CHAPTER 5 RIVER FLOODPLAIN

5.1 Chapter Synopsis

In BC, the 1:200 ARI instantaneous peak flow or the flood of record, whichever is greater, is typically used to define the local flood hazard for floodplain mapping. The 200-year unregulated (gates open) mid-century climate change scenario was selected as the design flood for the Okanagan River following on recommendations in Chapter 3 Hydrology.

Data was collected from a wide variety of sources including river surveys, hydraulic structure surveys (dams and bridges, etc.), bathymetric surveys of the lakes, Lidar, orthoimagery, and WSC gauges. It was used to develop, calibrate and validate a river hydraulic model in HEC-RAS software (the US Army Corps of Engineers Hydraulic Engineering Centre's River Analysis System) that extends from Okanagan Lake to Osoyoos Lake. The hydraulic model includes all the vertical drop structures, bridges, and culverts without flap gates within the river reach. McIntyre Dam is also included in the model extents. Okanagan Lake Dam and Okanagan Falls Dam are not included in the model.

The model results were compared with past observations from the 2017 and 2018 floods to verify the model prior to simulation of the design flood. The design flood and additional events were simulated with the outputs from the Raven model to develop flood extents for the river.

Several hydraulic model parameters were varied within reasonable limits to test the sensitivity of the model as a step to understand and address potential systematic errors from the simulations.

5.1.1 Limitations on the River Floodplain Component of this Study

The hydraulic model is limited by the accuracy of the available data and the assumptions implicit in the hydraulic model. Please see section 5.5.1 for more details.

5.2 Data Sources

Numerous data sets have been received and compiled for the hydraulic modelling. These data sets, usage, and any associated assumptions are described below. Unless noted otherwise, all data was delivered in the project standard datums of UTM Zone 11, NAD83 and CGVD2013.

Topographic and Bathymetric Survey Data

Survey data was provided by WSP Global Inc. The survey data includes bathymetry for the Okanagan River at historic cross sections locations. The survey captured:

- 43 cross sections along the Okanagan River from Okanagan Lake to Skaha Lake,
- 40 cross sections from Skaha Lake to Vaseux Lake, and
- 202 cross sections from Vaseux Lake to Osoyoos Lake.

The survey was completed during March and June of 2019. The survey points captured the geometry of the channel but also extended overbank to overlap and tie-in with the Lidar. The survey was conducted using a combination of post-process RTK GPS. USGS and WSC gauge benchmarks in the Okanagan Basin were also surveyed by WSP Global Inc. in order to convert the station data to the CVGD2013 datum. Hydraulic structures (vertical drop structures, bridges, culverts, dams) and flood control structures, such as dikes, were not captured by the ground survey.

Hydraulic Structures

There are a number of hydraulic structures within the study reach, including dams, vertical drop structures (VDS), bridges, and culverts. The hydraulic structure elevations and dimensions were extracted from the report and hydraulic model created by WaterSmith Resource Inc. and Streamworks Consulting Inc. (2014). The hydraulic structures were surveyed by Okanagan Survey & Design Ltd (sub-contracted to WaterSmith Resource Inc.) in the winter and early spring of 2014 using a combination of RTK GPS and conventional (total station) survey methods. Maximum vertical uncertainty was stated to be 0.02 m. The hydraulic structures extracted from the report and hydraulic model are listed below.

Vertical Drop Structures:

- VDS 1 through 17 (where VDS structures have decks (road crossing), decks were not included in the model)

Dams:

- Okanagan Lake Control Dam
- Skaha Lake Dam
- McIntyre Dam

Bridges:

- Hwy 97 North Bridge
- Penticton Footbridge
- KVR Abutments Bridge (no deck)
- Green Mountain Road Bridge
- West Green Avenue Bridge
- Hwy 97 South Bridge
- Hwy 97 McAlpine Bridge
- No 22 Road Bridge
- Oliver Siphon
- Oliver Footbridge

The WaterSmith report and hydraulic model did not contain culvert information. Therefore, culvert data for the Okanagan Lake Regulation System (OLRS) was obtained from the recent Comprehensive Engineering Assessment of the OLRS Drainage Works (Ecora, 2019a). The report provided an up-to-date assessment of all the drainage structures in the OLRS system. The inspections were completed between March 6 and 12, 2018 and, where access was available, included pictures, and surveying of the structure inlet and outlet.

Based on the assessment report there are 68 structures throughout the whole system (with a total of 72 culverts since some structures have more than one culvert). These culverts are located in the dikes and allow the transfer of water between the floodplain and the channel. Culverts with flood gates are assumed to be operational and therefore closed during a flood event and were not be included in the model.

Of the 72 culverts, 39 do not have flood gates and of those 39, only 14 have complete survey information. Only structures with complete survey information are able to be included in the model. Some additional structures without survey information but with culvert sizing were able to be located with orthoimagery and Google Earth model. Therefore 20 culverts without flood gates and with survey information were included.

Lake Bathymetry

The lake bathymetry for much of the study area was provided by OBWB. Historic lake bathymetry was originally compiled for a study completed by DHI Water and Environment (2010). DHI digitized and merged the historic bathymetry data with a topographic DEM to derive overbank elevations. The DEM has a 20 m resolution.

Due to the coarseness of the DHI DEM, some necessary features in the lakes were lost. Therefore, Vaseux Lake, Skaha Lake, and Osoyoos Lake were all digitized using bathymetry maps from BC Ministry of Environment – Environmental and Engineer Service Water Investigations Branch – Storage Inventory Programme – Bathymetric Surveys of Skaha (surveyed in 1979), Vaseux (surveyed in 1976), and Osoyoos Lake (surveyed in 1981). The lake bathymetry was converted to the CVGD2013 datum after it was digitized.

The remaining bathymetry was utilized from the DHI DEM for Okanagan Lake, and Kalamalka/Wood Lake (all surveyed in 1994) which were originally obtained from Canadian Hydrographic Services (Fisheries and Oceans Canada, 2019).

Ellison/Duck Lake was not included in this bathymetry file and was digitized from the data catalog of bathymetric maps of surveyed lakes completed in 1971 (Ministry of Environment and Climate Change Strategy, n.d.).

Lidar

2015 Lidar

2015 lidar obtained from the Washington Department of Natural Resources was used to provide supplemental topographic data south of the Canada-United States border.

2018 Lidar

A digital elevation model (DEM) of the floodplain, derived from 2018 Lidar data, was received from OBWB and was used as the main source of overbank topography for hydraulic modelling and mapping purposes. The DEM has a 1.0 m resolution and was generated from Lidar data flown by Eagle Mapping Services Ltd. (Eagle Mapping) between March 2018 and November 2018. The Lidar data extend over the Okanagan basin from the northern limit of Okanagan lake down to Osoyoos Lake.

The 2018 Lidar data has a calculated vertical root mean square error (RMSE) of 0.074 m; this value was determined by Eagle Mapping by comparing the Lidar data to control points and features. The 2018 Lidar bare earth point cloud includes only the ground elevation data.

Horizontal coordinates of the 2018 Lidar data are in UTM Zone 11, NAD83. Vertical coordinates are based on CGVD2013.

2017 Lidar

The 2017 Lidar was flown by the National Disaster Mitigation Program (NDMP) between May 29, 2017 and June 6, 2017. The Lidar covers the Okanagan basin from the northern limit of Okanagan Lake to the 49th parallel, including Kalamalka Lake and the Coldstream Creek basin to Lumby.

The Lidar was flown during the peak of the 2017 flood event and was used to extract a water surface profile and flood extents for hydraulic model calibration. The calculated horizontal root mean square (RMSE) is 0.35 m and vertical RMSE is 0.10 m; these values were determined by GeoBC by comparing the Lidar data to horizontal control points and features. The 2017 Lidar bare earth point cloud includes only the ground elevation data.

Horizontal coordinates of the 2017 Lidar data are in UTM Zone 11, NAD83. Vertical coordinates are based on the CGVD2013.

Orthoimagery

Colour orthoimagery was flown during the same period as the 2018 Lidar and provided by GeoBC. The 2018 orthoimagery coverage was not complete across the valley due to smoke from wildfires.

2017 colour orthoimagery was collected between May 29, 2017 and June 6, 2017 by NDMP during the freshet flood in the Okanagan Basin. The 2017 orthoimagery was used to interpret flooded features on the floodplain and to help establish flood extents and HWMs in conjunction with the 2017 Lidar.

The 2018 imagery was used to classify land use for the hydraulic modelling of the valley. Any gaps in the 2018 orthoimagery coverage were filled in with the 2017 orthoimagery.

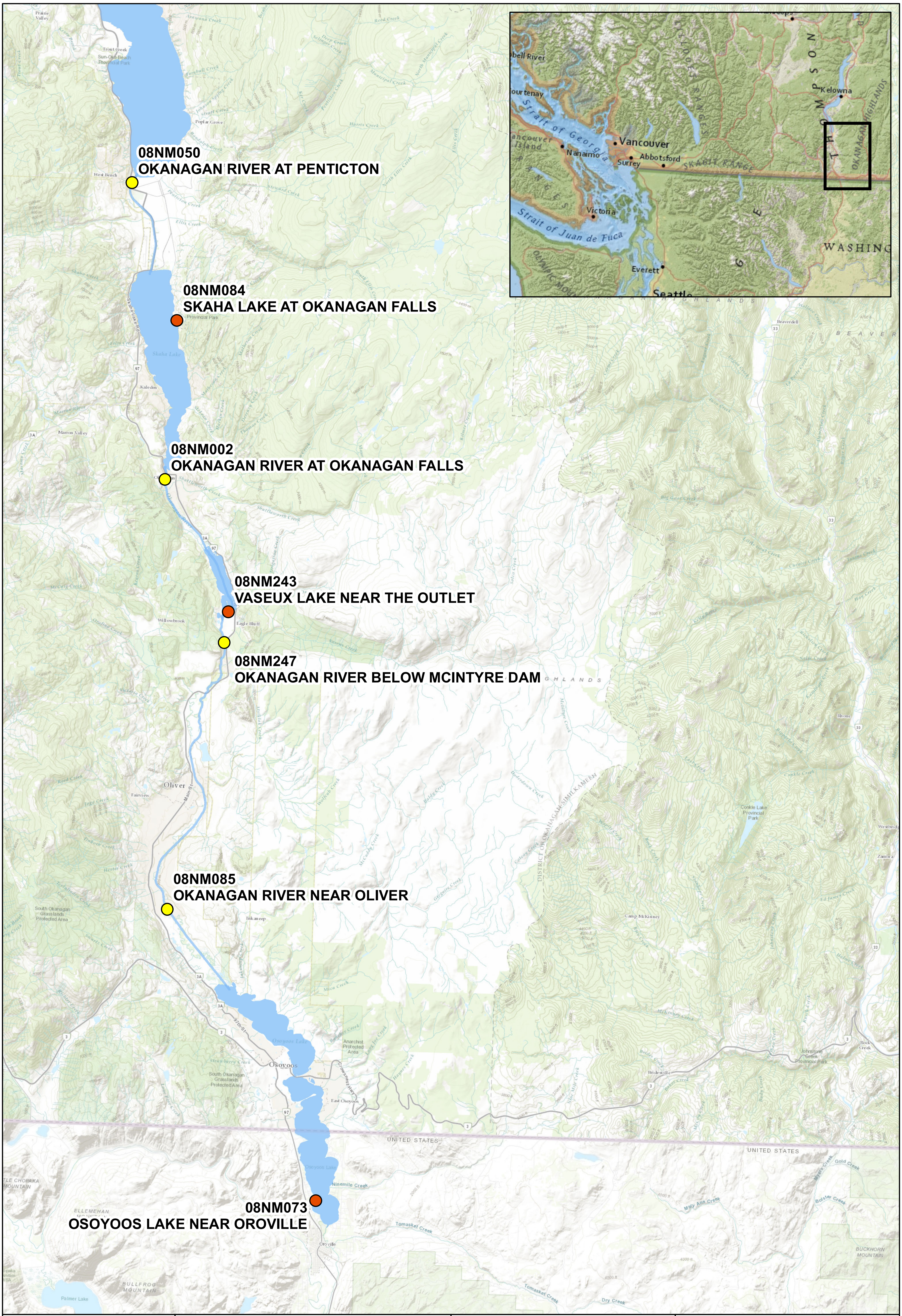
Hydrometric Data

Hydrometric data are described in detail under the hydrology section of this report. WSC and USGS operate several gauges within the study reaches. Those used in hydraulic model calibration are listed in Table 5-1 and shown in Figure 5-1.

Table 5-1 WSC and USGS gauge summary for hydraulic modelling.

ID	Name	Record Length
08NM050	Okanagan River at Penticton	2011-2018
08NM084	Skaha Lake at Okanagan Falls	1943-2018
08NM002	Okanagan River at Okanagan Falls	2011-2018
08NM243	Vaseux Lake near the Outlet	1991-2018
08NM247	Okanagan River below McIntyre Dam	2012-2018
08NM085	Okanagan River near Oliver	2011-2018
08NM073 (USGS 12439000)	WSC Osoyoos Lake near Oroville	1928-2017

The water level and discharge records for these gauges were obtained from WSC and/or USGS. Some of the gauges had elevations reported in a local datum. The elevations were converted to CGVD2013 using the benchmark data surveyed by WSP in 2019.



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Hydraulic Model Gauges

- Flow & WL
- WL

SCALE - 1:200,000

0 2 4 8 Kilometers

N

Coordinate System: NAD 1983 CSRS UTM ZONE 11N
Units: METERS

Job: 3004430 | DATE: 30-MAR-2020

OKANAGAN MAINSTEM FLOOD MAPPING

HYDRAULIC MODEL CALIBRATION GAUGES

FIGURE 5-1

High Water Marks

A large flood occurred in the Okanagan Basin in the spring of 2017. HWM were extracted based on the water surface elevation and flood extents in the 2017 Lidar flown during the peak of the flood event. The HWM's were used for hydraulic model calibration.

5.3 River Model Development

HEC-RAS, a computer program developed by USACE's Hydrologic Engineering Center (HEC), was used to simulate the flood conditions and calculate the flood profile. Version 5.0.7 was released in March of 2018 and was used for this study. The program is designed to perform one-dimensional (1D), two-dimensional (2D), or combined 1D and 2D hydraulic calculations for a full network of channels. The model includes a number of routines for simulation of various hydraulic structures, such as bridges, culverts, weirs, dikes, and spillways. For this project, a 1D-2D coupled unsteady flow model was used to determine the flood extents for the Okanagan Basin, with 1D used in the main channel and 2D for the floodplain areas behind the dikes. Model simulations were conducted using the full momentum St. Venant equations in both the 1D and 2D areas.

Unlike standard 2D models, the 2D computational cells used in HEC-RAS do not have a single averaged elevation. Instead, each cell and cell face of the computation mesh is pre-processed in order to develop detailed hydraulic property tables based on the underlying terrain. This allows a large cell (e.g. 50 m x 50 m) to be partially wet with the correct water volume based on the modelled water surface elevation and the digital elevation model resolution (e.g. 1 m x 1 m).

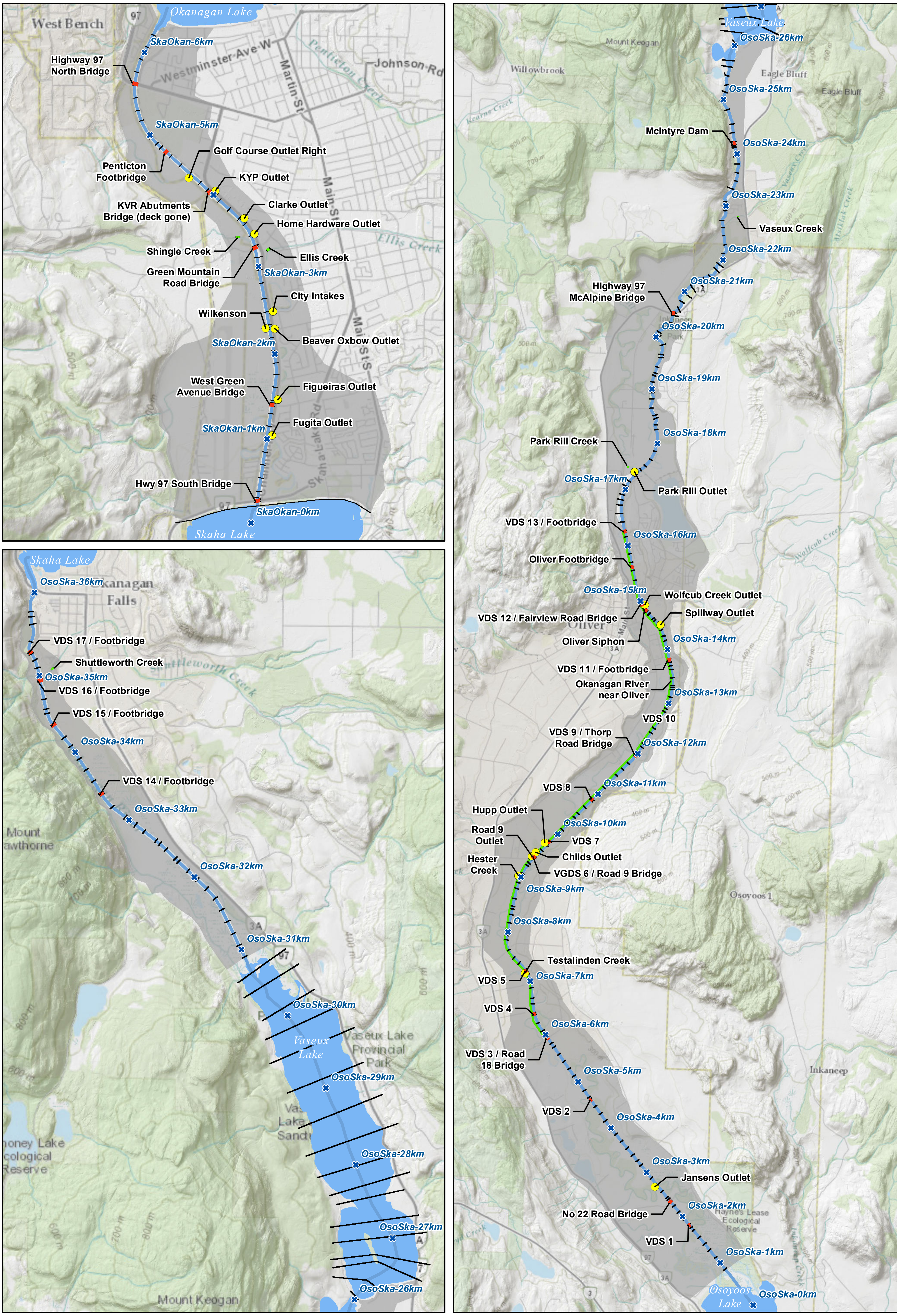
DEM Development

A DEM was generated by combining a one-metre horizontal resolution bare earth DEM based on the 2018 Lidar with the lake bathymetry. 2015 Lidar obtained from the Washington Department of Natural Resources was used to provide supplemental topographic data south of the Canada-United States border. The lake bathymetry and the US 2015 Lidar were converted to UTM Zone 11 NAD83 CSRS metres, CGVD2013 before merging the data. The final DEM has a one-metre horizontal resolution.

Where cross sections were needed in the hydraulic model, the DEM was combined with the surveyed cross section data. The DEM was used as is to represent the overbank areas in the hydraulic model.

Geometry Development

Two separate models were developed for the study area. The upstream model covers the river and floodplain between Okanagan and Skaha lakes. The downstream model begins immediately downstream of Skaha Lake and extends to Osoyoos Lake. Okanagan, Skaha and Osoyoos lakes are not represented in the model, but Vaseux Lake is Figure 5-2.



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- Culvert
- River Chainage
- Cross Section
- Tributary Inflow
- Modelled Hydraulic Structure
- 2D Model Mesh Extents

SCALE - 1:60,000

0 1 2 Kilometers

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Coordinate System: NORTH AMERICAN 1983 CSRS UTM ZONE 11N

Job: 3004430 DATE: 30-MAR-2020

OKANAGAN MAINSTEM FLOOD MAPPING

HYDRAULIC MODEL LAYOUT

FIGURE 5-2

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The 1D portion of the models includes the main river channel and Vaseux Lake and contains all the existing hydraulic structures affecting in-channel flows. The channels/lake are represented by a series of cross-sections surveyed by WSP Global in 2019. The dimensions of the existing hydraulic structures were obtained from the WaterSmith and Streamworks report and model (2014). The total channel and lake length is approximately 60 km.

The 2D portion of the models was developed for the floodplain areas using available Lidar data. The 2D grid cell size was established from preliminary test simulations to provide sufficient resolution of the topographic details and simulated hydrodynamic data while maintaining manageable model run times. The 1D and 2D models are linked via dikes and culverts to provide flow exchange between the channels/lake and floodplain areas during high flow events.

The bathymetric profile for the whole reach including the lakes is shown in Figure 5-3. The figure shows the river stationing in profile as well as location of hydraulic structures included and not included in the model to provide a frame of reference. Table 5-2, Table 5-3 and Table 5-4 list the hydraulic structures used in the modelling and their stationing.

Table 5-2 **Summary of bridges included in hydraulic model.**

Description	Reach	River Station (m)	Details
No 22 Road Bridge	Osoyoos to Skaha	2,326	45 m long, 1 pier, low chord elevation of 281.0 m, high chord elevation of 281.9 m
Oliver Siphon	Osoyoos to Skaha	14,819	39 m long, 3 piers, skewed crossing, low chord elevation of 296.5 m, high chord elevation of 298.63 m
Oliver Footbridge	Osoyoos to Skaha	15,606	37 m long clear span, low chord elevation of 298.5 m, high chord elevation of 299.9 m
Hwy 97 McAlpine Bridge	Osoyoos to Skaha	20,535	33 m long clear span, low chord elevation of 309.2 m and high chord elevation 310.5 m
Hwy 97 South Bridge	Skaha to Okanagan	284	45 m long, 3 piers, low chord elevation of 340.3 m, high chord elevation of 341.4 m
West Green Avenue Bridge	Skaha to Okanagan	1,395	40 m long, 2 pier, low chord elevation of 339.9 m, high chord elevation of 341.2 m
Green Mountain Road Bridge	Skaha to Okanagan	3,213	47 m long, 3 piers, low chord elevation of 342.7 m, high chord elevation of 343.74 m
KVR Abutments Bridge (no deck)	Skaha to Okanagan	4,051	Abutments only, no deck.
Penticton Footbridge	Skaha to Okanagan	4,730	36 m long clear span, low chord of 342.41 m, high chord of 343.9 m
Hwy 97 North Bridge	Skaha to Okanagan	5,623	48 m long, 3 piers, low chord elevation of 343.1m, high chord elevation of 344.1 m

Table 5-3 Summary of vertical drop structures included in hydraulic model.

Description	Reach	River Station (m)
VDS 17	Osoyoos to Skaha	35,286
VDS 16	Osoyoos to Skaha	34,934
VDS 15	Osoyoos to Skaha	34,402
VDS 14	Osoyoos to Skaha	33,435
VDS 13	Osoyoos to Skaha	16,248
VDS 12 - Fairview Road	Osoyoos to Skaha	14,928
VDS 11	Osoyoos to Skaha	13,815
VDS 10	Osoyoos to Skaha	12,747
VDS 9 - Thorp Road	Osoyoos to Skaha	11,952
VDS 8	Osoyoos to Skaha	10,858
VDS 7	Osoyoos to Skaha	9,803
VDS 6 - Road 9	Osoyoos to Skaha	9,419
VDS 5	Osoyoos to Skaha	7,197
VDS 4	Osoyoos to Skaha	6,418
VDS 3 - Road 18	Osoyoos to Skaha	5,932
VDS 2	Osoyoos to Skaha	4,605
VDS 1	Osoyoos to Skaha	1,795

Table 5-4 Summary of dams included in hydraulic model.

Description	Reach	River Station (m)	Details
McIntyre Dam	Osoyoos to Skaha	24,194	5 Gates

Flow between the river channel and floodplain is exchanged using lateral structures, a HEC-RAS model option most commonly used to represent dikes aligned parallel to the river channel. Dike alignments were digitized from the DEM and the crest elevations extracted to input into the lateral structures. In a few locations there is no true dike along the riverbanks, but the same procedure was used to delineate the top of bank elevations that control overbank flooding patterns. Bi-directional flow is allowed at lateral structures when water levels exceed dike crest elevations. Standard weir flow equations are used by the model to calculate flows overtopping the dikes. The coefficient of discharge was set for the lateral structures based on guidance from the HEC-RAS manual. Culverts without flood gates were also added to the lateral structures at the locations noted above.

Boundary Conditions

The upstream boundary conditions for the hydraulic model included an inflow just south of Okanagan Dam for the Skaha to Okanagan reach and an inflow just south of Okanagan Falls Dam for the Osoyoos to Skaha reach. The inflows for these locations were supplied by the output from the hydrology model discussed in Chapter 3.

The downstream boundaries for the model were stage boundaries set by the lakes. Skaha Lake level controlled the Skaha to Okanagan reach and Osoyoos Lake controlled the Osoyoos to Skaha reach. Only major tributaries to the river were included and the tributary inflows were set by the hydrology model. The tributaries included and their river station are presented in Table 5-5.

Table 5-5 Tributaries included in hydraulic model.

Tributaries	Boundary Type	River Station (m)
Ellis Creek	Point Source	3,000
Shingle Creek	Point Source	3,271
Shuttleworth Creek	Point Source	34,874
Vaseux Creek	Point Source	36,468
Park Rill	Point Source	17,343
Lateral Drainage near Oliver	Lateral Inflow	16,240

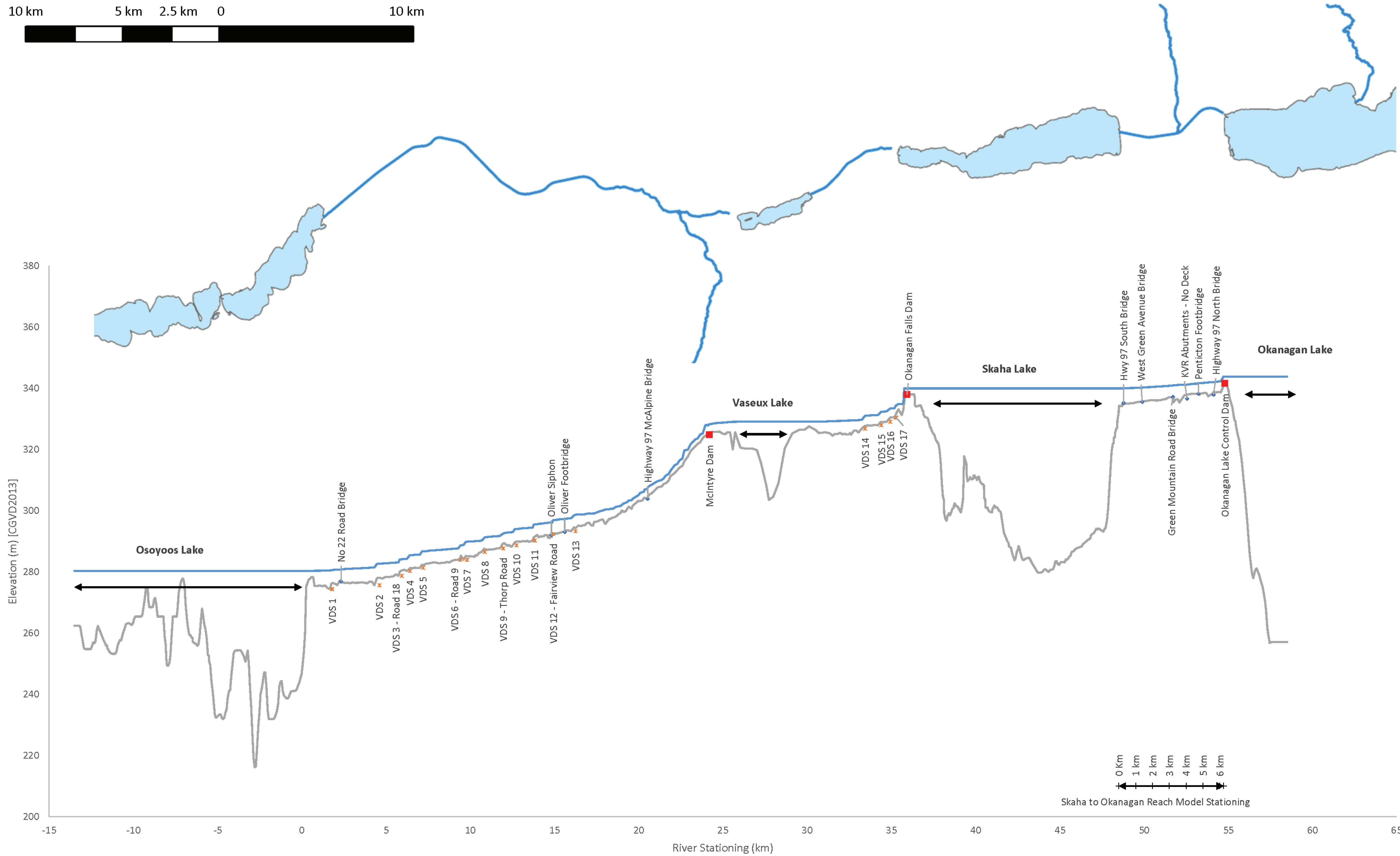

Figure 5-3 Okanagan River Profile.

5.4 Calibration and Validation

Roughness Coefficients

Within the 1D model, the calculated velocity and subsequent water surface profile is strongly dependent on the channel roughness. For a 1D model, the roughness factor accounts for friction losses resulting from surface roughness, vegetation, channel irregularities (variations in cross section size and shape), obstructions (stumps, roots, logs, isolated boulders), and channel alignment (degree of meandering). In a 2D model much of the friction losses (variations in channel shape and alignment) are accounted for in the momentum equation and consequently Manning's n-values in the 2D areas are generally lower.

The Okanagan River was divided into sub-reaches with similar channel bed material, sectional geometry, and plan form. Each sub-reach was then assigned a roughness value for the in-channel portion of the cross section. Initial roughness values were assigned based on values used in previous hydraulic models of the Okanagan River (WaterSmith Research Inc & Streamworks Consulting Inc, 2014) and verified with values referenced in the literature (Barnes, 1967; Brunner, 2016; Chow, 1959; Hicks and Mason, 1998). The roughness of the channel and overbank were specified in the model using Manning's n coefficients.

For the Okanagan River, a Manning's n coefficient of 0.029 was used for in-channel roughness. The overbank portion of the cross sections were assigned roughness values based on land use identified in the aerial imagery. The following overbank land use categories were used and were assigned Manning's n roughness values ranging from 0.024 to 0.1:

- Side channel,
- Grass (cultivated areas or pasture),
- Light brush or shrubs,
- Trees (heavy stand of timber but with dense undergrowth, and flow into branches),
- Lake or ponded water, and
- Urban development.

2017 Calibration

To best support model calibration or validation, HWMs should have been established at a known flood flow (such as the peak of a flood event), surveyed at or shortly after the event, and be recent enough to represent current channel and floodplain conditions. The Okanagan Basin experience a recent flood event in June 2017 where Lidar was flown during the highwater event allowing a large cache of potential HWMs to be captured.

The model was calibrated to that June 2017 flood event, with flows that reached the maximum output regulations allowed for Okanagan Dam during an emergency (78 m^3/s). Model boundary conditions for the calibration were based on the observed flows at WSC gauges listed in Table 5-1. The gauges that were not used to provide boundary conditions were used as calibration points (08NM243 – Vaseux lake near the outlet, 08NM247 – Okanagan River Below McIntyre, and 08NM085 – Okanagan River near

Oliver). More weight was attributed to the calibration values from the gauges than those provided by the Lidar. The Lidar calibration points were pulled using an average through all the points collected in a profile from the water surface. The scatter in the Lidar points covered a range of about 0.3 m.

A comparison of 2017 observed and final simulated water surface elevations (WSEs) is plotted in Figure 5-4 and Figure 5-5. As shown in the figure, the model somewhat over-predicts water levels. The mean absolute error (MAE) between observed Lidar WSEs and simulated water levels for the Skaha Lake to Okanagan Lake reach is 0.11 m and for the Osoyoos Lake to Skaha Lake reach is 0.23 m. The MAE for the observations pulled from the WSC gauges in the Osoyoos Lake to Skaha Lake reach is 0.05 m.

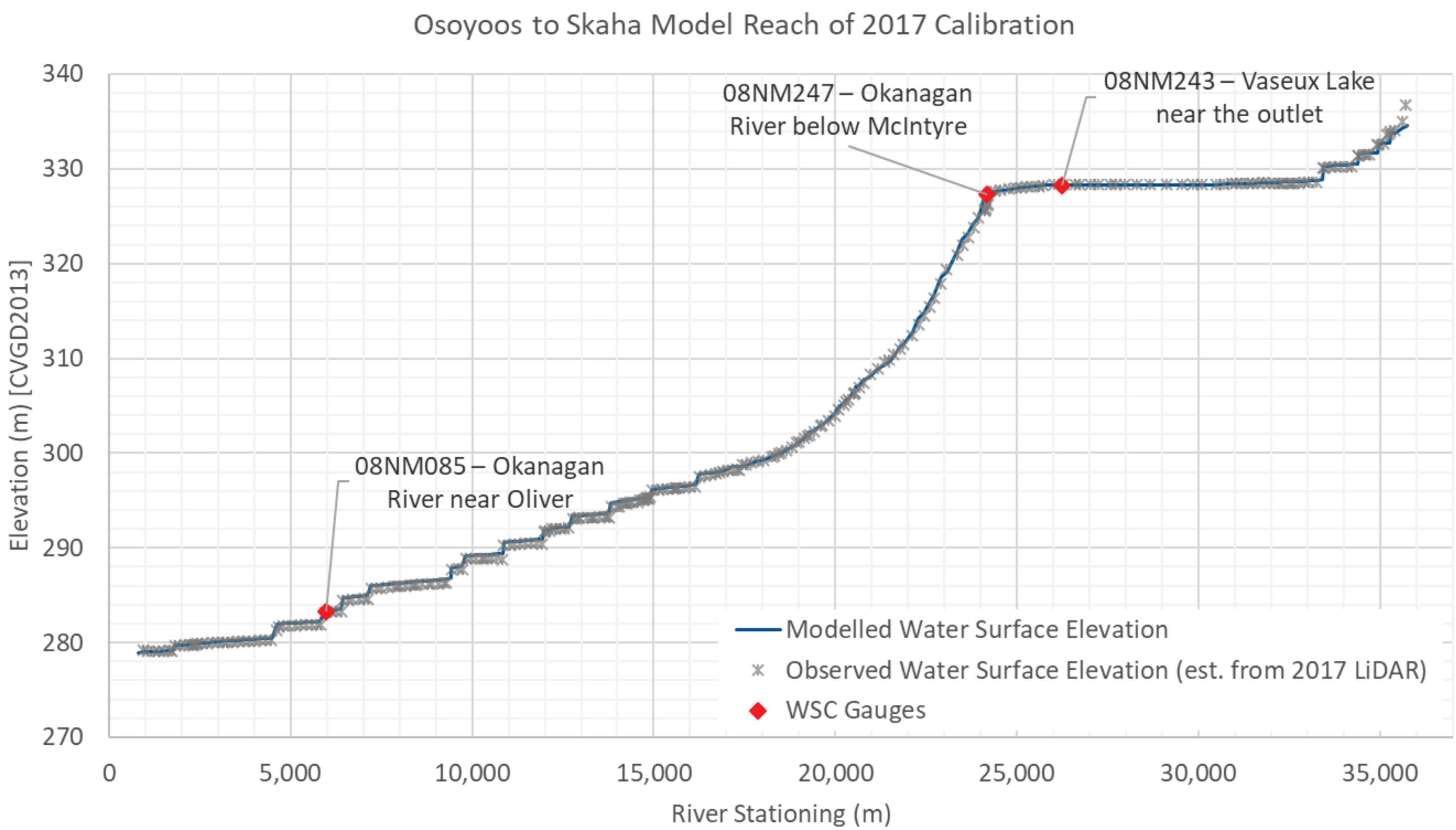

Figure 5-4 2017 calibration profile plot of Osoyoos Lake to Skaha Lake reach of Okanagan River.

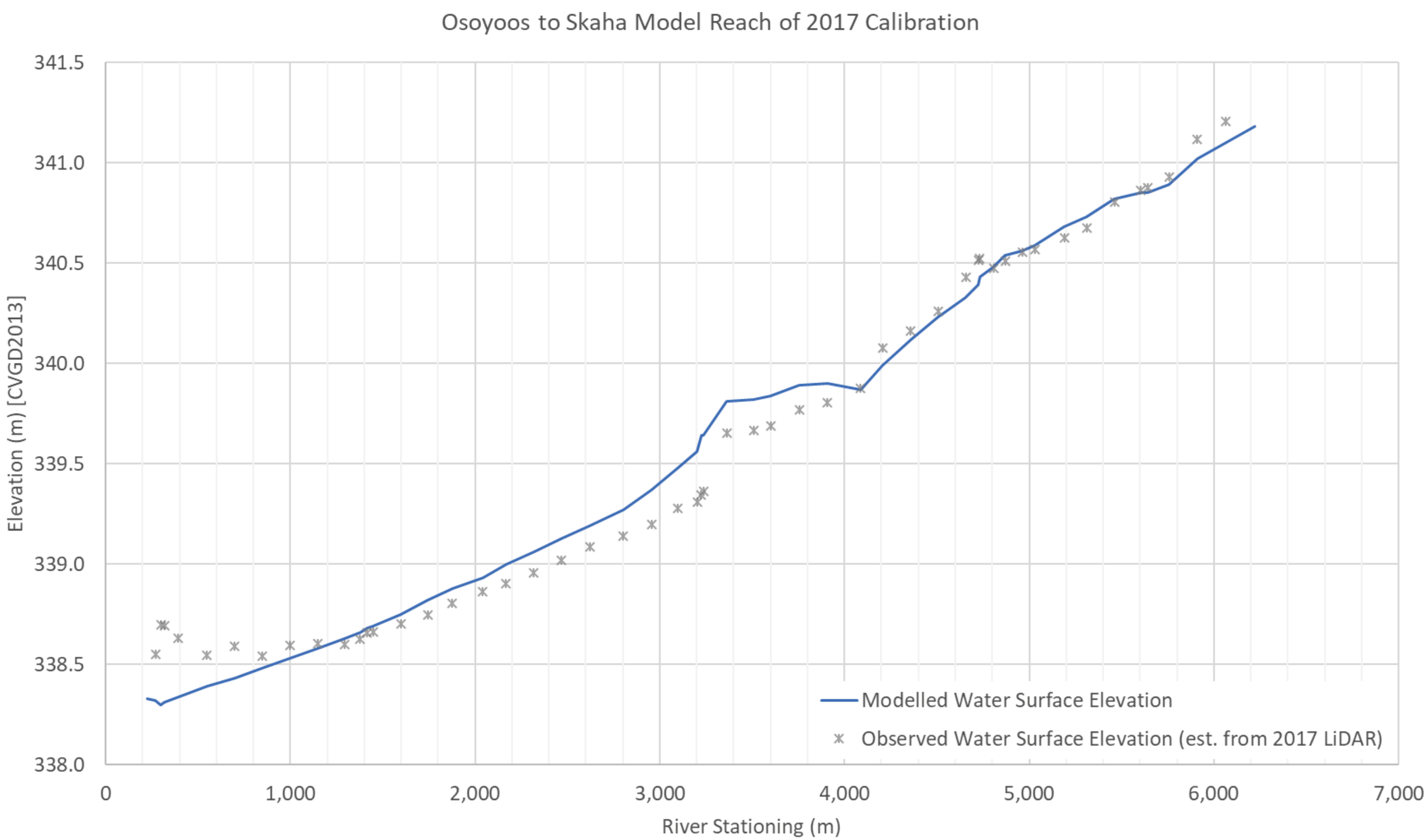

Figure 5-5 2017 calibration profile plot of Skaha Lake to Okanagan Lake reach of Okanagan River.

The difference between 2017 HWMs and simulated peak water levels is attributable to:

- Uncertainty in the Lidar points. It is not clear the extent of the Lidar's ability to pick up WSE from the rivers surface and under what conditions these may be inaccurate. There is also uncertainty in the collection time of the Lidar points. It was narrowed down to several days when the Lidar was flown, but several passes of the same body of water can show different levels if the flights were on different days. The HWMs therefore may not accurately reflect the highest water levels experienced during the 2017 flood.

Despite the comparison with the Lidar data suggesting that the model over-predicts the 2017 water level, channel roughness values were not further adjusted for the following reasons:

- The roughness values selected are at the low end of plausible values for the channel form, bed texture, and channel slope based on referenced literature and past modelling experience.
- The model shows good agreement with the WSC gauges which provides more reliable data than the Lidar.

2018 Validation

The flood event in late May / early June 2018 (66 m^3/s at Okanagan Lake outlet) was used as a validation event, which is to confirm the calibrated model appropriately represents flow conditions other than just the calibrated event. The 2018 event was not quite as high as the 2017 event and did not have HWMs other than from available gauge data. Since there are no gauges between 08NM050 – Okanagan River at Penticton and the inlet to Skaha Lake, there was no validation that was able to be completed through this upper reach.

Only the three gauges described above were able to be used as validation points for model from Osoyoos to Skaha. Since the river and the lakes all peak at separate times, the model was run from May 5, 2018 – June 5, 2018 using the observed gauges as boundary conditions. The results of the 2018 validation are summarized in the table below.

Table 5-6 Differences in simulated WSE for 2018 validation event.

WSC Gauge	Mean Absolute Error (m)
08NM243 – Vaseux lake near the outlet	0.05
08NM247 – Okanagan River Below McIntyre	0.15
08NM085 – Okanagan River near Oliver	0.09

5.5 Results

In BC, floodplain mapping is typically developed for the 200-year ARI flood or the flood of record if greater. For the Okanagan River, the 200-year mid-century climate change scenario with gates open was selected as the design flood event for floodplain mapping. The 20-year mid-century, 100-year mid-century and 500-year end of century floods were also modelled. Inflow to the model was set at the upstream end of the model as well as at each tributary as defined in the following subsection on boundary conditions. The tributaries for the Okanagan River, however, were not modelled except where controlled by backwater elevations from the river. The profile plot of the 200-year mid-century design flood can be seen in Figure 5-6 and Figure 5-7.

Boundary Conditions

To simulate the selected design floods, the boundary conditions specified in Table 5-7, Table 5-8, and Table 5-9 were used. See section 3.5 for recommended flow estimates of ARI events. Results from the hydrology model were used to define the simulation flows for the hydraulic model. These results were limited to the upstream and downstream end of each reach. The increase in flow along the reach was accounted for in the hydraulic model by incorporating inflow at the major tributaries (Table 5-9). The amount of flow assigned to each tributary was scaled based on the weighted average of each tributary's mean annual flood, as obtained from the hydrologic model.

Table 5-7 Flood flow estimates used in hydraulic model.

ARI	Flow Estimate at Outlet of Okanagan Lake (m^3/s)	Flow Estimate at Outlet of Skaha Lake (m^3/s)
20-year mid-century	119	131
100-year mid-century	140	152
200-year mid-century (Design Event)	153	168
500-year end of century	176	194

Table 5-8 Flood lake level estimates for the used in hydraulic model.

Lake	ARI Lake Level Estimate (m, CVGD 2013)			
	20-year mid-century	100-year mid-century	200-year mid-century (Design Event)	500-year end of century
Skaha Lake	339.37	339.98	339.72	340.38
Osoyoos Lake	279.52	280.36	280.07	280.99

Table 5-9 Tributary inflows estimates used in hydraulic model.

Tributaries	Tributary Inflow (m^3/s)			
	20-year mid-century	100-year mid-century	200-year mid-century (Design Event)	500-year end of century
Ellis Creek	8.3	8.8	10.7	11.4
Shingle Creek	6.2	6.5	8.0	8.5
Shuttleworth Creek	2.5	2.8	3.2	4.6
Vaseux Creek	16.0	17.4	19.7	31.4
Park Rill	1.4	1.5	1.7	2.8
Okanagan River near Oliver	0.7	0.8	0.9	1.4

Model Geometry

The model geometry used for calibration and validation simulations was unaltered for the design simulations and was assumed to be representative for all the flood events. No allowance for bed scour or localized deposition was introduced. Similarly, no debris blockages or avulsions were considered. Dikes were assumed to maintain their elevation as currently surveyed even if overtopped. Model development, calibration, and validation is based on large flood events. The floodplain drainage network, including culverts landward, beyond the dikes, and canals or ditches outside of the main river, was not modelled in detail. Hence, the model may not provide accurate representation of low to moderate flow events.

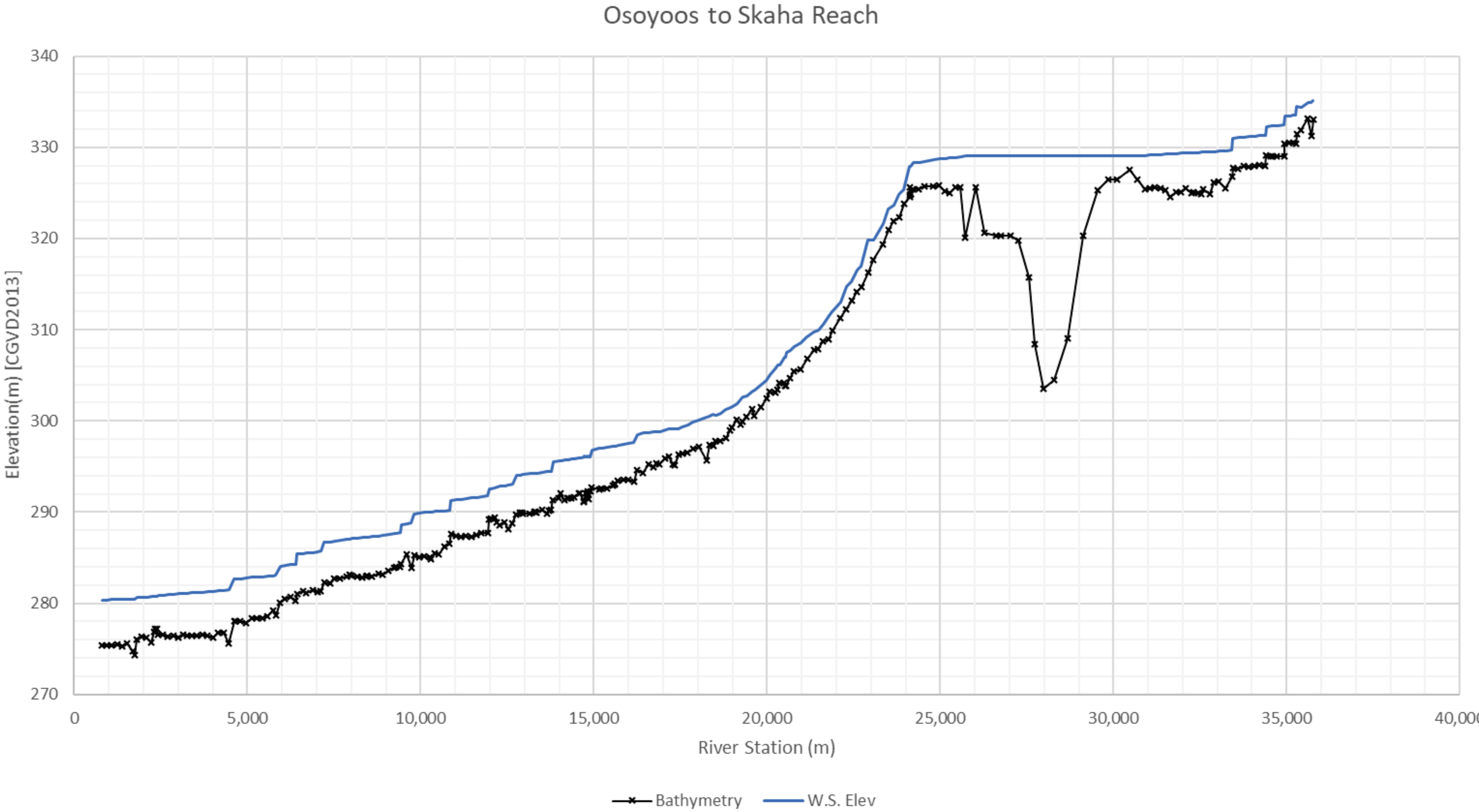

Figure 5-6 Water level profile of the 200-year mid-century design flood for the Osoyoos Lake to Skaha Lake reach of the Okanagan River.

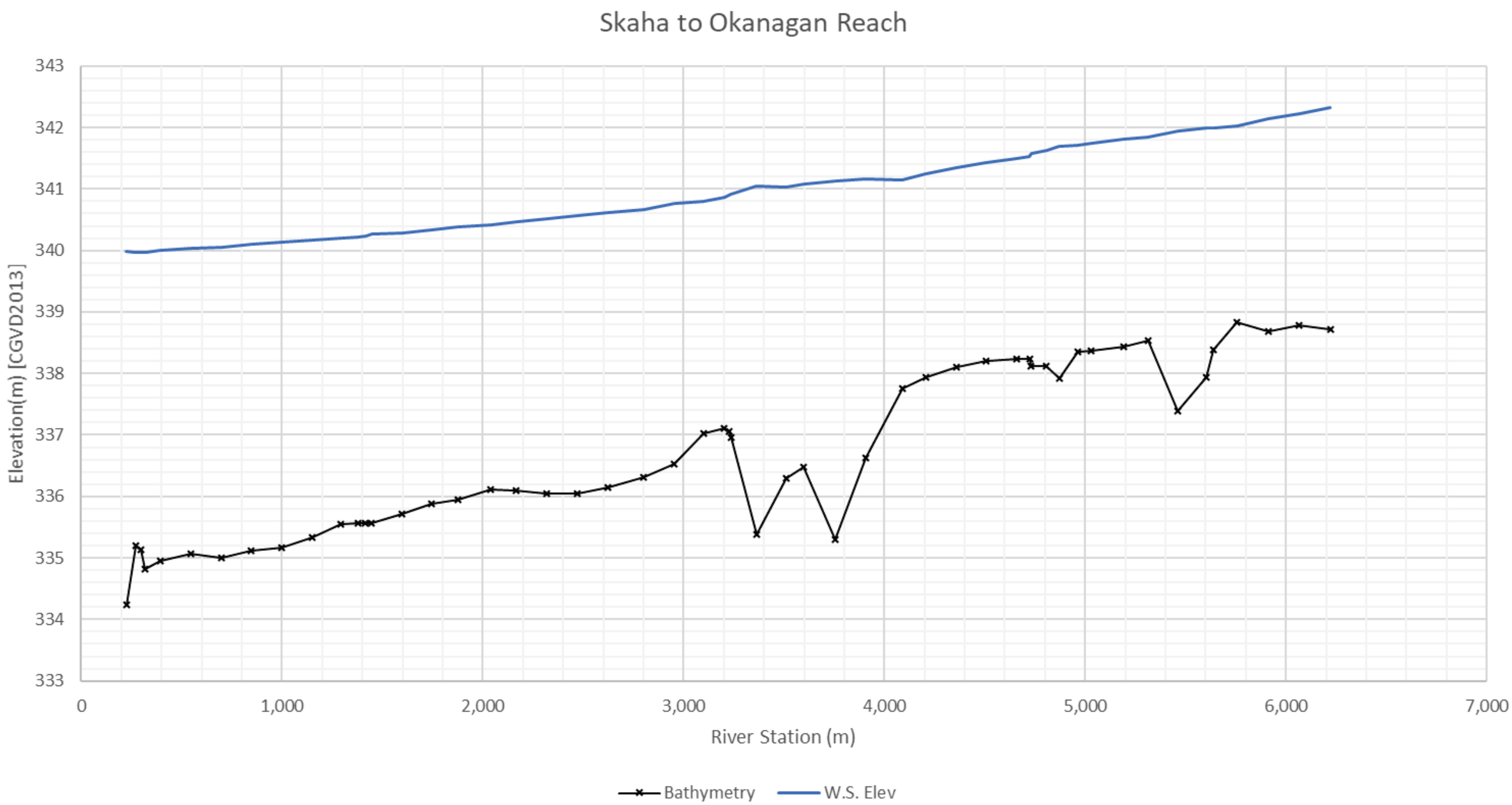

Figure 5-7 Water level profile of the 200-year mid-century design flood for the Skaha Lake to Okanagan Lake reach of the Okanagan River.

Model Sensitivity

The simulated model results (i.e. the flood level) are primarily dependent on the channel geometry and flow. Other model parameters can however also influence the results, such as:

- Boundary conditions (upstream inflow and downstream water levels),
- Channel roughness values,
- Overbank roughness values, and
- Topographic uncertainties.

Values for these parameters were varied within a reasonable range and simulations of the flood flows repeated. The resulting water level profile was compared with the design water level profile to determine the effect of potential error in each parameter on the model results. Results from the sensitivity analysis confirmed that the water profile within the study boundary would not be impacted by reasonable changes in the downstream boundary conditions and that potential misrepresentation of channel and overbank roughness would typically result in changes in design water level of less than or equal to 0.1 m and no more than 0.3 m. This magnitude of potential error is considered reasonable and is within typically applied freeboards to account for such potential errors.

5.5.1 Model and Data Uncertainties

The basic assumptions and limitations of the HEC-RAS model include:

- The channel bed and banks are fixed (the actual river is subject to scour and deposition during floods).
- A uniform hydrostatic pressure distribution is assumed across the channel sections resulting in a level water surface from one bank to the other (i.e. ignoring local variations in water level across the channel from local bed variations or superelevation around corners).

Additional uncertainties in available data:

- Uncertainties in survey data (0.10-0.15 m for topographic data and 0.05 m for gauge station data).
- Uncertainty in the Lidar data; see section 5.4 for Lidar error estimates.
- Although specified to contain bare-earth data, the Lidar used for developing the DEM may contain some artificially high points, especially in areas where the vegetation is dense, creating unrealistic “dry spots” for some floodplain model runs. Additionally, the DEM may contain low points or under predict the crest height on structures that are porous by natures (large rock constructs such as breakwaters or riprap structures).
- Some bathymetric gaps exist between where the lake bathymetry ends, and the river bathymetry starts. There is about 350 m of river above Okanagan Falls that is not in the hydraulic river model and not covered in the lake bathymetry.

- Hydraulic structures surveyed by WaterSmith Resource Inc. and Streamworks Consulting Inc. (2014) are assumed to be accurate representations of the hydraulic structures in the Okanagan River. This includes the vertical drop structures and the dams where applicable.
- Culverts, ditches/canals and other drainage features were not specifically modelled on the floodplain.
- Only culverts in the dikes of the OLRS without flap gates and with survey data as identified in the Comprehensive Engineering Assessment of the OLRS Drainage Works by Ecora (2019a) were included in modelling. This assumes culverts with flap gates are functioning fully and in good condition. Culverts are assumed to be free of debris and flowing smoothly.
- WSC flow and stage data for 2018 used in this study was classified as preliminary by WSC (therefore it is subject to change). The final data is not available at the time of this report and as such, the values were not updated beyond what was provided in the preliminary data.

5.6 Conclusions, Recommendations, and Future Work

Based on the available Lidar and channel survey, a 1D-2D coupled quasi-steady flow model was developed. The model was calibrated to the June 2017 flood (78 m^3/s) and further validated with the May 2018 flood (66 m^3/s). Sensitivity analysis was then conducted using the design flood event for a plausible range of model parameters. A design flood profile was generated from the model for the 200-year ARI (open gates) mid-century design flood as well as the 20-, 100-, and 500-year ARI mid-century (open gates) floods. A freeboard of 0.6 m is recommended for definition of design values, such as the FCL, to account for the level of uncertainty in the calculated water level indicated by the calibration, validation, and sensitivity analysis.

A formal comparison of the design water level profile to dike crest elevations is not part of the current scope of work. However, the dikes appear to be adequately high for much of the river to contain the design flood.

Recommended future work includes:

- Conduct a formal assessment of the dikes and flood mitigation measures to ensure they are adequate to withstand the newly developed design flood profile. Such an assessment should include survey of the dike but may also include visual inspection of dike condition and geotechnical evaluation.

- The current rating curves are limited to a single open gate scenario, for the structures at the outlet of Kalamalka Lake, Okanagan Lake (Penticton Dam), Skaha Lake (Okanagan Falls Dam), and Vaseux Lakes (McIntyre Dam). While total outflow is currently monitored with the use of near real-time discharge data from downstream gauges, this does not allow for such well-informed operations in the case of an outage (with the real-time data unavailable) potentially needed during an emergency. The real-time gauge data is also reliant on rating curves specifically developed for the river, which may shift and are preliminary until reviewed and published, so the discharge data reported by the gauge is uncertain during operation.

  Rating curves developed for the dams can be refined for complete operation dependent on water level and gate opening using numerical methods, computational fluid dynamics (CFD), and physical modelling. Although CFD modelling is often suitable for freeboarding condition, the level of accuracy decreases to 20% or worse when flow reaches the gate. Field measurements can be used to help calibrate and validate the assessment, however often it is challenging to operate at the most extreme values, which generally are of the most interest. Physical modelling of gates is therefore used for the most detailed development of gate rating curves.

  

  Inset 5-1 Example of a custom gate physical model, NHC-Vancouver Hydraulics Laboratory.

- HWMs should be collected during all high flow events. This information is useful for model calibration and validation which should be done following any large flood event. The HWM's should be taken along the entire profile of the modelled reach with sufficient spacing to capture any substantial breaks in slope (i.e. such as upstream and downstream of all hydraulic structures and any constrictions or change in slope). The HWM's should be collected at the same flow, ideally near the peak of the flood event. The HWM can be staked during the flood and surveyed after it recedes as long as the duration is not so long following the flood that the HWMs may be damaged or moved.