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northwest hydraulic consultants

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NHC Reference 3006613

Okanagan Basin Water Board
1450 KLO Road
Kelowna, BC V1W 3Z4

Attention: **Anna Warwick Sears, Ph.D., Executive Director**
Copy to: **Nelson R. Jatel, Dr. (cand.), P.Ag., Water Stewardship Director**
Via email: anna.warwick.sears@obwb.ca, nelson.jatel@obwb.ca

Re: **Supplemental to the Okanagan Mainstem Floodplain Mapping Project**
Current Operations Flood Construction Levels for Okanagan and Wood-Kalamalka Lakes
Final Report

Dear Dr. Anna Warwick Sears and Dr. Nelson R. Jatel:

Northwest Hydraulic Consultants Ltd. (NHC) is pleased to provide the Okanagan Basin Water Board (OBWB) with supplemental floodplain mapping for the Okanagan and Wood-Kalamalka lakes, based on the current Okanagan Lakes Regulation System (OLRS) Operating Plan and Guidelines ('current operations'). It is expected that the flood inundation extents from this study will be used by OBWB for comparison to counterpart floodplain mapping from OBWB's Okanagan Mainstem Floodplain Mapping Project (NHC, 2020b). The floodplain mapping in NHC (2020b) was based on assumed preliminary modifications to the current OLRS Operating Plan and guidelines ('modified operations') to mitigate the expectation of earlier snowmelt and more variable timing of peak inflows in the future, as a result of climate change. Without these modifications, the design flood levels for the lakes would be higher, as is shown in this study. The modified operations in NHC (2020b) only considered flood control and further work was recommended to review how changes to the current operations can be balanced with First Nations, fishery, agricultural, and recreational interests since the modified operations were in contrast to current fish and water management objectives. The floodplain mapping provided in this study is based on current operations, since at the time of this report, no changes have been made to the OLRS Operating Plan and guidelines to mitigate future flooding and there are no plans for adaptation through other means such as infrastructure upgrades and reactivation / rehabilitation of the natural floodplain.

1 Introduction

The floodplain mapping in NHC (2020b) was based on modified operations to adapt to the expectation of earlier snowmelt and more variable timing of peak inflows in the future as a result of projected climate change. The NHC (2020b) floodplain mapping is contingent on such modifications, and without them, the design flood level for Okanagan Lake, for example, would be 0.45 m higher. These modified operations were adopted for the design levels in NHC (2020b), as it is expected that lake operations will evolve over the decades as the hydrology changes and that infrastructure will be updated along with these changes. The flood inundation extents with no changes to the current operations have not been mapped previously and are provided in this study.

Specifically, this study provides the Current Operations Flood Construction Levels including a 0.60 m freeboard (COFCLs) for Okanagan and Kalamalka lakes[1] mid-century, which assumes no changes to current operations in the Okanagan Lake Regulatory System (OLRS). The intent of this supplemental study is to help the public understand what the unmitigated impacts of climate change are expected to be on design flood levels under current operations and assist in understanding why some changes to OLRS infrastructure and/or operations are necessary.

2 Hydrological Modelling

2.1 Overview

This section describes changes made to the design levels for Okanagan and Wood-Kalamalka lakes from NHC (2020b). The design levels described in this memo assume that no effort is undertaken to adapt reservoir management or infrastructure for Okanagan or Wood-Kalamalka lakes for climate change. The hydrologic and reservoir modelling from NHC (2020b), and alterations for the current project are described in this section.

The model alterations for the current project resulted in an increase of 0.45 m in the design level for Okanagan Lake and 0.54 m for Wood-Kalamalka Lake. The Okanagan Lake Dam embankments (low elevation land to the west and east of Okanagan Lake Dam) would overtop for the design flood level under strict adherence to the current operations, so the modelling assumes that the elevation of the embankments would be raised, with dam overtopping and breach not included in the current study.

2.2 Methods

The Okanagan and Wood-Kalamalka lakes design levels described in this memo were determined using a modified version of the Okanagan mainstem reservoir and hydrology model developed for NHC (2020b). This model was developed using the Raven hydrologic model framework (Craig et al., 2020) and incorporates reservoir modelling and operational rules, when available, for Ellison, Wood, Kalamalka, Okanagan, Skaha, Vaseux, and Osoyoos lakes.

As the system is heavily regulated, traditional flood frequency analysis is inappropriate for determining design levels. Thus, NHC used ensemble simulation of present and future weather to empirically calculate design flood levels on the Okanagan mainstem reservoirs in the current and prior NHC (2020b) modelling. Fifty realizations of the downscaled CanESM2 climate model, each ranging from 1950-2100, were simulated within the Raven hydrology and operations model. Results were split into 30-year blocks, each with 1,500 years of hydrologic simulation. These 1,500-year records allowed for empirical

[1] This study only evaluates Okanagan and Kalamalka lakes, since an unregulated (‘gates open’) mid-century climate change scenario was used as the design flood for the Okanagan River in NHC (2020), whereby for the purposes of floodplain mapping, changes in OLRS operations have no impact on areas downstream of Okanagan Lake Dam.

calculation of low probability lake levels, up to the 500-year average recurrence interval (ARI)[2] lake level. Refer to NHC (2020b) for more detail on the ensemble climate simulation.

Results in NHC (2020b) showed that the 2017 maximum lake levels on Okanagan and Wood-Kalamalka lakes were approximately equivalent to the present day 500-year ARI level for these systems. Thus, the 2017 maximum levels were used as base design levels (500-year ARI), with further increases due to climate change (e.g., the difference between a 500-year flood today and a 500-year flood in the year 2050) added to the 2017 level.

For the current project, changes to the hydrology and reservoir operations model were made to assume future scenarios where no effort is made to adjust reservoir management or infrastructure to mitigate the effects of future climate. The critical changes to modelling from NHC (2020b) are described in Table 2-1.

[2] A specified ARI event can occur in any year. The specified event's Annual Exceedance Probability (AEP) = 1/ARI. The AEP is the same in any year, given: the same type of event is being considered; there is no trend in this event type over time; and the events are independent from year to year, and also random. ARI is also referred to as 'return period', but the term is not used in this study due to its frequent misinterpretation: 'return period' can be misinterpreted to mean that the event only occurs once in the specified period; however, the event can occur in any year.

Table 2-1 Summary of differences in reservoir operations in NHC (2020b), 'modified operations', in comparison to the present study, 'current operations'

Okanagan Lake	
NHC (2020b) – 'modified operations'	Compared to the present day OLRS operating plan and guidelines, NHC (2020b)'s modified operations assumed 20 cm lower fall and winter drawdown prior to the spring freshet and allowed for earlier maximum reservoir releases (78 m^3/s February-September, versus current operations, which allow 78 m^3/s April-July). The above modifications would require formal changes to the OLRS operating plan and guidelines.
Present study – 'current operations'	Modelling for the present study followed the current OLRS rules strictly.
Implication	Current operations result in an inability for reservoir operators to prepare for or react to a freshet that occurs early in the spring or to mid-winter rain-on-snow melt events.
Wood-Kalamalka Lake	
NHC (2020b) – 'modified operations'	Increasing allowable maximum outflows to 6 m^3/s all year at Kalamalka Lake.
Present study – 'current operations'	Discussions with the reservoir operator indicated that even present-day operational rules are difficult to follow due to a lack of head drop across the Kalamalka Lake dam into Vernon Creek. Thus modelling for the current study used the empirical rating curve developed in NHC (2020a), based on the 2020 freshet, with maximum allowable flows limited to 6 m^3/s.
Implication	It is not always possible for the reservoir operator to draw Wood-Kalamalka Lake down to OLRS target levels following a high-volume freshet year. This leaves the lake vulnerable to flooding in a scenario of multiple high inflow years in a row.

2.3 Results

A comparison of lake level model results from the present and NHC (2020b) studies is shown in Table 2-2. In NHC (2020b), the 2017 maximum lake level – which has an ARI of approximately 500-years – was used as the present day design level for Okanagan and Wood-Kalamalka lakes. Future design levels in the present study and NHC (2020b) are calculated as the 2017 maximum lake level plus the predicted change between a present and future (2041-2070) 500-year ARI lake level.

Table 2-2 Summary of design level changes for Okanagan and Wood-Kalamalka lakes. All levels provided in metres (CGVD2013 datum).[3]

	Okanagan Lake	Wood-Kalamalka Lake
2017 maximum	343.48	392.80
NHC (2020b) design lake level (modified operations)	343.86	393.02
Current operations design lake level	344.32	393.56
Result of current operations with no changes	+0.45	+0.54

Along with calculation of the increase in the design level due to a lack of adaptation of infrastructure (in the case of Kalamalka Lake) or change in operations (in the case of Okanagan Lake), this exercise has allowed us to calculate the change in frequency of a flood the same size as the 2017 flood.

In NHC (2020b), we concluded that the 2017 event represented approximately a 500-year ARI for both Okanagan and Wood-Kalamalka lakes. In other words, the 2017 event represented a lake level that has approximately a 0.2% chance of being exceeded in any given year (the annual exceedance probability, AEP). Table 2-3 shows changes to the ARI and AEP of the 2017 flood in the future, which indicates that flooding similar to 2017 is expected to become more common in a future climate if shortcomings to the OLRS operating plan, guidelines, and infrastructure are not addressed.

Table 2-3 Approximate change in probability of lake levels matching or exceeding 2017 levels based on future operations (modified or current operations). Future represents future mid-century projections (2041-2070). The 2017 flood had an ARI of ~ 500-years and an AEP of 0.2%.

	Okanagan Lake	Wood-Kalamalka Lake
Modified operations - ARI of 2017 level in mid-century (2041-2070)	200-year	100-year
Current operations - ARI of 2017 level in mid-century (2041-2070)	20-year	20-year
Modified operations – AEP of 2017 level in mid-century (2041-2070)	0.5%	1%
Current operations – AEP of 2017 level in mid-century (2041-2070)	5%	5%

2.4 Discussion

Both the results in this report and NHC (2020b) required assumptions on the future of reservoir operation on Okanagan and Wood-Kalamalka lakes. These potential future changes, or lack of changes,

[3] In 2017, flood levels were often reported in the older, less accurate CGVD28 datum. For Okanagan Lake, the maximum level reported in the old datum was 343.25.

have been discussed with OBWB and the current OLRS reservoir manager, Shaun Reimer. However, these are only assumptions about future operations, and the actual changes are unknown. The results presented in this project are meant to be cautionary. They illustrate a scenario with no proactive changes to the reservoir operations or infrastructure to account for climate change. These results are presented only for the 2041-2070 climate period, a period that is less than 20 years away at the time of this study. Future end-of-century (2071 and later) changes in freshet timing and volume are expected to be even more severe.

The results from Okanagan and Wood-Kalamalka lakes both indicate the importance of building climate resilience; however, the problem each lake faces is different. Though changes to total precipitation are somewhat uncertain, we can say with reasonable certainty that climate change is causing earlier spring freshets and more rapid snowmelt. Reservoir operations and infrastructure and possibly floodplain use need to change to provide the reservoir operators with more ability to react quickly to changing conditions.

The need for changes in operating rules is most evident in Okanagan Lake, where currently the maximum reservoir release is not allowed until April 1. In a future where the spring freshet can potentially occur more than a month earlier, this release schedule will lead to rapid spikes in spring lake levels.

For Kalamalka Lake, this report illustrates the need for updated dam and channel infrastructure. The releases from Kalamalka Lake into Vernon Creek are primarily hampered by two structural issues. The first is the Kalamalka Lake Dam sill height into Vernon Creek. Even with gates fully open, the lack of head drop into Vernon Creek means that water cannot always be removed fast enough to meet reservoir targets in preparation for high spring inflows. Secondly, reservoir releases are limited to ~6 m^3/s into Vernon Creek in order to avoid damage within the City of Vernon. Channel upgrades within the City of Vernon to increase capacity (even slightly) would likely provide greater protection from high lake levels on Wood-Kalamalka lakes.

3 Lakeshore Modelling

3.1 Overview

Given the higher flood levels based on current operations discussed in Section 2, the wave model, wave breaking boundary and polygon, and empirical wave runup calculations from NHC (2020b) have been updated for this project to account for the higher lake levels. The outputs from the lakeshore modelling inform the development of shoreline COFCLs, which include wave effects and flood inundation COFCLs further inland (which do not include wave effects). As noted in Section 2, the elevation of the Okanagan Lake dam embankments was synthetically raised for modelling the flood inundation level. The flood extents in the dam embankment area were determined using the lake model boundary and professional judgement. This is similar to the process taken in NHC (2020b), but for a higher water level, and similar relevant limitations apply (e.g., Okanagan Dam breach and dam overtopping were not modelled).

3.2 Methods

The wave effects calculated for the current study are determined using the same methods utilized in NHC (2020b). The previously calculated 200-year ARI wind events for each design direction (northerly and southerly) were used to force the previously developed SWAN model (Simulating Waves Nearshore or SWAN, version 41.20) from NHC (2020b). For each event, a spatially varying wind field was applied to both the coarse and fine grid models. The resulting waves were used to calculate the wave runup at the shoreline over different zones for Okanagan and Wood-Kalamalka lakes.

As in NHC (2020b), following the provincial guidelines (BC MoE, 2011), the two percent wave runup ($R_{2\%}$) is used to assess the wave effect. This is the runup that only two percent of the (simulated) wave runup values associated with the design storm event will reach or exceed.

The wave runup for each section was estimated using either the method described in the European Overtopping Manual (EurOtop, 2018) or the method described in the US Army Corps of Engineers - Coastal Engineering Manual (CEM) (USACE, 2002). The CEM method is specifically for beaches with shallower slopes (<12%).

As explained in NHC (2020b), a generalized shoreline slope was applied to each of the lakes' shoreline zones. Within each shoreline zone, the selected generalized shoreline slope was one that was among the steeper shorelines within the zone and was exposed to the wave effects from the lake. This approach generally results in a more conservative wave runup value, and it is recognized that the wave runup will be overestimated for some individual properties. There is also the possibility the wave effects will be underestimated for some individual properties that have seawall type structures due to runup being greater for vertical walls.

3.3 Results

The results are shown in Table 3-1; the $R_{2\%}$ wave runup values were applied to determine the COFCLs for this study's design event on the shorelines. It is assumed in this analysis that the future foreshore slope and beach materials will be the same as that of the existing foreshore, and changes to the foreshore slopes would change the COFCL.

Table 3-1 Wave effects estimated for each wave effects zone in the study area.

Lake	Zone	Wave Properties			Shoreline Properties		Effect
		Significant Wave Height (Hs) (m)	Mean Wave Period (Tm) (sec)	Peak Wave Period (Tp) (sec)	Depth at the Toe (m)	Slope	R2% Wave Runup (m)
Okanagan	Zone 1	1.2	3.0	4.1	1.9	15%	1.4
Okanagan	Zone 2	1.1	3.1	4.6	2.5	58%	2.7
Okanagan	Zone 3	1.0	3.0	4.1	2.6	19%	1.4
Okanagan	Zone 4, 6, 8	1.5	3.7	5.2	2.1	43%	2.8
Okanagan	Zone 5	1.3	3.4	4.6	2.1	30%	1.8
Okanagan	Zone 7	1.3	3.4	4.6	1.8	17%	1.5
Kalamalka	Zone 1	0.9	2.6	4.1	0.6	25%	1.2
Wood	Zone 1	0.9	2.5	3.3	1.4	10%	0.9
Wood	Zone 2	0.9	2.6	3.3	1.4	55%	1.9

3.4 Discussion

Comparing the results of this study to NHC (2020b), there was very little difference observed in the significant wave heights, mean wave period, and peak wave periods for the lakes. Some small differences were observed near shore where there was more inundation than previously modelled, and waves were able to travel a little further and break either closer to shore or further onshore. The wave modelling results used in the runup calculations for this study were very similar to those used in NHC (2020b).

There were larger differences in the wave runup results in this study versus NHC (2020b). With increased lake levels, the slope that a wave runs up on a particular shoreline may be more or less steep than it was in NHC (2020b). The depth of water at the toe of the slope may also be more or less deep. Both these parameters impact the calculation of how much the water runs up the slope, and it was these parameters more than the offshore wave height that caused the runup to be the same or higher than in NHC (2020b). The change in runup ranged from 0 m to a 0.6 m increase. In the few instances where the wave runup would have decreased, it was left as the same as the previous study to account for slope uncertainty (detailed shoreline bathymetry was not available for this study).

The wave results were run using mid-century water levels for the lakes, and higher end-of-century water levels could potentially further increase wave impacts in some areas.

4 Floodplain Mapping

Floodplain mapping for this project covers Okanagan and Wood-Kalamalka lakes. The mapping was developed from hydrologic routing of flow through the lakes and lake wave modelling. GIS layers were produced to represent the COFCL lake inundation extents and the shoreline mapping zones. The mapping methodology used was consistent with the approach used in NHC (2020b). No conventional PDF maps were produced.

4.1 Coordinate System and Datum

The following has been used for the floodplain mapping:

- Coordinate system: UTM Zone 11. Coordinates in metres.
- Horizontal datum: NAD 83 (CSRS).
- Vertical datum: Geodetic – CGVD 2013.

4.2 Digital Elevation Model

A digital elevation model (DEM) based on 2018 LiDAR and lake bathymetry was previously developed for Okanagan floodplain mapping (NHC, 2020b), and this DEM was used to develop floodplain mapping for the present study.

4.3 Lake Inundation Extents

Lake inundation was developed through modelling of the flood elevation for each lake, called the 'still-water' level. On top of this still-water level, wind-setup (increase in water level due to the effect of the wind displacing the water in a direction due to shear) and freeboard were added. This elevation determined for each lake was projected on to the DEM surface to identify the flood extents. The COFCLs for the lake inundation zones are comprised of the modelled still-water level, wind setup, and freeboard.

4.4 Shoreline Zone Mapping

Along the shorelines of the lakes, additional flooding is expected due to the effects of waves. To show this hazard, a wave effect zone (area which may be impacted by waves) was developed using the same method as in NHC (2020b) through the following steps:

- The generalized shoreline (where the lake edge typically meets the land) was used as the lakeward edge of the wave effect zone.
- To characterize the waves, a wave model was run to determine wave heights and calculate runup. The model was run twice, for wind events from both the north and the south, and the maximum values were used.
- A wave height line was developed where waves are equal to 0.3 metres in height, which based on FEMA guidelines is a wave height that is expected to cause damage.

- The wave height line was offset 40 metres inland to define the landward edge of the wave effect zone. The line was then smoothed and reviewed to ensure appropriate representation of likely wave effects on the shoreline.
- To determine the height of the COFCL, estimated wave runup was added to the lake inundation COFCL elevation.

4.5 Freeboard Requirements

Freeboard is added to provide a safety factor to account for local variations in water level and uncertainty in the flood level estimates. A freeboard allowance of 0.6 m was used in NHC (2020), and the same freeboard was used in the present study. Further discussion on the freeboard can be found in NHC (2020b).

4.6 Results

Inundation extents for Okanagan and Wood-Kalamalka lakes increased under current operations in comparison to modified operations, and shoreline zones either remained the same or increased. The amount of increase varied throughout the study area, depending on topography and wave exposure. Inundation extent increases in the order of 100 to 200 metres are seen in the Kelowna area, as illustrated in Figure 4.1, with smaller changes seen elsewhere, as illustrated in Figure 4.2 for example. In some locations, waves impact a larger area under current operations, as seen in Kelowna (Figure 4.1) and at the south end of Wood Lake (Figure 4.3), for example.

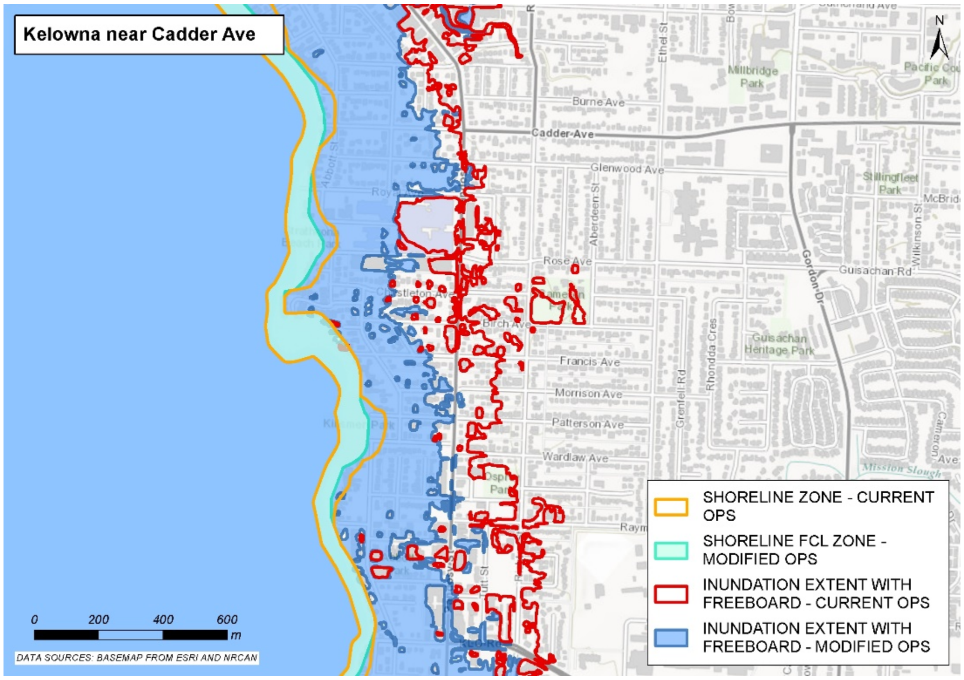

Figure 4.1 Flood extents under modified and current operations at Kelowna

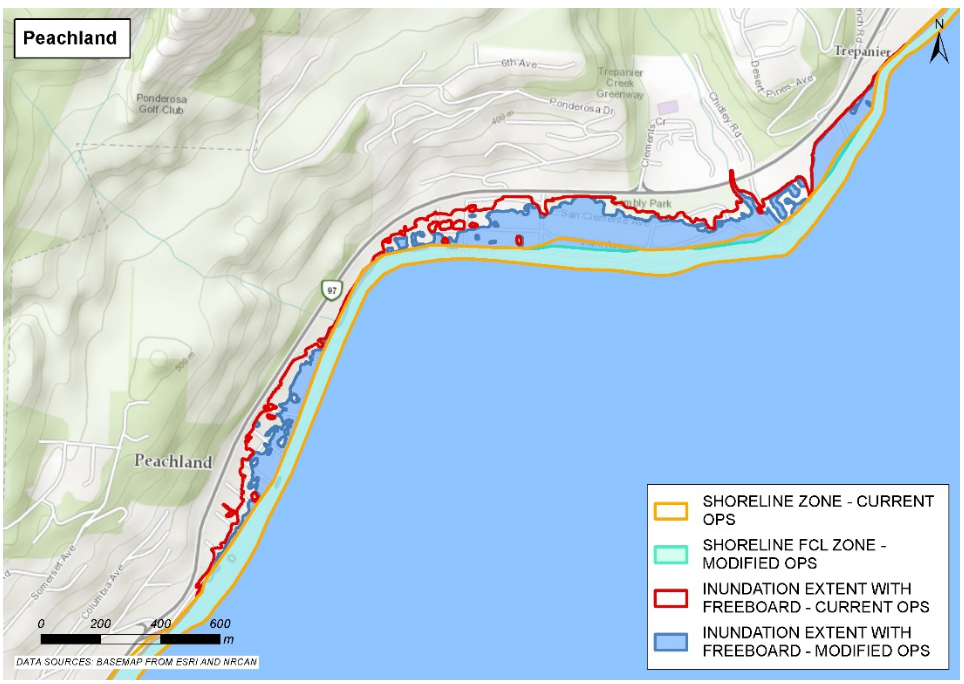

Figure 4.2 Flood extents under modified and current operations at Peachland

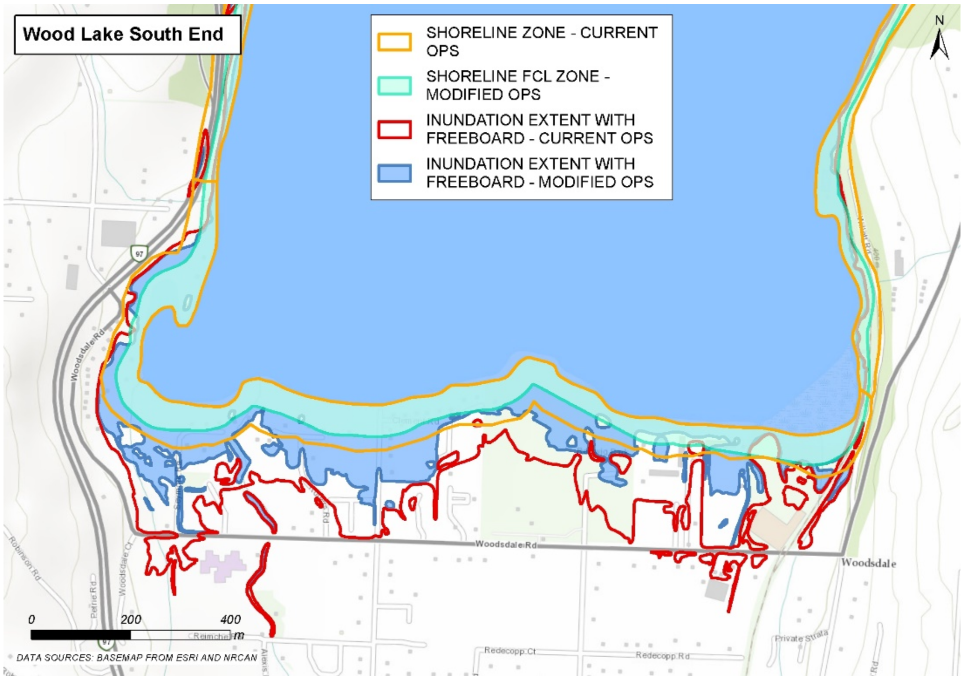

Figure 4.3 Flood extents under modified and current operations at the south end of Wood Lake

5 Conclusions

The hydrological modelling in this study provides a cautionary result that shows the importance of proactive updates of lake regulation, operation and infrastructure to mitigate the impacts of climate change. There is reasonable certainty that the Okanagan will see a future with typically earlier spring freshets and more rapid snowmelt. Reservoir operations and infrastructure need to be modified to adapt to these changes, to provide the reservoir operators with greater ability to react quickly to changing conditions. Specifically, Okanagan Lake illustrates the importance of updates to operations rules and forecasting and Wood-Kalamalka Lake illustrate the importance of infrastructure updates.

The wave effects calculated for the present study were determined using the same methods utilized in NHC (2020b). 200-year ARI spatially varying wind fields were used to force the previously developed SWAN models. The resulting waves were used to calculate the two percent wave runup ($R_{2\%}$) at the shoreline over different zones for Okanagan and Wood-Kalamalka lakes.

When the results of this study were compared to NHC (2020b), the wave properties modelled on both lakes were almost identical with only small differences observed near shore. Larger differences observed in the runup calculations were caused by differing slopes (steepness and depth of toe of slope).

The floodplain mapping was updated using the same process as NHC (2020b) to include the additional inundation that is expected due to current lake regulation operations. Included in this is the wave effect zone, which shows the higher wave extent and runup caused by a higher inundation level.

DISCLAIMER

This report has been prepared by **Northwest Hydraulic Consultants Ltd.** for the benefit of **Okanagan Basin Water Board** for specific application to the **Supplemental to the Okanagan Mainstem Floodplain Mapping Project (Okanagan Lake and Kalamalka / Wood Lakes).** The information and data contained herein represent **Northwest Hydraulic Consultants Ltd.** best professional judgment in light of the knowledge and information available to **Northwest Hydraulic Consultants Ltd.** at the time of preparation and was prepared in accordance with generally accepted engineering and geoscience practices.

Except as required by law, this report and the information and data contained herein are to be treated as confidential and may be used and relied upon only by Okanagan Basin Water Board, its officers and employees. Northwest Hydraulic Consultants Ltd. denies any liability whatsoever to other parties who may obtain access to this report for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this report or any of its contents.

Acknowledgements

The Geographic Information Systems component was completed by Sarah North, GISP.

Report prepared by:

PROFESSIONAL
PROVINCE OF
V. C. C. MCMASTER
48696
BRITISH COLUMBIA
ENGINEER
2022-08-18
Permit to Practice # 103221

Vanessa McMaster, MASc PEng
Hydrotechnical Engineer
Lakeshore Floodplain Mapping

2022-08-18
PROFESSIONAL
PROVINCE OF
Dr. J. W. TRUBILOWICZ
47960
BRITISH COLUMBIA
ENGINEER
Report prepared April 2022

Joel Trubilowicz, PhD, PEng
Environmental Data Scientist
Hydrology

Report reviewed by:

2022.08.18

Piotr Kuraś, MASc, PEng, RPF
Principal, Hydrologist
Project Lead, QAQC

2022 08 18

Grant Lamont, MASc, PEng
Principal, Coastal Engineer
Senior Review

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