes:

DAM SAFETY REVIEW AND RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR

Shawnigan Lake Flood Levels (Gate Open)

Project No. GK-18-020-CVD
Client: Cowichan Valley Regional District
Office: Kelowna
Scale: NTS
Date: OCT 31, 2018
DWN: AG CHK: AGC

Figure 9.5e



Notes:

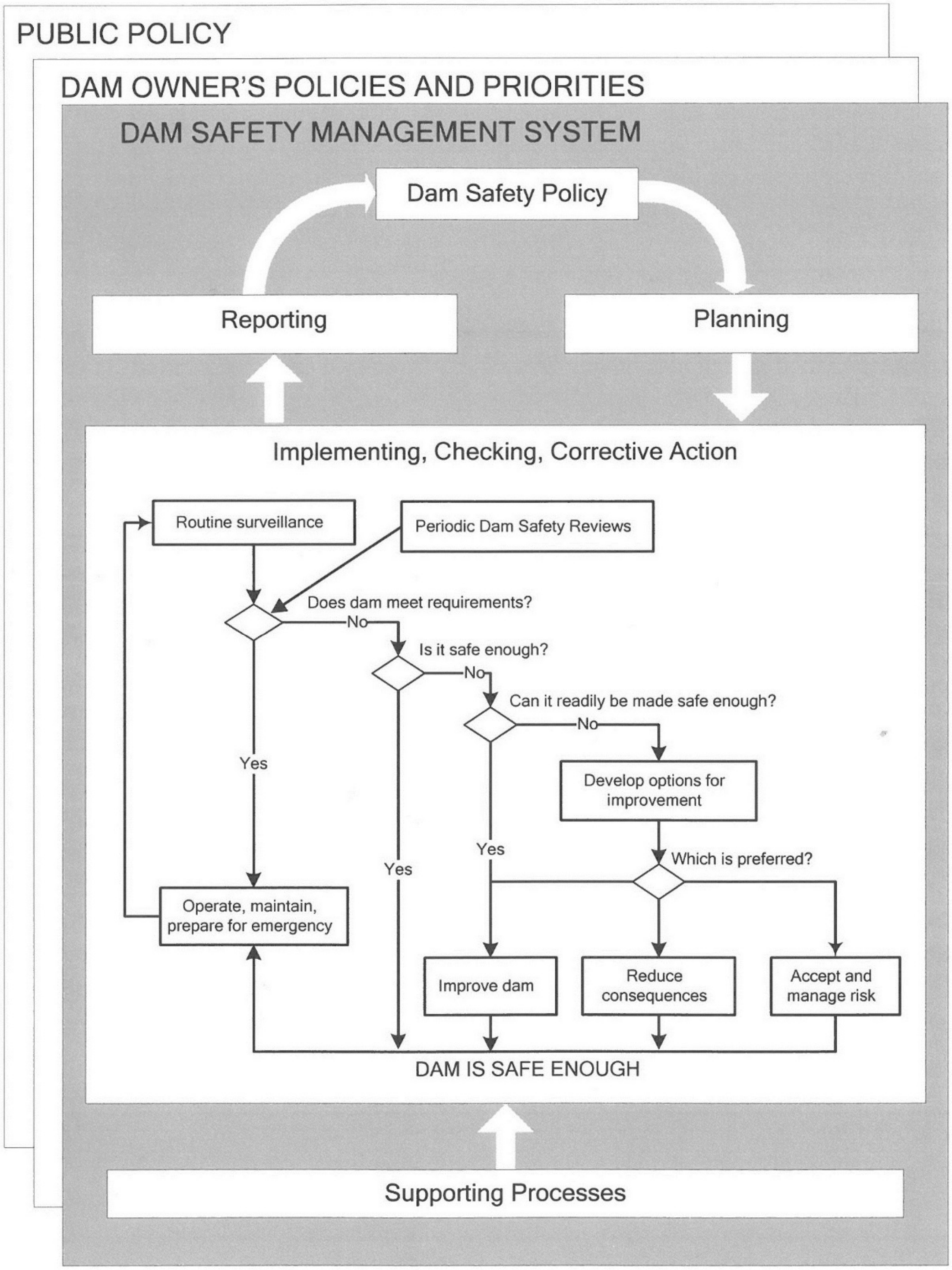
DAM SAFETY REVIEW AND RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR

Shawnigan Lake Flood Elevations (Gate Closed)

Project No. GK-18-020-CVD
Client: Cowichan Valley Regional District
Office: Kelowna
Scale: NTS
Date: OCT 31, 2018
DWN: AG CHK: AGC

ecora

Figure 9.5f



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

DAM SAFETY REVIEW AND RISK ASSESSMENT OF SHAWNIGAN LAKE WEIR

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

Figure 11.1

Photographs

Photo 1 Shawnigan Lake as viewed from entrance to Shawnigan Creek above the weir.

Photo 2 Shawnigan Creek looking downstream from Renfrew Road bridge.

Photo 3 Shawnigan Creek upstream of weir.

Photo 4 Upstream view of the structure.

Photo 5 Entrance to fish bypass channel.

Photo 6 Weir as viewed from the right abutment.

Photo 7 Retaining wall at right abutment.

Photo 8 Walkway with cable reel above the weir.

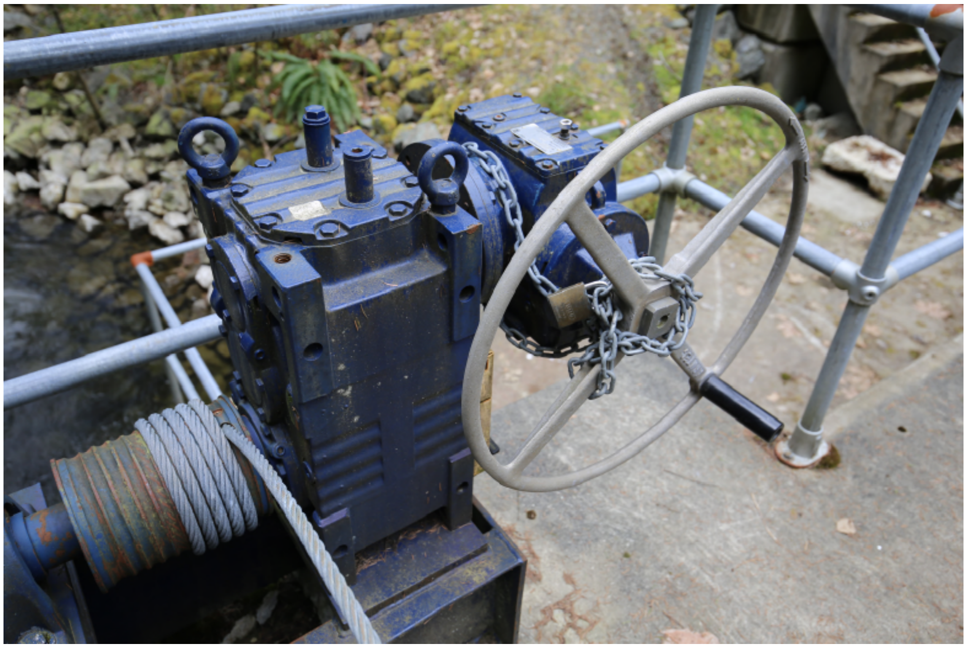


Photo 9 Cable reel hand crank. Locked in place.

Photo 10 Crack on the grout pad underneath mechanical lift (right side).

Photo 11 Crack on the grout pad underneath mechanical lift (left side).

Photo 12 Mild corrosion on steel guardrail pipe connections.

Photo 13 Underside of the walkway above the weir.

Photo 14 Moss growing on the fish bypass side wall.

Photo 15 Left side of the weir as viewed from the right.

Photo 16 Weir/gate at the center of the structure.

Photo 17 Riprap located on the downstream side of the weir.

Photo 18 Platform at the left side of the weir.

Photo 19 Downstream face of the weir structure.

Photo 20 Shawnigan Creek downstream of Shawnigan Lake Weir.

Appendix A

Background Information Reviewed

Background Review

- January 2007 – Shawnigan Creek Weir As-Builts, Drawing No. 202-00 to 202-03 – John Braybrooks Engineering
- September 2006 – Shawnigan Lake Weir Formwork Plan, Drawing No. F68A-SK1 – Brown and Grant Engineering
- April 1994 – Shawnigan Lake Reservoir Outlet Channel Plan and Profile, Drawing No. 4984-8C – BC Ministry of Environment, Lands and Parks
- January 1981 – Shawnigan Lake Reservoir, Plan and Elevation of Dam Including Profile and Cross-Sections of Outlet Channel, Drawing 4984-8B – BC Ministry of Environment
- March 1979 – Shawnigan Lake Reservoir Plan of Reservoir, Drawing No. 4984-8 – BC Ministry of Environment
- February 1979 – Shawnigan Lake Reservoir Plan of Reservoir, Drawing No. 4984-8A Sheets 1 to 3 – BC Ministry of Environment
- Unknown Date – Shawnigan Lake Control Weir Construction Photographs (Power Point) – John Braybrooks Engineering
- Unknown Date – 2016 Shawnigan Lake Levels vs. Weir Elevation – Unknown Author
- Unknown Date – 2016 Shawnigan Lake Weir Elevations & Discharge – Unknown Author
- Unknown Date – Mill Bay Weather 2007 (Excel) – Unknown Author
- Unknown Date – Shawnigan Creek Watershed Map – Unknown Author
- Unknown Date – Shawnigan Historic Lake Level (Excel) – Unknown Author
- Unknown Date – Shawnigan Weather Data 2007 (Excel) – Unknown Author
- Unknown Date – Shawnigan Creek Watershed: A Fisheries Perspective – Unknown Author

Appendix B

Historical Dam Drawings

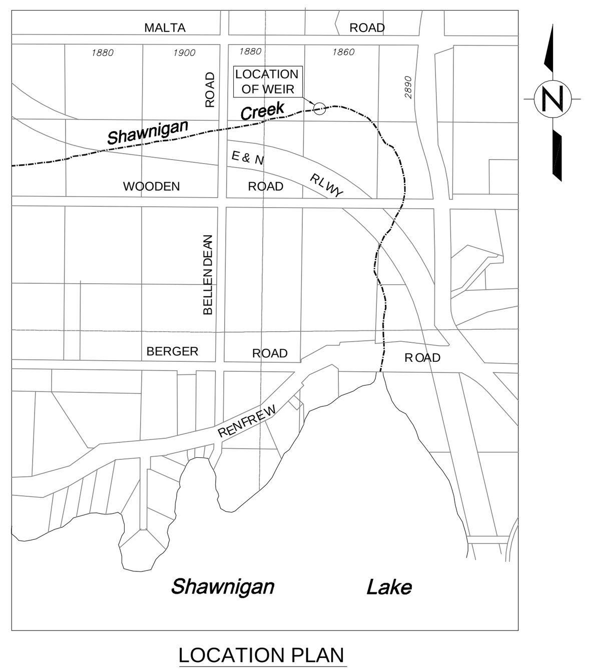
Shawnigan Lake Weir Committee

Proposed Shawnigan Creek Weir

Prepared by John Braybrooks Engineering 2658 CAMERON TAGGART ROAD, MILL BAY B.C. VOR-2P2 250-743-0039

Site Plan

1:250 0 5 15m



LOCATION PLAN

List of Drawings	
Dwg No.	Title
202-00	Location Plan, Site Plan & Notes
202-01	Weir - General Arrangement
202-02	Weir - Miscellaneous Details - Sheet 1
202-03	Weir - Miscellaneous Details - Sheet 2
	Armtec Shop Drawings

Notes:

1. Shawnigan Lake Weir Committee comprises
   Cowichan Valley Regional District
   Mill Bay Water works
   Lidstech Holdings Ltd

NO.	DATE	REVISION	BY	APPROVED
B	02/01/07	AS BUILT	DG	
A	28/08/05	BYPASS CHANNEL ADDED	DG	

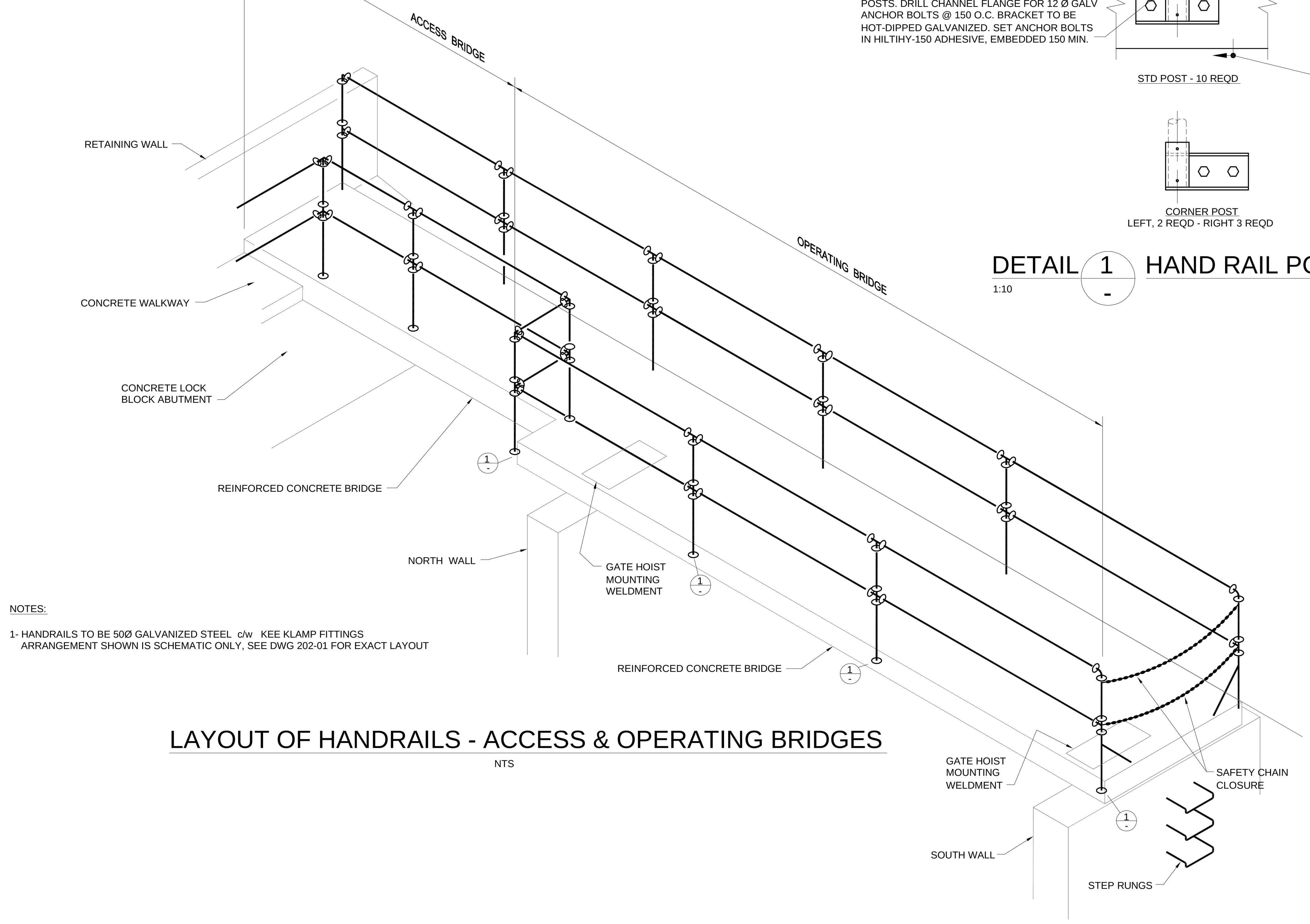
PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — JOHN BRAYBROOKS

John Braybrooks Engineering
2658 CAMERON TAGGART ROAD, MILL BAY B.C. V0R 2P2 250-743-0039

SHAWNIGAN LAKE WEIR COMMITTEE
SHAWNIGAN CREEK WEIR
WEIR
GENERAL ARRANGEMENT

DESIGNED	DRAWN
JB	DG
DATE: JULY 2005	SCALE: AS NOTED
CHECKED	FILE: 202
APPROVED	
DRAWING NO.: 202-01	REV: B

CANCEL PRINTS BEARING EARLIER LETTER



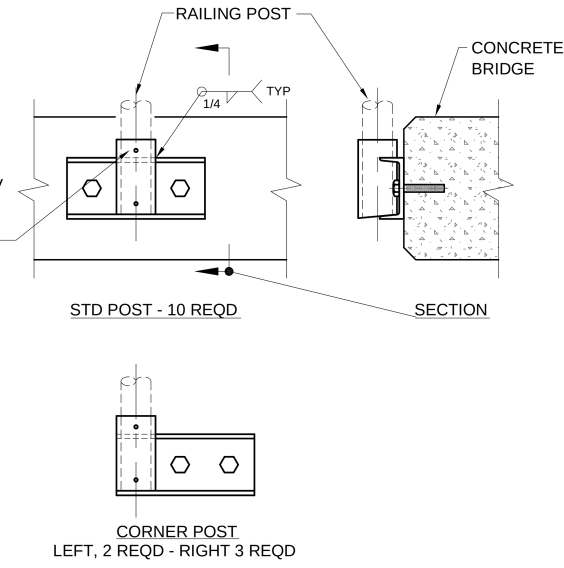
NOTES:

1- HANDRAILS TO BE 50Ø GALVANIZED STEEL c/w KEE KLAMP FITTINGS
ARRANGEMENT SHOWN IS SCHEMATIC ONLY, SEE DWG 202-01 FOR EXACT LAYOUT

LAYOUT OF HANDRAILS - ACCESS & OPERATING BRIDGES

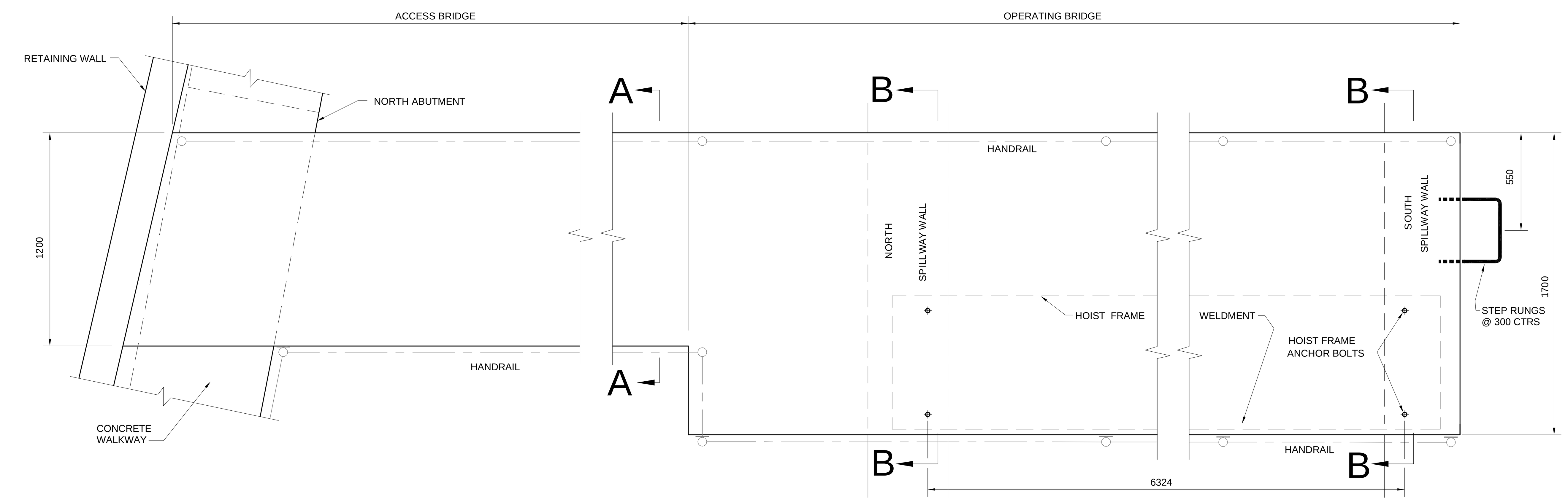
NTS

C100x8 x 230 LONG. DAP TOP FLANGE TO FIT AROUND 125mm LONG SECTION OF DN65 STD PIPE. BEVEL CUT LOWER END OF PIPE TO MATCH FLANGE SLOPE. DRILL & TAP FOR 6 Ø SET SCREWS (NTS) FOR ATTACHING RAILING POSTS. DRILL CHANNEL FLANGE FOR 12 Ø GALV ANCHOR BOLTS @ 150 O.C. BRACKET TO BE HOT-DIPPED GALVANIZED. SET ANCHOR BOLTS IN HILTIHY-150 ADHESIVE, EMBEDDED 150 MIN.



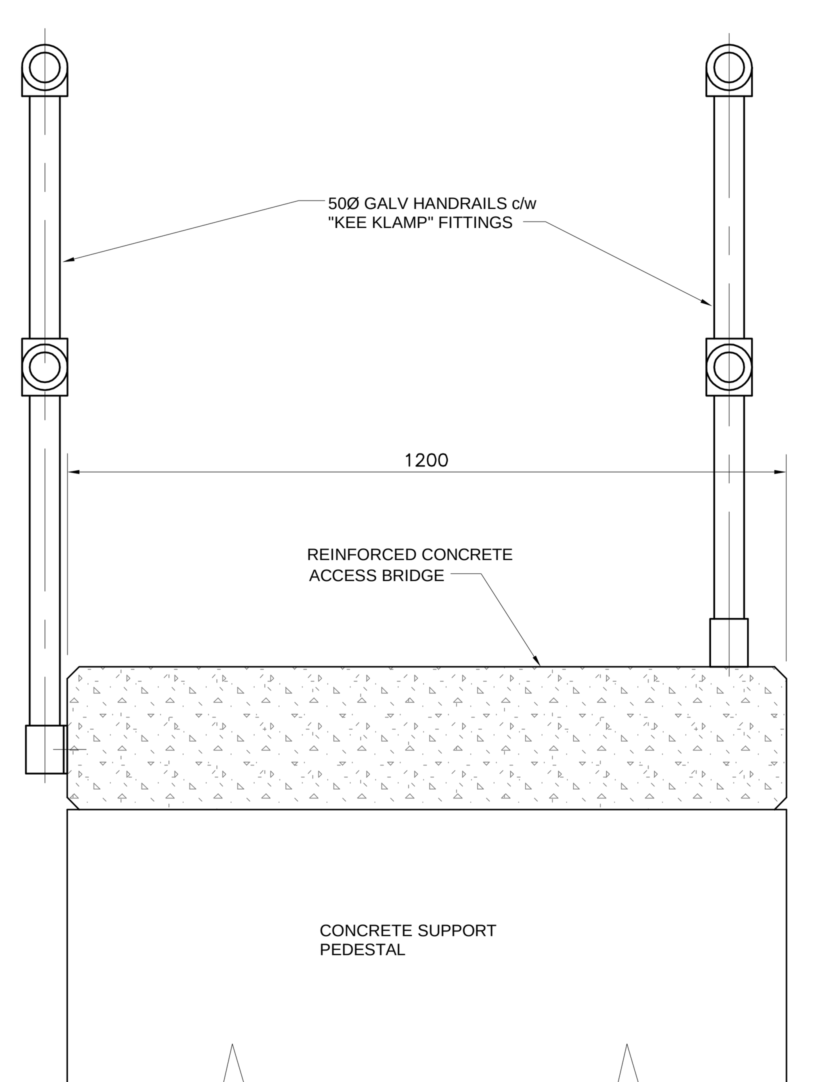
DETAIL 1 HAND RAIL POST BASE

1:10



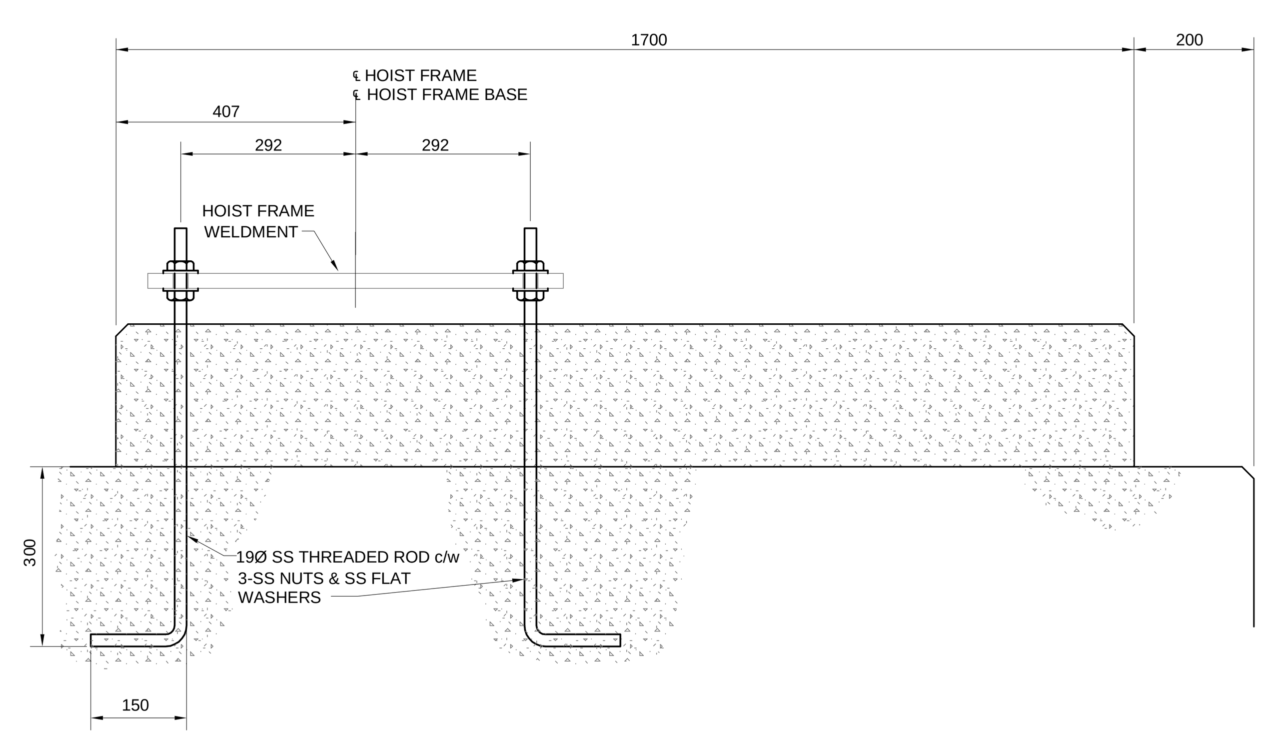
PLAN - ACCESS & OPERATING BRIDGES

NTS



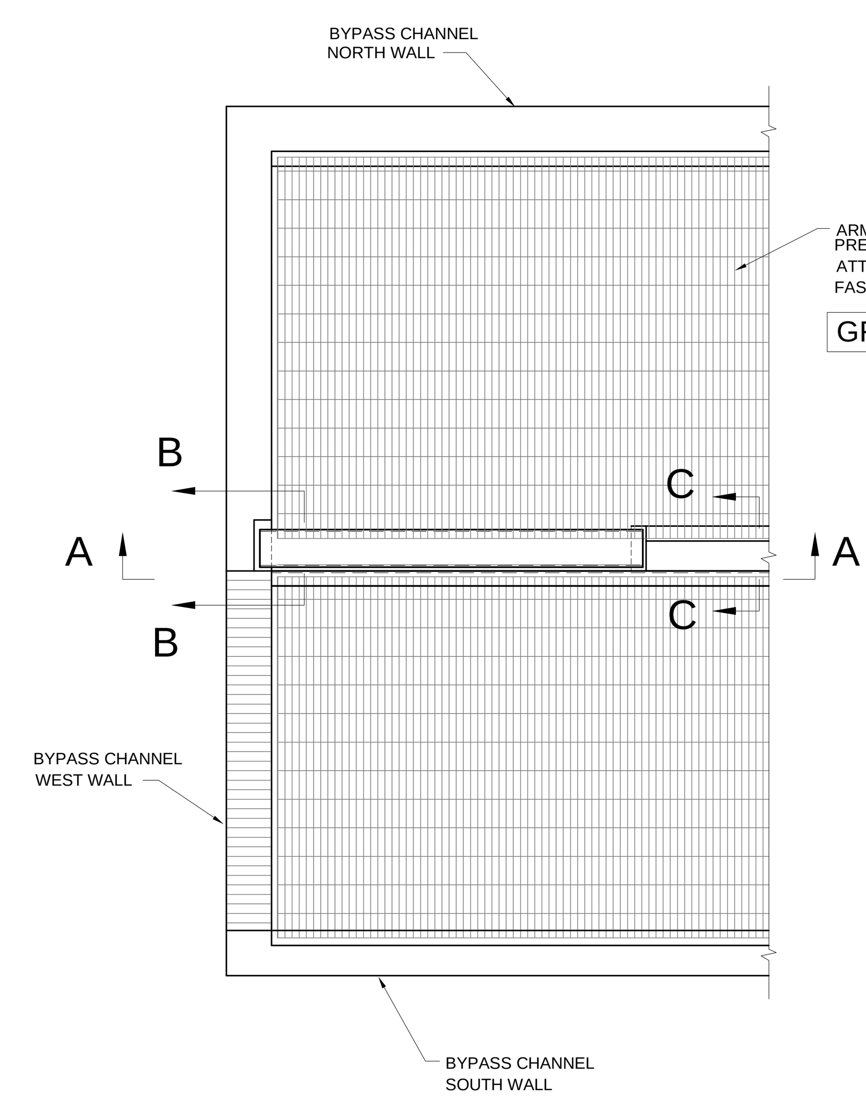
SECTION A-A - ACCESS BRIDGE

1:10



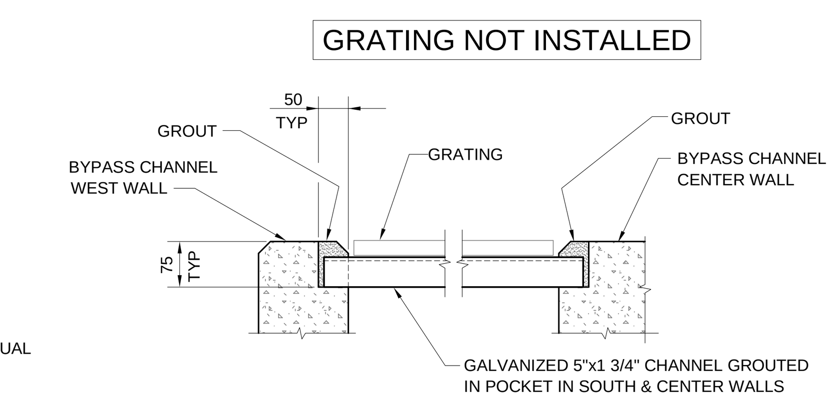
SECTION B-B - OPERATION BRIDGE

1:10



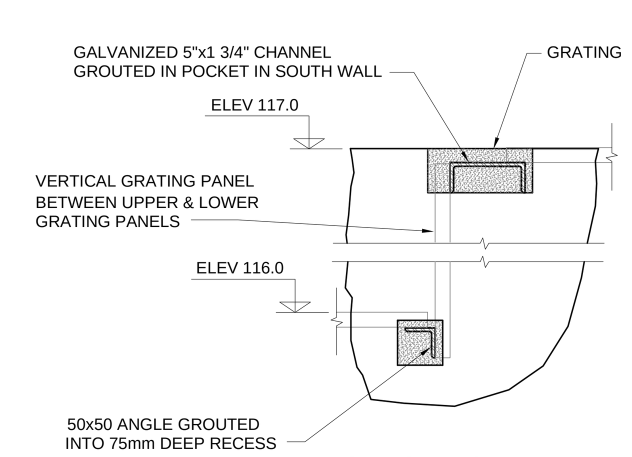
PART PLAN

1:20



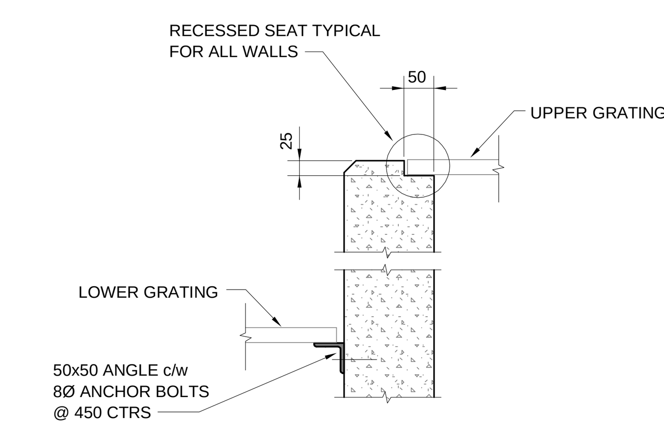
SECTION A-A

1:10



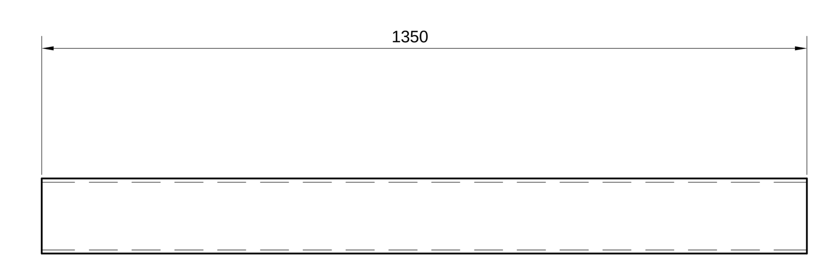
SECTION B-B

1:10

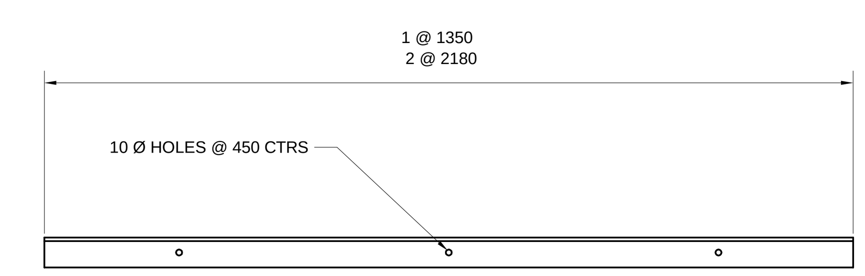


SECTION C-C

1:10



CHANNEL 5" x 1 3/4" - 1 REQD



50 x50 ANGLE

DETAIL 2/01 BYPASS CHANNEL GRATING

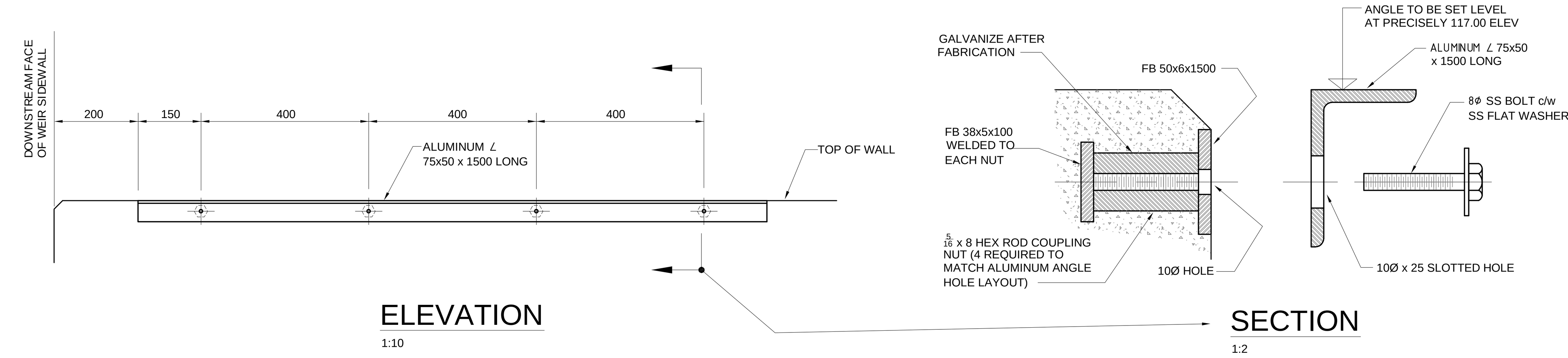
NO.	DATE	REVISION	BY	APPROVED
B	02/01/07	AS BUILT	DG	
A	29/08/05	RAILING POST BASE & GRATING DETAILS ADDED, STOP LOG FRAME MOVED TO DWG 03	DG	

PROFESSIONAL ENGINEER – PROVINCE OF BRITISH COLUMBIA – J. BRAYBROOKS

John Braybrooks Engineering
2658 CAMERON TAGGART ROAD, MILL BAY B.C. V0R-2P2 250-743-0039

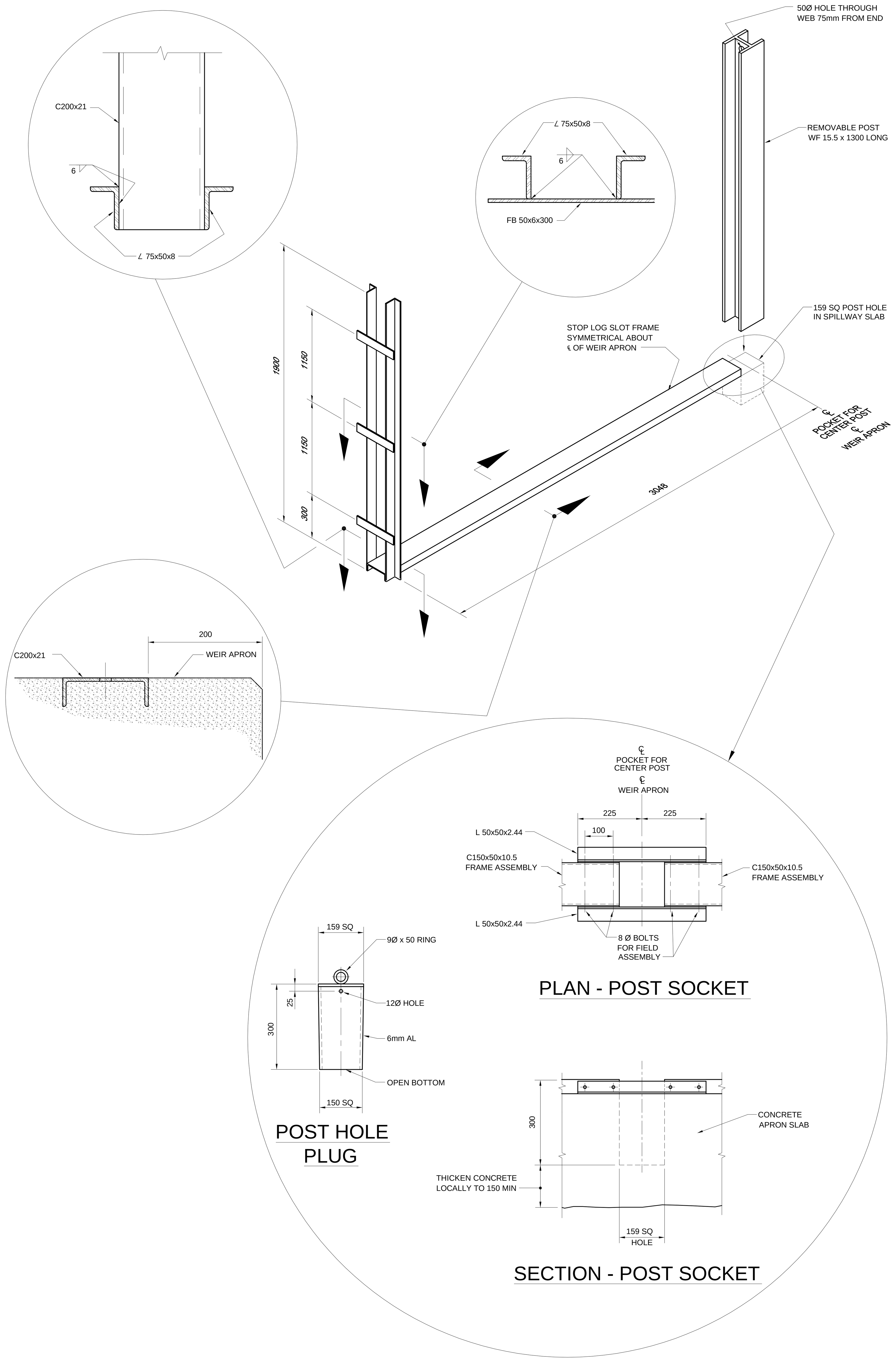
SHAWNIGAN LAKE WEIR COMMITTEE
SHAWNIGAN CREEK WEIR
WEIR
MISCELLANEOUS DETAILS – SHEET 2

DESIGNED: JB	DRAWN: DG
DATE: JULY 2005	SCALE: AS NOTED
CHECKED:	FILE: 202
APPROVED:	
DRAWING NO.: 202-02	REV: B



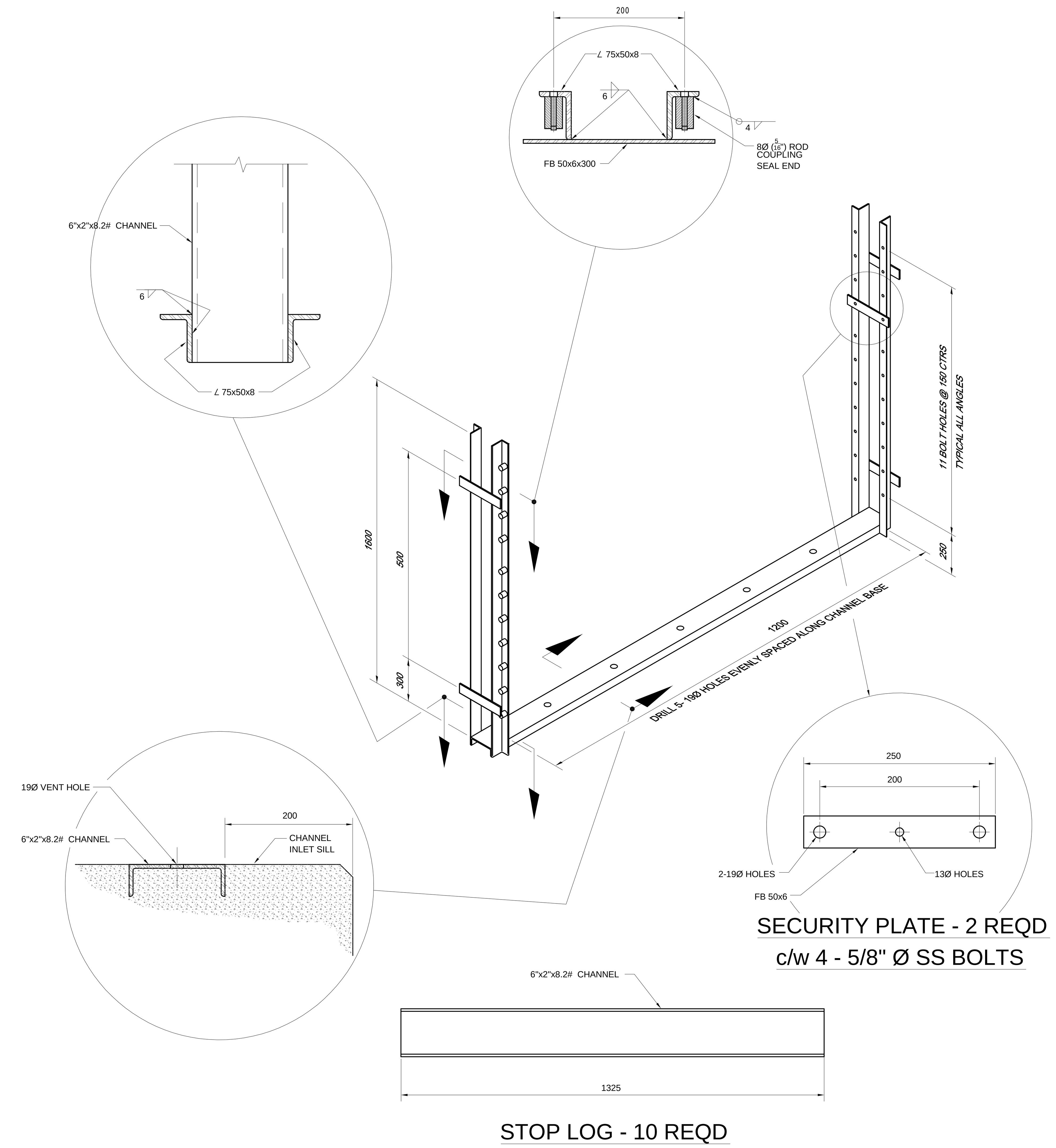
DETAIL 3/01 WEIR SIDEWALL LEVEL REFERENCE

AS NOTED



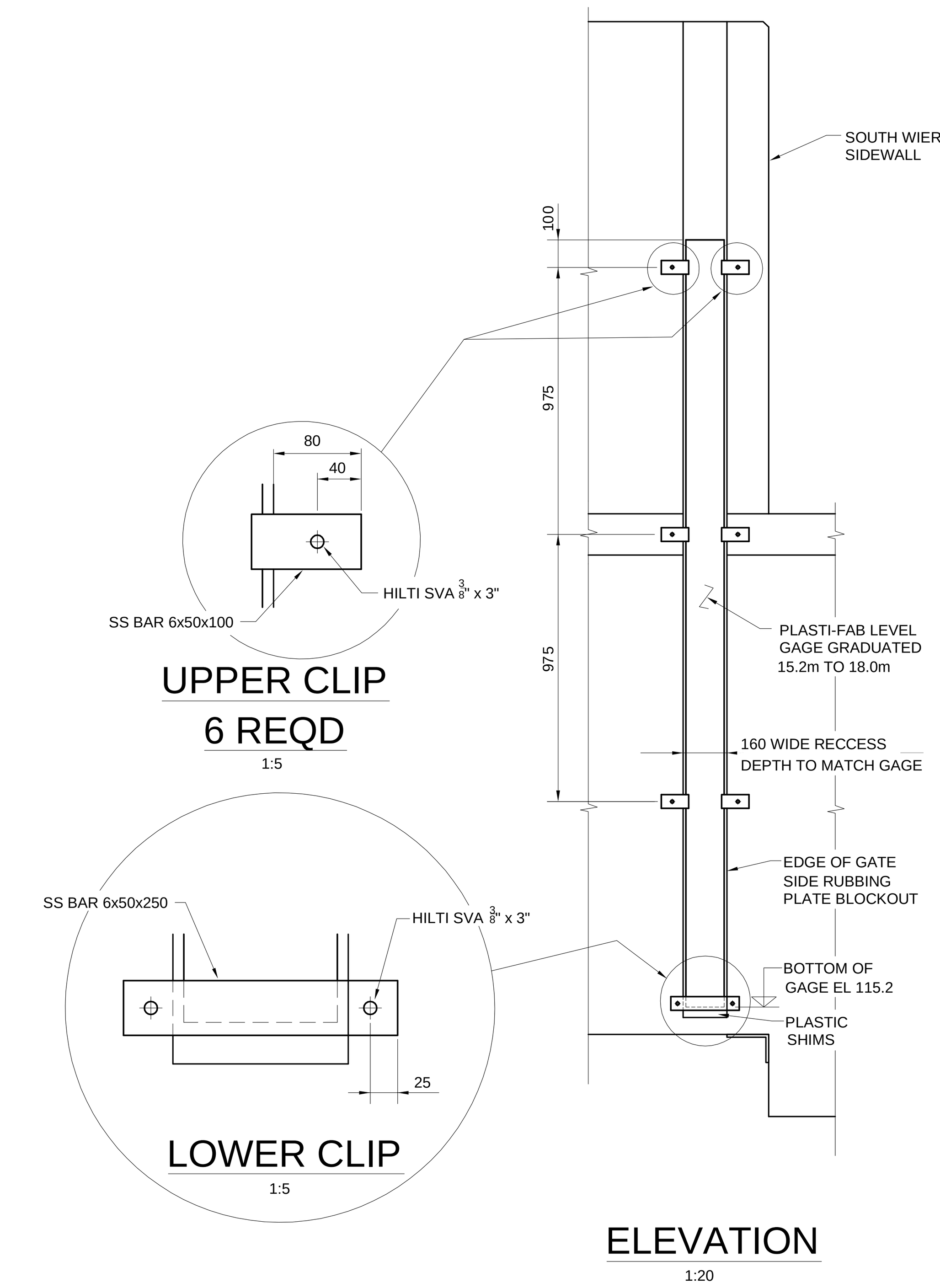
DETAIL 1/01 WEIR TOP LOG SLOT FRAMES & REMOVEABLE CENTER POST

NTS



DETAIL 2/01 BYPASS CHANNEL STOP LOGS & STOP LOG FRAME

NTS



DETAIL 4/01 WATER LEVEL GAGE

NO.	DATE	REVISION	BY	APPROVED
B	02/01/07	AS BUILT	DG	
A	29/08/05	WEIR AND BYPASS CHANNEL STOP LOG FRAMES ADDED	DG	

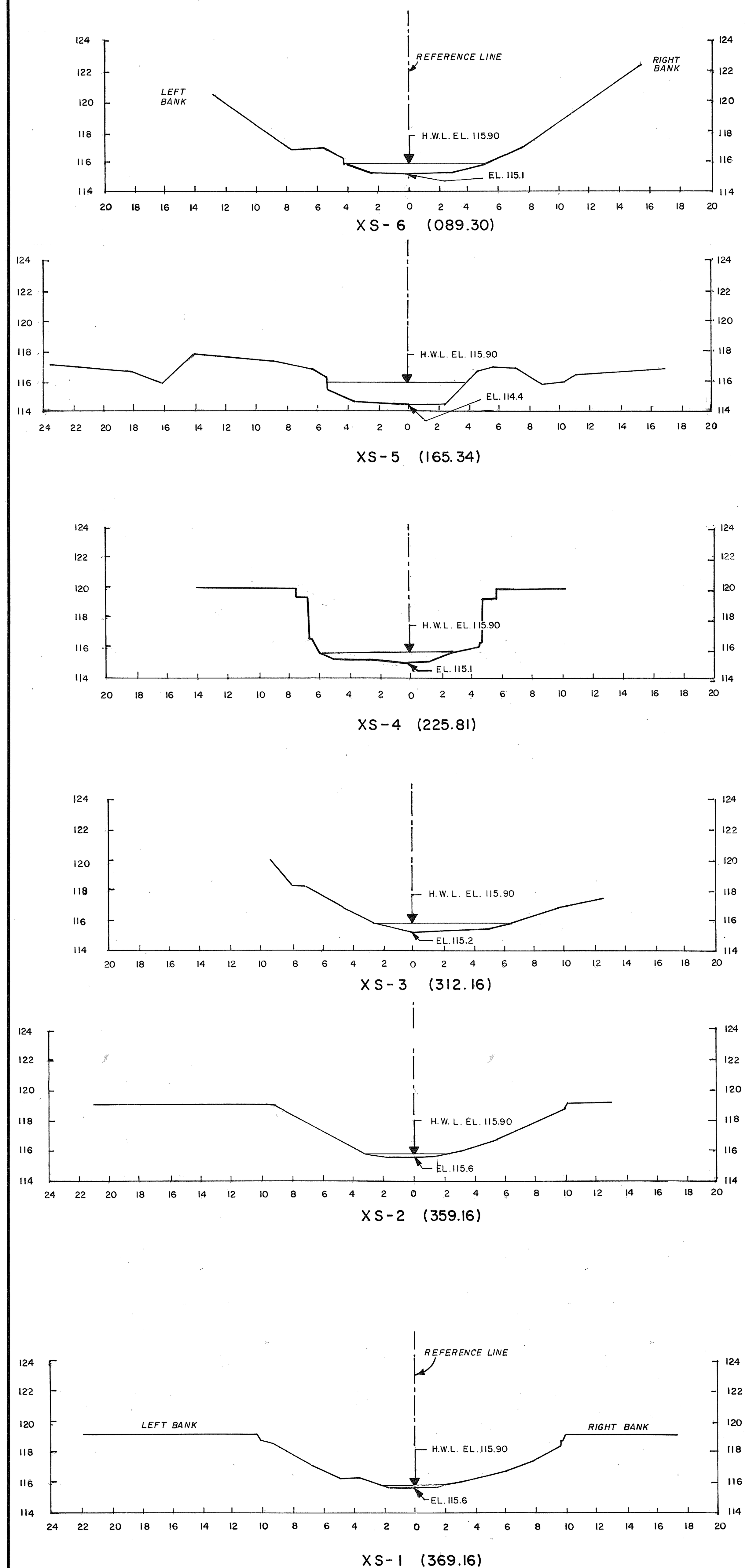
PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — JOHN BRAYBROOKS

John Braybrooks Engineering
2658 CAMERON TAGGART ROAD, MILL BAY B.C. V0R-2P2 250-743-0039

SHAWNIGAN LAKE WEIR COMMITTEE
SHAWNIGAN CREEK WEIR
WEIR
MISCELLANEOUS DETAILS – SHEET 2

DESIGNED: JB	DRAWN: DG
DATE: JULY 2005	SCALE: AS NOTED
CHECKED:	FILE: 202
APPROVED:	
DRAWING NO.: 202–03	REV: B

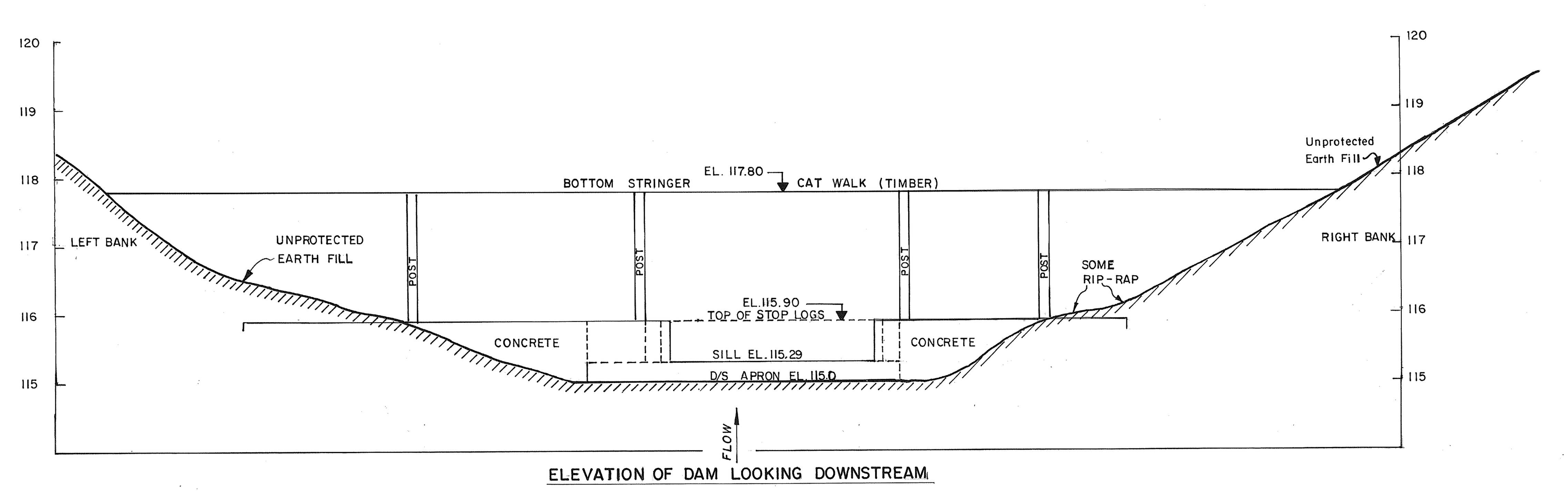
CANCEL PRINTS BEARING EARLIER LETTER



CROSS-SECTIONS OF OUTLET CHANNEL

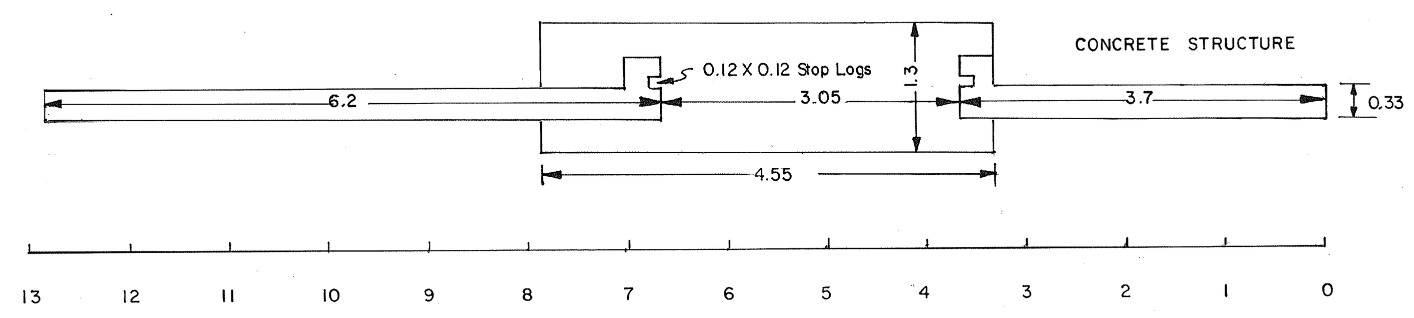
(LOOKING DOWNSTREAM)

SCALE: HOR. 1:200
VERT. 1:200



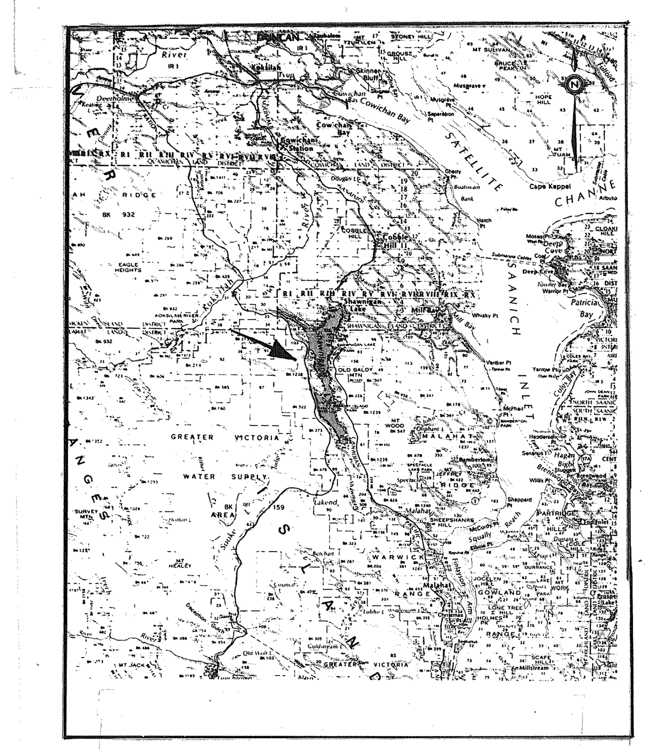
ELEVATION OF DAM LOOKING DOWNSTREAM

SCALE HOR. 1:50
VERT. 1:50



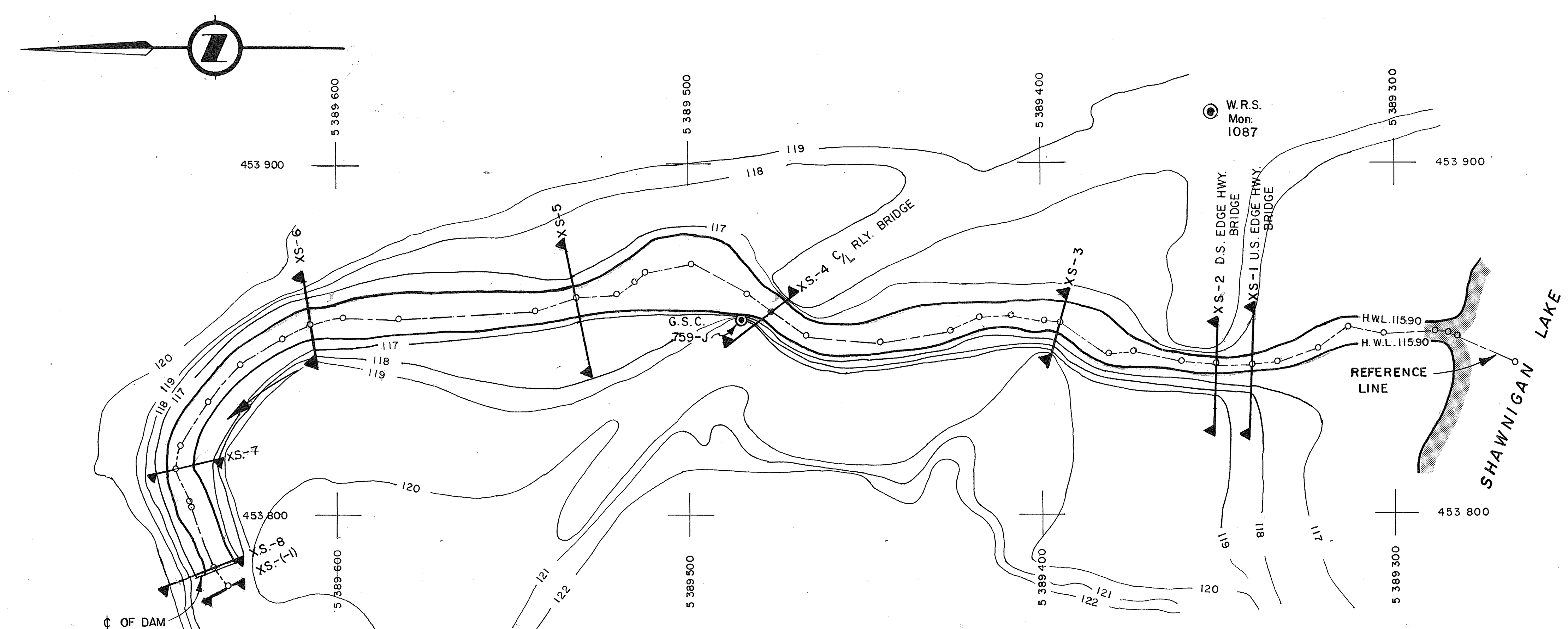
PLAN OF DAM

SCALE 1:50



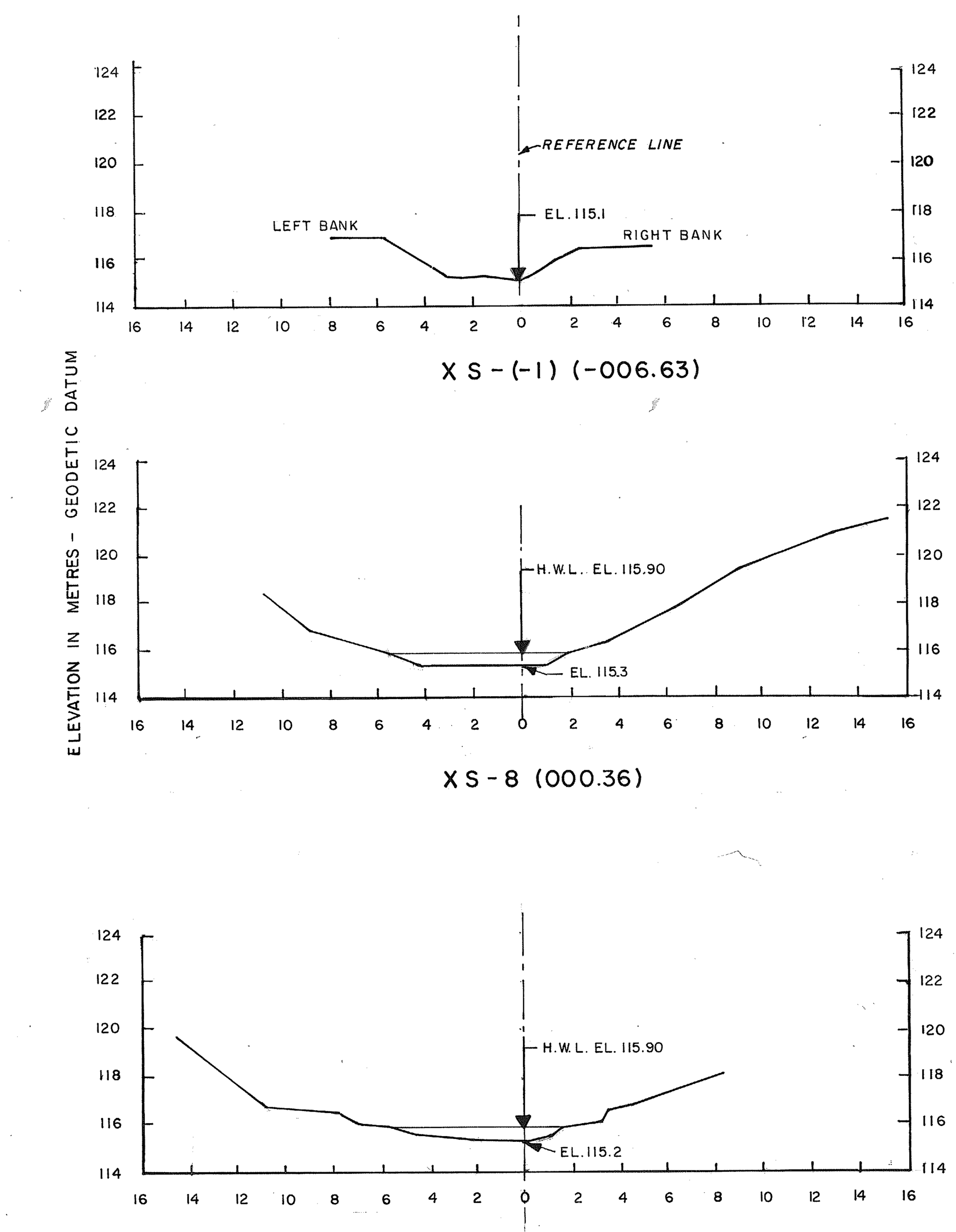
NOTE:

This information is considered historical as it represents channel conditions and configuration at the time of the survey only. User must accept responsibility of ensuring that the accuracy and completeness of provided data is suitable for the needs of the project or study. It is provided "as is" without warranty of any kind, whether express or implied. Under no circumstances will the Government of British Columbia be liable to any person or business entity for any direct, indirect, special, incidental, consequential, or other damages based on any use of this information.

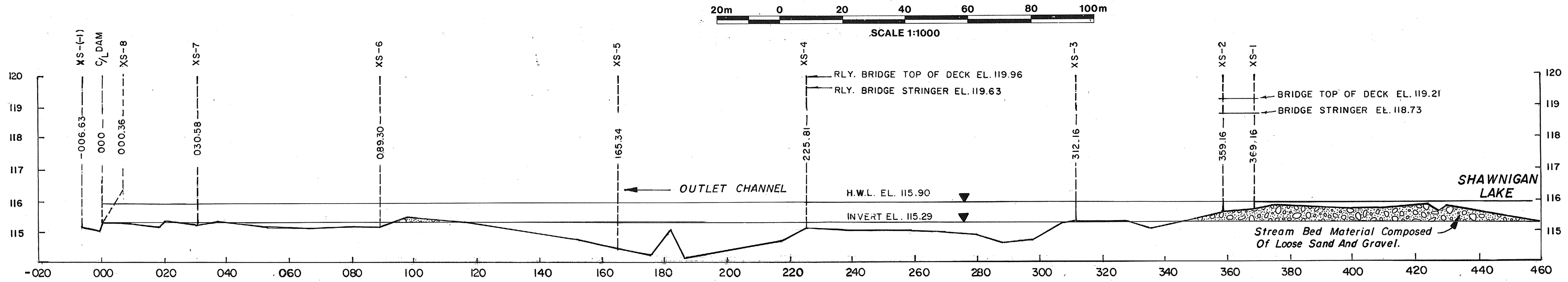


LOCATION OF CROSS-SECTIONS ON OUTLET CHANNEL

SCALE 1:1000



SCALE, HOR. 1:200
VERT. 1:200



PROFILE OF SHAWNIGAN LAKE OUTLET CHANNEL

SCALE: HOR. 1:1000
VERT. 1:100

DIMENSIONS ARE IN SI METRIC

(All dimensions are in metres unless otherwise noted)

NOTES

1) This plan has been prepared from field surveys carried out by the Surveys Sub-Section, Planning and Surveys Section, Inventory and Engineering Branch, Ministry of Environment, Province of British Columbia.

2) SURVEY DATA:
a) Channel sections and profile were obtained by stadia traverse.
b) Structural details were measured using tape and level.
c) The survey was carried out in October, 1980.

3) DATUM:
a) The horizontal control is based on Department of National Defence Post No's. 60 and 66.
b) Coordinates are Universal Transverse Mercator, Zone 11, Central Meridian 123°.
c) Elevations are in metric and referred to Bench Mark No. 759-J, Shawnigan Lake, established by Geodetic Survey of Canada, 1973.

4) FIELD BOOKS:
Survey data are recorded in Field Book No's. 2160 F-1 and 2160 L-1.

5) REFERENCE MONUMENTS:

	Northing	Easting	Elevation
WRS Mon. 1087	5 389 352.048	453 914.539	119.073
G.S.C. 759-J	5 389 484.773	453 855.163	119.529
WRS Mon. 1087 →	GSC 759-J N 24° 06' 07" W	145.457 m	

BCIL-6998 E-GP

LEGEND

- TRIANGULATION STATION
- REFERENCE MONUMENT (P.CON or P.ROCK)
- 50000 HORIZ. CONTROL POINT
- 60000 VERT. CONTROL POINT
- AIR PHOTO CENTER
- ROAD, TRAIL, CREEK, CREEK INTERMITTENT, SWAMP
- BOUNDARIES
- BASIN
- SUB BASIN

STORAGE LICENCES

LICENCE	PRIORITY DATE	AUTHORIZED ACRE-FEET	DEVELOPED ACRE-FEET

REFERENCES

DWG. No.	DESCRIPTION	DATE
4984-8	PLAN OF RESERVOIR SCALE 1:10 000	MARCH, 1979
4984-8A Sheets 1-3	PLAN OF RESERVOIR SCALE 1:5000	FEB, 1979

REVISIONS

No.	DESCRIPTION	DATE
	REVISE XS-4	APRIL 1994

SURVEYED M. PRONK
DATE OCT., 1980
COMPILED M. PRONK J. TAM
CHECKED J. Walersh
DATE JAN. 1981
DRAWN R.M.
CHECKED P. Dixon
DATE DEC., 1980
ENGINEER

Province of British Columbia
Ministry of Environment
INVENTORY AND ENGINEERING BRANCH

STORAGE INVENTORY PROGRAMME
COWICHAN BASIN - VANCOUVER ISLAND SYSTEM

SHAWNIGAN LAKE RESERVOIR

PLAN AND ELEVATION OF DAM INCLUDING PROFILE AND CROSS-SECTIONS OF OUTLET CHANNEL

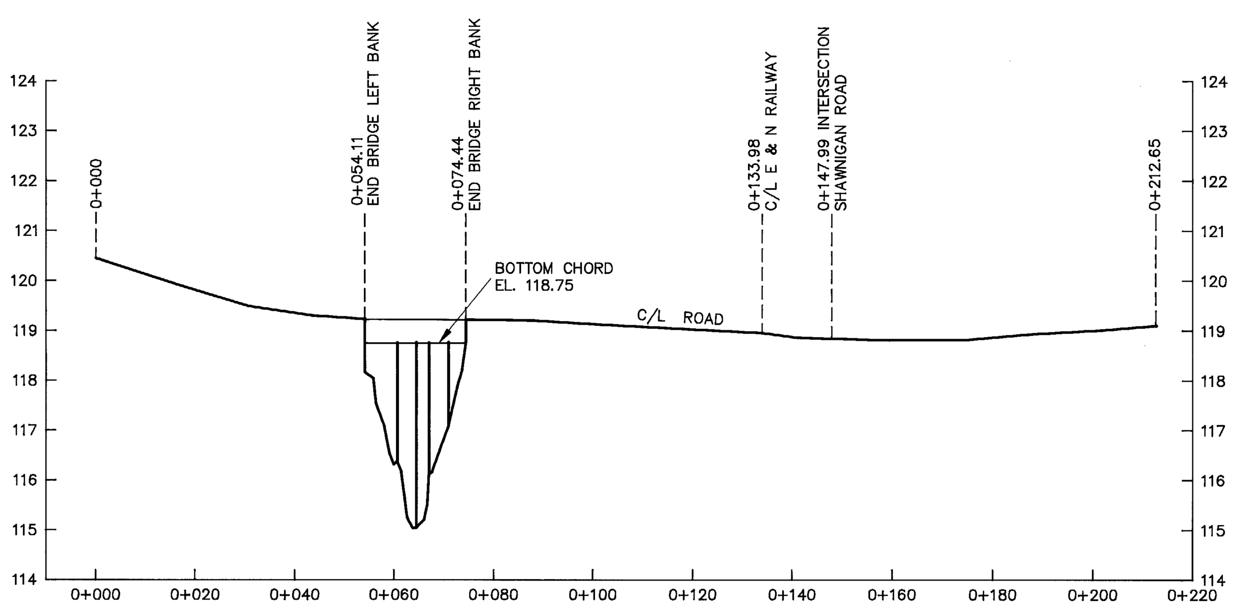
APPROVED Robert G. Harris
HEAD, SURVEYS SUBSECTION
DATE JAN. 1981

FILE No.
Branch
Inventory 0305080-36
SURVEY PROJECT No. 77-SIP-5
NTS Map No. 92B/NW
SCALE AS SHOWN
DRAWING No. 4984-8B
SHEET 1 of 1

272046 DD

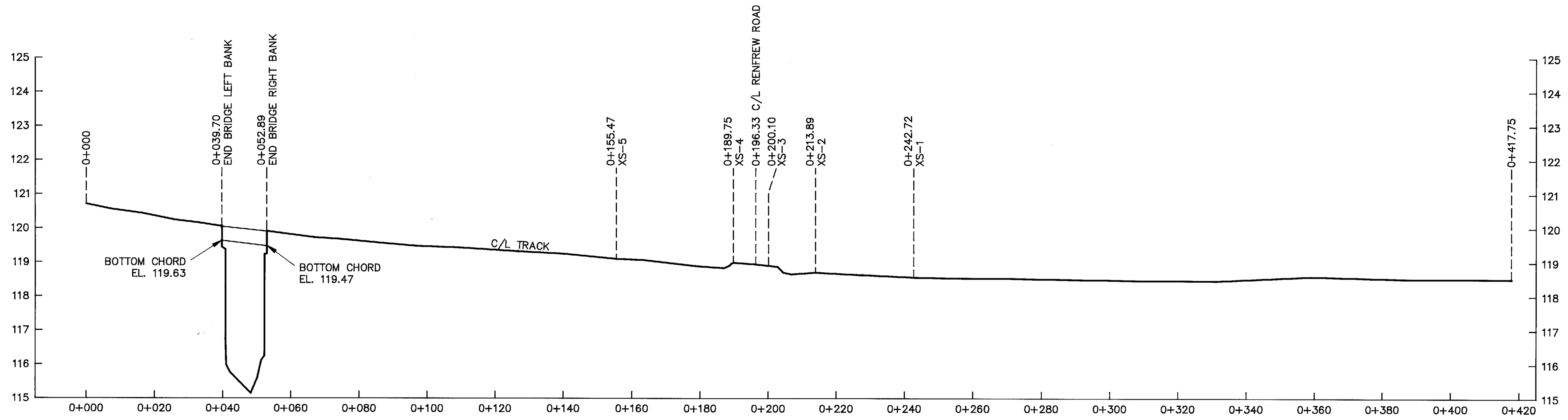
NOTE:

This information is considered historical as it represents channel conditions and configuration at the time of the survey only. User must accept responsibility of ensuring that the accuracy and completeness of provided data is suitable for the needs of the project or study. It is provided "as is" without warranty of any kind, whether express or implied. Under no circumstances will the Government of British Columbia be liable to any person or business entity for any direct, indirect, special, incidental, consequential, or other damages based on any use of this information.



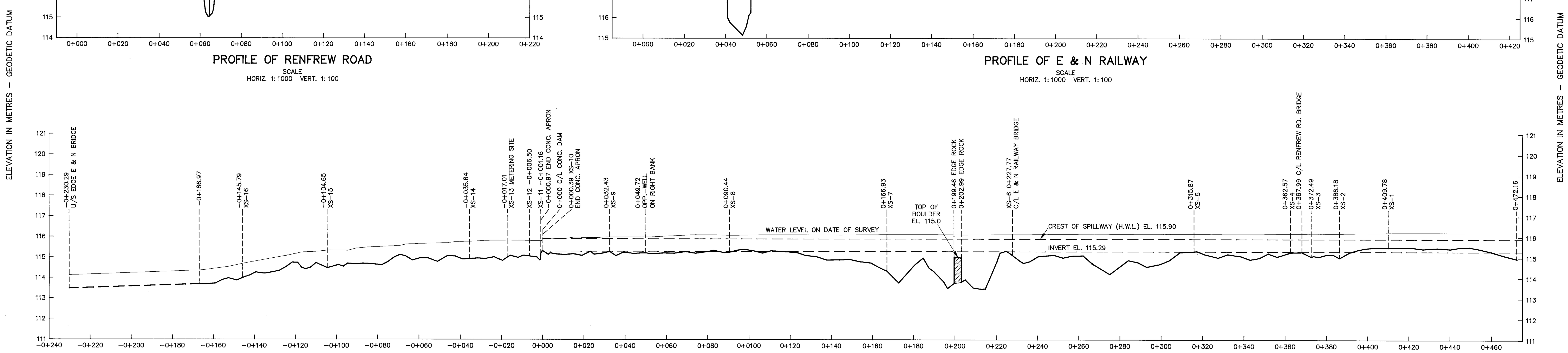
PROFILE OF RENFREW ROAD

SCALE HORIZ. 1:1000 VERT. 1:100



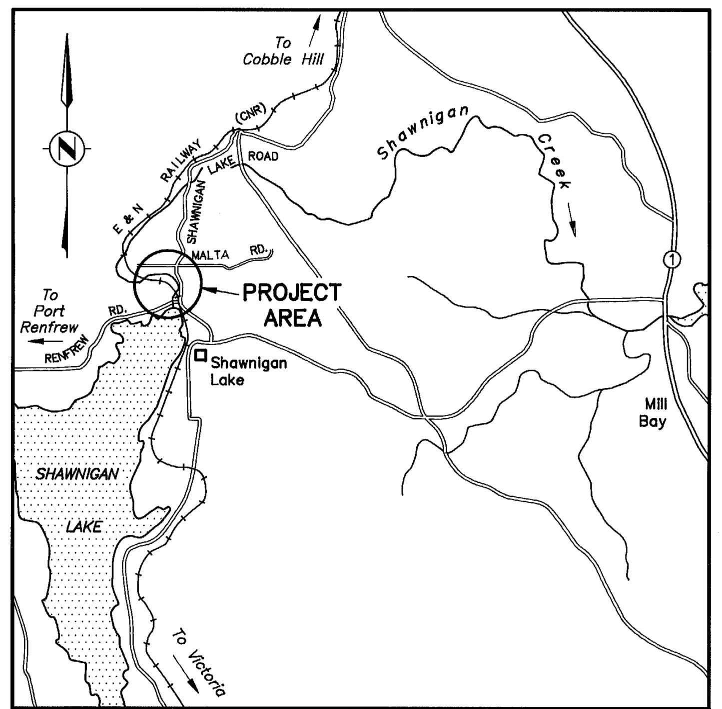
PROFILE OF E & N RAILWAY

SCALE HORIZ. 1:1000 VERT. 1:100



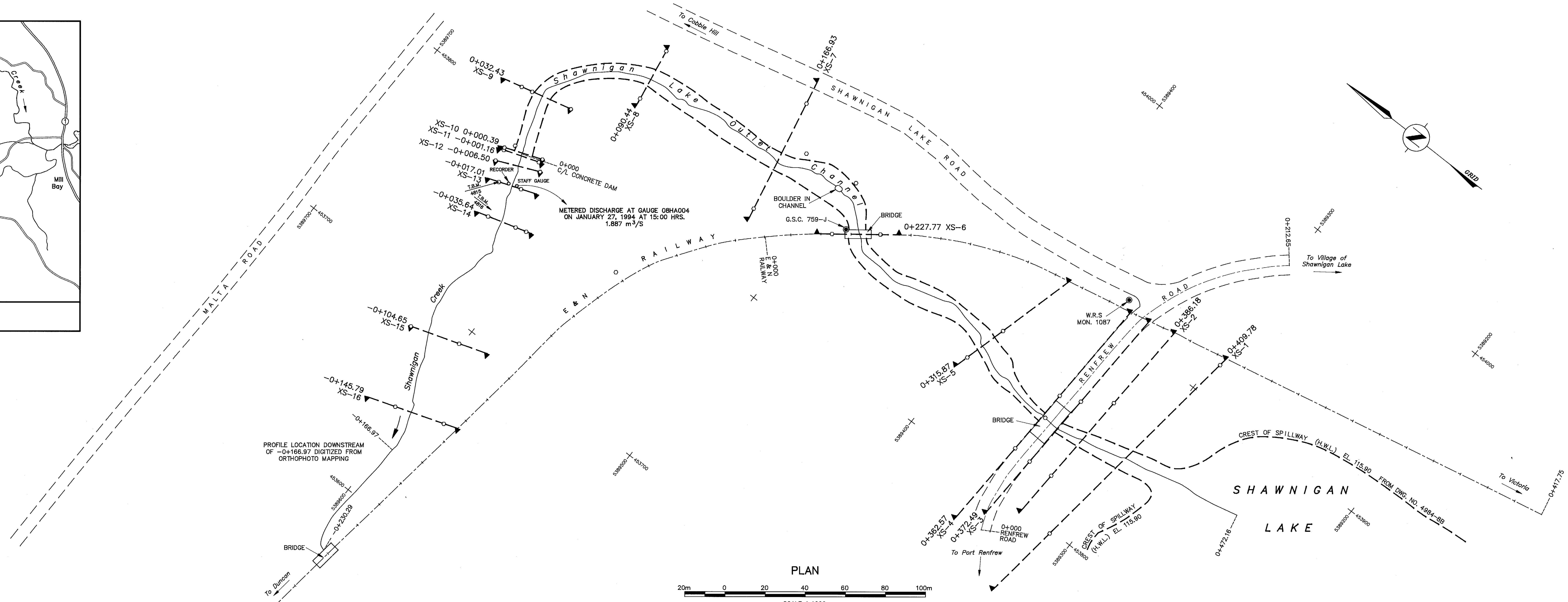
PROFILE OF SHAWNIGAN LAKE OUTLET CHANNEL / SHAWNIGAN CREEK

SCALE HORIZ. 1:1000 VERT. 1:100



KEY MAP

SCALE 1:50,000



PLAN

SCALE 1:1000

NOTES

1) This plan has been prepared by the Ministry of Environment, Lands and Parks, Province of British Columbia.

2) SURVEY DATA:
   a) Field surveys were carried out by the Technical Support Section, Hydrology Branch, Water Management Division.
   b) Horizontal control was established by EDM traverse using a total station theodolite.
   c) Vertical control was established by reciprocal height traversing using a total station theodolite and confirmed by differential levelling.
   d) Cross sections and profiles were obtained using a total station theodolite.
   e) Additional planimetric details of railway, creek and roads were obtained by digitizing orthophoto floodplain mapping drawing A5250 sheet 2, scale 1:5000.

3) DATUM:
   a) Horizontal control is based on reference points established by the Technical Support Section in May 1977 under Projects 77FDC07 and 77SIP05 during Shawnigan Lake Floodplain and Storage Inventory Surveys.
      Reference points were tied to monuments 60 and 66 established by the Department of National Defense in 1930.
   b) Coordinates are Universal Transverse Mercator, Zone 10, Central Meridian 123 degrees, NAD27.
   c) Vertical control is based on bench mark 759J established by Geodetic Survey of Canada, as listed in Vertical Control Data Publication for Quad. No.48123, Revision No.2, October 1973.
   d) Elevations are in metres and are referred to the Canadian Geodetic Datum.

4) FIELD BOOKS:
   Survey data are recorded on Disc labelled 2639D and Field Book 2639F.

5) REFERENCE POINTS:

a) Geodetic Survey of Canada

Bench Mark	Northing	Easting	Elevation
759J	5389484.772	453855.164	119.529

b) Water Management Division

Bench Mark	Northing	Easting	Elevation
WRS Mon. 1087	5389352.047	453914.540	119.076

GSC 759J → WRS Mon. 1087 S24 06 08E 145.401

Distance between reference points as shown is Grid or Projection distance.

LEGEND

- REFERENCE POINT
- T.B.M. TEMPORARY BENCH MARK
- TEMPORARY REFERENCE POINT
- B.C. ENVIRONMENT GAUGE

STORAGE LICENCES

LICENCE	PRIORITY DATE	AUTHORIZED ACRE–FEET	DEVELOPED ACRE–FEET

REFERENCES

DWG. No.	DESCRIPTION	DATE
4984–8	PLAN OF RESERVOIR SCALE 1:10,000	MAR. 1979
4984–8A SHEETS 1–3	PLAN OF RESERVOIR SCALE 1:5000	FEB. 1979
4984–8B	PLAN AND ELEVATION OF DAM INCLUDING PROFILE AND CROSS SECTIONS OF OUTLET CHANNEL	JAN. 1981
A5250 SHEETS 1–3	ORTHOPHOTO FLOODPLAIN MAPPING	SEPT. 1979

REVISIONS

No.	DESCRIPTION	DATE

SURVEYED M. PRONK DATE JAN. 1994
COMPILED J. DUNCAN
CHECKED M. Pronk DATE
DRAWN B.WOODS
APPROVED
DATE APR. 1994
ENGINEER

Province of British Columbia — Ministry of Environment, Lands and Parks, WATER MANAGEMENT DIVISION

STORAGE INVENTORY PROGRAMME
COWICHAN BASIN – VANCOUVER ISLAND SYSTEM

SHAWNIGAN LAKE RESERVOIR
OUTLET CHANNEL
PLAN AND PROFILE

APPROVED Bernd R. Schubert — MANAGER, TECHNICAL SUPPORT SECTION — DATE April 5/'94

FILE Nos. Branch

SURVEY PROJECT No. 94 01 P 019

NTS Map No. 92B/12 Map Scale 1:50,000

SCALE AS SHOWN

NEGATIVE NO.

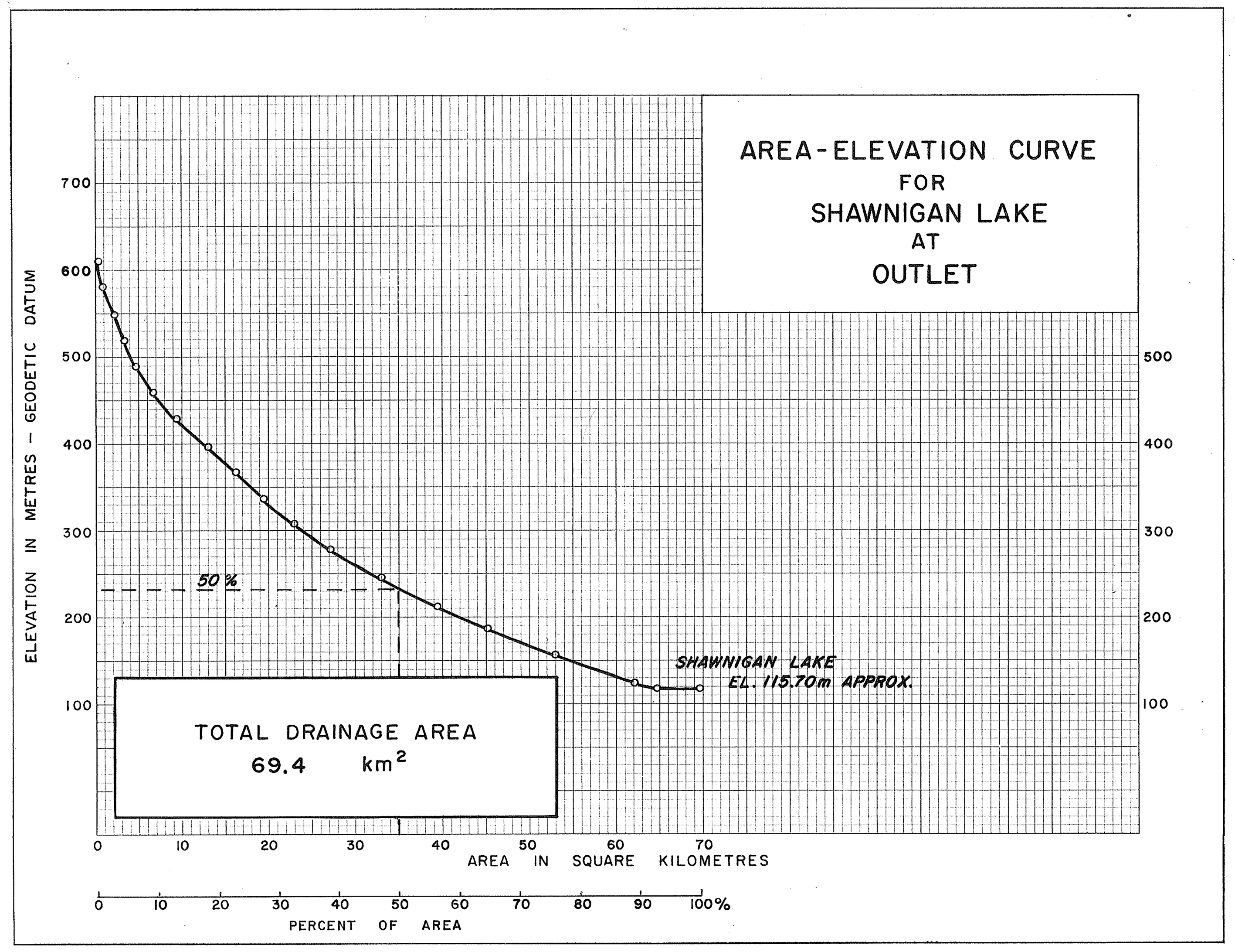
DRAWING No. 4984-8C

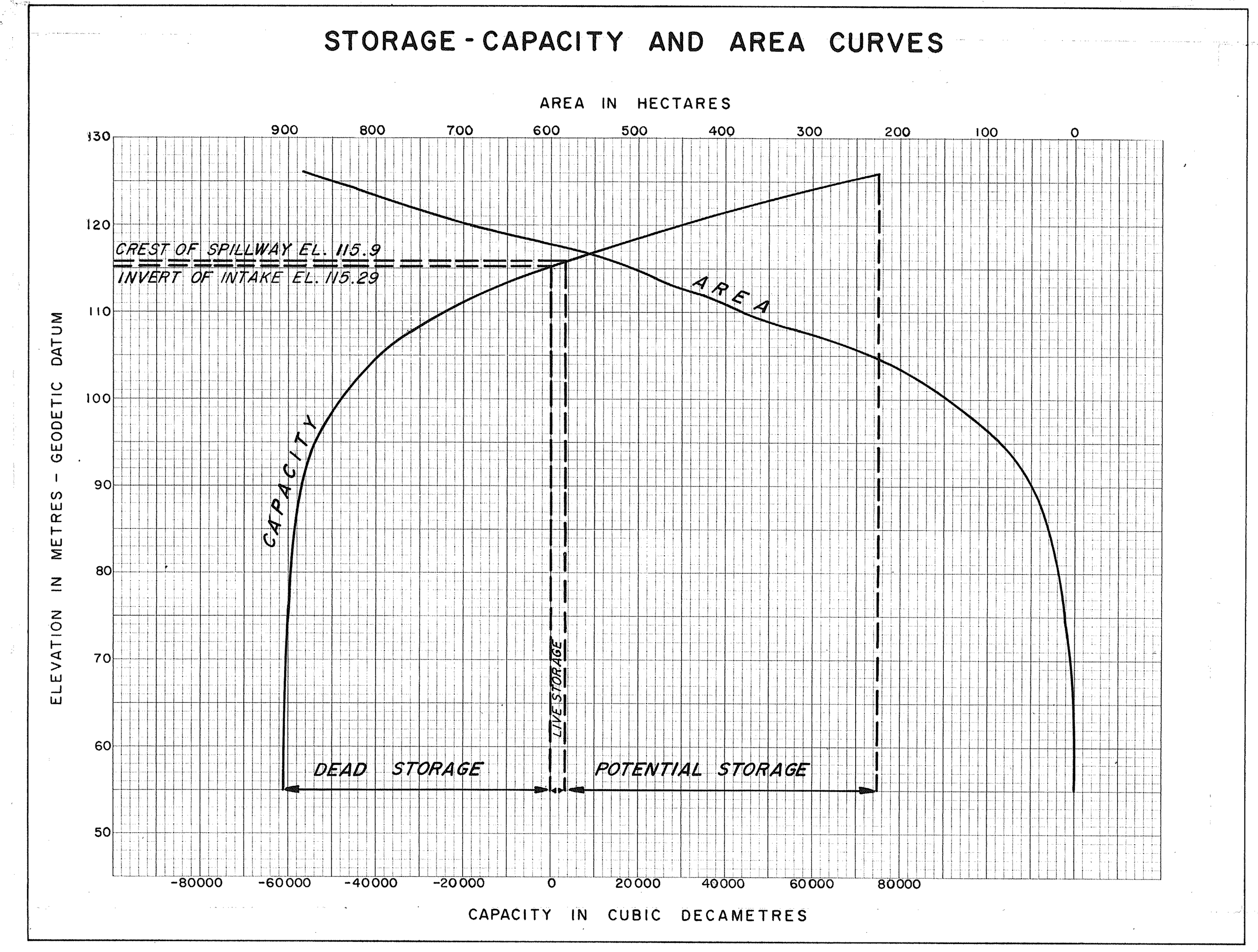
TOTAL No. OF DWGS. 1

DDs

STORAGE - CAPACITY TABLE

MAPPING DATA			STORAGE CAPACITY				REMARKS
CONTOUR ELEVATION		Area in Hectares	Depth of Storage in Metres	Area in Hectares	STORAGE IN DECAMETRES^3		
Geodetic Datum	Local Datum				Net	Gross	
55.5		0.00	-59.8	0.00		60885	LOW POINT IN LAKE
			-50	0.99	48	60837	
66		1.06			7		
			-48	1.87	19	60811	
68		2.32			15		
			-46	3.43	37	60759	
70		4.04			26		
			-44	5.13	60	60673	
72		5.73			38		
			-42	8.29	91	60544	
74		9.70			44		
			-40	11.5	157	60343	
76		12.5			85		
			-38	14.3	173	60085	
78		15.3			105		
			-36	17.1	210	59770	
80		18.1			125		
			-34	19.7	244	59401	
82		20.6			143		
			-32	22.8	280	58978	
84		24.0			166		STORAGE
			-30	27.8	334	58478	
86		29.9			205		
			-28	36.0	425	57848	
88		39.3			267		
			-26	45.6	547	57034	
90		49.1			336		
			-24	56.8	683	56015	
92		61.1			419		
			-22	68.4	835	54761	
94		72.4			500		
			-20	86.9	1028	53233	
96		94.8			645		
			-18	110.4	1323	51265	
98		118.9			814		
			-16	135.2	1640	48811	
100		144.2			992		
			-14	162.9	1981	45838	
102		173.2			1193		
			-12	196.2	2382	42263	
104		208.9			1438		DEAD
			-10	238.0	2883	37942	
106		254.1			1747		
			- 8	295.8	3547	32648	
108		318.7			2181		
			- 6	356.6	4356	26111	
110		377.5			2606		
			- 4	408.4	5070	18435	
112		425.4			2960		
			- 2	461.4	5720	9755	
114		481.2			3346		
			- 1.0	488.2	1405	5004	
			- 0.9	490.6	489	4515	
			- 0.8	493.1	492	4023	
			- 0.7	495.5	494	3529	
			- 0.6	497.9	496	3033	
			- 0.5	500.4	499	2532	
			- 0.4	502.8	502	2030	
			- 0.3	505.2	504	1526	
			- 0.2	507.7	506	1020	
			- 0.1	510.1	509	511	
115.29			0.0	512.5	511	0	INVERT OF INTAKE
			0.1	514.9	514	514	
			0.2	517.4	516	1030	
			0.3	519.8	518	1548	LIVE STORAGE
			0.4	522.2	521	2069	
			0.5	524.7	524	2593	
			0.6	527.1	526	3119	
115.9			0.61	527.3	53	3172	CREST OF SPILLWAY
			0.7	529.5	475	3647	
			0.8	531.9	531	4178	
			0.9	534.4	533	4711	
116.22		535.1			161		
			1.0	538.1	375	5247	
			2.0	580.3	5592	10839	
118		610.3			4227		STORAGE
			4.0	661.5	8203	23269	
120		689.7			4796		
			6.0	734.5	9186	37251	
122		759.2			5303		POTENTIAL
			8.0	799.7	10055	52609	
124		822.0			5757		
			10.0	862.0	10861	69227	
126		884.0	10.71	884.0	6198	75425	





NOTE:

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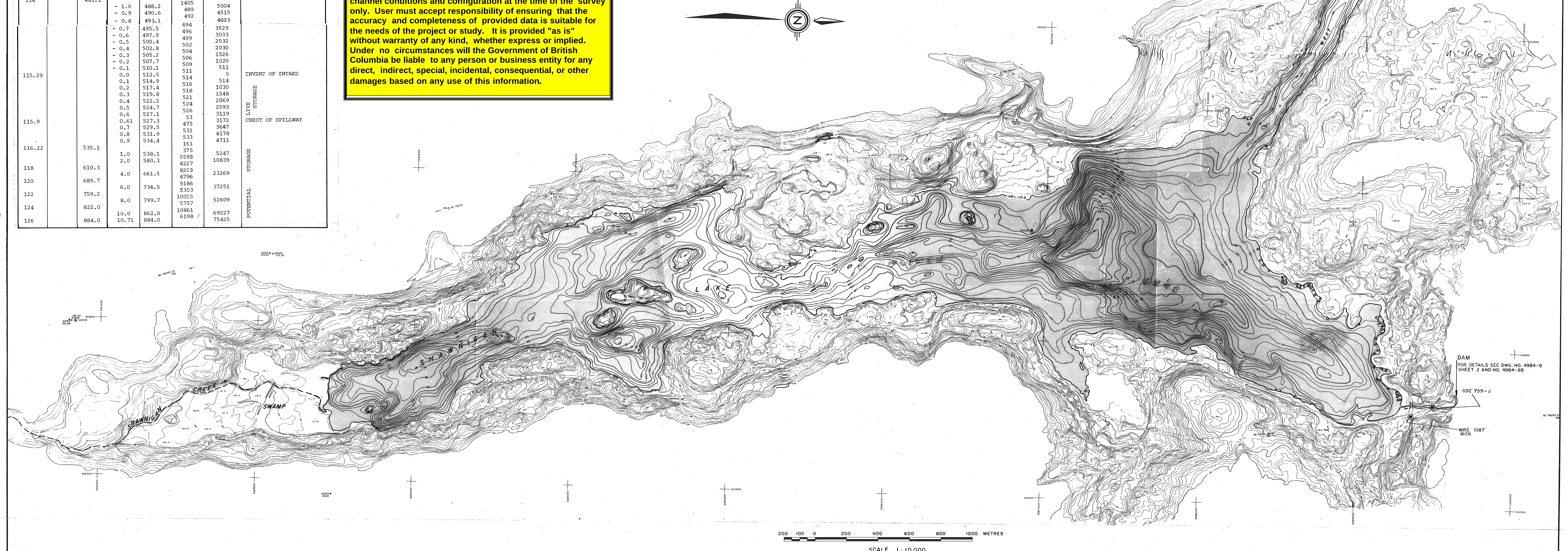

NOTES

1) This map has been prepared from field surveys carried out by the Surveys Section, Planning and Surveys Division, Water Investigations Branch and photogrammetric mapping, prepared by the Surveys and Mapping Branch, Ministry of Environment, Province of British Columbia.
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   a) Horizotal control was established by traverse, using Hewlett-Packard Distance Meter, Model 3800B.
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   c) Position control for bathymetry was maintained by simultaneous fixes from theodolites which were set over coordinated shore stations.
   d) The survey was carried out in May and June, 1977.
3) DATUM:
   a) The horizonal control is based on Department of National Defense Post No's. 60 and 66.
   b) Coordinates are Universal Transverse Mercator, Zone 11, Central Meridian 123°.
   c) Elevation (metre) is referred to Bench Mark No. 759-J, Shawnigan Lake, established by Geodetic Survey of Canada, 1973.
4) FIELD BOOKS:
   Survey data are recorded in Field Book No's. 2160-F-1, 2160 L-1 and 2160 I-1 to 2160 I-10.
5) AIR PHOTOGRAPHS:
   B.C. 5769: Frames 1 to 37, inclusive, exposed April 5, 1978. Photo scale = Approx. 1:10000
6) MAPPING:
   a) Mapping Project No. 78-74T-0, Map Production Division.
   b) The reservoir area above water level was mapped using a Wild B8 Stereo Plotter, at a scale = 1:5000
   c) For planimetric details see Orthophoto Project No. 78-74T-0, sheets 1 to 7.
7) REFERENCE MONUMENTS:

	Northing	Easting	Elevation
WRS Mon. 1087	5 389 352.048	453 914.539	119.073
GSC 759-J	5 389 484.773	453 855.163	119.529

   WRS Mon. 1087 → GSC 759-J -N 24° 06' 07"W-145.457 m
8) H.W.L. = Crest of Spillway

LEGEND

- TRIANGULATION STATION
- REFERENCE MONUMENTS: P. CON. OR P. ROCK
- 50000 HORIZ. CONTROL POINT
- 60000 VERT. CONTROL POINT
- AIR PHOTO CENTRE
- ROAD, ----TRAIL, CREEK,
- CREEK INTERMITTENT, SWAMP
- BOUNDARIES:
- BASINS
- SUB-BASIN

STORAGE LICENCES

LICENCE	PRIORITY DATE	AUTHORIZED ACRE - FEET	DEVELOPED
C.L. 27948	OCT. 18, 1962	1000	3172 dam^3

1 ACRE-FOOT = 1.233482 CUBIC DECAMETRES

REFERENCES

DWG. No.	DESCRIPTION	DATE
4984-8A SHEETS 1-3	PLAN OF RESERVOIR SCALE 1:5000	FEBRUARY 1979
PROJECT NO. 78-74T-0 SHEETS 1-7	ORTHOPHOTO MAP SCALE 1:5 000	MAY 1978
4984-8B	PLAN AND ELEVATION OF DAM INCLUDING PROFILE AND CROSS-SECTIONS OF OUTLET CHANNEL	JAN. 1981

REVISIONS

No.	DESCRIPTION	DATE
1	TABLE AND DETAILS	OCT. 1981

SURVEYS SECTION

SURVEYED: M. PRONK
DATE: OCT. 1980 MAY 1977
COMPILED: M. PRONK
CHECKED: G. Wabusk
DATE: MARCH 1979

DRAUGHTING SECTION

DRAWN: J.T.
CHECKED: P. Dixon
DATE: MARCH 1979

Province of British Columbia
Ministry of the Environment
ENVIRONMENTAL AND ENGINEERING SERVICE
WATER INVESTIGATIONS BRANCH

STORAGE INVENTORY PROGRAMME
COWICHAN BASIN - VANCOUVER ISLAND SYSTEM

SHAWNIGAN LAKE RESERVOIR

PLAN OF RESERVOIR

APPROVED Robert G. Harris DATE MARCH 1979
HEAD, SURVEYS SECTION, PLANNING & SURVEYS DIVISION

FILE No.
Branch
Inventory 0305080-36
SCALE 1:10 000
SURVEY PROJECT No. 77-S.I.P.-5
DRAWING No. 4984-8
SHEET 1 of 1

272042 DD1
SURVEYS

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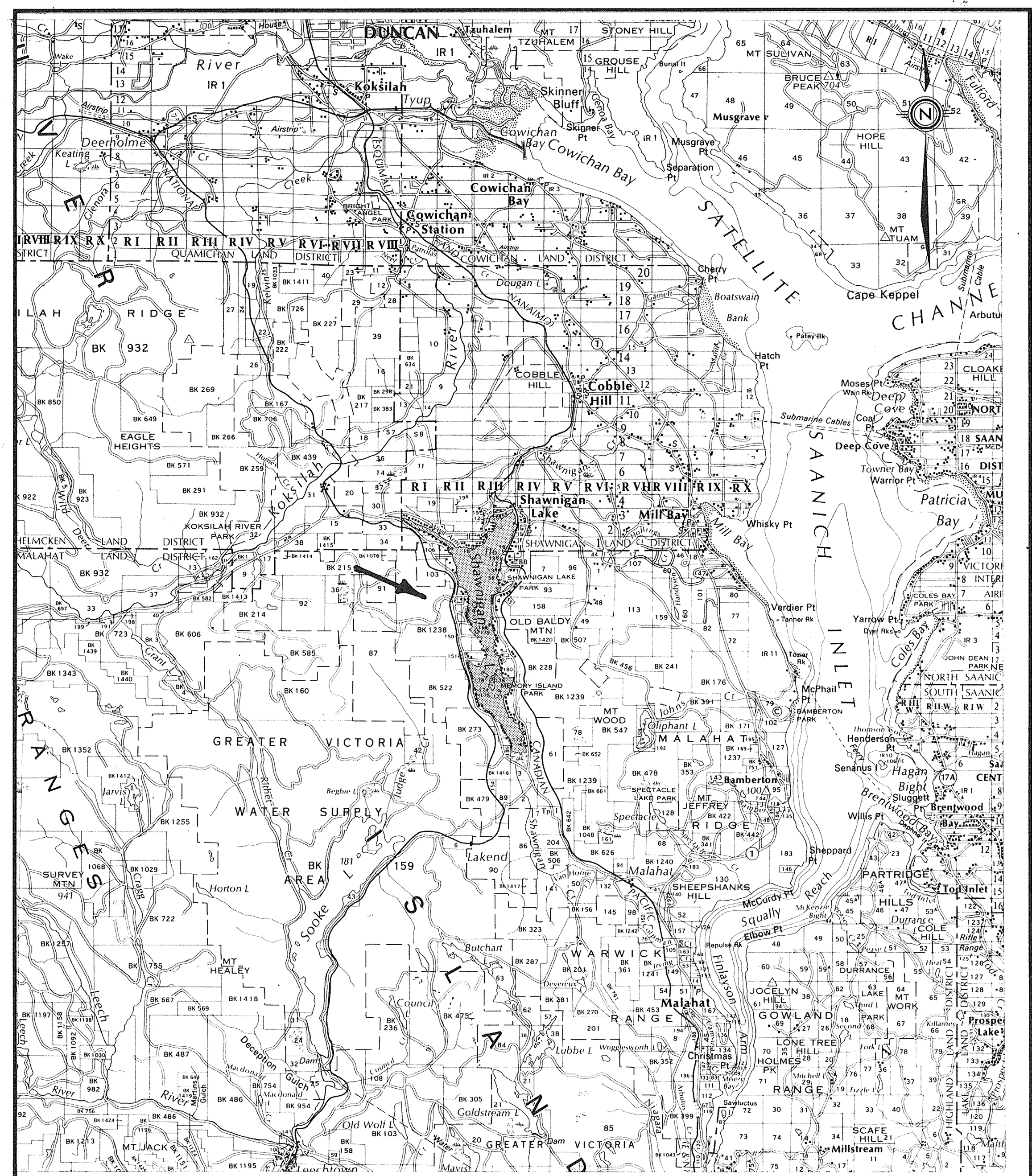
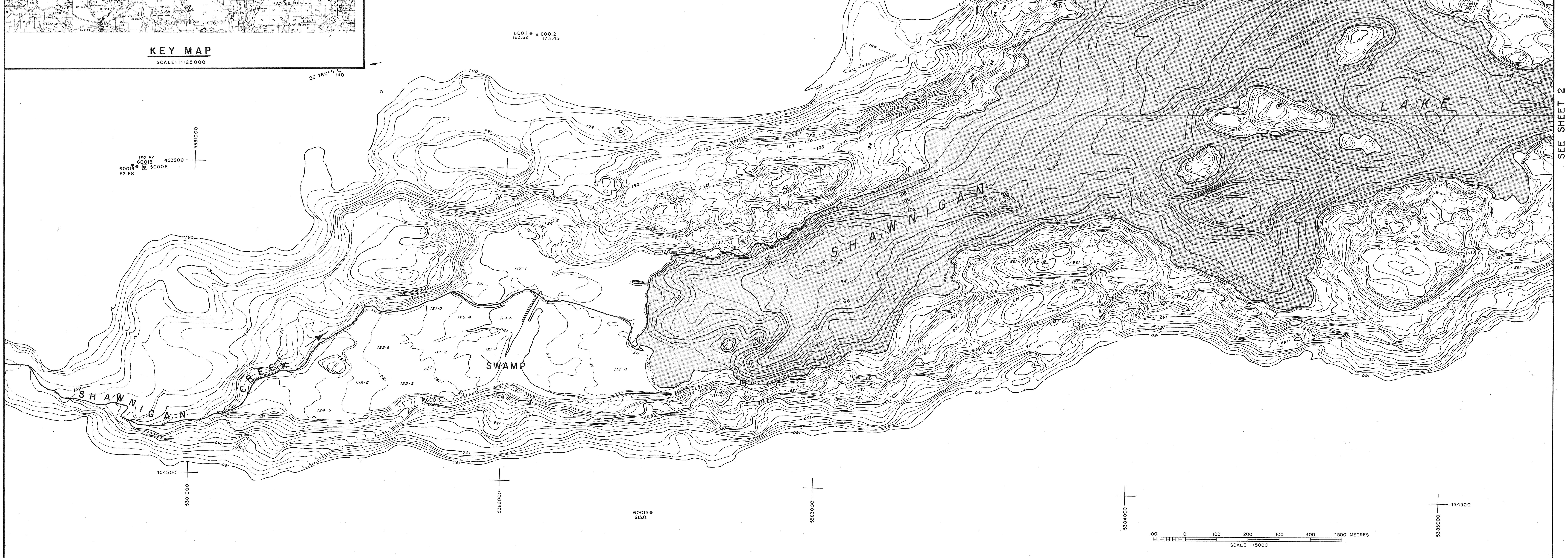


KEY MAP

SCALE: 1:125000



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PROJECT NO. 78·74T·0 SHEETS 1-7	ORTHOPHOTO MAP, SCALE 1:5000	MAY 1978
4984-8B	PLAN AND ELEVATION OF DAM INCLUDING PROFILE AND CROSS-SECTIONS OF OUTLET CHANNEL.	JAN. 1981

REVISIONS

No.	DESCRIPTION	DATE
1	REFERENCES	MARCH 1979
2	DETAILS	OCT. 1981

SURVEYS SECTION

SURVEYED: M. PRONK OCT., 1980

DATE: JUNE, 1977

COMPILED: M. PRONK

CHECKED: J. Wabersh.

DATE: FEBRUARY 1979

DRAUGHTING SECTION

DRAWN: J. Lesueur

CHECKED: P. Owen

DATE: FEBRUARY 1979

Province of British Columbia

Ministry of the Environment

ENVIRONMENTAL AND ENGINEERING SERVICE

WATER INVESTIGATIONS BRANCH

STORAGE INVENTORY PROGRAMME

COWICHAN BASIN – VANCOUVER ISLAND SYSTEM

SHAWNIGAN LAKE RESERVOIR

PLAN OF RESERVOIR

APPROVED Robert G. Harris DATE FEB. 1979

HEAD, SURVEYS SECTION, PLANNING & SURVEYS DIVISION

FILE No.

Branch

Inventory 0305080-36

SCALE 1:5000

SURVEY PROJECT No. 77 S.I.P.-5

DRAWING No. 4984-8A

SHEET 1 of 3

272043

DD1

SURVEYS

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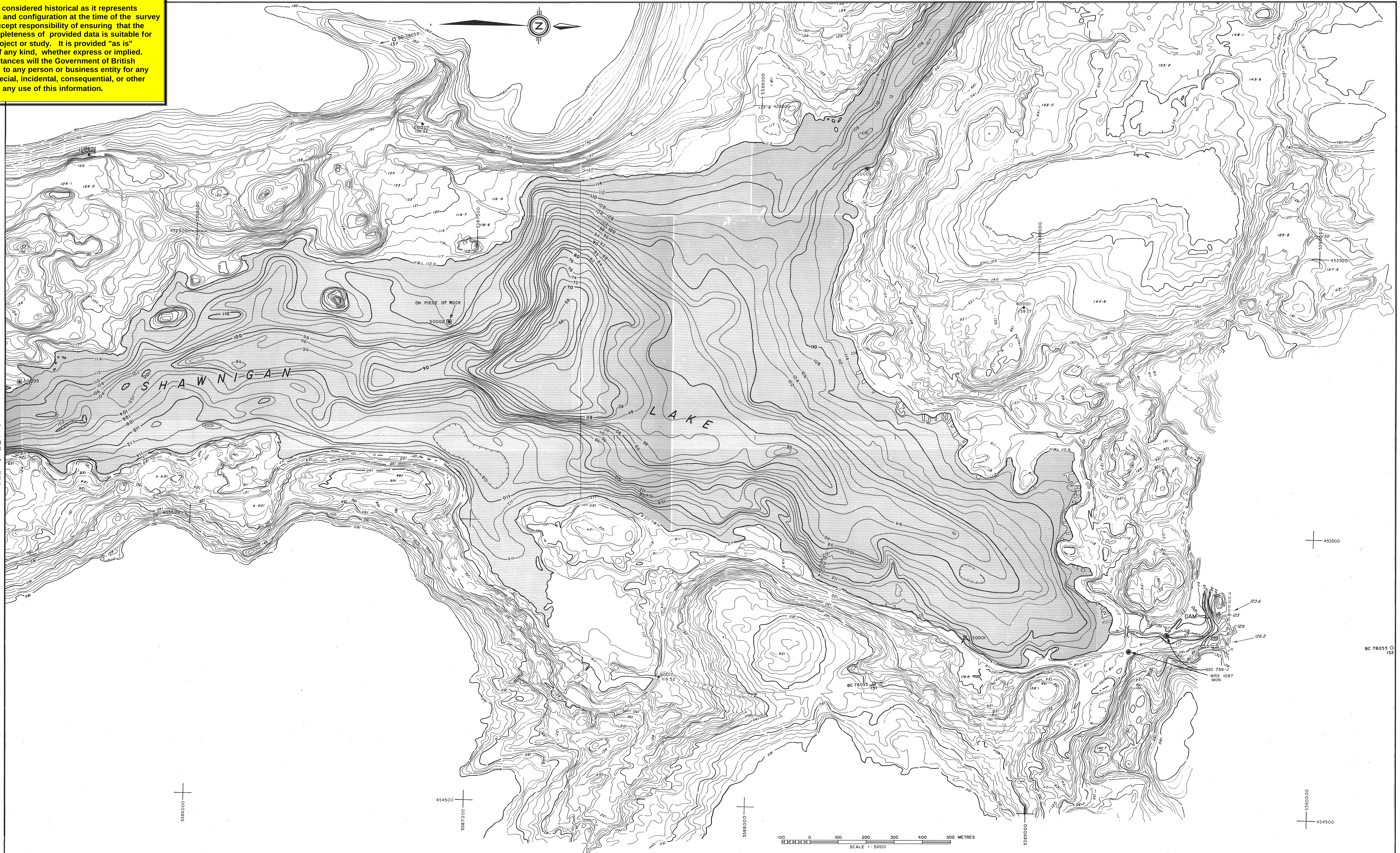
SEE SHEET 3

SEE SHEET 1



NOTES	
FOR NOTES SEE SHEET 1	

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STORAGE LICENCES

LICENCE	PRIORITY DATE	AUTHORIZED ACRE - FEET	DEVELOPED ACRE-FEET
SEE SHEET 1			

REFERENCES

DWG. No.	DESCRIPTION	DATE
	SEE SHEET 1	

REVISIONS

No.	DESCRIPTION	DATE
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SURVEYS SECTION

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DATE: OCT., 1980 MAY, 1977
COMPILED: M. PRONK
CHECKED: J. Waberski
DATE: FEBRUARY 1979

DRAUGHTING SECTION

DRAWN: J. Schuurr
CHECKED: P. Dixon
DATE: FEBRUARY 1979

Province of British Columbia
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ENVIRONMENTAL AND ENGINEERING SERVICE
WATER INVESTIGATIONS BRANCH

STORAGE INVENTORY PROGRAMME
COWICHAN BASIN-VANCOUVER ISLAND SYSTEM

SHAWNIGAN LAKE RESERVOIR

PLAN OF RESERVOIR

APPROVED Robert G. Harris DATE FEB. 1979
HEAD, SURVEYS SECTION, PLANNING & SURVEYS DIVISION

FILE No.
Branch
Inventory 0305080-36
SCALE 1:5000
SURVEY PROJECT No. 77 S.I.P.-5
DRAWING No. 4984-8A
SHEET 2 of 3

272044 DD1
SURVEYS

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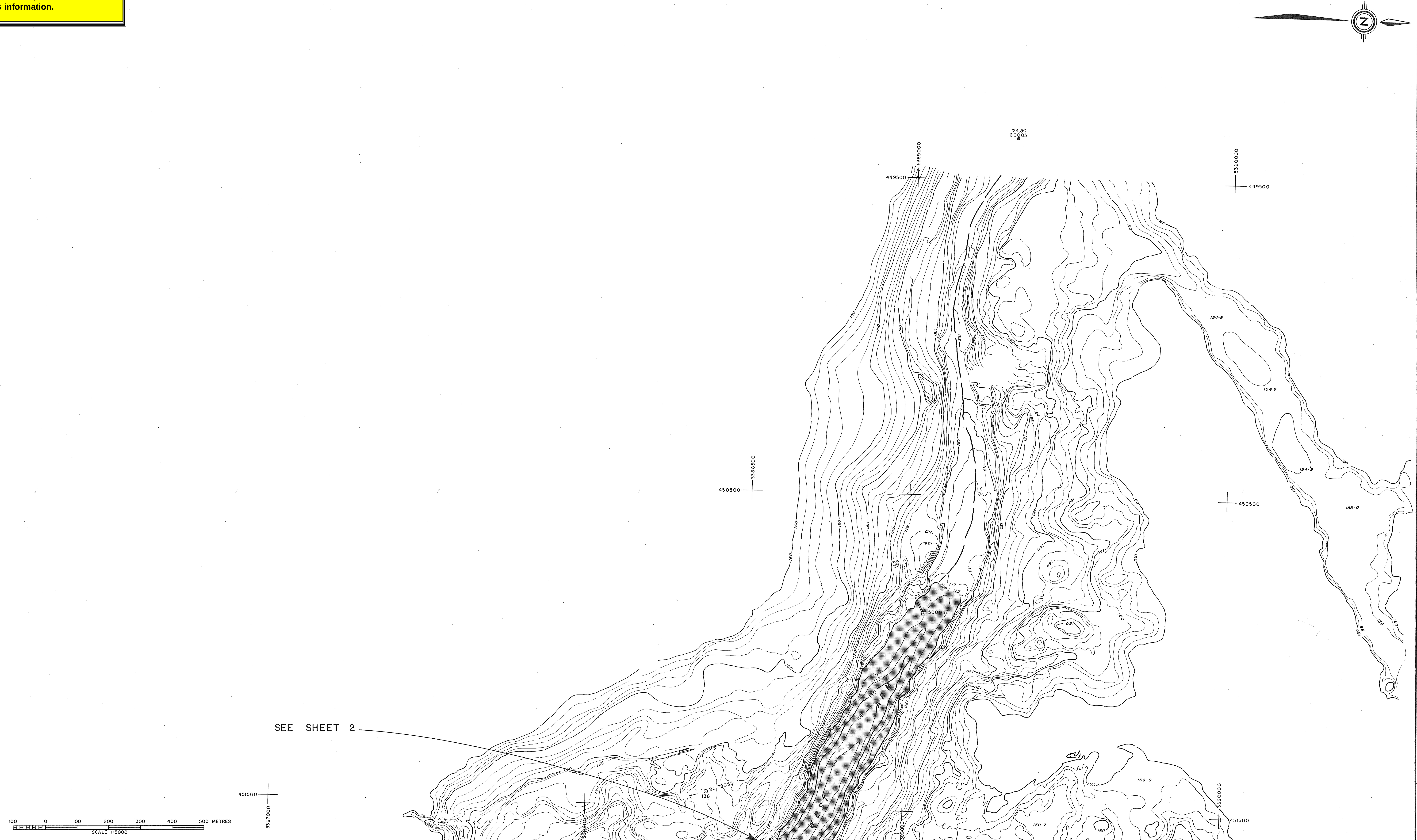

NOTES	
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- ROAD, TRAIL, CREEK, CREEK INTERMITTENT, SWAMP
- BOUNDARIES: BASINS, SUB-BASIN

STORAGE LICENCES

LICENCE	PRIORITY DATE	AUTHORIZED ACRE - FEET	DEVELOPED ACRE - FEET
SEE SHEET 1			

REFERENCES

DWG. No.	DESCRIPTION	DATE
	SEE SHEET 1	

REVISIONS

No.	DESCRIPTION	DATE
1	DETAILS	OCT. 1981

SURVEYS SECTION

SURVEYED: M. PRONK
DATE: OCT., 1980 / MAY, 1977
COMPILED: M. PRONK
CHECKED: J. Waberski
DATE: FEBRUARY 1979

DRAUGHTING SECTION

DRAWN: J. LeSueur
CHECKED: P. Dixon
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ENVIRONMENTAL AND ENGINEERING SERVICE
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STORAGE INVENTORY PROGRAMME
COWICHAN BASIN - VANCOUVER ISLAND SYSTEM

SHAWNIGAN LAKE RESERVOIR

PLAN OF RESERVOIR

APPROVED Robert G. Harris DATE FEB. 1979
HEAD, SURVEYS SECTION, PLANNING & SURVEYS DIVISION

FILE No.
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SCALE 1:5000
SURVEY PROJECT No. 77 S.I.P.-5
DRAWING No. 4984-8A
SHEET 3 of 3

272045 DD1 SURVEYS

Appendix C

Dam Inspection Notes

Table C Site Inspection Observations of the Shawnigan Lake Weir

General Description of Dam			
Date:	March 28, 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:	17.5 m	Outlet type:	Gated Weir
Max. Gate Height:	116.3 m	Sluice gate:	N/A
Crest Elevation:	117.0 m	Spillway:	Gated Weir
Gate Width:	6.1 m	Weir Sill Elevation Elevation:	115.1 m
Water Level:	116.4 m	Walkway Bottom Elevation:	118.8 m
Appurtenances:	Overshot Gate, Fish Ladder	Latitude/Longitude:	48°39’35”N 123°37’43”W
Location	**Observations**		
Upstream	Log boom on lake, debris has been an historical issue and can get over boom		
Left Bank	Left bank might not have 1 m of freeboard		
Gate	Flywheel is locked in place with a padlock and chain		
Gate	Grout pads on the underside of hoist were noted to have cracks		
Gate	Corrosion noted on the lower bounds of the cable on the gate lift mechanism		
Fish Ladder	Moss was noted to be growing on the wingwall of the fish ladder		
Downstream	Riprap has been placed on both sides of the downstream channel		
Downstream	Some erosion at downstream end, no displacement of rip-rap		
Downstream	Several logs had fallen into the channel downstream		
Safety	Guardrails were noted to have some minor corrosion		
Safety	Signage on either side of the upper walkway, says “Danger Restricted Area Keep out”		

Appendix D

Hazards and Failure Modes Analysis

Table D: 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 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 or internal 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 cause 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 E

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:	Shawnigan Lake Weir DSR
Dam:	Shawnigan Lake Weir
Owner:	CVRD
Dam location:	Shawnigan Lake, BC
Project engineer:	John Braybrooks Engineering
Analysis performed by:	CE
Date:	11/26/2018

Load Combination Factors:

	Usual	Flood	Seismic #1	Seismic #2	Post-seismic #1
Self-weight	1.0000	1.0000	1.0000		
Hydrostatic (upstream)	1.0000	1.0000	1.0000		
Hydrostatic (downstream)	1.0000	1.0000	1.0000		
Uplift pressures	1.0000	1.0000	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		
Residual sliding factor	1.5000	1.1000	1.0000		
Overturning factor	1.2000	1.1000	1.0000		
Uplifting factor	1.2000	1.1000	1.0000		

Combination allowable stresses:

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

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			-14.947	-41.766	0.000	-9000.000	0.000	7.128	50.000	0.000

Usual Combination (Stability):

Joint		Safety factors					Resultants over ligament				Final uplift	Rock wedge
ID	U/S elevation (m)	Sliding Peak	Sliding Residual	Overturning toward U/S	Overturning toward D/S	Uplifting	Normal (kN)	Shear (kN)	Moment (kN·m)	Position % of joint	Normal (kN)	Resistance (kN)
1	Base joint	8.52256	8.52256	7.08395	2.88902	4.19585	-79.40	13.30	17.5	57.88156	22.66	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			-3.493	-59.449	0.000	-15000.000	0.000	17.473	50.000	0.000

Flood Combination (Stability):

Joint		Safety factors					Resultants over ligament				Final uplift	Rock wedge
ID	U/S elevation (m)	Sliding Peak	Sliding Residual	Overturning toward U/S	Overturning toward D/S	Uplifting	Normal (kN)	Shear (kN)	Moment (kN·m)	Position % of joint	Uplift (kN)	Resistance (kN)
1	Base joint	3.85844	3.85844	5.27263	1.89408	3.08386	-88.12	32.62	36.6	64.81674	40.10	0.000
	Required:	1.100	1.100	1.100	1.100	1.100						

Seismic #1 Combination (1/1,000 year) - 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	19.56085		0.000	-70.503	0.000	0.000				

Seismic #1 Combination (1/1,000 year) - Peak accelerations analysis (Stability):

Joint		Safety factors					Resultants over ligament				Final uplift	Rock wedge
ID	U/S elevation (m)	Sliding Peak	Sliding Residual	Overturning toward U/S	Overturning toward D/S	Uplifting	Normal (kN)	Shear (kN)	Moment (kN·m)	Position % of joint	Uplift (kN)	Resistance (kN)
1	Base joint	1.99711	1.99711	8.69271	1.71308	4.19585	-79.40	56.78	29.8	73.18693	22.66	0.000
	Required:	1.000	1.000	1.000	1.000	1.000						

Seismic #1 Combination (1/2,475) - 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	37.17567		0.000	-90.271	0.000	0.000				

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Seismic #1 Combination (1/2,475) - Peak accelerations analysis (Stability):

Joint		Safety factors					Resultants over ligament				Final uplift	Rock wedge
ID	U/S elevation (m)	Sliding Peak	Sliding Residual	Overturning toward U/S	Overturning toward D/S	Uplifting	Normal (kN)	Shear (kN)	Moment (kN·m)	Position % of joint	Uplift (kN)	Resistance (kN)
1	Base joint	1.54368	1.54368	9.30988	1.48171	4.19585	-79.40	73.45	23.3	79.05856	22.66	0.000
	Required:	1.000	1.000	1.000	1.000	1.000						

CADAM - Results report

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General Information:

Project:	Shawnigan Lake Weir DSR
Dam:	Shawnigan Lake Weir
Owner:	CVRD
Dam location:	Shawnigan Lake, BC
Project engineer:	John Braybrooks Engineering
Analysis performed by:	CE
Date:	11/26/2018

Load Combination Factors:

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

Combination Required Safety Factors:

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

Combination allowable stresses:

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

Post-Seismic (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			-14.947	-26.560	0.000	-15000.000	0.000	7.128	50.000	0.000

Post-Seismic (Stability):

Joint		Safety factors					Resultants over ligament				Final uplift	Rock wedge
ID	U/S elevation (m)	Sliding Peak	Sliding Residual	Overturning toward U/S	Overturning toward D/S	Uplifting	Normal (kN)	Shear (kN)	Moment (kN·m)	Position % of joint	Normal (kN)	Resistance (kN)
1	Base joint	6.23752	6.23752	2.46074	2.06236	2.25965	-58.11	13.30	7.6	54.66325	43.95	0.000
	Required:	1.100	1.100	1.100	1.100	1.100						

Appendix F

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 F2: Dam Safety Expectations for the Shawnigan Lake Weir

	Dam Safety Expectations	Yes	N/A	No	Deficiencies Actual	Deficiencies Potential	Non-Conformances	Comments
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						
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	Au			The capacity of the main outlet channel will be exceeded during the IDF
1.10	The dam has adequate freeboard for all applicable operating conditions (normal, winter, earthquake, and flood).			X	Au			The abutments on the left and right side of the main outlet channel will be overtopped during the IDF event
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						
1.13	The dams, abutments and foundations are not subject to unacceptable deformation or overstressing.	X						
1.14	Adequate filter and drainage facilities are provided to intercept and control the maximum anticipated seepage and to prevent internal erosion.		X					Dam is constructed out of concrete and thus should not be susceptible to internal erosion.
1.15	Hydraulic gradients in the dams, abutments, foundations and along embedded structures are sufficiently low to prevent piping and instability.	X						
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 Youbou 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 Youbou 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 Youbou 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 Youbou 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						

	Dam Safety Expectations	Yes	N/A	No	Deficiencies Actual	Deficiencies Potential	Non-Conformances	Comments
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 are available.
d.	Management of debris and ice is carried out to ensure operability of discharge facilities.	X						
2.6	Operating procedures take into account:							
a.	Outflow from upstream dams		X					
b.	Reservoir levels and rates of drawdown			X			NCo	No procedures for drawdown rates are available.
c.	Reservoir control and discharge during an emergency			X			NCo	No emergency procedures specific to Shawnigan Lake Weir are available.
d.	Reliable flood forecasting information	X						
e.	Operator safety			X			NCo	No safe work procedures were available.
	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			NCs	Comparison of actual conditions to expected conditions documents were not available.
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			NCs	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			NCs	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			NCs	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			NCs	Assumed to be a non-conformance as no supporting documentation provided.
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 Shawnigan Lake Weir

	Dam Safety Expectations	Yes	N/A	No	Deficiencies Actual	Deficiencies Potential	Non-Conformances	Comments
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 Shawnigan Lake Weir.
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 Shawnigan Lake Weir.
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 Shawnigan Lake Weir.
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 Shawnigan Lake Weir.
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 Shawnigan Lake Weir.
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 Shawnigan Lake Weir.
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 Shawnigan Lake Weir
b.	Responsibilities			X			NCo	An OMS Manual needs to be prepared for Shawnigan Lake Weir
c.	Plans and procedures including OMS, public safety and security			X			NCo	An OMS Manual needs to be prepared for Shawnigan Lake Weir
d.	Documentation			X			NCo	Documentation of inspections prior to 2016 are missing, other documentation is limited.
e.	Training and review			X			NCo	An OMS Manual needs to be prepared for Shawnigan Lake Weir
f.	Prioritization and correction of deficiencies and non-conformances	X						
g.	Supporting infrastructure	X						
5.2	Deficiencies are: documented, reviewed, and resolved in a timely manner. Decisions are justified and documented.			X			NCo	
5.3	Applicable regulations are met.			X			NCo	An OMS Manual needs to be prepared for Shawnigan Lake Weir

Appendix G

NDMP Risk Assessment Information Template

Public Safety Canada Sécurité publique Canada

Ottawa, Canada
K1A 0P8

UNCLASSIFIED

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: 20/08/2018	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 Shawnigan Lake Weir in 2018 to meet the CVRD's obligation as a water licensee under the BC Dam Safety Regulations. The dam safety review included a dam breach analysis, flood routing, inundation mapping and assessment of the performance of the dam structure to various meteorological and seismic hazards. Flood routing and inundation mapping indicates that hazardous flow conditions downstream of the weir would occur quickly after the initiation of the failure of the main channels gate during a 100-year inflow event. The results of the dam safety review and risk assessment indicated the following infrastructure is at risk in the event of a dam breach: 1. Southern Vancouver Island Railway 2. Road Crossings Including: - Hartl Road - Shawnigan Lake Road - Shinrock Road/Stein Way - Cameron Taggart Road - Campbell Road 3. Damage to low lying properties within close proximity to Shawnigan Creek	
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 restoration of road/rail crossings impacted and replacing/fixing the mechanical gate on the weir structure.
Recovery Costs Related to the Risk Event	Provide details on the costs, in dollars, associated with implementing recovery strategies following the event.	Damage to road/rail crossings and properties: between $300,000 and $3 million
Recovery Time Related to the Risk Event	Provide details on the recovery time needed to return to normal operations following the event.	Unknown. Alternative access routes exist through most of study area that will limit extent of disruption.

National Disaster Mitigation Program
Risk Assessment Information Template

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.	Shawnigan Lake Watershed Shawnigan Lake and Mill Bay Southern Vancouver Island Region British Columbia Area type: Shawnigan Creek Watershed Population Size of Shawnigan Lake: 3,945 people Population of Mill Bay: 2,881 people Population Variance: Unknown Main Economic Interests: Forestry, Tourism, Agriculture Special considerations: N/A 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 Shawnigan Lake Weir, prepared by Ecora Engineering & Resource Group Ltd. Report includes: Dam embankment stability analysis, dam breach assessment, dam hydrotechnical assessment. Hazards, vulnerability, likelihood, impact, risks are assign as a result of 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. Breach of Shawnigan Lake Weir 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 Shawnigan Lake Weir prepared by Ecora Engineering & Resource Group Ltd. Dam breach scenario that was chosen for the consequence classification review included the main channel gate failing during a 100-year inflow event while gate is fully elevated.
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."	Gate failure and overland flooding due to a one-in-a-hundred year flood.
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 over-topping 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 failure 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, the Ministry of Transportation and Infrastructure and Emergency Management BC would be the primary organizations with a mandate to respond to a 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 primary risk event is a failure of the gate during the 100-year flood. In the event of a breach significant damage to public infrastructure would occur including damage to the Southern Vancouver Island Railway, multiple road crossings downstream and damage to low lying areas around Shawnigan Creek. The event would most likely occur during the winter months when lake levels are at their highest coupled with higher inflows.

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.	Shawnigan Lake Weir is located on the outlet of Shawnigan Lake on the east side of Vancouver Island. The creek passes through the communities of Shawnigan Lake, BC and Mill Bay, BC. A breach has the potential to disrupt transportation on several minor roads and the currently inactive Southern Vancouver Island Railway. Damage may also extend to properties in close proximity to Shawnigan Creek. A breach will also result in the loss of control on Shawnigan Lake which would result in a rapid draw down of the lake.
Natural environment considerations	
Document relevant physical or environmental characteristics of the defined geographic area.	The Shawnigan Lake watershed consists of areas that are heavily forested, residential neighbourhoods and agricultural areas near the outlet into Mill Bay. Logging has historically taken place in areas in the upper catchment. Elevation of the affected area varies from 115 m to sea level.
Meteorological conditions	
Identify the relevant meteorological conditions that may influence the outcome of the risk event.	Relevant meteorological conditions may include: - Extreme Rainfall - Large accumulation of snow in the watershed - Extreme rain on snow - High temperatures as snow thaws

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 logging, development, wildfire or 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 Shawnigan Lake: 541 per square km. Population density of Mill Bay: 426 per square km. Hazardous area is identified on hazard maps included with the 2018 Comprehesive Dam Safety Review and Risk Assessment completed by Ecora. Area around the creek is mostly loosely packed residential neighbourhoods separated by forest. Key local infrastructure: 1. Southern Vancouver Island Railway 2. Hartl Road 3. Shawnigan Lake Road 4. Shinrock Road/Stein Way 5. Cameron Taggart Road 6. Campbell Road Damage is expected to impact a multiple residences and outbuildings. Economic and political considerations: A breach will impact a number of road crossings which will disrupt local traffic. If Shinrock Road/Stein Way is washed out several properties will loss their access.

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 high hazard areas include: 1. Southern Vancouver Island Railway 2. Hartl Road 3. Shawnigan Lake Road 4. Shinrock Road/Stein Way 5. Cameron Taggart Road 6. Campbell Road Possible further damage from overland flooding in areas with a medium hazard rating. No detailed cost estimate has taken place, however total impact costs have been estimated to be below $3 million based on the scope of the infrastructure. Daily costs to operate the infrastructure and the time the infrastructure would be out of service is unknown.
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.	Uncertainty exists with the breach as it is difficult to establish the point at which the gate fails and how much water would released. The breach also assumes that the gate is operating near the full extent of its range during an extreme event which is consistent with the Canadian Dam Association (CDA) guidelines that specify for the most conservative scenario is considered for a dam breach. Some variation between the modeled dam breach and a real dam breach may exist due to variations in terrain that may not be entirely captured in the digital terrain model (DTM) used.
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 creek crossings downstream on Shawnigan Creek would be sized for a 200-year flood event. It is anticipated that the dam breach peak outflow would be greater than the 200-year event and as such it is expected that the infrastructure will fail 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.	Risk event evaluated includes an event with a 100-year return period. It is difficult to assess due to uncertainty pertaining to wear on the components and the stresses the mechanical gate components can withstand.
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.	
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.	1
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.	Random functional failure of the gate on the weir structure was considered during a storm with a return period of 100-year. It is anticipated that the likelihood of this scenario is lower due to the requirement that the gate is left in the closed position during a 100-year inflow event and for the gate to fail during the peak of this event.

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	1
	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)	Warning time is likely to be sufficient enough to prevent fatalities however possibility of fatalities is still present within the residents impacted or from a temporary population near the creek.		
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)	The closest hospital (Cowichan District Hospital) is approximately 20 km to the north of the structure.		

National Disaster Mitigation Program
Risk Assessment Information Template

		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)		Displacement of individuals will be minimal however those that are displaced will either be displaced until access can be restored or until their home is rebuilt/repaired.		

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	1
	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)	Limited environmental impacts are expected, areas of the creek are already not ideal for fish habitat.		

C) Local economic impacts			
	Risk Rating	**Definition**	**Assigned risk rating**
	5	> 15 % of local economy impacted	
	4	10 - 14.9 % of local economy impacted	
	3	6 - 9.9 % of local economy impacted	1
	2	3 - 5.9 % of local economy impacted	
	1	0 - 2.9 % of local economy impacted	
Supplemental information (optional)	Local economic impacts are expected to limited as alternative routes exist.		

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)	Impacts will be limited to areas in close proximity to the creek.		
Energy and Utilities	5	Duration of impacts > 72 hours; > 20% of local population without service or product; or having an international level impact	1
	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)	Event will have limited impact as the natural gas pipeline is not in the inundation area and the flow will pass fully outside the footprint of the electrical transmission lines.		
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	1
	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	
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	C
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 incorporated analysis from Comprehensive Dam Safety Review and Risk Assessment Report completed by Ecora which includes hydrotechnical, mechanical and electric review and a geotechnical and structural assessment. The risk assessment considered multiple risk events included 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).

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 Shawnigan Lake Weir, prepared by Ecora Engineering & Resource Group Ltd. 2019 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 H

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): E453693, N5389834 (Zone 10)

Located at (Description): Malta Road & Shawnigan Lake Road, just north of Shawnigan Lake, BC

Name of dam or description: Shawnigan Lake Weir

Provincial dam number: D730200-00

Dam function: Control for outflows from Shawnigan Lake

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.
11.5, 13 & 14

☐ 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.

Michael J. Laws, P.Eng.
Name

March 19, 2019
Date

Signature

579 Lawrence Avenue, Kelowna, BC V1Y 6L8
Address

250.469.9757
Telephone

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

(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 I

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.