SHAWNIGAN LAKE FLOOD PREPAREDNESS MONITORING PROJECT

FINAL

Prepared for:

Cowichan Valley Regional District
Duncan, BC

9 July 2020

NHC Ref. No. 3005433

northwest hydraulic consultants
water resource specialists

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Cowichan Valley Regional District
175 Ingram Street, Duncan, BC

Prepared by:

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9 July 2020

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CREDITS AND ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The Cowichan Valley Regional District retained Northwest Hydraulic Consultants Ltd. to install flood warning stations and prepare floodplain maps for Shawnigan Lake. This report provides information on project methodologies, key findings, and deliverables including a user manual for the flood warning system and updated floodplain maps.

The results of this study will be used to mitigate damage due to flooding. The flood monitoring station will provide information to the CVRD on lake levels during flood events to assist in emergency response planning and warning to the public. The floodplain maps will provide updated information for future development in and adjacent to the floodplain as well as to inform existing property owners on the need for adaptation and floodproofing measures. The updated flood maps incorporate updated guidelines for assessing flood hazards that supersede the previous mapping prepared by the BC Ministry of Environment in 1979. An important requirement of current floodplain mapping practice is to account for future climate change to the year 2100. The climate change projections for the region (CVRD 2017) were used to inform this assessment. Based on this information and a review of current practice guidelines an increase in discharge of 20% was adopted for estimating flood levels for the year 2100. This increase is in line with other mapping work on Vancouver Island.

The work carried out in this study included:

- compilation of geospatial data;
- hydrological analysis, including an assessment of climate change effects on peak discharges;
- hydraulic modelling analysis;
- field surveys to obtain high water marks, discharge and water level measurements and topography; and
- installation of the flood warning station.

Five large floods over the last 100 years, including the February 2020 event, were compared and used in a flood frequency analysis (FFA). The FFA of Shawnigan Lake used 33 years of discharge data and the FFA of Shawnigan Creek used 36 years. Results of the flood frequency analysis were used as boundary conditions for the hydraulic model. The hydraulic model was used to determine flood extents and designated flood levels for use in floodplain mapping. The 200-year return period discharge plus climate change increase were used to determine the designated flood level using the hydraulic model. The hydraulic model used discharge at the outlet from the lake, the topography of the creek, and roughness characteristics of the channel and floodplain as known inputs and then solved the equations of motion to estimate the water level, mean velocity, and depth at Shawnigan Lake and along Shawnigan Creek. Review of previous studies resulted in five independent estimates of the 200-year return period lake level; all were within 0.3 m. This increased confidence in results from the hydraulic model and suggests that hydrologic and hydraulic conditions on Shawnigan Lake have been relatively stable for the last 50 years.

Four 1:5000 scale floodplain maps were prepared to represent the flood extents and Flood Construction Levels (FCLs) on Shawnigan Lake and Shawnigan Creek upstream of the weir. The FCL along Shawnigan Creek was calculated as follows:

FCL = DFL + FB where DFL is the designated 200 year flood level (incorporating projected climate change to the year 2100) and FB is the freeboard.

The freeboard on the creek accounts for hydrological uncertainties, potential effects from log jam debris, sediment accumulation as well as model limitations, waves and surging, and local variations in bends. A freeboard of 0.6 m was adopted for determining the FCL along Shawnigan Creek, which is consistent with current practice on most Vancouver Island streams.

Winds and waves during flooding potentially raise the still water level on the lake. The FCL on Shawnigan Lake was calculated as follows:

FCL =DFL + $R_{2\%}$ + FB, where DFL is the designated 200 year still water lake level (incorporating climate change effects to the year 2100), $R_{2\%}$ is the wave runup and FB is the freeboard.

Based on an analysis of coincident winds and extreme lake levels, a wave runup of between 0.4 and 0.6 m was adopted for the shoreline of Shawnigan Lake. The updated FCL is between 0.5 m to 0.7 m higher than the level established by the BC Ministry of Environment in 1979.

It is recommended that the floodplain maps be updated if new, more accurate LiDAR comes available. Furthermore, the maps should be reviewed at least every 10 years or after any extreme flood event which could cause changes to the lake outlet and channel of the creek. New information on future climate change and its impacts to flooding will need to be reviewed and may require further mapping updates.

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1 INTRODUCTION

1.1 Project Objectives

In December 2019, the Cowichan Valley Regional District (CVRD) retained Northwest Hydraulic Consultants Ltd. (NHC) to install flood warning stations and to prepare floodplain maps for Shawnigan Lake. The objectives of the project include:

- Installation of recording water level gauges for Shawnigan Lake and the Shawnigan Lake Weir;
- Installation of automated flood alert warning systems as part of the gauge installations; and
- Updating and refining previous estimates of flood levels, flood inundation extents, and floodplain maps.

This report summarizes methodologies, key findings, and deliverables for the project, including:

- Background information and review of existing studies/data;
- Field investigations, gauge installation, and flood alert warning system user manual;
- Hydrologic and hydraulic analysis;
- Floodplain delineation; and
- Updated floodplain maps.

1.2 Location

The study area includes Shawnigan Lake and a portion of Shawnigan Creek from the outlet of the lake downstream approximately 0.5 km to Shawnigan Creek Weir (**Figure 1**). A more detailed map of the study area downstream of Shawnigan Lake is shown in **Figure 2**.

Shawnigan Lake is located near the southern boundary of the Cowichan Valley Regional District (CVRD), on the east coast of Vancouver Island. The study area forms a portion of CVRD Electoral Area B. The village of Shawnigan Lake is located on the eastern shore, with the remainder of the shoreline comprising rural and undeveloped properties. The community is approximately 48 km north of Victoria and is adjacent to Cobble Hill and Mill Bay. The village of Shawnigan Lake had a population of 3,945 (2016 StatsCan) and included 1,525 private dwellings. Previous studies indicated 130 residences were situated adjacent to the lake foreshore and were vulnerable to flooding (NHC, 2017).

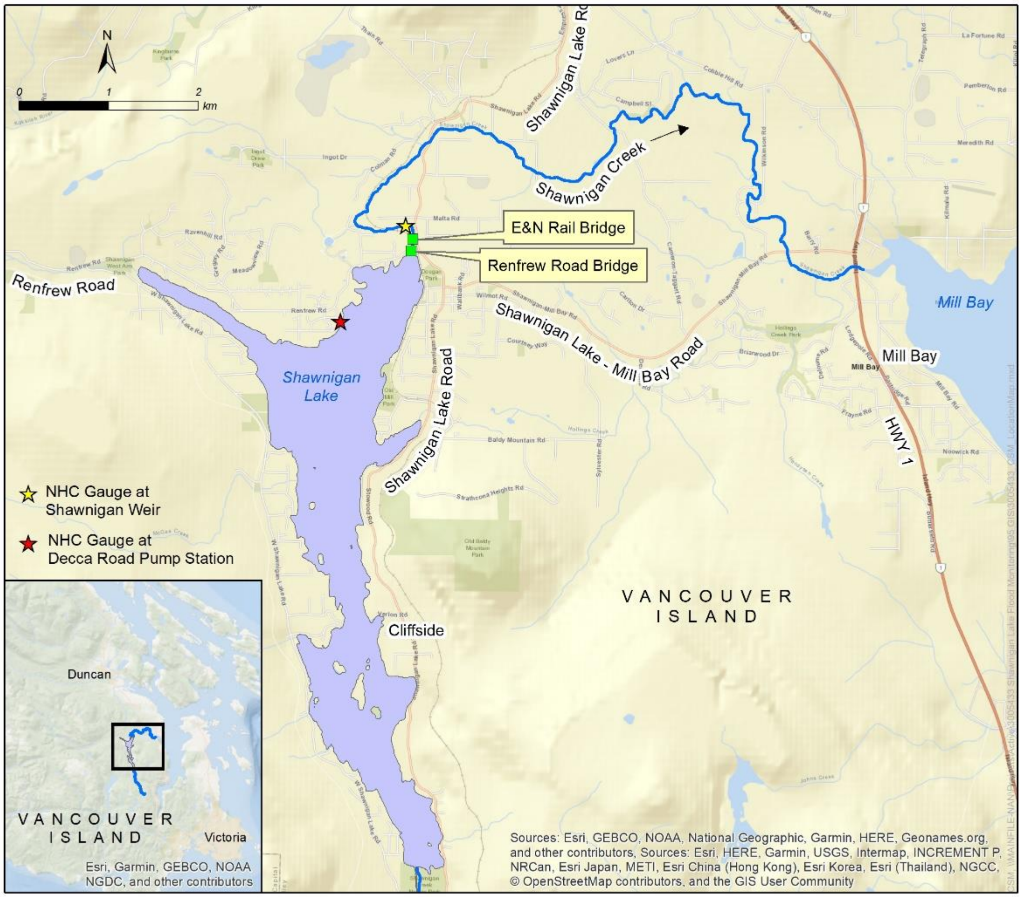


Figure 1: Overview of study area

1.3 Method of Approach

The study uses historical hydrologic data and hydraulic modelling to estimate the Designated Flood Level (DFL) and Flood Construction level (FCL) on Shawnigan Creek and Shawnigan Lake. The DFL is the estimated maximum instantaneous water level for a flood event having a return period of 200 years, adjusted to account for climate change in the year 2100.

The FCL for Shawnigan Lake was computed as follows:

$$FCL = DFL + R_{2\%} + FB\text{, where}$$

$R_{2\%}$ is the wave runup and FB is the freeboard. Wave runup does not apply to Shawnigan Creek.

Determining the FCL consists of the following steps:

1) Determine the 200-year return period peak discharge for Shawnigan Creek below Shawnigan Lake;

2) Assess the potential future impacts of climate change on peak discharges for Shawnigan Creek;

3) Develop a hydraulic model to estimate flood levels along sections of Shawnigan Creek up to Shawnigan Lake;

4) Estimate the potential wave runup in Shawnigan Lake at the time of the peak lake level;

5) Calculate the FCL by adding a freeboard and wave runup to the DFL; and

6) Compare the results to previous flood study estimates, as well as hydrologic “checks”.

The adopted freeboard for the creek and lake are discussed further in **Section 6.2**.

1.4 Governing Standards and Guidelines

The following standards and guidelines were utilized in carrying out the project:

- *Federal Airborne LiDAR Data Acquisition Guideline V2.0* (Natural Resources Canada and Public Safety Canada, 2018a)
- *Federal Flood Mapping Framework V2.0* (Natural Resources Canada and Public Safety Canada, 2018b)
- *Federal Geomatics Guidelines for Flood Mapping V1.0* (Natural Resources Canada and Public Safety Canada, 2019)
- *Flood Mapping in BC* (APEGBC, 2017)
- *Legislated Flood Assessments in a Changing Climate in BC* (APEGBC, 2012)

1.5 Overview of Study Area

Shawnigan Lake watershed drains approximately 71 km^2 of relatively low-gradient forest land, ranging in elevation from 380 m to 117 m at the lake outlet. The surface area of the lake is 5.4 km^2, which accounts for approximately 8% of the watershed area. Floods are generated in the autumn and winter months during periods of high rainfall. Due to the low elevation of the watershed, the contribution from snowmelt is believed to be relatively minor.

Shawnigan Creek forms the outlet at the north end of the lake and flows east into Mill Bay. Prior to the 1960s, water levels in Shawnigan Lake were controlled by a natural constriction in Shawnigan Creek. In 1964 a weir was constructed near the location of the current weir, comprising a simple stop log structure and concrete wingwalls. The weir was modified in 1983, and in 1984 a rule curve was developed to regulate summer lake levels. The new weir (**Photo 1**) was constructed between 2005 and 2007, consisting of a concrete wingwall structure, an overshot gate, a fishway, and a bypass channel. The weir is jointly owned and operated by the CVRD and partner utility companies for the purpose of source water storage as a water extraction permit requirement.

Photo 1: Shawnigan Weir, looking upstream from right bank

During the low flow season (spring and summer) the weir is raised to control lake levels. In the winter, the gate is fully open. Previous studies stated that during high flows in the winter season, the weir is drowned out and has no effect on water levels in the lake (Talbot, 1985).

1.6 Work Carried Out

1.6.1 Topographic Surveys

All elevations in this study are referenced to CGVD2013 vertical datum, unless explicitly indicated otherwise. Field surveys commenced on 9 December 2019, with the establishment of survey control points at the site. Due to high flows in the creek, completion of the surveys was delayed until the creek could be safely waded. Cross sections of Shawnigan Creek were surveyed from the lake outlet downstream past Shawnigan Creek Weir (**Figure 2**), ending before the E & N Railway bridge crossing on 16 and 17 March 2020. The surveys were conducted using an RTK-GPS and Total Station.

Elevations from previous studies have been converted to CGVD2013 where necessary using mapping software available from Natural Resources Canada, or measured directly by topographic survey.

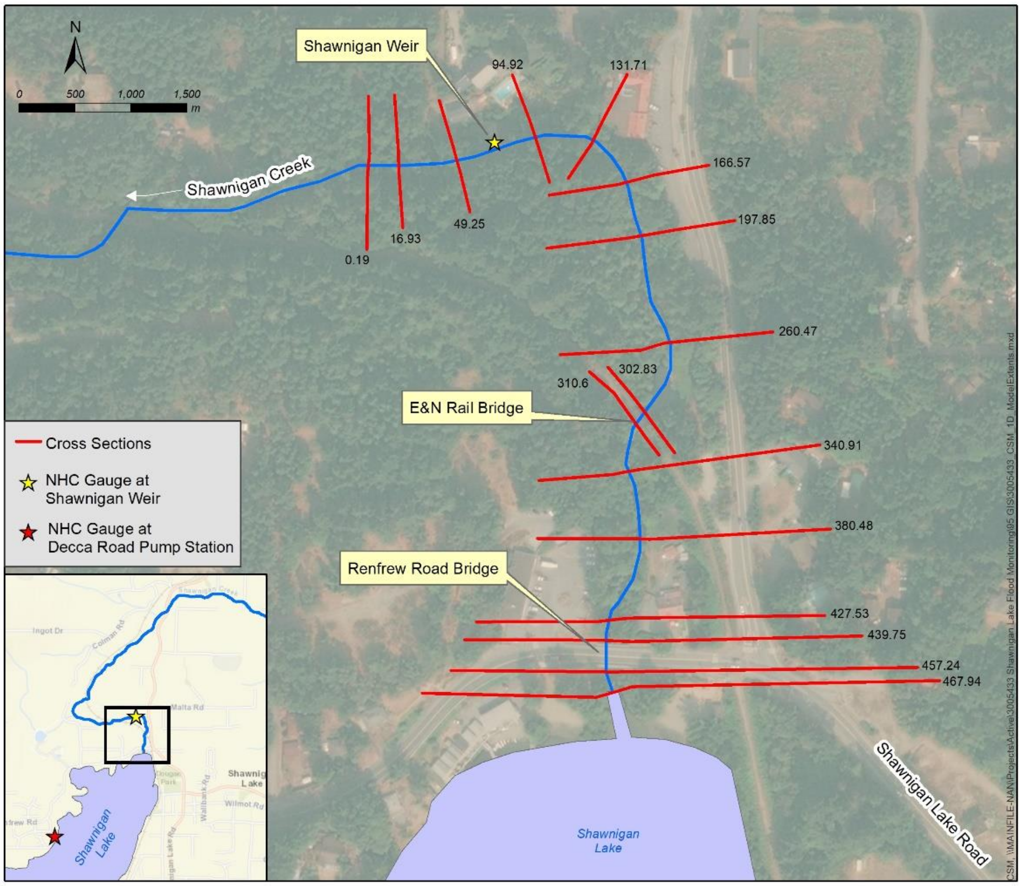


Figure 2: Shawnigan Creek channel and floodplain cross sections

1.6.2 High Water Mark Surveys

A large flood occurred in the region during the period between 31 January and 2 February 2020 (see **Section 3.3** for a description of the meteorological conditions during the event). NHC surveyed High water marks (HWMs) during the survey of Shawnigan Creek. HWMs indicate the approximate vertical limits of recent flooding, and typically include rafted wood and other debris. One HWM was surveyed along the creek. Additional HWMs were surveyed for the largest flood of record observed in 1935 (see **Section 3.2**). Historical photographs from the event showed flood levels over the rail tracks at Renfrew Road bridge. During the 16-17 March 2020 survey, elevations were obtained for these flood levels.

1.6.3 Compilation of Geospatial Data

CVRD provided Geospatial data for the study, including 2010 topographic LiDAR data and 2019 orthophotography for the study area. The metadata provided by the CVRD were reviewed and compared to geospatial data standards recommended by the Federal Geomatics Guidelines (Natural Resources Canada, and Public Safety Canada, 2019).

To further investigate the LiDAR data quality, NHC completed a series of LiDAR check point surveys during the channel topographic surveys (**Section 1.6.1**). A comparison of surveyed elevations with LiDAR elevations at the check points is summarized in **Table 1**. The locations of the check points are provided in **Figure 3**. Root mean standard error (RMSE) for the checkpoints is 0.099 m. Federal flood mapping guidelines (2018a) indicate that quality LiDAR data should have a vertical RMSE of 0.10 m or less. The bare earth point density was not reported; however, the full feature point density is 7 to 10 points/m^2. This suggests that the bare earth point density is below the suggested federal guidelines of 2 to 4 points/m^2 for medium risk areas, which the Shawnigan Lake area would fall under. Horizontal accuracy was undetermined. While the 2010 LiDAR used for the Shawnigan Lake area falls within the federal guideline for vertical accuracy, it is at the threshold and the bare earth point density is likely below the recommended range. The current study does not require federal guidelines to be met. However, it is recommended that these standards be followed for future studies, and more accurate LiDAR data be obtained.

1.6.4 Discharge Measurements

Discharge measurements were carried out at the weir on 23 January and 18 March 2020 (**Photo 2**) using an Acoustic Doppler Current Profiler (ADCP). Results of the discharge measurements are summarized in **Table 2**. Obtaining discharge and water level measurements on the same day and as close in time as possible was important for later use in calibrating the hydraulic model and increasing accuracy of the final DFL and FCL results (see **Section 5.3.3**).

Table 1: Summary of LiDAR elevation checkpoints

Point ID	Northing (m)	Easting (m)	Surveyed Elevation (m)	LiDAR Elevation (m)	Absolute Difference (m)	Squared Difference (m)
1672	5389179.51	454742.32	144.754	144.649	0.105	0.011
1673	5388976.23	453920.42	119.687	119.664	0.023	0.001
1674	5388372.71	453993.19	147.536	147.416	0.120	0.014
1675	5386193.98	453327.59	126.49	126.365	0.125	0.016
1676	5382170.67	454092.80	120.647	120.574	0.073	0.005
1677	5381599.30	454141.59	125.534	125.416	0.118	0.014
1678	5382903.18	453498.72	134.815	134.786	0.029	0.001
1679	5385273.01	452397.78	122.402	122.333	0.069	0.005
1680	5386019.58	452616.60	121.158	120.980	0.178	0.032
1681	5387138.95	452366.42	119.347	119.217	0.130	0.017
1682	5389491.80	450768.85	134.673	134.582	0.091	0.008
1683	5389182.25	451495.63	143.43	143.399	0.031	0.001
1684	5389708.51	451533.71	156.346	156.326	0.020	0.0004
1685	5389615.34	452163.25	164.902	164.808	0.094	0.009
1686	5388778.08	452429.39	140.059	139.913	0.146	0.021
1687	5389591.43	453720.77	120.438	120.934	0.044	0.002
1688	5389903.18	454547.27	148.819	148.727	0.092	0.008

Table 2: Summary of ADCP discharge measurements at Shawnigan Lake Weir

Date	Measured Discharge (m^3/s)	Water Surface Elevation at Weir (m)	Water Surface Elevation at Lake (m)
23 Jan 2020	11.6	116.77	117.49
18 Mar 2020	0.5	116.18	116.23

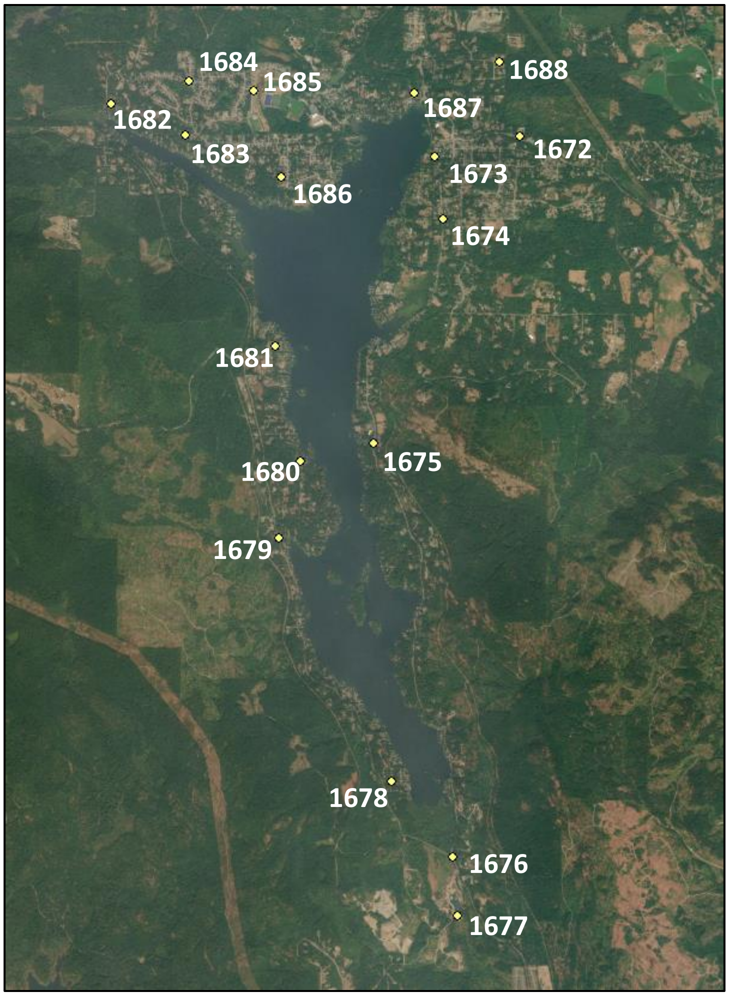


Figure 3: LiDAR check point locations around Shawnigan Lake

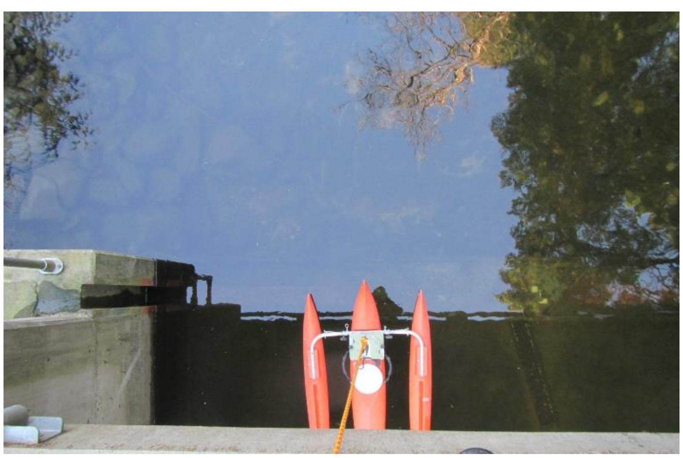


Photo 2: ADCP discharge measurement at Shawnigan Lake Weir

1.6.5 Installation of Water Level Sensors

NHC installed temporary water level sensors at the Shawnigan Creek Weir and at the lake on 23 and 24 January 2020. The purpose of the sensors was to gather data to quantify the hydraulic relationships between lake level and creek discharge. The sensor at the weir was installed upstream of the structure along the right bank. The sensor on the lake was installed on an existing staff gauge at the CVRD's water treatment building on Decca Road. Both sensors were Solinst M10 Levelogger non-vented pressure transducers, with a sampling interval of 15 minutes. A Solinst Barologger barometric pressure sensor was also installed at the weir site to correct the non-vented pressure transducers for atmospheric pressure effects.

1.6.6 Installation of Flood Warning Station

A permanent water level monitoring station was installed on the lake at the CVRD's water treatment building on Decca Road. The monitoring station consists of the following equipment:

- Ott Pressure Level Sensor
- Campbell Scientific CR310 Cell 205 Data Logger
- 12 volt battery and Oxford Smart Battery Charger

Data from the station is automatically uploaded to the Aquarius hydrometric software system. Aquarius is currently used by many water management agencies such as Water Survey of Canada (WSC) and British Columbia (BC) Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) due to its flexibility and ease of use. The flood alert warning system is programmed into Aquarius and includes flood level thresholds above which an alert will be sent by email and/or SMS to pre-determined parties. The thresholds and alert methods are easily customizable to suit the needs of the CVRD. A user manual for the station, as developed by NHC, is included in Appendix A. The user manual provides equipment operations and maintenance instructions, as well as instructions for utilizing the Aquarius system and modifying flood alert parameters.

1.6.7 Hydraulic Model Analysis

A standard step backwater analysis was conducted using the Hydrologic Engineering Center River Analysis System (HEC-RAS) hydraulic model to analyze the relationship between Shawnigan Lake levels and water level at the Shawnigan Creek Weir (see **Section 5**). The model was created by combining the surveyed channel cross sections (see **Section 1.6.1**) with LiDAR to model the floodplain (see **Section 1.6.3**). Results of the hydraulic model were used to determine the DFL and FCL using the 200-year return period flow including climate change impacts (see **Section 4.4**).

2 PREVIOUS STUDIES

2.1 BC Ministry of Environment, 1979

Three floodplain map sheets for Shawnigan Lake were prepared by the BC Ministry of Environment (1979), with an adopted FCL value of 119.2 m (CGVD 1928 vertical datum). The new geodetic datum adopted for Lidar and floodplain mapping in BC is referenced to CGVD 2013 datum). Using this new datum, the corresponding FCL value is approximately 119.4 m (CGVD 2013).

No information is available on how the FCL was determined, or what freeboard was adopted. Based on other similar studies, it is likely that a freeboard between 0.3 and 0.6 m was adopted. The designated flood level (DFL) associated with the FCL was likely on the order of 118.8 m to 119.1 m.

2.2 Talbot, 1985

The BC Ministry of Environment (Talbot, 1985) completed a study of Shawnigan Lake levels to determine storage and water supply requirements, as well as to determine design parameters for a new lake outlet structure. The report included an estimate of the 200-year return period outflow from Shawnigan Lake (39.6 m^3/s) and the corresponding 200-year lake level (119.03 m). The report also provided a hydraulic rating curve, relating lake water surface elevation to discharge in Shawnigan Creek.

2.3 Ecora, 2019

Ecora (2019) completed a dam safety review and risk assessment for the Shawnigan Lake Weir. As part of its Inflow Design Flood hydrology assessment, Ecora estimated lake outflow and corresponding lake level for several flood return periods. The 100-year return period lake outflow and lake level were 27 m^3/s and 117.87 m, respectively.

2.4 NHC, 2019

NHC (2019) completed a risk assessment of floodplains and coastal sea level rise for the CVRD, with a focus on climate change. As part of the study, NHC completed a planning-level floodplain assessment for Shawnigan Lake. The assessment included a review of existing floodplain studies, a hydrologic analysis, determination of flood discharges and associated lake levels, and a risk assessment of floodplain impacts. For historical climate conditions, the 200-year outflow from Shawnigan Creek and its corresponding DFL were estimated as 43.0 m^3/s and 118.8 m, respectively. Historical 200-year discharges were increased by 10%, 20%, and 40% to represent a range of plausible future climate change scenarios. The corresponding lake levels were calculated as 119.3, 119.5, and 119.6 m, respectively. The climate change scenario that was adopted for the current study is described in **Section 4.4**.

The preliminary risk assessment noted that there were uncertainties and limitations associated with the flood level predictions and available mapping. The hydrologic analysis was based on limited historical hydrologic data, and it was necessary to complete much of the assessment using regional, rather than local, hydrologic data. Additionally, the relationship between Shawnigan Creek discharge and its associated lake level was based on historical rating curves and simplified hydraulic analysis which were not verified in the field. The assessment was suitable for planning-level purposes, however it was recommended that additional work be carried out to update the hydrologic analysis and verify hydraulic relationships in the field. These recommendations form much of the basis for the present study.

3 FLOODING ISSUES AND FLOOD HISTORY

3.1 Background Information

3.1.1 Watershed Characteristics

The watershed draining into Shawnigan Lake generally consists of low-gradient forested land and rural properties. A watershed map is provided in **Figure 4**. Key watershed parameters are summarized in **Table 3**, as taken from Bryden and Barr (2002) and Talbot (1985).

Environment Canada has operated a climate station at Shawnigan Lake since 1911. Published 1981-2010 climate normals for the station (Environment Canada, 2020) are provided in **Figure 5**.

Table 3: Shawnigan Lake watershed parameters

Watershed Parameter	Value
Drainage area	69 km^2
Lake surface area	5.4 km^2
Elevation range	115-610 m
Land cover	Predominantly secondary growth coniferous forest

Based on historical data, the majority of floods on the lake occur between November and January. Floods are largely precipitation-driven, though snowpack may be an aggravating factor in some cases.

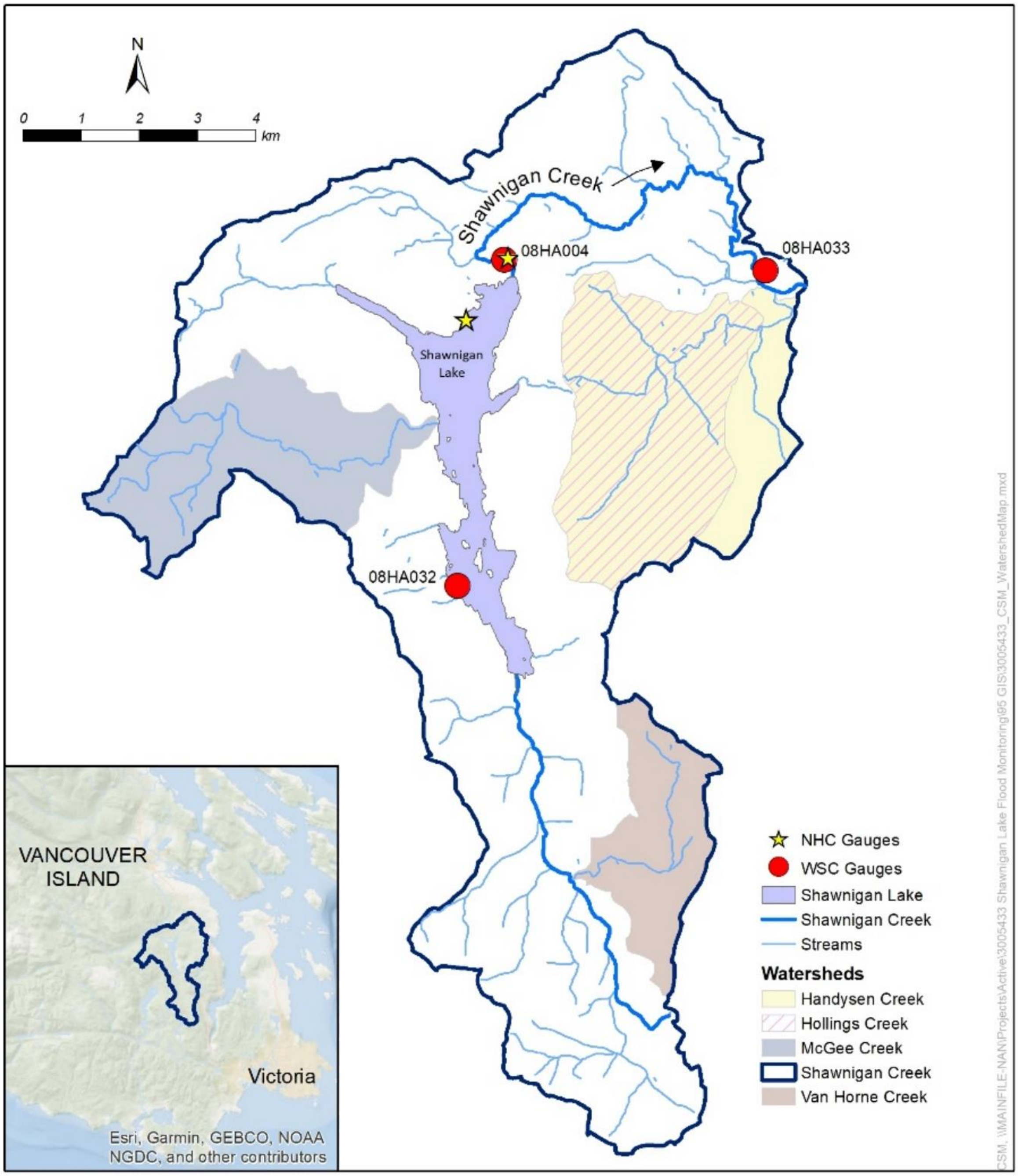


Figure 4: Map of Shawnigan Lake watershed

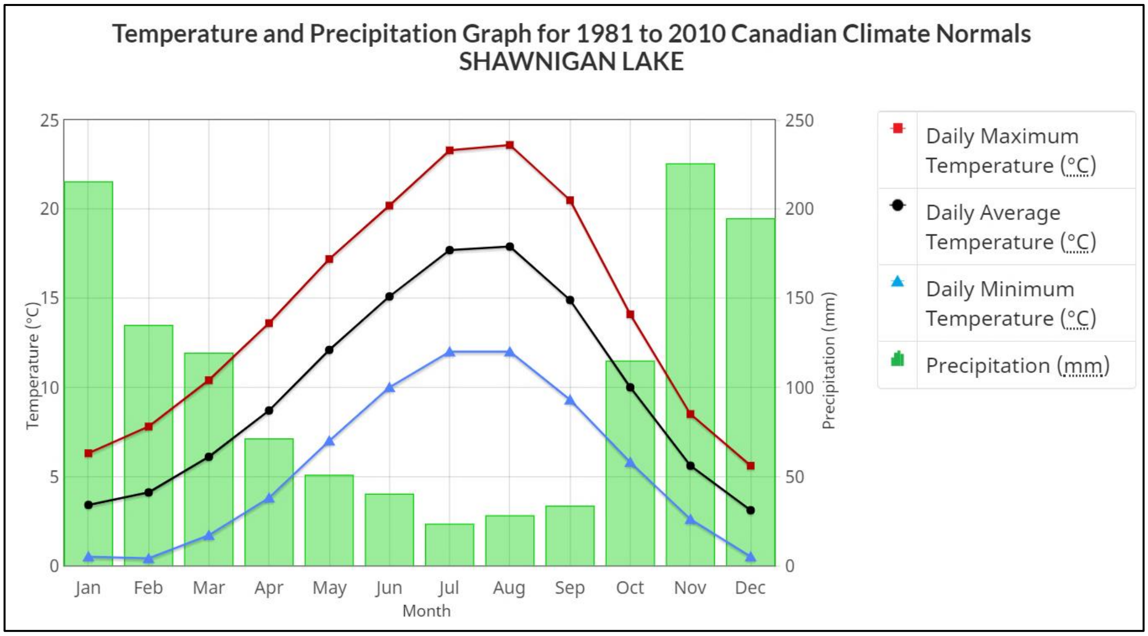


Figure 5: 1981-2010 Environment Canada climate normals for Shawnigan Lake

3.1.2 Shawnigan Lake

Shawnigan Lake has a surface area of approximately 527 ha and a total volume of 64 M m^3 (64,000 dam) at elevation 116 m. The lake has a maximum depth of 55.5 m and a mean depth of 12 m (Bryden and Barr, 2002).

3.1.3 Shawnigan Creek Weir

Originally, the levels in Shawnigan Lake were controlled only by the hydraulic properties of Shawnigan Creek. In 1964 a simple 0.6 m high concrete wall was constructed approximately 450 m downstream of the lake. The dam was allowed to fall into disrepair and by 1979 the dam had been virtually abandoned. Sedimentation and debris in the channel had built up to almost the same elevation as the top of the dam structure (Bryden and Barr, 2002). The flood on 18 December 1979 had been blamed on the bar build up, though this was not confirmed (Talbot, 1985). In 1981 the BC Ministry of Environment excavated a shallow channel through a bar that was forming at the outlet of the lake as illustrated in **Figure 6**. The excavation of the bar was believed to have contributed to low lake levels during the summer period, which resulted in a number of complaints from local residents. In 1984, flashboards were installed and a rule curve was established to try to regulate the lake levels during the low flow summer period.

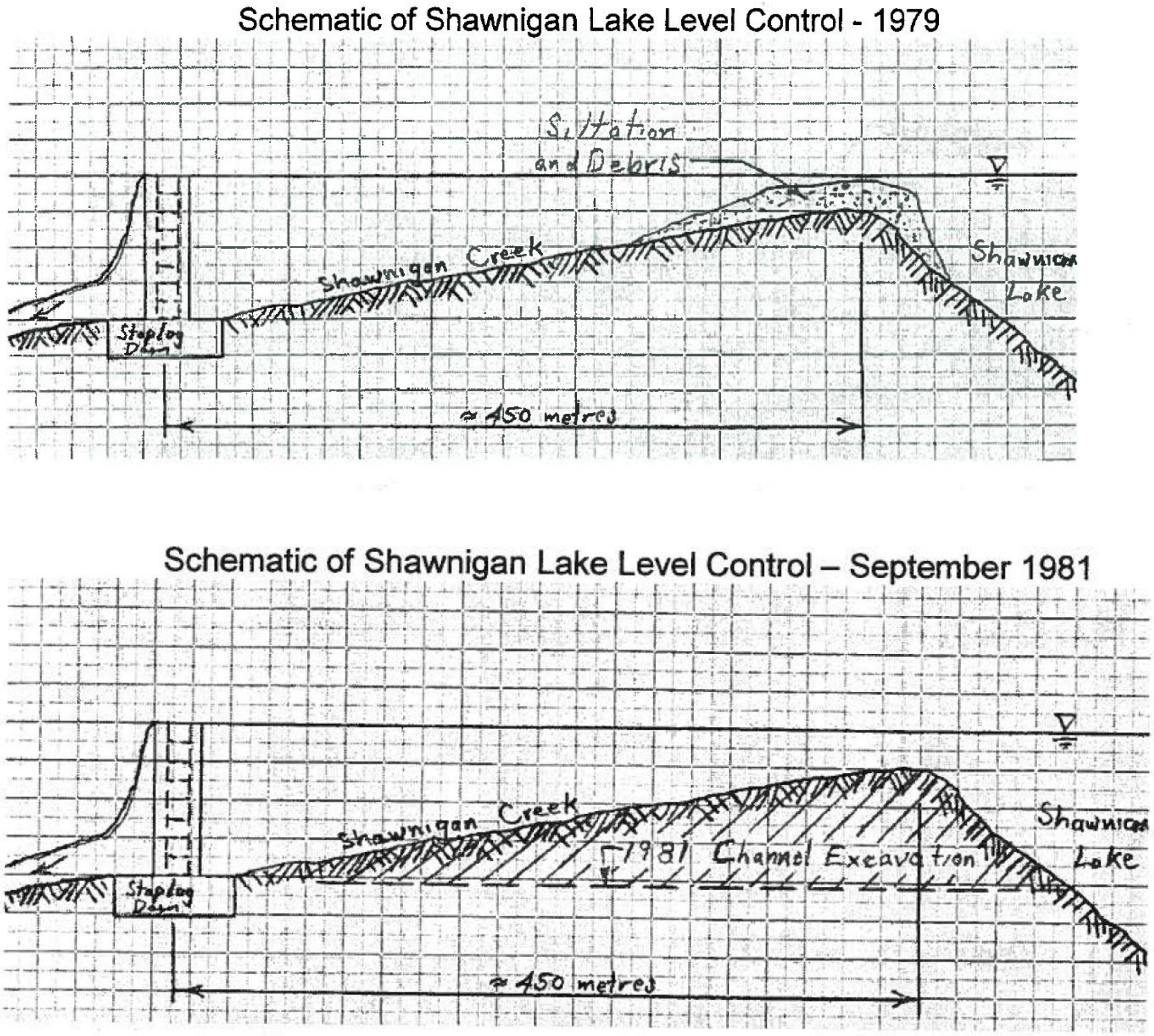


Figure 6: Varying lake level control due to sediment accumulation and excavation carried out in 1981 by BC MoE (reproduced from Bryden and Barr, 2002)

The Shawnigan Lake dam was replaced by a new weir structure in 2006. Key dimensions and parameters for the weir were determined through a review of construction record documentation (John Braybrooks Engineering, 2005), dam safety reviews (Ecora, 2019), and field topographic surveys (see **Section 1.6.1**). A summary is provided in **Table 4**.

Table 4: Shawnigan Creek Weir structural parameters

Parameter	Value
Structure type	Reinforced concrete with abutment overflow aprons
Control structure	Overshot gate
Control elevation (gate closed)	116.44 m
Control elevation (gate open)	115.24 m
Gate width	6.1 m
Abutment overflow apron elevation	117.14 m
Total waterway opening (gate width and abutment overflow aprons)	16.6 m
Appurtenance structures	Fishway and bypass channel

The weir is currently operated on a rule curve, with the period of control typically lasting from early March to early November. During controlled periods, the overshot gate elevation is adjusted manually to regulate discharges in Shawnigan Creek and corresponding water levels at the lake. During uncontrolled periods, the overshot gate is fully opened and the creek and lake are naturally regulated.

3.2 Historical Flood Events

The Shawnigan Museum and British Columbia Archives both contain useful information on historical flooding on Shawnigan Lake. Valuable historical accounts are also recorded in local community publications (Gibson, 1986; Shawnigan Lake Residents Association, 2003) and past provincial water management technical reports (MacLean, 1953; Talbot, 1985). Based on this information, significant flooding on Shawnigan Lake was recorded in 1909, 1935, 1972, and 1979. **Table 5** summarizes information on these historical floods and compares them with the recent event of 1 February 2020.

The flood of 25 January 1935 was described in Gibson (1986) quoting accounts from the newspaper “The Daily Colonist”:

> *The heavy snow on Sunday turned to a precipitation of rain which has continued increasingly bringing the lake to its highest level since 1909. Many lakeside residents are surrounded by water and while at least three have been vacated by their occupants. The E & N Railway track is covered by water to a depth of ten inches. The bridge at the lake outlet is surrounded by a swirling current and the West Arm Road is covered by three and one half feet of water.*

The newspaper account described this event as an “ice storm” and indicated large-scale flooding occurred in other areas of southwestern British Columbia as far away as the Lower Fraser Valley. Property damage was reported during the 1972 and 1979 events, but no detailed information is available. However, Water Survey of Canada recorded the lake levels in 1972 and 1979 and peak values are also reported in Talbot (1985).

Photo 3: Flooding of Shawnigan Lake, January 1935 (E-00748 BC Archives, Royal BC Museum)

Table 5: Historical floods on Shawnigan Lake

Year	Date	Lake Level (CGVD 1928 m)	Lake Level (CGVD 2013m)	Rank	Source
1909		?			Gibson (1986)
1935	Jan 25	118.9	119.1	1	NHC 2020[1]
1972	Dec 25	118.2	118.4	2	Talbot (1985)
1979	Dec 18	118.1	118.3	3	Talbot (1985)
2020	Feb 1		118.1	4	NHC

1. NHC surveyed the rail tracks near Renfrew Road bridge to estimate the flood levels associated with the 1935 flood (see Photo 4)

Photo 4: Bottom photo: Flood of 1935 at the corner of Shawnigan Lake Road and Renfrew Road (track barely visible (from Shawnigan Museum). Top photo: Similar view today (Google Street View)

3.3 2020 Flood Event

3.3.1 Meteorological Conditions

A strong low pressure system passed over Vancouver Island and the south coast of BC during the period between 30 January and 1 February 2020 causing heavy rainfalls and rising freezing levels which contributed to increased snowmelt. These events are commonly referred to as “atmospheric rivers”. A summary of the meteorological conditions during this event were described in MacDonald et al. (2020). Total (3-day) precipitation ranged from 430 mm on the west side of Vancouver Island, 95.6 mm at Shawnigan Lake, and 76.4 mm at North Cowichan. **Figure 7** shows weather charts produced by Environment Canada on 31 January and 1 February 2020.

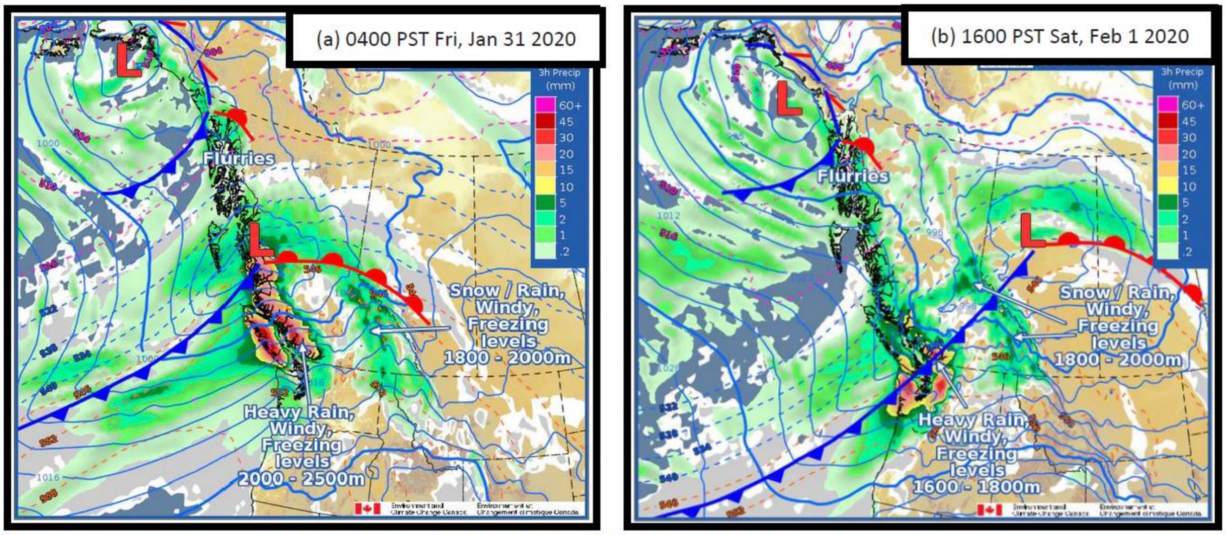


Figure 7: Weather charts showing the low-pressure system (red L) and associated fronts crossing the BC coast on 31 Jan and 1 Feb. The colour shading represents 3-hr precipitation amounts (from ECCC 2020)

Peak flows were most extreme on Vancouver Island, particularly on the San Juan, Cowichan, Koksilah and Chemainus Rivers. The return period of the peak floods on these rivers ranged between 5 and 50 years (ECCC, 2020).

3.3.2 Flooding on Shawnigan Lake

The water level sensors installed at the Shawnigan Lake Weir and on Shawnigan Lake at Decca Road intake captured the rise and recession of the 2020 flood event (**Figure 8**). During the week prior to the flood, the lake level remained steady near elevation 117.4 m. The level rose approximately 0.7 m over one day, reaching a peak level of 118.1 m by 17:30 on 1 February. The peak level at the lake was approximately 0.9 m higher than at the weir (117.2 m). Water levels at the weir rose approximately 0.4 m from steady pre-flood levels. The lake remained high for one week, reaching the pre-flood level on the morning of 7 February. During March, the flows continued to recede and by 16 March the weir was raised. This is visualized as the jump up in water level at the weir in **Figure 8**. At that time, the level of the creek upstream of the weir was within 0.1 m of the lake level.

The 2020 storm produced the fourth highest flood level on Shawnigan Lake since 1909 (**Table 5**). Damages to property have not been reported. However, the debris boom on Shawnigan Lake failed during the flood and some sections were carried downstream of the weir.

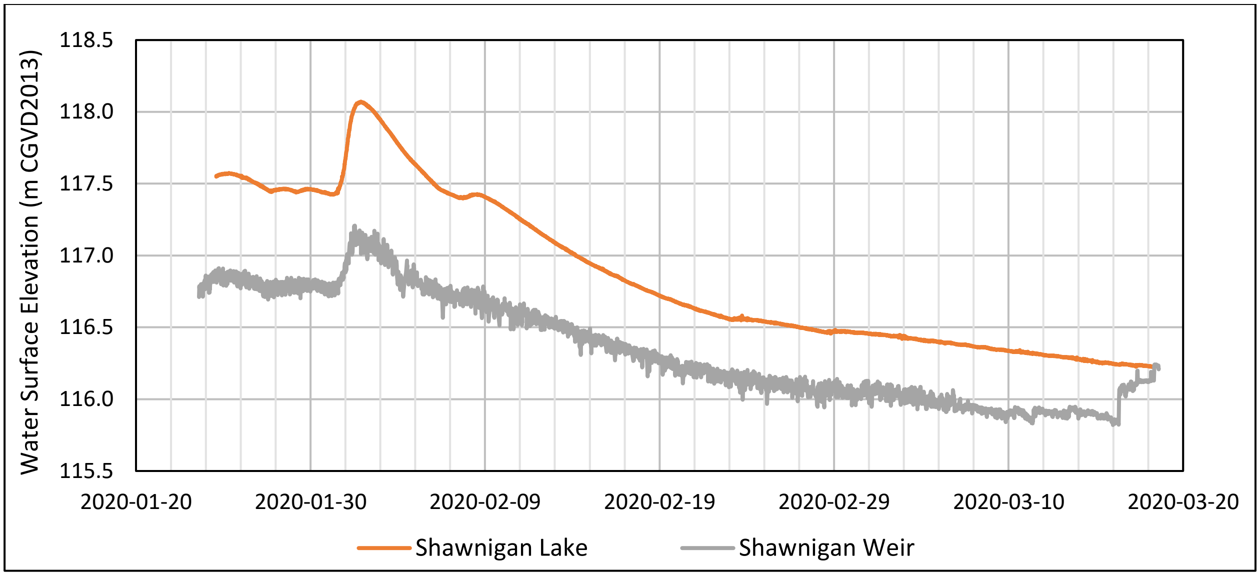


Figure 8: Lake levels at Shawnigan Lake Weir and Shawnigan Lake at Decca Road intake (2020 flood event)

3.4 Flooding Issues

There have been at least five large flood events over the last 100 years, with the highest lake levels occurring in the early part of the 20th century (1909 and 1935). The high water in February 2020 was at least 1 m lower than these extreme events and 0.1 to 0.2 m lower than the floods in 1972 and 1979. The designated flood level (without freeboard) adopted by BC Ministry of Environment in 1979 for the previous floodplain maps appears to be very similar to the historical flood level in 1935 (119.1 m).

Under normal operations, Shawnigan Lake Weir has no effect on flood levels on Shawnigan Lake. During high flows, the weir is completely submerged by backwater and has no hydraulic control on upstream water levels. Instead, lake levels are controlled by the reach-scale hydraulic characteristics of Shawnigan Creek. There is no single section in the creek that controls levels in the lake. Instead, the lake level is controlled by the creek's overall conveyance and hydraulic resistance. Debris accumulation and sedimentation in the creek will affect the outlet hydraulics of the lake. Some reports suggest that the very high flood levels in 1909 and 1935 were partly due to obstructions and the limited conveyance of the creek at that time. Therefore, the debris boom near the lake outlet plays an important role in mitigating future floods. During the February 2020 flood, the debris boom was destroyed and sections were found downstream of the weir. It is recommended that engineered booms be installed in future.

4 HYDROLOGIC CHARACTERISTICS OF SHAWNIGAN LAKE

The purpose of this section is to characterize the historical and future flood discharges on Shawnigan Creek. These values were used as boundary conditions for the hydraulic model that was used to estimate flood levels in the lake. This section also describes a flood frequency analysis of historical lake levels which were used as an independent check on the hydraulic model results.

4.1 Available Hydrometric Data

Table 6 lists the hydrometric information available for assessing flood levels on Shawnigan Lake. The CVRD provided measurements of lake levels made intermittently between 1999 and 2017. The WSC gauge on the lake (08HA032), operated between 1970 and 1994, consists of manual measurements made typically once weekly. Annual maximum and minimum observations for the period 1970 to 1982 were compiled from a study by the Water Management branch (Talbot, 1985). This report also described the gauge history, benchmarks and other relevant information.[1]

The gauges on Shawnigan Creek recorded discharge and stage, although the record lengths for both are relatively short. Fortunately, both stations were operating in December 1979, which coincided with a relatively large flood event.

Table 6: Available hydrometric data on Shawnigan Lake

WSC Gauge	Name	Period of Record
08HA004	Shawnigan Creek below Shawnigan Lake	1914-1917, 1976-1979, 1984-1989
08HA033	Shawnigan Creek near Mill Bay	1974-2009
08HA032	Shawnigan Lake opposite Memory Island	1970-1994
	CVRD observed lake levels	1999-2019
	Water Management Branch Report (Talbot, 1985)	1970-1982 (annual minimum and maximum only, extracted from daily manual measurements)

4.2 Recorded Lake Level

Peak annual water level records for Shawnigan Lake (station 08HA032) are available from Water Survey of Canada for the years 1970-1982. Limited daily data is also available from 1982 to 1990. The CVRD maintains approximately weekly lake level records at its Decca Road water treatment facility staff gauge, with the most complete records covering the years 2000-2019. NHC's gauge installations (see **Section**

[1] Gauge zero elevation of WSC gauge 08HA032 was reported to be 115.527 m GSC (CGVD 1928 datum).

1.6.5) recorded water level data for both Shawnigan Lake and Shawnigan Creek upstream of the weir beginning 23 and 24 January 2020, respectively. The three data sets were used to compile a composite record of annual maximum lake levels over a combined 33 years of data. The record length is short for estimating extreme events such as a 100-year or 200-year flood (Kite, 1977).

The composite lake level record was used to complete a second flood frequency analysis. The analysis considered the Log Normal, Log Pearson III, and Gumbel distributions. The Gumbel distribution was selected for use because it provided a good visual fit to the historical data and resulted in the most conservative lake level estimates of the three distributions. **Figure 9** shows the Gumbel distribution and a "best fit by eye" plot including the 1935 high water event (reported as the highest flood experienced since 1909). The results of the flood frequency analysis are presented in **Table 7**. Using these results, the 2020 flood had a return period of 15 to 20 years, while the highest lake level recorded by WSC (1972) had a return period of approximately 50 years. The 1935 event had a return period of at least 200 years.

It must be noted that lake level records for the CVRD's Decca Road gauge are available at approximately weekly intervals. Each data point represents a single instantaneous measurement and not a daily average or daily peak. It is highly likely that many, if not most, true peak lake levels are not captured by the CVRD's level records. Therefore, calculated annual maximum lake levels for the gauge likely underestimate the true annual maxima. By extension, the flood frequency analysis presented in **Table 7** likely underestimates the true lake level associated with each return period flood.

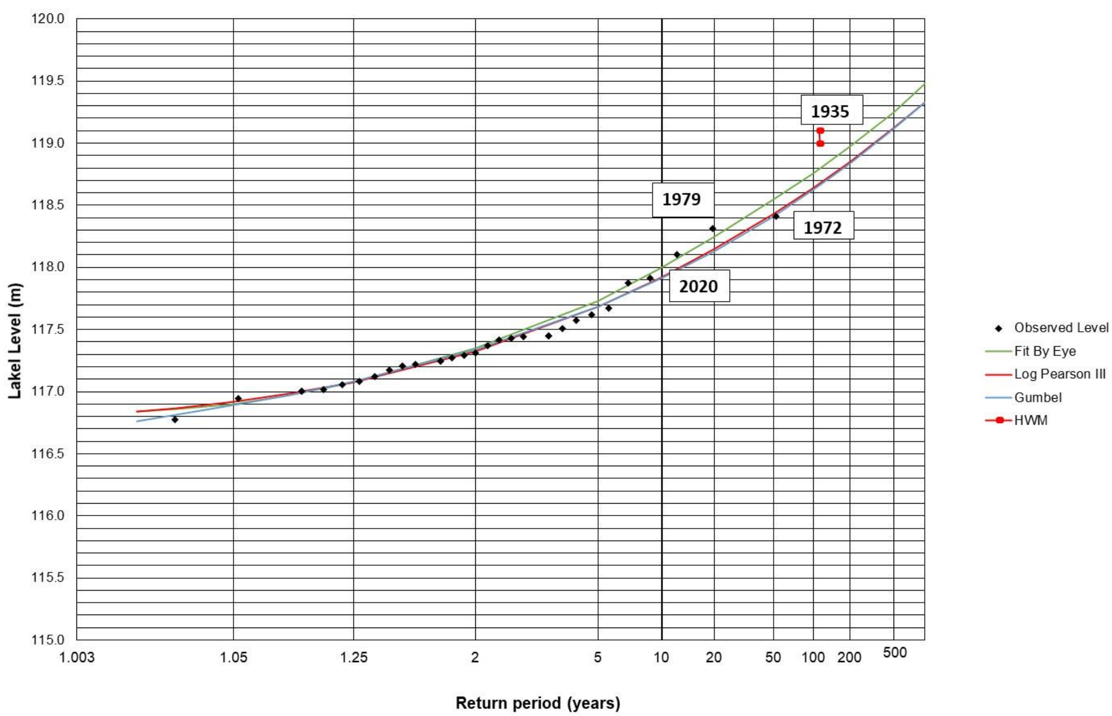


Figure 9: Flood frequency analysis of annual maximum levels on Shawnigan Lake

Table 7: Flood frequency analysis results for Shawnigan Lake water levels

Return Period (Years)	Gumbel	Best Fit by Eye
2	117.34	117.35
10	117.91	118.00
20	118.13	118.25
50	118.41	118.55
100	118.63	188.76
200	118.84	119.0

The flood frequency analysis of lake levels provides a useful, independent check on the subsequent results from the hydraulic modelling analysis. The main limitation of the flood frequency results is that they only represent past (historic) conditions, not future climate change conditions.

4.3 Discharge at Outlet of Shawnigan Lake

4.3.1 Extension of WSC Records

Water Survey of Canada gauge 08HA004 (Shawnigan Creek below Shawnigan Lake) is the ideal station for determining design flood hydrology for Shawnigan Lake and Shawnigan Creek. However, its period of record (10 complete years) is too short for reliable flood frequency analysis. To address this, the lower gauge near Mill Bay (08HA033) was used to extend the period of record for 08HA004.

Discharge hydrographs for the two stations were compared for all annual-scale flood events ($Q \geq 5$ m^3/s). Smaller discharges were excluded from the analysis because extension of the 08HA004 station record focused on flood events only, rather than low-flow events. Peak Average Daily Discharge (ADD) values for each station's flood hydrograph were tabulated and compared. A power law was developed (R^2=0.89, n=15) to model the relationship between hydrograph peaks at the two stations. The results of the analysis are presented in **Figure 10**.

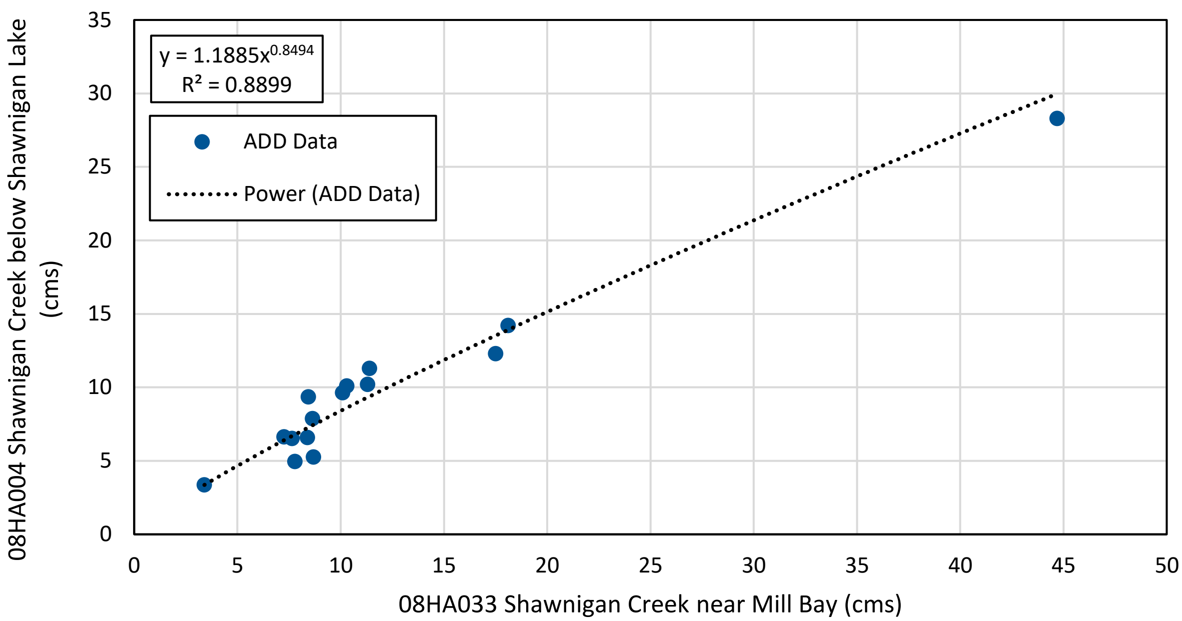


Figure 10: Comparison of flood peak ADD data for Water Survey Canada gauges on Shawnigan Creek

The power law was used to estimate Maximum Daily Discharge (MDD) values at 08HA004 for those years in which data was available at 08HA033. The 08HA004 extended station record (36 years in total) was then used to complete a flood frequency analysis of annual MDD values for Shawnigan Creek. The flood frequency analysis considered the Log Normal, Log Pearson III, and Gumbel distributions. The Log Normal Distribution was ultimately selected for use because it provided a good visual fit to the historical data and resulted in the most conservative flood discharge estimates of the three distributions.

Peak discharge records are not available for the 08HA004 gauge; however, they are available for 08HA033. On average, the ratio of peak discharge to MDD was 1.05 over the period of record. 08HA033 is lower in the watershed than 08HA004 and its total watershed area is less buffered by Shawnigan Lake than 08HA004. It is therefore expected that 08HA033 would have a higher peak discharge to MDD ratio than 08HA004. This is the case on the Cowichan River, where the lower WSC gauge at Duncan has a greater peaking ratio than the upper gauge at the outlet of Lake Cowichan. However, in the absence of peak discharge data for 08HA004 a peaking ratio of 1.05 has been adopted for the present study as a conservative estimate. Results of the flood frequency analysis for MDD and peak discharge are presented in **Table 8**, along with the station's discharge of record as a comparator.

Table 8: Flood frequency analysis results for WSC 08HA004 (extended) Shawnigan Creek below Shawnigan Lake

Return Period (Years)	08HA004 MDD (m^3/s)	08HA004 Peak Discharge (m^3/s)
2	10.7	11.3
10	18.6	19.5
20	21.7	22.8
50	25.9	27.2
100	29.1	30.5
200	32.3	33.9
Discharge of record (1979[1])	28.3	-

1. The empirical return period of this event was determined using the Gringorten plotting position formula (Bedient and Huber, 2008)

4.3.2 Lake Outlet Rating Relation

The historical lake level and discharge data on Shawnigan Creek were used to develop an approximate rating curve at the lake outlet. This relation provides a means to predict the lake level for the corresponding 200-year flood discharge in Shawnigan Creek. The main limitation with this method is that the coincident records of lake levels and stream discharges are short and end in the mid 1970s. Therefore, the relation may not be representative of present conditions due to topographic changes at the outlet and along the creek. Additionally, a single discharge measurement governs the curve after approximately 15 m^3/s. Consequently, the accuracy of the rating curve for greater discharges is uncertain. **Figure 11** shows the rating curve established at the lake outlet using the historical hydrometric data. NHC's measurement of discharge and lake level on 23 January 2020 has also been added.

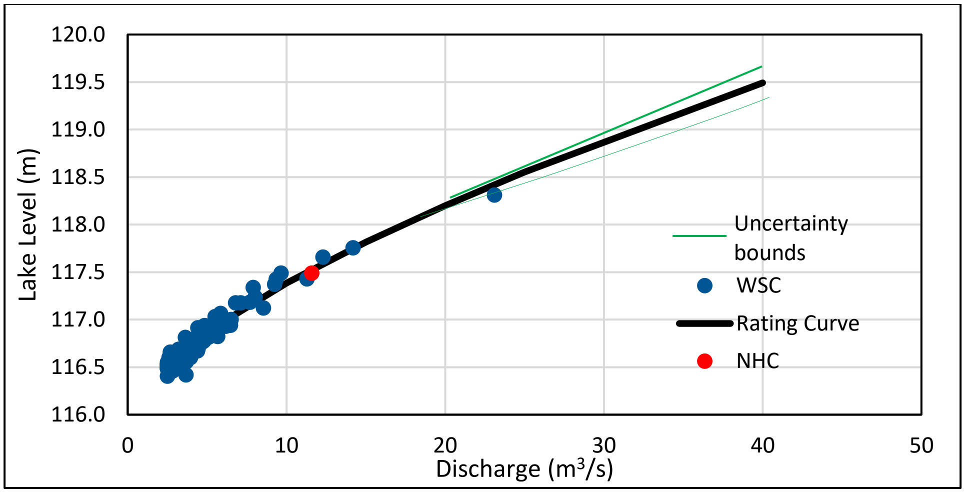


Figure 11: Rating curve for the outlet of Shawnigan Lake as determined from coincident lake levels and discharges in Shawnigan Creek

The measurement in 2020 is consistent with the historical data, suggesting the overall rating curve has remained relatively stable during the winter high flow season.

4.4 Climate Change Assessment

4.4.1 CVRD Climate Change Projections

The CVRD publication *Climate Change Projections for the Cowichan Valley Regional District* (2017) provides estimates of key climate change indicators for CVRD watersheds. The estimates are based on RCP8.5 climate change scenario, corresponding to "business as usual" greenhouse gas emissions.

The publication differentiates three watershed types in its analysis: developed area watersheds, water supply watersheds, and west coast watersheds. The Shawnigan Lake watershed is classified as a developed area watershed.

For flood hydrology at Shawnigan Lake, the most important climate change indicator is extreme precipitation. Snowpack is another important indicator; however, historical floods of record have been largely precipitation-driven rather than snowmelt-driven. Extreme precipitation indicators for the developed area watersheds are summarized in **Table 9**. Mean estimates correspond to the mean of RCP8.5 ensemble predictions, while estimate ranges correspond to the 10th and 90th percentiles of the ensemble predictions.

Table 9: CVRD key climate change projections for developed area watersheds

Climate Change Indicator	2050s Change	2080s Change
24-Hour annual maximum precipitation	Mean estimate: +16% Range: 3 to 31%	Mean estimate: +30% Range: 10 to 46%
5-Day annual maximum precipitation	Mean estimate: +10% Range: 4 to 21%	Mean estimate: +24% Range: 6 to 34%
20-Year return period 24-hour precipitation	Mean estimate: +24% Range: 8 to 43%	Mean estimate: +36% Range: 14 to 55%

4.4.2 Trend Analysis

A detailed climate change flood assessment for Shawnigan Lake would require watershed hydrometeorological modelling outside the scope of the present study. Instead, a simplified approach has been adopted based on the Engineers and Geoscientists of British Columbia (EGBC) guideline *Legislated Flood Assessments in a Changing Climate in BC* (2012). This approach has been utilized by NHC for other CVRD projects, including the current Cowichan-Koksilah Floodplain Mapping Project. The guideline recommends the following approach for determining the potential impacts of climate change on design flood discharges when specific climate modelling and analysis is not available:

1) For a waterbody of interest, complete a temporal trend analysis of available historical peak discharge data. In the absence of such data, regional streamflow data may be utilized. In the absence of regional streamflow data, precipitation data may be utilized;

2) If an increasing trend is detected in any of the analyses, it is recommended that design discharges be increased by 20% to account for the potential future effects of climate change;

3) If no increasing trend is detected, it is recommended that design discharges be increased by 10% to account for the potential future effects of climate change.

Discharge records are available for Shawnigan Creek (**Section 4.1**), as well as for regional stations from Water Survey Canada. Regional stations were selected based on proximity to the Shawnigan Lake watershed and length of station record. A trend analysis was completed for each station by applying the non-parametric Mann-Kendall test to annual MDD values (significance α=0.05). The analysis results are presented in **Table 10**. A statistically significant increasing trend was detected only for the Chemainus River (08HA001). No statistically significant trend was detected for Shawnigan Creek (08HA033). It should be noted that the 08HA033 record extends only to 2008, and recent increasing trends in flood magnitude may not be captured by that station's records. Therefore, the trend assessment is not very definitive in this case.

Table 10: Trend analysis results for regional WSC gauges

WSC Gauge	Years of Record	Mann-Kendall p-value	Statistical Significance
08HA033 Shawnigan Creek near Mill Bay	34	0.801	Non-significant
08HA003 Koksilah River at Cowichan Station	62	0.349	Non-significant
08HA002 Cowichan River below Cowichan Lake	84	0.206	Non-significant
08HA011 Cowichan River near Duncan	59	0.250	Non-significant
08HA001 Chemainus River near Westholme	**66**	**0.018**	**Significant**
08HA010 San Juan River near Port Renfrew	51	0.553	Non-Significant

4.4.3 Rainfall-Discharge Analysis

As a check on the EGBC guidelines recommendation, an ancillary climate change analysis was completed. The analysis focused on the relationships between rainfall and flood discharges for the Shawnigan Creek watershed, and how projected increases in extreme precipitation due to climate change could translate to increases in flood discharge. In lake settings, this relationship is complex due to hydrologic "memory" effects. For example, an extreme precipitation event occurring during a low to moderate antecedent lake level may produce a lower peak lake level than a lesser precipitation event occurring during a moderate to high antecedent lake level. Furthermore, lakes are often most sensitive to high-volume rainfall events, rather than shorter duration high intensity rainfall events where lake attenuation better dampens peak flows.

To explore this concept, extended flood records (model presented in **Section 4.3.1**) for Shawnigan Creek (WSC 08HA004) were compared against precipitation records from the Environment Canada climate station at Shawnigan Creek. Spearman rank correlations (ρ) were developed between peak ADD flood discharges and 24-Hour and 5-Day antecedent precipitation totals over 41 flood events ($3.2 \le Q \le 44.7$ m^3/s). The 5-Day antecedent precipitation totals showed a higher correlation with peak discharge (ρ=0.83) than the 24-Hour antecedent precipitation totals (ρ=0.67). This indicates that 5-Day precipitation is a better predictor of peak flood discharges than 24-Hour precipitation, and that precipitation volume events likely drive extreme floods for the lake.

A simplified linear model (R^2=0.7443, n=41) was developed to quantify the relationship between peak ADD flood discharges at Shawnigan Creek and 5-Day antecedent precipitation, the results of which are presented in **Figure 12**. There is one significant outlier at the upper end of the dataset, associated with the flood of 1979. Significant precipitation occurred in the weeks before the event, in addition to the significant precipitation in the 5 days preceding the event. The additional lead-up precipitation is not captured in the 5-Day precipitation totals, and it is therefore unsurprising that the modelled relationship underpredicts peak flood flows for this event.

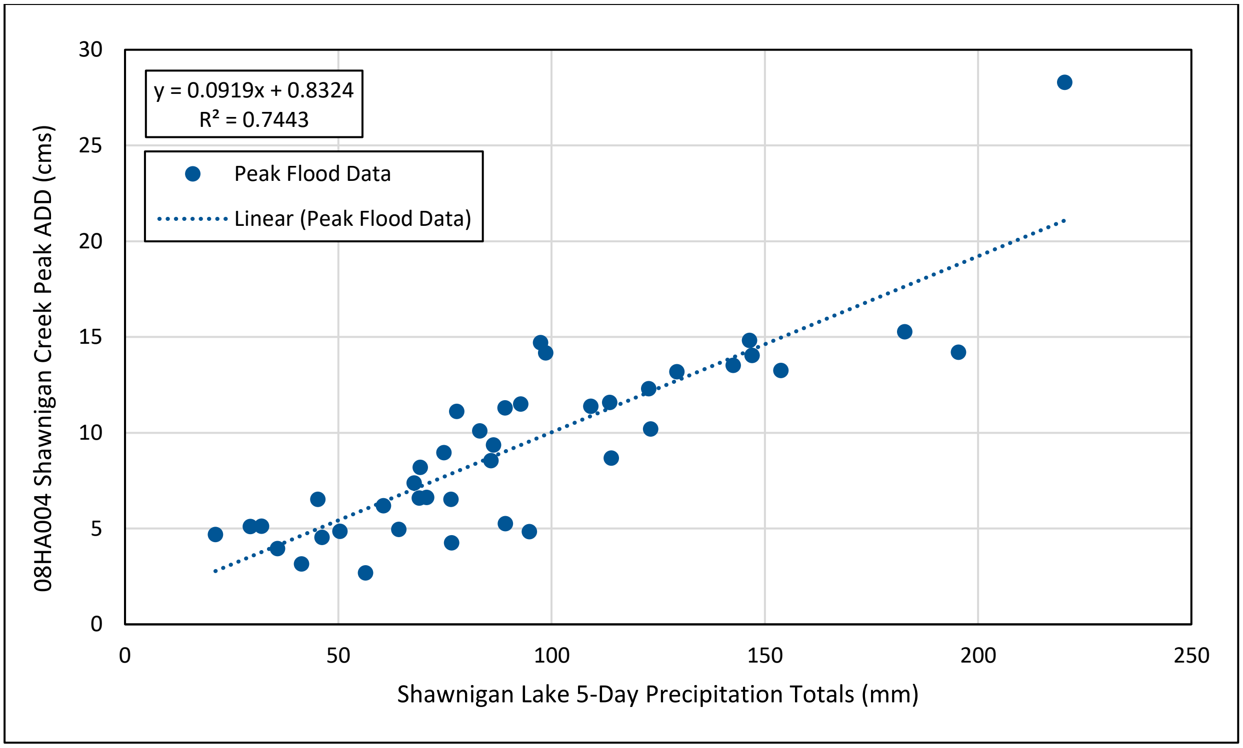


Figure 12: Shawnigan Creek flood peaks vs. antecedent precipitation analysis

The linear model was combined with mean 5-Day precipitation indicators (**Table 9**) to estimate the impacts of 5-Day precipitation increases on peak ADD flood flows for Shawnigan Creek. The following analysis steps were completed:

1) For each flood of return period T (Q_T) presented in **Table 8**, calculate the associated 5-Day precipitation (P_T) using the linear model presented in **Figure 12**;

2) Apply the mean climate change factors presented in **Table 9** to the P_T values;

3) Recalculate the Q_T values using the linear model (**Figure 12**) and the climate change-adjusted P_T values from step 2.

The results of the analysis are presented in **Table 11**, indicating mean increases to flood flows of 10% and 23% by the 2050s and 2080s, respectively. It should be noted that these results are subject to significant uncertainty, including, but not limited to:

- Ensemble uncertainty in the CVRD climate projections;
- Microclimate effects at Shawnigan Lake which may differ from regional averages in the CVRD's developed watersheds study area;
- Uncertainty in applying precipitation indicators for annual extremes to precipitation events at high return periods;

- Station record uncertainty for 08HA004, stemming from the model used to extend the station records;
- Flood frequency analysis uncertainty; and
- Uncertainty in the relationship between precipitation and flood discharge, particularly for precipitation events above those observed historically.

Nevertheless, the analysis results indicate that the 20% increase in design flood discharges recommended by the EGBC guideline is appropriate for Shawnigan Creek. The adopted flood discharges utilized for the remainder of the present study are summarized in **Table 12**.

Table 11: Estimated impacts of precipitation on flood discharges for Shawnigan Creek under climate change conditions

Flood Return Period	Historical Flood Frequency Estimate (m^3/s)	2050s Climate Change Estimate (m^3/s)	2080s Climate Change Estimate (m^3/s)
Q_2	11.3	12.4	13.8
Q_{10}	19.5	21.4	24.0
Q_{50}	27.2	29.9	33.5
Q_{100}	30.5	33.5	37.5
Q_{200}	33.9	37.2	41.8

Table 12: Adopted flood discharges for Shawnigan Creek

Flood Return Period	Historical Conditions Discharge (m^3/s)	Climate Change Factor	Climate Change Conditions Discharge (m^3/s)
Q_2	11.3	+20%	13.6
Q_{10}	19.5	+20%	23.4
Q_{50}	27.2	+20%	32.6
Q_{100}	30.5	+20%	36.6
Q_{200}	33.9	+20%	40.7

Ongoing research and data analysis will continue to refine predictions of future climate change. Also, ongoing monitoring of lake levels should assist in identifying long-term trends. Consequently, it is recommended that the future climate change scenario be reviewed every ten years.

4.5 Wave Effects on Shawnigan Lake

4.5.1 Site Topography

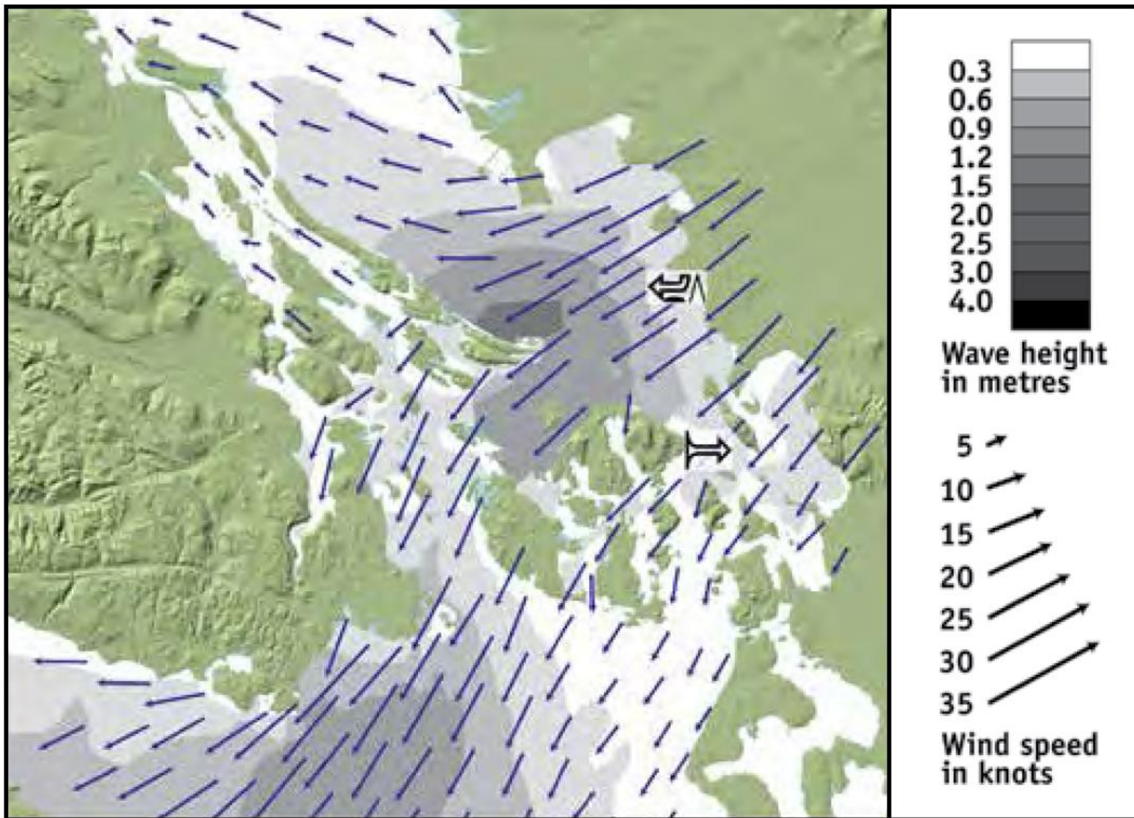
Shawnigan Lake is oriented north-south and is surrounded by relatively low hills and uplands that range in elevation from 150 m to 500 m. The relatively high-elevation Malahat bluffs shelter the lake from the southeast while Cobble Hill has a similar effect on the northeast. The very irregular shape and the narrow sections of the lake limit the exposed fetch length over which winds can blow. At the north end, near the outlet of Shawnigan Creek the maximum fetch length is about 2.4 km (measured from the south west). The width of the lake typically varies from 0.2 km up to 1.2 km, and averages about 0.6 km. These distances define the typical fetch length from west to east.

4.5.2 Local Wind Patterns

The information in this section is extracted primarily from Environment Canada (2015) and Klock and Mullock (2001). EC (2015) describes five principle weather pattern categories: easterly, northerly, southerly, westerly and coastal low (which can include all of the others over the course of its passage). In autumn, the dominant wind is from the east (easterly); because of the orientation of the coastline, southeasterlies are frequent. During winter, easterly winds still prevail but the occasional northerly outflow winds can occur. The main types of wind patterns that are likely to generate waves on Shawnigan Lake during winter flood conditions are described below.

Northeasterly Pressure Systems

North outflow winds can occur any time of year but most frequently in winter. The strong northeast wind flows out of the Fraser Valley, crosses over the Gulf Islands and then typically splits, with most passing south over the San Juan Islands through Haro Strait and towards Victoria (**Figure 13**). A secondary stream turns northwards across Saltspring Island, resulting in southerly or easterly winds near Cowichan Bay and the Shawnigan Lake region.



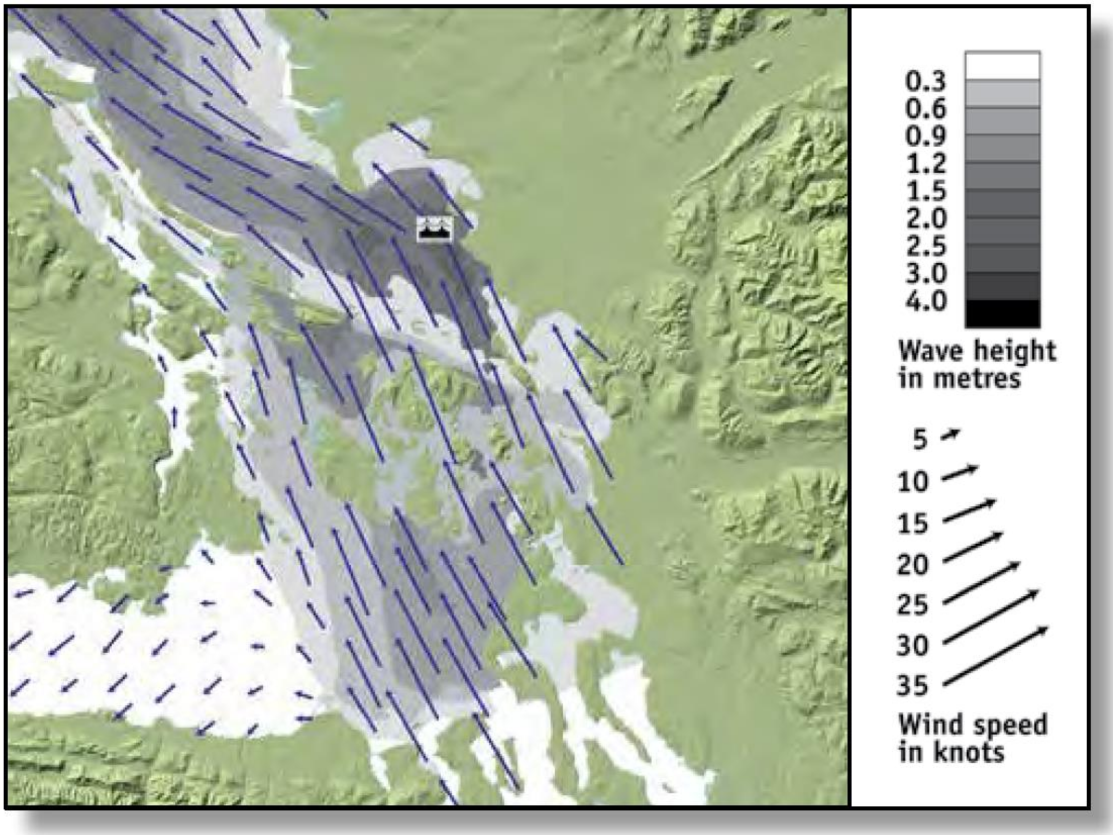
Northeasterly winds and waves using the example of 2400 hrs, 28 December 1996 with a pressure-slope direction of 045° and a slope steepness of 7.0 mb per 60 nm.

Figure 13: Northeasterly winds and waves from 28 December 1996 (from EC, 2015)

Easterly Winds

The strongest southeast winds occur ahead of a low pressure front, which typically occurs in winter (**Figure 14**). The pattern of winds depends on whether the frontal system approaches from the northwest or southwest. The usual pattern is for a deep low-pressure system to approach the coast from the southwest or west. Ahead of the approaching low, a warm front will spread steady precipitation and strong southeast winds across the region. Flooding can be intensified when a deepening trough of low pressure offshore causes the front to stall over the south coast, resulting in extremely heavy precipitation. The flooding on 1 February 2020 was generated by a low pressure front approaching from the southwest (**Figure 7**).

After the passage of a front, precipitation usually ends or becomes intermittent and winds usually shift to moderate to strong, west or southwest through Juan de Fuca Strait, Victoria and the Gulf Islands. With fronts that approach from the west or southwest, the southwest winds will be lighter than the southeast winds that preceded them. With fronts approaching from the northwest, the southwesterly winds can reach speeds equal to or greater than the southeast winds. Finally, behind the cold front, strong gusty northwest winds often occur.



Southeast winds and waves using the example of 0400 hrs, 20 December 1997 with a pressure-slope direction of 115° and a slope steepness of 4.0 mb per 60 nm.

Figure 14: Example of southeasterly winds during the passage of a low-pressure system

4.5.3 Review of Available Wind Data

Environment Canada has published hourly wind speed and direction at several locations near Shawnigan Lake, including Victoria Airport (1953 to present), Patricia Bay (2001 to present), Victoria Gonzales (2000 to present) and Esquimalt Harbour (1950 to present). Victoria Airport is at an elevation of 20 m and is 16 km east of Shawnigan Lake. Although not ideal, due to its proximity to the site and long record length it was used as a reference station for assessing wind conditions at Shawnigan Lake.

Wind speed and wind direction have also been recorded at Shawnigan Lake Museum since 2007 under the auspices of the Vancouver Island School-Based Weather Station Network (VISN). The program was developed and is maintained by the department of Earth and Ocean Sciences at the University of Victoria. The data are available online http://www.victoriaweather.ca/station.php?id=93, and provide high resolution records (one minute interval) output, which are very useful for assessing local storm events over a period of a few days. However, the station is operated primarily for educational purposes and is not an official Environment Canada weather station. Therefore, the data has been used for qualitative purposes to compare with other data sets.

Environment Canada's High Resolution Deterministic Prediction System (HRDPS) provides graphical visualizations of local wind patterns over portions of the British Columbia coast. Output from the model is published online using the Windgram software at http://www.canadarasp.com/aboutcanadarasp.html.

4.5.4 Measured Wind Speed and Direction

Wind speed and direction have not been recorded at Shawnigan Lake. However, historical wind records are available from the Environment Canada (EC) meteorological station at Patricia Bay (2001-2014) and from Meteorological Services of Canada (MSC) meteorological station at Victoria International Airport (1953-2014). These stations are both close to the project site. The frequency, direction, and speed of the wind was assessed using a wind rose: a graphic presentation that utilizes arrows at the cardinal and inter-cardinal compass points to show the direction from which the winds blow and the magnitude and frequency for a given period of time. **Figure 15** summarizes the results for the entire period of record at the two stations.

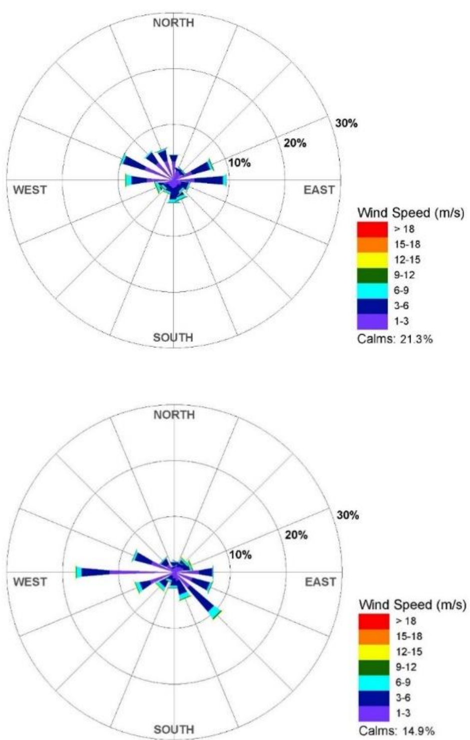


Figure 15: Wind rose at Patricia Bay (top) and Victoria Airport (bottom) (annual observations)

The strongest winds occur most frequently in winter and early spring and are predominantly from the southeast and east. The results from the two stations are generally similar; however, Victoria Airport has a much longer period of record, making it more representative for statistical analysis. Therefore, the remaining discussion quotes results from this station. In order to apply the data for wave hindcasting, it was necessary to apply corrections to adjust for the height above sea level and overland conditions. A summary of the wind analysis is as follows:

- 15% of the winds are less than 1 m/s (or 4 km/hr).
- 6.6% of the winds are from N, NNE, and NE; 0.52% are greater than 6 m/s (or 22 km/hr).
- 10.2% of the winds are from ENE and E; 0.64% are greater than 6 m/s (or 22 km/hr).
- 23.1% of the winds are from ESE, SE, and SSE; 3.1% are greater than 6 m/s (or 22km/hr).

A frequency analysis of annual maximum winds was made using the published hourly data at Victoria International Airport. Frequency estimates for southeasterly events were as follows:

- 5-year wind: 15.3 m/s (or 55.1 km/hr).
- 10-year wind: 16.5 m/s (or 59.4 km/hr).
- 25 year wind: 18.0 m/s (or 64.8 km/hr).

Although Environment Canada maintains a climate station at Shawnigan Lake, it does not record continuous wind speed. The short-term records at Shawnigan Lake museum and Environment Canada's High Resolution Deterministic Prediction System (HRDPS) program were used to verify that the results at Victoria Airport were representative of conditions at Shawnigan Lake.

4.5.5 Occurrence of High Winds and High Shawnigan Lake Water Levels

The effects of winds and waves during a flood event depends on the joint occurrence of high water levels and strong winds as well as the directions the winds blow over the lake. A comparison of historical maximum wind speeds (hourly) and measured water levels on Shawnigan Lake (WSC 08HA033) shows the period of highest wind speeds generally does not coincide with the period of highest lake levels (**Figure 16**).

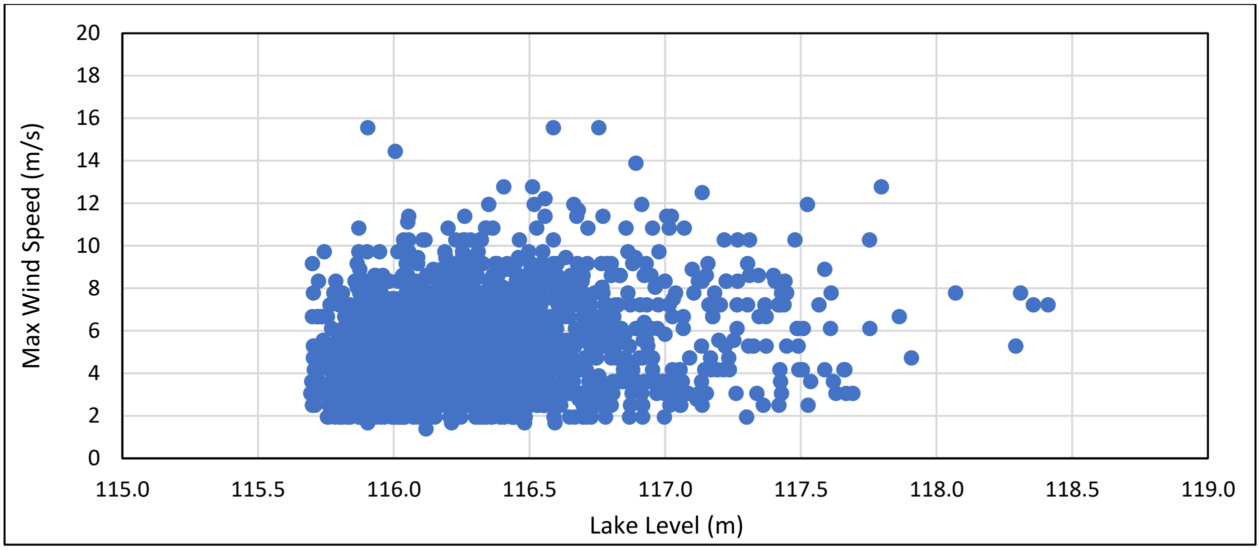


Figure 16: Observations of maximum wind speeds and water levels on Shawnigan Lake (1972-1994)

This is most likely due to the relatively long time response of the lake to the precipitation event as well as the tendency for the strongest winds to lead in advance of the storm event. A detailed comparison of maximum wind speeds and peak lake levels was made for the four largest recorded flood events (**Table 13**).

Table 13: Lake levels and wind speeds during three historical flood events

Flood Event	Lake Level (m)	Maximum Wind Speed on Day of Flood (m/s)	Maximum Wind Speed Within 30 Days of Flood (m/s)
26 Dec 1972	118.4	7.2	
			9.4 (24 Dec)
			12.5 (18 Jan)
18 Dec 1979	118.3	7.8	
			10.3 (23 Dec)
5 Dec 2007	118.2	7.8	
			10.8 (3 Dec)
1 Feb 2020	118.2 (14:00)	8.1 (14:00)	
	117.9 (07:00)	10.3 (07:00)	
			12.5 (15 Jan)

During these events, the maximum wind speeds around the time that the lake peaked ranged between 8 and 11 m/s, substantially lower than the highest wind speeds (> 15 m/s) that have been recorded on other dates. **Figure 17** shows the pattern of wind speed at Victoria International Airport and Shawnigan Lake Museum and the response of the lake level to the 31 January 2020 storm event.

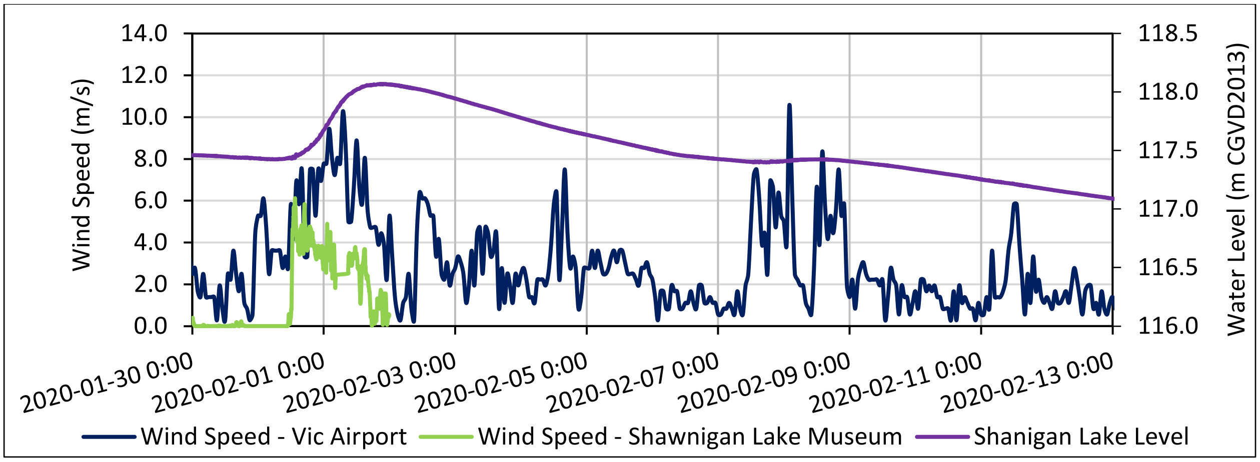


Figure 17: Wind speed and lake level January 30 to February 13, 2020

According to the data at Victoria Airport, the winds veered from southerly to westerly at 05:00 on 1 February and reached their peak speed of 10.3 m/s at 07:00. The station at Shawnigan Lake Museum showed the strongest winds occurred from 13:00 on 31 January to 02:00 on 1 February. The winds were from the southwest during this time. The Windgram program also showed the strongest winds at Shawnigan Lake were from the southwest during the storm.

4.5.6 Wave Effects

Wave heights were estimated for a range of wind speeds and exposures using standard wave hindcasting methods developed by the US Army Corps of Engineers EM 1110-2-1100. A fetch of 2.4 km was used to represent the maximum exposure at the north end of the lake from southerly winds. A fetch of 1.2 km was used to represent the maximum exposure along the eastern shoreline from westerly winds. Estimated wave heights (Hs) and wave periods (Tp) are shown in **Table 14**. These values represent the wave conditions in the lake before shoaling and wave breaking occurs. The wave runup ($R_{2\%}$) represents the maximum vertical distance of wave uprush on a shoreline or structure, as measured above the still water surface. Runup is governed by the wave conditions (wave height and period) and by the slope of the shoreline that the waves break against as well as the surface roughness of the slope. Runup is commonly specified in terms of a probability of exceedance. $R_{2\%}$ indicates 2% of waves during a given time period will exceed the given value. The wave runup has been calculated for a relatively steep beach slope (1V:5H) and for a riprap revetment structure (1V:2H).

Table 14: Estimated wave height (Hs) and wave runup ($R_{2\%}$)

Fetch (km)	Wind Speed (m/s)	Hs (m)	Tp (sec)	$R_{2\%}$ (m)	
				1V:5H	1V:2H
2.4	16.6	0.55	1.8	0.3	0.7
	12.0	0.4	1.8	0.3	0.6
	10.0	0.3	1.7	0.2	0.5
1.2	16.6	0.4	1.4	0.2	0.5
	12.0	0.3	1.4	0.2	0.4
	10.0	0.2	1.4	0.1	0.3

The exposure to waves, beach topography, slope, and roughness characteristics all vary widely around the lake. During times when the still water lake level is at an extreme flood condition, the wave runup ($R_{2\%}$) is expected to range between 0.3 and 0.6 m. For estimating the flood construction level, a wave runup of 0.6 m was adopted for portions of the shoreline exposed to southerly waves and 0.4 m for other areas.

5 HYDRAULIC MODEL ANALYSIS

5.1 Purpose

A one-dimensional (1D) HEC-RAS model was created to estimate the water levels along Shawnigan Creek up to Shawnigan Lake during the designated flood event. The hydraulic model uses the discharge at the outlet from the lake, the topography of the creek, and roughness characteristics of the channel and floodplain as known inputs and then solves the equations of motion to estimate the water level, mean velocity, and depth at each cross section. The model can also represent various structures such as bridges and weirs.

5.2 Model Extent

The topographic survey completed by NHC between 16 and 17 March 2020 (see **Section 1.6.1**) was used to model the channel characteristics of Shawnigan Creek. The survey began at Shawnigan Lake outlet and ended approximately 100 m downstream of the Shawnigan Lake Weir. Cross sections were surveyed immediately upstream and downstream of both the bridge at Renfrew Road and the E & N Railway bridge at William Rivers Park. This improved accuracy of modelled water levels by accounting for energy loss due to contraction and expansion of flow at these structures. Cross sections immediately adjacent to the weir could not be surveyed due to unsafe water depth and velocity. Vegetated overbank areas were surveyed where feasible.

The survey completed by NHC was extended downstream by approximately 150 m using the survey completed by BC MOE in January 1994. This allowed the hydraulic model to end at the E & N Railway bridge downstream of the weir.

5.3 Model Development

5.3.1 Geometry

The model geometry was developed in HEC-RAS using a combination of surveyed cross sections and 2010 LiDAR data. Cross sections were extended to high ground above the limits of the floodplain using LiDAR such that flood levels would not be influenced by lack of cross sectional data. Model geometry included 16 cross sections from the survey completed by NHC (see **Section 1.6.1**). These cross sections were between 30 m and 60 m apart, except where immediately upstream and downstream of bridge structures.

Two surveyed cross sections from BC WSS were included in the model downstream of where NHC’s survey ended. A third cross section was added at the downstream E & N Railway bridge where BC WSS provided a thalweg elevation. This cross section was approximated using the last surveyed cross section from BC WSS, and elevations were adjusted using the thalweg at the railway bridge. Because the channel geometry was relatively uniform between the weir and downstream railway bridge, the duplication of the cross section was acceptable.

The downstream normal depth was approximated using the bed slope of the last 63 m of the survey from BC WSS, where the channel slope decreased. The BC WSS surveyed cross sections were used only to confirm convergence of modelled water surface elevations past the weir. Therefore, uncertainty in the downstream reach approximated normal depth, and water surface slope had little to no affect on modelled water surface elevations upstream of the weir.

Surveyed cross sections approximately 17 m upstream and 23 m downstream of the weir were duplicated and used to represent channel characteristics immediately at the weir. This improved accuracy of modelled discharge characteristics by better representing the expansion and contraction of flow at the structure. Due to the relatively uniform channel characteristics within this channel length, the duplicated cross sections were acceptably representative of channel characteristics at the weir.

The survey conducted by NHC included features of the bridges and weir such as abutments, low chords, and top of decks. The elevation of the weir when fully open was surveyed by NHC on 20 January 2020 during the control survey in preparation for the March bathymetric survey.

5.3.2 Boundary Conditions

Manning’s n values were initialized using the method recommended by Arcement and Schneider (1989). The initial Manning’s n values used for the channel and floodplain at each cross section were determined based on six factors: the base material composing the channel or floodplain, the degree of irregularity of the channel or floodplain, the variation in channel cross section (this was not considered in the floodplain roughness calculation), the effects of obstructions, the amount of vegetation, and the degree of meandering (this was not considered for floodplain roughness). The characteristics of greatest importance for channel roughness are the type and size of the base material, and the shape of the channel; floodplain roughness is highly influenced by vegetation (Arcement and Schneider, 1989). The average channel and left and right floodplain Manning's n values were 0.063, 0.147, and 0.138, respectively. These values were used as a starting point prior to calibration and validation of the model (see **Section 5.3.3**). **Photo 5** provides a visual of Shawnigan Creek channel and floodplain roughness.

Photo 5: Left photo: Representative floodplain vegetation along Shawnigan Creek, photo looking upstream taken from right bank at weir. Right photo: Shawnigan Creek channel roughness, photo looking downstream taken from right bank at weir.

Ineffective flow areas were delineated based on anticipated ponding locations noted during the topographic survey. An abandoned channel of Shawnigan Creek was included as an ineffective flow area. The abandoned channel is located along the current straight length downstream of the E & N Railway bridge at William Rivers Park up to the bend before the Shawnigan Lake Weir. Historical imagery from Google Earth (2020) on 10 June 2012 shows the now abandoned channel was active as recently as eight years ago (**Photo 6**). Due to foliage it is difficult to determine from aerial imagery when the channel became abandoned.

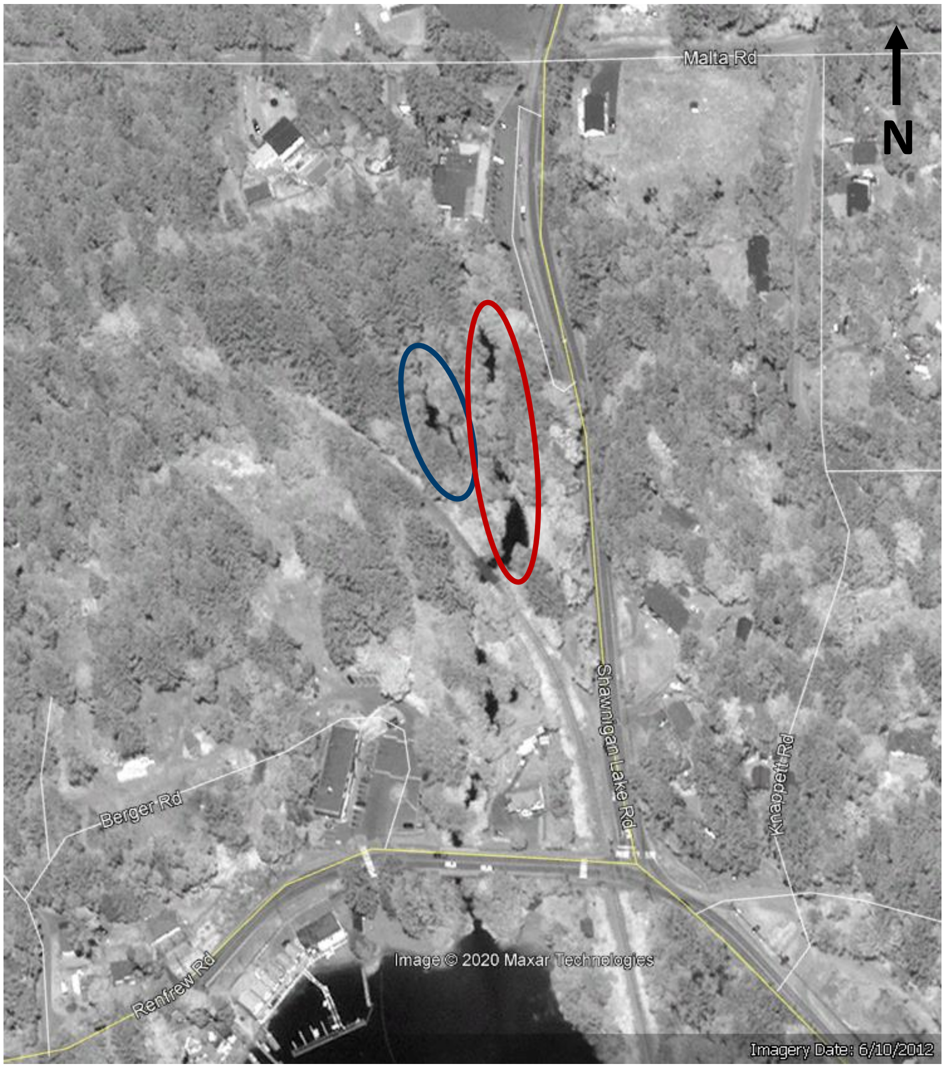


Photo 6: Historical imagery of Shawnigan Creek, 10 June 2012. Blue circled area indicates used channel that is currently abandoned. Red circled area indicates current channel (Google Earth, historical imagery archives)

The model was run using steady state analysis. The boundary condition for flow data was set to normal depth, with a slope condition of 0.0034%. The downstream boundary is 220 m downstream of the weir and 150 m downstream of the study limit, where NHC's survey ended.

5.3.3 Calibration and Validation

Model calibration was carried out using the discharge (11.6 m^3/s) and water levels measured at 15:15 on 23 January 2020. At this time, water level at the weir was measured at 116.77 m and the weir was fully open. Water level in Shawnigan Lake was approximated for this time, as the first water level measurement was not until 14:15 on 24 January 2020. The head difference between the lake and weir would not have changed significantly during this 23 hour time difference. The difference in water levels between the weir and lake (0.72 m) from the time of the first lake level measurement was used to approximate the lake level when the discharge was measured (117.49 m). Since the weir was fully open when discharge and water level measurements were obtained, model calibration was completed using an open weir scenario.

Calibration was completed by varying the channel Manning's n values to minimize error between the modelled water surface elevations and those measured in the field. There was a negligible effect on water level from the change in overbank roughness, which is likely because most of the flow remained within the main channel for the calibration discharge. Therefore, floodplain roughness was not altered from the initial best estimate (**Section 5.3.2**). Average channel and left and right overbank Manning's n values after calibration were 0.069, 0.147, and 0.138, respectively.

The modelled water levels were 1.6 mm higher than the measured values at both the weir and the lake. Differences below 10 mm between modelled and measured water levels are considered acceptable. The weir was modelled as fully open during calibration to replicate conditions during field measurements of discharge and water levels.

Once Manning's n values were calibrated, the model was validated using data from the 2020 flood event. Level loggers installed by NHC recorded the peak water level on 1 February 2020 as 118.1 m at Shawnigan Lake, and 117.2 m at the Shawnigan Lake Weir. According to the rating curve created from the model, these water levels would have resulted in a discharge of 20.5 m^3/s. This discharge was run through the calibrated HEC-RAS model to determine what the modelled lake level would be for the 2020 flood event discharge. The modelled water levels were the same as those measured by the level loggers: 118.1m for the lake. The calibration and validation results support the reasonableness of the model geometry and final Manning's n values.

An additional rough check was completed through comparison of results to the historical rating curve presented in **Figure 11** (**Section 4.3.2**). Model results for the Shawnigan Lake rating curve were close to the historical rating curve up to approximately 15 m^3/s (**Table 15**). In 1979 a discharge of 23.1 m^3/s was recorded, and is the only discharge governing the rating curve for flows greater than 15 m^3/s. The modelled and historical rating curves are very similar for the range of conditions covered by the historical data.

Table 15: Historical and modelled rating curve results

Discharge (m^3/s)	Shawnigan Lake Level (m)	
	Historical Rating Curve	Modelled Rating Curve
2.5	116.5	116.5
5	116.9	116.9
10	117.4	117.4
15	117.8	117.7
20	118.2	118.1
25	118.6	118.3

5.4 Flood Event Modelling

The model was run for a range of floods between the 2-year and 200-year return period and for both historical conditions and the future climate change scenario. The runs were also repeated with the weir gates fully opened (normal winter operations) and then with the gates closed (representing a gate failure or weir blockage due to debris). No other changes were made to the model geometry or roughness parameters.

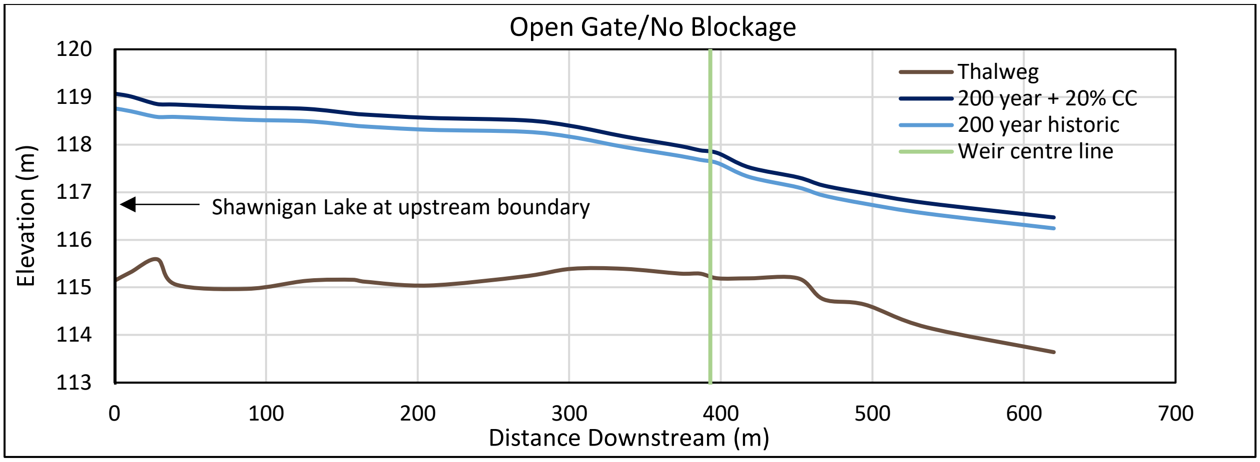
5.4.1 Effect of Weir Gate Closure or Blockage

Figure 18 shows the computed water surface profiles along Shawnigan Creek up to Shawnigan Lake for the 200-year and 200-year plus climate change scenarios. The runs were made under two different assumptions at the weir:

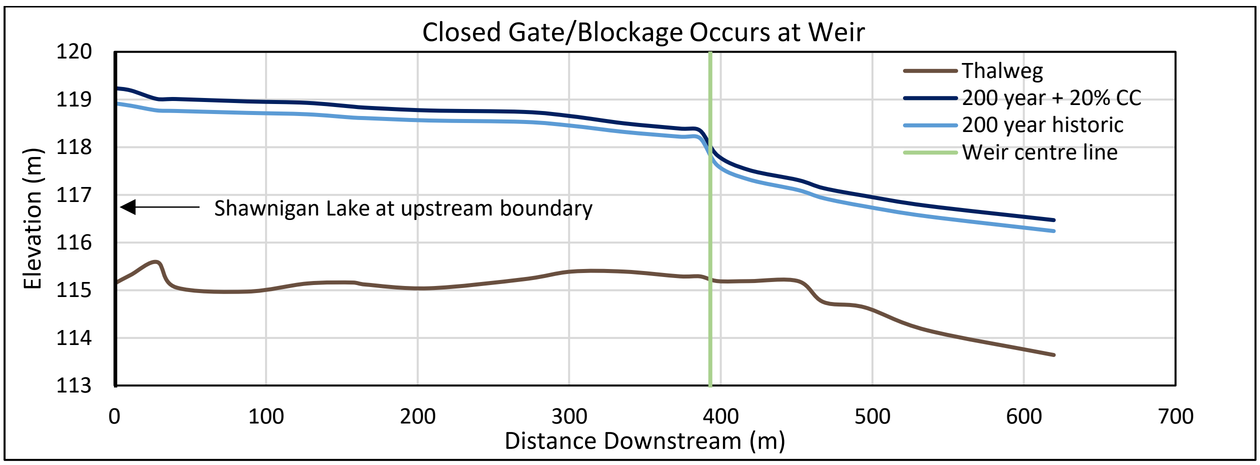
- **Figure 18A** (top) shows the profiles under normal weir operations with the gate open;
- **Figure 18B** (bottom) shows the profiles under a worst-case situation with the gate closed. This represents a situation where the weir was partially or fully obstructed by log debris.

Figure 19 shows rating curves (water level versus discharge) plots at the weir and at Shawnigan Lake, for the two assumed gate positions.

With the gate closed, the water levels were raised by 0.16 m at Shawnigan Lake under the 200-year climate change condition. For floodplain mapping purposes it is standard practice to assume that structures such as dikes or weir gates do not function, in order to represent a conservative flooding condition. For example, all floodplain maps in BC assume even well maintained, recently constructed flood dikes fail during the 200-year flood condition. Furthermore, the weir is a potential point of log debris accumulation and flow obstruction, particularly if floating log debris in the lake can pass down the creek.

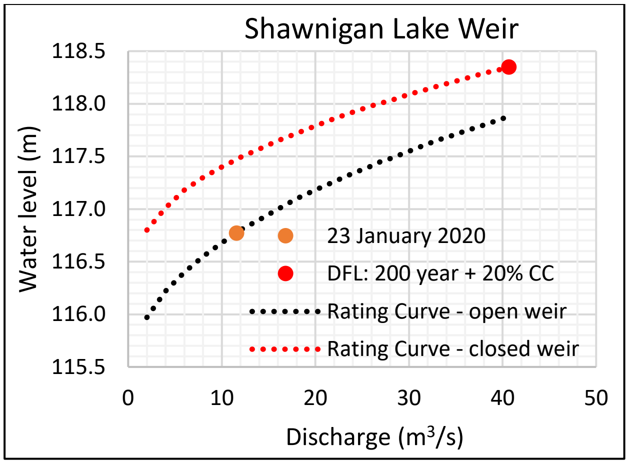


A: Gate open/no blockage



B: Gate closed/blockage occurs at weir

Figure 18: Flood profiles for the 200-year (historical) and 200-year plus climate change scenario



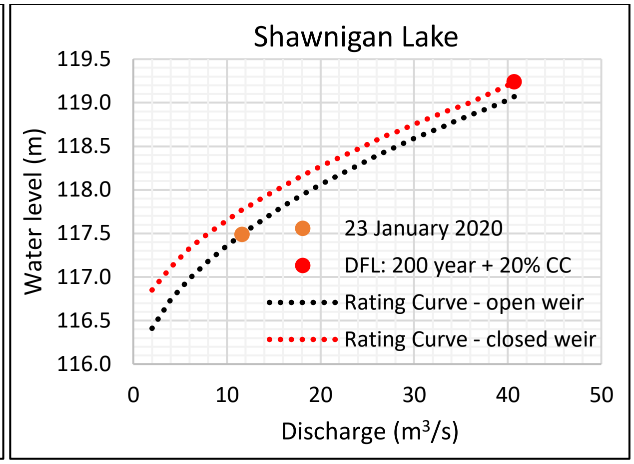


Figure 19: Rating Curves for open and closed weir scenarios at Shawnigan Lake Weir (left) and Shawnigan Lake (right) using calibrated HEC-RAS model

5.4.2 Effect of Climate Change on 200-Year Flood Levels

Table 16 provides a comparison of model results for historical and climate change conditions. These results show the effect of climate change increases with the severity of the flood event. For example, at Shawnigan Lake, increasing the discharge by 20% raises the water level by 0.15 m for the 2-year flood and by 0.34 m for the 200-year flood. The effect on water levels was considerably lower at the weir than at the lake.

Table 16: Estimated lake levels for present and Year 2100 climate change scenario

Return Period (Years)	Historical Conditions		Adopted Climate Change Scenario	
	Discharge (m^3/s)	Lake Level (m)	Discharge (m^3/s)	Lake Level (m)
2	11.3	117.75	13.6	117.90
10	19.5	118.24	23.4	118.44
20	22.8	118.41	27.4	118.64
50	27.2	118.63	32.6	118.86
100	30.5	118.77	36.6	119.04
200	33.9	118.92	40.7	119.24

5.5 Sensitivity Analysis

A sensitivity analysis was carried out to determine the influence of flow and Manning's n uncertainty on the hydraulic modelling results. The 200-year return period discharge (Q200) accounting for climate change (CC) was used to conduct this analysis, since this was the discharge used to calculate the DFL and FCL. The closed weir scenario was used for this analysis to account for the worst case scenario of potential blockage at the weir and the possibility of users having the gate up during flooding.

For flow uncertainty, the sensitivity analysis considered the mean, 68% confidence interval, and 95% confidence interval flows. These confidence intervals were calculated using the bootstrapping method. Results are presented in **Figure 20**. The blue lines represent the change in modelled water surface elevations associated with the 68% confidence interval of Q200 plus CC flows. The average of these was +13 and - 19 cm. The red lines represent the change associated with the 95% confidence interval. The average of these was +/- 30 cm. Changes in modelled water surface elevation were greatest at the upstream boundary at the Shawnigan Lake outlet (+/- 40 cm), and smallest just upstream of Shawnigan Lake Weir (+/- 20 cm).

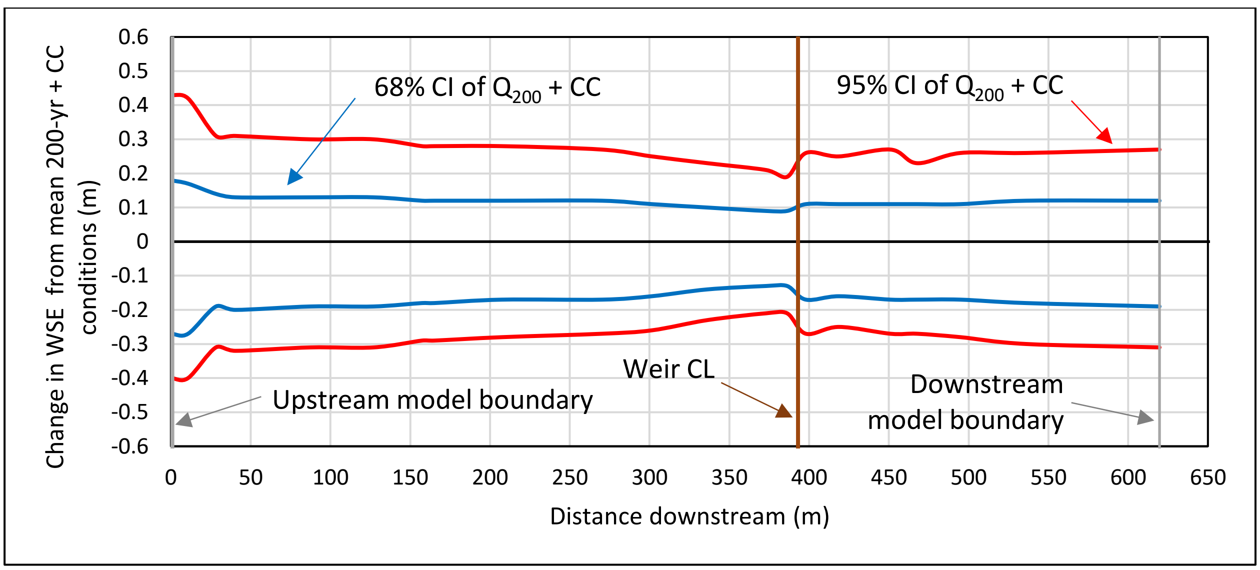


Figure 20: Model sensitivity analysis results for change in Q200 plus CC flood flow for the closed Shawnigan Lake Weir scenario

For Manning's n uncertainty, reasonable upper and lower bounds on the Manning's n values were set at +/- 20%. The high average channel roughness limits the upper bounds of globally varying Manning's n. It is very rare to have natural channels with a roughness near 0.1, and for Shawnigan Creek, the roughness should be well above 0.05. This limits the upper bounds to a reasonable global variance of +/- 20%. An additional check of +/- 10% was conducted as a less extreme, midpoint estimate.

The results of the Manning's n sensitivity analysis for Q200 plus CC flood conditions are presented in **Figure 21**. The blue lines represent the change in modelled water surface elevations associated with a

+/- 10% global change in Manning's n. The average of these was + 8 cm and - 9 cm. The red lines represent the change associated with a +/- 20% global change in Manning's n. The average of these was +/- 17 cm. Changes in modelled water surface elevation were generally greatest downstream of the weir, and smallest just upstream of the weir. The downstream boundary is particularly sensitive to changes in Manning's n, due to the assumption of normal depth at this location.

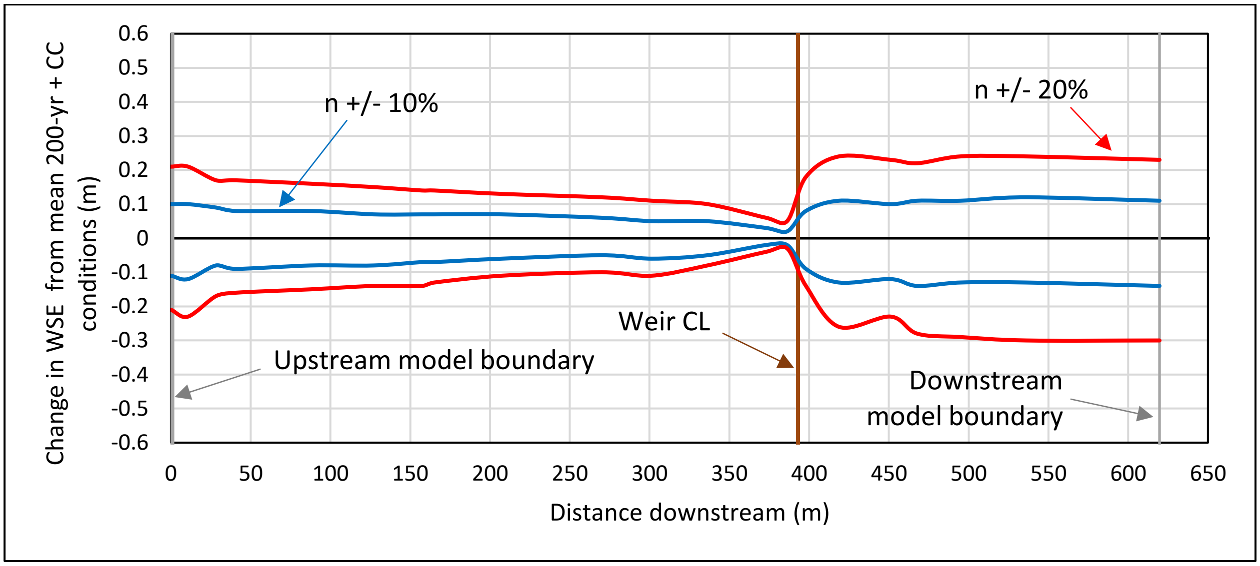


Figure 21: Model sensitivity analysis results for change in Manning's n for the closed Shawnigan Lake Weir scenario

In addition to uncertainty in flow and Manning's n, hydraulic modelling results for the design flood conditions are subject to the following uncertainties:

- Numerical uncertainty inherent to the model;
- Changes in channel geometry during floods;
- Potential for channel obstruction by wood debris and sediment (partially accounted for by running the model with the weir gates closed).

5.6 Assessment of Model Results

5.6.1 Comparison of Model Estimates With Historical 200-Year Flood Level Predictions

The estimated 200-year water level at Shawnigan Lake from the hydraulic model was 118.9 m. The previous studies by BC MoE, recorded high water marks, analysis of historical lake levels, and lake-outflow rating curves all provide checks on the results from the hydraulic model. **Table 17** summarizes the results of five independent estimates of the 200-year water level at Shawnigan Lake. The following discussion highlights the basis and limitation of each estimate.

1979 BC MoE Floodplain Maps

BC MoE (1979) adopted an FCL of 119.4 m for the 1979 floodplain maps. At this time, typical freeboards were 0.3 m or 0.6 m. The corresponding flood level of Shawnigan Lake would have been between 118.8 m and 119.1 m. Unfortunately, there is no information on the methodology that was used for the analysis.

Frequency Analysis of Lake Levels

The historical time series of annual maximum lake levels was used to estimate the historical 200-year still water lake level. Results of this analysis were presented previously in **Section 4.2**. **Table 7** summarizes the estimated annual maximum lake levels for various flood return periods. The 200-year lake level (historical conditions) was estimated to range between 118.9 and 119.0 m.

Frequency analysis is commonly used on lakes that have a long record of daily water levels. The record on Shawnigan Lake is relatively short and often incomplete. Another limitation is that the historical frequency analysis of observed lake levels cannot be directly used to account for future climate change scenarios.

Historic Lake Outlet Rating Curve

Section 4.3.2 described the historical relation between winter lake levels and discharges on Shawnigan Creek using data collected by Water Survey of Canada during the 1970s and 1980s. Extrapolating the line to the 200-year discharge of 33.9 m^3/s results in an estimated 200-year lake level of approximately 119.1 m, with the likely range of 118.9 m to 119.2 m. The main limitation of this analysis is that the highest discharge measurement during the period of record was only 23 m^3/s, which is considerably lower than the adopted 200-year flood magnitude.

1935 High Water Mark

NHC surveyed the 1935 high water mark from the historical photos (**Photo 3** and **Photo 4**). The estimated water level at the tracks was approximately 119.1 m. This event was reported to be the largest flood since 1909.

Assessment of Predictions

The 200-year historical lake levels from these four check calculations are within 0.3 m of the hydraulic model estimates. This agreement increases confidence in the results and suggests that the hydrologic and hydraulic conditions on Shawnigan Lake have remained relatively stable over the last 50 years.

Table 17: Comparison of estimated 200-year water levels on Shawnigan Lake

200-year event (historical conditions)	Shawnigan Lake Level (m)
1979 BC MoE	118.8 - 119.1
Flood frequency of observed lake levels (extrapolated)	118.8 - 119.0
Historical lake level-outflow rating curve-extrapolation	118.9 - 119.2
1935 Flood high water mark	119.1
HEC-RAS Modelled lake level	118.9

5.6.2 Designated Flood Levels

The 200-year instantaneous maximum discharge, increased by 20% to account for climate change, was adopted to determine the DFLs for the flood mapping. The estimated DFL values at some representative locations are given in **Table 18**.

Table 18: Designated flood levels on Shawnigan Creek and Shawnigan Lake

Model Chainage (m)	Distance below Shawnigan Lake (m)	Elevation (m)	Comment
467.9	0	119.24	Shawnigan Lake at outlet of Shawnigan Creek
457.2	11	119.19	Upstream of Renfrew Road Bridge
310.6	157	118.83	Upstream of E & N Railway Bridge
82.0	386	118.35	Upstream of Shawnigan Lake Weir

Figure 22 depicts the adopted DFLs as well as some historical events along Shawnigan Creek. **Figure 23** shows similar examples along Shawnigan Lake. Additional examples are included in Appendix B. **Note that the levels shown on the photos refer to the position of the person on the ground and not to the background landmarks shown on the photos.**

Figure 22: Visualization of flood levels on Shawnigan Creek: flood event from February 2020 (yellow), 50-year return period (black), 200-year return period (purple), and DFL (red)

Figure 23: Visualization of flood levels on Shawnigan Lake: historical mean annual maximum level (green), flood event from February 2020 (yellow), largest flood of record (blue), and DFL (red)

6 FLOOD MAPPING

6.1 Overview

Four 1:5,000 maps (2019 orthophotography) were used to represent the flood extent and flood construction levels (FCLs) on Shawnigan Lake and a portion of Shawnigan Creek (upstream of Shawnigan Weir to lake outlet). **All elevations on the maps are referenced to CGVD 2013 vertical datum.**

The FCL was computed as follows:

$FCL = DFL + R_{2\%} + FB$, where

DFL is the 200-year flood level adjusted for climate change (for Shawnigan Lake, this corresponds to the still water level without wave effects);

$R_{2\%}$ is the allowance for wave runup effects (Shawnigan Lake only);

FB is the Freeboard, which accounts for uncertainty in the computed flood levels

Therefore, both the FCL values and the horizontal extent of the flooding depicted on the maps incorporates an allowance for freeboard.

6.2 Shawnigan Creek

The freeboard on Shawnigan Creek is intended to account for uncertainties in estimating the 200-year flood discharge, hydraulic modelling uncertainties, as well as effects of debris and obstructions in the creek and local variations in water levels due to bends, standing waves and surging. Historically, flood mapping guidelines recommended freeboard values on streams of between 0.3 m and 0.6 m, but increasing up to 0.9 m on streams subject to high rates of channel shifting, obstruction from log jams, or sedimentation. A freeboard of 0.6 m was adopted for Shawnigan Creek. This value is consistent with practice on other nearby streams on Vancouver Island, including the Cowichan and Koksilah Rivers.

The FCL values along Shawnigan Creek range from 119.79 m at the Renfrew Road bridge crossing to 118.95 m at the upstream side of Shawnigan Weir.

6.3 Shawnigan Lake

Based on the HEC-RAS model results, the computed 200 year still water lake level is 118.9 m. The designated flood level (200 year still water lake level adjusted to account for climate change in the year 2100) is 119.24 m. Accounting for climate change increases the still water flood level on the lake by 0.34 m.

The computed 200-year flood level on Shawnigan Lake was compared against other independent estimates, all of which agreed relatively closely (within 0.3 m). These additional check computations provide additional support to the reasonableness of the hydraulic model results.

The final adopted DFL on the lake assumed the weir was obstructed by debris (represented by raising the gate in the hydraulic model), which is a conservative assumption and resulted in a 0.17 m increase in flood levels at the lake. After discussions with the CVRD, a freeboard of 0.3 m was adopted for the lake.

Wave runup will increase the potential flood levels above the still water lake level and need to be accounted for when determining the FCL. Wave runup ($R_{2\%}$) during the time of peak lake levels was estimated in **Section 4.5**. The wave runup was computed for an assumed slope of 1V:2H. Values of wave runup ranged from 0.6 m along areas exposed to southerly winds to 0.4 m along other sections of the shoreline.

The FCL on the lake ranged from 120.14 m to 119.94. This level is up to 0.7 m higher than the 1979 BC MoE study. The main reason for the increase in FCL is that the 1979 study had very limited hydrological data at the time, whereas the present study has a much longer hydrological record and incorporates the potential effects of increased flows due to climate change in the year 2100. Furthermore, the present study includes wave runup in determining the FCL, whereas the 1979 did not appear to assess wave runup effects.

6.4 Limitations and Use of Floodplain Maps

The following limitations should be reviewed prior to use of the floodplain maps:

- Floodplain maps are an administrative tool that depict the potential flood extent and minimum recommended Flood Construction Levels for the adopted designated flood. A Qualified Professional must be consulted for any site-specific engineering analysis.
- The maps depict the flooding conditions at the time of surveys. Future changes to the creek, floodplain, and future climate change will render the maps obsolete. The information on the maps should be reviewed after 10 years have elapsed since publication or after any large flood occurrence (similar or greater than the 2020 flood).
- The floodplain limits have not been established on the ground by legal survey. The accuracy of the flood boundaries is limited by the LiDAR base mapping and orthophotography. The Lidar data available for this study was flown in 2010 and may not meet current federal mapping standards for floodplain mapping. The mapping should be reviewed when new, higher resolution Lidar data comes available and may need to be updated.
- The floodplain maps do not represent flooding from local stormwater runoff, ponding from rainwater on the floodplain, groundwater seepage, or local drainage courses. Consequently, additional flooding may occur outside of the designated boundaries.

- Roads, railways, bridges, new dikes, and future developments on the floodplain can restrict water flow and increase local water levels. Obstructions such as debris jams and channel sedimentation can also increase flood levels above the levels shown on the maps.
- The floodplain maps do not represent hazards due to erosion, avulsion or channel migration.
- Wave runup on the lake are generalized estimates and do not represent local site-specific features such as seawalls or structures. Construction of new structures in the shoreline such as docks, breakwaters, revetments, seawalls, or bulkheads require site-specific analysis and design.
- Industry best practices were followed to generate the floodplain maps. However, actual flood levels and extents may vary from those shown; Northwest Hydraulic Consultants Ltd. and the Cowichan Valley Regional District do not assume any liability for such variations.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

NHC installed flood warning stations, conducted updated flood assessments and created floodplain maps for Shawnigan Lake, as requested by the CVRD. The following project objectives have been completed as part of this study:

- Installation of recording water level gauges for Shawnigan Lake and the Shawnigan Lake Weir;
- Installation of automated flood alert warning systems as part of the gauge installations; and
- Updating and refining previous estimates of flood levels, flood inundation extents, and floodplain maps.

This study reviewed several methods and results for determining accurate designated flood level and flood construction level recommendations: flood frequency analysis, historical rating curve extrapolation, previous reported FCL by BC MoE in 1979, largest flood of record in 1935, and modelled results for DFL. Results are all within 30 cm. The agreement of the results from the five independent checks reinforced confidence in the model results.

7.2 Recommendations

Key recommendations are presented below:

- Update the historical floodplain maps developed by the BC Ministry of Environment in 1979 using the results in this study, which are based on a longer period of hydrometric observations and data and account for potential climate change.
- Review the flood mapping at least every 10 years or after any major floods. Changes to the channel outlet and condition of the creek may result in changes to water levels in the creek and

at the lake. New information on climate change will need to be assessed as it becomes available and may require further updating of the flood levels over time.

- The CVRD should continue to monitor lake levels and climatic conditions to improve accuracy in future analysis/studies.
- If new, more accurate LiDAR is available it is recommended this be used to improve the resolution and accuracy of the available mapping.
- The CVRD should assess operational and response procedures for the flood warning system. Identification of appropriate alert thresholds for the system should be defined prior to the next flood season.

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APPENDIX A

SHAWNIGAN LAKE FLOOD MONITORING STATION USER MANUAL

1 OVERVIEW

An automated flood level monitoring sensor was installed by NHC on Shawnigan Lake in May 2020 at the Decca Rd pump station. The station is comprised of a pressure transducer which is mounted to an intake pipe approximately 40 meters southeast from the shoreline. An instrument enclosure is mounted to the Decca Rd pump house, approximately 25 meters above the shoreline, and contains a datalogger and modem used to transmit data real time. The pressure transducer reports five-minute average data of water depth and temperature hourly through the NHC web portal which are available for public viewing.

2 FLOOD LEVEL MONITORING SYSTEM

Table 1 details the components and coordinates of the Shawnigan Lake Flood Level Monitoring Station and Figure 1 shows the location of the monitoring station. The station has an automated sensor that outputs near real-time water levels via a cell modem. Water surface elevations are referenced to the NAD83 (CSRS) coordinate system. The OTT Pressure Level Sensor (PLS) records a depth range of 0-10 meters and has an accuracy of 0.05%

Table 1: Summary of key components installed at Shawnigan Lake flood monitoring site

Flood Level Monitoring Station	Equipment and Instrumentation	Location (see Figure 1)
Shawnigan Lake at Decca Rd Pump House	OTT Pressure Level Sensor (0-10m range), Campbell Scientific CR310 Cell 205 Datalogger and Modem, 12V battery, Oxford Smart Battery Charger, Baird Antenna	48.649912°, -123.638169°

Figure 1: Flood Level Monitoring Station Location Map

2.1 Shawnigan Lake at Decca Rd Pump house

The Shawnigan Lake station is located on the northern end of the lake at the Decca rd Pump House. The OTT PLS is securely encased inside a 2.5 meter long 1.5" aluminum pipe to protect the sensor. The aluminum pipe was attached to an intake pipe, approximately 3.5 meters below the surface, by divers using multiple hose clamps to ensure that the sensor will not move. The sensor cable is protected with ½" conduit and both secured to the intake pipe and anchored down to the lake bottom to prevent any movement or damage. The sensor cable was trenched approximately 4" below surface for 25 meters from the shoreline to the enclosure box. The enclosure is powered using on site AC power from the pump house. The AC power is connected to a smart battery charger which ensures that the 12V battery (powers the OTT PLS and datalogger) is on a constant charge. In the event of a power outage at the pump house, no data would be lost as the 12V battery would be able to power the station for many weeks. NHC has set up notifications to be sent in the event that battery voltage drops below 12.1V, as this will indicate that a service trip is required.

Three benchmarks were installed and surveyed in order to obtain accurate manual water level readings to be compared to the sensor for quality control and quality assurance measures. Manual water levels are collected by completing using a level survey method. The benchmarks' relative locations and geodetic elevations are as follows:

1. NHC 1111: Southwest corner of concrete pad at the pump station; 119.483m
2. NHC 1119: Spike nailed into stump near shoreline; 117.434m
3. NHC 4476: Horizontal spike in second fence post from end of fence; 117.356m

Data is transmitted from the datalogger to an online server, which is then pulled into the NHC database system, Aquatic Informatics AQUARIUS Time Series ™ software. Transmissions of five-minute average data are scheduled once per hour and contain the parameters water depth, water temperature, internal equipment temperature, and battery voltage.

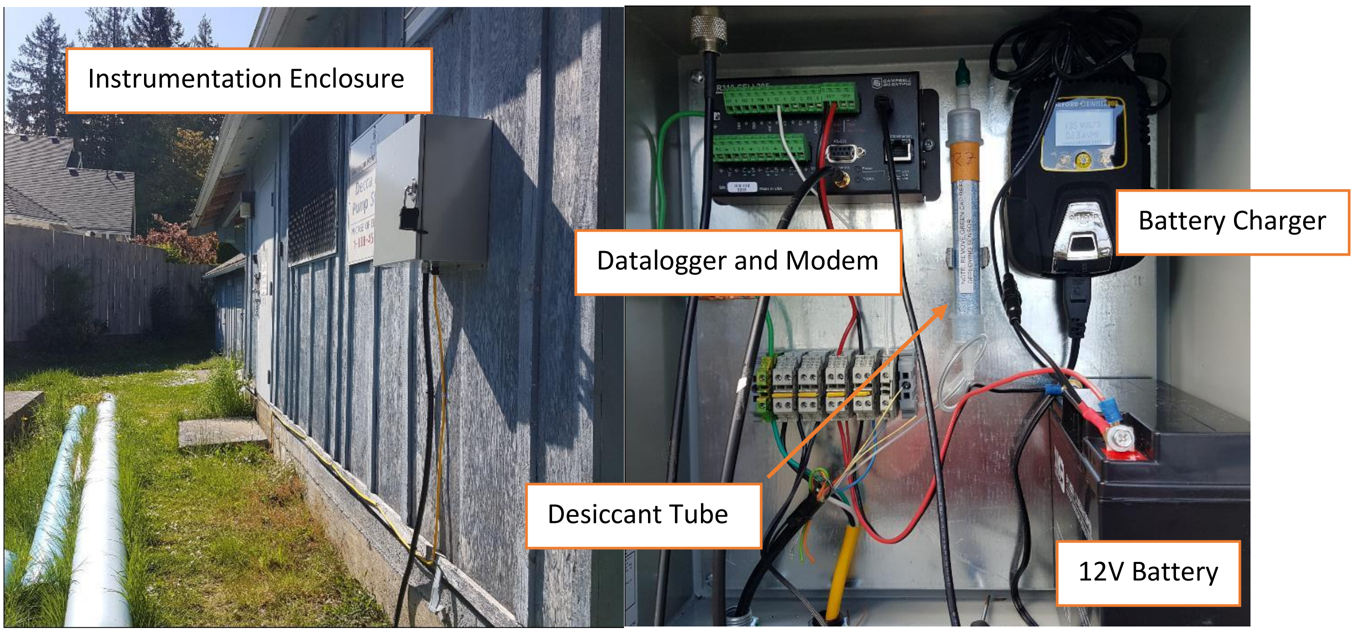

Photo 1: Instrumentation enclosure and components

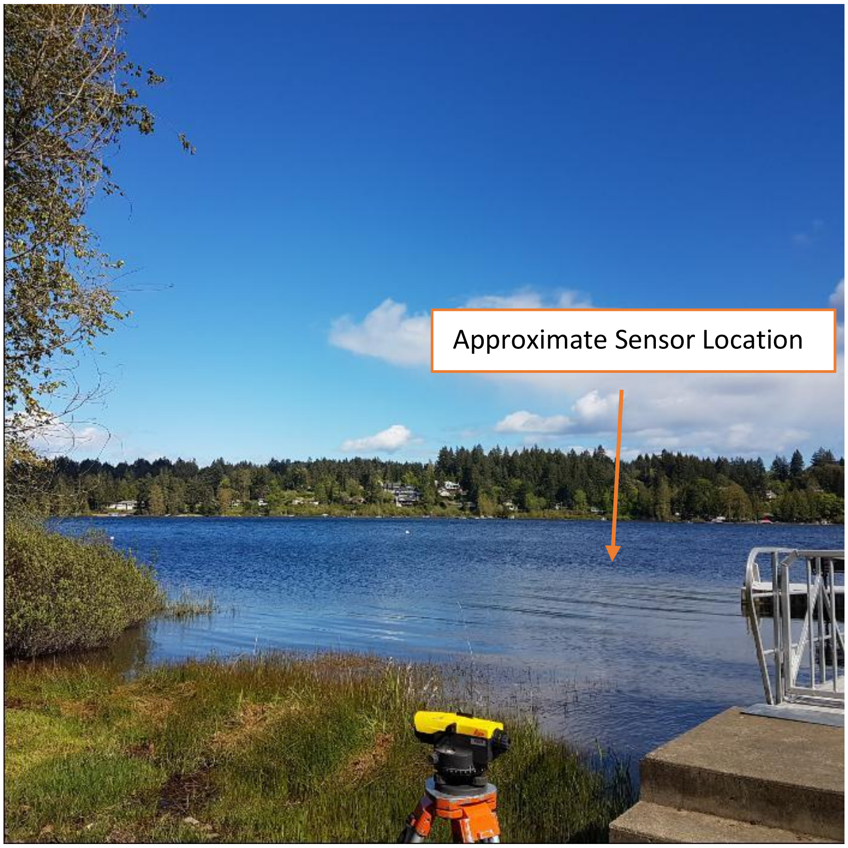

Photo 2: Approximate sensor location, 40m southeast from shoreline

Photo 3: Benchmark NHC1111 (elevation= 119.483m), corner of concrete pad

Photo 4: Benchmark NHC 1119 (elevation= 117.434m), stump near waters edge

Photo 5: Benchmark NHC 4496 (elevation= 117.356m), spike in fence post

3 ACCESSING REAL-TIME HYDROMETRIC DATA

Real-time (updated hourly) hydrometric data for Shawnigan Lake can be accessed online using NHC's public web hosting site. Reported water levels are corrected to the January 20 and May 6, 2020 RTK surveys and are displayed as geodetic elevations. The web portal can be accessed using these credentials:

Web portal: http://water.nhcweb.com/
Username: public
Password: nhcwater!

The Shawnigan Lake station can be viewed by choosing "CVRD_Shawnigan_Lake" in the location tab or zooming into the location in map view. The relevant time series to view stage data is "Stage.Ott@CVRD_Shawnigan_Lake" and "Water Temp.Ott@CVRD_Shawnigan_Lake" for water temperature.

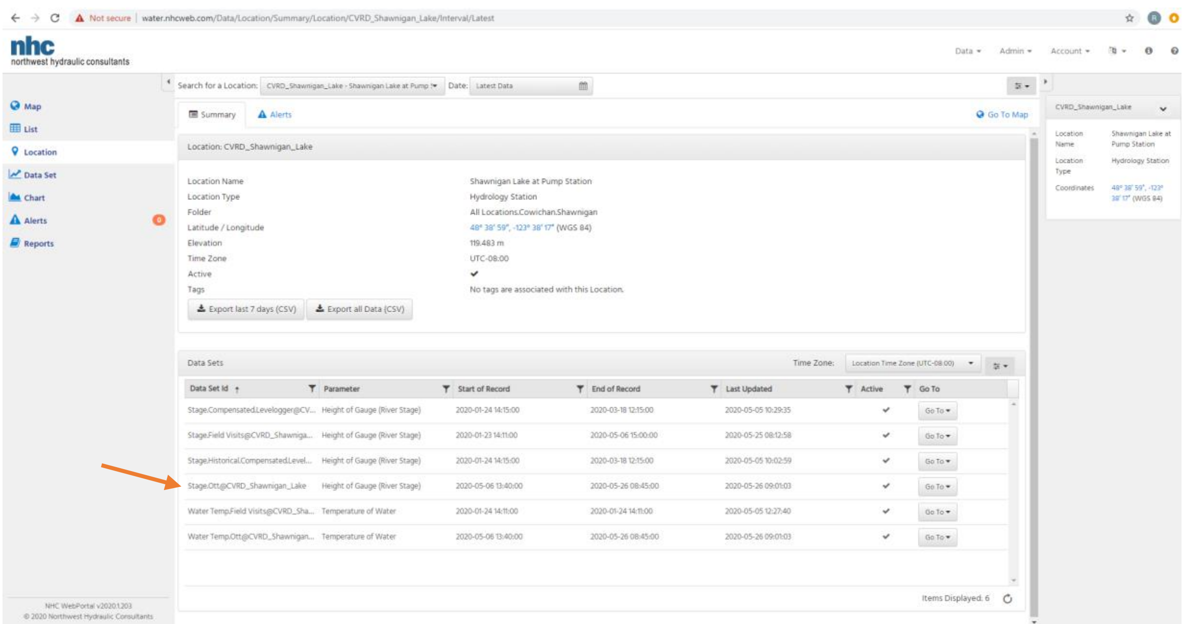

Figure 2: NHC web portal

4 NEXT STEPS

In order to operate as a flood warning system, the station need to be set to provide alert notifications at specified water levels. Provisional levels were programmed at the time of installation for initial testing purposes. For example, CVRD may wish to specify an initial high water alert when the water level exceeds a 2-year flood condition and a follow-up message when levels exceed a 10 year level. The key levels, specific messages and individuals who receive the messages can all be modified as required. Furthermore, the stakeholders will need to develop plans and specific responses when the notifications are received. NHC can collaborate with the stakeholders to set up the alerts and to customize the raw water level outputs that are currently being generated.

It should be noted that some maintenance will need to be carried at the station periodically. Water levels and logger elevations should be confirmed twice each year. Other issues such as damage to the units from vandalism or accidents may also require periodic repairs.

APPENDIX B

FLOOD LEVELS AROUND SHAWNIGAN LAKE[1]

[1] Note: All levels shown on the photos refer to the position of the person on the ground and not to the background landmarks shown on the photos

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Figure 1: Visualization of flood levels on Shawnigan Lake at Renfrew Road Bridge: historical mean annual maximum level (green), flood event from February 2020 (yellow), largest flood of record (blue), and DFL (red)

Figure 2: Visualization of flood levels on Shawnigan Lake at Decca Road pumphouse (bottom left), Shawnigan Warf Park (bottom right), and at Shawnigan Lake Private School (top left): historical mean annual maximum level (green), flood event from February 2020 (yellow), largest flood of record (blue), and DFL (red)

Figure 3: Visualization of flood levels on Shawnigan Lake near Shawnigan Lake Waterdome: historical mean annual maximum level (green), flood event from February 2020 (yellow), largest flood of record (blue), and DFL (red)

Figure 4: Visualization of flood levels on Shawnigan Creek: flood event from February 2020 (yellow), 50-year return period (black), 200-year return period (purple), and DFL (red)